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Blois V: Experimental Summary

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BLOIS V : EXPERIMENTAL SUMMARY

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1. Introduction

A (perhaps the *only*) good thing about giving an experimental summary talk is that you get to show the best data of the conference. On the other hand (a) it is not "my" data (b) you've seen it all before , and (c) everybody will get upset by what I do *not* show. How should I put some order into all these topics? The talk has to be linear and I decided to order the topics as shown in Fig.1, although in fact our problem is highly non-linear and is multiply connected as shown by the wavy lines! Hopefully one day we will achieve a unified understanding of all these many facets of particle interactions.

2. Total and Elastic Cross Sections

The most global measurement of hadron-hadron collisions is the total cross section, σ_T, and an important new result was reported by Paolo Giromini [1] of the CDF Collaboration. At the Tevatron with $\sqrt{s}$ = 1800 GeV the $p\bar{p}$ cross section was reported[1] to be 80.03 $\pm$ 2.24 mb, significantly above the E710 published value of 72.1 $\pm$ 3.3 mb. The method used in both cases was the "luminosity independent method" measuring simultaneously the total inelastic rate and the elastic scattering rate at small t, extrapolating the latter to t=0, and using the optical theorem. The new value is also above the preliminary (not published) value of 72.0mb using the same data reported at the last Blois meeting. The new CDF results include a new measurement at $\sqrt{s}$ = 546 GeV which, at 61.26 $\pm$ 0.93 mb, is in excellent agreement with the UA4 measurement at the CERN S$p\bar{p}$S of 61.9 $\pm$ 1.5 mb. A compilation of $p\bar{p}$ total cross section measurements is given in Fig.2. The new measurement, assuming it to be correct, will increase our expectations for LHC/SSC energies. The derivation of the total cross section by the luminosity independent method requires a knowledge of ρ, the ratio of real:imaginary forward scattering amplitudes. Equation 1 shows the relationship.

$$\sigma_T = \frac{16\pi(\hbar c)^2}{1+\rho^2}\frac{dN_{el}/dt\,|_{t=0}}{N_{el}+N_{inel}} \quad (1)$$

It just requires simultaneous measurement of the total rate of (elastic and inelastic) collisions and the elastic rate (per GeV^2) extrapolated to 0 deg. Amazing! The anomalously high value for ρ at $\sqrt{s}$ = 546 GeV previously measured by the UA4 Collaboration is now considered to be dead, as an improved reincarnation of the

[1]Some CDF numbers have changed slightly since the Conference. I give the final values here.

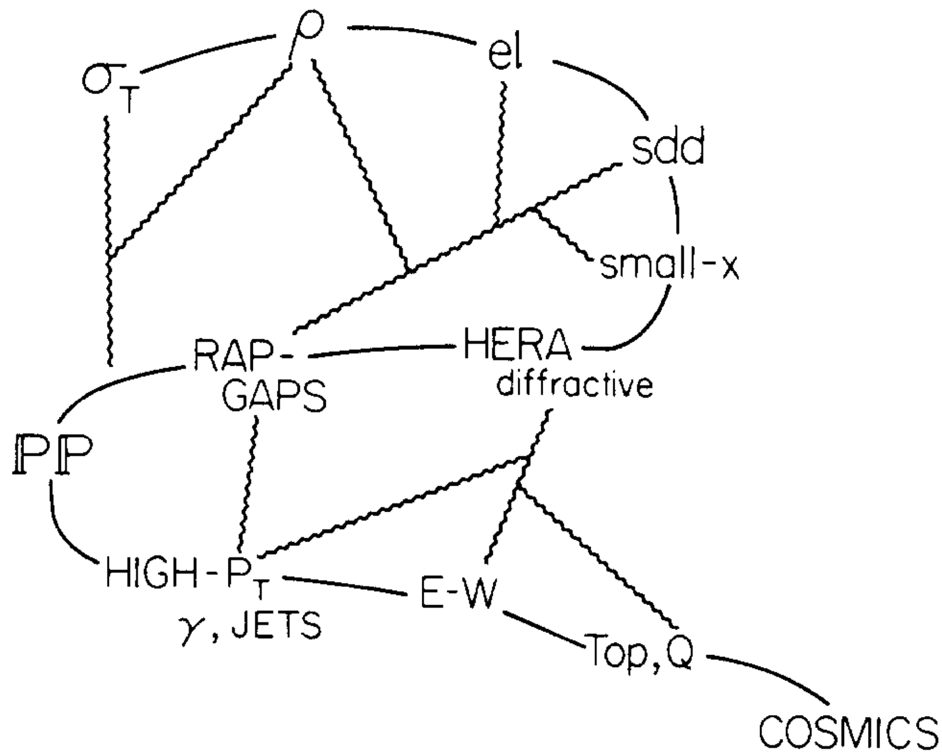

Figure 1: An outline of my talk illustrating the multiply-connected and non-linear nature of our subject (and the Pomeron!).

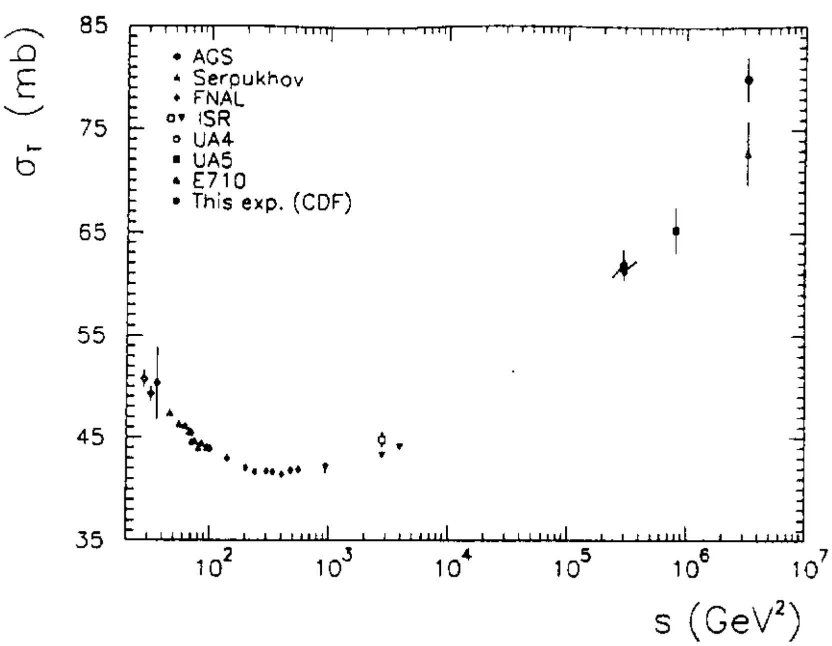

Figure 2: The energy dependence of the $p\bar{p}$ total cross section, with the two new points by the CDF Collaboration.

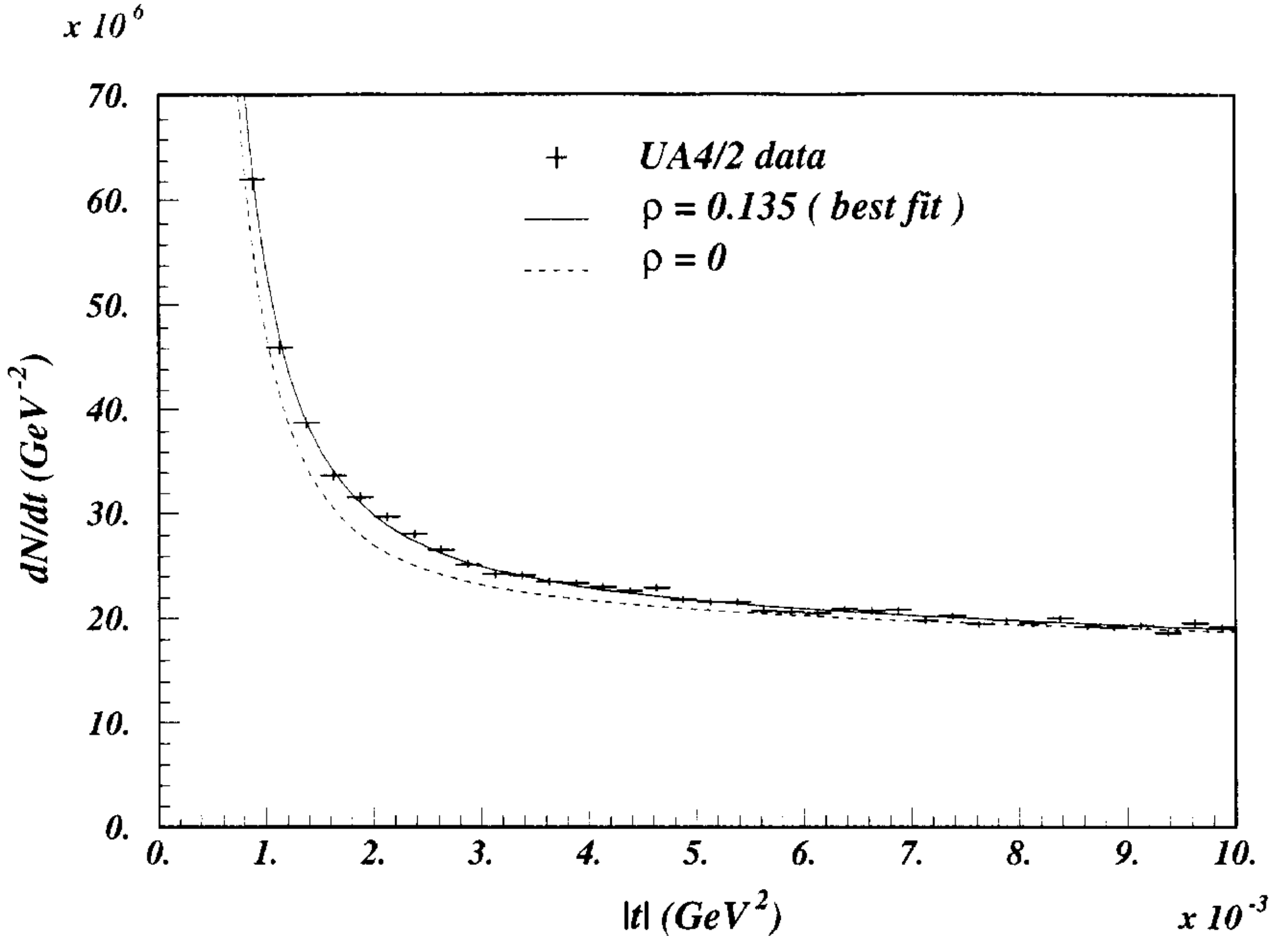

Figure 3: Elastic scattering cross section in the Coulomb interference region from the UA4/2 experiment at the CERN $p\bar{p}$ Collider.

experiment, UA4/2, reported here by Marco Bozzo [2], derived $\rho = 0.135 \pm 0.007$. Improvements include an increased t range and better knowledge of the t scale, better machine optics with larger β and no magnetic field at the interaction point, a more precise measurement of the beam momentum and of the scattered protons, and a factor of 10 increase in statistics. The data look beautiful; Fig.3 shows the cross-section over just the Coulomb interference region. A good measurement of the larger t exponential slope is also obtained, B = 15.5 $\pm$ 0.07 GeV^{-2}.

A new set of ρ measurements at much lower energies was reported for the E760 Collaboration by Steven Tronkenheim [3]. This was done at the Fermilab antiproton Accumulator Ring, colliding the circulating beam (from 3.8 GeV/c to 8.7 GeV/c) on a gas jet target. The data (see Fig.4) are in a region where ρ appears to change sign but the errors on most previous measurements are relatively large. E760 also extract measurements of the elastic slope and total cross section. Antonio Bueno [4] presented fits to the total cross section and ρ values over a wide energy range, including extrapolations beyond SSC energies. The ρ parameter ($p\bar{p}$) rises through zero around $\sqrt{s}$ = 13 GeV and reaches an almost constant value by the collider energies : 0.135 at $\sqrt{s}$ = 546 GeV, 0.134 at 1800 GeV, 0.126 at LHC (14 TeV) and 0.120 at SSC (40 TeV). The projected values of σ_T to these supercolliders are 106 $\pm$ 7 mb and 125 $\pm$ 10 mb respectively, but these fits do not include the new CDF measurement. By these energies ρ, as well as σ_T, is expected to be practically indistinguishable between pp and $p\bar{p}$. The $\sqrt{s}$ = 1800 GeV result mentioned

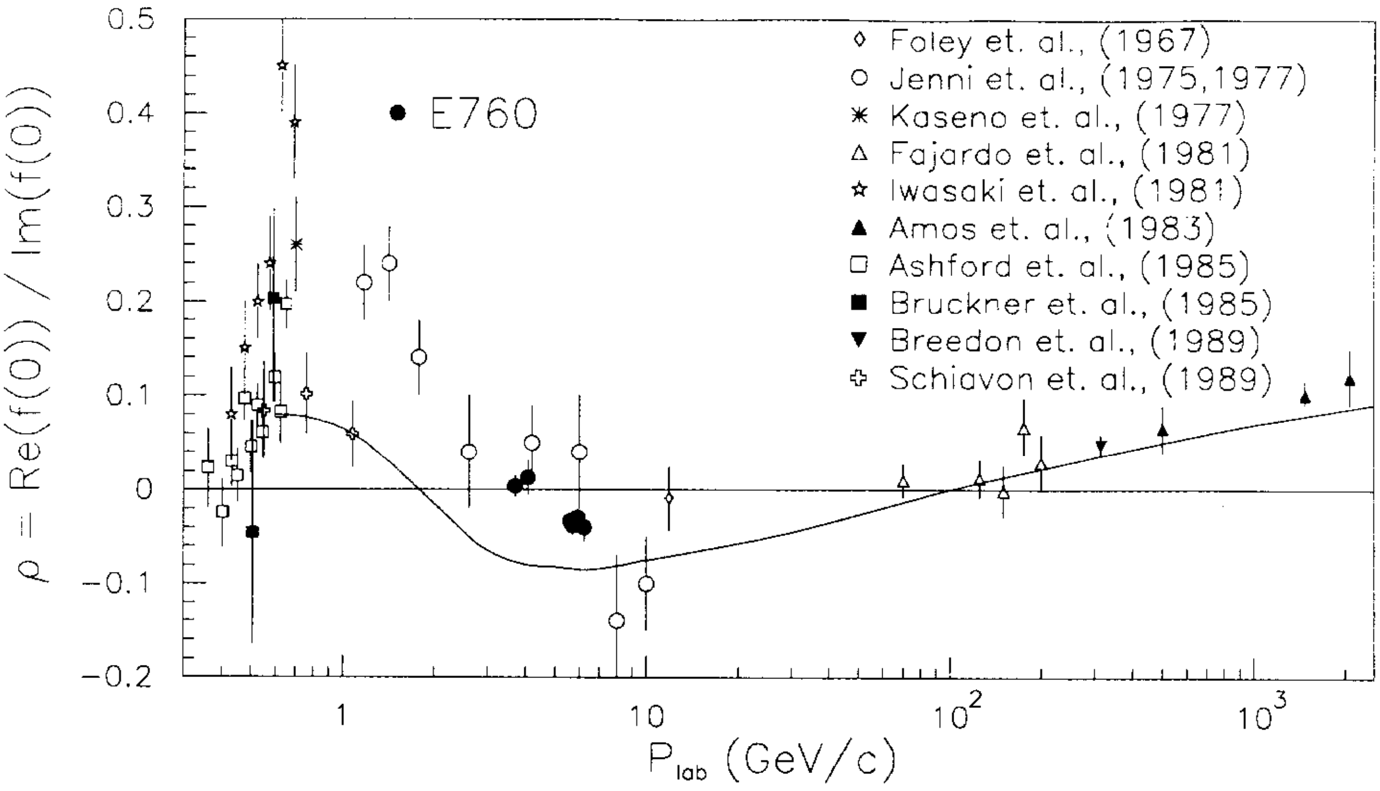

Figure 4: New measurements of ρ in $p\bar{p}$ elastic scattering from Experiment E760 (gas jet target).

above was presented at this meeting by Sasan Sadr [5] for the E710 Collaboration; it is an update on the 1991 results with lower $|\ t\ |_{min}= 0.00075GeV^2$. They gave $\sigma_T = 72.2 \pm 2.7mb, B = 16.72 \pm 0.44GeV^{-2}$ and $\rho = 0.134 \pm 0.069$. So there is a nearly 3 σ discrepancy between CDF and E710 for the total cross section.

Moving our discussion to $p\bar{p}$ elastic scattering beyond the Coulomb region, we have new measurements of the slope, B, and the extrapolated integral, σ_{el}, from CDF [1] at c.m. energies of 546 and 1800 GeV. The agreement with both UA4 at CERN and E710 at Fermilab is perfect, as seen in Fig.5, which also shows that the rise from fixed target and ISR energies seems to be faster than simply logarithmic. Also (Fig.6) the fraction of the total cross section which is elastic continues to rise, now reaching 0.248 $\pm$ 0.005. This is still far from the black disc limit of 0.5; however the Fourier transformation of the t-distribution to derive the form factor shows that the center of the distribution has reached its maximum value, i.e. the center of the proton has become opaque.

What can we expect in the future for high energy elastic scattering? Of course the future machines will provide a great challenge, and Jay Orear [6] described EOI-2 which is the SSC Expression of Interest in measuring ρ, B, and σ_T at 40 TeV, and which requires an angular precision of 10^{-7} radians! It now seems that this experiment may be able to coexist in an interaction region with SDC or GEM which should make it easier to approve. Also, I wonder, perhaps it could allow some joint running for both single diffractive excitation and double Pomeron exchange (with up to more

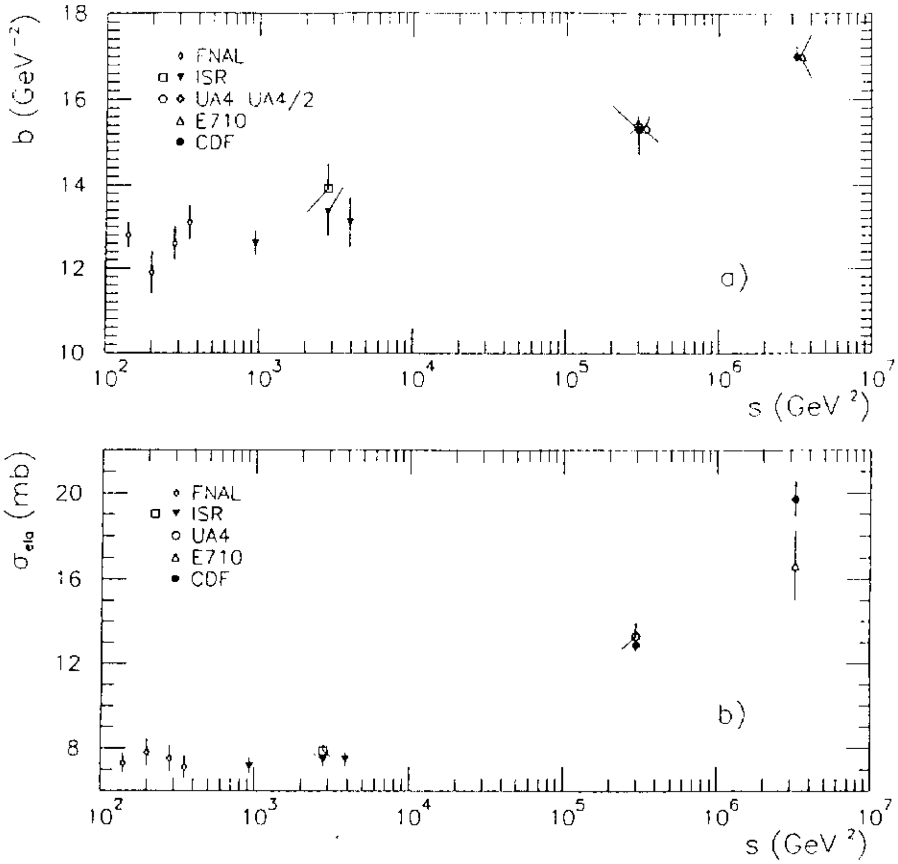

Figure 5: (a)Slope of the $p\bar{p}$ elastic scattering t-distribution versus s. (b) Total $p\bar{p}$ elastic scattering cross section versus s

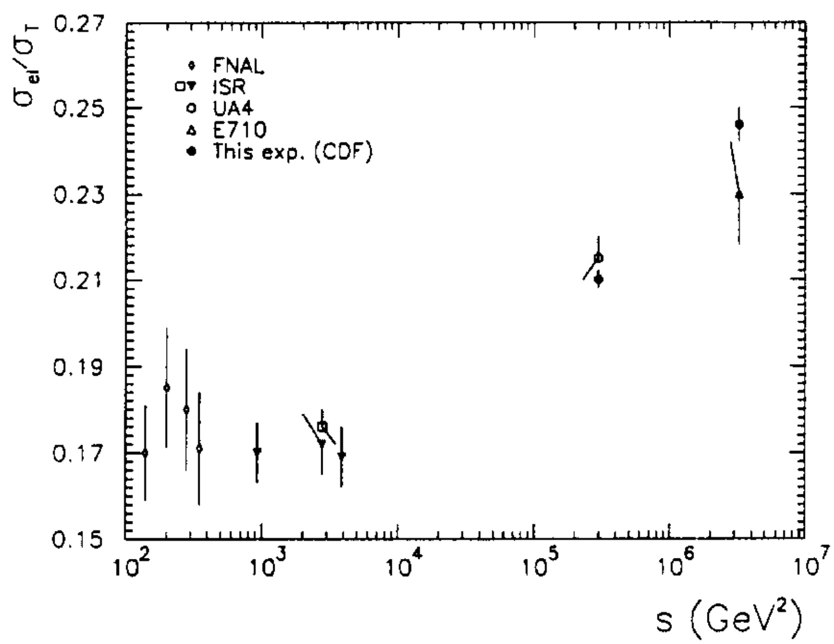

Figure 6: Ratio of the elastic to total cross sections for $p\bar{p}$ collisions, versus s

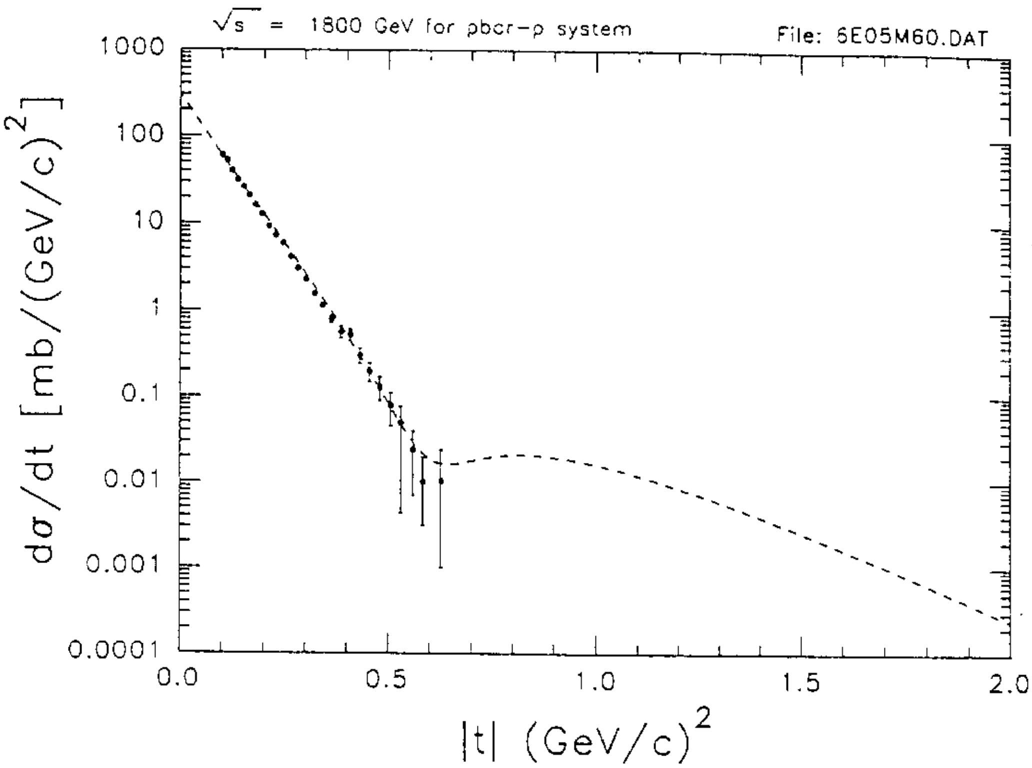

Figure 7: Elastic $p\bar{p}$ scattering at larger angles at the Tevatron (E710 data) at 1800 GeV, with a fit by Block et al.

than 2 TeV central masses!). As a precursor to the SSC running, the E811 apparatus will be applied at the Tevatron as a new generation Coulomb interference experiment. Another glaring gap in our knowledge is in the $\mid t \mid$ region beyond 0.6 GeV^2 where structure occurs, see Fig.7 which shows the prediction of Block, Halzen, Margolis and White [7]. Donnachie and Landshoff have an almost identical prediction [8] where the structure is due to one-Pomeron exchange at low $\mid t \mid$ becoming two-Pomeron and eventually three gluon exchange at higher $\mid t \mid$. CDF is analysing data which should extend to about 1 GeV^2; it would be good to have another experiment in this region and beyond (data at the ISR extended to t-values around 10 GeV^2). At lower energies, Wlodek Guryn [9] described an experiment that can be done at RHIC in proton-proton mode with $\sqrt{s}$ up to 500 GeV, measuring all the parameters of elastic scattering and the total cross section. This could run by late 1997.

2. Single Diffractive Excitation

Single diffractive excitation of one proton by the other gives rise to a large peak in the inclusive proton spectrum for Feynman x above 0.95. From the ISR to the Tevatron Collider, the data can be fit as the sum of the diffractive (peaking) term — in triple Regge language the sum of PPP and PPR terms — and the non-diffractive (RRP + RRR) term which decreases with x. The terms are equal around x = 0.95 (depending a little on $\sqrt{s}$). Especially below that, beware of the large non-diffractive contribution. Fig.8 illustrates this with new spectra from Giromini's group in CDF. The "Roman Pot" spectrometer measures the quasi-elastic scattered antiproton with

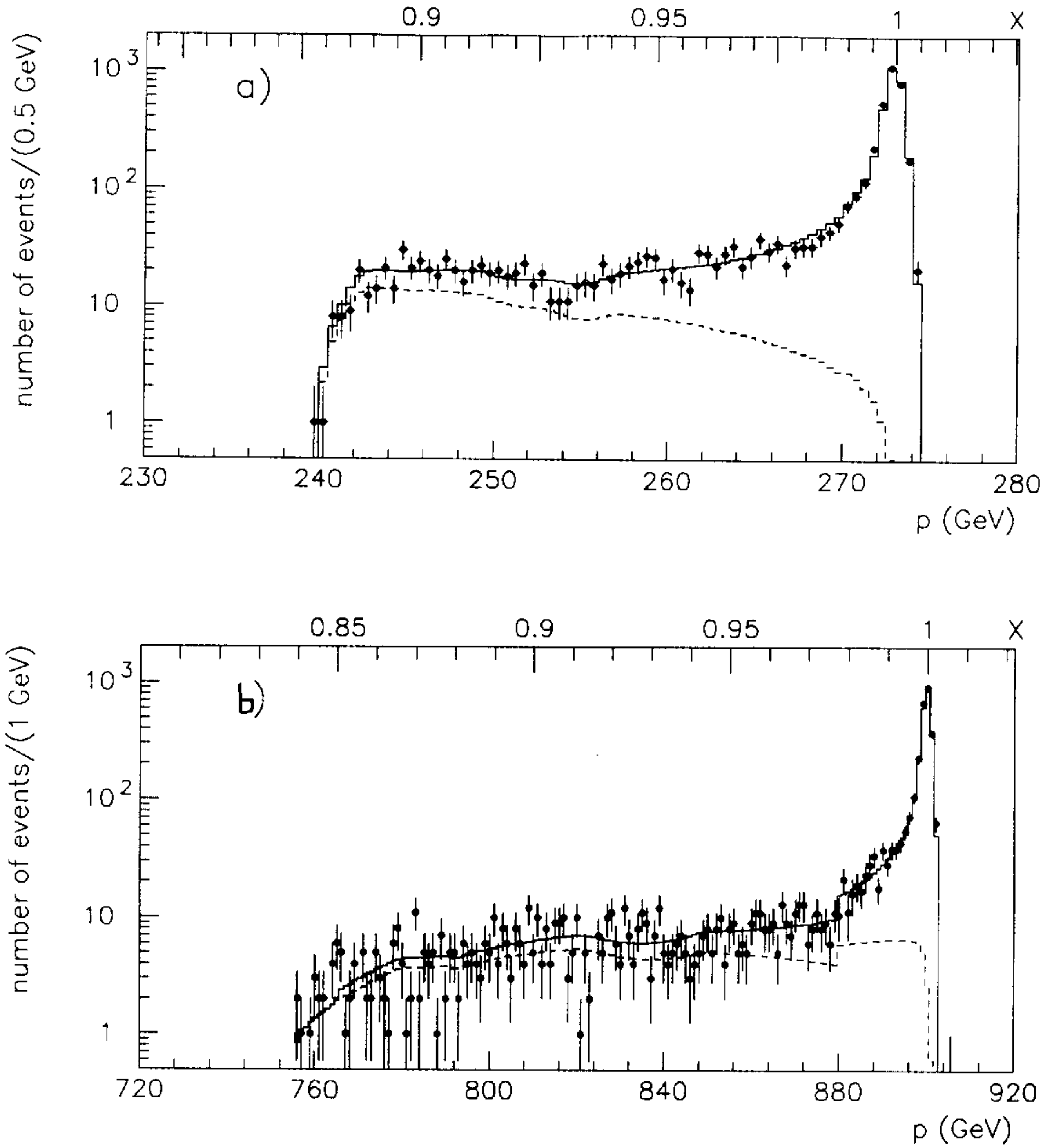

Figure 8: Momentum distribution of high-x antiprotons in the Roman Pot Spectrometer of CDF at (a) 546 GeV (b) 1800 GeV. Uncorrected data are the solid points, the dashed line is the fitted non-diffractive contribution, and the solid line is the total fit including the Regge form of diffractive contribution.

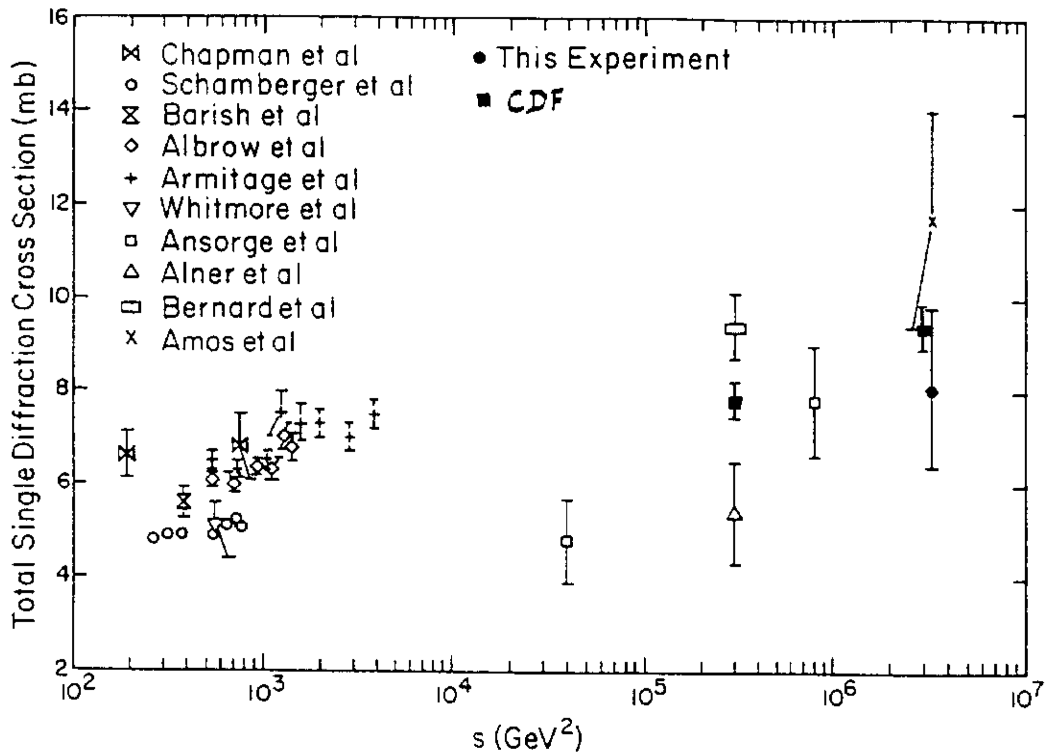

Figure 9: A compilation of measurements of the total single diffractive cross section in pp or $p\bar{p}$ collisions versus s. "This experiment" is E710.

a resolution of about 2.5 GeV (σ) at 900 GeV. Fitting the data at both $\sqrt{s}$ values, 546 and 1800 GeV^2, they obtain integrated single diffractive cross sections of 7.89 $\pm$ 0.33 and 9.86 $\pm$ 0.44 mb respectively. Put together in a compilation by Roy Rubinstein [10] (Fig.9) these show that the single diffractive excitation cross section is rather independent of energy all the way from the ISR. The bad scatter of the high energy points is at least partly due to choices in defining this cross section and the non-diffractive background. The shape of the mass distribution, traditionally considered to be $1/M^2$, is in fact different, the power in M being not 2 but $2(1+\epsilon)$ where $1+\epsilon$ is the intercept of the Pomeron trajectory at t = 0 and describes also the rise in the total cross section. A value of ϵ around 0.12 describes both the σ_T rise and the single diffractive mass spectrum, which is very satisfying. Experiment E710 [10] also presented a mass distribution, best fit with ϵ about 0.13.

You can see in Fig.8 that the diffractive component is still large (although not dominant) at $x = 0.95$ which corresponds (Equation 2) to a mass around 400 GeV at 1800 GeV.

$$x = 1.0 - M^2/s \tag{2}$$

If we can think of these events as due to Pomeron-proton collisions with $\sqrt{s}$ equal to a few hundred GeV, we should be able to learn a great deal about the Pomeron by studying the final state. For example, seeing pairs of high E_T jets is a signal for parton scattering, and hence of partons in the Pomeron, and measuring these jets and inputting the proton structure function enables us to extract an effective (q and g mixed) Pomeron structure function. Separating the quark and gluon contributions is much harder, but is possible in principle by measuring Drell-Yan pairs for the

$q\bar{q}$ and heavy flavor pairs for the gluons. Can a self-consistent description of high mass diffractive interactions be obtained? Is there a t-dependence to the Pomeron structure? These are questions which we would like to eventually answer in CDF by combining the full central apparatus with a forward proton detector (the single diffractive excitation measurements reported here by Giromini did not include the full CDF central detector). Meanwhile a start at this program was made by Peter Schlein [11] and collaborators, who combined a forward proton detector with the UA2 central experiment at CERN. They (UA8) selected events with a forward proton, $x_F > 0.90$, in association with a total central $E_T > 20$ GeV in the UA2 calorimeter. They observe that a large fraction of these events have two central jets with $E_T > 8$ GeV; typically the events are more strikingly jet-like than typical $p\bar{p}$ collisions at $\sqrt{s} =$ 150 GeV (their typical mass) or even 630 GeV. This is taken as evidence for partons in the Pomeron, and it is very important to follow this with more experiments. In particular an experiment at the same t and M but at different $\sqrt{s}$ is crucial to see whether it is actually Pomeron exchange that is occuring in these events, rather than (say) non-diffractive Reggeon exchange.

The UA8 team go further in attempting to extract information on the distribution of momentum carried by these partons, and from the distribution of x(2-jet) they conclude that there is a "superhard" component in which, for about 30% of the events, the entire momentum of the Pomeron seems to participate in the hard scattering! The Pomeron behaves like a single parton! It obviously needs further investigation; the evidence can not yet be considered compelling, but if confirmed this will be an important discovery.

Before leaving the subject of single diffraction I should mention the experiment reported by Chong Zhang [12] with the E653 multiparticle spectrometer at Fermilab. They looked for charm in hadronic systems up to 12 GeV mass, diffractively produced from 800 GeV/c protons on a silicon target. They find no signal, and claim that less than 0.2% of events, from the charm threshold up to 12 GeV, contain a charm pair.

4. Electron-proton Scattering

This was the first Blois meeting to have results from HERA. At last an e-p collider! Welcome! 27 GeV electrons are scattered off 820 GeV protons, and one subject of great interest to us is that of the low-x structure functions. Previously known only down to about x = 10^{-2}, new data from both H1 and ZEUS extend these to about 5x10^{-4} at $Q^2 < 30 GeV^2$ (the x-limit rises with Q^2). Fig.10 shows some H1 and ZEUS data shown by Marc Besancon [13] and Maciek Krzyzanowski [14] which tend to favor the highest of the various extrapolations of fits to higher x data (such as GRV or MRSD-). This is promising for future studies of saturation effects and other such phenomena. The rate of central, modest p_T charm and b-quark production at LHC and SSC depends strongly on the parton densities (primarily gluons) below x = 10^{-3}. There are also possibilities of measuring the gluon structure function around x = 10^{-3} using very forward photon-jet and jet-jet pairs at the Tevatron Collider. I will discuss the jet-jet measurements later. Norbert Magnussen [15] presented the

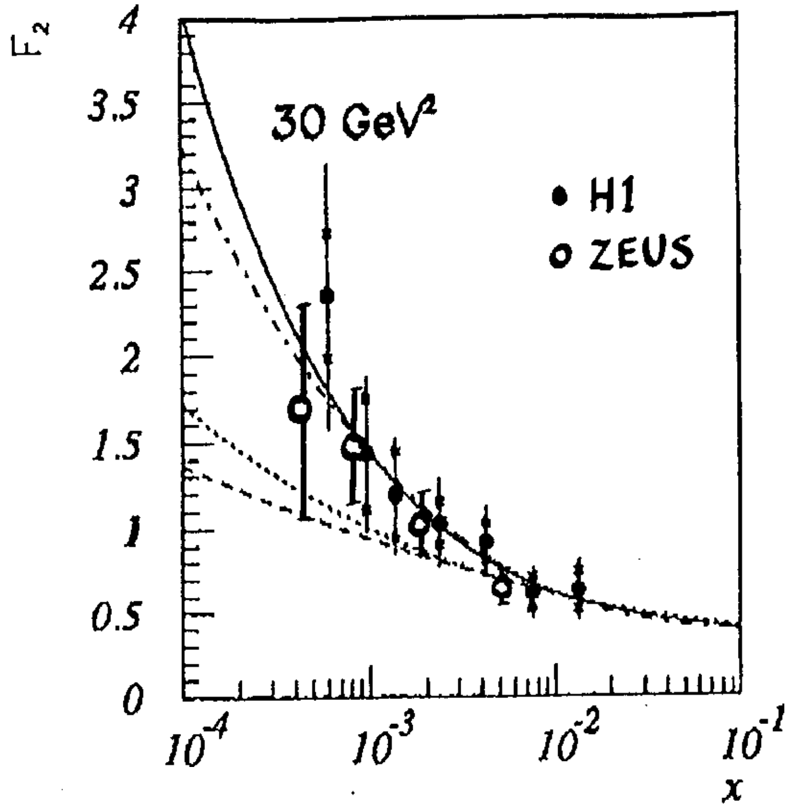

Figure 10: Data by both H1 and ZEUS on the structure function F_2 of the proton, at $Q^2 = 30 GeV^2$ down to record low values of x. The lines are (top to bottom) MRS D-, GRV, CTEQ1MS and MRS D0 extrapolations.

H1 measurement of the photon-proton total cross section at an average c.m. (γ-p) energy of 200 GeV; it is (156 $\pm$ 2 $\pm$ 19) μb. This agrees well with a prediction of Donnachie and Landshoff, but not with some other models. He also showed data in which the photon gives rise to two high p_T jets (the so-called "resolved photon") and the inferred distribution of $x_\gamma = x(parton/photon)$, see Fig.11. The data are quite well described by the GRV-LO distribution provided gluons are included; they seem to be important. At HERA we still can see the importance of vector meson dominance in data shown by Magnussen : the mass spectrum of $\pi^+\pi^-$ in the photon direction shows predominantly the ρ. The t-dependence is exponential with a slope b = 9.7 $\pm$ 1.8 GeV^{-2} which agrees with an extrapolation of lower energy data.

A very interesting observation of rapidity gaps in HERA ep events was reported [16] by Joe Milana, from ZEUS. Think of the virtual photon, even when it has high Q^2, behaving occasionally as a hadronic state (Vector Meson Dominance?) which can be diffractively excited by the proton. This gives rise to a rapidity gap up to more than 3 units from the "quasi-elastically" scattered proton. There are not yet many events of this type (78 $\pm$ 10 with $\Delta\eta > 2.8$) but only about 10 would be expected by a Monte Carlo which does not include diffraction. The hadronic cluster resulting from the photon excitation has a roughly M^{-2} behavior as expected for diffraction. Now the question, at least for me, is whether these events should be seen as "boring" vector-meson proton diffractive scattering or exciting photon-Pomeron collisions with

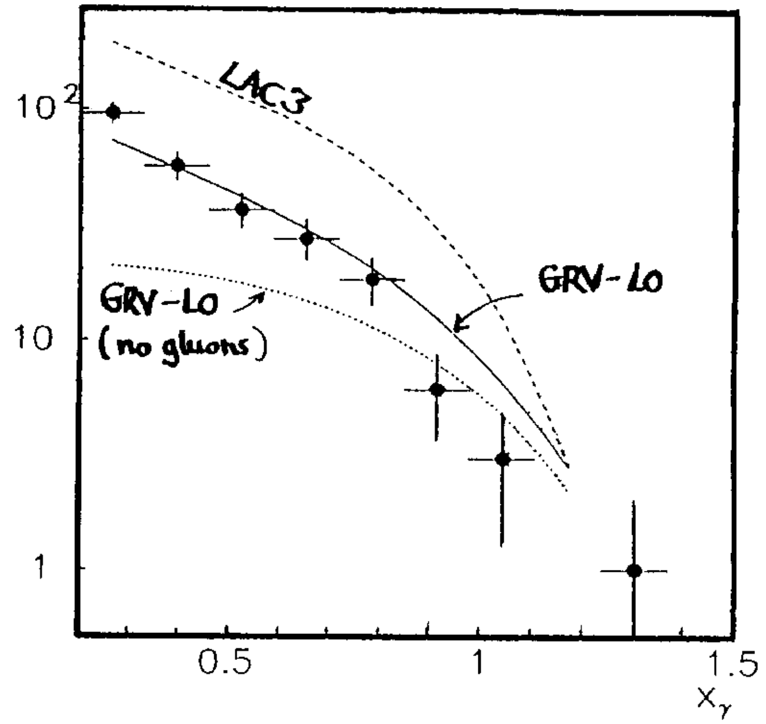

Figure 11: Distribution of x_γ, the fractional momentum x carried by partons in photons. The ordinate is the number of events. A gluonic component is needed to describe the data (solid line).

the intriguing possibility of measuring the Pomeron structure another way. In the latter case it would presumably be necessary to detect the quasi-elastic proton to "tag" the Pomeron; this is planned for future running.

An experiment with some sensitivity to shadowing in the low x region was reported [17] by Carlos Salgado. Experiment E665 (Fermilab) looked for one or two jets from 490 GeV muon-nucleus collisions and muon-proton collisions. One result shown is the ratio of 2-jet events to 1-jet events in a nucleus, divided by the same ratio for deuterium. The ratio drops from about 1.0 at $x = 0.1$ to about 0.8 near $x = 10^{-3}$, and this is interpreted as evidence of shadowing. The idea is that the 1-jet events come mostly from photons being absorbed on a quark, while the 2-jet come from $\gamma + g \Rightarrow \bar{q} + q$ jets. I think this is quite a complicated situation and any conclusions should be drawn with caution at this stage.

5. Di-jets and Rapidity Gaps

I return now to the question of di-jet events (especially forward jets) at the Tevatron and rapidity gaps in such events. Both CDF and D0 are now actively studying this question : can we find events with two balancing high p_T jets, far apart in rapidity and with a large hadronless gap in between? A gap is strictly speaking defined as a region in (pseudo-)rapidity with no particles at all, like a vacuum (Pomeron $\Longleftrightarrow$

vacuum!), and "large" means large enough that the probability of a gap that big being a fluctuation in a non-diffractive collision is negligible. A q-q scatter by a colorless exchanged object such as W,Z or photon could leave a gap if it is not extinguished by hadronization between spectators, for example (the "Gap Survival Probability" is at the center of the debate). The classical soft Pomeron can hardly carry 4-momentum transfers exceeding 100 GeV^2, so if jet-gap-jet events are seen at a rate above that expected for W,Z or photon exchange it signals a "hard Pomeron", strongly interacting but colorless and interacting with something like a point-like coupling to quarks and maybe gluons. This would be a very important discovery. Fig.12 illustrates the situation.

Paul Draper [18] presented a study by D0, selecting events with a pair of jets each above 30 GeV E_T, anywhere in the detector. Around each jet axis a circle of radius 0.7 in η,ϕ space is drawn, and if the jets are more than 1.4 units of η apart the space $(\Delta\eta, \Delta\phi = 360°)$ between the tangents is examined. This is called the $\Delta\eta$ interval, and Fig.13 shows the fraction of these intervals which appear empty (gap-like) as a function of $\Delta\eta$. Empty is defined as no electromagnetic towers of the calorimeter having a signal exceeding 200 MeV, a level as low as possible without having too much noise. The curve has to go through 1.0 at $\Delta\eta = 0.0$, and it falls off in a continuous curve but with an apparent flattening for $\Delta\eta$ exceeding 3.0. If this is real it looks like the interesting signal. However as Draper pointed out there are many systematic effects that can change the level: uranium or other noise in the interval or multiple interactions (pile-up) decrease the level while inefficiencies or regions of poor acceptance (for example between the cryostats) pull it up. So for now D0 quote an upper limit of 9.3×10^{-3} (95%cl) for the gap fraction for $\Delta\eta > 3.0$. So, strong colorless large-t exchanges may be there but they are not "common".

Dino Goulianos [19] presented the results of a Monte Carlo study, looking at the gap signatures that may be present even in non-diffractive collisions. Their Monte Carlo is simple and phenomenological, but it reproduces non-diffractive multiplicity distributions, rapidity and p_T distributions, so it is instructive to see what gap distributions all that implies. Making a "D0"-plot of the fraction of intervals that are empty vs interval size shows a gradual flattening out not dissimilar to that seen in the D0 data. It comes about just from energy-momentum conservation; if you have events with an unusually low multiplicity, just a few particles, because their p_T is small they must be well spaced out in rapidity and a big gap is thus likely. Of course the *cross section* for such events might be tiny if we did not have diffraction; furthermore the D0 events are active high multiplicity, still this study is a warning that things may not always be as they seem.

CDF has also started a search for "gap" events. They study the charged multiplicity distribution between the jet cones (between the $\Delta R = 0.7$ tangents) and look for an excess of zeros compared with a control region, or compared with a smooth extrapolation to zero. This data was not presented here, and I shall only say that the conclusion appears to be consistent with D0. CDF have recently added a special trigger on two forward jets with a reduced (20 GeV) E_T threshold to study this further, at the same time collecting data with two forward ($|\eta| > 1.7$) jets on the same

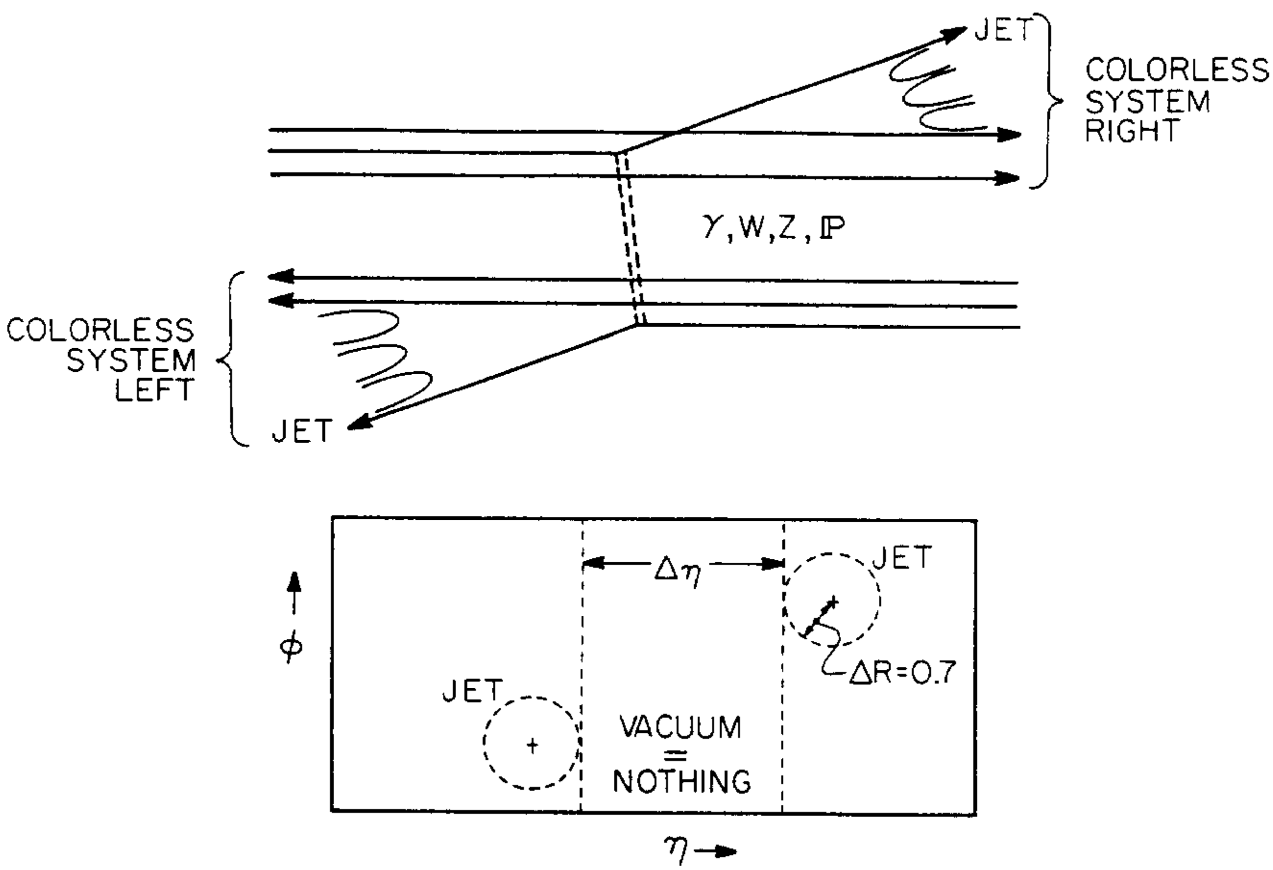

Figure 12: Diagram showing a large t colorless exchange in a $p\bar{p}$ collision, and the resulting signature in η, ϕ space for those events (how rare?) where the gap survives.

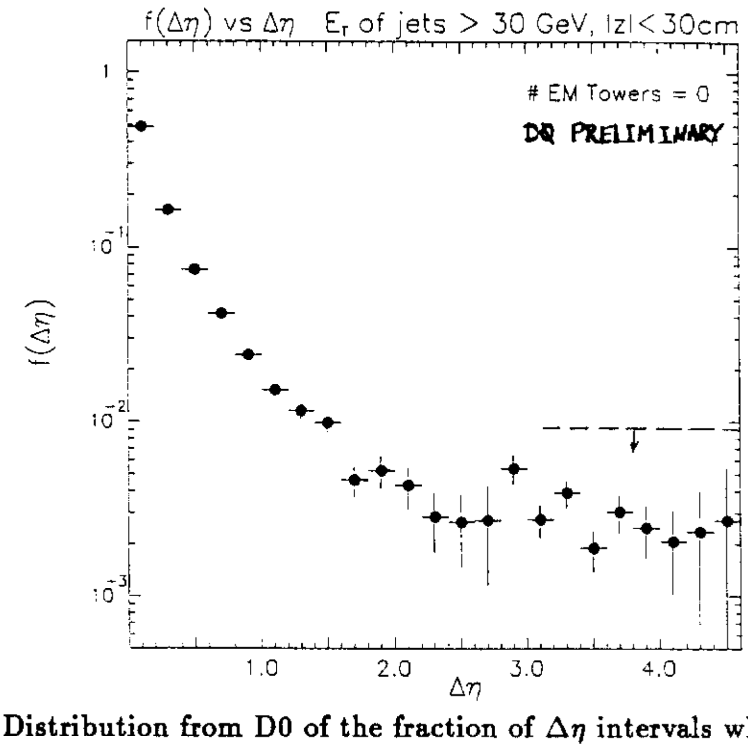

Figure 13: Distribution from D0 of the fraction of $\Delta\eta$ intervals which are empty (no e.m. towers above 200 MeV) *versus* $\Delta\eta$.

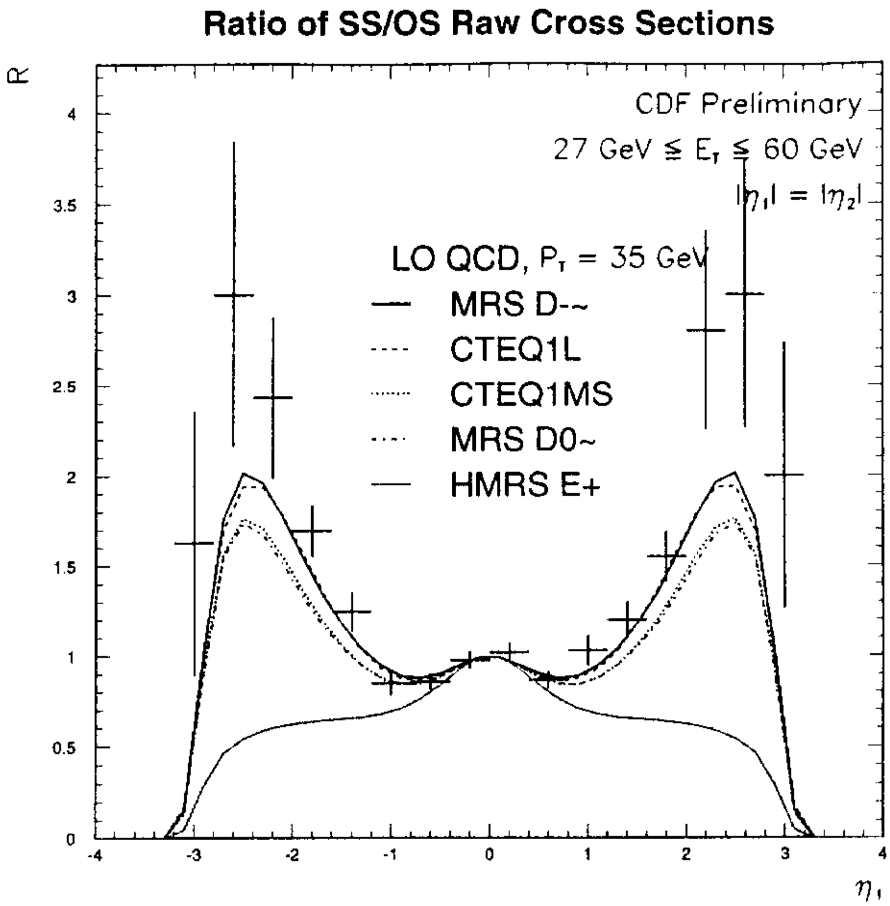

Figure 14: The ratio of cross sections for two jets to be at the same rapidity $\eta_1 = \eta_2$, or equal but opposite rapidities $\eta_1 = -\eta_2$, compared with various structure functions.

side (η both positive or both negative). The point of this, with jets still at modestly high E_T but as far forward as possible, is twofold. A fast forward same side jet pair comes from a collision between a high-x (e.g. $x \approx 0.5$) parton with a very low-x (e.g. 10^{-3}) parton, so we have a new way of measuring the low-x parton densities. It will however probably be difficult, requiring complicated corrections to the jet measurements to get at the partons. A first attempt (Fig.14) simply compares the ratio of jet pair rates at equal $|\eta|$ between same side (SS) and opposite side (OS) configurations and compares this with various structure functions. The lowest x-values contribute to the highest $|\eta|$. The lowest curve labelled HMRS E+ has already been excluded by other data, it is just left in to show the effect. Many systematic checks are needed before one could conclude that the data favor a high structure function at low x, and the data are preliminary. The same general idea would be better done with direct photons (γ + jet) which can be more cleanly measured and which select the q-g collisions, with the gluon mostly being the low x parton. A second use for the data with two forward (same side) jets is to extend the search for rapidity gap events, now with a much larger area of $\eta - \phi$ space to work in. Events with the whole of one polar hemisphere apparently empty (presumably having a high-x (anti)proton unobserved) are jetty high mass diffraction, of the type apparently seen by UA8.

6. Future Studies

Considering a "wish list" of other high energy diffraction experiments that one might like to see done in the future, I would include a measurement of double diffraction dissociation with both protons being excited via Pomeron exchange. This is similar to the jet-gap-jet configuration but not necessarily requiring high $|t|$. Compared to single diffraction, do we find factorization? The t-dependence could be very flat but is almost impossible to measure, especially at colliders. A fixed target experiment might be worthwhile. Next, we should study "Central Vacuum Excitation" or Double Pomeron Exchange (DPE) at the Tevatron and later at LHC/SSC. The masses excited reach 100 GeV at the Tevatron and 2000 GeV at the SSC (using the $x > 0.95$ rule of thumb). What about jets, heavy flavor and Drell-Yan (including W and Z production) in these vacuum excitations? Low p_T studies including Bose Einstein correlations can tell us the size of the Pomeron, and whether the concept itself makes sense. If so, how does the Pomeron "radius" depend on t?

Finally, let me suggest that a revealing experiment on the existence of the Odderon could be to look for centrally produced and totally isolated single omega mesons. Double Pomeron exchange forbids this, but Pomeron-Odderon would allow it. Schäfer et al.[20] have also suggested using central exclusive J/Ψ production to detect Odderons. At this conference Suh-Urk Chung advertised [21] the DPE mechanism as a powerful tool for spectroscopy at RHIC, the Relativistic Heavy Ion Collider under construction at Brookhaven. This has a precedent in a glueball search with the Axial Field Spectrometer (AFS) at the late ISR. Double Pomeron Exchange acts as a quantum number filter, selecting only $I^G J^{PC} = 0^+ EVEN^{++}$ states.

7. Spins and Asymmetries

Time did not allow me to do justice to some fascinating spin and asymmetry effects. Alan Krisch [22] talked about the persistence of spin effects at high p_T, where the ratio of cross sections for p p with [spins parallel : spins antiparallel] can be surprisingly large (a factor 4) for p_T around 2.0 - 3.0 GeV/c. Krisch described future possibilities at Fermilab in the Main Injector, at the SSC and at UNK. Aldo Penzo [14] also argued the case for polarized beams in the Main Injector and at RHIC to measure spin flip cross sections in elastic and other diffractive processes. Akihiko Yokosawa [23] showed that there are asymmetries in pion production at large Feynman-x, with π^+ and π^- showing opposite behaviors in their production with respect to the spin direction of the target proton. What is Nature trying to tell us here? Perhaps also W production with polarized protons has interesting asymmetries.

8. High Transverse Momenta and Masses at the Tevatron

Included in the experimental part of this workshop were reports from both CDF and D0 on high p_T and high mass physics, not obviously coming under the topic of diffraction but we can hopefully see the gap closing. It is not outrageous to suggest [24] that 15% of W and Z at the Tevatron could be diffractively produced (this is for a quark-dominated Pomeron, it would be much less for a gluonic Pomeron). It will be interesting to see what other high-mass/high p_T phenomena now studied by CDF and D0 have some diffractive component. Until recently CDF required a coincidence between forward hodoscopes (the Beam-Beam Counters) in the trigger and would have rejected most diffractive events; fortunately this has now been rectified. So many results were shown that I somewhat arbitrarily selected one or two from each experiment. Michael Fortner [25] talked on jet E_T and η distributions and showed how QCD non-scaling effects are necessary to fit the data. He then presented both photon + jet and W + jet data. The direct photon spectrum is shown in Fig.15 (there are about 3000 events above 30 GeV) and fits NLO QCD well except below 20 GeV. CDF found a similar discrepancy below 20 GeV [26]

Using their sample of about 10,000 Ws D0 presented, among other things, a plot of the number of associated jets above 15,20 and 25 GeV. Each extra jet costs about a factor of 10 in rate (α_S!) and there is no visible excess in the 4-jet bin as an optimist would hope to see from $t\bar{t}$ production. It is not so easy!

Srini Rajagopalan [27] reported electroweak results from D0, mainly W and Z production cross sections in both electron and muon decay channels and masses and widths. I will not reproduce the many numbers here, but apart from a problem with the electron energy scale they agree well with CDF measurements reported by Henry Frisch [28]. For example the W width is measured to be (2.06 $\pm$ 0.27) GeV compared with (2.033 $\pm$ 0.069 $\pm$ 0.057) reported by Frisch, and the ratio ($W \rightarrow e\nu/Z \rightarrow ee$) is 10.55 and 10.65 in the two experiments, equal within errors. Both CDF and D0 are studying events with both a W and a direct photon, from which information on the electric quadrupole moment and magnetic dipole moment of the W can be extracted. No surprises yet, but there are only only a few events. Pushpalatha Bhat [29] showed an event display of D0's best top candidate, with a near-100 GeV electron, a similarly stiff muon, two jets above 25 GeV E_T and large missing E_T. Without claiming it to *be* top, they say *if* it is, then the mass is (90% c.l.) between 130 and 170 GeV. They put a lower limit on the top mass of 103 GeV (95% c.l.) using 7.5 pb^{-1} of data, very similar to the CDF limit of 108 GeV with 16 pb^{-1} shown by Teruki Kamon [30]. Although the CDF analysis included more running the limit is only marginally higher because two candidates had been found! The talk by Kamon included limits on SUSY squarks and gluinos; it is difficult to summarize the results because they are multi-dimensional. As one example, if there are no cascade decays and assuming a light photino we have, at 90% c.l., $M_{\tilde{q}} > 126 GeV, M_{\tilde{g}} > 141 GeV$. The gluino and squark mass limits are however correlated. D0 also works on SUSY limits through the channel "3 jets + missing E_T" but did not present numbers yet; they did however exclude leptoquarks which would decay to an electron and a jet. Based on an integrated luminosity of $7.5 pb^{-1}$ they are excluded up to 126 GeV for 100% branching fraction to electrons, or 109 GeV for 50% branching fraction. Selecting from the many results in these CDF and D0 talks is difficult; but I present a picture (Fig. 16) of a CDF candidate

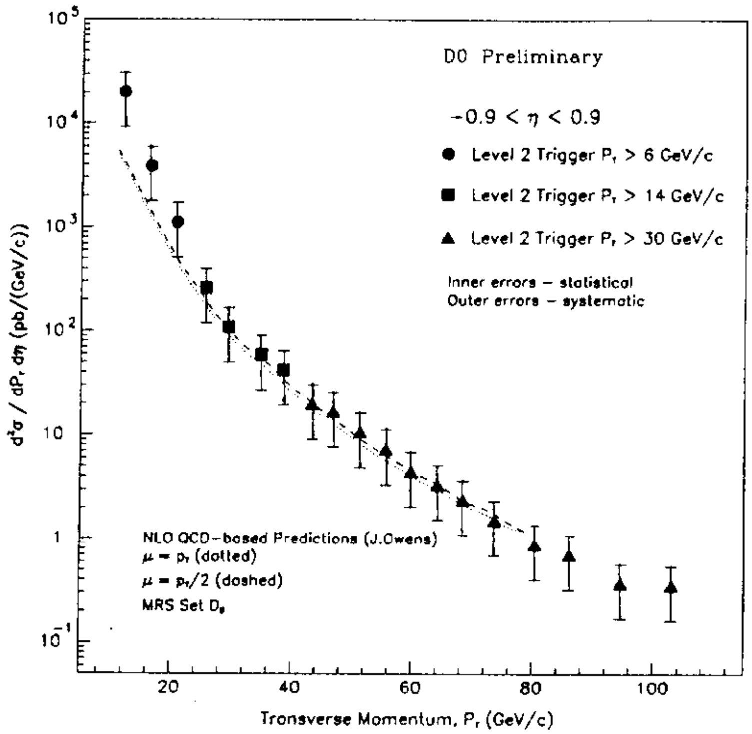

Figure 15: The spectrum of direct photons at large angles measured by D0. It is compared with NLO QCD calculations by Owens.

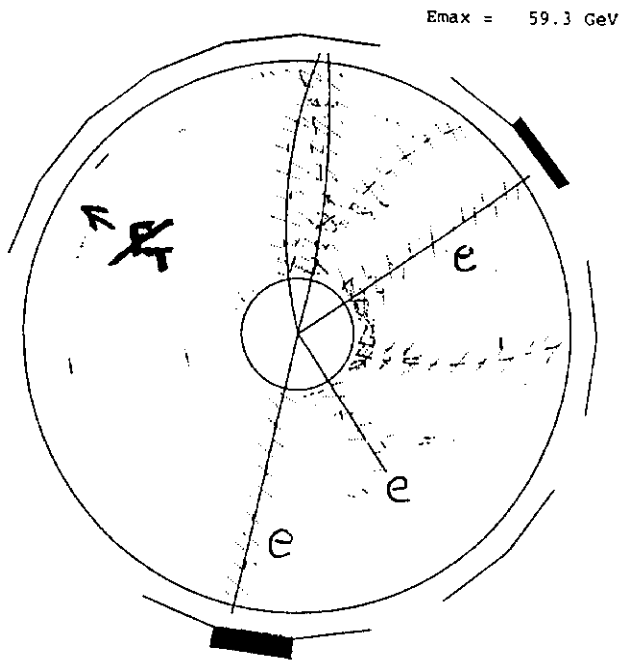

Figure 16: Transverse view of a CDF event containing three isolated high p_T electrons and missing E_T, probably due to associated W + Z production. Notice the low associated multiplicity.

(shown by Henry Frisch [28]) of associated production of Z and W, both decaying through the electron channel. This is perhaps "a bit lucky"; allowing both electron and muon channels we expect about 0.1 - 0.2 such events in 20 pb^{-1}. W^+W^- events are more common, and of course constitute a background for the top search. Notice how remarkably clean the event is, the associated hadronic activity being even less than a typical "minimum bias" event.

9. Disoriented Chiral Condensates and Cosmic Rays

Another collider experiment, E-864 or MiniMax, was described by Cyrus Taylor [31]. This experiment, with Bjorken and others, is to search for disoriented chiral condensates, a theoretical idea inspired by some cosmic ray events (Centauro, some JACEE events) which show an extraordinary fluctuation in the charged:photon ratio over some region of phase space. The idea is that the vacuum can get an abnormal orientation in isospin space, and this can be radiated away in "all π^o" or "all $\pi^\pm$". They plan to get some test data this fall. A talk by E.Feinberg [32] discussed the cosmic ray evidence (from Pamir) for aligned high energy jets interpretable as hard DDD = Double Diffractive Dissociation. The center of mass energy, if they are nucleon-nucleon collisions, is $\sqrt{s}$ = 5-15 TeV, a bit above the Tevatron. Another talk on cosmic ray phenomena by Hasegawa (Chacaltaya and Pamir Collaborations) interpreted data as indicating the existence of "hadrons in a new state". These particles appear to have a very short mean free path in lead, and are called "Chiron particles"; they have a cross section about twice the geometrical cross section on nuclei, and then when they interact give rise to particles with abnormally small p_T and frequently "abnormal persistency" in lead chambers. All this is very strange; perhaps more of us should spend more time in trying to understand what is going on. Often cosmic rays have given the first signs of genuine new physics. Maybe SSC physics will be wierder than we can imagine.

I apologize to experimental speakers whose work I have misrepresented or (horror!) left out, and I thank the organizers for inviting me to give this summary talk.

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