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# A Transient New Coherent Condition of Matter: The Signal for New Physics in Hadronic Diffractive Scattering

Saul Barshay[a] and Patrick Heiliger[b]

[a]III. Physikalisches Institut (A), RWTH Aachen

D–52056 Aachen, Germany

[b]Institut für Theoretische Teilchenphysik

Universität Karlsruhe

D–76128 Karlsruhe, Germany

**Abstract**

We demonstrate the existence of an anomalous structure in the data on the diffractive elastic scattering of hadrons at high energies and small momentum transfer. We analyze five sets of experimental data on $p(\overline{p}) - p$ scattering from five different experiments with colliding beams, ranging from the first– and second–generation experiments at $\sqrt{s} = 53$ GeV to the most recent experiments at 546 GeV and at 1800 GeV. All of the data sets exhibit a localized anomalous structure in momentum transfer. We represent the anomalous behavior by a phenomenological formula. This is based upon the idea that a

transient coherent condition of matter occurs in some of the intermediate inelastic states which give rise, via unitarity, to diffractive elastic scattering. The Fourier–Bessel transform into momentum–transfer space of a spatial oscillatory behavior of matter in the impact–parameter plane results in a small piece of the diffractive amplitude which exhibits a localized anomalous behavior near a definite value of $-t$. We emphasize in addition, possible signals coming directly from such a new condition of matter, that may be present in current experiments on inelastic processes.

There exists an anomalous structure in the diffractive elastic scattering of hadrons at high energies and small momentum transfer. This anomaly exists in at least five sets of experimental data from five different experiments on $p(\overline{p}) - p$ scattering. These experiments have been performed with colliding beams over a period of some twenty years, at center–of–mass energies, $\sqrt{s}$, equal to 53 GeV [1], [2], [3], 546 GeV [4], [5] and 1800 GeV [6]. The anomalous behavior in the differential cross section consists of a small, narrow peak at a point near to a four–momentum transfer $-t \simeq 0.08\,(\mathrm{GeV/c})^2$. This is followed by a marked dip near $-t \simeq 0.10\,(\mathrm{GeV/c})^2$ and by a subsequent narrow peak at $-t$ in the range $0.12 - 0.16\,(\mathrm{GeV/c})^2$. The anomalous behavior can be exhibited by taking the ratio of the experimental data to a good–fit, smoothly–varying theoretical or phenomenological representation of all of the data at small momentum transfers. It can also be exhibited in absolute value by taking the difference between the experimental data and the smoothly–varying theoretical representation. This is seen in Fig. 1 which, for illustration, we reproduce from an early analysis [7] of the apparent anomaly in the data from the first–generation collider experiment at 53 GeV [1], [8]. In this paper we analyze the new $\overline{p}p$ data [5] at 541 GeV from the UA4/2 experiment at CERN and the $\overline{p}p$ data [6] at 1800 GeV from the E–710 experiment at Fermilab. We also analyze the data [4] at 546 GeV from the original UA4 experiment. We go back and analyze the very extensive $pp$ data at 53 GeV from the second–generation experiment at the CERN intersecting storage rings. We find that a localized anomalous behavior is present in all of these sets of data. It also appears to be present in the fixed–target experiments performed at Fermilab with very high statistics [9] on $\pi^{\mp}p$ elastic scattering at 200 GeV/c, (commented upon further below). On the basis of the present analysis of the data, we consider that there is evidence for an unusual phenomenon which is giving a signal in hadronic diffractive scattering. This is probably new physics. Guided by a definite physical possibility [7], we represent the anomalous behavior in the data by a phenomenological formula. The idea is that in the physical intermediate states which occur from the dominant inelastic processes that give rise, via unitarity, to diffractive elastic scattering, there is a small fraction involving the formation of a coherent condition in hadronic matter. This system is relatively long–lived due to small effective velocities for signal propagation within it. The system becomes extended over the impact–parameter plane. In this plane, there occurs within the system a coherent oscillatory behavior of matter, characterized by a definite non–zero momentum. The Fourier–Bessel transform of this spatial oscillatory behavior into momentum–transfer space gives rise to a small piece of the diffractive amplitude which exhibits a localized anomalous behavior near a definite value of $-t$. An oscillatory behavior in $t$ occurs in the region near this value. This is because of the approximate localization of the center of mass of the coherent system which moves to a distant point along the collision axis before the system breaks down into pions. In concluding we emphasize in addition possible signals coming directly from such a coherent system, signals which may be present in past and current experiments on inelastic processes [10], [11], [12].

To augment Fig. 1, we begin our present analysis by exhibiting in Fig. 2 the ratio of the experimental differential cross section $\frac{d\sigma_{el}(pp)}{dt}$ at 53 GeV, from the second–generation ISR experiment [2], [3] to a good theoretical representation [13], [14] (on a $\chi^2$–basis [F1]) of all of the data from $-t \simeq 0$ to $-t \simeq 2\,(\mathrm{GeV/c})^2$. In Fig. 2 as in Fig.1, we are concentrating our analysis on the region of a hypothetical, quite localized anomalous behavior, that is the region $0.07 < -t < 0.2\,(\mathrm{GeV/c})^2$. In Fig. 2 one observes the anomalous structure, the same as that in Fig. 1.

With a big jump in energy, we turn to the new UA4/2 data [5] for $\frac{d\sigma_{el}(\overline{p}p)}{dt}$ at 541 GeV. In Fig. 3 we show the ratio of this data to a good theoretical representation [13], [14], [15] (again on a $\chi^2$–basis) of all of the data [F2]. The data from the UA4/2 experiment stops at the last interval [F3] $0.117 \le -t \le 0.12$ $(\mathrm{GeV/c})^2$. We promptly augment this data with the data from the first UA4 experiment [4] at 546 GeV; the ratio is shown in Fig. 4 for the relevant region $0.07 < -t < 0.2\,(\mathrm{GeV/c})^2$. Aspects of the anomalous structure at 53 GeV appear again in the data from the two separate experiments at 541 and 546 GeV. The evident part of the structure at 53 GeV, the peak at $-t \simeq 0.16\,(\mathrm{GeV/c})^2$, has moved in to about $0.12\,(\mathrm{GeV/c})^2$. The dip at $-t \simeq 0.12\,(\mathrm{GeV/c})^2$ has moved in to about $0.10\,(\mathrm{GeV/c})^2$, and there is again a lesser peak at about $0.08\,(\mathrm{GeV/c})^2$. In the more extensive data from the first UA4 experiment, there may be a dip at about $0.14\,(\mathrm{GeV/c})^2$, followed by a lesser peak as $-t$ moves out toward $0.2\,(\mathrm{GeV/c})^2$. Actually, the indication of structure in the data is directly visible in the data for $\frac{d\sigma_{el}}{dt}$ near $-t = 0.1\,(\mathrm{GeV/c})^2$: observe the insert in Fig. 2 of ref. [13].

We come now to the data [6] for $\frac{d\sigma_{el}(p\overline{p})}{dt}$ at $\sqrt{s}$ = 1800 GeV, the highest energy presently measured. The ratio of this data to a theoretical representation [15] is shown in Fig. 5. The structure at $-t \simeq 0.12\,(\mathrm{GeV/c})^2$ is again present, as is the possible structure following this. Data points in the region of the dip at $-t \simeq 0.10\,(\mathrm{GeV/c})^2$ are lacking in this experiment. The CDF collaboration at Fermilab has measured $\frac{d\sigma_{el}}{dt}$ for $\overline{p}p$ scattering at 546 and 1800 GeV [16]. The data is not tabulated in the paper [16]; at 546 GeV, data points are plotted in Fig. 9a of the paper only out to $-t \leq 0.08\,(\mathrm{GeV/c})^2$. At 1800 GeV the data for $\frac{d\sigma_{el}}{dt}$, measured in each spectrometer arm separately, indicates visually in Fig. 9c of the paper the possibility of structure near $-t = 0.1\,(\mathrm{GeV/c})^2$. This is so in particular for the data measured in arm –0 which detected symmetrically scattered elastic events with respect to the beam. The new experiment on elastic scattering being performed at Fermilab should try to probe the region $0.06 \leq -t < 0.2\,(\mathrm{GeV/c})^2$ with new precision.

Before going on to a more detailed analysis of the anomalous structure, we emphasize an essential point. The evidence for a local structure in the diffraction pattern does not depend upon the theoretical details of the smoothly–varying representation of all of the data which is used as a reference for comparison (to form the above ratios). As long as the theory represents the data well overall at any of the above energies, the local structure will appear in the ratio. As evidence of this fact, we note that in the original analysis [7] of the first 53 GeV data [1] reproduced in Fig. 1, the comparison was made to an adequate early phenomenological representation [8] based upon parameterization of the eikonal [17], [18], [19]. Indeed, the deviations are directly visible in the data for $\frac{d\sigma_{el}}{dt}$ itself: note Figs. 2c and 2d of reference [1]. Recently, the new data [5] at 541 GeV has been compared to a further good representation [20] based upon the eikonal [17], [18], [19] with emphasis on the $t$–region of Coulomb–nuclear interference [21]. The authors have noted [21] that there appears to be oscillatory structure in the last bins of $t$ to which the data extends. We shall have additional evidence below where we comment upon comparison of the fixed–target $\pi^{\mp} - p$ data [9] from Fermilab with a smoothly–varying, phenomenological representation [9] of all of that data.

In our present analysis we have used a form for the $p(\overline{p})-p$ diffractive (imaginary) amplitude which contains a new general structure; this structure is the result of a derivation [22], [13], [14], [15] which incorporates fluctuations [13] in the eikonal into the general geometric picture [17], [18], [19]. Since we have published comprehensive calculations [13], [14], [15] of the experimental consequences of the new structure for energies up to 1000 TeV, as well as detailed comparison [14] with another good representation [20] of the present data, we make only a couple of general statements here. One is that at super–high energies which we have estimated [15] to be $\sqrt{s} \sim$ 1000 TeV, the new structure closely approaches a new limiting form [22] for the $S$–matrix in impact–parameter ($b$) space as a function of energy $S(b, s) \sim 1/(1+s^{\lambda} f(b))$ where $\lambda(s)$ approaches a small limiting value of the order of magnitude of 0.15. The second remark is that there is a very important physical difference between the behavior of the new structure [22] in the geometric picture and the behavior of the usual structure [17], [18], [19] with parameterization of the eikonal [20], as $\sqrt{s}$ increases into the TeV range. The new structure gives rise to more increase [15] in the total cross section in each succesively higher domain of $\sqrt{s}$. Via the dispersion relation [23], [15], this gives rise to a slowly but steadily increasing value of $\rho$, the ratio of real to imaginary part of the hadronic amplitude. We predict that $\rho$ rises to a value of about [15] 17 % at 17 TeV instead of decreasing to less [20] than 12 %. In summary, with $Im\,\overline{F}(s,t)$ given explicitly by eqs. (1, 2, 3) in the second paper of reference [15], our theoretical representation is

$$\frac{d\sigma}{dt} = \left| i\, Im\,\overline{F}(s,t) + \rho \frac{d}{dt}\left\{ t\, Im\,\overline{F}(s,t)\right\} \pm \frac{2\alpha}{|t|}\, e^{\mp i\alpha\phi(t)}\, G^2(t) \right|^2 \qquad (1)$$

Although it becomes negligibly small in the region of $t$ that we are emphasizing in this analysis of anomalous structure, we have included the Coulomb amplitude [23], [5] with $\alpha = 1/137$, $\phi(t) = \{\ln(\frac{0.08}{|t|}) - 0.577\}$, $G(t) = 1/(1 + \frac{|t|}{0.71})^2$, and the $+(-)$ sign relevant for $\overline{p}(p) - p$ scattering. We include the contribution to $\dfrac{d\sigma}{dt}$ of the real part of the hadronic amplitude, proportional to $\rho$, using Martin's approximate form [24] with empirical values for $\rho$. For $pp$ scattering [23] at 53 GeV $\rho = 8\,\%$; for $\overline{p}p$ scattering we use our calculated [15] values $\rho = 13.9\,\%$ at 546 GeV and $\rho = 15\,\%$ at 1800 GeV. These predictions agree with experiment [5], [25]. We have checked that including the real amplitude in an alternative manner, simply in the form $\rho\, Im\,\overline{F}$, a common phenomenological practice [5], [9], [20], [23], [25], does not influence the actual evidence for the anomalous structure. We comment upon this in detail below.

We proceed now to extract the anomalous structure as a definite quantity. The addition of a small unusual diffractive amplitude $\Delta(s,t)$ to the main diffractive amplitude $\overline{F}(s,t)$ results in an addition to the differential cross section of a small piece given by

$$\Delta\left(\frac{d\sigma}{dt}\right) = 2\overline{F}(s,t)\Delta(s,t) \tag{2}$$

A good way to extract the anomalous amplitude $\Delta(s,t)$ (a quantity measured in $\{\mathrm{mb}/(\mathrm{GeV/c})^2\}^{1/2}$ ) is then to study the quantity $D$ defined by

$$\begin{aligned} D(s,t) &= \frac{\left\{\left(\frac{d\sigma}{dt}\right)_{expt.} - \left(\frac{d\sigma}{dt}\right)\right\}}{\left(\frac{d\sigma}{dt}\right)^{1/2}} \\ &= \left(\frac{d\sigma}{dt}\right)^{1/2}\{R(s,t)-1\} \end{aligned} \tag{3}$$

where $\frac{d\sigma}{dt}$ is the theoretical representation in eq. (1) and $R(s,t)$ are the ratios exhibited in Figs. (2–5). This we have done with the results shown in Fig. 6 for the second–generation [F4] $pp$ data at 53 GeV, in Fig. 7 for the new UA4/2 $\overline{p}p$ data at 541 GeV, in Fig. 8 for the original UA4 data at 546 GeV, and in Fig. 9 for the E–710 $\overline{p}p$ data at 1800 GeV. In Fig. 10 we have placed the data from 546 and 1800 GeV on a single graph in order to clearly exhibit the consistent pattern from these two different scattering experiments at the highest present energies. The similar definite structure in Figs. (6–10) constitutes evidence for a localized anomalous amplitude. A prominent aspect in this amplitude is a small narrow peak which is at $-t \simeq 0.156\,(\mathrm{GeV/c})^2$ at 53 GeV; this peak moves in to $-t \simeq 0.12\,(\mathrm{GeV/c})^2$ at 546 and 1800 GeV. There is a dip near $-t = 0.1\,(\mathrm{GeV/c})^2$ and a peak near $-t = 0.08\,(\mathrm{GeV/c})^2$. There is a damped, slightly irregular oscillatory behavior prior to this peak at 53 GeV. The oscillatory behavior, present on both sides of the peak, becomes more pronounced, more rapid and more regular at 546 GeV. With a magnitude of about 0.35 $\{\mathrm{mb}/(\mathrm{GeV/c})^2\}^{1/2}$ the peak amplitude (times 2) is 10 % of $(\frac{d\sigma}{dt})^{1/2}_{expt.}$ at $-t \simeq 0.156\,(\mathrm{GeV/c})^2$ at 53 GeV. At 546 GeV the anomaly is about 6.5 % of $(\frac{d\sigma}{dt})^{1/2}_{expt.}$ at $-t \simeq 0.12\,(\mathrm{GeV/c})^2$; the reduction factor is simply the ratio of total cross sections at 53 and 546 GeV, i.e. $\sim\ (\frac{42\,mb}{61\,mb})$. The uncertainty in our extraction of the anomalous amplitude as a definite quantity lies essentially in the uncertainty in overall scale shifts of the ratios $R$ in Figs. (2–5). Overall scale shifts do <u>not</u> affect the evidence for a similar localized structure in all of these ratios. They do affect the extraction of a consistent anomalous amplitude. At 53 GeV and 546 GeV the $(\frac{d\sigma}{dt})_{expt.}$ have an uncertainty of about 2 %, corresponding to about $\pm 1$ mb in the total cross sections. Our theoretical representation in eq. (1) has at least a similar uncertainty. Thus the overall scale of $R$ in Fig. 2 and in Fig. 4 has a $4 - 5$ % uncertainty [F5]. In Fig. 2 we have already placed the $R$ essentially uniformly down by lowering $(\frac{d\sigma}{dt})_{expt.}$ by 2 % and raising $\frac{d\sigma}{dt}$ by 3 %. This 53 GeV data is in agreement with the 53 GeV data from the different experiment shown in Fig. 1. In Fig. 4 for the $R$ at 546 GeV we have lowered $(\frac{d\sigma}{dt})_{expt.}$ by 2 % and raised $\frac{d\sigma}{dt}$ by 2 %. At 1800 GeV, where our $\frac{d\sigma}{dt}$ constitutes a prediction [15] based upon two parameters [F6] which are fit to the total cross sections at 53 and 546 GeV, we have raised $R$ in Fig. 5 uniformly by raising $(\frac{d\sigma}{dt})_{expt.}$ by 5 %. This is because we believe that the central value of the total cross section ($\sigma_t = 72.8 \pm 3.1$ mb) obtained in this experiment [6] is low. We predict [15] about 76 mb; it is noteworthy that the CDF collaboration at Fermilab has recently stated [26] a value of $80.03 \pm 2.24$ mb. The size and the overall structure of the extracted anomalous amplitude is really consistent from 53 up to 1800 GeV. Also the inclusion of the real hadronic amplitude in the alternative manner as $\rho \, Im \, \overline{F}$ in eq. (1) results in a consistent structure. The effect at 53 GeV is negligible since $\rho^2 \approx 0.64\,\%$ empirically [23]. The presence of the anomalous structure at 53 GeV is thus the best evidence for its not depending essentially upon $\rho$. The quantitative effect at 541–546 GeV ($\rho^2 \approx 2\,\%$) is essentially an overall rescaling of the extracted anomalous amplitude: The peaks are a little lower and the dip correspondingly a little deeper, by about 0.1 $\{\mathrm{mb}/(\mathrm{GeV/c})^2\}^{1/2}$. This effect is immediately understandable, because Martin's theoretically–motivated form for taking account of the $\rho$ term in eq. (1) has a smooth shallow minimum (zero) in the region of $-t$ between 0.1 and 0.2 $(\mathrm{GeV/c})^2$; this is absent in the alternative form. This slight overall scale change can be compensated by an overall rescaling of the ratios $R$ in Figs. (3, 4), back up by about $2\,\%$. The structure in the anomalous amplitude is not changed, although its precise size as we have extracted it, has some uncertainty related to the correlated uncertainties in the overall scale of the $R$ and in the manner of taking account of the small contribution to $\dfrac{d\sigma}{dt}$ from the $\rho^2$ term. We remark that we have generated and studied some 200 plots to check out these statements. Thus we now attempt to quantitatively describe the anomalous structure in terms of the properties of a physical model.

From the outset we have been motivated in our analysis to consistently isolate the localized anomaly in all of the data by a definite physical model whose general characteristics would give rise to such behavior. Diffractive elastic scattering is the "shadow" of all inelastic processes. In a small fraction of these intermediate states the formation of a hypothetical coherent condition in a system of hadronic matter evolves. The system in which this coherent condition develops is hypothetically long–lived on the usual scale of hadronization times ($\sim 2\cdot 10^{-23}$ sec), and the system becomes extended over the impact–parameter plane (the plane perpendicular to the collision axis). A coherent oscillatory behavior of matter develops within the system in the plane. The coherent oscillation is characterized by a fairly definite non–zero momentum. The relevant Fourier–Bessel transform [17] of this spatial oscillatory behavior into momentum–transfer space (the space of transverse momentum at small scattering angles with $\sqrt{-t} \simeq \frac{\sqrt{s}}{2}\Theta$ ) gives rise, in general, to a small piece of the diffractive amplitude which exhibits a localized anomalous behavior near a definite value of momentum transfer given by the non–zero momentum $\sqrt{-t_0}$. This is the essential feature of the physical idea and we parameterize this by a factor in the anomalous amplitude, $e^{-R_b^2(\sqrt{-t}-\sqrt{-t_0})^2/4}$. It is possible for the center of mass of the coherent system to move rather rapidly along the collision axis in the collision c.m., and thus the system's dimension is Lorentz contracted in the longitudinal direction. During its extended intrinsic lifetime prior to its breaking down into pions (which lifetime is Lorentz–dilated by the $\gamma(s)$ factor from its motion), the c.m. of the coherent system can reach a fairly definite, distant point (from the collision origin) along the collision axis. The ordinary Fourier transform of an approximately localized position for the system to break down, into the space of a relevant conjugate momentum which is the change in the longitudinal momentum $\sim -t/\sqrt{s}$ in the diffractive scattering, gives rise in general to an oscillatory piece of the amplitude.

We parameterize this secondary feature by an oscillatory factor in the anomalous amplitude which is either damped and a bit irregular as described by a Bessel function $J_0$, or is not damped and regular as described by a cosine. The general simplified structure of the anomalous amplitude, with possible energy dependence of the parameters, is thus

$$2\,\Delta(s,t) = A(s)\; e^{-R_b^2(s)(y-y_0(s))^2/4} \;\cdot \begin{cases} J_0\left\{\left(\frac{T}{2m(s)}\right)(y^2 - y_0^2(s))\right\} \\ \text{or } \cos\left\{\left(\frac{T}{2m(s)}\right)(y^2 - y_0^2(s))\right\} \end{cases} \tag{4}$$

$$\text{with} \quad y = \sqrt{-t}, \;\; A \text{ in } \left\{\mathrm{mb}/(\mathrm{GeV/c})^2\right\}^{1/2}$$

Note that in the argument of the oscillating factor the $1/\sqrt{s}$ energy dependence coming from the longitudinal momentum–transfer variable is cancelled by the $\sqrt{s}$ coming from time–dilation factor $\gamma(s) = \sqrt{s}/2m(s)$ where $m(s)$ is an effective mass–like parameter which includes $1/\lambda$ where $\lambda$ is the fraction of $\sqrt{s}/2$ involved in the system's motion ($0 < \lambda < 1$) [F7]. The non–zero momentum characterizing coherent oscillation in the impact–parameter plane is $y_0$. Apart from the overall amplitude $A(s)$ which depends also upon details of the particular collision process, there are intrinsic length ($R_b$) and time ($T$) parameters, with $R_b(s)$ essentially determining the narrowness of the structure around $y_0$. Although evolving to some extension on the impact–parameter plane significantly larger than the dimension characterizing the initial collision $\sim 1/m_\pi = 1.4$ fm, the condensate dimension is finite and this limits attaining a very definite value for $y_0$, because of the uncertainty of order $1/R_b(s)$. The hypothetical coherent system is evolving toward some equilibrium condition, but it is limited by the intrinsic, though extended hadronization time

$\sim T$. The parameters $y_0, R_b$ and $T$ characterize the essential physical aspects of the coherent system, and are necessary [F7]. We have investigated a definite model patterned after studies of pion condensation in a nuclear medium [27], but involving quasi–pions (correlated quark–antiquark pairs with small (mass)$^2$) propagating in a dense medium of "dressing" quarks and antiquarks, looking for the onset of a coherent condition [28] that contributes a negative energy density in the medium. The essential dynamical element which makes this possible is the existence of a pseudoscalar (quasi–)boson with quite small (mass)$^2$ and strong, low–energy, $P$–wave interaction with fermions. This allows for the possibility of cancellation of the positive, kinetic and (mass)$^2$ terms by the attractive momentum–dependent interaction [27]. For orientation we have attempted to roughly estimate [28], in such a coherent system, the parameters relevant for the anomalous amplitude in eq. (4). One result [27] is that $T$ is significantly increased from an apriori hadronization time of about $2 \cdot 10^{-23}$ sec because the effective velocity for signal propagation by which parts of the medium communicate (and hence hadronization is carried out) is much smaller than that of light. This is related to the fact that $R_b$ increases only as $\sqrt{T}$. The region of the coherent momentum is of the order of magnitude of $2\, m_\pi$. Using estimated parameters [28] in eq. (4) $y_0 = 0.395\,(\mathrm{GeV/c}), R_b = (2.7/m_\pi), \{T/m\} = \{22/m_\pi(1\,\mathrm{GeV})\}$ with the $J_0$, and taking $A = 0.35$, we obtain the curve for the anomalous amplitude shown in Fig. 6. In the big jump in energy from 53 to 546 GeV, one guesses that the coherent system may become more "sharply" defined, that is $R_b(s)$ could increase, the parameter $\left\{\frac{T}{m(s)}\right\}$ could increase and the oscillatory factor can become regular with little damping. In addition, the increasing density of the fermionic medium in general allows for a somewhat smaller value of momentum $y_0$. The single curve compared to all of the data in Figs. 7, 8, 9, 10 is from eq. (4) with the cosine and with $A = 0.35$, $y_0(s) = 0.346\,(\mathrm{GeV/c})$, $\{T/m(s)\}$ increased by 2 to $\{44/m_\pi(1\,\mathrm{GeV})\}$, and $R_b(s)$ increased by $\sqrt{2}$ to $(3.8/m_\pi)$.

We have isolated a localized anomalous structure in five sets of collider data on $p(\overline{p}) - p$ diffractive scattering. This anomaly apparently also exists in the high–statistics fixed–target data from Fermilab [9], in particular for $\pi^{\mp}p$ scattering at 200 GeV/c. For $\pi^- p$ scattering this can be seen directly in the differential cross section data near to $-t = 0.1\,(\mathrm{GeV/c})^2$ in Fig. 14 of the first paper in reference [9]. It can be seen well in Fig. 6 of the second paper, which we have reproduced here in Fig. 11. There, the local slopes $b(t)$ from the data $(\frac{d\sigma}{dt} \propto e^{b(t)t})$ are compared to those occurring in a smoothly–varying phenomenological fit to all of the data established by the experimentalists themselves [9]. The anomalous, low value of the local slope just below $-t = 0.1\,(\mathrm{GeV/c})^2$ is evident for $\pi^- p$ and $\pi^+ p$, and is possibly also present for $pp$.

We have shown that the localized anomalous structure in hadronic diffractive scattering can be represented [F8] by certain rather general features of a model based upon a transient new coherent condition of matter occurring in some of the inelastic intermediate states. Such a coherent condition could give direct unusual signals in current (and past) experiments on inelastic processes. An important signal would be an anomalous level of soft photons. If charged currents exist during the evolution of the coherent system, then it has been shown that soft photons will be emitted [29]. In the system, the energies can be very small on the usual scale of $m_\pi$, down to $E_\gamma$ of the order of $1/T \simeq 6$ MeV with a bremsstrahlung–like spectrum [29], [28]. We have estimated [28] that the level of anomalous emission can reach several times the level of the bremsstrahlung from incoming and outgoing charged hadrons. Since the latter is at the level [12] of about 2 %, this corresponds to a soft photon occurring in of the order of 10 % of inelastic collisions. In fact this is about the same as the relative size of the anomalous effect in diffractive scattering that we have analyzed in this paper. Anomalous emission of soft photons has been observed [10], [11], [12] and is being observed presently [30] in certain experiments at CERN. For a coherent system without charged currents, an unusual signal would be the materialization into some neutral pions with anomalously small transverse momenta $\sim 1/R_b < 50$ (MeV/c). These estimates for very small momenta have used the parameters $T$ and $R_b$ from our representation of the anomalous structure in Fig. 6.

High–energy particle physics has been a science guided by careful attention to the results of laboratory experiments (including originally those using cosmic rays). Attention to all experimental results, including unusual effects that do not seem to fit in, is important today. In this spirit it would seem that the unusual structure that we have exhibited in the present analysis of old and new scattering data deserves further experimental investigation [F3] in an effort to establish new physics. It can be a signal for a transient new coherent condition of hadronic matter.

## Added Note (April 19, 1994)

The CDF collaboration has kindly sent us their (combined–arm) data for $\frac{d\sigma_{el}}{dt}$ at 1800 GeV. In Fig. 12 we show the ratio function for this data (stars). To facilitate comparison, Fig. 12 also contains the ratio function for the E–710 data (circles) reproduced from Fig. 5. Both data sets are normalized to $\sigma_{tot}(\text{theor}) \simeq 76$ mb. We thank Paolo Giromini and the CDF collaboration.

## Footnotes

[F 1 ] For the detailed demonstration of the $\chi^2$ quality we refer the reader to Fig. 1 of reference [14] and Fig. 3 of reference [13].

[F 2 ] Here we refer to the more complete data from the first UA4 experiment (reference [4]) in the domain $0 < -t < 1\,(\mathrm{GeV/c})^2$. For the detailed demonstration of the $\chi^2$ quality of the theoretical representation, we refer the reader to Fig. 2 of reference [13] and Fig. 3 of reference [14].

[F 3 ] S.B. thanks Maurice Hagenauer for explaining to him at CERN the technical reasons for this unfortunate fact. The UA4/2 experiment was of course designed to measure again the value of $\rho$ (reference [5]), and hence to concentrate upon the region of the main interference between hadronic and Coulomb real amplitude; this region is near $-t = 0.001\,(\mathrm{GeV/c})^2$. Experiments to concentrate upon the limited $t$ region of the hypothetical anomalous structure have never been carried out. They should be.

[F 4 ] We mention here that we have examined the data at 62.5 GeV (references [2], [3]). There is also structure in this data as one approaches $-t = 0.1\,(\mathrm{GeV/c})^2$, but this data has a curious, complete absence of data points between $-t = 0.1$ and $0.2\,(\mathrm{GeV/c})^2$.

[F 5 ] The new but limited data at 541 GeV is not tabulated in $\{\mathrm{mb}/(\mathrm{GeV/c})^2\}$ (reference [5]). We have fixed the ratio $R$ at the dip to agree with that at 546 GeV.

[F 6 ] These are the two parameters which determine the logarithmic growth with energy of the central opacity, given in eq. (4) of the first paper in reference [15].

[F 7 ] The quanitity $\{\frac{T}{m(s)}\}$ can of course be taken as a single phenomenological parameter, giving together with $A$, $y_0$, and $R_b$, four physical parameters.

[F 8 ] We use the word "representation" because the main thrust of the present paper is to demonstrate and to isolate the anomalous structure in the data. The fact that the anomaly can be reasonably represented within a definite physical model perhaps lends some force to its existence.

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## Figure Captions

Fig. 1 The figure reproduced from ref. [7] shows in a) in the relevant region of $t$ the data on $\frac{d\sigma_{el}}{dt}$ from the first–generation CERN ISR experiment for $pp$ elastic scattering at $\sqrt{s} = 53$ GeV [1] in ratio to a smoothly–varying, good phenomenological fit from that time to all of the data [8]. In b) the absolute difference between experiment and theory is shown. The curve is simply a phenomenological representation of the peak structure given in ref. [7].

Fig. 2 The data on $\frac{d\sigma_{el}}{dt}$ from the second–generation CERN ISR experiment for $pp$ elastic scattering at $\sqrt{s} = 53$ GeV [2], [3] in ratio to a smoothly–varying, good theoretical representation of all of the data, using eq. (1) in the text below and eqs. (1, 2, 3) in the second paper of ref. [15] for $Im\,\overline{F}(s,t)$.

Fig. 3 The data on $\frac{d\sigma_{el}}{dt}$ from the new UA4/2 experiment at the CERN $\overline{p}p$ collider at $\sqrt{s} = 541$ GeV [5] in ratio to a smoothly–varying, good theoretical representation of all of the data at 546 GeV [4], using eq. (1) in the text below and eqs. (1, 2, 3) in the second paper of ref. [15] for $Im\,\overline{F}(s,t)$.

Fig. 4 The data on $\frac{d\sigma_{el}}{dt}$ from the UA4 experiment at the CERN $\overline{p}p$ collider at $\sqrt{s} = 546$ GeV [4] in ratio to the same smoothly–varying, good theoretical representation as in Fig. 3.

Fig. 5 The data on $\frac{d\sigma_{el}}{dt}$ from the E–710 experiment at the Fermilab $\overline{p}p$ collider at $\sqrt{s} = 1800$ GeV [6] in ratio to a smoothly–varying, good theoretical representation of all of the data, using eq. (1) in the text below and eqs. (1, 2, 3) in the second paper of ref. [15] for $Im\,\overline{F}(s,t)$.

Fig. 6 The amplitude extracted from the data using eq. (3) and the ratio $R$ at 53 GeV from Fig. 2 with $\frac{d\sigma}{dt}$ from eq. (1). The curve is the representation of the anomalous structure by eq. (4) with $A = 0.35$, $y_0 = 0.395\,(\mathrm{GeV/c})$, $R_b = (2.7/m_\pi)$, and $\{T/m\} = \{22/m_\pi(1\,\mathrm{GeV})\}$ using the $J_0$.

Fig. 7 The anomalous amplitude extracted from the data using eq. (3) and the ratio $R$ at 541 GeV from Fig. 3 with $\frac{d\sigma}{dt}$ from eq. (1). The curve is the representation of the anomalous structure by eq. (4) with $A = 0.35$, $y_0 = 0.346\,(\mathrm{GeV/c})$, $R_b = (3.8/m_\pi)$, and $\{T/m\} = \{44/m_\pi(1\,\mathrm{GeV})\}$ using the cosine.

Fig. 8 The anomalous amplitude extracted from the data using eq. (3) and the ratio $R$ at 546 GeV from Fig. 4 with $\frac{d\sigma}{dt}$ from eq. (1). The curve is the same as in Fig. 7.

Fig. 9 The anomalous amplitude extracted from the data using eq. (3) and the ratio $R$ at 1800 GeV from Fig. 5 with $\frac{d\sigma}{dt}$ from eq. (1). The curve is the same as in Figs. (7, 8).

Fig. 10 The amplitudes at 546 and 1800 GeV from Figs. 8, 9 are placed on a single graph together with the representation of the anomalous structure by eq. (4).

Fig. 11 The figure, a reproduction of Fig. 6 from the second paper in ref. [9], shows the data on the local slopes $b(t)$ ($\frac{d\sigma}{dt} \propto e^{b(t)t}$) for $\pi^{\mp}p$ and $pp$ elastic scattering from the Fermilab high–statistics, fixed–target experiments at 200 GeV/c. The data is compared with the local slopes (solid curves) from good phenomenological fits to all of the data established by the experimentalists themselves (ref. [9]). The dashed lines show the envelope of uncertainties from their overall fits.