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Abstract

In models of extended hadrons, in which small bits of matter carrying charge and effective mass exist confined within a medium, oscillations in the matter density may occur. We suggest a way of investigating this possibility experimentally in high-energy hadron-hadron elastic diffraction scattering, and we illustrate the effect by examining some existing data which might be relevant to the question.

It has become common to speak of extended hadrons as objects in which relatively small pieces of matter, carrying charge and effective mass (quarks) *exist confined within a* medium *called the* "glue" (*massless* and *electrically-*neutral vector fields). The medium is assumed to carry some fraction of the energy-momentum of an interacting hadron. In such a system it would be natural for oscillations in the matter density to occur. After all, certain oscillations in the matter and electric charge densities do occur in nuclei [1]). The shell structure of nuclei give rise to small oscillatory deviations from monotonic charge-density distributions [2,3,4]). Such oscillatory behavior can *also arise, in principle, from a coherent mode of the neutral pion field* permeating the entire nucleus [5]) -the so-called π°- condensate [6]) which has been much studied recently [7,8,9]). Thus, within a hadron, density oscillations may occur as a consequence of 1) localization properties of quark wave functions [10]), and 2) the presence of coherent oscillating modes of "gluonic" matter (energy in the fourth components of vector fields [11]), or scalar fields [10,11])). It is perhaps noteworthy that, in gauge theories [12], the momentum-dependent, cubic self-interaction of vector gluon fields resembles the usual P-wave pion-nucleon interaction ; it is the latter that can give rise to neutral pion condensation [5]) in sufficiently dense nuclear matter. Recently, there has been considerable theoretical discussion of the possibility of coherent modes within hadronic matter, but little discussion of how one might try to detect these phenomena experimentally. In this note we suggest and illustrate one general way of investigating this possibility experimentally. Further, we observe that existing data from first-generation experiments on proton-proton elastic diffraction scattering at the highest energies does not exclude the possibility that phenomena of this general nature exist.

If small density oscillations exist within hadrons, then very precise *measurements of high-energy elastic diffraction scattering might be capable of* revealing the effect. The smooth part of the diffractive (imaginary) scattering amplitude $F(t)$, as a function of four-momentum transfer t, will be modified. We may define this modification as an addition $\Delta F(t)$, and express it in the impact-parameter representation in terms of an addition, $\Delta\Omega(b)$, to the opacity $\Omega(b)$.

$$\{ F(t) + \Delta F(t) \} = \int_0^\infty b\, db\, J_o(\sqrt{-t}\ b) \ \{ \sigma(b) + \Delta\sigma(b) \} \qquad (1a)$$

where $\sigma(b) = 1 - e^{-\Omega(b)}$ (1b)

$$\Delta\sigma(b) \cong e^{-\Omega(b)} \{ \Delta\Omega(b) \}$$

The opacity is naturally interpreted [13] as reflecting an overlap of the matter distributions of the colliding hadrons whose centers are separated by an impact parameter b. At a given energy, the observable effect is then, in general, a local anomaly in the scattering amplitude near some $t = t_o$, and an oscillatory behavior in a domain about this point. This follows from the transform of an oscillating $\Delta\sigma(b)$ in eq. (1). In order to precisely illustrate what we mean, we consider, as an example, an analysis of the first-generation data [14] on proton-proton elastic diffraction scattering at a total center-of-mass energy $\sqrt{s}$ = 53 GeV. In fig. 1a the data for the differential cross section, $d\sigma/dt$, is plotted in ratio to a smooth best fit for $d\sigma/dt = \pi|F(t)|^2$ with F(t) obtained [15,16] via eq. (1) from $\Omega(b)$ which is taken as the transform of the square of the dipole form factor, $C(1 - t/\mu^2)^{-4}$. As remarked in the original experimental paper [14], in the analysis [15], and by Amaldi [17] in a summary of the data from the CERN Intersecting Storage Rings, there are indications, at the level of a few percent, of a possible structure (a local anomaly) near $-t = 0.16$ $(GeV/c)^2$ and oscillations. The effect can be instrumental [18]. A second-generation of experiments has now been performed utilizing different detectors [19]. In the region studied of $-t < 0.10$ $(GeV/c)^2$, local structure may be present in some of the data at the level of a few per cent [19] (representing deviations above a smooth curve of ~ 500 events out of ~ 15 000). However again, the effect can be attributed to uncertainties associated with the detection instruments, at least at the present stage of the analysis [19]. It appears that experiments to date have not been designed to specifically probe possible small structure [20]. It is thus solely in the spirit of examining the possible physics involved in such structure, that we have performed a fit to the absolute deviations of the data, $\Delta(d\sigma/dt)$, from the smooth best fit, which deviations are plotted in fig. 1b. We have used a four-parameter [21] function of the following form

$$\Delta\left(\frac{d\sigma}{dt}\right) = A \left\{ e^{-(y-y_o)^2 R^2} \cos\left[\tilde{R}(y-y_o)\right] + e^{-(y+y_o)^2 R^2} \cos\left[\tilde{R}(y+y_o)\right] \right\} \tag{2}$$

where $y = \sqrt{-t}$, $y_o = \sqrt{-t_o}$.

This function has been used in recent relatively sophisticated phenomenological analyses of small anomalies in nuclear form factors obta[illegible] from electron scattering [3]. (The second term gives rise to a function even under $|\vec{r}| \to -|\vec{r}|$ in the ordinary Fourier transform which is relevant to electron scattering). The curve in fig. 1b, for the fit parameters given in the caption, has a $\chi^2 = 23$ for the 20 data points around the anomaly, where a regularity is clearly possible. If we fit all 54 data points, the parameters do not change and the $\chi^2 \cong 2$ per degree of freedom. We note that this is the same as the χ^2 achieved with the "structureless" fit [15]. Simply to illustrate the nature of the oscillations, we have transformed the fit for $\Delta F(t)$ into b-space by inverting eq. (1a). In fig. 2 we plot $\Delta\Omega(b)/\Omega(0)$ versus b, where $\Delta\Omega(b)$ is obtained from $\Delta\sigma(b)$ using eq. (1b). We observe : 1) that the effect at $b = 0$ is only a small fraction of a percent , and 2) that the oscillations persist, at the level of some parts in 10^5, out to very large b. This is a general feature. necessary in order to build up a highly localized anomaly in $\Delta F(t)$. In the context of current ideas about hadronic structure, a coherent oscillating mode of neutral gluonic matter, generated perhaps by self-interaction, would appear to be one possible origin for such unusual behavior in the hadronic matter density as reflected in the opacity function. Experimental information bearing upon this speculation would be difficult to obtain, except perhaps in this type of experiment.

Experimental scattering amplitudes and form factors arising from other hadronic probes of the proton may be studied for evidence of this kind of phenomenon [22]. Diffractive elastic scattering would appear to be the best place to look, because the overlapping matter densities are probed in a general manner through the opacity function in the general formula, eq. (1). An example of a non-diffractive probe is elastic electron scattering. At moderate energies and very small $q^2 = -t$, the virtual photon behaves like neutral hadronic vector mesons. In fact, possible anomalous behavior of this general nature has been reported [23] for the electromagnetic [24] form factor near $q^2 = 0.15\ (\mathrm{GeV}/c)^2$.

Experimental evidence for the kind of structure that we have discussed in proton-proton elastic diffraction scattering would clearly be important for the general notions involved in quark-glue models of hadrons. In particular, coherent effects of the neutral gluonic matter (and the quarks) can be involved in these diffractive hadron-hadron interactions, in contrast to the largely incoherent processes involved in deep inelastic lepton-hadron scattering. In this sense, the two types of scattering are complementary probes. Experiments at the highest energies may be preferable, because in this region where pionization increases the "glue" may play an important role in the collision process itself [25,26]. The empirical tendency of the interaction region, $r(s)$, to expand slightly with increasing energy might be reflected in a decrease in $(\sqrt{-t_0})_{min} \cong (2\pi/r(s))$, causing a corresponding shift with energy in the position of the anomaly and in the oscillatory pattern. Judging from experience in nuclear physics [1,3,4] very precise differential cross section measurements (to < 1 %) are probably required. However the cross sections are large, and very high statistics are more readily reached than with the small cross sections that are involved in probing the proton with leptons. Given the suggestion of structure in pro on-proton elastic diffraction scattering, present in both the first [14] and the second-generation [19] experiments at the ISR, any further experiments might well be designed to specifically look for this phenomenon, which, as we have illustrated, may be related to current ideas about the internal structure of hadrons.

We thank U. Amaldi, G. Cocconi and G. Tarnopolsky for discussions and for information concerning the present generation of very high-energy proton-proton scattering experiments at small t. One of us (S.B.) thanks Professors G.E. Brown and C.N. Yang for discussions and for their hospitality at Stony Brook, where this study was begun.

Figure captions

Fig. 1 (a) The ratio of the differential cross section data at $\sqrt{s}$ = 53 GeV from ref. 14 to the best fit obtained with the functional form for F(t) in ref. 15, after our adjustment of parameters to the correct total cross section.

(b) The results in fig. 1a are displayed as an absolute deviation of the data, $\Delta(\frac{d\sigma}{dt})$, from the smooth best fit. The curve represents the best fit to 54 data points around the possible structure with the function in eq. (2) (parameters : $A = 0.59 \pm 0.08$ mb $(GeV/c)^{-2}$, $y_o = 0.399 \pm 0.001$ (GeV/c), $R = 16.5 \pm 8$ fm, $\tilde{R} \sim 0.45$ fm). There is clearly a large uncertainty in the possibility of oscillations and hence in $\tilde{R}$.

Fig. 2 Plot of $\Delta\Omega(b)/\Omega(0)$ versus b.

References and footnotes

1) H.A. BETHE, Ann. Rev. of Nucl. Sci. 21 (1971) 93

2) For early analyses, along these lines, of data on electron scattering from nuclei, see J. BELLICARD et al., Phys. Rev. Lett. 19 (1967) 527 ; J. HEISENBERG et al., Phys. Rev. Lett. 23 (1969) 1402

3) For recent analyses see I. SICK and J.S. Mc CARTHY, Nucl. Phys. A 150 (1970) 631 ; I. SICK, Nucl. Phys. A 208 (1973) 557

4) The theoretical implications of this type of analysis for nuclear shell structure are summarized in ref. 1 above and J.W. NEGELE, Phys. Rev. C 1 (1970) 1260 ; J.L. FRIAR and J.W. NEGELE, Comm. Nucl. Part. Phys. V (1972) 181

5) A.B. MIGDAL, Zh ETF 63 (1972) 1993 (Sov. Phys. JETP 36 (1973) 1052)

6) A.B. MIGDAL, Phys. Lett. 52 B (1974) 264 ; Zh ETF Pis. Red. 19 (1974) 539 (JETP Lett. 19 (1974) 284)

7) S. BARSHAY, G. VAGRADOV and G.E. BROWN, Phys. Lett. 43 B (1973) 359

8) S. BARSHAY and G.E. BROWN, Phys. Lett. 47 B (1973) 107

9) N.A. KIRICHENKO and G.A. SOROKIN, Landau Institute preprint, Chernogolovka, U.S.S.R. (1976) (to be published)

10) For example, in the SLAC "bag" the quarks are mainly near the surface. W.A. BARDEEN et al., Phys. Rev. D 11 (1975) 1094

11) J.D. WALECKA, Ann. of Physics 83 (1974) 491

12) See for example, J. BERNSTEIN, Rev. Mod. Phys. 46 (1974) 7

13) T.T. CHOU and C.N. YANG, High-energy physics and nuclear structure, (G. Alexander, ed., North-Holland, Amsterdam, Holland, 1967) 348

14) G. BARBIELLINI et al., Phys. Lett. 39 B (1972) 663

15) J.N.J. WHITE, Nucl. Phys. B 51 (1973) 23

16) The parameter C used in ref. 15 above underestimates the total cross section (whose increase was not measured at the time). We have performed an adjustment of C, and of the fit-parameter μ^2 in ref. 15, to obtain a total cross section of 42.6 mb and a logarithmic slope near t = 0 of 12.75 $(\mathrm{GeV/c})^{-2}$ in agreement with present measurements (ref. 17 below) (C = 10.75 $(\mathrm{GeV/c})^{-2}$, $\mu^2 = 0.702\ (\mathrm{GeV/c})^2$). Thus fig. 1a shows the ratio of the data to our adjusted fit. The deviations near $-t = 0.16\ (\mathrm{GeV/c})^2$ must be similar to those in fig. 1d of ref. 15, because these deviations are directly visible

in the data for dσ/dt (see fig. 2d of ref. 14 above).

17) U. AMALDI, in Highlights in particle physics, (A. Zichichi, ed., Editrice Compositori, Bologna, Italy, 1973).

18) The experiment was not designed to minimize certain possible defects in the wires of the detection apparatus which could give rise to such effects. We thank C. RUBBIA for discussion.

19) Private communication from G. TARNOPOLSKY concerning the second-generation experiments carried out by himself, others , and members of the ACHGT collaboration (ref. 14 above). We are grateful to Dr. TARNOPOLSKY for showing and explaining to us the data bearing upon the question raised in this paper, prior to its forthcoming publication.

20) The current CERN-Rome experiment, designed to measure the real part of the pp elastic scattering amplitude near t = 0 at the highest ISR energies, can perhaps also look for structure in the region $-t < 0.15$ $(GeV/c)^2$. We thank U. AMALDI for information and for his interest in this matter.

21) The minimal number of parameters is three : an amplitude A, the anomaly point t_0, and oscillation and damping scales (which can be different), taken as a single R.

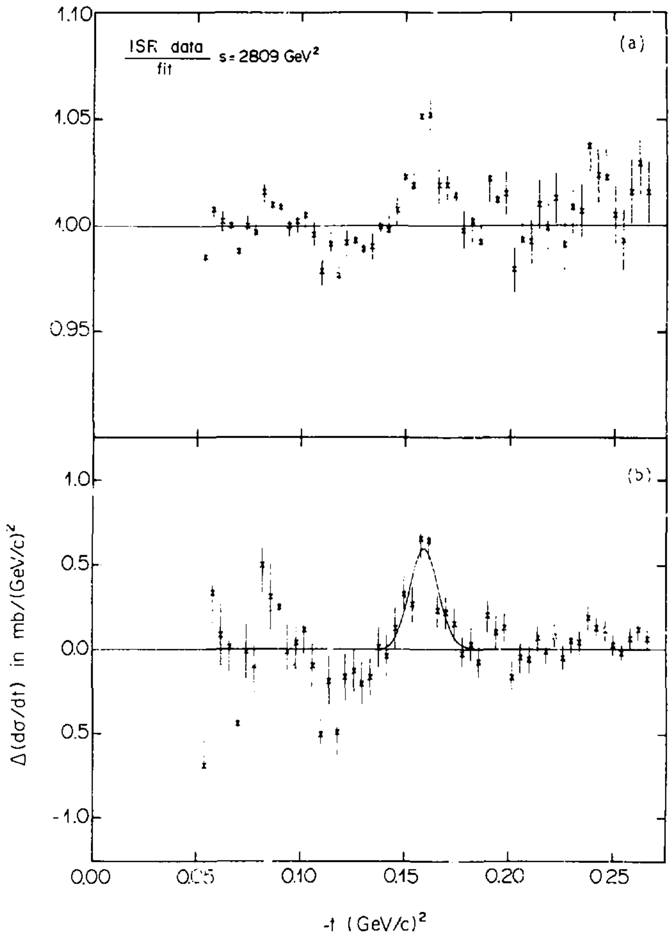
22) Very recent experiments (Fermilab Single Arm Spectrometer Group, Phys. Rev. Lett. 18 (1974) 1195) on hadron-proton elastic diffraction scattering from $\sqrt{s}$ = 9.7 GeV to 18.2 GeV confirm the concavity of diffraction peaks as $t \to 0$, observed for pp at ISR energies. At these lower energies possible small structure near $-t = 0.2$ $(GeV/c)^2$ in pp scattering, in particular, might be investigated within the t-dependent experimental uncertainties of a few per cent. However again, these experiments have not been designed to look for structure at small t. We thank J. LITT for giving us unpublished data and for helpful discussion.

23) D.R. BOTTERILL et al., Phys. Lett. 46 B (1973) 125.

24) Even a miniscule (parts in 10^5) oscillatory piece of the proton's electrical properties, which is very spatially extended (see fig. 2), might be tested in QED experiments. In terms of gluons, it seems likely that the effect is solely in the electrically-neutral matter density, which is difficult to test experimentally other than in the manner that we have suggested here.

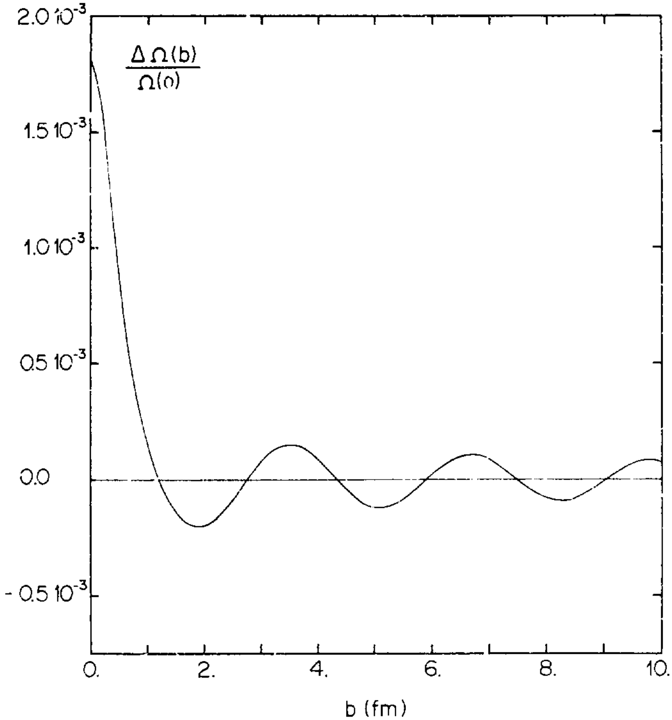
25) S. POKORSKI and L. VAN HOVE, Acta Phys. Pol. B 5 (1974) 229

26) Coherent oscillatory behavior may be established in gluonic matter involved in the collision process.



1.10
1.05
1.00
0.95
ISR data / fit s = 2809 GeV²
(a)
1.0
0.5
0.0
0.5
-1.0
(b)
Δ(dσ/dt) in mb/(GeV/c)²
0.00
0.05
0.10
0.15
0.20
0.25
-t (GeV/c)²

Fig. 1



$\frac{\Delta\Omega(b)}{\Omega(0)}$
2.0 10^{-3}
1.5 10^{-3}
1.0 10^{-3}
0.5 10^{-3}
0.0
- 0.5 10^{-3}
0.
2.
4.
6.
8.
10.
b (fm)

Fig. 2