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CFTI PRICES

On the 1.40 Gev Maximum in p-p Inelastic Scattering*

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Recent high energy p-p experiments at CERN and Brookhaven show a large maximum at a missing mass of 1.40 Gev in the inelastic spectrum. This bump is striking at very small angles; and rapidly disappears with increasing angle of the detected proton. Bumps at 1.512 and 1.688 Gev are also seen, corresponding to the well known d_{13} and f_{15} πN isobars. These, however, are smaller than the 1.40 Gev bump at the smallest angles (several mrad.), and decrease less rapidly with angle; they are still very prominent when the 1.40 has disappeared.

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It has been suggested¹ that this 1.40 Gev object is a recoiling πN resonance in the p_{11} ^{3,4} state. Several questions still remain, however,

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about the observed data. The phase shift analysis is still not clear.⁴
 The existence of a p_{11} resonance at 1.40 Gev is not well-established.
 Why should such an object be so large and prominent at high energies and small angles, relative to the d_{13} and f_{15} , as distinguished from its behavior at low energies in elastic and photo-production experiments? Closely related is the problem of explaining the energy and angle dependence of the 1.40 Gev bump.

We would like to suggest, as a plausible mechanism, the Drell-⁵ Hiida (DH) model (see Fig. 1) in which the incident proton diffraction scatters off a virtual pion in the cloud of the target proton, putting it on the mass shell. This is known to give a bump in $\frac{d^2\sigma}{d\Omega_{q'}dq'}$, when plotted as a function of the invariant mass $W = ((p'+k')^2)^{\frac{1}{2}}$.

Let q, q' be the lab momenta of the incoming and scattered protons, respectively, θ is the lab angle between $\tilde{q}$ and $\tilde{q}'$. p, p' , and k' are the target and recoil protons, and produced pion, respectively. In this model, the off-shell πp diffraction scattering is assumed pure imaginary, and related through a universal shape and the optical theorem to the (constant) total πp cross-section. All that remains is a phase space-factor, which on neglecting the pion mass μ , is $(q' \cdot k')^2$. The pion propagator contributes $(\mu^2 - \Delta^2)^{-2}$, with $\Delta^2 = (p - p')^2$, so that $\frac{d^2\sigma}{d\Omega_{q'}dq'} \propto \int d\Omega_{k'}^W (q' \cdot k')^2 \Delta^2 (\mu^2 - \Delta^2)^{-2}$. The extra Δ^2 comes from the πNN vertex; superscript W always denotes W c.m. (i.e., $\tilde{k}'^W + \tilde{p}'^W = 0$). If $\tilde{p}^W$ is chosen as polar axis, Δ^2 is a function only of z , the cosine of the polar angle; and the ϕ^W dependence of $q'^W \cdot k'^W$ allows $\int d\phi^W$ to be explicitly performed. The final result is

$$\frac{d^2\sigma}{d\Omega_q dq'} = \frac{3}{16} \frac{Gr^2}{(2\pi)^4} \frac{q'}{q} \frac{1}{m^2} \frac{\sigma_{tot}^2 g(t)}{K} \int_A^B d\Delta^2 \Delta^2 (\mu^2 - \Delta^2)^{-2} h \quad (1)$$

where $\frac{Gr^2}{4\pi} = 14.4$; $\sigma_{tot} \approx 28$ mbarns; $t = (q-q')^2$; $g(t) = e^{9t+2.5t^2}$; K is $|\tilde{k}+\tilde{p}'|$, the lab recoil momentum; and $h \equiv \frac{1}{2\pi} \int d\phi^W (k^W \cdot q^W)^2$ is a known quadratic function of Δ^2 .

Numerical calculations show: (i) (1) is a maximum at $W = 1.40$, for $\theta = 0$, $q = 20$ Gev. This maximum is very insensitive to q and θ , though it does shift by $\approx +0.1$ Gev with increasing q and/or θ in the range 10-30 Gev, 0-15 mrad; (ii) the magnitude of the peak at $\theta = 0$ increases rapidly with q ; it is 0.86, 3.8, 8.8 barns/st/Gev at $q = 10, 20, 30$ Gev; (iii) for fixed q , it decreases rapidly with θ because of the diffraction factor $g(t)$. However, the peak is too wide to explain the experimental bump; it arises because of the increase from inelastic threshold at $W = 1.08$ Gev, and a decreasing $\frac{1}{K}$. The latter is partially compensated by the integral. Since in the latter, $|\Delta^2|$ can be quite large ($B \approx 29\mu^2$ at $q = 20$ Gev, $\theta = 0$, $W = 1.4$ Gev, and increases rapidly with W), there can be important effects from the virtuality of the pion, so the introduction of a form factor seems reasonable. This suppresses large $|\Delta^2|$, which at small θ , (where $A \approx 0$) acts to suppress large W . The result of various functions tried indicate that square shapes with cut-off $\gtrsim 30\mu^2$ still give a peak at $W = 1.4$ with a much swifter drop for large W ; but the wide top on the low W side is unaffected. For cutoffs $< 30\mu^2$, the peak is shifted to smaller values than 1.40 Gev; this also occurs for exponential and Gaussian shapes fitted to 1 at $\Delta^2 = +\mu^2$ and $\approx \frac{1}{2}$ at $\Delta^2 = -10\mu^2$ or $-15\mu^2$. (see Fig. 2).

So far, the question of final state interactions of k' and p' ; following the original DH process, has been ignored. If there is indeed a p_{11} resonance at $W = 1.40$ Gev, such a final state interaction might result in the sharpened peak actually seen. The contributions of the DH effect (1) in the various (j, P, T) states of the (k', p') system is then desired. If the diffraction scattering at the high energy vertex is considered as the exchange of a vacuum-like system, only $T = \frac{1}{2}$ states contribute. The projections for angular momentum j , parity $(-1)^{j-\frac{1}{2}}$, for the transition (scalar object) $\pi + N \rightarrow \pi + N$ yield

$$I_j = \int_{-1}^1 dz [J_+ J_- P_{j-\frac{1}{2}} - J_- J_+ P_{j+\frac{1}{2}}] \bar{h} (\mu^2 - \Delta^2)^{-1} \quad (2)$$

Here, $P_{j\pm\frac{1}{2}}$ are Legendre polynomials; $\bar{h} = \frac{1}{2\pi} \int d\phi q'^W \cdot k'^W$; and $J_{\pm} = (E_p^W \pm m)^{\frac{1}{2}}$, $J'_{\pm} = (E_{p'}^W \pm m)^{\frac{1}{2}}$. The contribution to the cross-section, $d^2\sigma_{T=\frac{1}{2}, j-}$ is proportional to $|I_j|^2$.

Now at $\theta = 0$, $\bar{h}(z) (\mu^2 - \Delta^2(z))^{-1}$ is almost constant, though each factor separately is strongly dependent on z . Thus, only $j = \frac{1}{2}$ contributes in (2); $j = 3/2, 5/2$ give 0. At $\theta = 0$, there is a very strong suppression of d_{13} and f_{15} relative to p_{11} (s_{11} is $\approx 10\%$ larger than p_{11} except near threshold). The contribution of p_{11} for $20 \lesssim q \lesssim 30$ Gev and $0 \lesssim \theta \lesssim 10$ mrad is between 0.7 and 2 barns/st-Gev; beyond $\theta \sim 10$ mr, $d^2\sigma_{p_{11}}$ decreases very rapidly, faster than exponential; d_{13} and f_{15} are always < 0.01 barns/st-Gev. Introducing a form-factor in (2) adds an extra anisotropy, increasing d_{13} and f_{15} and decreasing p_{11} . However, for reasonable form factors as above, p_{11} is still dominant at angles $\lesssim 15$ mrad by a large factor (between 4 and 20).

The reason what the DH model gives isotropy in z at $\theta = 0$ is easily understood. At $\theta = 0$, $q'^W \cdot k'^W$ is independent of ϕ^W (with $\hat{p}^W$ as polar axis) so $\bar{h} = q' \cdot k'$. Also, for $|\tilde{q}|$ large and $\theta = 0$, $t \approx 0$, while $k' \cdot (q' - q) \approx -k' \cdot q' \epsilon / |\tilde{q}'|$, where $\epsilon = E_q - E_{q'}$, $\approx |\tilde{q}| - |\tilde{q}'|$. Then, since $\Delta^2 = (q' + k' - q)^2 = t + \mu^2 + 2k' \cdot (q' - q)$, we have $k' \cdot q' (\mu^2 - \Delta^2)^{-1} \approx |\tilde{q}'| / 2\epsilon =$ large constant.

Aside from the stated simplifications used in the DH model, and ambiguity due to unknown off-shell form factors, there remains the question of other graphs not considered. Taking for granted an off-shell, quasi-elastic diffraction model, there are more graphs in which the protons diffraction scatter off-shell, with pion emission either before or after the scattering. One such graph (contributing only to the p_{11} channel) has been calculated. It is comparable in magnitude and shape to the contribution from (1), i.e., Figs. 1 and 2(a). Perhaps such nucleon pole graphs are cancelled by continuum contributions. This is an open question.

Summarizing, if a p_{11} 1.4 Gev resonance exists, the above model can explain why it behaves differently from the d_{13} and f_{15} resonances. In any case, one can argue that phase-space and momentum transfer in quasi-elastic diffraction scattering combine in such a way as to suppress large j at small θ ; this might be true generally, independently of OPE considered above. Then the 1.4 Gev object is a possibly complex effect of kinematics and/or (final-state-interaction) dynamics; the absolute magnitude, energy, and angle dependence can at least be understood.

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FIGURE CAPTIONS

Fig. 1 The diagram for the DH process. q, q' are the incoming and scattered protons. p, p' are the target and recoil protons. k' is the produced pion. $\Delta^2 = (p-p')^2 < 0$; $t = (q-q')^2 < 0$; $W^2 = (k'+p')^2$.

Fig. 2 The cross section from DH process (1) as a function of missing mass W , for incoming proton momentum 20 Gev/c and scattering angle 10 mrad. (a) no form factor (b) square-shaped form factor. Cut-off at $\Delta^2 = -30\mu^2$ (c) exponential form factor, $e^{-3.2(\mu^2 - \Delta^2)}$. Factor = $\frac{1}{2}$ at $\Delta^2 = -10\mu^2$.

FIG. I

FIG. 2