1 Possible Signal for Decreasing ϕ Meson Size with $\mathbf{Q^2}$

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This proposal is for a 6 GeV extension to an approved Hall B $\phi(1020)$ meson electroproduction experiment, E93-022. The extension is to find evidence of the meson's decreasing size with Q^2.

1.1 Vector Meson Electroproduction

In vector meson (VM) electroproduction, the "bare" photon fluctuates in a time t^{lab}_{fluc} into a VM that diffractively scatters from the proton target [1].

$$t^{lab}_{fluc} \approx \frac{2\nu}{|Q^2| + M^2_{VM}} \tag{1}$$

where ν is the electron energy loss. Asymptotically, $(t^{lab}_{fluc}) \propto x^{-1}_{Bjorken}$.
The t distribution of the scattering is diffractive:

$$\frac{d\sigma}{dt} \propto e^{-b|t|}. \tag{2}$$

b measures the transverse size of the interaction region, R^{trans}_{int}. (For an incident wave onto a black disk of radius R, $\;b \approx \frac{1}{4}R^2$). R^{trans}_{int}, the is sum of the VM transverse size, R^{trans}_{VM}, and the target size, R_{hadron}. $R^{trans}_{int} \approx\; 2\; fm$. An increase in Q^2, i.e, a "smaller" virtual photon, VM, and R^{trans}_{int}, is expected to result in a "hardening" or decrease in the value of b.
Among the low-mass vector mesons, ϕ electroproduction should best test possible shrinking; the ϕ, an $s\bar{s}$ meson, has minimal q exchange with the target and its width is only 4 MeV.

1.2 R^{trans}_{ϕ} Shrinkage with Q^2

R^{trans}_{ϕ} shrinkage can be calculated via two approaches:
a) - A hadronic description; in the ϕ rest frame the transverse size is proptional to ct^{lab}_{fluc}:

$$R^{trans}_{\phi}(|Q^2|) = c\frac{M_\phi}{M^2_\phi + |Q^2|}. \tag{3}$$

b) A quark description; in the Breit frame the transverse size is proportional to the maximum longitudinal separation of the meson's quark pair:

$$R^{trans}_{\phi}(|Q^2|) = \frac{R_{hadron}M_\phi}{\sqrt{M^2_\phi + |Q^2|}}. \tag{4}$$

1.3 Additional Dependence of b on ct^{lab}_{fluc} and ct^{lab}_{form}

Besides its dependence on $R^{trans}_{\phi}(|Q^2|)$, b also depends explicitly on : A) ct^{lab}_{fluc} and B) ct^{lab}_{form}, the meson's expansion distance:
A) For $ct^{lab}_{fluc} >> R_{int} \approx 2\ fm$, the incident photon is completely "dressed" hadronically during the interaction and b saturates to a maximum value of $b_{sat} \approx 7\ \ \mathrm{GeV}^{-2}$ characteristic of solely hadronic diffractive scattering.
For $\mathrm{c}t^{lab}_{fluc}$ decreasing below R_{int}, b enters a transition region, b_{trans}; the "bare" point-like photon component becomes important. The scattering becomes harder. b decreases with decreasing $\mathrm{c}t^{lab}_{fluc}$ and, from equation 1, increasing $|Q^2|$. For the kinematics of this proposal, $\mathrm{c}t^{lab}_{fluc}$ is in the transition region.
B) The expansion distance, ct_{form}, over which a "shrunken" ϕ expands back into a conventional hadron is, in the meson's rest frame, approximately given by the $s\bar{s}$ multiplet-mass splitting $m_{\phi} - m_{\eta}$. For the kinematics of this proposal, $ct_{form} \approx 3$ fm.

1.4 Data Analysis Techniques

To determine VM shrinkage with Q^2 independent of $\mathrm{c}t^{lab}_{fluc}$, data should be analyzed, in the transition t^{lab}_{fluc} region, at a constant $\mathrm{c}t^{lab}_{fluc}$, i.e., along a line in a Q^2 (y-axis), W^2 (x-axis) space. Fig. 1, displays data taken in a short CLAS run this spring at 5.5 GeV. Kinematically accessable regions around $ct^{lab}_{fluc} = 0.6,\ 0.8\ fm$ lines are shown.

1.5 Existing b Data

The most extensive VM b data exists for ρ mesons. b clearly displays the above behavior with $\mathrm{c}t^{lab}_{fluc}$. The $|Q^2|$ behavior of b agrees with the quark model in both the transition (b determined at constant $\mathrm{c}t^{lab}_{fluc}$) and saturation regions.
Data from ω and ϕ mesons is sparse and exists only in the transition region. In this region both b_{ω} and b_{ϕ} exhibit the same behavior with $\mathrm{c}t^{lab}_{fluc}$ as that for ρ mesons. There is no useful data to determine the b_{ω} or b_{ϕ} variation with $|Q^2|$ at constant $\mathrm{c}t^{lab}_{fluc}$.

1.6 The ϕ Electroproduction Reaction: $e + p \rightarrow e' + p' + K^+ + X$

b_{ϕ} will be determined from the t behavior of reconstructed ϕ mesons using the $e + p \rightarrow e' + p' + K^+ + X$ reaction. The outgoing K^- will be reconstructed from the X missing mass. The ϕ will then be reconstructed from the $K^+\ K^-_{recon}$ pair. The variation of $b_{\phi}(t^{lab}_{fluc}, |Q^2|)$ with $|Q^2|$, Δb, will be determined within two W^2, Q^2 regions, one centered along the line $ct^{lab}_{fluc} = 0.6$, the other along $ct^{lab}_{fluc} = 0.8$ fm as shown in Fig. 1.
The $|Q^2|$ range will be extended by using ϕ photoproduction data of Tedeschi [3] at values of W given by the intersection of the two above lines with the $Q^2 = 0$ axis: $W^2 = 3.6$ (threshold) and 5.3 GeV^2, ($E_{\gamma} =$ 1.5 and 2.4 GeV respectively). By combining the photo [3] and electroproduction data, constant t^{lab}_{fluc} measurements of the Q^2 variation of b can be made over a Q^2 range $0 \rightarrow \approx 2$ (GeV/c)^2.

1.7 Estimation of Measurement Uncertainties

Scaling the $\approx$ 2 day 5.5 GeV CLAS electroproduction data to a 40 day run results in ≈ 1500 reconstructed ϕ mesons in each of the two above regions with a ϕ peak to (phase space + background) ratio of $\approx 2/1$.

A 5.5 GeV GSIM simulation of the ϕ event rate using an electroproduction cross section of Cassel et al [2] interpolated to the proposed kinematics agreed with the data to within 20%. The simulation yielded a 2% ϕ acceptance, flat in t within $\approx 20\%$ ($t > 2\ GeV^2$), and a relative statistical error in the measured exponential slope parameter b of $\delta b/b \ \approx\ 8\%$.
Photoproduction data of Tedeschi [3] will yield similar relative error, $\delta b/b = \approx 8\%$.
The combined electro and photo ϕ production data for the $ct^{lab}_{fluc} = 0.8\ fm$ region (Fig 1) will have a relative error in the measured $|Q^2|$ relative variation of b, $(\frac{\Delta b}{b}) \approx\ 12\%$. This is to be compared with the relative variation of b, $\frac{\Delta b}{b}$ expected from the above VMD and QM descriptions:

$$\frac{\Delta b}{b} = \frac{b_{photo} - b_{electro}}{b_{photo}}\ \approx\ 50\%\ (\text{VMD}),\ 30\%\ (\text{QM}). \tag{5}$$

Possible transition region dampening of Δb is uncertain. At maximum dampening, the above percentage variations in b could be reduced by a factor of 2.

A 40 day electroproduction run, together with the photoproduction data, can distinguish between the QM and VMD descriptions. Under maximum Δb dampening, the experiment can confirm the validity of VMD.

1.8 Possible Additional Measurements

1.8.1 L,T ϕ Polarization Measurements

CLAS will also permit determination of the σ_L and σ_T components of the ϕ through the decay angular distribution data of the K^+K^- final state. At high energies, $\bar{q}$ helicity = - q helicity, and the $q\bar{q}$ state is longitudinal. b, evaluated for the longitudinal components of the virtual photon and ϕ meson, should show preferential b hardening with $|Q^2|$ relative to the transverse components. ρ electroproduction data analysis, affecting L,T separation by assuming s-channel helicity conservation, supports this idea.

References

[1] T.H. Bauer *et al.*, Rev. Mod. Phys. **50**, 261 (1978).

[2] D.G. Cassel *et al.*, Phys. Rev. D **24**, 2803 (1981).

[3] D.J. Tedeschi, official CLAS approved project, G1 and subsequent runs.