Summary

Results and discussions

Model for $\phi$ production

Motivation

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Probing Strangeeness Content of the Proton

with $\phi$ Meson Photo- and Electroproduction
Strange quark sea ($s$) is strongly polarized

quark spin contributes little to proton spin

Theoretical interpretation:

Spin asymmetry is measured.

Longitudinally polarized $N$'s & $p$'s

$2\cdot$ EMC (1989) : $\pi^{-} p \rightarrow deep$ Inelastic scattering with

sensitive to quarks

proton might contain an admixture of 20% strange

analysis suggests that $L \cdot Q$ term in $\pi N$ scattering

"Strange lines in the nucleon"

Possible experimental indications for
Admixture of (\(s\)) in proton is 1.9%.

\[
\frac{W + (X + p p \leftarrow B + N) W + (X + m \leftarrow B + N) W}{Z + (X + s s \leftarrow B + N) W} = Z
\]

\(0.339 \pm 0.023\) \(> |Z| > (0.272 \pm 0.025)\)

Strong violation of Q2I rule

\[
\begin{array}{c}
\frac{\phi}{\phi_0} = 1.4 \pm 0.24 \pm 0.31
\\
\phi_0 = 0.4
\end{array}
\]

\[
\langle (\bar{d} N | F_1^{\pi} - F_1^{K} | d N) \rangle
\]

Sensitive to

\[
\langle (\bar{d} N | F_1^{\pi} - F_1^{K} | d N) \rangle = 0.45 \pm 0.09
\]

Sensitive to

3. Low energy elastic VP cross section (BNL, 1987)

4. Sample experiment at Bates (McKeehan et al., 1984)

5. 90 experimental at Jlab (Deck et al.)

6. 90 experiment at Jlab (Deck et al.)
20-25% admixture of strange quarks in the proton

\[ \frac{< (d)_N | ss + pp + m | (d)_N >}{<(d)_N | ss | (d)_N >} \approx (0.0) \sigma = \mp \Delta \]

Experimental value of \( \Delta \) is about 45 - 65 MeV.

\[ \left( \frac{< (d)_N | ss - pp + m | (d)_N >}{<(d)_N | ss | (d)_N >} + 1 \right) \approx 2.2 \text{ MeV} \]

\[ \left( \frac{< ss zn - pp + m >}{<(ss) >} + 1 \right)^n W = \frac{-(m + m)}{\varepsilon} \]

It can be shown that, up to first order in SU(3) breaking,

\[ ss + pp + m = 8s^H \]

**Chiral symmetry breaking term**

\[ < (d)_N | [[ 8s^H, 8\bar{s}], 8\bar{s}] | (d)_N > \frac{\varepsilon}{\lambda} = \]

\[ < (d)_N | [[ 8H, 8\bar{s}], 8\bar{s}] | (d)_N > \frac{\varepsilon}{\lambda} = (0) \sigma \]
If no strange quarks in hadron:

\[ \phi \{ p \} \rightarrow \frac{1}{6} \{ n \} \frac{1}{6} \{ \bar{n} \} \]

\[ \phi \{ \bar{s} \} \rightarrow \frac{1}{6} \{ s \} \frac{1}{6} \{ \bar{s} \} \]

\[ \phi \{ p \} \rightarrow p \]

\[ \phi \{ \bar{p} \} \rightarrow \bar{p} \]

\[ \phi \{ n \} \rightarrow n \]

\[ \phi \{ \bar{n} \} \rightarrow \bar{n} \]

\[ \text{BR} = 84\% \]

\[ \text{BR} = 2\% \]

OZI Rule: Strong processes which require annihilation (or creation) of isolated constituent \( q \bar{q} \)-pair are suppressed (empirical).
\[
\langle X \rangle \sim \sum_{m=0}^{\infty} \frac{a^m}{m!} \left\langle \mathcal{O}_{m} \right\rangle \quad (m=0, 1, 2, \ldots)
\]

\[
\langle X \rangle \mid_{\mathcal{O}_{m}} = \langle \mathcal{O}_{m} \rangle \quad (m=0, 1, 2, \ldots)
\]

\[
f \cdot g = \frac{(X_{m} + \delta g)\sigma}{(X_{f} - \delta g)\sigma} \quad \Rightarrow
\]

\[
\frac{\mathcal{O} \text{ mean}}{\mathcal{O} \text{ mean} + \mathcal{Z}} = \mathcal{Z}
\]

\[
(X + pp \rightarrow g + \nu)(W + (X + \eta \nu \rightarrow g + \nu)(W = \mathcal{Z}
\]

\[
f \cdot (X_{m} - \delta g \phi) = \Re
\]

\[
\text{Gell-Mann-Oakes-Renner mass formula gives } \theta = 39.9^\circ \text{ and hence}
\]

\[
f \cdot (X_{m} \rightarrow g + \nu)\sigma = \langle \mathcal{O} \rangle
\]

\[
\text{OZI rule predicts:}
\]

\[
\text{Violation of OZI rule in pp annihilation}
\]

\[
\text{with a small deviation } \phi = \theta - \theta^* \text{ from the ideal mixing angle } \phi = 39.9^\circ.
\]

\[
\text{is almost a pure } \eta \text{ state, containing just a small admixture of } \eta \text{ associated}
\]
\[ \frac{16\pi W_{LM}^2}{|b|^2 M_T^2} = a \phi \]

where

\[ \int |T|^2 |d\phi \]

Frame is the scattering angle.

**Fig. 2.** The coordinate system and kinematical variables for \( \phi \) meson production in c.m.

**Fig. 1.** Kinematics for the \( \phi \) meson production from proton p+p.

**Fig. and Explanation of \( \phi \) meson production.**
Fig. 1. Diagrammatic representation of production mechanism of \( \phi \) meson exchange.

\( (a) \) Nucleon pole terms, and \( (b) \) direct hadron processes.

\( (c) \) Nucleon pole terms, and \( (d) \) direct hadron processes.
\[
\left\{ (\omega W + \beta + \lambda A) \tilde{A} (\omega W + \beta + \lambda A) \tilde{A} (\omega W + \beta + \lambda A) \tilde{A} \right\} \propto \left[ \Gamma_{\omega W} \right]
\]

Assume \( I \) and \( \Gamma \) and \( \Gamma \) and \( \Gamma \)

\[
(d) n \tilde{A} (d) n = \mathcal{L}_f
\]
\[ |h|\|k| + 2e\theta + 2e - \frac{N}{2} = \text{var} \]

where

\[ (|\text{var}| - 2|\phi_q^z|) \exp \frac{\kappa Z}{\phi_q(M)^{\lambda_o}} \sqrt{\frac{NM}{\xi M - \xi M}} = 0 \]

\[ \leftarrow \]

\[ \forall \text{ C}\vee 3 \text{ GeV} \]

with \( \xi \approx 2 = M \) around 0.\text{ GeV} and 4.\text{ GeV} = \phi_q \)

\[ (|\text{var}| - 2|\phi_q^z|) \exp \phi_q(M)^{\lambda_o} = \left( \frac{\varphi}{\varphi} \right) \]

obtained from which describes the dynamics of the Pomeron-hadron interactions is

\[ \mathcal{L} \]

where

\[ \mathcal{L} = \mathcal{L} \]

To preserve gauge invariance, here we simply replace...
The matrix element of OPE process then reads

\[
\langle N N \ldots N N \; \delta g \rangle = S_F J \\
\langle N \; \Theta \; \Phi \; \Phi \; \Phi \; \Phi \; \Phi \; \Phi \; \delta g \rangle = \Phi \Phi J
\]

Fig. 5. One photon exchange process in the photoproduction.
\[
\gamma^* W^+ e^- \rightarrow \gamma^* f f \rightarrow \gamma f f
\]

where the elements respectively with the hadron and electron electromagnetic current matrices are given by:

\[
\gamma f f \rightarrow \gamma W^+ e^- \rightarrow \gamma f f
\]

The knock-out amplitude in Fig. 6 (a) may be written in the form of Fig. 6 (b) from knock-out contributions to meson photoproduction.

\[\gamma f f \rightarrow \gamma W^+ e^- \rightarrow \gamma f f\]

\[\gamma f f \rightarrow \gamma W^+ e^- \rightarrow \gamma f f\]
$\chi$ is odd, we take it to be $1$ plus the angular momentum of the two clusters.

$$\{ \langle \phi_1 | s \otimes f[pnn] | 1 \rangle + \langle \phi_0 | s \otimes f[pnn] | 0 \rangle \} \mathbf{B} + \langle f[pnn] | \mathbf{A} = \langle d | \}$$

We further approximate and decompose it as

$$\langle \psi_{\text{nnps}} | \mathbf{B} + \langle pnn | \mathbf{A} = \langle d |$$

For simplicity and for our qualitative study, we approximate the proton wave function as $\langle d |$ and the neutron wave function as $\langle n |$.
\[
\left( \frac{2\pi}{\Delta \times \sigma} (x - x|g \sum_{I=1}^{I=1} \int_{x}^{1} I = 0 \right) = \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \eta \et
with \( \rho = \frac{a}{2} \).

\[
0 = \Phi \left[ \frac{\partial}{\partial x} \left( x^2 \gamma - a \gamma \right) \sum \gamma + x \gamma \right]
\]

and becomes

The equation can be diagonalized using the relativistic Jacobian coordinates:

\[
0 = \Phi \left( \frac{\partial}{\partial x} \left( \sum \gamma - 1 \right) \right)
\]

In RHM, the spatial motion of a quark system is described by

\[ \text{Coherent Form Factor} \]

- natural explanation of the dipole-like dependence of the elastic nu-
- composite particle wave function
- Double one to take into account the Lorentz contraction effect of the

\[ \text{Relativistic Harmonic Oscillator Model (RHM)} \]
\[ (N, W) \frac{\varepsilon}{\alpha \cdot d} \varepsilon - \varepsilon^2 = (\varepsilon \alpha + \varepsilon^2) - \]

using the identity \( (d, d', D) = d \)

The wave function can be written covariantly in an arbitrary frame with

\[ \cdot (\varepsilon \chi \pm i \chi) \frac{\hbar}{\mu} = i \mp \varepsilon \chi = 0 \chi \]

with

\[ \left[ (\varepsilon \chi + \varepsilon \chi) \chi_{m_{\perp}} - \right] d \chi \chi \left( \frac{\mu}{\chi m_{\perp}} \right) \chi_{m_{\perp}} = (\chi) \chi \phi \\
\left[ (\varepsilon \chi + \varepsilon \chi) \chi_{m_{\perp}} - \right] d \chi \phi \left( \frac{\mu}{\chi m_{\perp}} \right) = (\chi) \phi \\
\]

where

\[ d, v, v' = \alpha \]

\[ (\chi \chi \phi (\alpha) \phi) \prod = (\chi \cdot d, v, v')_{\text{rest frame}} \]

and

\[ \left( (\chi \cdot d, v, v')_{\text{rest frame}} \right) \frac{\chi}{\Phi} = \frac{\chi}{\Phi} \]

the ground state spatial wave function in the rest frame

\[ (N, W) = d \]

\[ \text{In the rest frame} \]
Wave function.

Absorption of the incoming photon by the $\bar{q}$-quark component of the proton

Note that all knockon amplitudes are pure imaginary, which means the

\[
\begin{align*}
\psi^b \theta \cos \frac{2^b \theta}{1} = \frac{0^b \psi}{2^b} & \quad \psi^b \theta \sin \frac{2^b \theta}{1} = \frac{1^b \psi}{2^b} \\
\psi^b \theta \sin \frac{2^b \theta}{1} = \frac{1^b \psi}{2^b} & \quad \psi^b \theta \sin \frac{2^b \theta}{1} = \frac{1^b \psi}{2^b}
\end{align*}
\]

where

\[
\begin{align*}
\sum_{\nu=1}^{\nu=0} (\nu \omega \frac{2}{1} \phi \omega 1 \nu \omega \delta) (\nu \omega \frac{2}{1} \phi \omega 1 \nu \omega \delta 1) & = \sum_{\nu=1}^{\nu=0} \epsilon^\nu = \nu S \\
(\nu \omega \frac{2}{1} \phi \omega 1 \nu \omega \delta) (\nu \omega \frac{2}{1} \phi \omega 1 \nu \omega \delta 1) & = \sum_{\nu=1}^{\nu=0} \epsilon^\nu = \nu S
\end{align*}
\]

and

\[
\begin{align*}
\frac{\frac{N W}{Z}}{\frac{I}{\phi \omega \delta}} (d)_{p n n} A (\frac{\rho n b}{T} T)_{p m n} j (0, T \overline{p} \phi \delta) \frac{j \phi \delta}{q} V & = \frac{N W}{Z} (d)_{p n n} A (\frac{\rho n b}{T} T)_{p m n} j (0, T \overline{p} \phi \delta) \frac{j \phi \delta}{q} V \\
\frac{\frac{N W}{Z}}{\frac{I}{\phi \omega \delta}} (d)_{p n n} A (\frac{\rho n b}{T} T)_{p m n} j (0, T \overline{p} \phi \delta) \frac{j \phi \delta}{q} V & = \frac{N W}{Z} (d)_{p n n} A (\frac{\rho n b}{T} T)_{p m n} j (0, T \overline{p} \phi \delta) \frac{j \phi \delta}{q} V
\end{align*}
\]

Explicitly they have the form

\[\begin{align*}
\text{transfer of the amplitudes and } \text{contain the spin structure.}
\end{align*}\]

Here $L, S$ and include the dependence on the energy and momentum

\[
\begin{align*}
\nu \omega \frac{2}{1} \phi \omega \delta & = \nu \omega \frac{2}{1} \phi \omega \delta \quad \frac{0^b \psi}{2^b} \\
\nu \omega \frac{2}{1} \phi \omega \delta 1 & = \nu \omega \frac{2}{1} \phi \omega \delta 1 \quad \frac{1^b \psi}{2^b}
\end{align*}
\]

Knockout amplitudes in CM frame.
FIG. 7. The unpolarized photoproduction cross section $\sigma_{\gamma p}(\theta)$ at $W = 2.156$ GeV ($E_p = 2.0$ GeV). The solid, dotted, dashed, and dot-dashed lines give the cross section of VDM, OPE, $s \bar{s}$-knockout, and $u \bar{u}$-knockout, respectively, with strangeness admixture $B' = 1/\sqrt{2}$. The experimental data are from Ref.
FIG. 10. Notation same as in Fig. but for (a) $\gamma_{2\nu}$ and (b) $\gamma_{2\nu}$.

(a)

(b)

Assuming that $|q| = |q|$, the phase factors are explicitly given in each graph.

FIG. 9. *The double spin asymmetry $\langle a \rangle = M W (\theta)_{\text{exp}} S_{\text{exp}} (\theta)$ and (c) $\text{CF}_{\text{exp}} (\theta) (9)$ and (d) $\text{CF}_{\text{exp}} (\theta) (9)$*.

FIG. 8. The single spin observables $\langle a \rangle$.

\[
\frac{\langle \pi \pi \gamma \pi \gamma \rangle_0}{\langle \pi \pi \gamma \pi \gamma \rangle_0} = \frac{15}{18}.
\]
\[ \text{Fig. 12: Notation same as in Fig. 10 for (a) and (b).} \]

\[ \text{Fig. 11: Notation same as in Fig. 8 for (a) and (b).} \]
FIG. 8. The absolute value of beam-target asymmetry as a function of $E_\gamma$, calculated by exclusive $p\gamma \rightarrow \phi$ (GeV) normalization, and the HEMES result shown as black curve, big curve, and black solid circle, respectively.

The non-strangeness contribution, calculation including strangeness knockout, and the HEMES result are shown as black curve, big curve, and black solid circle, respectively.

FIG. 9. The $C_v$ calculated by Oh et al. as a function of $\phi$ center-of-mass angle for a photon energy of 1.925 GeV. The solid (purple), dashed (blue), and dashed (blue) lines correspond to VMD+OPE (no strangeness), 0.25% $\phi$ probability, and 1% $\phi$, respectively.
Summary

1. A model for EM production, which includes the direct knock-out mechanism in addition to VDM & OPE, is constructed.

2. We find that some bubble operators like $C_{71/2, 8^{+}}$, $C_{71/2, 2^{+}}$, $CT_{6, 6^{+}}$, and $C_{71/2, 4^{+}}$ are very sensitive to the hidden strangeness content of the proton in the small $1^{+}$ region.

3. Several experiments can be performed to check the predictions to production.

4. Similar approach can be applied to $\pi N$ production.