Taming the pion cloud

Gerald A. Miller, UW Mary Alberg, Seattle U, UW

vs

Arrington arXiv:1208.4047

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Fundamental Question: meson cloud or $4q\overline{q}$

Hidden color

Important implications for nuclear force and nuclear structure if meson cloud picture is shown to fail

Experimental Progress Drell-Yan contributions from the *J*yc and Y resonance families. The data clearly show that the Drell-Yan cross section per nucleon for *p* 1 *d* exceeds *p* 1 *p* over an appreciable range in *x*2. Figure 1 also shows the predictions for next-to-leading order calculations \Box ratio, weighted by the E866 spectrometer's acceptance, in either parametrization, is the rapid decrease towards of \mathbf{r} unity of the *d*¯y*u*¯ ratio beyond *x* ≠ 0.2. At *x* ≠ 0.18, the extracted *d*¯ y*u*¯ ratio is somewhat smaller than the value obtained by NA51. Although the average value of *Q*² (*M*² m1m2) is different for the two data sets, the change in *d*¯ y*u*¯ predicted by the parton distributions due to *Q*² i di L \bullet and \bullet address the GSR violation observed by NMC, the GSR violation observed by NMC, the NMC, the NMC, the NMC, the NMC, the NMC violation observed by NMC, the NMC violation observed by NMC, the NMC violation obser

- NMC measured integral quantity for Gottfried sum using the CTEQ4M \sim 10 μ and \sim 10 μ parton distribution distribution distribution distribution distriasured integral quantity for Gottfried sum a modified $\mathcal{L}_{\mathcal{A}}$ modified maintains which maintains $\mathcal{L}_{\mathcal{A}}$
- E866 FermiLab measured x-dependence **is clear that** *d p inclusive x*² α *p d p ondones*

J. C. PENG *et al.* PHYSICAL REVIEW D **58** 092004 $TCTGAT$ DEVIEW D 50.00004 *x*F *x x*₂ *x*₂ *x x* $\frac{1}{20}$ *x*² $\frac{1}{20}$ *x*² . *A x*₂ . *A*

FIG. 1. Comparison of the E866 $\overline{d} - \overline{u}$ results at $Q = 7.35$ GeV with the predictions of various models as described in the text. and is various models as described in the text.

 $\overline{1}(\)$ \rightarrow $\overline{1}(\)$ \rightarrow $\overline{1}(\)$ $a(x) > u(x)$ what about a/u . ,^{ax,}0.345. Since CTEQ4M provides a reasonable description and since $\mathcal{L}^{\mathcal{A}}$ $d(x) > \bar{u}(x)$ what about d/\bar{u} tribution from the high-*x* region is small, we have used the high $d\bar{d}(x) > \bar{u}(x)$ what about \bar{d}/\bar{u} ? $\frac{1}{\sqrt{2}}$ effects in deuterium are significantly less than $\frac{1}{\sqrt{2}}$ (eq.) x) what about d/u ? Some of the data, especially at higher *x*2, do not

Exnect large ratio at large v \Box apport idigo ratio de largo A Expost large ratio at large v Expect large ratio at large x

J. C. PENG *et al.* PHYSICAL REVIEW D **58** 092004 Hawker et al PRL 80, 3715

More data- E866 (1999) error of "0.018 in *D*. The ^v meson, like any other is a set of the solution of \mathbf{U} is that from the pion alone. In Fig. 2 the solid curve *M. Alberg et al.*r*Physics Letters B 471 2000 396–399 ()* 397 **Acknowledgements** 1 MUS 1 partial support of this work. We thank R.J. Holt for a \mathcal{L}

 \leftarrow $\left\{\begin{array}{c} \begin{array}{c} 2 \\ 1 \end{array}\right\}$ with ω

with longitudinal momentum fraction \mathcal{N} and \mathcal{N} and \mathcal{N} and \mathcal{N}

M $\frac{1.5}{7}$ *M* $\frac{1}{7}$ **T** $\frac{1}{7}$ **T** $\frac{1}{7}$

The quark distribution function *q x*Ž . of a proton

 $\left| \begin{array}{c} 2.5 \end{array} \right|$

Ž ² ^f *y*,*k* . is the probability amplitude for finding a *BM* ^H

description of the present data.

 $\frac{1}{\sqrt{1 + \frac{1}{\sqrt{1 +$

nucleon interaction. In the set of \mathbf{I}

 $v_{\rm c}$

is given by α

 $\mathbf{0}$.

 \circ .

 0.2

 0.05

 0.1

 0.15 \mathbf{x} 0.2

 $\overline{d} - \overline{u}$

' 2 2 ^N*p*: : ^s *^Z* ^N*^p* bare^q ÝH*dy d ^k*^H ^f*BM* ^Ž *^y*,*k*H.

 \overline{a} here, which contribute to the proton sea. In addition, \mathcal{L}_{max} \overline{a} could include the s meson, which would also tend to suppress *d*r*u*. Including these effects is likely to improve the description of th

=N*B y* Ž ,*k*H H . *M*Ž1y*y*,y*k* .: . 1Ž .

 \mathcal{F} and better data would provide a set of better data would provide a set of \mathcal{F} \mathbb{R} severe test of the present model, and the present model, and the problem, and the problem, \mathbb{R} such seem in the seem in the \mathcal{L} that the use of the v along with the previously \mathbf{I} suggested meson cloud effects does allow for a good

Drell-Yan Measured $\bar{d} - \bar{u}$ and $\frac{\bar{d}}{\bar{u}}$ \mathcal{D} in \mathcal{F} and \mathcal{F} and *D*rell-Yand Meas ω stants used to describe the nucleon-term in \overline{d} n Measured $a-u$ and $\frac{u}{\bar{u}}$

Alberg, Henley and Miller PLB 471, 396 (2000) α the ration α and the ration function for α α s_{av} and Miller DLR 471, 306 (2000) sider its effects for a proton target.

With pions get too large a ratio $\frac{\bar{d}}{\bar{u}}$ value of *d*r*u* to be too large and to appear at too high a value of $\bf v$ $\bf v$ $\bf r$ $T_{\rm eff}$ mesons are not included in the notation in when a ded to the v meson that \overline{d} arge α $\overline{1}$ get too large a ratio $\frac{a}{z}$ ω

 $T_{\rm eff}$ required in the model are taken from Form factor at the KFZ in Juelich.

$$
G_M(t,u) = \exp\left(\frac{t - m_M^2}{2 A_M^2}\right) \exp\left(\frac{u - m_B^2}{2 A_M^2}\right),
$$

J. Speth, A.w. Thomas, Advances in Nuclear Physics, vol.
24, J.W. Negele, E.W. Vogt (Eds.), Plenum Press, New J. Speth, A.W. Thomas, Advances in Nuclear Physics, vol.

Is there an isoscalar non-perturbative sea (omega meson)? Is there an isoscalar non-perturbative sea (omega mes P is the paper, we only the paper of the results of th α 5 α 5 μ α collaboration, E.A. α . A. Hawker et al., α -perturbative sea (omega 092004. \mathcal{L} <u>UI</u> where \mathcal{L}

> $\operatorname{Without}_i \omega$ The omega represents any non-perturbative isoscalar sea It is constructed a good description of the good description of the good description of the good description of t the present data is present data is present data is provided by the inclusion of t Without ω successful. As mentioned above there are a number for portanealive lococalar oca w x 8 S. Kupi 30 1991 306

> > What's going on at high x? We need to discuss the functions *q x ^M* Ž . and *'*hat's going on at high x?

SeaQuest aims at better measurement, so we try to improve 1 *x* **di** α *i* α *i x* α *i x* α *i x* α *i x* α function of the r and p are the same. Thus we use the same \mathcal{L}

Theory problems

- \cdot Results depend on form factor parameter $\,\Lambda$
- form factors enter as three dimensional functions even though expressed in terms of t and u
- how to derive ????
- Why do we need form factors? Form factors oppose chiral perturbation theory

Why do we need form factors? \blacksquare Why do we need form factors? Lagrangian of the free pion field, and *^L*(1) *^N* describes the dynamics of the nucleon field and its

Using form factors opposes chiral perturbation theory

$$
\mathcal{L}_N^{(1)} = \bar{\psi}(i\gamma\cdot\partial - M)\psi - \frac{g_A}{2f_\pi}\bar{\psi}\gamma_\mu\gamma_5\tau^a\psi\,\partial_\mu\pi^a - \frac{1}{f_\pi^2}\bar{\psi}\gamma_\mu\tau^a\psi\ \epsilon^{abc}\pi^b\partial_\mu\pi^c
$$

Non-renormalizable \mathcal{L} , expand in powers of momentum add counter terms order-by order -LECs. results **INDEPENDENT OF CUTOFF** Not sufficient for DIS, IMHO because momenta $\mathcal{O} \sim m_N$

Form factor relates the LECs in a very specific way

different philosophy

Comment talk last week titled " \cdots with chiral perturbation theory"

is NOT – no LEC's, but yes to cutoff dependence

pion-nucleon Form factor takes composite nature of pion and nucleon into account

$$
MG_A(Q^2) = f_{\pi}g_{\pi NN}(Q^2).
$$
 E,[GeV] (3.10)

1000 $10₁$ 100

of 3 % (with $g_A = G_A(0) = 1.267 \pm 0.004$, $g_{\pi NN} = g_{\pi NN}(0) = 13.2 \pm 0.1$ and $M =$ At $Q^2 = 0$ this is known as the Goldberger-Treiman relation and it is satisfied at the level man relation

Figure 3.1: Pion pole model for the induced pseudoscalar form factor.

1We neglect a small non-pole correction given by Adler and Dothan [AD 66]. See also [BHM 01]. See also [BHM 01

 $\mathcal{G}_{\pi\mathsf{N},\dots}$ / \Box Figure 3.2 summarizes the total cross section data from the three major groups working on the problem in the second in the 10 and σ of the data take the vector form factors from electron scattering data and employ the approxi-Pion-Nucleon form factor determined for on-mass-shell nucleons, off shell pion

monopole or tripole form led to fits that were worse by 1.5 standard deviations. With *GA*(0)

fixed at 1.26 from neutron -decay (as explained below) the data is then analyzed for *M^A*

Family 1-Alberg & Miller
\n
$$
PRL \quad 108 (2012) 172001
$$
\n
$$
g_{\pi NN}(Q^2) \propto G_A(Q^2) = \frac{G_A(0)}{(1 + \frac{Q^2}{M_A^2})^2}
$$
\nPion-Nucleon form factor determined for on-mass-shell nucleons, off shell pion
\nNucleon self energy-intermediate nucleon and Delta
\n
$$
g_{\pi NN}(Q^2) = \frac{G_A(0)}{(1 + \frac{Q^2}{M_A^2})^2}
$$
\n
$$
P_{\pi NN}(Q^2) = \frac{G_A(0)}{(1 + \frac{Q^2}{M_A^2})^2}
$$
\n
$$
P_{\pi NN}(Q^2) = \frac{G_A(0)}{(1 + \frac{Q^2}{M_A^2})^2}
$$
\n
$$
P_{\pi NN}(Q^2) \propto G_A(Q^2) = \frac{G_A(0)}{(1 + \frac{Q^2}{M_A^2})^2}
$$
\n
$$
= \frac{G_A(0)}{(1 + \frac{Q^2}{M_A^2})^2}
$$
\

Pion-Nucleon form factor determined for on-mass-shell nucleons, off shell pion off ! $\overline{}$ x

 dependence inherent in Eq. (Nucleon self energy -intermediate nucleon and Delta Prime 108, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 1720, 172
Physical Review Letters were week to allow the state were week to allow the state were were well as a state we
 violate the purported consequence of momentum conserva- tion. Similarly, the pionic coupling between nucleons and

Family I - Alk
PRL 108 (20

$$
g_{\pi NN}(Q^2) \propto G_A(Q^2)
$$
Pion-Nucleon form factor determinant
lucleon self energy-intermediate nucleon

 $\overline{?}$ e state the contract of the state of the Parameter free calculation! 0.109 So what's the problem?

violation de purpose of momentum consequence of momentum consequence of momentum conservation. The pionic coupling between nucleons and $\frac{1}{2}$ in the pionic coupling $\frac{1}{2}$ ` Taming II- recent

To get \bar{u} and \bar{d} need to calculate the graphs: include the e $\frac{1}{\sqrt{2}}$ while the meson is in the meson is

x In a light-front description, the proton-wave function can be expressed as a sum of Fockstates components,. If one assumes that the meson cloud is an e↵ective description of the nucleon's non-perturbative sea, the di↵erent components are the bare nucleon and mesonbaryon states. This is the hypothesis that we are testing. Given such a wave function, and assuming the lack of interference e↵ects one can represent the quark distribution function in terms of distributions *fMB*(*y*) that represent the probability that a nucleon will fluctuate into

FIG. 1 (color online). (a) Pionic (dashed line) contribution to Both pion and nucleon are off-shell in the Feynman graphs need to reconsider the formalism a meson, *M*, of light front momentum fraction *y* and a baryon, *B*, of light front momentum **fraction 1 is a set of the meson contribution contribution in the Feynman graphs** $\frac{1}{2}$ in the flavor $\frac{1}{2}$ in the fl

$$
q_N^f(x) = Z_2 q_{N0}^f(x) + \sum_{B,M} \int_x^1 \frac{dy}{y} f_{MB}(y) q_M^f(\frac{x}{y}) + \sum_{B,M} \int_x^1 \frac{dy}{y} f_{BM}(y) q_B^f(\frac{x}{y})
$$

$$
Z_2^{-1} - 1 = \sum_{B,M} \int dy f_{BM}(y),
$$

Brodsky-Lepage Fock space representation:

$$
|\pi N\rangle \propto \int_0^1 \frac{dy}{\sqrt{y}} d^2 k_{\perp \pi} \int_0^1 \frac{dy_N}{\sqrt{y_N}} d^2 k_{\perp N} \delta(1 - y - y_N) \delta(\vec{k}_{\perp \pi} + \vec{k}_{\perp N}) \psi_{\pi N}(y, \vec{k}_{\perp \pi}; y_N, \vec{k}_{\perp N}) | \cdots \rangle
$$

$$
f_{\pi N}(y) = \int d^2 k_{\perp \pi} \left| \psi_{\pi N}(y, \vec{k}_{\perp \pi}; 1 - y, -\vec{k}_{\perp \pi}) \right|^2 = f_{N \pi}(1 - y)
$$

violation de purpose of momentum consequence of momentum consequence of momentum conservation. The pionic coupling between nucleons and $\frac{1}{2}$ in the pionic coupling $\frac{1}{2}$ ` Taming II- recent

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$$

$$
Z_2^{-1} - 1 = \sum_{B,M} \int dy f_{BM}(y),
$$

 Z_2 would change $\text{If } f_{MB} \text{ has } \delta(y).$ Z_2 would change, but NO delta functions here!

Brodsky-Lepage Fock space representation:

$$
|\pi N\rangle \propto \int_0^1 \frac{dy}{\sqrt{y}} d^2 k_{\perp \pi} \int_0^1 \frac{dy_N}{\sqrt{y_N}} d^2 k_{\perp N} \delta(1 - y - y_N) \delta(\vec{k}_{\perp \pi} + \vec{k}_{\perp N}) \psi_{\pi N}(y, \vec{k}_{\perp \pi}; y_N, \vec{k}_{\perp N}) | \cdots \rangle
$$

$$
f_{\pi N}(y) = \int d^2 k_{\perp \pi} \left| \psi_{\pi N}(y, \vec{k}_{\perp \pi}; 1 - y, -\vec{k}_{\perp \pi}) \right|^2 = f_{N \pi}(1 - y)
$$

Light front perturbation theory for chiral lagrangian G A Miller PR C56, 2789 **1997**

 $\begin{aligned} + \qquad \qquad \qquad + \qquad \qquad \qquad \mathbf{V} = \mathbf{V} \end{aligned}$ Schroedinger eq: $(\hat{P} - \hat{P} - \hat{P}^2_{\perp})|p\rangle = M_p^2|p\rangle = (M_0^2 + V)|p\rangle$ $|p\rangle \approx Z$ $\sqrt{2}$ $|p\rangle_0 + \left(\frac{1}{M^2 - M_0^2} V|p\rangle_0\right)$ $\overline{\mathcal{L}}$ \hat{P}^- is Hamiltonian operator, construct from energy-momentum tensor $T^{+-}{=}$ free particle kinetic energy M_0^2 plus interactions V $\left|\pi N\right>$ component weinberg-Tomazowa term is the hallmark of chiral symmetry $\mathcal{B}(\mathcal{S})$. The hallmark of chiral symmetry $\mathcal{B}(\mathcal{S})$ V. ⇡-NUCLEON TERMS Schroedinger eq: $(\hat{P}^{\dagger} - \hat{P}^2) |p\rangle = M_e^2 |p\rangle = (M_0^2 + V)|p\rangle$ $\frac{1}{\sqrt{2}} \left(\frac{1}{1} \frac{1}{1} \frac{1}{1} \right) \frac{p}{p} - \frac{M_p}{p} = \frac{(M_0 + V) p}{(1 - V)}$ $|p\rangle \approx Z_o (|p\rangle_0 + \left(\frac{1}{M^2 - M_0^2}V|p\rangle_0\right)$ *^N* describes the dynamics of the nucleon field and its $\mathcal{L}_N^{(1)} = \bar{\psi}(i\gamma \cdot \partial - M)\psi - \frac{g_A}{2f}$ $2f_\pi$ $\bar{\psi} \gamma_{\mu} \gamma_5 \tau^a \psi \, \partial_{\mu} \pi^a = \frac{1}{f^2}$ f_{π}^2 $\bar{\psi} \gamma_{\mu} \tau^a \psi \; \epsilon^{abc} \pi^b \partial_{\mu} \pi^c$ 2

Form factors absent. At least α the pion decay constant α

Form factors

- Including form factors goes beyond usual LF treatment
- Need form factors in frame independent manner (4-space)
- Maintain momentum conservation, unique LF wave function Keep experimental input
- For use in light front wave function-virtual N, π

 Γ contains form factor.

Integrate over UH k^- plane = integrate over LH k^- plane w. stated form factor $n = 1$ gives form factor very close to dipole, maintain experimental input!

Summary

- Have formalism to get light front wave functions and meson distribution functions needed for light flavor nucleon sea
- Meson-nucleon coupling constants are known
- Form factors included in frame independent manner that incorporates experimental input
- Given the meson cloud model can make calculations with reasonably-well understood uncertainties
- True test of meson cloud model!
- See Alberg's talk