AdS/QCD and Gluon Matter Distribution in the Proton and Pion

Perceiving EHM through AMBER@CERN

11th May 2022

 a_x (fm) _{0.0}

 0.5

 a_y (†m) $_0$

$^{-0.5}$ Tianbo Liu (対天博)

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Research Center for Particle Science and Technology

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鄙 ivsics and Particle Irradiation (MOE)

Gauge/Gravity Duality and LF holography

Maldacena's conjecture

J.M. Maldacena, Int. J. Theor. Phys. 38, 1113 (1999).

Gauge field theory in *d*-dim

Gravitational theory in *d+1*-dim

A realization: AdS / CFT

semiclassical gravity approximation to strongly coupled QFTs

Light-front holographic QCD

QCD: conformal symmetry is broken by quark masses and quantum effects

Asymptotic freedom

Confinement and an infrared fixed point

"bottom-up" approach: modify the background AdS space

impact LF variable-*ζ* ⇔ *z* holographic variable in AdS measuring the separation of partons in a hadron

G.F. de Téramond and S.J. Brodsky, Phys. Rev. Lett. 102, 081601 (2009); S.J. Brodsky and G.F. de Téramond, Phys. Rev. Lett. 96, 201601 (2006); Phys. Rev. D 77, 056007 (2008); Phys. Rev. D 78, 025032 (2008).

[Brodsky & de Téramond]

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المرور المرور المرو **arXiv:2205.01169 [hep-ph]. Company** (solid triangles) and \overline{X} (solid \overline{X} (solid \overline{X}) and \overline{X} (solid square).

Hadron Spectrum in LF Holography

explained by the different paints of the different configurations and suppose ϵ H.G. Dosch, G.F. de Téramond, S.J. Brodsky, Phys. Rev. D 91, 045040 (2015); D91, 085016 (2015). $\frac{1}{\sqrt{2}}$ states with S $\frac{1}{\sqrt{2}}$ اردا بن عليه المسلم العربي العربي العربي العداد المسلم التي تعليم المسلم التي تعليم التي تعليم العداد التي تعل
2015): H.G. Dosch. G.F. de Téramond. S.J. Brodsky. Phys. Rev. D 91. 045040 (2015): D91. 085016 precision measurement at Company and a new resonance named the *a*¹/₁ which found a mass 1.42 GeV, the *a*¹/₁ with a mass 1.42 GeV, the *a*¹/₁ with a mass 1.42 GeV, the angle of a mass 1.42 GeV, the α S.J. Brodsky, G.F. de Teramond, H.G. Dosch, J. Erlich, Phys. Rep. 584, 1 (2015);
H.G. Dosch, G.F. de Téramond, S.J. Brodsky, Phys. Rev. D 91, 045040 (2015); D91, 085016 (2015).

EM Form Factors in Holographic QCD electromagnetic FF corresponds to the coupling of an **EXTERNAL FORM FACTORS IN H** em Factors in Holographic **a** de de de de de de la hadron de la posta In holographic Queens arise at high virtuality, whereas gluons with small virtuality Cactors in Holographic C **RACIOIS III FIOIOGIAPHIC QUD** \blacksquare **EM Form Factors in Holographic QCD** 0.775 GeV, gives the value of κ χρόνια στην επιτροπή της και το καταστικό της και το καταστικό της επιτροπής τ
Ο καταστικό της επιτροπής της επιτροπής της επιτροπής της επιτροπής της επιτροπής της επιτροπής της επιτροπής
 incoming electromagnetic probe \blacksquare $\mathbf{S} \cdot \mathbf{A}$ **IC QUD** $\bf D$ imposing further physically motivated constraints is ETT FOLM FACTOLS IN LIONS APM ðxÞwðxÞ[−]t=4λ−¹ M Form Factors in Holograph dependence and a plane wave in provided wave in provided was in provided was a planet of the space representation of the space representation of the space representation of the space representation of the space representat \mathbf{c} OCD \sim

Form factor of a spinless hadron \overline{P} Γ subset of effective confining potential $\mathcal{S}_{\mathcal{A}}$. Form factor of a spinle Form factor of a spinthe formalism in order to examine the contribution of \mathbf{f}_t Form factor of a spinless hadron local coupling of the quark current June 1999 of the quark current June 1999 of the quark current June 1999 of
The quark current June 1999 of the quark current June 1999 of the quark current June 1999 of the quark current i onin ractor of a spilltess in auton ing to $L_{\rm eff}$ for arbitrary twist twist the FF for arbitrary twist twist the format σ arbitrary twist twist the format σ Form factor of a spinless hadron \mathcal{L} in \mathcal{L} and \mathcal{L} in the physical dependence of \mathcal{L}

$$
\int d^4x dz \sqrt{g} \Phi_{p'}^*(x, z) \overleftrightarrow{\partial}_M \Phi_p(x, z) A^M(x, z)
$$
\nThe coupling of an external EM field
\npropagating in AdS space to a hadron mode
\n $\sim (2\pi)^4 \delta^4 (P' - P - q) \epsilon_\mu (P + P')^\mu F(q^2)$ \nEM form factor in physical spacetime
\n $x^M = (x^\mu, z) \qquad \sqrt{g} = (R/z)^5$ \nJ. Polchinski and M.J. Strassler,
\nJHEP 05 (2003) 012.
\n $A_\mu(x, z) = e^{i q \cdot x} V(q^2, z) \epsilon_\mu(q), \qquad A_z = 0$

Extracting the momentum conservation factor but the experimental data of a different combination of E=Gp Extracting the momentum \dot{h} convenience we have function α and α ; α and α ; α and α ; α and α ; $\lim_{\mu \to 0} \frac{1}{\mu}$ Extracting the momentum conservation factor where the bulk-to-boundary propagator \mathbb{R}^2 ; zb has the bulk-toation factor h

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$$
F(Q^2) = \int \frac{dz}{z^3} V(Q^2, z) \Phi_\tau^2(z)
$$

 Γ the hadron by the polarization Γ the polarization Γ For hadron modes scale as $\Phi_{\tau} \sim z^{\nu}$ at small described. More recent works [57,58] by the same group $\frac{1}{\sqrt{1-\frac{1$ For hadron modes scale as $\Phi_{\tau} \sim z^{\epsilon}$ at small $z \sim 1/Q$ all $z \sim 1/Q$ $\begin{array}{ccc} \tau & \tau & \text{if} & \frac{11}{4} & \frac{1}{2} & \end{array}$ For hauton modes searc as $\Psi_{\tau} \sim \chi$ at small values of Ψ_{τ} $\sim 1/O$ \mathcal{L} For hadron modes scale as r hadron modes scale as $\Phi_{\tau} \sim z^{\tau}$ at small $z \sim 1/Q$ $\overline{\text{For hadron modes scale as}}$ $\overline{\text{O}}$ $\alpha, \overline{\tau}$ at s For hadron modes scale as $\Phi_{\tau} \sim z^{\tau}$ at small $z \sim 1/Q$ $\overline{2}$

Fødslei

$$
F_{\tau}(Q^2) \sim \left(\frac{1}{Q^2}\right)^{\tau-1}
$$
 recover the hard-scatter power scaling

In contrast with the GPD twist that is determined by the GPD twist that is determined by the GPD twist that is
In the GPD twist that is determined by the GPD twist that is determined by the GPD twist that is determined by

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alir Q² recover the nard-s
mower scaling $p_{\rm c}(\mathcal{Q}^2) \sim \left(\frac{1}{\Omega^2}\right)$ is recover the hard-seathering photographs recover the hard-scattering power scaling

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S.J. Brodsky and G.R. Farrar, expressed as a product of τ − 1 poles along the vector Phys. Rev. Lett. 31, 1153 (1973). ord scattering **S.J. Brodsky and G.R. Farrar,** 31, 1153 (1973). **precise relation between the twist of each Fock state in a set of each Fock state in a set of each Fock state i** , 1153 (1973).
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ower soaring
W.A. Matveev, R.M. Muradian, A.N. Tevkhelidze,
where Forms of the Pluove Cimento 7, 719 (1973) the EM current Commento 7, 719 (1973).
The EM current support of the sup lidze, $\frac{f_{\rm eff}}{f_{\rm eff}}$ is given by a product of thus establishing a product of thus establishing a product of the stabilistic and $\frac{f_{\rm eff}}{f_{\rm eff}}$ V.A. Matveev, R.M. Muradian, A.N. Tevkhelidze, Lett. Nuovo Cimento 7, 719 (1973). nance *(, (*19 (1973).
And the low energy service services Nτ **Lett. Nuovo Cimento 7, 719 (1973).** ito 7, 719 (1973).

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EM Form Factors in Holographic QCD S] Holographic OCD incorporates the correct hard-scattering twist-scaling nance at low energy [65]. rm acto rs in Holographic OCD of in Factors in Holographic QCD den av 2002
1 av 2002 - xo2
2 av 2002 - xo2 e−k2z2x tation (162) where F is given by Eq. (9). Since the charge is a diagonal control of \mathbb{R}^n \blacksquare oranhic Ω CD components in the initial states contribution in the initial states contribute to the init

Hadron wave function of twist-τ (soft-wall) on wave function of twist-t (soft-wall) $\frac{1}{2}$

$$
\Phi_{\tau}(z) = \sqrt{\frac{2}{\Gamma(\tau - 1)}} \kappa^{\tau - 1} z^{\tau} e^{-\kappa^2 z^2/2}
$$

Vector current

$$
V(Q^2, z) = \kappa^2 z^2 \int_0^1 \frac{dx}{(1 - x)^2} x^{Q^2/4\kappa^2} e^{-\kappa^2 z^2 x/(1 - x)} = 4\kappa^4 z^2 \sum_{n=0}^\infty \frac{L_n^1(\kappa^2 z^2)}{M_n^2 + Q^2}
$$

H.R. Grigoryan and A.V. Radyushkin,

 $s = \frac{1}{2}a + \frac{1}{2}a^2 - \frac{1}{2}(n+1)$ the integral integral in Eq. (6) contains the poles at $-Q^2 = M_n^2 = 4\kappa^2(n+1)$ Phys. Rev. have poles at $-Q^2 = M_n^2 = 4\kappa^2(n+1)$ $\frac{60}{x^2}$ $\frac{1}{2}$ $\overline{4}$

spectral 1 function of the associated Laguerre polynomials $\mathcal{L}_{\mathcal{A}}$ compare with L FHQCD spectral formul compare with LFHQCD spectral formula M_n^2

 $\frac{1}{2}$ \overline{a} $+ L$ $\frac{1}{2}$ sum in Eq. (10). Normalization at \mathcal{L}^2 -2 if -2 \leftarrow $\frac{J+L}{m}$ form factor is $\frac{1}{2}$ Phys. Rev. D 76, 095007 (2007). compare with the data, $d + L$ tral formula $M_n^2 = 4\kappa^2 \left(n + \frac{1}{2}\right)$ τ is τ $\delta f^2 = 4\kappa^2 \left(\eta + \frac{J+L}{L} \right)$ determine the coefficients $\frac{1}{2}$ $n^2 = 4\kappa^2$ \overline{a} $n +$ *J* + *L* 2 $=4\kappa^2\left(n+\frac{J+L}{2}\right)$ a $M_n = 4\kappa (n)$
 $I - I - 1$

 v and in σ to the R ge trajectory $J =$
 $I + 1 = 1$ $\frac{1}{2}$ corresponding to the Regge trajectory $J = L = 1$ corresponding to the Pegge trajectory $I = I = 1$ corresponding to the Regge trajectory $J = L = 1$

ρ meson trajectory is
$$
J = L + 1 = 1
$$
 shift poles to $-Q^2 = M_{\rho_n}^2 = 4\kappa^2 \left(n + \frac{1}{2}\right)$

function of the associated Laguerre polynomials Laguerre polynomials Laguerre polynomials Laguerre polynomials L
The associated Laguerre polynomials Laguerre polynomials Laguerre polynomials Laguerre polynomials Laguerre p dsky, G.F. eramond, H.G. Dosch, J. Erlich,
Phys. Ren. 584, 1 (2015) form factor is written as a single-pole expansion r_{H} ys. Nep. 304, T (2013). S.J. Brodsky, G.F. de Téramond, H.G. Dosch, J. Erlich, In the second contract of the second by a hadron is described by a hadro **Phys. Rep. 584, 1 (2015).**

nv. Origoryan and A.v. K
hys. Rev. D 76, 095007 (2

 $\frac{1}{2}$ Form factor ¼ 0; ð2Þ $\int f \cdot r$ integration Form factor

 ρ meson

$$
F_{\tau}(Q^2) = \frac{1}{\left(1 + \frac{Q^2}{M_{\rho_{n=0}}^2}\right)\left(1 + \frac{Q^2}{M_{\rho_{n=1}}^2}\right)\cdots\left(1 + \frac{Q^2}{M_{\rho_{n=\tau-2}}^2}\right)}
$$

S.J. Brodsky and G.F. de Téramond,
Phys. Rev. D 77, 056007 (2008). where *κ* μ προσταλλικός και το προσπάθει και το προσπάθει της προσπ
Επιτροποιημείου στη συνθετική προσπάθει της προσπάθει S.J. Brodsky and G.F. de Téramond,
S.J. Brodsky and G.F. de Téramond, Phys. Rev. D 77, 056007 (2008).

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 $\sum_{i=1}^{n}$

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kev. D 76, 095007 (2007).

Pion EM Form Factor

Pion form factor compared with data

G.F. de Téramond and S.J. Brodsky, Proc. Sci. LC2010 (2010) 029. S.J. Brodsky, G.F. de Téramond, H.G. Dosch, J. Erlich, Phys. Rep. 584, 1 (2015). [Sec. 6.1.5]

レ东大子(青岛)

EM Form Factors in Holographic QCD I FULIN FACIO Z graphic QCD \overline{P} Holographie Ω \mathbf{F} \mathbf{S} Z **Franhic OCD** and tangent indices in flat five-dimensional space are A, B. Form Factors in Holographic QCD $\mathcal{L}_{\mathcal{L}}$, \sim

Nucleon EM form factor: spin-nonflip (Dirac form factor) ∤pin-nontup (Dirac form tactor) where the curved space indices in AdS⁵ space are M, N, M form factor: spin-nonflip (Dirac form factor) $\frac{1}{2}$ Ref. $\frac{1}{2}$ and $\frac{1}{2}$

$$
\int d^4x dz \sqrt{g} \bar{\Psi}_{P'}(x, z) e_A^M \Gamma^A A_M(x, z) \Psi_P(x, z)
$$
\nThe coupling of an external EM field
\n
$$
\sim (2\pi)^4 \delta^4 (P' - P - q) \epsilon_\mu \bar{u}(P') \gamma^\mu F_1(q^2) u(P)
$$
\nDirac form factor in physical spacetime
\n
$$
\{\Gamma^A, \Gamma^B\} = 2\eta^{AB} \qquad \Gamma^A = (\gamma^\mu, -i\gamma^5) \qquad e_A^M = (\frac{z}{R}) \delta_A^M
$$

Nucleon wave function Nucleon wave function and relation wave runction Nucleon wave function

$$
\Psi_+(z) \sim z^{\tau+1/2} e^{-\kappa^2 z^2/2}, \qquad \Psi_-(z) \sim z^{\tau+3/2} e^{-\kappa^2 z^2/2}
$$

Dirac form factor $\mathbf{D}_{\text{true}}^{\star}$ for the functional gravity theory nucleons are \mathbf{D}_{H} at functions \mathbf{D}_{H} and \mathbf{D}_{H} and \mathbf{D}_{H} and \mathbf{D}_{H} and \mathbf{D}_{H} are \mathbf{D}_{H} and \mathbf{D}_{H} and \mathbf{D}_{H} are \mathbf{D}_{H} and \mathbf{D}_{H} and \mathbf{D}_{H} Dirac form factor

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Δεν αγγελβασιακό της Σεντραπουλίας
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G.F. de Téramond, H.G. Dosch, S.J. Brodsky,
Phys. Rey, D.87, 075005 (2013) **the spin-nontify and the spin-non-tensor** (1.5), it is become controlled the spin-
Phys. Rev. D 87, 075005 (2013). described by plus and minus and minus wave functions wave functions was very many manufacture $\frac{1}{2}$ and $\frac{1}{2}$ and corresponding to the positive and negative and negative and negative chirality of the phys. Rev. D 87, 075005 (2013). J. Brodsky,
5005 (2042) in both expressions. This difference arises from two described by plus and minus and minus and minus and H−G and H−G and Broadsky and H−G G.F. de Téramond, H.G. Dosch, S.J. Brodsky,
Phys. Rev. D 87. 075005 (2013).

$$
F_1^N(Q^2) = \int \frac{dz}{z^4} V(Q^2, z) [g_+ \Psi_+^2(z) + g_- \Psi_-^2(z)]
$$

; ^Ψ−ðz^Þ [∼] ^z^τþ3=²e[−]κ2z2=²

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1940 - Henrik Sterner
1940 - Henrik Sterner

Infolographic OCD σ in σ i ostove in Holographic OCD actul **VI Form Factors in Holograph** the Fock expansion of the hadron state. It controls the short **EM Form Factors in Holographic QCD**

Form factor for arbitrary twist-*τ* state te \mathbf{r} twist $\boldsymbol{\tau}$ state distance behavior of the hadronic state and thus the powerctor for arbitrary twist- τ

 $F_1(t) = c_\tau F_\tau(t) + c_{\tau+1} F_{\tau+1}(t)$

distance behavior of the State State and S.J. Brodsky and G.F. de Téramond, S.J. Brodsky and G.F. de Téramond, law asymptotic behavior of the property of the
Second property of the property **Phys. Rev. D 77, 056007 (2008);**
 $\begin{array}{ccc} \mathbf{P} & \mathbf{P} \end{array}$ For integer τ Eq. (1) generates the pole structure pole structure [52]. By a structure for pole structure [52]
The pole structure [52] generates the pole structure [52] generates the pole structure [52] generates the pole d C E de Téramons $56007(2008);$

S.J. Brodsky, G.F. de Téramond, H.G. **Dosch, J. Erlich, Phys. Rep. 584, 1 (2015).** 1 2 − t " values at the integration limits given by the constraints Dosch, J.

$$
F_{\tau} = \frac{1}{N_{\tau}} B\left(\tau - 1, \frac{1}{2} - \frac{t}{4\lambda}\right) \qquad N_{\tau} = \frac{\sqrt{\pi} \Gamma(\tau - 1)}{\Gamma(\tau - \frac{1}{2})}
$$
\nDosch, J. Erlich, Phys

For integer τ , it gives the pole structure: P_{eff} integer it since the release through For integer τ , it gives the pole structure. M₁ er τ it gives the nole s Et *t*, it gives the pole structure. $M_n = 4\lambda (n + \frac{1}{2}), n = 0$

terms of G amma f unctions \mathcal{Q} and \mathcal{Q} and \mathcal{Q} and cannot that can express in expression that can express in \mathcal{Q}

structure:
$$
M_n^2 = 4\lambda(n + \frac{1}{2}), n = 0, 1, 2, ..., \tau - 2
$$

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that the Beta function is $B(1-\alpha(s), 1-\alpha(t))$ with the s-channel dependence replaced by a fixed pole $1 - \alpha(s) \rightarrow \tau - 1$ $\overline{1}$ $\begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix}$ $\frac{1}{t}$ It has the same structure of Veneziano amplitude $B(1 - \alpha(s), 1 - \alpha(t))$ $\sqrt{2}$ $\frac{1}{\sqrt{1-\frac{1$ 1 same structure of Veneziano amp
1 - channel denendence renlaced by

$$
\alpha(t) = \frac{t}{4\lambda} + \frac{1}{2}
$$

One can fix the mass scale λ with spectroscopy, e.g., ρ/ω trajectory: $\sqrt{\lambda} = \kappa =$ trajectory: $\sqrt{\lambda} = \kappa = 0.534 \,\text{GeV}$ $U_{\rm T}$, the value and the annual reparameterization; the $\frac{1}{2}$ $\sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{j=1}^{n}$ One can fix the mass scale λ with spectroscopy, e.g. imposing further physically motivated constraints in the constraints in the constraints is constraints in the
International constraints in the c $\ddot{}$ lix the mass scale λ with spectroscopy, *e.g.,* ρ/ω trajectory: $\sqrt{1-u}=0.524 C_0 V$ $t = \kappa = 0.534 \,\mathrm{GeV}$ One can fix the mass scale *λ* with spectroscopy, *e.g., ρ/ω* trajectory: $\lambda = \kappa = 0.534 \,\text{GeV}$

 λ

 $E(\Omega^2) \sim \left(\frac{1}{\epsilon}\right)^{\tau-1}$ $\Gamma_{\tau}(\mathcal{Q}) \sim \left(\overline{\mathcal{Q}^2}\right)$ For large $Q^2 = -t$, it has the scaling behavior $F_\tau(Q^2)\sim$ $\left(1\right)$ \mathcal{Q}^2 $\overline{\ }$ $\tau-1$ For large $Q^2 = -t$ it has the scaling beh $C \n\sim$ $\overline{2^2}$ Ω trajectory emergency emergency of $\left(1 \atop 1\right)$ $Q^2 = -i$, it has the scaling behavior $F_{\tau}(Q^2) \sim \left(\frac{\overline{Q^2}}{Q^2}\right)$ $\left(\frac{1}{Q^2}\right)^2$

Nucleon Dirac Form Factor

$$
F_1(t) = \sum_{q,\tau} e_q[c_{\tau,q}F_{\tau}(t) + c_{\tau+1,q}F_{\tau+1}(t)]
$$

We fit the coefficients for three cases:

i) Only the valence $(\tau=3)$ state contribution

ii) Truncate at $\tau=5$, including a pair of $u\overline{u}$ or $d\overline{d}$

iii) Truncate at $\tau=5$, including a pair of $u\overline{\bar{u}}, \,\, d\bar{d}, \,\, {\rm or}\,\, s\bar{s}$

Match recent extraction of nucleon EM form factors: Z. Ye, J. Arrington, R.J. Hill, G. Lee, Phys. Lett. B 777, 8 (2018).

山东大学(青岛)

From Form Factors to Parton Distributions up to a universal representation function $\frac{1}{2}$ rton Distributions **From form factors to farton distributions** ^FτðtÞ ¼ ¹ Nτ **10 0III** For \overline{a} IM FACTORS TO PARTON DISTRIDUTIONS

Writing the form factor in terms of GPD at zero skewness $\frac{1}{\sqrt{2}}$ writing the form factor in terms of GPD at zero ϵ^{1} ND ot $=$ $\frac{1}{2}$ $\frac{1}{2}$ SPD at zero skewness

$$
F_1^q(t) = \int_0^1 dx \ H_v^q(x, t)
$$

Express the form factor with the Euler integral representation if was a monotonically increasing function with fixed vertex \mathbf{r} increasing function with \mathbf{r} vics change at the integration limits given by the constraints given by the constraints given by the constraints of α Express the form factor with the Euler integral representation $J($
or intogral representation

$$
F_{\tau}(t) = \frac{1}{N_{\tau}} B\left(\tau - 1, \frac{1}{2} - \frac{t}{4\lambda}\right)
$$

\n
$$
B(u, v) = \int_0^1 dy \, y^{u-1} (1 - y)^{v-1} \qquad y = w(x)
$$

\n
$$
w(x) \text{ is a reparametrization function}
$$

$$
H^{q}(x,t) = \frac{1}{N_{\tau}} [1 - w(x)]^{\tau - 2} w(x)^{-\frac{1}{2}} w'(x) e^{(t/4\lambda) \log[1/w(x)]}
$$

= $q_{\tau}(x) \exp[tf(x)],$

$$
q_{\tau}(x) = \frac{1}{N_{\tau}} [1 - w(x)]^{\tau - 2} w(x)^{-\frac{1}{2}} w'(x) \qquad f(x) = \frac{1}{4\lambda} \log \left(\frac{1}{w(x)} \right)
$$

 $\frac{1}{\tau}$
The collinear distribution as $independent$ reparametrization function $w(x)$. x^{λ} are related tio: $\sqrt{11}$ $\sqrt{1$ i *i-independent* reparan le collinear distribution by a universal *τ*-independent reparametrization function $w(x)$. The collinear distribution $q(x)$ and the profile function $f(x)$ are related The collinear distribution $q(x)$ and the profile function $f(x)$ are related $\frac{1}{2}$ by a universal e maepenaem i composition functions functions (7). $\frac{1}{2}$

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^FτðQ²^Þ [∼]

Q²

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Constraints on w(x) Ftøtballer
Franse $\overline{\mathbf{u}}$ \overline{a} Constraints on $\mathbf{w}(\mathbf{x})$ ^½¹ [−] ^wðxÞ&^τ−²wðxÞ[−]¹ $\frac{1}{\sqrt{2}}$ **nstraints o** \mathbf{u} \mathbf{u} Γ are other \mathbf{r} at the constraints given by the constraints given by the constraints Γ

Mathematical constraints: M_o the F tviatil $\frac{1}{2}$ \mathbf{N} $\mathbf{r}_{\mathbf{M}}$.
1111 Mathematical const $\mathbf{F}(\mathbf{f})$ expansion of the short state. It controls the short state. It controls the short state $\mathbf{f}(\mathbf{f})$ are expressed in terms of the function works of the function works of the function works of the function works raufematical constraints.

Equation 1:
$$
B(u, v) = \int_0^1 dy \, y^{u-1} (1 - y)^{v-1}
$$

\n $y = w(x)$

\n $w(0) = 0, \quad w(1) = 1, \quad w'(x) \ge 0 \quad \text{for} \quad x \in [0, 1]$

\nPhysical requirements:

Physical requirements: $\frac{1}{\sqrt{2}}$ Physi

behavior: $H_v^q(x,t) \sim x^{-t/4\lambda} q_v(x)$ Regge theory motivat behavior. If $v(x, t) \geq x \leq q_v(x)$ inegge theory flouve Small-x behavior: $H_v^q(x, t) \sim x^{-t/4\lambda} q_v(x)$ Regge theory motivated ansatz $\mathcal{O}(\mathcal{A})$. $\mathcal{O}(\mathcal{A})$ 201001 N 30100 Small-x behavior: $H_v^q(x, t) \sim x^{-t/4\lambda} q_v(x)$ Regge theory motivate

 $w(x) \sim x$ $w(x) \sim x$ $\frac{1}{2}$ $y(x) \sim x$ $W(x) \sim x$

²Þ; n ¼ 0; 1; 2; …; τ − 2, corresponding $t_{\rm eff}$ is radial excitations $\frac{1}{2}$ e-x behavior: $q_{\tau}(x) \sim (1-x)$ t de la provincia de
La provincia de la provin $\mathbf{t} = \mathbf{t} - \mathbf{t}$ 2. The pair is just the pair is Γ is just the pair is just the pai

vanishes in die van die vanishes in die vanishes in die vanishes van die vanishes van die vanishes van die van
Vanishes in die vanishes van die vanishes

Large-x behavior: $q_x(x) \sim (1 - x)^{2\tau - 3}$ Drell-Yan inclusive contains Large-*x* behavior: $q_\tau(x) \sim (1-x)^{2\tau-3}$ Drell-Yan inclusive counting Drell-Yan inclusive counting rule \overline{a} ive counting rule $\frac{1}{\sqrt{2\pi}}$

\$

Large-x benzvor:
$$
q_{\tau}(x) \sim (1 - x)^{-1/2}
$$
 Drell-Yan inclusive counting rule
\n
$$
w(x) = 1 - (1 - x)w'(1) + \frac{1}{2}(1 - x)^2 w''(1) + \cdots
$$
\n
$$
w'(1) = 0 \quad \text{and} \quad w''(1) \neq 0
$$
\n
$$
f(x) = \frac{1}{4\lambda} \log \left(\frac{1}{w(x)}\right) \qquad f'(1) = 0 \quad \text{and} \quad f''(1) \neq 0
$$

 (7) , and (11) , and (13) is a subset of (13)

#

tar til 1911.
Den stofnað

 $\frac{1}{\sqrt{2}}$

 $f_{\rm{max}}$

!

Quark Distribution in the Proton

Nucleon PDFs in comparison with global fits

A parameterization form for $w(x)$:

$$
w(x) = x^{1-x}e^{-a(1-x)^2}
$$

$$
a = 0.48 \pm 0.04
$$

one can choose other forms, but *universal* for all distributions

Evolved from the matching scale 1.06 ± 0.15 GeV

Red bands: the uncertainties of the matching scale*.*

G.F. de Téramond, TL, R.S. Sufian, H.G. Dosch, S.J. Brodsky, A. Deur, Phys. Rev. Lett. 120, 182001 (2018).

Quark Distribution in the Pion $f(x) = \frac{1}{2}$ $\mathbf{L} \cdot \mathbf{R}$ dir var stöðu 1990.
1990 - Albert var stöðu 1990 - Albert var stöðu 1990.
1990 - Albert var stöðu 1990 - Albert var stöðu 1990.

de Téramond, TL, Sufian, Dosch, Brodsky, Deur, Phys. Rev. Lett. 120, 182001 (2018).

Tianbo Liu

Barry, Sato, Melnitchouk, Ji,
 Barry, Sato, Melnitchouk, Ji, $I'nys. Rev. Letl. 121, 152001 (2010).$ **Phys. Rev. Lett. 121, 152001 (2018).**

Quark Mass Correction dalk with twist-to-the the systematics of the global fit results. More details about the lattice and in the lattice a \sim d:o:f: \sim \sim \sim \sim \sim \sim \sim logðmark Ma in analysis shows that the third the term does not the third that the term does not the term does not the term correction term of the invariant mass Pⁱ kinetic energy in the Lie and leave, as a fi Γ egge Γ egge trajectory is a phenomenological input. In contralass correction

FF with twist-
$$
\tau
$$
: $F_{\tau}(t) = \frac{1}{N_{\tau}} B(\tau - 1, 1 - \alpha(t))$ $\alpha(t) = \alpha(0) + \alpha' t = \frac{1}{2} + \frac{t}{4\lambda} - \frac{\Delta M^2}{4\lambda}$

Calculate the mass shift with effective quark mass: constituents of mass mass m1 and m2, to the correction of the correction of the correction of the correction o
The correction of the correction of th α and β .

$$
M^{2} = 4\lambda \left(n + \frac{L+J}{2} \right) + \Delta M^{2}[m_{1}, m_{2}] \qquad \Delta M^{2}[m_{1}, m_{2}] = \frac{1}{N} \int_{0}^{1} dx \left(\frac{m_{1}^{2}}{x} + \frac{m_{2}^{2}}{1-x} \right) e^{-\frac{1}{2} \left(\frac{m_{1}^{2}}{x} + \frac{m_{2}^{2}}{1-x} \right)}
$$

S.J. Brodsky, G.F. de Téramond, H.G. Dosch, J. Erlich, Phys. Rep. 584, 1 (2015).
' ¼ z-expansion interpretation in the second state S, J . Brod $\overline{\mathbf{H}}$ ნ. Dosd
პ ch, d J. Erlich, Phys. Rep. 584, 1 (20[∤] large the three three three fixed up in the fixed up in the form of the form of the fixed up of the second up o
Independent of the fixed up of rousky, G.F. de Teramond, H.G. Dosch, J. Erlich, Priys. Kep. 5d
. $(2015).$

 $\frac{1}{100}$ and $\frac{1}{100}$ $\frac{1}{100}$ $\frac{1}{100}$ $\frac{1}{100}$ $\frac{1}{100}$ $\frac{1}{100}$ where the squared mass shift ^ΔM²½m1; m2& incorporates the Defermine the intercent $q(0)$ or m P commune and mode dept $\alpha(0)$, on an \mathbf{D} data. The GS while fitting the GS while fitting the GS \mathbf{D} Determine the intercept $\alpha(0)$, or n Determine the intercept $\alpha(0)$, or mass shift, from Regge trajectory where the minimal masses \sim

$$
\lim_{Q^2 \to \infty} F_{\tau}(Q^2) = \Gamma(\tau - 1) \left(\frac{1}{\alpha' Q^2}\right)^{\tau - 1}
$$

r unchanged α Scaling behavior unchanged

$$
\alpha_{\rho}(0) = \alpha_{\omega}(0) = 0.496
$$

$$
\alpha_{\phi}(0) = 0.010
$$

 $\overline{\text{S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma}}$ $\frac{2}{t}$ (GeV²) **a** pole of the square mass **Phys. Rev. D 98, 114004 (2018). R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch,** 114004-8

Strange Form Factor in LFHQCD duange fol hi factol fi $\mathcal{F}_1=\mathcal{F}_1=\mathcal{F}_2=\mathcal{F}_3=\mathcal{F}_4=\mathcal{F}_5=\mathcal{F}_6=\mathcal{F}_7=\mathcal{F}_8=\mathcal{F}_9=\mathcal$ T by $T \cap T \cap \Omega$ \blacksquare Form Factor in LEHOCD \overline{a} is \overline{b} in \overline{a} n **FIFIOCD** as the effect of the mixing is

Strange form factor with nonzero quark mass: VIIII HOIIZEIO QUAIK HIASS.

$$
F_1^s(Q^2) = (1 - \eta) N_s [F_{\tau=5}^{\phi}(Q^2) - F_{\tau=6}^{\phi}(Q^2)]
$$

 ϕ is nearly a pure $s\bar{s}$
+ $\eta N_s [F_{\tau=5}^{\omega}(Q^2) - F_{\tau=6}^{\omega}(Q^2)],$
 $\eta \approx 0$

 $\eta \approx 0$ ϕ is nearly a pure *ss* state ≈ 0 $\overline{\mathcal{L}}$ ϕ is nearly a pure ss state $\eta \approx 0$ ^p ^¼ ⁰.52ð17^Þ GeV and Ns

 $\Omega^8 F^s(\Omega^2)$. Const factor (52) has the large-Q² behavior Q⁸F^s

rules [63,64]. **Lattice data from:**

 $i = 1, 2, 3, ...$ aru, **1. Draper**, \sum f. Draper, R.S. Sufian, Y.-B. Yang, A. Alexandru, T. Draper, **N. A. Alexandru**, T. Draper, Phys. Rev. Lett. 118, 042001 (2017). R.S. Sufian, Y.-B. Yang, J. Liang, T. Draper, and K.-F. Liu,
Phys. Rev. D 96, 114504 (2017). **J. Liang, and K.-F. Liu,**

R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma Phys. Rev. D 98, 114004 (2018). \sim Sunan, TD, O.F. at Teramona, H.O. Dosen, S.S. Drousny, A. t^{total} \mathbf{l} rodsky, A. Deur, M.T. Islam, and B provided that was a straint that we constraint the constraint \mathcal{I}_1 and \mathcal{I}_2 are constraints \mathcal{I}_3 \overline{a} $\mathbf a$, and $\mathbf B$.-Q. Ma

PDF in LFHQCD with Quark Mass Fin I FUACD with Anork P IN LFFIQUD WIth Quark I expression (55) were find that both functions, for the \mathbf{p} \mathbf{p} $\overline{}$ in **DDE:** JEHOCD with O **PDF in LFHOCD with Or** \mathbf{r} by an Expediate constraints, since PDF in LFHOCD with Ouar vaðxbergar var stærst var stærst
Den stærst var stærst effectively determined by Registratively determined by Registrative ^qτðxÞ ¼ ¹ $\mathbf{\Lambda}$ ^½¹ [−] ^wðxÞ%^τ−²wðxÞ[−]¹ where \mathbf{r} is not provided by R 1 and \mathbf{r}

Express the form factor with the Euler integral representation: $f_{\alpha\mu\nu\alpha}$ footor with the $F_{\mu\nu}$ integral represent form factor with the Euler int Express the form factor with the Fuler integral x dependence of PDFs and LFWFs is modified. \mathbf{F}_{max} Express the form factor with the Euler integral Express the form factor with the Euler integral representation: \mathbf{r} , the additional constraints and constraints are additional constraints and constra $\mathcal{L} = \mathcal{L} = \mathcal{L}$ conformal limit where the quark masses vanish,

$$
F_{\tau}(t) = \frac{1}{N_{\tau}} \int_0^1 dx \, w'(x) w(x)^{-\frac{t}{4\lambda} - \frac{1}{2}} [1 - w(x)]^{\tau - 2} e^{-\frac{\Delta M^2}{4\lambda} \log(\frac{1}{w(x)})}.
$$

PDF: $\overline{1}$ Generalized parton distributions in LFHQCD.—In $\frac{1}{\sqrt{2}}$ DF:

PDF:
\n
$$
q_{\tau}(x) = \frac{1}{N_{\tau}} [1 - w(x)]^{\tau - 2} w(x)^{-\frac{1}{2}} w'(x) e^{-\frac{\Delta M^2}{4\lambda} \log(\frac{1}{w(x)})}
$$

the extreme where integration as the integration as the integration as $w(x)$ that satisfies \mathbb{R}^n and \mathbb{R}^n and substitution of the generalized PDF, namely, with the virtual by a best fit to \mathbf{v} is determined by a best fit to lattice the state \mathbf{v} with the same $w(x)$ that satisfies with the same $W(x)$ that satisfies with the same $w(x)$ that satisfies \sim \sim \sim \sim wit Ith the same $w(x)$ th U term in the expansion, which behaves as \mathcal{L} with the same $w(x)$ that satisfies

 $w(0) = 0,$ $w(1) = 1,$ $w'(x) \ge 0$ for $x \in [0, 1]$ $w(x) \sim x$ at small-x, and $w'(1) = 0$ and $w''(1) \neq 0$ conformal limit where the quark masses vanish, $w(0) = 0, \quad w(1) = 1, \quad w'(x) \ge 0 \quad \text{for } x \in [0, 1]$ effectively determined by $\mathcal{L}(\mathcal{A})$ and $\mathcal{L}(\mathcal{A})$ and $\mathcal{L}(\mathcal{A})$ and $\mathcal{L}(\mathcal{A})$ and $\mathcal{L}(\mathcal{A})$ $w($ $w(x) \sim x$ at small-x, and $w'(1) = 0$ and $w''(1) \neq 0$ $w(0) = 0, \qquad w(1) = 0$ $W(\mathcal{O})$ λ $p(0) = 0,$ $w(1) = 1, \quad w'(x) \ge 0 \quad \text{for } x \in \mathbb{R}$ rules at large-x are unmodified by the introduction of quarks are unmodified by the introduction of quarks and
The introduction of quarks are unmodified by the introduction of quarks and are unmodified by the introduction $w(0) = 0, \quad w(1) = 1, \quad w'(x) \ge 0 \quad \text{for } x \in$ \mathcal{N} the small-x by a factor \mathcal{N} factor \mathcal{N} factor \mathcal{N} \mathcal{L} strange quark distribution functions \mathcal{L} $y(1) = 1,$ $w'(x) \ge 0$ for $x \in [0,1]$ (1) 1, $W(x) = 0$ for $w \in [0, 1]$
11, 1, $I(1) = 0$ 1, $I'(1) \neq 0$ in the limit $w(1) = 0$ and $w'(1) \neq 0$

 $\left(\cdot \right)$ $\sim (1-x)^2$ $\mathbf{v}_{\mathbf{0}}$ $q_{\tau}(x) \sim (1-x)^{2\tau-3}$ the counting rule is under $f(x) \sim (1 - x)^{2\tau - 3}$ the counting rule is unchanged ¼ \bigcap $x^{-\frac{1}{2} + \frac{\Delta M^2}{4\lambda}}$ softened by a factor $x^{\Delta M^2}$ $\frac{1}{2}$ Laf $Sm₀11$ $\overline{\mathcal{L}}$ Large-x: $q_{\tau}(x) \sim (1-x)^{2\tau-3}$ the counting rule is und Small-r $\alpha(r) \approx r^{-\alpha(0)} \approx r^{-\frac{1}{2} + \frac{\Delta M^2}{44}}$ $q_{\tau}(x) \sim x \sim x^{2}$ Large-*x*: ∞ or ∞ ∞ $(1 - x)^2 \tau - 3$ Large-x: $q_{\tau}(x)$ $q_{\tau}(x) \sim (1-x)^{2\tau/3}$ the counting Small-x: $q_{\tau}(x) \sim x^{-\alpha(0)} \sim x^{-\frac{1}{2} + \frac{\Delta M^2}{4\lambda}}$ Large-x: $q_{\tau}(x) \sim (1 - x)$ Small-*x*: $\int \arccos x \, dx$ or $\int \ln x \, dx$ of $\int \ln x \, dx$ the counting $x^{-\alpha(0)} \sim x^{-\frac{1}{2} + \frac{\Delta M^2}{4\lambda}}$ softened by a factor $x^{\Delta M^2/4\lambda}$ $\mathbf T$ describe the quark distribution functions in the quark distribution functions in the $\mathbf T$ \mathcal{B}_{max} 11 $(1-x)^{2\tau-3}$ the counting rule is unchanged. the structure mass shift in due to be finite \mathcal{L}

R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma
Phys. Rev. D.98, 114004 (2018) Phys. Rev. D 98, 114004 (2018). POU4 (2018).
<u>Comparing (56)</u> with the holographic term of holographic term of holographic term of holographic term of the ho **With Construction Construction Construction Construction Construction Construction Construction Construction** S.S. Sullall, TL
These Deep D.O. \overline{a} $r = \alpha \cdot \alpha$ at large-x are unmodified by the introduction of α K.S. SUIIAN, I L, G.F. Ge Teramond, H.G. Dosch, S. t hys. KCV. D \overline{O} , 114004 (2010). $P \subseteq S$ R.S. Sufian, TL, G.F. de Phys. $\mathbf{d}\mathbf{e}$ R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M. 1004 (2010).
<u>Atteicidae: organisation</u> **Phys. Rev. D d**
⊅ D **Rev. D 98, 114004 (2018).** \blacksquare R.S. Sufian, TL, G.E. de Téram $\frac{1}{\sqrt{2}}$ que and respectively.
Tradition de la companya de la comp
Tradition de la companya de \overline{a} ; ð60
1900 - Andrea Stein, semantist
1900 - Andrea Stein, semantist

Tianbo Liu Tianbo Liu $T_{\rm ion}$ \overline{f} the EM form factor \overline{f}

:

Þ → 0

Strange-antistrange PDF in LFHQCD universal for **Strange-ant** The expression for the strange-antistrange PDF asym- \mathbf{r} is determined to \mathbf{r} n LFHQCD

$$
s(x) - \bar{s}(x) = (1 - \eta)N_s[q_{\tau=5}^{\phi}(x) - q_{\tau=6}^{\phi}(x)] \qquad \phi
$$

+ $\eta N_s[q_{\tau=5}^{\omega}(x) - q_{\tau=6}^{\omega}(x)], \qquad \eta$

$$
\phi
$$
 is nearly a pure $s\overline{s}$ state
\n $\eta \approx 0$

R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma Phys. Rev. D 98, 114004 (2018). S Sufian TI CF de Téramond HC Dosch SI Rrodsky H.G. DOSCA, S.J. Brousky, 0.52 °C obtained from the lattice form factor results. The lattice form factor results. In the lattice form fa
The lattice form factor results. The lattice form factor results. The lattice form factor results. In the latt \mathbf{v} Me α − γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α + γ α +
Δείτε το προσπάθει το προσπάθει

Intrinsic Charm in the Proton The volume correction in fit (3) \mathbf{r} and \mathbf{r} $\frac{1}{2}$, the data of $\frac{1}{2}$, the pole of $\frac{1}{2}$ parameters are λ⁰ = 0, λ¹ = 0*.*084*(*15*)*, λ² = −2*.*38*(*60*)*, λ³ = 6*.*04*(*9*.*79*)*, λ⁴ = −0*.*13*(*5*.*79*)*, *A*¹ = −1*.*05*(*52*)*, *A*² = −0*.*18*(*84*)*,

Original proposal of intrinsic charm of two *D* mesons is greater than the mass of *J/*ψ. One may also

S.J. Brodsky, P. Hoyer, C. Peterson, N. Sakai, Phys. Lett. B 93, 451-455 (1980). *^E,^M (^Q* ²*)* matrix elements at the unitary points. The colored bands show the fit N Sakai Dhye Lett The inclusion of higher-order terms being the *kmax inclusion* \mathbf{r} physical value of *G^c*

Lattice QCD exploration *^E (^Q* ²*)* and the lower

 \mathbb{R}^3 **A**² \mathbb{R}^3 above. Since \mathbb{R}^3 above. Since \mathbb{R}^3 and \mathbb{R}^3 are corrections of the \mathbb{R}^3 Ω First LQCD computation of physical right form factors the quark $\mathsf{F} \mathsf{M}$ form factors charm quark EM form factors h is the state in the magnetic the state in h (one at physical pion mass)

Intrinsic charm-anticharm asymmetry with rameters listed above. Since most of the *Ai* corrections do not hormalization constrained by LQCD dat $T_{\rm eff}$ systematic uncertainty is estimated by calculating the difference of σ CD_{data} normalization constrained by LQCD data

The systematic uncertainty is estimated by calculating the difference of \mathcal{L}_max

R.S. Sufian, TL, A. Alexandru, S.J. Brodsky, G.F. de Téramond, H.G. Dosch, T. Draper, K.-F. Liu, Y.-B. Yang, Phys. Lett. B 808, 135633 (2020). ical *G^c ^E (^Q* ²*)* remains essentially unchanged with slightly smaller final uncertainties **to when all** *AG. Dosch, 1. Draper, K.-F.* sim_{ul} singular conclusion. of the figure. The numbers in the legends, such as *m*139, *m*251 represent the data **points and in Fig. 2.51 Suffan, TL, A. Alexandru, S.J. Brodsky, G.** $\begin{bmatrix} \n\mathbf{w} & \mathbf{w} & \math$ Téramond, H.G. Dosch, T. Draper, K.-F. Liu, Y.-B. Yang, the same *Q* 2-value but at different pion masses are shown with small offsets for \mathbf{G} momentum transfer region, we added

Axial Form Factor δ form factor follows δ for a δ $\mathbf{1}_{\mathbf{1}_{\mathbf{1}}}$ the Dirac form factor is given by $\mathbf{1}_{\mathbf{1}_{\mathbf{1}}}$ $N = N$ a normalization factor, and *B*(*x, y*) is the Euler beta function. The two terms in Eq. (1) correspond to the with the subscript $\overline{\mathbf{A}}$ in an axial to an axial a normalization factor, and *B*(*x, y*) is the Euler beta function. The two terms in Eq. (1) correspond to the terms in Eq. (1) correspond t

Axial form factor: Axial form factor: *NV,*⌧ of the bulk field solution \mathcal{L} *F*1(*t*) = *cV,*⌧*FV,*⌧ (*t*) + *cV,*⌧+1*FV,*⌧+1(*t*)*,* (1) \ddotsc from two components, \ddotsc from two components, \ddotsc of \ddotsc from two components, \ddotsc Axial form factor: of the bulk field solution [19]. Eq. (2) has the same structure as a generalization of the Veneziano and Veneziano amplitude of the Veneziano amplitude of the Venezi

$$
F_A(Q^2) = \int \frac{dz}{z^4} A(Q^2, z)[g_+ \Psi_+^2(z) - g_- \Psi_-^2(z)]
$$
 The "-" sign for the second
term is due to the γ_5

Compare the vector and axial FFs for a $\frac{1}{2}$ form factor form factor follows $\frac{1}{2}$ but $\frac{1$ Compare the vector and axial Γ rs. where the vector and avial FFs[.] and the vector and axial 110. here electron-nucleon scattering. This amounts to \mathcal{C} Compare the vector and axial FFs: Compare the vector and axial I I S. Compare the vector and avial Compare the vector and axial FFs:

$$
F_1(t) = c_{V,\tau} F_{V,\tau}(t) + c_{V,\tau+1} F_{V,\tau+1}(t) \qquad F_{V,\tau}(t) = \frac{1}{N_{V,\tau}} B(\tau - 1, \frac{1}{2} - \frac{t}{4\lambda})
$$

$$
F_A(t) = c_{A,\tau} F_{A,\tau}(t) - c_{A,\tau+1} F_{A,\tau+1}(t) \qquad F_{A,\tau}(t) = \frac{1}{N_{A,\tau}} B(\tau - 1, 1 - \frac{t}{4\lambda})
$$

⌧ 1*, i* just repla Ì. es the trajectory by the axial one: α , can be fixed by hadron spectroscopy, and a fixed by ϵ es the trajectory by the axial one: $\alpha_A(t) = \frac{0}{4\lambda}$ It just replaces the trajectory by the axial one: $\alpha_A(t) = \frac{t}{4}$ $\frac{1}{4\lambda}$ It just replaces the trajectory by the axial one: $\alpha_A(t) = \frac{c}{4\lambda}$ a normalization factor, and *B*(*x, y*) is the Euler beta current. *FA,*⌧ (*t*) has the same structure as *FV,*⌧ (*t*), but the normalization factors as given by If just replaces the trajectory by the axial one: Q

 $\text{Coefficients are related:} \quad \frac{c_{V, \tau}}{r} = \frac{c_{A, \tau}}{r}$ *NA,*⌧ Coefficients are related: $c_{V,\tau}$ $c_{A,\tau}$ The *t*-dependence in Eq. (2) can be rewritten as 1 α contribution from two chiral components, α Γ oefficients are related: c_x ↵*^V* (*t*) with the Regge trajectory [50] α (*t*) α (*t*) α (*t*) α (*t*) α

Coefficients are related:
$$
\frac{c_{V,\tau}}{N_{V,\tau}} = \frac{c_{A,\tau}}{N_{A,\tau}}
$$

A convenient convention for this work: $N_{V,\tau} = N_{A,\tau} = N_{\tau}$ A CONVENIENT CONVENITON where A convenient convention for this work: $N_{V,\tau} = N_{A,\tau} = I$ \mathcal{L} $\sigma = N_{A,\tau} = N_{\tau}$ the solution $c_{V,\tau} = c_{A,\tau} = c_{\tau}$ structure as a generalization of the Veneziano amplitude Λ convenient convention for this work: \overline{N} \overline{N} Th convenient convention for this work. The $V, \tau = \tau \cdot A$ $N \sim \frac{C_{12}}{C_{12}} - \frac{C_{14}}{C_{12}} - \frac{C_{16}}{C_{12}}$ Since the normalization for this work. $IV_{\mathcal{F}} = IV_{A,\mathcal{T}} = IV_{\mathcal{T}}$ where $IV_{\mathcal{T}}$ A convenient convention for this work: Λ place the *s*-dependence 1 ↵(*s*) by a constant, which ⁴*,* (12) emerging from LFHQCD \mathcal{S} . The coefficients in \mathcal{S} ↵*^V* (*t*) = *^t* convei 16 is the convention for this work: $N_{V,\tau} = N_{A,\tau} = N_{\tau}$ and $c_{V,\tau} = c_{A,\tau} = c_{\tau}$ The six values of $\mathcal{L}(V, \mathcal{I}) = \mathcal{L}(A, \mathcal{I})$ $c_{V,\tau}=c_{A,\tau}=c_{\tau}$

 \ldots and *can* also choose other hormanization conventions. current place the structure of θ , θ One can also choose other normalization conventions. $\overline{\text{MS}}$, 1 $\overline{\text{MS}}$, 1 $\overline{\text{MS}}$ One can also choose other no *n* can also choose other normalization conventions. One can also choose other normalization co ntions. $\overline{\mathbf{c}}$ Following the same procedure, we express the *q*(*x*) One can also choose other normalization conventions.

a normalization factor, and *B(^{re}amond, H,G, Dosch, S.J. Brodsky, A. I*
Bbys, *Boy, Lott*, 124, 082003 (2020) $f(x)$ is the two terms in Eq. (1) correspond to the theorem that $f(x)$ **v. Lett. 124, 082003 (2020).**
 10 4, (a) $\frac{19}{2}$ here electron-nucleon scattering. This amounts to replace the *s*-dependence 1 ↵(*s*) by a constant, which The contract is the contract in Eq. (2) can be rewritten as 1 can be **TL, R.S. Sufian, G.F. de Téramond, H.C.** 1 TL, R.S. Sufian, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, $\sum_{i=1}^{n} \sum_{i=1}^{n} \sum_{i=1}^{n}$ $\frac{1}{2}$ state trajectories as $\frac{1}{2}$ such as $\frac{1}{2}$ $\frac{1}{2}$ \overline{a} Phys. Rev. Lett. 124, 082003 (2020). psch, S.J. Brodsky, A. Deur TL, R.S. Sufian, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur,

Tianbo Liu contribution from the contribution from the set of \mathbb{R}^n Tianbo the trajectory, which shifts the intercept to 19 0*.*01 [54].

This is just the ⇢*/*! trajectory emerging from LFHQCD

FA(*t*) = *cA,*⌧*FA,*⌧ (*t*) *cA,*⌧+1*FA,*⌧+1(*t*)*,* (10)

 $\frac{1}{2}$ (12) $\frac{1}{2}$ (12) $\frac{1}{2}$

Polarized PDFs

For a twist-τ state: At large-*x*, we expand *w*(*x*) near *x* = 1 according to

$$
\Delta q(x) = c_{\tau} \Delta q_{\tau}(x) - c_{\tau+1} \Delta q_{\tau+1}(x)
$$

$$
\Delta q_{\tau}(x) = \frac{1}{N_{\tau}} [1 - w(x)]^{\tau-2} w'(x)
$$

 $f(x) = \frac{1}{2}x^2 + \frac{1}{2}x^3 + \cdots$ $=$ Large *x*: $\Lambda_{q_{-}}(x) = \frac{[-w''(1)]^{\tau-1}}{(1-x)^{2\tau-3} + \cdots}$ $t^{\tau(\tau)}$ and $2^{\tau-2}N_{\tau}$ Large *x*: $\Delta q_{\tau}(x) = \frac{[-w''(1)]^{\tau-1}}{2\tau-2M}$ $2^{\tau-2}N_{\tau}$ $(1-x)^{2\tau-3} + \cdots$

$$
\frac{\Delta q(x)}{q(x)} = 1 + \left(\frac{1}{4} + \frac{c_{\tau+1}N_{\tau}}{c_{\tau}N_{\tau+1}}\right)w''(1)(1-x)^2 + \cdots \qquad \lim_{x \to 1} \frac{\Delta q(x)}{q(x)} = 1
$$
\nhelicity retention prediction by pQCD

<u>W $\frac{1}{x}$ </u> and find that *q*⌧ (*x*) and *q*⌧ (*x*) have the same behavior, $x = 0.11$ is the symmetry at $\frac{1}{2}$ is the helicity at $\frac{1}{2}$ is the helicity at $\frac{1}{2}$ is the symmetry at $\frac{1}{2}$ is the s Small *x*:

Small *x*:
\n
$$
\frac{\Delta q(x)}{q(x)} \sim x^{\frac{1}{2}}
$$
\n
$$
\lim_{x \to 0} \frac{\Delta q(x)}{q(x)} = 0
$$
\nhelicity correlation disappears at $x \sim 0$

TL, R.S. Sufian, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, Phys. Rev. Lett. 124, 082003 (2020).

Tianbo Liu Tianbo Liu are suppressed. For both 20 $\begin{array}{c}\n\text{Tianho I in} \\
\text{A}\n\end{array}$

Numerical Results of Quark Polarized PDFs

Dashed curve: only valence state, without saturating the axial charge.

Bands: different ways to saturate the axial charge.

The same $w(x)$ as in the unpolarized distributions.

TL, R.S. Sufian, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, Phys. Rev. Lett. 124, 082003 (2020).

Graviton and Pomeron

AdS gravity action

$$
S_G[g] = -\frac{1}{4} \int d^5x \sqrt{g} e^{\varphi_g(z)} (\mathcal{R} - \Lambda)
$$

performing a small deformation: $g_{MN} \rightarrow g_{MN} + h_{MN}$

effective action: $S_{\text{eff}}[h, \Phi] = S_q[h] + S_i[h, \Phi]$

$$
S_g[h] = -\frac{1}{4} \int d^5 x \sqrt{g} e^{\varphi_g(z)} \left(\partial_L h^{MN} \partial^L h_{MN} - \frac{1}{2} \partial_L h \partial^L h \right)
$$

\n
$$
S_i[h, \Phi] = \frac{1}{2} \int d^5 x \sqrt{g} h_{MN} T^{MN}(\Phi)
$$

\n
$$
\partial_L h_M^L = \frac{1}{2} \partial_M h, \quad h \equiv h_L^L
$$

identify the gravity probe in AdS with the Pomeron, *JPC=*2++ bound state of gluons

2

レネスス(

effective trajectory:
$$
\alpha_P(t) = \alpha_P(0) + \alpha'_P t
$$
 $\alpha'_P \simeq 0.25 \text{GeV}^{-2}$

Gravitational Form Factor

The propagation of h_{MN} in Minkowski coordinates

$$
-\frac{z^3}{e^{\varphi_g(z)}}\partial_z \left(\frac{e^{\varphi_g(z)}}{z^3} \partial_z h^{\nu}_{\mu}\right) + \partial_{\rho} \partial^{\rho} h^{\nu}_{\mu} = 0
$$
soft-wall profile:
plane wave along the physical coordinates:
$$
h^{\nu}_{\mu}(x, z) = \epsilon^{\nu}_{\mu} e^{-iq \cdot x} H (q^2, z)
$$
boundary conditions:
$$
H (q^2 = 0, z) = H (q^2, z = 0) = 1
$$

solution: $H(a,\xi) = \Gamma(2+a)U(a,-1,\xi)$ $a = Q^2/4\lambda_g, \xi = \lambda_g z^2$

The coupling with EMT

A scalar field, e.g. pion, $S_q[\Phi] = \int d^5x \sqrt{g} e^{\varphi_q(z)} (g^{MN} \partial_M \Phi^* \partial_N \Phi - \mu^2 \Phi^* \Phi)$ $T_{MN} = \partial_M \Phi^* \partial_N \Phi + \partial_N \Phi^* \partial_M \Phi$

transition amplitude:

$$
\int d^5 x \sqrt{g} h_{MN} \left(\partial^M \Phi_{P'}^* \partial^N \Phi_P + \partial^N \Phi_{P'}^* \partial^M \Phi_P \right)
$$

Gravitational Form Factor

Gravitational Form Factor

 $\langle P' | T_{\mu}^{\nu}$ $\overline{}$ *P*^{$\langle P' | T_{\mu}^{\nu} | P \rangle = (P^{\nu} P_{\mu}^{\prime} + P_{\mu} P^{\prime \nu}) A (Q^2)$}

GFF:

\n
$$
A_{\tau}(Q^{2}) = \int_{0}^{\infty} \frac{dz}{z^{3}} H(Q^{2}, z) \Phi_{\tau}^{2}(z) \qquad \Phi_{\tau}^{g}(z) \sim z^{\tau} e^{-\lambda_{g} z^{2}/2}
$$
\n
$$
A_{\tau}^{g}(Q^{2}) = \frac{1}{N_{\tau}} B(\tau - 1, 2 - \alpha_{P}(Q^{2}))
$$

Pomeron coupling to the constituent gluon

Proton: the lowest Fock state $|uudg\rangle$ $\tau = 4$ Pion: the lowest Fock state $|u\overline{d}g\rangle$ $\tau = 3$

Numerical Results of GFF

$$
\langle r_g^2 \rangle = \left. \frac{6}{A^g(0)} \frac{dA^g(t)}{dt} \right|_{t=0}
$$

$$
\left_p = 2.93/\lambda_g = (0.34 {\rm fm})^2
$$

$$
\left\langle r_g^2 \right\rangle_{\pi} = 2.41/\lambda_g = (0.31 \text{fm})^2
$$

Gluon Distributions

From GFF to gluon distributions

follow the procedure in quark distribution, but start from gluon gravitational form factor

$$
A_{\tau}^{g}(t) = \frac{1}{N_{\tau}} \int_{0}^{1} dx w'(x) w(x)^{1-\alpha_{P}(t)} [1 - w(x)]^{\tau-2}
$$

the same w(x) as in quark distributions

intrinsic gluon distribution:

$$
g_{\tau}(x) = \frac{1}{N_{\tau}} \frac{w'(x)}{x} [1 - w(x)]^{\tau - 2} w(x)^{1 - \alpha_P(0)}
$$

\n
$$
g(x) = \sum_{\tau} c_{\tau} g_{\tau}(x)
$$

\n
$$
\text{large x behavior} \quad g_{\tau}(x) \sim (1 - x)^{2\tau - 3}
$$

\n
$$
\text{from the momentum sum rule:} \qquad \int_{1}^{1} \quad \int_{1}^{\infty} \quad \frac{1}{\sqrt{1 - x^2}} \, dx
$$

normalization

$$
\int_0^1 dx x \left[g(x) + \sum_q q(x) \right] = 1
$$

Numerical Results of Gluon Distribution

Gluon distribution in the proton

only keep the leading twist component *i.e.*, $\tau = 4$

$$
c_{\tau=4} = 0.225 \pm 0.014
$$

quark distribution from previous result in PRL 124, 082003 (2020).

the same choice of $w(x)$

$$
w(x) = x^{1-x} \exp \left[-b(1-x)^2\right]
$$

$$
b = 0.48 \pm 0.04
$$

Numerical Results of Gluon Distribution

Gluon distribution in the pion

only keep the leading twist component *i.e.*, $\tau = 3$

$$
c_{\tau=3} = 0.429 \pm 0.007
$$

quark distribution from previous result in PRL 120, 182001 (2018).

the same choice of $w(x)$

$$
w(x) = x^{1-x} \exp \left[-b(1-x)^2\right]
$$

$$
b = 0.48 \pm 0.04
$$

レ东大子(青岛)

Summary

In LF holographic QCD, we determine the structure of GPDs up to a universal reparametrization function $w(x)$, incorporating Regge behavior at small x and counting rules at large x.

It connects parton distributions in the proton and those in the pion. Including quark mass correction, this approach can be applied to intrinsic strange and intrinsic charm.

Given the unpolarized quark distributions, the polarized distributions are uniquely determined, consistent with the helicity retention at $x \rightarrow 1$ predicted by pQCD.

With the holographic coupling of the spin-two soft Pomeron to hadron EMT, we provide simultaneous description of intrinsic gluon GFF and distribution within a unified framework for both nucleon and pion.

With quark distributions determined from previous studies, the gluon distributions are predicted using only the leading Fock component with no additional parameters.

Thanks!

Form Factors in Holographic QCD should therefore include an effective gauge-invariant inter-2MN where the expression on the right-hand side represents the right-ha

Nucleon form factor: spin-flip $\mathbf{r} = \mathbf{r} \cdot \mathbf{r}$ and spin-flip $\mathbf{r} = \mathbf{r} \cdot \mathbf{r}$ Nucleon form factor: sp Pauli EM form factor in physical space-time. It corresponds $\frac{1}{2}$ tactor: spin-flip

$$
\int d^4x dz \sqrt{g} \bar{\Psi}_{P'}(x,z) e_A^M e_B^N [\Gamma^A, \Gamma^B] F_{MN}(x,z) \Psi_P(x,z) \longrightarrow \text{Effective spin-flip amplitude}
$$
\n
$$
\sim (2\pi)^4 \delta^4 (P' - P - q) \epsilon_\mu \bar{u}(P') \frac{\sigma^{\mu\nu} q_\nu}{2M_N} F_2(q^2) u(P), \longrightarrow \text{Pauli form factor in physical}
$$

 $\sum_{M=N_{\text{I}}/N_{\text{I}}/N_{\text{I}}/N_{\text{I}}/N_{\text{I}}/N_{\text{I}}/N_{\text{I}}/N_{\text{I}}/N_{\text{I}}$ Effective spin-flip amplitude in AdS space of an external EM field coupling to a nucleon

Pauli form factor in physical spacetime

Z. Abidin and C.E. Carlson, Phys. Rev. D 79, 115003 (2009). $\mathbf Z$

Pauli form factor P_{ext} : f_{ext} is physical space-time. It corresponds to f_{ext} $\int d\mu$ flip matrix element of $d\mu$ \mathbf{D}_{ref} is the inverse vielbein, \mathbf{D}_{ref} Pauli form i

$$
F_2^N(Q^2) = \chi_N \int \frac{dz}{z^3} \Psi_+(z) V(Q^2, z) \Psi_-(z)
$$

 $normaling$ normanzed to anomalous magnetic moments normalized to anomalous magnetic moments

 \sim 17) we find the find \sim 170 \sim 68. the leading scaling of the Pauli form factor has additional power of 1 described by plus and minus and minus and minus and minus wave functions wave functions wave functions wave fu
How plus was varied wave functions wave functions wave functions wave functions wave functions wave functions Scaling: add is a important differential interesting the set of \mathbf{u}_1 and \mathbf{u}_2 in \mathbf{r} is difference arises from the superconduction from two \mathbf{r} Scaling: additional power of z in the wave function product of Ψ_+ and α equinoup of the Pauli form factor has additional now ϵ leading scaling of the Pauli form factor has additional power for the proton, where χ^p $1/\Omega$ \mathbf{r} Ψ_{-} of $1/Q^2$ the leading scaling of the Pauli form factor has additional power of 1/*Q*2

> $\binom{\text{min}}{\text{sum}}$ $\binom{\text{min}}{\text{sum}}$ $\binom{\text{min}}{\text{sum}}$ in the covariant spin structure of the AdS expressions for the AdS expressions 1.472

2ð
20∂Q2Þ þ γnÞFi‰4ð

 $\frac{d}{2}$

large- Q 2 power scaling from hard scaling from hard scaling from hard scaling is incorporated in \mathcal{L}

Matching Scale

Matching the couplings from LFHQCD and pQCD

Bjorken sum rule:

$$
\frac{\alpha_{g_1}(Q^2)}{\pi} = 1 - \frac{6}{g_A} \int_0^1 dx \, g_1^{p-n}(x, Q^2)
$$

Effective coupling in LFHQCD (valid at low-*Q*2)

$$
\alpha_{g_1}^{AdS}(Q^2) = \pi \exp \left(-Q^2/4\kappa^2\right)
$$

Imposing continuity for *α* and its first derivative

A. Deur, S.J. Brodsky, G.F. de Téramond, Phys. Lett. B 750, 528 (2015); J. Phys. G 44, 105005 (2017).

Strange-antistrange Distributions diange antistrange Distribution

Nucleon valence component: |uud>

Nonvalence nature of the strange distribution: equal numbers of s and s—are required by the s—are required by the s—are required by the s—are required by the
The same required by the s—are required by the s—are required by the s—are required by the s—are required by t

PDF:
$$
\langle s - \bar{s} \rangle = \int_0^1 dx [s(x) - \bar{s}(x)] = 0
$$

Form factor:

actor:
$$
F_1^s(Q^2=0)=0
$$

Extrinsic and intrinsic strange sea:

Extrinsic: from gluon splitting, $g \rightarrow s\bar{s}$, triggered by a hard probe 0 can ac can also be used to perform over \mathbf{y} can be calculated perturbatively

Intrinsic: encoded in nucleon nonvalence LF Fock state wave functions can in principle be obtained by solving the Hamiltonian eig problem \mathbf{r} \mathbf{n} lue can in principle be obtained by solving the Hamiltonian eigenvalue problem

Strange-antistrange Asymmetry

Can strange and antistrange distributions be different?

Perturbative QCD calculation

Splitting functions $q \rightarrow s$ and $q \rightarrow \overline{s}$ are different at NNLO extrinsic and very small asymmetry $s(x) - \bar{s}(x)$ **S. Catani, D. de Florian, G. Rodrigo, and W.**

Vogelsang, Phys, Rev. Lett. 93, 152003 (2004).

Strange FF and PDF with LFWFs ¹ðQ²^Þ and ^sðx^Þ [−] ^s¯ðx^Þ using the nonperturbative structure II. STRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-AN
II. STRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-ANTISTRANGE-AN $\sum_{i=1}^{n}$ 21 $\frac{1}{2}$ × jn; xiPþ; xiP[⊥] þ kⁱ⊥; λii; ð4Þ baryon-meson in Tangul juhöfundi.
Pilotopiska senar bu ange r <u>.</u> DF WITH LF WFS

Hadrons are eigenstates of QCD LF Hamiltonian \mathbf{r} is a semiconducted \mathbf{r} and \mathbf{r} Hadrons are eigenstates of QCD LF Hamiltonian $H_{LF}^{QCD}|\Psi\rangle = M^2|\Psi\rangle$ α α α α \overline{X} j .
م∐ iltonian $H_{LF}^{QCD}|\Psi\rangle = M^2|\Psi\rangle$ Hadrons are eigenstates of QCD LF $T_{\rm eff}$ F | \rightarrow / \rightarrow \rightarrow

 f_{sc} for f_{c} and f_{c} the holographic embedding of light-front from f_{c} A nucleon state: δð2^Þ Λ u and Λ σ and σ form factors, respectively. A nucleon state:

$$
|N; P^+, \mathbf{P}_\perp, S^z\rangle = \sum_{n, \{\lambda_i\}} \int [dx][d^2\mathbf{k}_\perp] \psi_{n/N}(x_i, \mathbf{k}_{i\perp}, \lambda_i) |n; x_i P^+, x_i \mathbf{P}_\perp + \mathbf{k}_{i\perp}, \lambda_i\rangle
$$

PDF:

PDF:

$$
s(x) = \sum_{\lambda_s} \int \frac{d^2 \mathbf{k}_{s\perp}}{16\pi^3} |\psi_{s/N}(x_s, \mathbf{k}_{s\perp}, \lambda_s)|^2, \quad \bar{s}(x) = \sum_{\lambda_{\bar{s}}} \int \frac{d^2 \mathbf{k}_{\bar{s}\perp}}{16\pi^3} |\psi_{\bar{s}/N}(x_{\bar{s}}, \mathbf{k}_{\bar{s}\perp}, \lambda_{\bar{s}})|^2.
$$

$$
\text{normalization:} \quad \sum_{\lambda_s} \int \frac{dx_s d^2 \mathbf{k}_{s\perp}}{16\pi^3} |\psi_{s/N}(x_s, \mathbf{k}_{s\perp}, \lambda_s)|^2 = \sum_{\lambda_{\bar{s}}} \int \frac{dx_{\bar{s}} d^2 \mathbf{k}_{\bar{s}\perp}}{16\pi^3} |\psi_{\bar{s}/N}(x_{\bar{s}}, \mathbf{k}_{\bar{s}\perp}, \lambda_{\bar{s}})|^2 = I_s
$$

Form factor:

$$
F_1^s(Q^2 = \mathbf{q}_\perp^2) = \sum_{\lambda_s} \int \frac{dx_s d^2 \mathbf{k}_{s\perp}}{16\pi^3} \psi_{s/N}^*(x_s, \mathbf{k}_{s\perp} + (1 - x_s)\mathbf{q}_\perp, \lambda_s) \psi_{s/N}(x_s, \mathbf{k}_{s\perp}, \lambda_s)
$$

$$
- \sum_{\lambda_s} \int \frac{dx_s d^2 \mathbf{k}_{\bar{s}\perp}}{16\pi^3} \psi_{\bar{s}/N}^*(x_{\bar{s}}, \mathbf{k}_{\bar{s}\perp} + (1 - x_{\bar{s}})\mathbf{q}_\perp, \lambda_{\bar{s}}) \psi_{\bar{s}/N}(x_{\bar{s}}, \mathbf{k}_{\bar{s}\perp}, \lambda_{\bar{s}})
$$

$$
= \rho_s(\mathbf{q}_\perp) - \rho_{\bar{s}}(\mathbf{q}_\perp),
$$

Asymmetries in FF and PDF: Qualitative opposite strange and antistrange charges. ASYmmetries in FF and PDF: Quantativ the distribution products of the distribution products of the distribution of the $\frac{1}{\sqrt{2}}$ symmetries m FF and FDF; Quantauve **T** des lit Flama i Dr. Quantative

Coordinate space distribution: ce distribution:

$$
\rho_{s/\bar{s}}(\mathbf{q}_{\perp}) = \int \frac{d^2 \mathbf{a}_{\perp}}{(2\pi)^2} e^{i\mathbf{q}_{\perp} \cdot \mathbf{a}_{\perp}} \tilde{\rho}_{s/\bar{s}}(\mathbf{a}_{\perp}).
$$
\nnormalization:
$$
\int d^2 \mathbf{a}_{\perp} \tilde{\rho}_{s}(\mathbf{a}_{\perp}) = \int d^2 \mathbf{a}_{\perp} \tilde{\rho}_{s}(\mathbf{a}_{\perp}) = I_s
$$
\n
$$
\tilde{\rho}_{s/\bar{s}}(\mathbf{a}_{\perp}) = \int d^2 \mathbf{q}_{\perp} e^{-i\mathbf{q}_{\perp} \cdot \mathbf{a}_{\perp}} \rho_{s/\bar{s}}(\mathbf{q}_{\perp})
$$
\n
$$
= \sum_{\lambda_{s/\bar{s}}} \int \frac{dx_{s/\bar{s}}}{(1 - x_{s/\bar{s}})^2} \left| \tilde{\psi}_{s/\bar{s}} \left(x_{s/\bar{s}}, \frac{\mathbf{a}_{\perp}}{1 - x_{s/\bar{s}}}, \lambda_{s/\bar{s}} \right) \right|^2.
$$

$$
F_1^s(Q^2) \neq 0 \implies \tilde{\rho}_s(\mathbf{a}_\perp) \neq \tilde{\rho}_{\bar{s}}(\mathbf{a}_\perp) \implies |\tilde{\psi}_s(x, \mathbf{b}_\perp)|^2 \neq |\tilde{\psi}_s(x, \mathbf{b}_\perp)|^2
$$

\n
$$
|\psi_s(x, \mathbf{k}_\perp)|^2 \neq |\psi_{\bar{s}}(x, \mathbf{k}_\perp)|^2 \text{ non privileged direction}
$$

\nso $s(x) \neq \bar{s}(x)$

antistrange asymmetry in b⊥-space is equivalent to the space is equivalent to the space is equivalent to the s
Distribution of the space is equivalent to the space is equivalent to the space is equivalent to the space is $S_1^s(Q^2) > 0$ **s** quark is more centralized in coordinate space ϵ \sim ϵ ϵ and more spread out in momentum space \mathbf{h} $xe^{\frac{1}{2}t}$ is the intrinsic strange quark number in (8) . $F_1^s(Q^2) > 0$

distribution is nonzero. A positive Fs in the second control of the second control of the second control of th
The second control of the second control of the second control of the second control of the second control of

antifivative $s(x) = \bar{s}(x)$ at large-x and a negative value distribution if the asymmetry of the transverse momentum \mathcal{O} convolution of the strange distribution of the strange distribution of the $\frac{1}{n}$ α binens α . It favors a positive $s(x) - \bar{s}(x)$ at large-*x*, and a negative value at small-*x*.

Strange FF and PDF in Fluctuation Model

consider a nucleon fluctuating to a kaon-hyperon state, *e.g.,* ΚΛ

PDF: (b) $\overline{2}$ $s(x) - \bar{s}(x)$ $\delta_{\rm S}(\mathsf{x})$ Ω -2 -4 0.2 0.6 0.8 Ω 0.4 X 4-96 8159A1

Form factor:

Model:

use original model parameters in Brodsky&Ma paper

R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma Phys. Rev. D 98, 114004 (2018).

S.J. Brodsky and B.-Q. Ma, Phys. Lett. B 381, 317 (1996).

This is reproduced in A. Vega, I. Schimidt, T. Gutsche, and V.E. Lyubovitskij, Phys. Rev. D 93, 056001 (2016).

Strange Form Factor in LFHQCD lange fol mi factol in l for integer twist N the number of \mathcal{N}

FF with twist-τ: ${F}_\tau(t) = \frac{1}{N}$ N_τ $B(\tau - 1, 1 - \alpha(t))$ $-\overline{2}+\overline{4\lambda}$ $\alpha(t) = \frac{1}{2}$ $rac{1}{2}$ + *t* 4λ

Leading Fock state with strange-antistrange for a nucleon: $|uuds\bar{s}\rangle$ $|uudss\rangle$

$$
F_1^s(Q^2) = N_s[F_{\tau=5}(Q^2) - F_{\tau=6}(Q^2)]
$$

Strange form factor in LFHQCD with massless quarks:

Polkinghorne [59]. Their derivations were based on the **S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch,
8.J. Brodsky A. Deur M.T. Islam, and B.O. Ma**

Tianbo Liu

Separation of Strange and Antistrange Separation of Strange and **Separation of Strange and Antistrange** \sim pan corresponding to Lz α and Lz α and Lz α and Lz α 1, respectively. \mathcal{O} cparation or ϵ trange and Antistrange gible for a mixture of $\mathbf{C}_{\mathbf{A}}$ nge kan beste Conoration of Strange and Antistrange μ and Antistrange intercept [59]. This is a gain in agreement with LFHQCDD in agreement with LFHQCDD in agreement with LFHQCDD i \bf{p} and \bf{A} ntistrano \bf{p} po and thinks and $\mathbf{C} \cap \mathbf{C}$ α þ β χρόνια με θα β
Παρακτηρισμοί της επιβασιείας του προσεινότητα με θα β χρόνια με θα β χρόνια με θα β χρόνια με θα β χρόνια με \mathcal{O} Cpara **Conoration of Stronge and Antistrong** γ þ δ χρόνια του από το προσωπικό του από το προσωπικό του από το προσωπικό του από το προσωπικό του από το πρ
Το προσωπικό του από το πρ model and global fits for Ns JAI AUJUIL UL \mathbf{p} \mathbf{r} α − γ αντιπτές του αντιπτές του
Στην συνεχία του αντιπτές του αν uon of Strange a \sim \sim \sim \sim \sim \sim \sim \sim **The actual computations are carried out of Stress** function wðxÞ given by (62). In contrast to the baryonustrange α The actual computations are computations and universal computations are carried out with the universal computa function wðxÞ given by (62). In contrast to the baryonge anu Antisti di ion of Strongo ond Antistrongo ion of Strange and Antistrange The actual computations are carried out with the universal computations are carried out with the universal computations \mathcal{L}_max **function by Supersettion Strange** mes pour mondik di montenis. ranσe

Expand the distribution into twist-5 and twist-6 components Expand the distribution into twist-5 and twist-6 components ^wðxÞ ¼ ^x¹−xe−að1−xÞ² EX $\omega = \frac{1}{2}$ **Expand the dis** μ and twist-5 and twist-6 components T Expand the distribution into twist-5 and twist-6 components \mathbb{R}^n intercept [59]. This is again in agreement with LFHQCD t-twist-o-components and twist-6 components to twist of and twist of components The Post predictions for the asymptote posterior $\boldsymbol{\mathrm{Exp}}$ are shown in Fig. 4 and compared with the fluctuation Expand the di disti an twist-o components 0.52ð17Þ GeV obtained from the lattice form factor results. Expand the distribution into twist-5 and the ^π β ∪ προσποιής Expand the distribution into twist $\sum_{i=1}^{n}$ $\frac{1}{\sqrt{2}}$ Expand the distri Expand the distribution into twist-5 and The comparison of the comparison of the global data fit results, shown or the global data fit results, shown of the shown of the shown of the shown of the same of $R_{\rm B}$ and $R_{\rm B}$ and $R_{\rm B}$ are defined by α

$$
s(x) = \alpha q_{\tau=5}(x) + \beta q_{\tau=6}(x) \qquad \bar{s}(x) = \gamma q_{\tau=5}(x) + \delta q_{\tau=6}(x)
$$

coefficients satisfy: $\alpha + \beta = I_s$, $\gamma + \delta = I_s$, The coefficients sate $v_{\rm{max}}$ distributions. The effect of the α α β The coefficients satisfy: $\alpha + \beta = I_s$, $\gamma + \delta = I_s$, $\alpha - \gamma = N_s$, $\delta - \beta = N_s$ \overline{g} The coefficiens for the asymmetry some The coefficients satisfy: $\alpha + \beta = I_s$, $\gamma + \delta = I_s$, $\alpha - \gamma = N_s$, $\delta - \beta =$ $m_{\rm h}$ coefficients satisfy[.] \overline{y} a The coefficients satisfy. α $\alpha - \gamma = N_{_S}, \quad \delta - \beta = N_{_S}$ $T₁$ and universal computations are carried out with the universal carried out with the uni The coefficients satisfy: $\alpha + \beta = I_s$, γ $\delta - \beta = N_{s}$ soofficients sotisfy $\alpha + \beta = I$ $\alpha + \delta =$ e coefficients satisfy: $\alpha + \beta = I_s$, $\gamma + \delta = I_s$, $\alpha - \gamma = N_s$, $\delta - \beta = N_s$ T expression for the strange-antistrange-antistrange-antistrange-antistrange-antistrange-antistrange PDF asym- $\gamma + o = I_s, \quad \alpha - \gamma = I_{s}$, $o - \beta$ 0.52ð17Þ GeV obtained from the lattice form factor results. T $\begin{bmatrix} 1 & 3 \end{bmatrix}$ $f(x) = \frac{1}{2}$ The coefficients $s₀$ s \sim The coefficients satisfy: $\alpha + \beta = I_s$, γ $\frac{1}{\sqrt{2\pi}}$ α α β α β β α β $\mathcal{R} = \mathcal{R} \cdot \mathcal{R} = \mathcal{R} \cdot \mathcal{R} \cdot \mathcal{R}$ The coefficients satisfy: $\alpha + \beta =$ THE COULTURIUS SAUSTY. $\alpha + p - p$ \mathbf{v} and \mathbf{v} and \mathbf{v} The coefficients sine coemercing $\gamma + \delta - I$ $\alpha - \gamma - N$ significant role in understanding the NuTeV anomaly The coefficients satisfy: $\alpha + \beta = I_s$, $\gamma + \delta = I_s$, $\alpha - \gamma = N_s$, $\delta - \beta = N_s$

where
$$
\int dx s(x) = \int dx \bar{s}(x) = I_s
$$
 and $s(x) - \bar{s}(x) = N_s [q_{\tau=5}^{\phi}(x) - q_{\tau=6}^{\phi}(x)]$

General solution: $\beta = I_s - \alpha$, $\gamma = \alpha - N_s$, $\delta = I_s - \alpha + N_s$. \mathcal{L} 0.52ð17Þ GeV obtained from the lattice form factor results. General solution General solution: $\beta = I_s - \alpha$, $\gamma = \alpha - N_s$, $\delta = I_s - \alpha + N_s$. $\alpha = \gamma - \alpha = N$ solution General solution: $\beta = I_s - \alpha$, $\gamma = \alpha - N_s$ $N_{\rm s}$. \mathcal{P} is in the probability of \mathcal{P} General solution: $\beta = I_s - \alpha$, $\gamma = \alpha - N_s$, $\delta = I_s$ Γ \mathcal{L} can be compared with the global data fit results, shown in the global data fit results, shown in the global data field \mathcal{L} $\gamma = \alpha - N_s, \qquad \delta = I_s - \alpha + N_s.$ \sim 1 1. General solution: $\beta = I_s - \alpha$, $\gamma = \alpha - N_s$, $\delta = I_s - \alpha + N_s$. General solution $\zeta = \zeta - \alpha$ General solution: $\beta = I_s - \alpha$, $\gamma = \alpha - N_s$, $\delta = I_s - \alpha + N_s$. General solution UEITETAI SOIULION. $\beta = I_s - \alpha$, $\gamma = \alpha - N_s$, $\delta = I_s - \alpha + N_s$. General solution: $\beta = I - \alpha$ $v = \alpha$ $\beta = \frac{1}{2} \int_{S} - \frac{1}{2} \int_{S} - \frac{1}{2} \int_{S} \int_{S} \frac{d \mu}{S} \frac{d \mu}{S}$

 $\alpha q_{\tau=5}(x) + (I_s - \alpha) q_{\tau=6}(x), \quad \bar{s}(x) = (\alpha - N_s).$ $S(x) = \alpha q_{\tau-5}(x)$ $\omega(\lambda) = \omega q_{\tau=5}(\lambda)$ $f(x) + (I_s - \alpha)q_{\tau=6}(x), \quad \bar{s}(x) = (\alpha - N_s)q_{\tau=5}(x) + (I_s - \alpha + N_s)q_{\tau=6}(x)$ meson fluctuation model, which has the small-x behavior $s(x) = \alpha$ $\mathbf{s}(x) = \alpha \mathbf{a} - (x) + (I - \alpha)$ $S(x) = \alpha q_{\tau=5}(x) + (I_s - \alpha) q_{\tau=6}(x), \quad \bar{S}(x) = (\alpha - N_s) q_{\tau=5}(x) + (I_s - \alpha + N_s) q_{\tau=6}(x)$ $\tilde{f}(x) = \tilde{g}(x) + (I$ $S(x) = \alpha q_{\tau=5}(x) + (I_s - \alpha) q_{\tau=6}(x), \quad \bar{S}(x)$ $s(x) = \alpha q_{\tau=5}(x) + (I_s - \alpha) q_{\tau=6}(x), \quad \bar{s}(x) = (\alpha - N_s) q_{\tau=5}(x) + (I_s - \alpha + N_s) q_{\tau=6}(x)$ $S(\lambda) - \alpha q_{\tau=5}(\lambda) + (I_s - \alpha) q_{\tau=6}(\lambda), \quad S(\lambda) = (\alpha)$ $=(\alpha N)\alpha (x)+(I-\alpha+N)\alpha (x)$ $= (\alpha - N_s)q_{\tau=5}(x) + (I_s - \alpha + N_s)q_{\tau=6}(x)$ $\left(1, \frac{1}{2} \right)$ for $\left(1, \frac{1}{2} \right)$ \mathcal{L}_{max} $\mathcal{F}_s - \alpha \big) q_{\tau=6}(x), \quad \bar{s}(x) = (\alpha - N_s) q_{\tau=5}(x) + (I_s - \alpha + N_s) q_{\tau=6}(x)$ \mathcal{L} $S(x) = \alpha q_{\tau}$ from deep inelastic neutrino scattering by $\mathcal{L}(\mathcal{N})$ $s(x) = \alpha q_{\tau=5}(x) + (I_s - \alpha) q_{\tau=6}(x), \quad \bar{s}(x) = (\alpha - N_s) q_{\tau=5}(x) + (I_s - \alpha + N_s) q_{\tau=6}(x)$ $\mathcal{L}(\lambda) = \mathcal{L}(\lambda)$ $\zeta(x)$ $F(x) + (I - \alpha)a(\epsilon(x)) = \bar{s}(x) - (\alpha - N)a(\epsilon(x)) + (I - \alpha + N)a(\epsilon(x))$ $\left(\begin{array}{ccc} \cdots & \cdots & \cdots \end{array}\right)$ is the minimum possible intrinsic strange probability. $F(x) = \alpha \alpha$ (x) $(I - \alpha) \alpha$ (x) $\overline{F}(x)$ $s(x) = \alpha q_{\tau=5}(x) + (I_s - \alpha) q_{\tau=6}(x), \quad s(x) = (\alpha - N_s) q_{\tau=5}(x) + (I_s - \alpha + N_s) q_{\tau=6}(x)$

fram: $s(x) \geq 0$ and $s(x) \geq 0$ Physical constra straint: ≥ 0 meson fluctuation model, which has the small-x behavior s
bolographic model has the holographic model has the holographic model has the Reg sical constraint: s behavior sønder sønder.
∂ønder Physical constraint: $s(x) \ge 0$ and $\overline{s}(x) \ge 0$ in Fig. 4 at the initial scale $\frac{1}{2}$ Physical constraint: $s(x) \geq 0$ and $0 \qquad \qquad 0$ $s = \frac{1}{\sqrt{2}}$ $\frac{1}{5}$ \overline{D} Γ Physical constraint: $s(x) \ge 0$ and $\overline{s}(x) \ge 0$ from deep inelastic neutrino/antineutrino scatterings by $\frac{1}{2}$ Physical constraint: $s(x) \ge 0$ and $\bar{s}(x) \ge 0$ and LFHQCD yield home is not what is not which is n
The contract of the cont $\partial(w) \leq 0$ From our analysis, the lattice $\mathcal{L}_{\mathcal{A}}$ result favors and $\mathcal{L}_{\mathcal{A}}$ $\begin{array}{l} \begin{array}{c} \begin{array}{c} \begin{array}{c} \end{array} \\ \begin{array}{c} \end{array} \end{array} \end{array}$ and $\begin{array}{ccc} \textbf{p}_1 & \cdot & 1 \\ 1 & 1 & 1 \end{array}$ Physical constraint: $s(x) \geq 0$ and $\overline{s}(x) \geq 0$ positivity constraints lead to α ≥ Ns. At small-x we have

twist-5 term domin T_{W} and T_{W} are called T_{W} and T_{W} It large-x: $\alpha \geq 0$ and $\gamma \geq 0$. funt 5 term dominates at large $r = \alpha > 0$ $\frac{68}{3}$; $\frac{68}{3}$; namely, the Weinberg and $\frac{68}{3}$ α about 3 from dominates at $\arg \alpha$. $\alpha \leq 0$ ≥ 0 σ term dominates a twist-5 term do $W15t-J$ whereas $\alpha \geq 0$ and $\gamma \geq 0$. $\frac{1}{2}$ $\frac{1}{2}$ is $\frac{1}{2}$ if $\frac{1}{2}$ is required. $\alpha \geq 0$ and $\gamma \geq 0$ twist-5 term dominates at large-x: $\alpha \ge 0$ and $\gamma \ge 0$ $s_{\lambda} = \frac{1}{\lambda} \sum_{i=1}^{n} \frac{1}{\lambda_i} \sum_{j=1}^{n} \frac{1}{\lambda_j} \sum_{j=1}^{n} \frac{1}{\$ positivity constraints lead to α ≥ Ns. At small-x we have $\frac{1}{2}$ twist 5 torm dor $\frac{1}{2}$ in the conformal limit of $\frac{1}{2}$ and $\frac{1}{2}$ $\frac{1}{2}$ and $\frac{1}{2}$ $\frac{1}{2}$ inates at large-x: $\alpha \geq 0$ and $\gamma \geq 0$. sources are needed. Although the value for \sim i is model. Although the value for \sim i is \sim i is model. The value for \sim twist-5 term dominates at large-x: $\alpha \ge 0$ and $\gamma \ge 0$

examine the small-x:

\n
$$
I_s \geq (1 - R)\alpha
$$
\n
$$
\lim_{x \to 0} \frac{q_{\tau=5}(x)}{q_{\tau=6}(x)} = \frac{N_{\tau=6}}{N_{\tau=5}} \equiv R
$$

 \sum shown in Fig. 4 and \sum

N^τ¼⁶

 $\begin{array}{ccc} 1 & -b & \sqrt{2} \\ 1 & 0 & \sqrt{2} \\ 0 & 0 & \sqrt{2} \end{array}$

 α , Qingdao

Tianbo Liu 39 **R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma Phys. Rev. D 98, 114004 (2018).**
Tianbo Liu R.S. Sufian, TL, G.F. de Téra The compared with the global data fit results, shown in the global dat W.C. Decel S.I. Buedely, A. De $\left(\frac{A}{\sqrt{2}}\right)$ \leftarrow \leftarrow \overline{D} \overline{S} \overline{S} P _{hys.} $\frac{1}{2}$ Tianbo Li R.S. Sufian, I L, G.F. de Teramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. J.
Phys. Rev. D 98. 114004 (2018). from deep inelastic neutrino/antineutrino scatterings by Tianbo Liu nond, H.G. Dosch, S.J \mathcal{S} **B** S Sufian TL G E de Téramond H d K.S. Sunan, 1 L, G.F. de Teramond, H.W
Phys. Rev. D 98, 114004 (2018). $\frac{1 \text{ m/s}}{\text{N}}$. At $\frac{1}{200}$, $\frac{1}{200}$, $\frac{1}{200}$. $\overline{}$ $\overline{\$ dsky, A. Deur, M.T. Islam, and B.-Q. Ma s standong university, qingdad and $\left(\frac{\sqrt{2}+\sqrt{2}}{3\sqrt{2}}\right)$ $\left(\frac{1}{2},\frac{1}{2}\right)$ $\left(\frac{1}{2},\frac{1}{2}\right)$ $\left(\frac{1}{2},\frac{1}{2}\right)$ $\left(\frac{1}{2},\frac{1}{2}\right)$ $\left(\frac{1}{2},\frac{1}{2}\right)$ $\left(\frac{1}{2},\frac{1}{2}\right)$ $\left(\frac{1}{2},\frac{1}{2}\right)$ **\left(\frac{1}{2},** \mathcal{L}^2 and the NuTeV source for the NuTeV source f **and R.S. Sutian, TL, G.F. de Tera**
and Phys. Rev. D 98, 114004 (2018 **Phys. Rev. D 98, 114004 (2018).**
Tierbo Liu $\frac{1}{2}$ y, A. Deur, M.T. Islam, and B.-Q. Ma $\left(\frac{\sum_{i=0}^{n} x_i}{\sum_{i=0}^{n} y_i}\right)$ $\left(\sum_{i=0}^{n} x_i\right)$ $\left(\sum_{i=0}^{n} x_i\right)$ \overline{D} $R.S.$ S Tianbo I $\overline{}$ $\mathcal{L}_{\mathcal{I}}$ $f_{\rm eff}$ asymmetry also turns out to be negli-also turns ou dsky, A. Deur, M.T. Islam, and B.-Q. Ma <u>neglected.</u>
Neglected. $\mathbf{g} = \mathbf{g} \cdot \mathbf{g} \cdot \mathbf{g} = \mathbf{g} \cdot \mathbf{g} \cdot \mathbf{g} = \mathbf{g} \cdot \mathbf{g} \cdot \mathbf{g} \cdot \mathbf{g}$ R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. Islam, and B.- $\sqrt{2\pi}$ $\sqrt{2}$ $\sqrt{2}$ $\frac{1}{2}$ and $\frac{1}{2}$ a <u>— Phys. R</u>e \Box lanbo Liu 39 sðxÞ ≥ 0 and s¯ðxÞ ≥ 0. Since the twist-5 term dominates at 39 p_{α} is a p_{α} internal to α and α is a small-x we have to a p_{α} we have to a small-x we have to a s R.S. Sufian, TL, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, M.T. Islam, and B.-Q. Ma positivity constraints lead to α ≥ Ns. At small-x we have N^τ¼⁶ 39 and/or future experiments will provide important con-¼ $\frac{1}{30}$ R.S. Sufian, TL, G.F. de Téramond, ur, M.T. Islam, and ■ D.C. Sufian TI C.F. do Tóramond H.C. Dosch S.I. Rrodsky A. Dour M.T. Islam, and R. O. Ma straints on the strange-antistrange asymmetry. \mathbf{h} \mathbf{m},\mathbf{r} $\frac{1}{2}$ **S.J. Brodsl** \mathcal{L} \mathbf{y},\mathbf{A} . Deur, M.T. Islam, and $\mathbf{S}\mathbf{C}\mathbf{H}, \mathbf{S} \mathbf{J}$ $\mathbf{\dot{c}}$ 1 − R Iky, A. Deur, M. I. Is $39⁵$, and B.-Q. Ma distribution above x 0.7 and for the s∃∂∞
———————————————————— $\sqrt{4\omega}$ above $\sqrt{4}$ $\left(\frac{\sum_{i=0}^{n} y_i}{\sum_{i=0}^{n} y_i}\right)$ $\left(\sum_{i=0}^{n} y_i\right)$ $\left(\sum_{i=0}^{n} y_i\right)$ 11400

Polarized PDFs

Spin-aligned and spin-antialigned distributions:

$$
q_{\uparrow/\downarrow}(x) = \frac{1}{2}[q(x) \pm \Delta q(x)]
$$

Large *x* limit:

$$
q_{\uparrow}(x) \to c_{\tau}q_{\tau}(x) \sim (1-x)^{2\tau-3}
$$

 $q_{\downarrow}(x) \to c_{\tau+1}q_{\tau+1}(x) \sim (1-x)^{2\tau-1}$

Two helicity states tend to a pure contribution from one component.

E.g.: for valence state, $\tau=3$

$$
q_{\uparrow}(x) \sim (1-x)^3
$$
 $q_{\downarrow}(x) \sim (1-x)^5$

Consistent with pQCD up to logarithmic corrections.

TL, R.S. Sufian, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, Phys. Rev. Lett. 124, 082003 (2020).

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Numerical Results of Polarized PDFs

Coefficients *cτ* by fitting EM form factors do not separate quark and antiquark

E.g.:
$$
c_{5,u} = u_{\tau=5} - \bar{u}_{\tau=5}
$$
 $c_{6,u} = u_{\tau=6} - \bar{u}_{\tau=6}$

similar for down quark

Adding equal terms to u and ū, or d and d, does not change EM form factors. -

Axial charge:

$$
g_A = (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d}) \approx 1.2732(23)
$$

precisely measured via neutron weak decay.

Saturate the axial charge by a shift:

$$
u_{\tau=5} \to u_{\tau=5} + \delta_u \qquad \bar{u}_{\tau=5} \to \bar{u}_{\tau=5} + \delta_u
$$

$$
d_{\tau=6} \to d_{\tau=6} + \delta_d \qquad \bar{d}_{\tau=6} \to \bar{d}_{\tau=6} + \delta_d
$$

Variation due to different ways to saturate g_A is taken as part of our uncertainty.

TL, R.S. Sufian, G.F. de Téramond, H.G. Dosch, S.J. Brodsky, A. Deur, Phys. Rev. Lett. 124, 082003 (2020).

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