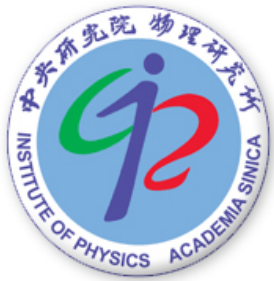


Hadronic structure of the photon at small x in holographic QCD



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Based on:
AW, H. n. Li, Phys. Lett. B 751, 321 (2015)
AW, H. n. Li, (in preparation)

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Photon's “internal structure”?

- In high energy scattering (here electron-photon DIS), a photon can fluctuate into $q\bar{q}$ pairs or vector mesons.
-> “dressed photon”
- One can investigate the partonic structure of (the cloud of) the photon, which has both pointlike and hadronic components.

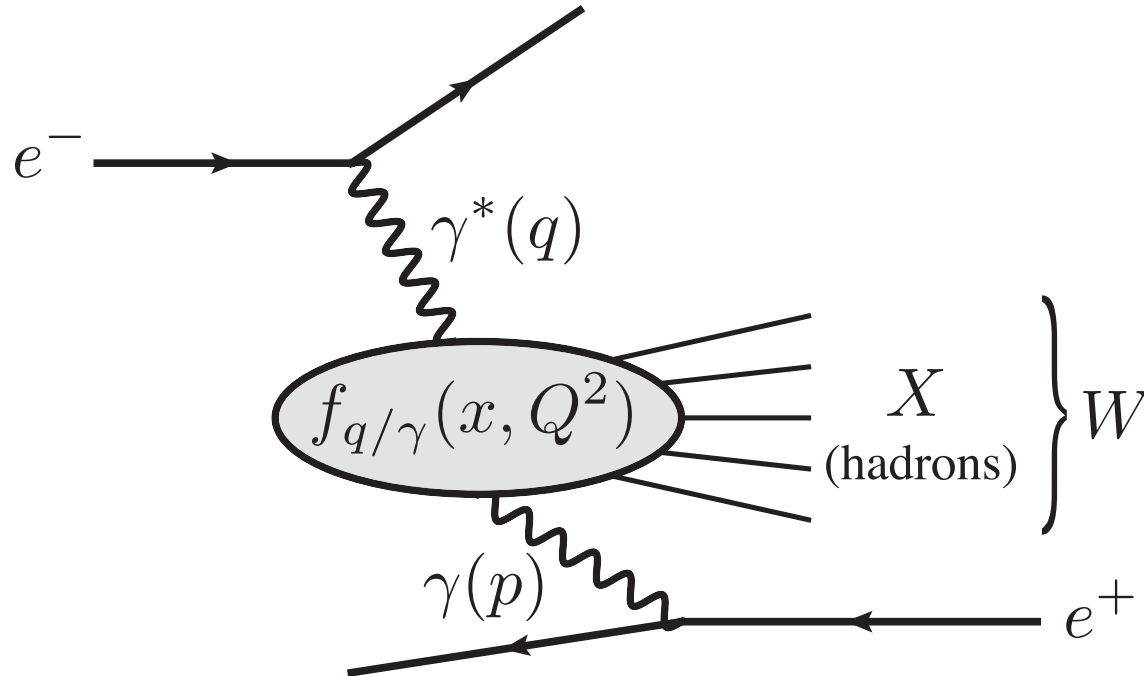
Motivation

- A solid understanding of properties of the elementary particles is basically important.
- Hadronic contribution to cross sections of electron-photon DIS becomes dominant at small x . (→ Pomeron exchange may work)
- Two of three adjustable parameters of the model have been fixed in previous studies of nucleon structure functions. We shall test the predictive power.
- Electron-photon DIS is a cleaner process.
- Preceding studies at small x are quite limited.
- The predictions can be tested at ILC in the future.

Deep inelastic electron-photon scattering

$$\frac{d^2\sigma_{e\gamma\rightarrow eX}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left[\left\{ 1 + (1-y)^2 \right\} F_2^\gamma(x, Q^2) - y^2 F_L^\gamma(x, Q^2) \right]$$

$$x = \frac{Q^2}{Q^2 + W^2 + P^2} \quad \text{when} \quad W^2 \gg Q^2 \gg P^2 \quad \rightarrow \quad x \approx \frac{Q^2}{W^2}$$



Two components in electron-photon DIS

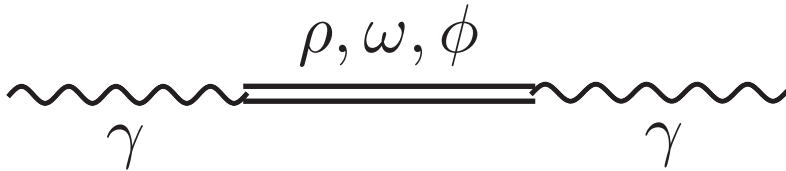
$$\frac{d^2\sigma}{dQ^2 dx} = \frac{2\pi\alpha^2}{\pi Q^4} \left[\left\{ 1 + (1-y)^2 \right\} F_2^\gamma - y^2 F_L^\gamma \right]$$

$$x = \frac{Q^2}{Q^2 + W^2}, \quad y = \frac{Q^2}{xs}$$

in quark model

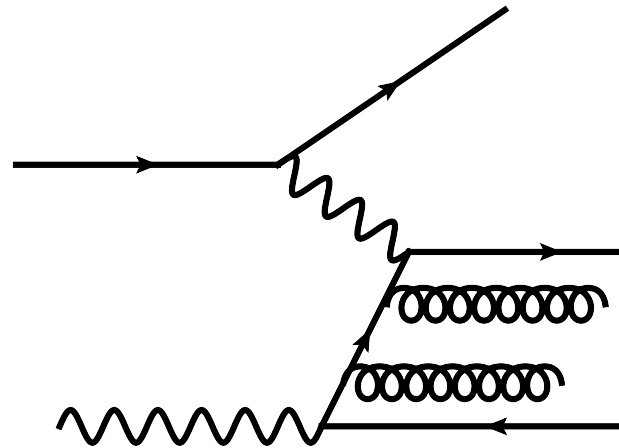
$$F_2^\gamma(x, Q^2) = 2x \sum_q e_q^2 q^\gamma(x, Q^2), \quad F_L^\gamma = 0$$

“hadronic” (small x)



- A photon behaves like ρ meson (and other vector mesons)
- Utilizing the vector meson dominance model is the only way to calculate cross sections

“pointlike” (large x)



- One can predict cross sections by pQCD

Holographic description of structure functions

- **Polchinski-Strassler (2003)**
- **Brower-Polchinski-Strassler-Tan (2007)**
- **Brower-Djuric-Sarcevic-Tan (2010)**

derived Pomeron
exchange kernel

studied nucleon
structure functions

$$\mathcal{A}(s,t) = 2is \int d^2b e^{iq \cdot b} \int dz dz' P_{13}(z) P_{24}(z') \left\{ 1 - e^{i\chi(s,b,z,z')} \right\}$$

$$F_2(x, Q^2) = \frac{Q^2}{2\pi^2} \int dz dz' P_{13}(z, Q^2) P_{24}(z', Q'^2) \text{Im}[\chi(s, z, z')]$$

z and z' : 5th coordinate

χ : Pomeron exchange kernel in the AdS space

$P_{13}(z, Q^2)$: incident particle
(Q : 4-momentum)

$P_{24}(z', Q'^2)$: target particle

overlap functions
(density distributions
in the AdS space)

Pomeron exchange kernel

Brower-Polchinski-Strassler-Tan (2007)

Brower-Strassler-Tan (2009)

$$F_i(x, Q^2) = \frac{g_0^2 \rho^{3/2} Q^2}{32\pi^{5/2}} \int dz dz' P_{13}^{(i)}(z, Q^2) P_{24}(z', Q'^2) (zz') \text{Im}[\chi(s, z, z')]$$

$i = 2 \text{ or } L$

$$\text{Im}[\chi_c(s, z, z')] \equiv e^{(1-\rho)\tau} e^{-\frac{\log^2 z/z'}{\rho\tau}} / \tau^{1/2}$$

$$\tau = \log(\rho z z' s / 2)$$

$$\text{Im}[\chi_{\text{mod}}(s, z, z')] \equiv \text{Im}[\chi_c(s, z, z')] + \mathcal{F}(z, z', \tau) \text{Im}[\chi_c(s, z, z_0^2 / z')]$$

$$\mathcal{F}(z, z', \tau) = 1 - 2\sqrt{\rho\pi\tau} e^{\eta^2} \text{erfc}(\eta)$$

$$\eta = \left(-\log \frac{zz'}{z_0^2} + \rho\tau \right) / \sqrt{\rho\tau}$$

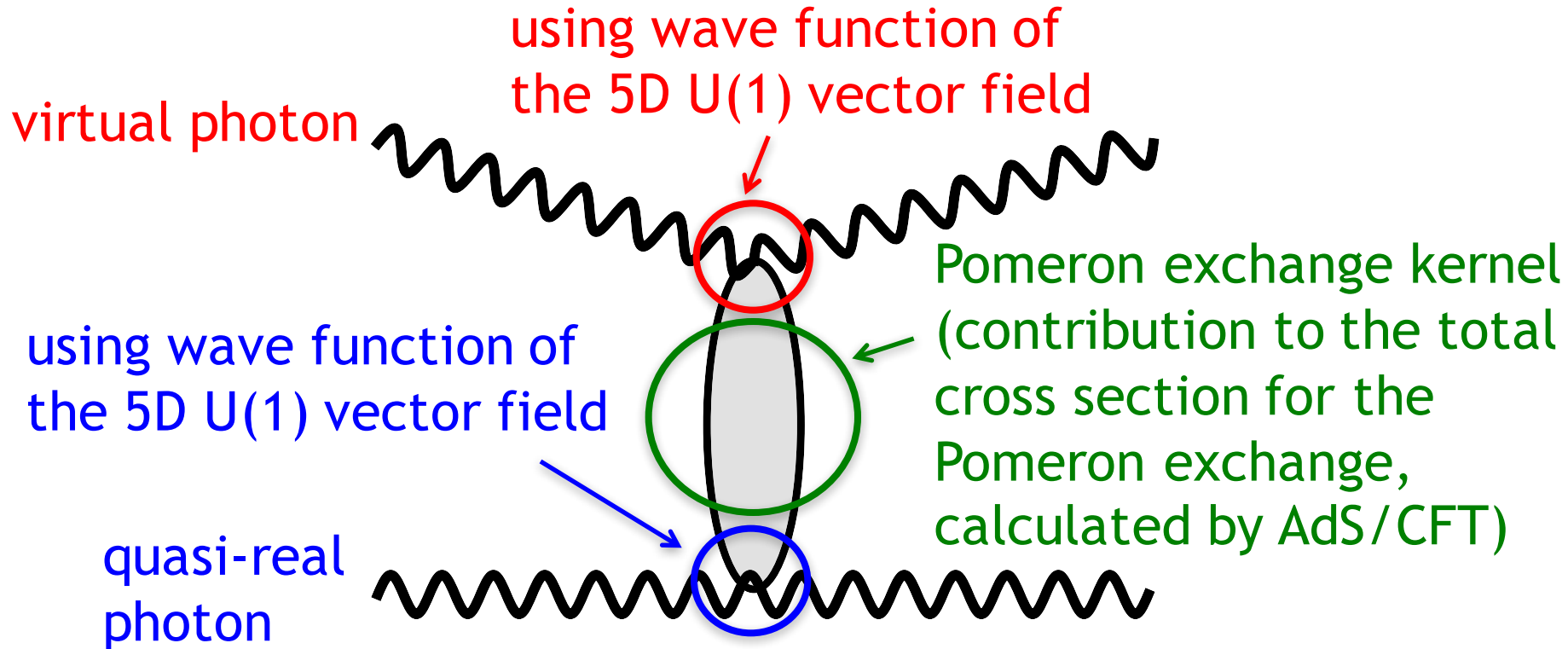
confinement
effect

3 adjustable parameters :

$$\rho, g_0^2, z_0$$

Virtual photon – quasi-real photon scattering

$$F_i^\gamma(x, Q^2) = \frac{\alpha g_0^2 \rho^{3/2} Q^2}{32\pi^{5/2}} \int dz dz' \boxed{P_{13}^{(i)}(z, Q^2)} \boxed{P_{24}(z', P^2 \ll 1 \text{ GeV}^2)} \boxed{\text{Im}[\chi(W^2, z, z')]}$$

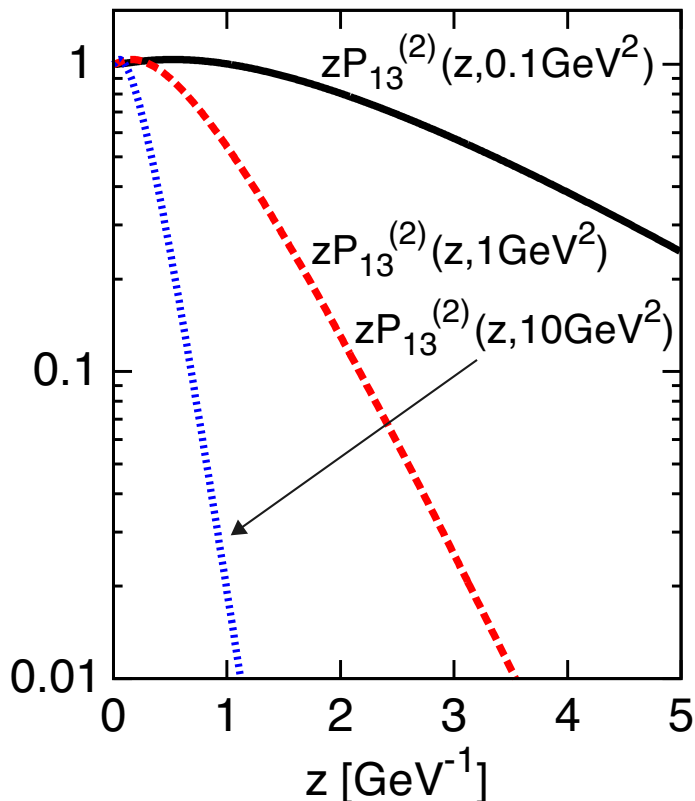


We reuse the parameters ρ and z_0 which have been fixed in the calculations for the nucleon F_2 structure function.

Density distribution of the photon

Polchinski-Strassler (2003)

- As a density distribution of the virtual photon, we use wave function of the 5D U(1) vector field



$$P_{13}^{(2)}(z, Q^2) = Q^2 z \left(K_0^2(Qz) + K_1^2(Qz) \right)$$

(to calculate F_2)

$$P_{13}^{(L)}(z, Q^2) = Q^2 z K_0^2(Qz)$$

(to calculate F_L)

$P_{13}^{(2)}$ are localized at the origin
with Q^2 increasing
(the behavior of $P_{13}^{(L)}$ is similar)

Directions

- Since the target is a non-normalizable mode, we need to newly fix the overall factor by experimental data.
- We adopt the data measured by the OPAL collaboration at LEP. Abbiendi, et al. (2000)
- Since the available experimental data in the small x region are quite limited, we also compare our calculations (predictions) with those calculated from a well-known PDF set GRS (Glück-Reya-Schienbein). Glück-Reya-Schienbein (1999)

F_2 from PDFs (GRS)

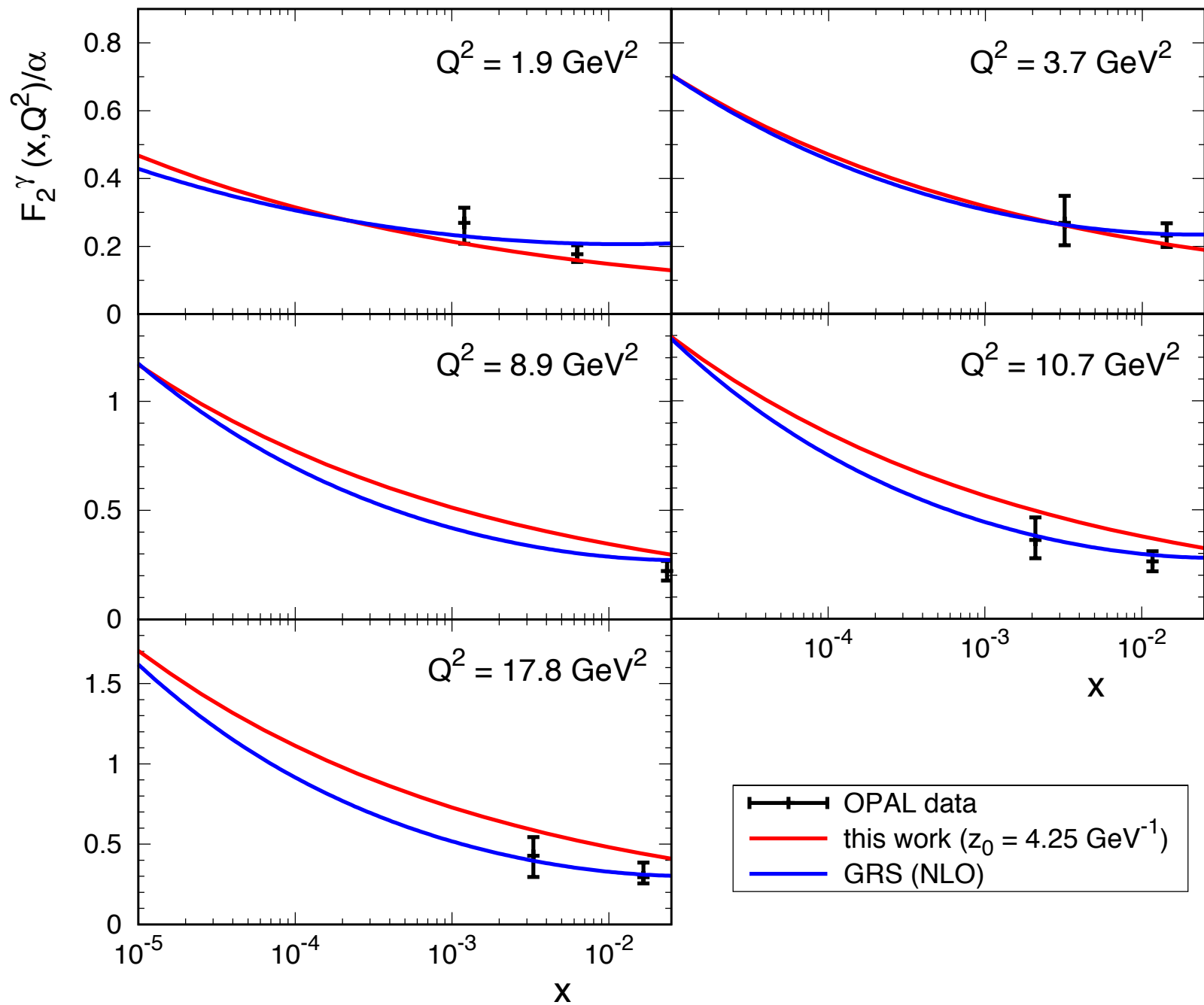
Glück-Reya-Schienbein (1999)

$$\begin{aligned} \frac{1}{x} F_2^\gamma(x, Q^2) = & 2 \sum_{q=u,d,s} e_q^2 \left\{ q^\gamma(x, Q^2) + \frac{\alpha_s(Q^2)}{2\pi} \right. \\ & \times [C_q \otimes q^\gamma + C_g \otimes g^\gamma] \left. \right\} + \frac{1}{x} F_{2,c}^\gamma(x, Q^2) \\ & + \frac{1}{x} F_{2,c}^{g\gamma}(x, Q^2), \end{aligned}$$

$$\begin{aligned} f^\gamma(x, Q^2) = & \underline{f_{pl}^\gamma(x, Q^2)} \\ & + \alpha \left[G_f^2 f^\pi(x, Q^2) + \delta_f \frac{1}{2} (G_u^2 - G_d^2) s^\pi(x, Q^2) \right] \end{aligned}$$

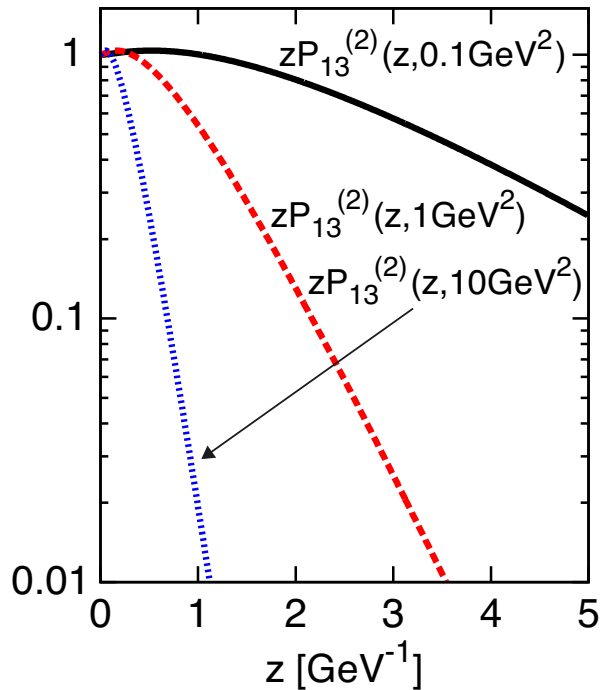
pointlike component

hadronic component
from PDFs of a pion



Flavor number dependence of z_0

Photon

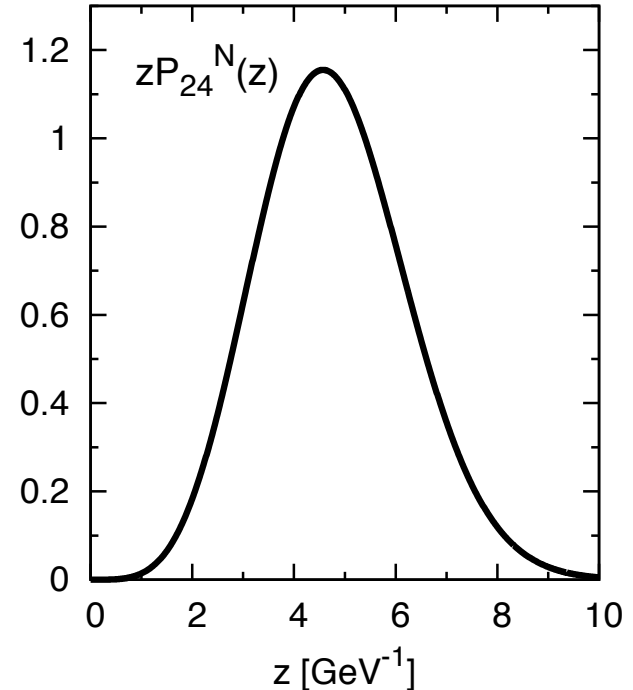


$$z_0 = 6 \text{ GeV}^{-1}$$

$$1/z_0 = 167 \text{ MeV}$$

$$f = 6 (?)$$

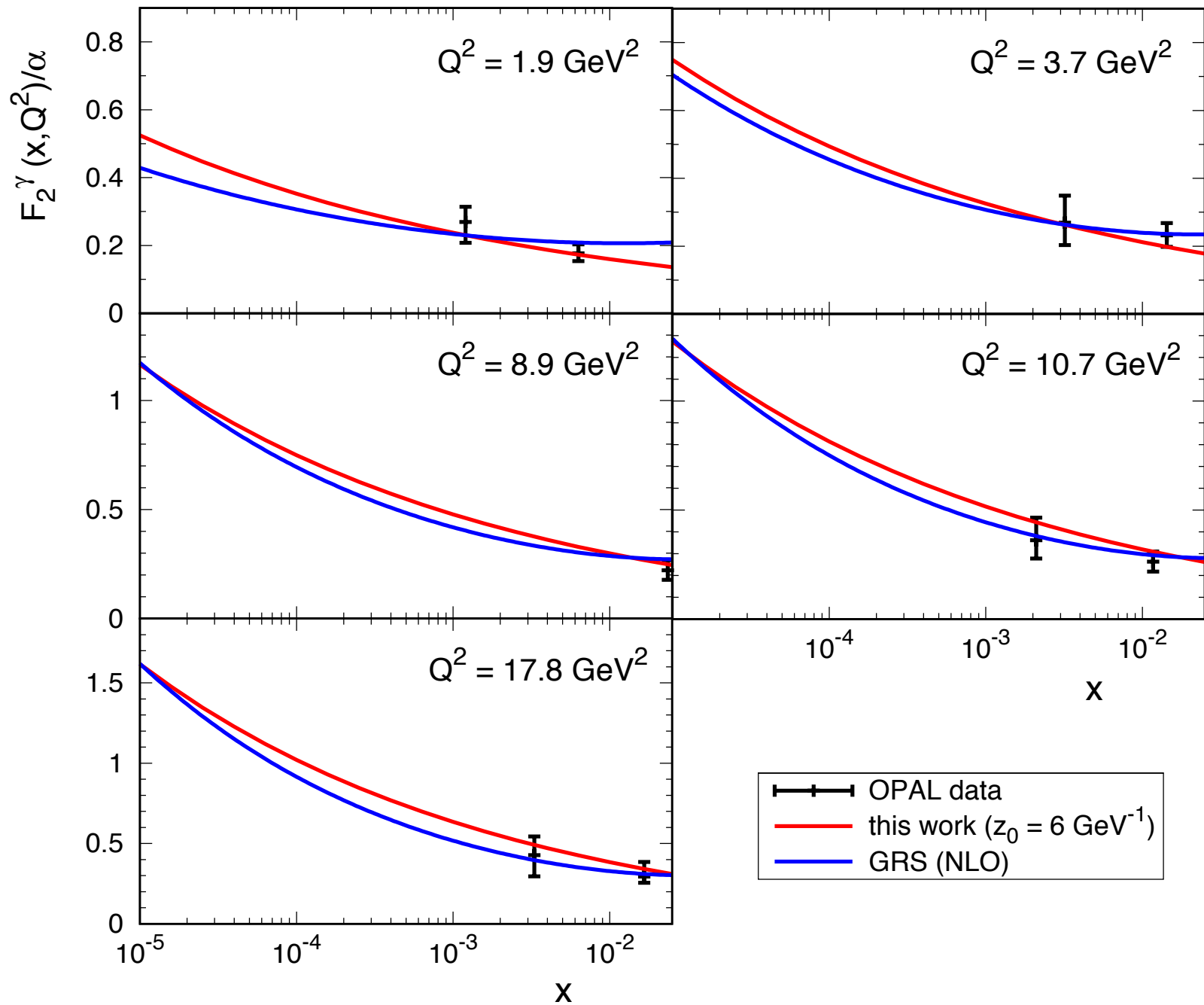
Hadron



$$z_0 = 4.25 \text{ GeV}^{-1} \text{ (original)}$$

$$1/z_0 = 235 \text{ MeV}$$

$$f = 4 (?)$$



Virtual photon – ρ meson scattering

$$F_i^\gamma(x, Q^2) = \frac{\alpha g_0^2 \rho^{3/2} Q^2}{32\pi^{5/2}} \int dz dz' P_{13}^{(i)}(z, Q^2) P_{24}(z') \text{Im}[\chi(W^2, z, z')]$$

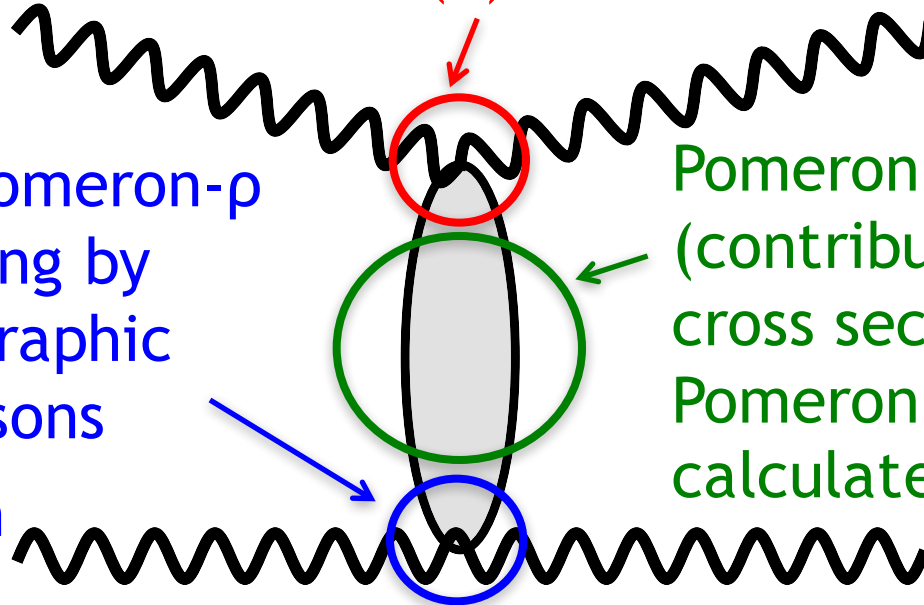
using wave function of
the 5D U(1) vector field

virtual photon

calculating Pomeron- ρ
meson coupling by
using a holographic
model of mesons

real photon
(ρ meson)

Pomeron exchange kernel
(contribution to the total
cross section for the
Pomeron exchange,
calculated by AdS/CFT)



We reuse the parameters ρ and z_0 which have been fixed in the calculations for the nucleon F_2 structure function.

A holographic model of mesons

Erlich-Katz-Son-Stephanov (2005)

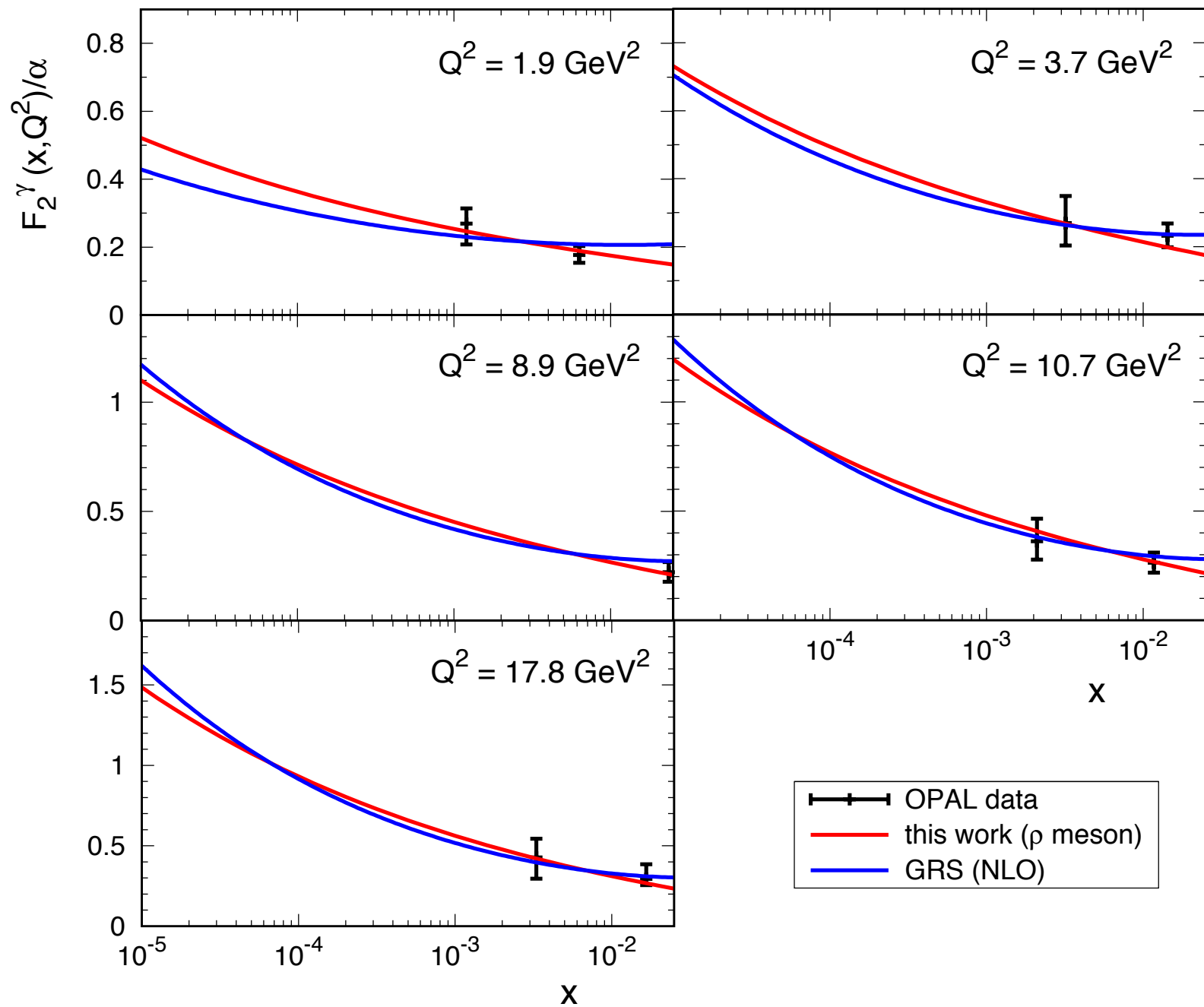
$$S_{\text{AdS}} = \text{Tr} \int d^4x dz \left[\frac{1}{z^3} |DX|^2 + \frac{3}{z^5} |X|^2 - \frac{1}{2g_5^2 z} (F_V^2 + F_A^2) \right]$$

$$\left\{ \begin{array}{l} X = X_0 \exp(2i\pi^a t^a) \\ D^M X = \partial^M X - i [V^M, X] - i \{A^M, X\} \\ F_V^{MN} \equiv \partial^M V^N - \partial^N V^M - i ([V^M, V^N] + [A^M, A^N]) \\ F_A^{MN} \equiv \partial^M A^N - \partial^N A^M - i ([V^M, A^N] + [A^M, V^N]) \\ X_0(z) = \underline{m_q z/2 + \sigma z^3/2} \end{array} \right.$$

chiral symmetry breaking
(explicit and spontaneous)

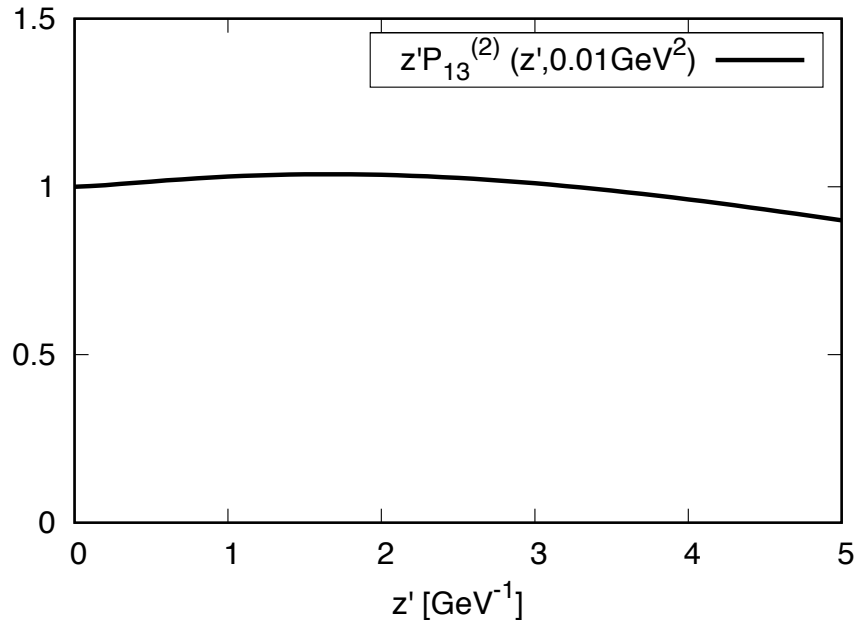
$$M, N = 0 \sim 3, z$$

$$V_z = A_z = 0$$

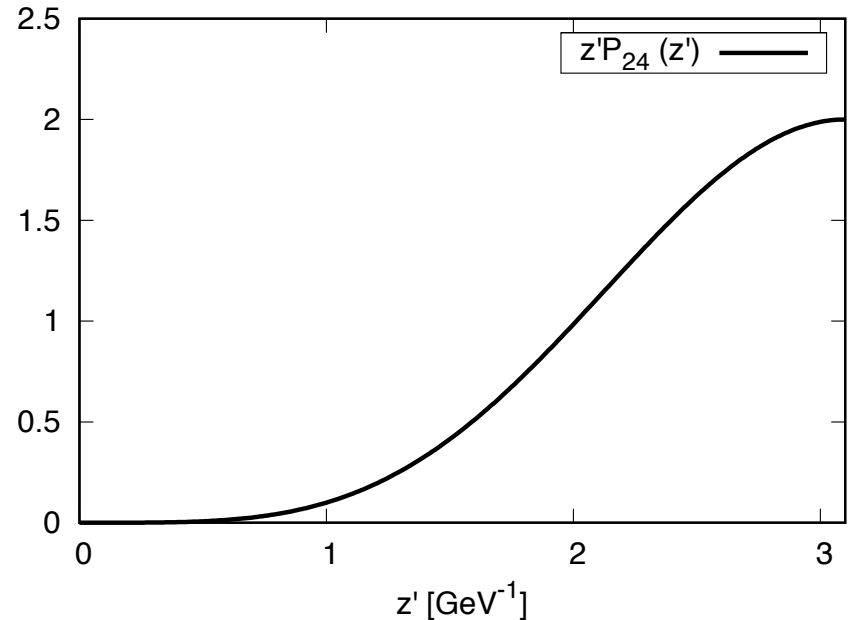


Density distributions of quasi-real photon and ρ meson

quasi-real photon



ρ meson



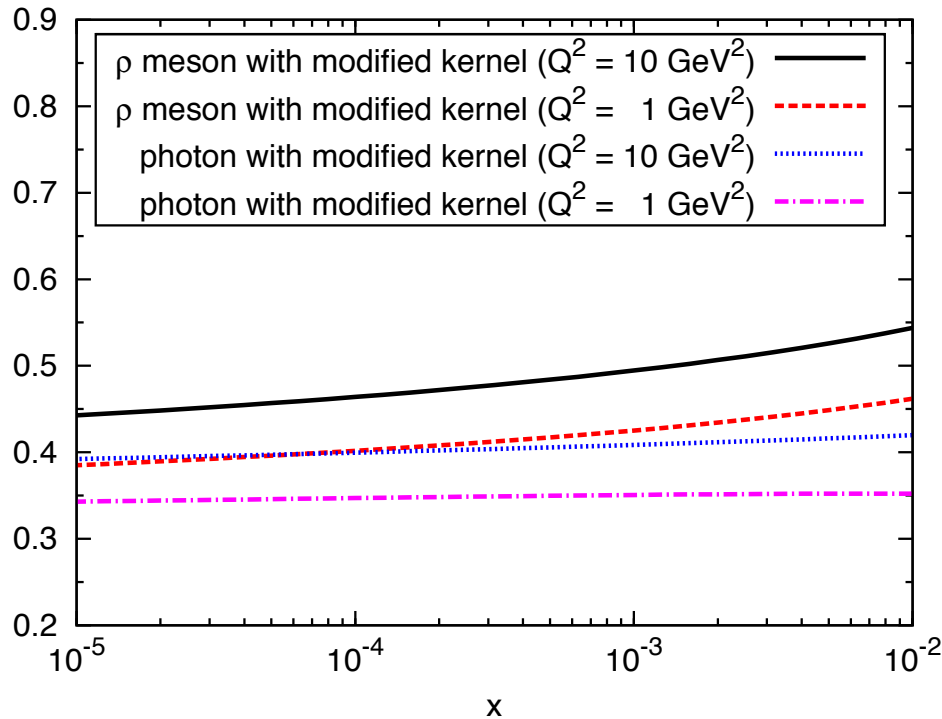
Both distributions are not similar to each other, but obtained contributions after integration over $z(z')$ are similar.

*Realization of the vector meson dominance
in the present model setup!*

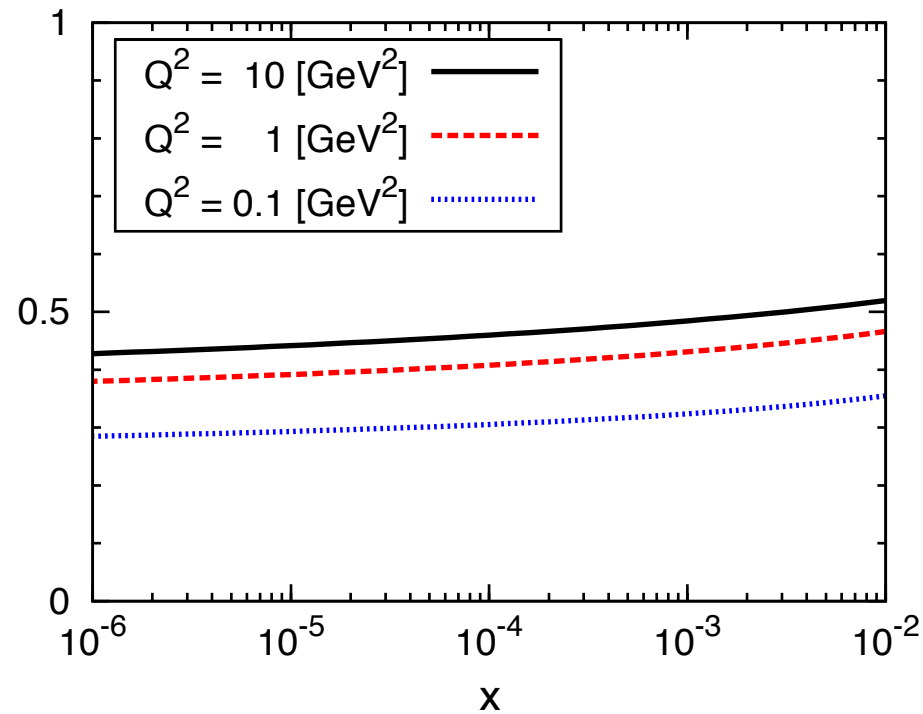
Longitudinal-to-transverse ratio $R = F_L/F_T$

AW-Suzuki (2014)

Photon



Nucleon



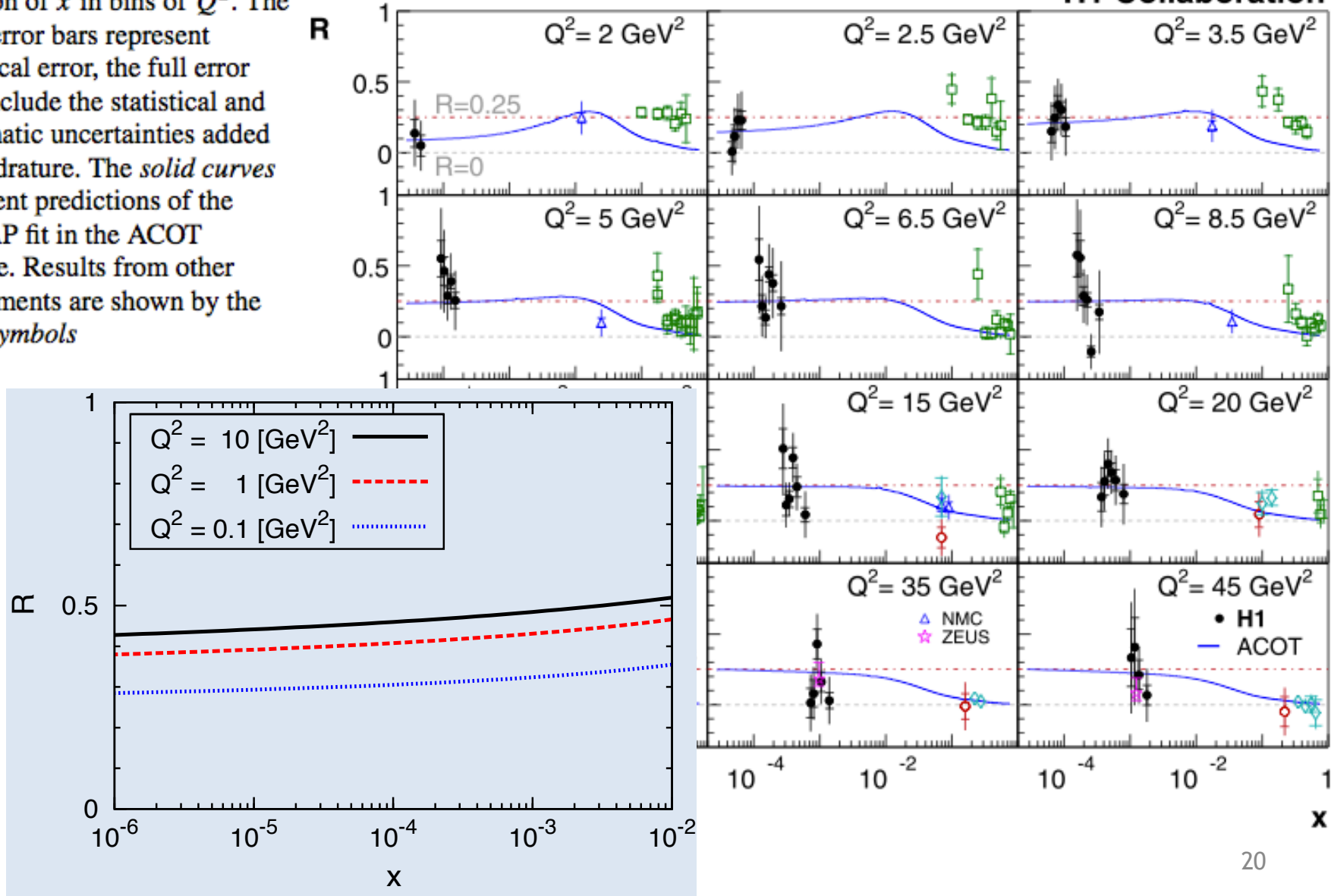
The longitudinal structure function is not negligible in this kinematic region.

x dependence of R

H1 Collaboration (2011)

Fig. 14 The ratio R as a function of x in bins of Q^2 . The inner error bars represent statistical error, the full error bars include the statistical and systematic uncertainties added in quadrature. The *solid curves* represent predictions of the DGLAP fit in the ACOT scheme. Results from other experiments are shown by the *open symbols*

H1 Collaboration



Summary

- We have studied the photon structure functions at small x in the framework of holographic QCD with a single adjustable parameter.
- Our calculations are in agreement with the experimental data and the GRS predictions.
 - Single Pomeron exchange works.
 - Vector meson dominance model works.
 - Similarity between the ρ meson and the pion?
- The results can be tested at future linear colliders, such as the planned ILC.