Electron-photon deep inelastic scattering at small x in holographic QCD

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AW, Hsiang-nan Li, Phys. Lett. B **751**, 321 (2015)
AW, Hsiang-nan Li, (in preparation)

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Photon’s “internal structure”?

- In high energy scattering (here electron-photon DIS), a photon can fluctuate into qqbar 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.

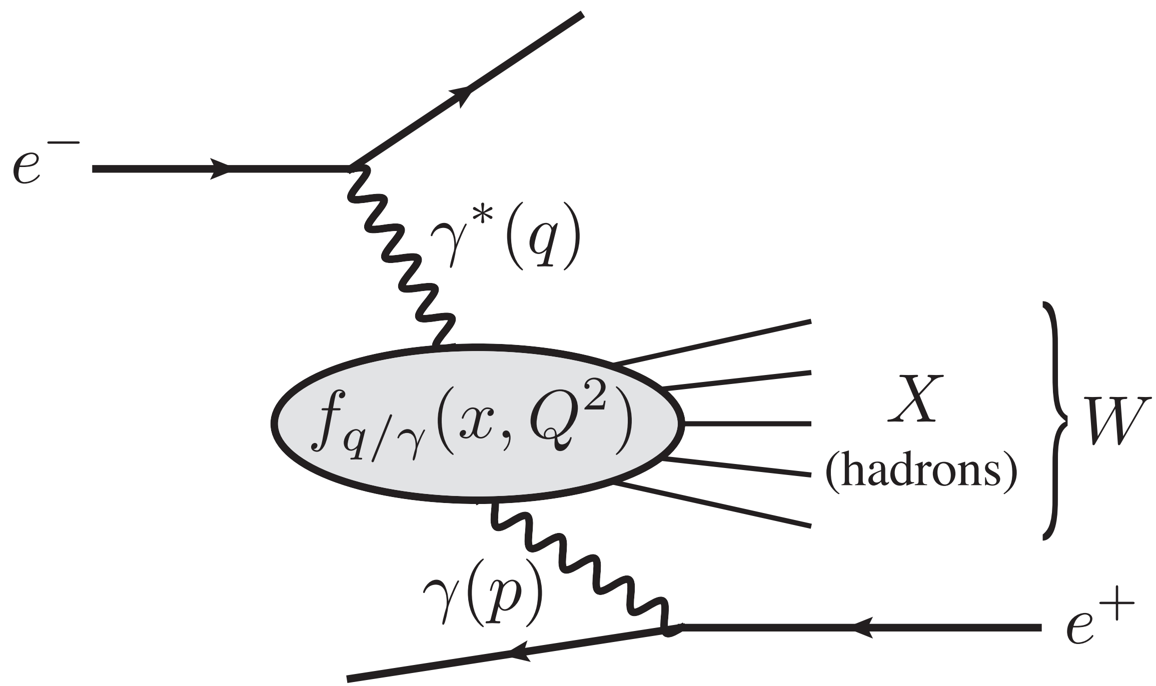
Motivation

- A solid understanding of properties of the elementary particles is basically important.
- Hadronic contribution to cross sections of electron-photon DIS becomes dominant in the small x region. (--> Pomeron exchange may work)
- One of three adjustable parameters of the model has 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.

Deeply inelastic electron-photon scattering

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

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



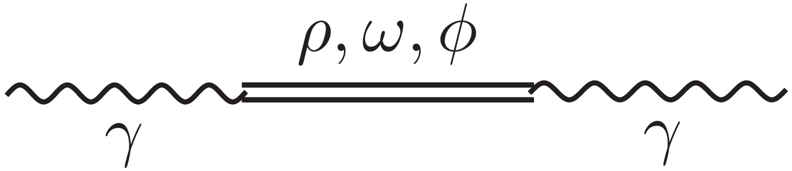
Two components in electron-photon DIS

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

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

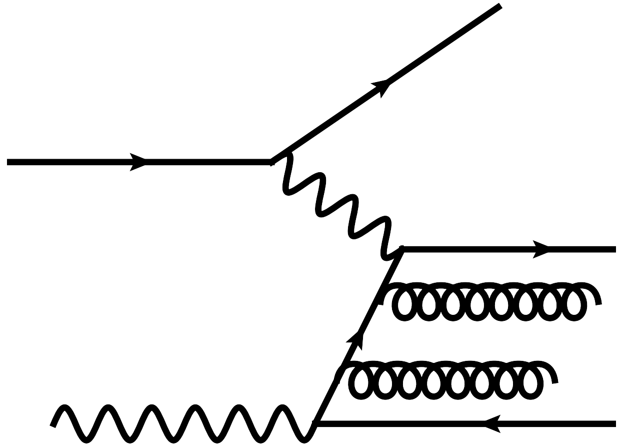
in quark model $F_2^\gamma\left(x,Q^2\right) = 2x\sum_q e_q^2 q^\gamma\left(x,Q^2\right),\ F_L^\gamma = 0$

“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

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

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

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)

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

$i = 2$ or L

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

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

mimicking confinement effect

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

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

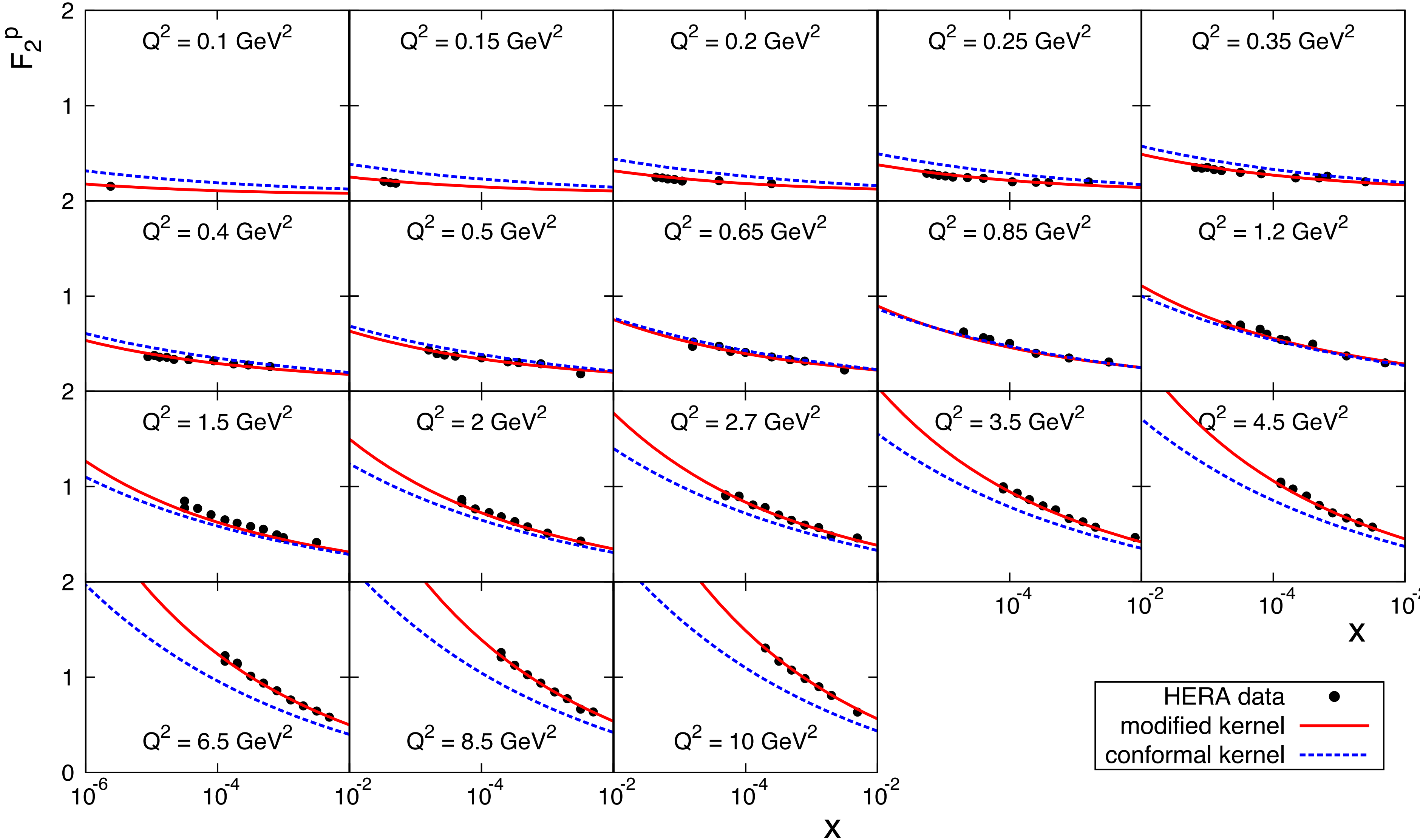
$$\eta = \left(-\log\frac{zz'}{z_0^2} + \rho\tau\right) / \sqrt{\rho\tau}$$

energy dependence — magnitude — strength of confinement effect

3 adjustable parameters : ρ, g_0^2, z_0

Proton structure function

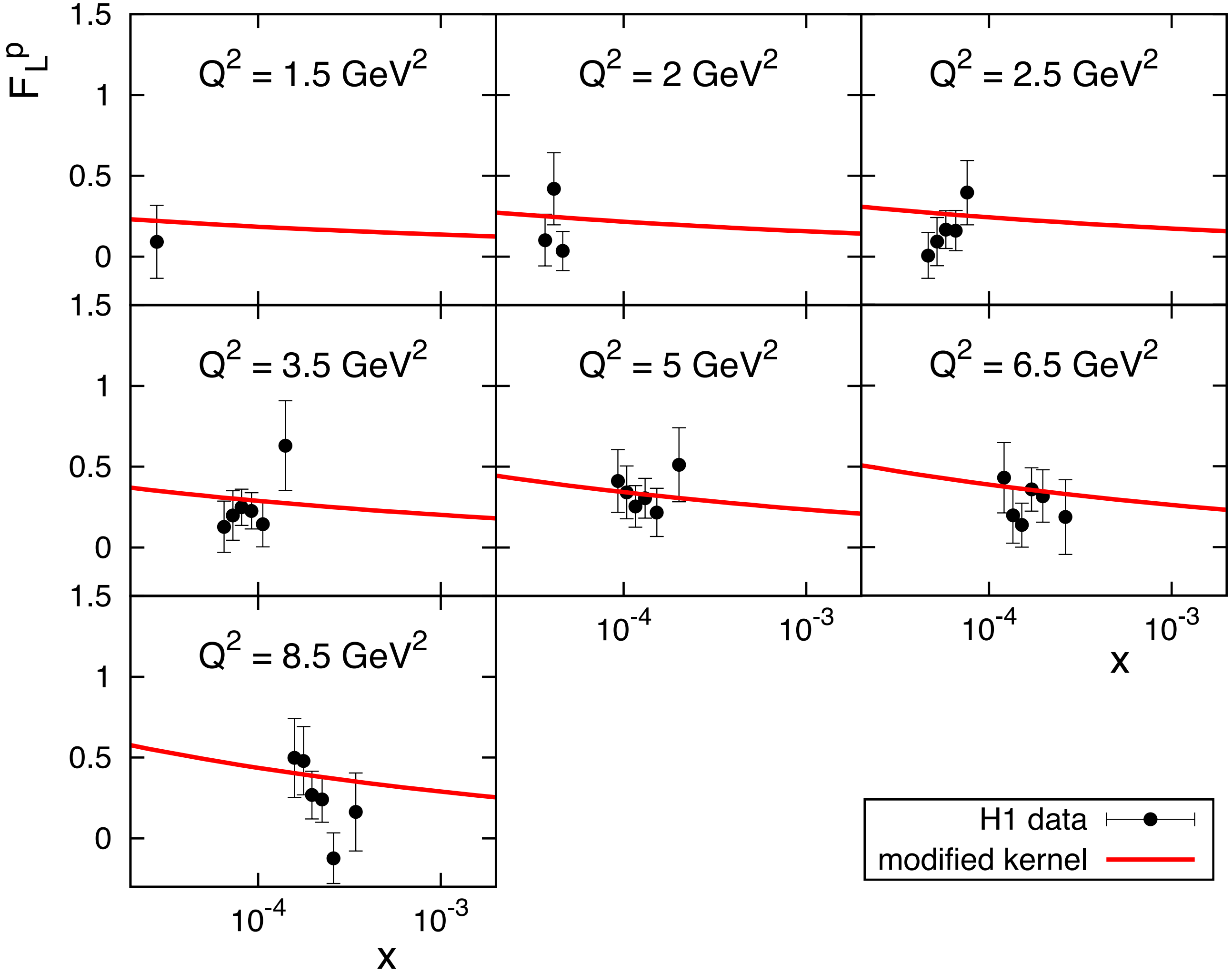
AW-Suzuki (2014)



Proton longitudinal structure function

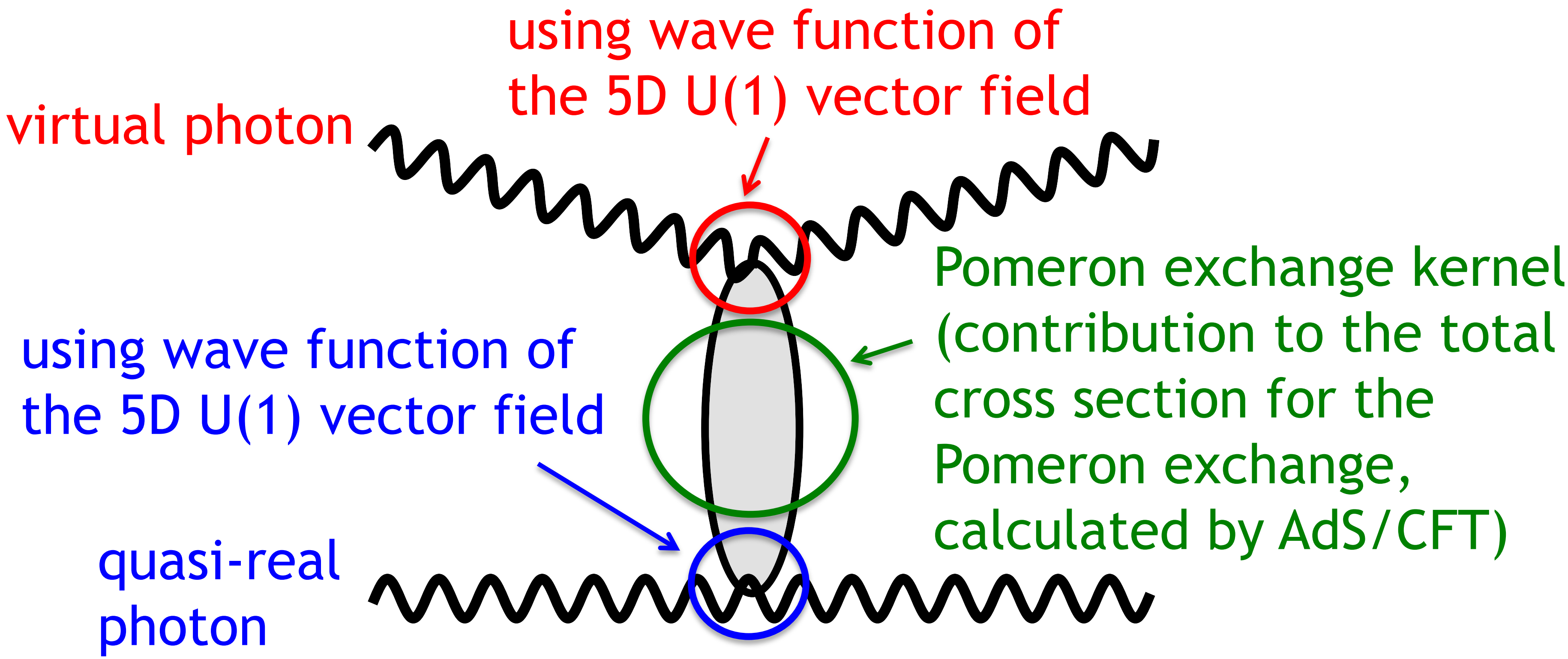
- Replacing the density distribution of the probe photon with its longitudinal component

AW-Suzuki (2014)



Virtual photon – quasi-real photon scattering

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

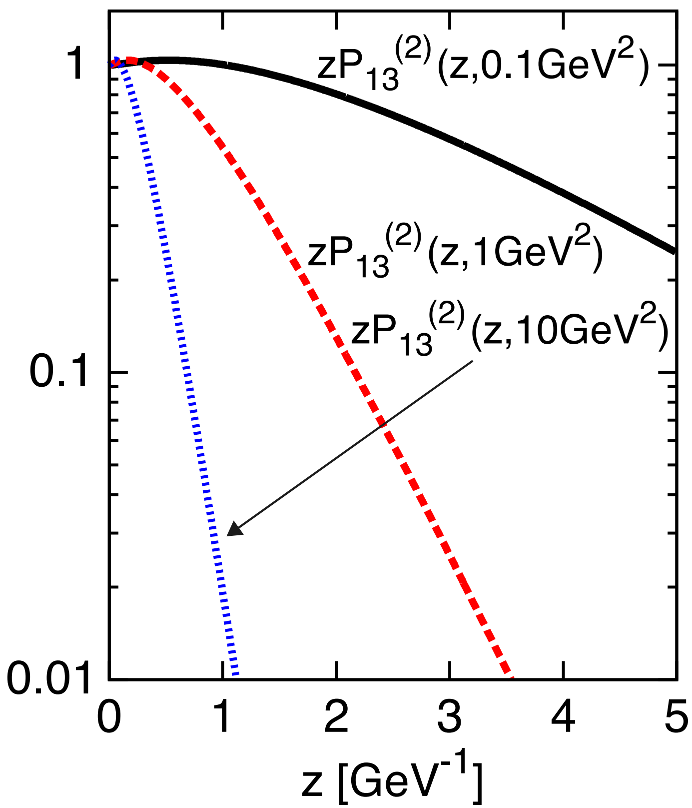


We reuse the parameter ρ which has been determined in the analysis on the nucleon F_2 structure function.

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 determine 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)

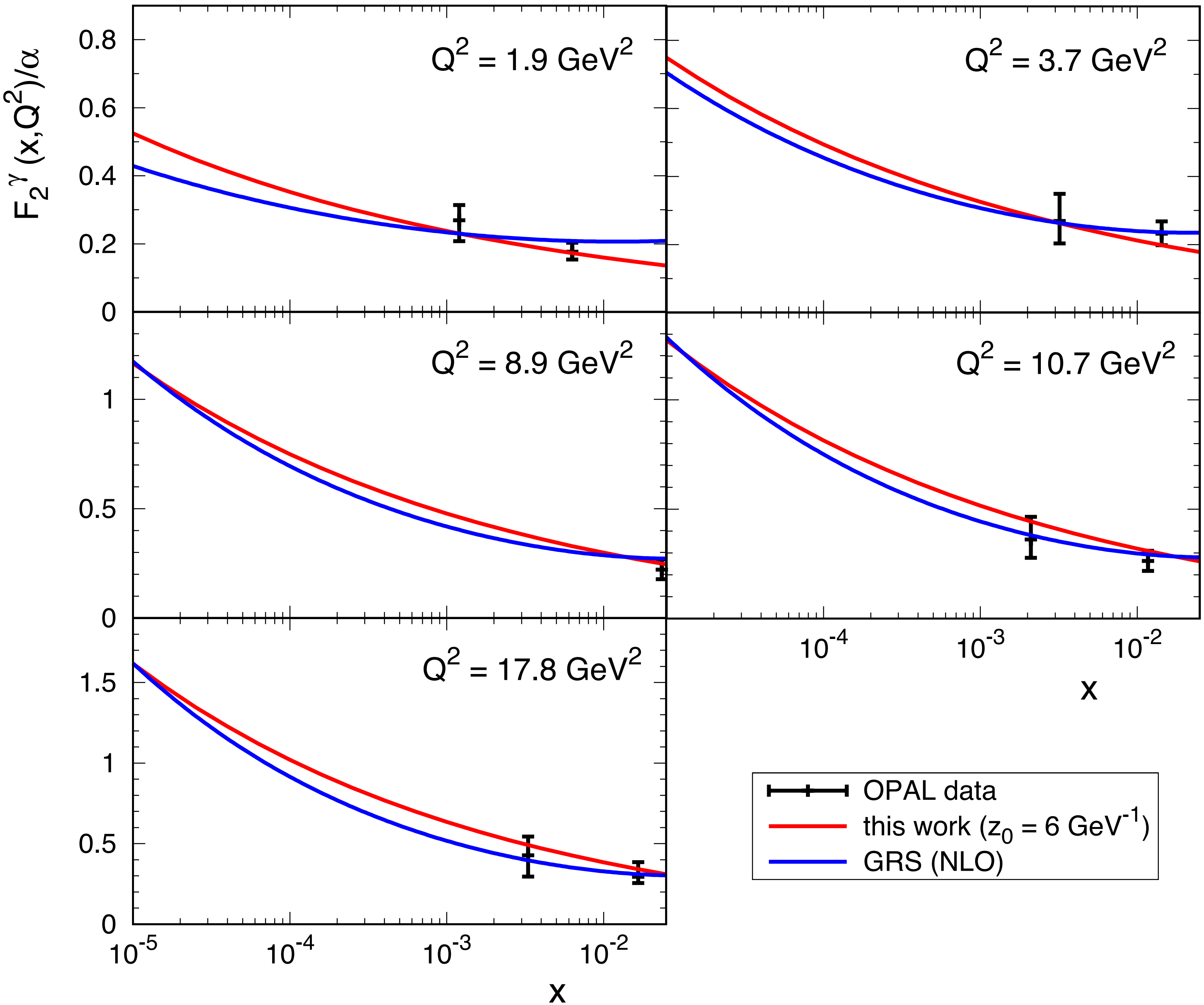
Glück-Reya-Schienbein (1999)

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

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

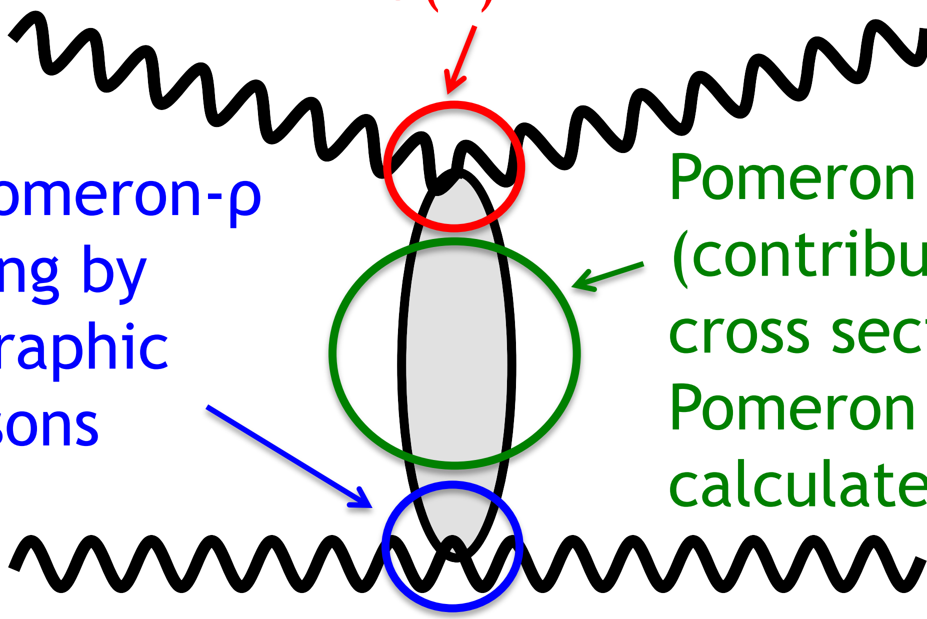
pointlike component

hadronic component from PDFs of a pion


$F_2^\gamma(x,Q^2)/\alpha$
$Q^2 = 1.9\ GeV^2$
$Q^2 = 3.7\ GeV^2$
$Q^2 = 8.9\ GeV^2$
$Q^2 = 10.7\ GeV^2$
$Q^2 = 17.8\ GeV^2$
0.8
0.6
0.4
0.2
0
1
0.5
1.5
10^{-5}
10^{-4}
10^{-3}
10^{-2}
x
OPAL data
this work (z_0 = 6 GeV^{-1})
GRS (NLO)

Virtual photon – ρ meson scattering

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



We reuse the parameter ρ which has been determined in the analysis on the nucleon F_2 structure function.

A holographic model of mesons

Erlich-Katz-Son-Stephanov (2005)

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

5D coupling

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

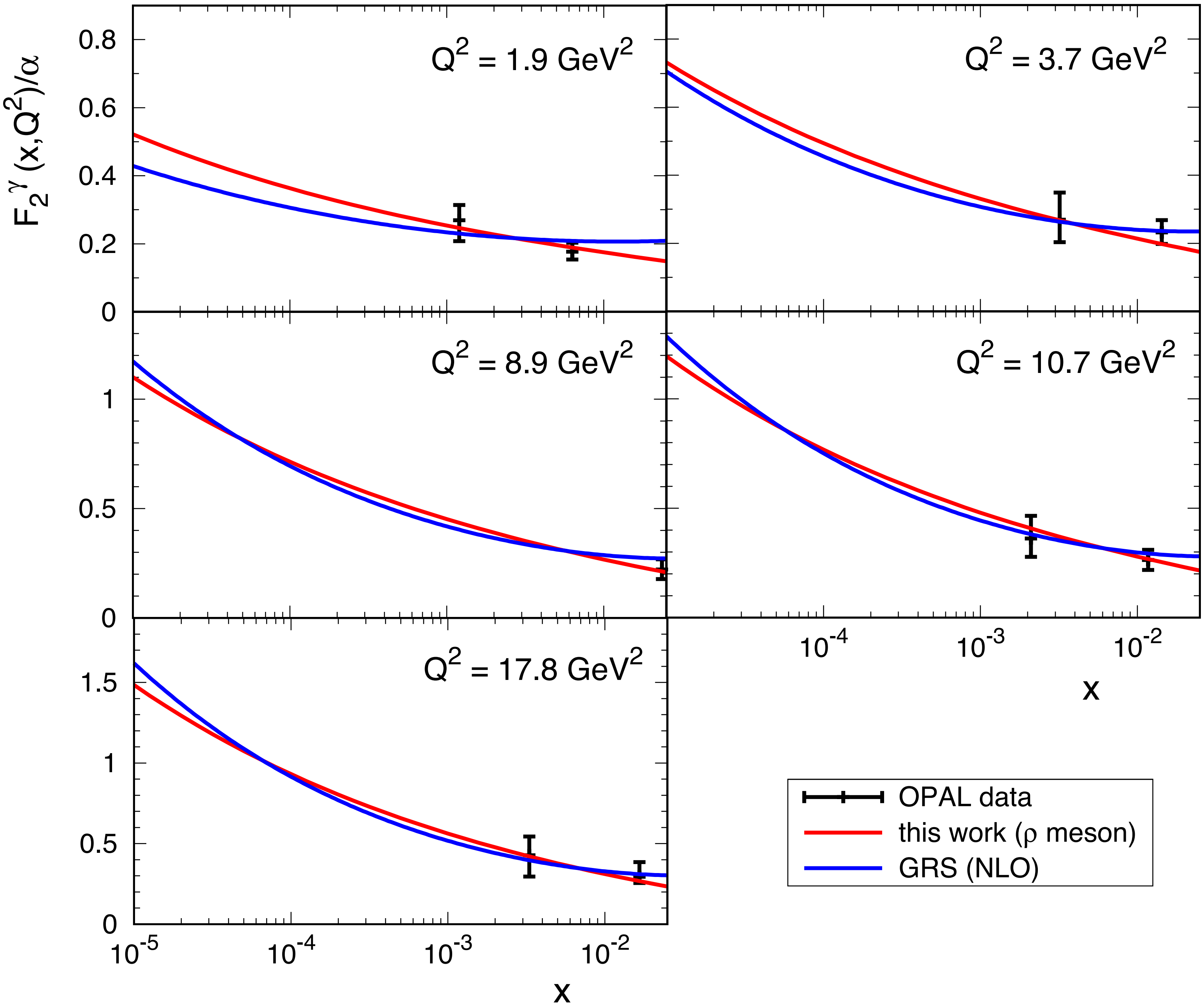
vector

axial vector

chiral symmetry breaking
(explicit and spontaneous)

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

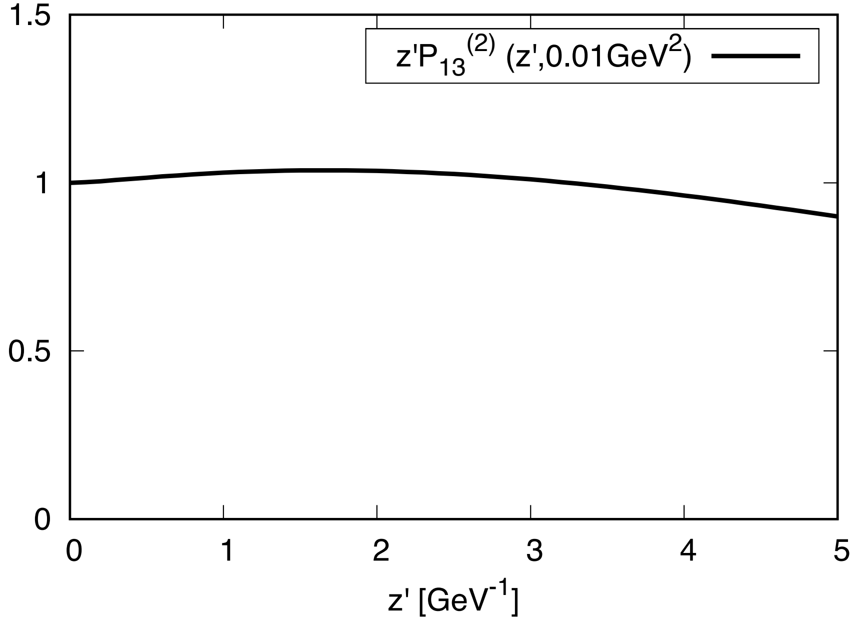
$V_z = A_z = 0$



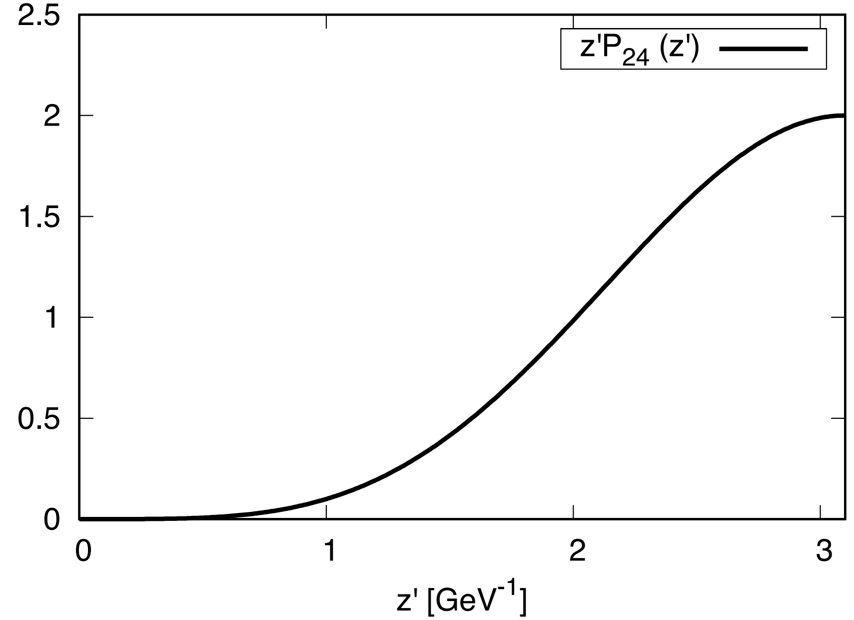
$F_2^\gamma(x,Q^2)/\alpha$
Q^2 = 1.9 GeV^2
Q^2 = 3.7 GeV^2
Q^2 = 8.9 GeV^2
Q^2 = 10.7 GeV^2
Q^2 = 17.8 GeV^2
0.8
0.6
0.4
0.2
0
1
0.5
1.5
10^{-5}
10^{-4}
10^{-3}
10^{-2}
x
OPAL data
this work (ρ meson)
GRS (NLO)

Density distributions of quasi-real photon and ρ meson

quasi-real photon



ρ meson



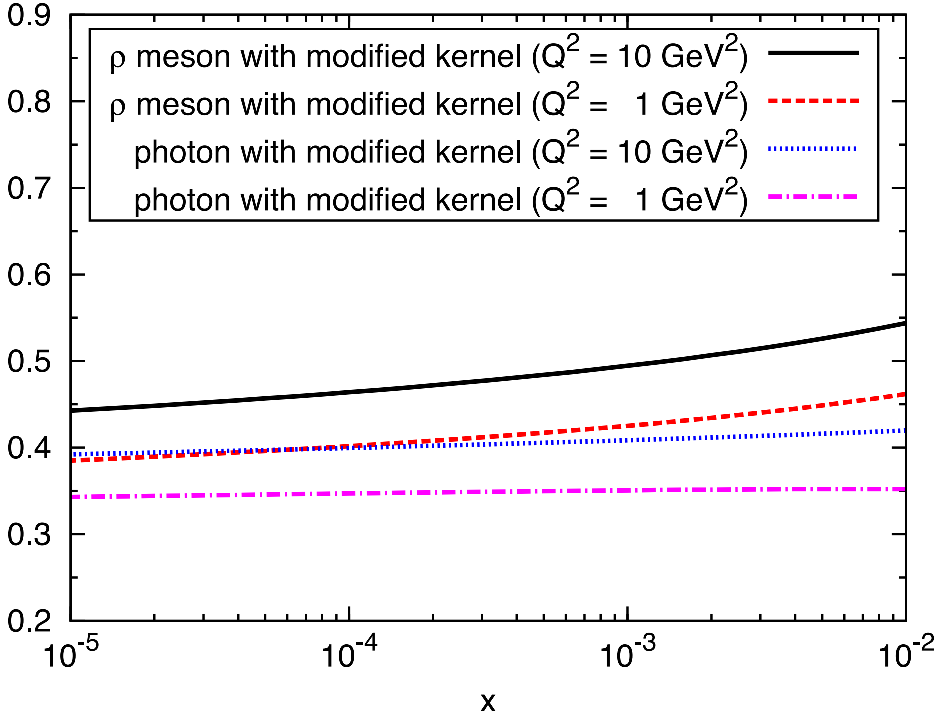
Both distributions are totally different from each other, but obtained contributions after integration over z(z') are similar.

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

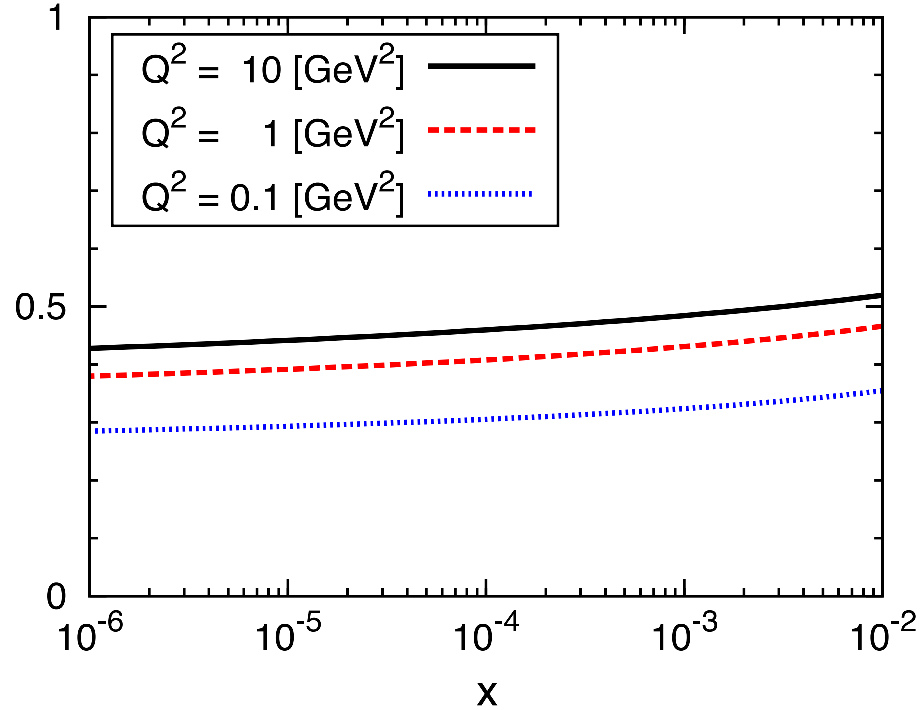
Longitudinal-to-transverse ratio $R = F_L/F_T$

AW-Suzuki (2014)

Photon



Nucleon

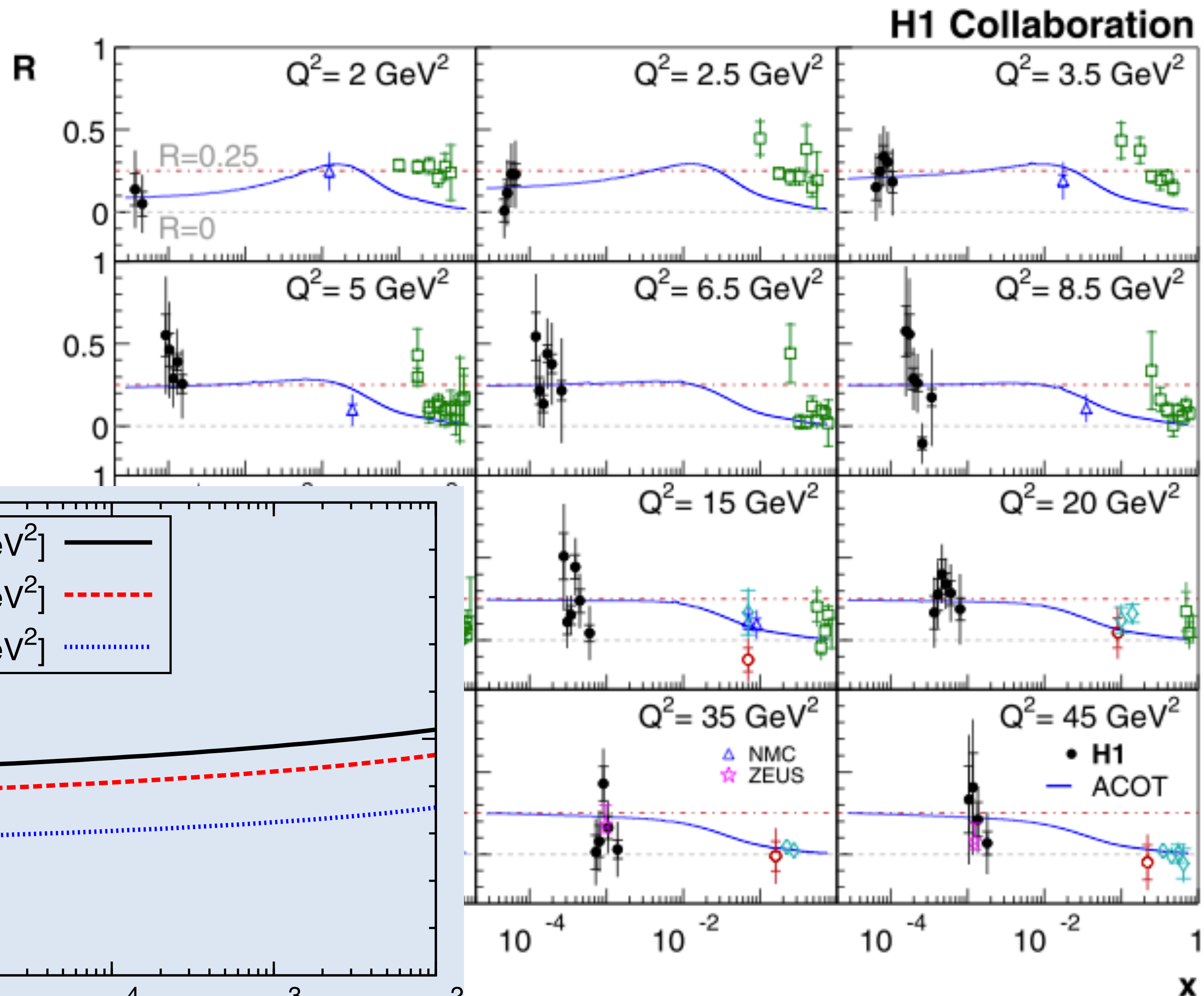


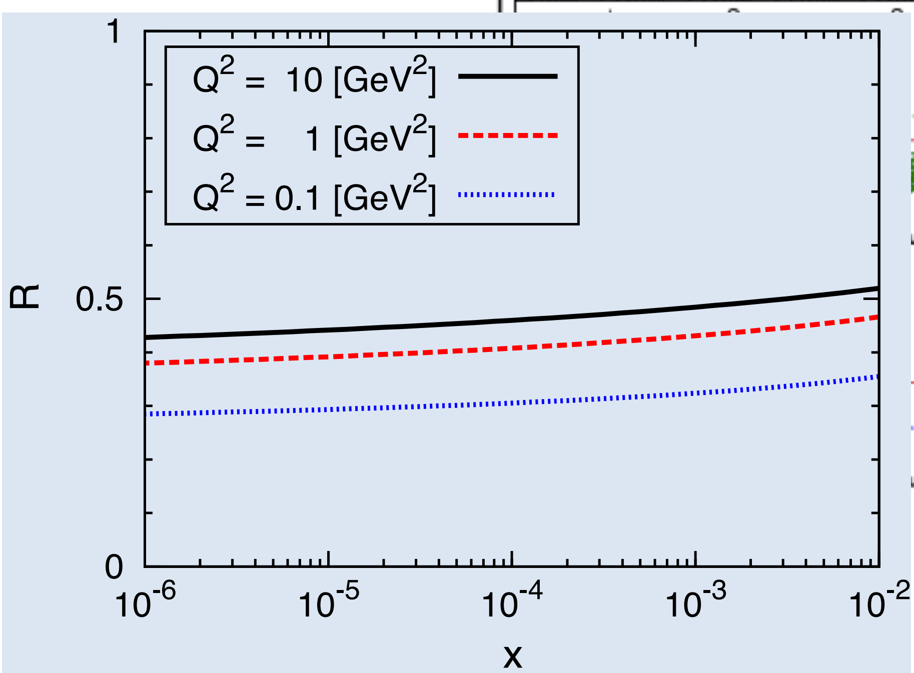
The longitudinal structure function is not negligible in this kinematic region.

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*





Summary

- We have studied the photon structure functions at small x in the framework of holographic QCD.
- 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.