Parton Distributions from Proton to nuclei

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The Fifth Workshop on Hadron Physics in China and Opportunities in US, 2013

Outline

- Parton distributions and QCD evolution equations;
- A new approach to parton distributions in the proton and nuclei;
- Quark saturation in low Q^2 range.

Parton distributions and QCD evolution equations

- Quark and gluon distributions are important knowledge of nucleon and nuclei.
- Worldwide proposing EIC will complete our knowledge of sea quark, gluon and nuclear media modification.

MEIC, eRHIC, EIC@HIAF…

Parton distributions and QCD evolution equations

* "QCD is successful and we believe QCD"

QCD evolution equations

DGLAP $x > 10^{-3}$, $Q^2 > 1 \sim 4$ GeV^2

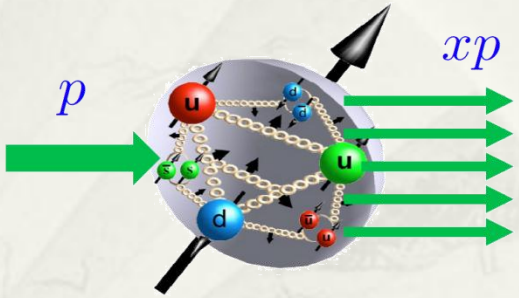
GLR-MQ $x <\sim 10^{-2}$

BFKL $x <\sim 10^{-4}$

BK $x <\sim 10^{-4}$

JIMWLK $x <\sim 10^{-4}$, $Q^2 > 1$ GeV^2

ZSR **$x > 10^{-4}$, $Q^2 > 0.06$ GeV^2**



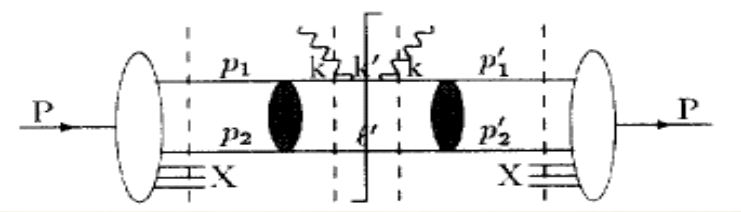
Parton distributions and QCD evolution equations

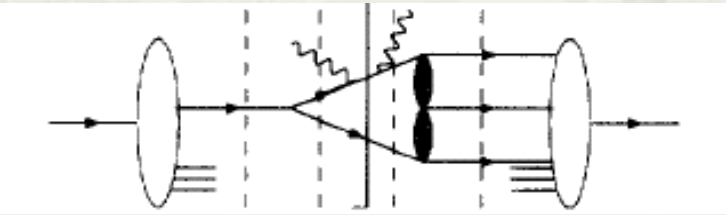
GLR-MQ-ZSR: DGLAP + Leading high twist corrections

W. Zhu, Nucl. Phys. B551, 245 (1999);

W. Zhu and J.H.Ruan, Nucl. Phys. B559, 378 (1999);

W. Zhu, Z.Q. Shen and J.H. Ruan, Nucl. Phys. B692 ,417.(2004)





GLR-MQ-ZSR

For valence quark $Q^2\frac{dx f_{v_j}(x,Q^2)}{dQ^2}$

$$= \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y} P_{qq}(z) x f_{v_j}(y,Q^2)$$

$$-\frac{\alpha_s(Q^2)}{2\pi} x f_{v_j}(x,Q^2)\int_0^1 dz P_{qq}(z)$$

$$-\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_x^{1/2}\frac{dy}{y} x P_{qg\to qg}(z)[y f_g(y,Q^2) y f_{v_j}(y,Q^2)]$$

$$+\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_{x/2}^{x}\frac{dy}{y} x P_{qg\to qg}(z)[y f_g(y,Q^2) y f_{v_j}(y,Q^2)]$$

$$-\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_x^{1/2}\frac{dy}{y} x P_{qq\to qq}(z)[y \Sigma_{sea}(y,Q^2) y f_{v_j}(y,Q^2)]$$

$$+\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_{x/2}^{x}\frac{dy}{y} x P_{qq\to qq}(z)[y \Sigma_{sea}(y,Q^2) y f_{v_j}(y,Q^2)],$$

GLR-MQ-ZSR

$$
\begin{aligned}
&Q^2\frac{dx f_{\overline{q}_i}(x,Q^2)}{dQ^2} \\
&= \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y} P_{qq}(z) x f_{\overline{q}_i}(y,Q^2) \\
&-\frac{\alpha_s(Q^2)}{2\pi} x f_{\overline{q}_i}(x,Q^2)\int_0^1 dz P_{qq}(z) \\
&+\frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dy}{y} P_{qg}(z) x f_g(y,Q^2) \\
&-\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_x^{1/2}\frac{dy}{y} x P_{gg\to q\overline{q}}(z)[y f_g(y,Q^2)]^2 \\
&+\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_{x/2}^{x}\frac{dy}{y} x P_{gg\to q\overline{q}}(z)[y f_g(y,Q^2)]^2 \\
&-\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_x^{1/2}\frac{dy}{y} x P_{q\overline{q}\to q\overline{q}}(z) y f_{q_i}(x,Q^2) y f_{\overline{q}_i}(y,Q^2) \\
&+\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_{x/2}^{x}\frac{dy}{y} x P_{q\overline{q}\to q\overline{q}}(z) y f_{q_i}(x,Q^2) y f_{\overline{q}_i}(y,Q^2) \\
&-\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_x^{1/2}\frac{dy}{y} x P_{qq\to qq}(z) y[\Sigma(x,Q^2)-f_{q_i}(x,Q^2)] y f_{\overline{q}_i}(y,Q^2) \\
&+\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_{x/2}^{x}\frac{dy}{y} x P_{qq\to qq}(z) y[\Sigma(x,Q^2)-f_{q_i}(x,Q^2)] y f_{\overline{q}_i}(y,Q^2) \\
&-\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_x^{1/2}\frac{dy}{y} x P_{qg\to qg}(z)[y f_g(y,Q^2) y f_{\overline{q}_i(}y,Q^2)] \\
&+\frac{\alpha_s^2(Q^2)}{4\pi R^2 Q^2}\int_{x/2}^{x}\frac{dy}{y} x P_{qg\to qg}(z)[y f_g(y,Q^2) y f_{\overline{q}_i}(y,Q^2)],
\end{aligned}
$$

For sea quark

GLR-MQ-ZSR

$$
\begin{aligned}
&Q^2\frac{dxf_g(x,Q^2)}{dQ^2}\\
&=\frac{\alpha_s(Q^2)}{2\pi}\int_x^1\frac{dy}{y}P_{gq}(z)x\Sigma(y,Q^2)\\
&+\frac{\alpha_s(Q^2)}{2\pi}\int_x^1\frac{dy}{y}P_{gg}(z)xf_g(y,Q^2)\\
&-f\frac{\alpha_s(Q^2)}{2\pi}xf_g(x,Q^2)\int_0^1 dzP_{qg}(z)\\
&-\frac{1}{2}\frac{\alpha_s(Q^2)}{2\pi}xf_g(x,Q^2)\int_0^1 dzP_{gg}(z)\\
&-\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_x^{1/2}\frac{dy}{y}xP_{gg\to gg}(z)[yf_g(y,Q^2)]^2\\
&+\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_{x/2}^{x}\frac{dy}{y}xP_{gg\to gg}(z)[yf_g(y,Q^2)]^2
\end{aligned}
$$

$$
\begin{aligned}
&-\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_x^{1/2}\frac{dy}{y}xP_{q\overline{q}\to gg}(z)\sum_{i=1}^{f}[yf_{\overline{q}_i}(y,Q^2)]^2\\
&+\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_{x/2}^{x}\frac{dy}{y}xP_{q\overline{q}\to gg}(z)\sum_{i=1}^{f}[yf_{\overline{q}_i}(y,Q^2)]^2\\
&-\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_x^{1/2}\frac{dy}{y}xP_{qg\to qg}(z)[y\Sigma(y,Q^2)yf_g(y,Q^2)]\\
&+\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_{x/2}^{x}\frac{dy}{y}xP_{qg\to qg}(z)[y\Sigma(y,Q^2)yf_g(y,Q^2)],
\end{aligned}
$$

For gluon

Parton distributions in the proton

Proton(global analysis)

GRV 23 parameters+DGLAP

CTEQ 36 parameters+DGLAP

nuclei HKM +16 parameters

EPS +24 parameters

A large uncretainty (>100%) in nuclear gluon density. We need to pin it down.

Parton distributions in the proton

* GLR-MQ-ZSR + natural input

We have only 4 free parameters to give PDF predictions.

And first realize three valence quark input as the non-perturbative input.

Parton distributions in the proton

Natural input:
$\mu^2 = 0.064\ \mathrm{GeV}^2$

$$x f_{v_u}(x,\mu^2) = A_u x^{B_u}(1-x)^{C_u},$$

$$x f_{v_d}(x,\mu^2) = A_d x^{B_d}(1-x)^{C_d},$$

$$f_g(x,\mu^2) = 0, \quad f_{q_i}(x,\mu^2) = f_{\overline{q}_i}(x,\mu^2) = 0.$$

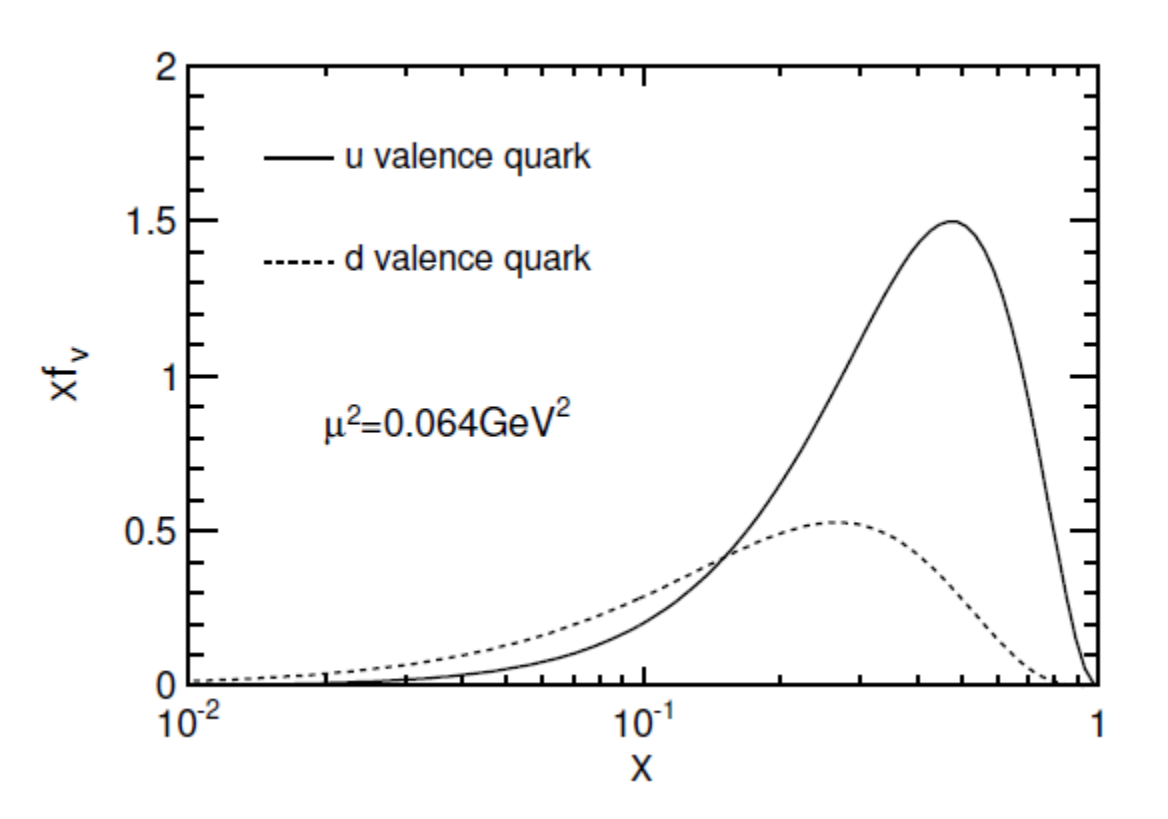
$$\int_0^1 dx x[f_{v_u}(x,\mu^2) + f_{v_d}(x,\mu^2)] = 1.$$

$$\int_0^1 dx f_{v_u}(x,\mu^2) = 2, \quad \int_0^1 dx f_{v_d}(x,\mu^2) = 1.$$

Another free parameter
in GLR-MQ-ZSR equation.

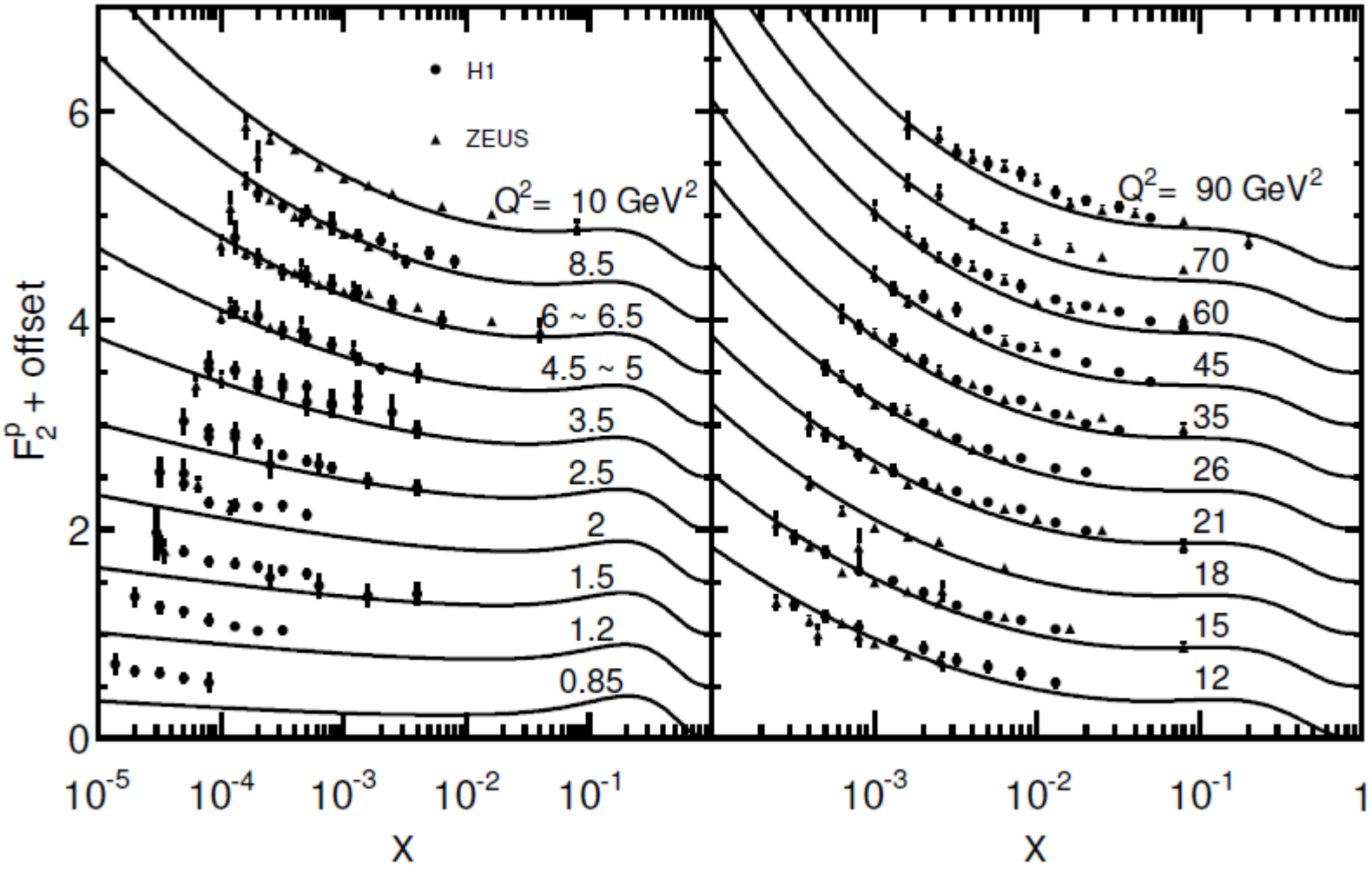
$$R = 4.17\ \mathrm{GeV}^{-1}$$

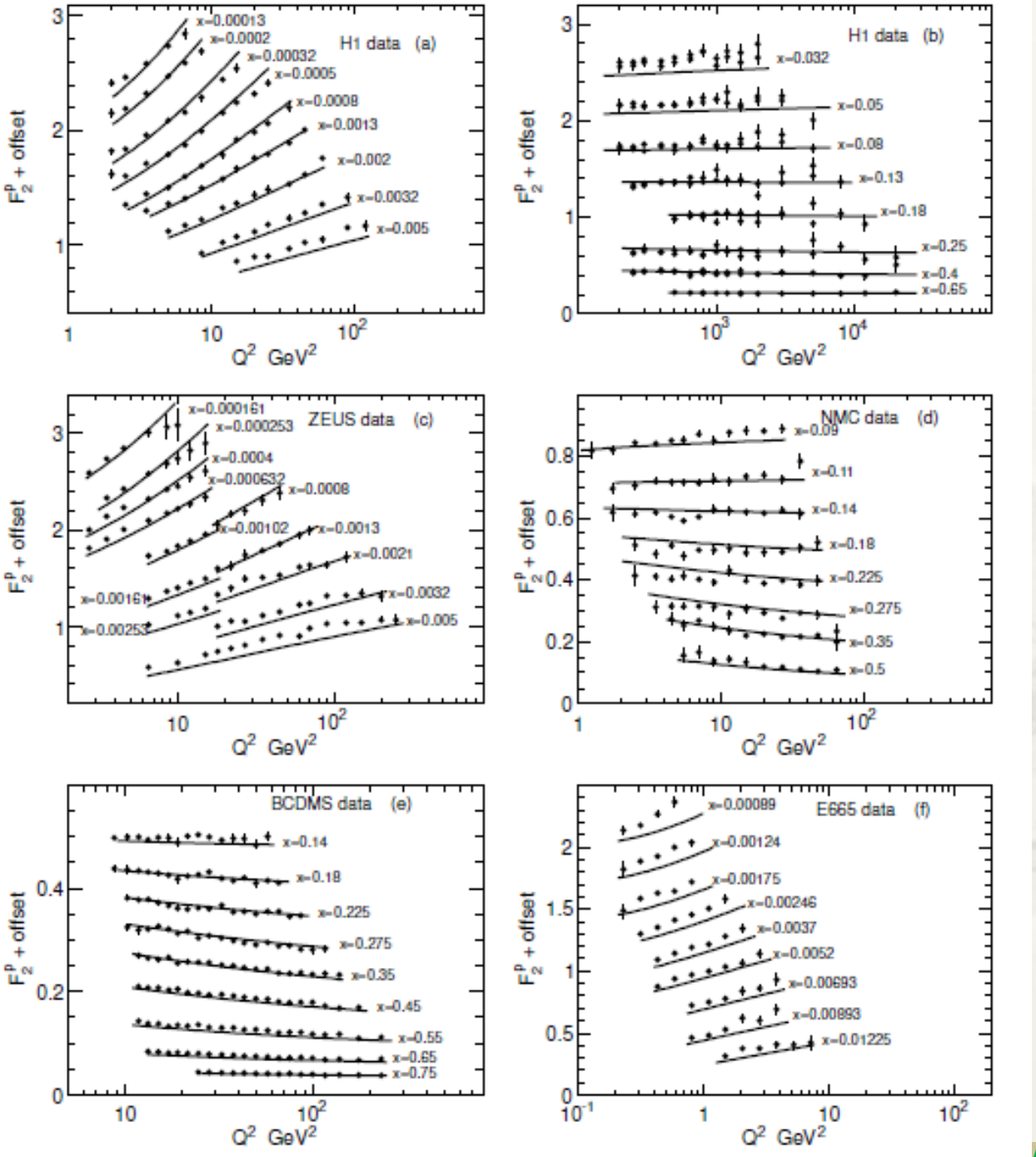
Parton distributions in the proton



The initial input for GLR-MQ-ZSR evolution.

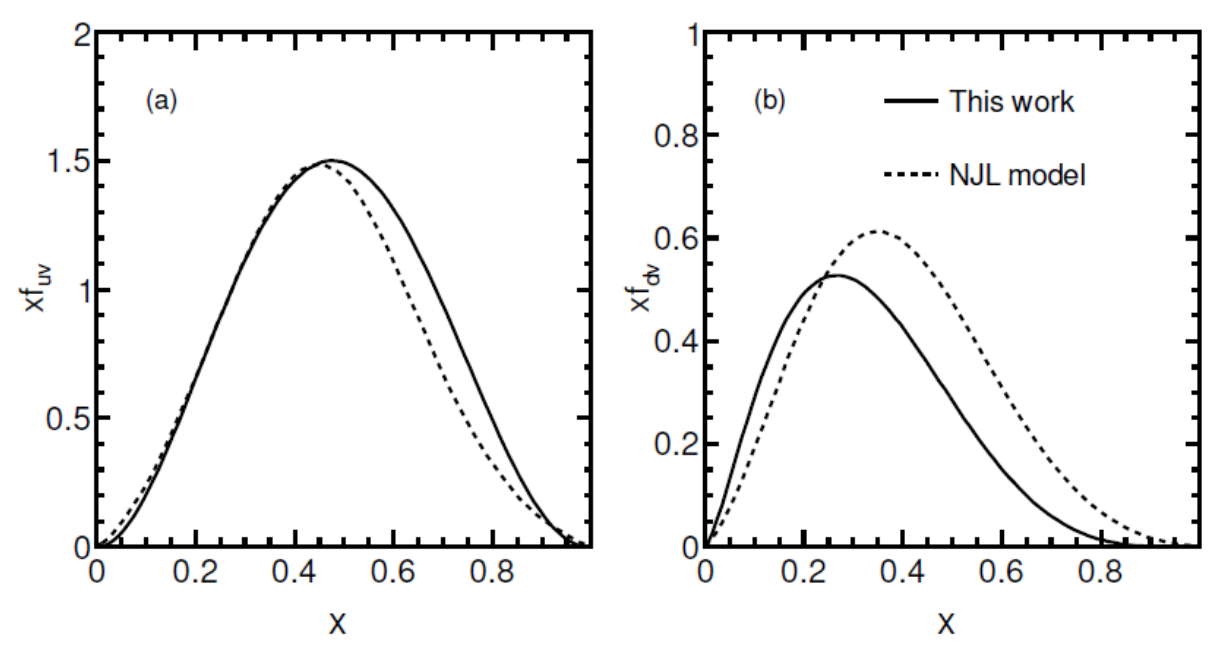
Parton distributions in the proton




H1 data (a)
x=0.00013
x=0.0002
x=0.00032
x=0.0005
x=0.0008
x=0.0013
x=0.002
x=0.0032
x=0.005
F_2^p + offset
Q^2 GeV^2
H1 data (b)
x=0.032
x=0.05
x=0.08
x=0.13
x=0.18
x=0.25
x=0.4
x=0.65
F_2^p + offset
Q^2 GeV^2
ZEUS data (c)
x=0.000161
x=0.000253
x=0.0004
x=0.000632
x=0.0008
x=0.00102
x=0.0013
x=0.0021
x=0.0032
x=0.005
F_2^p + offset
Q^2 GeV^2
NMC data (d)
x=0.09
x=0.11
x=0.14
x=0.18
x=0.225
x=0.275
x=0.35
x=0.5
F_2^p + offset
Q^2 GeV^2
BCDMS data (e)
x=0.14
x=0.18
x=0.225
x=0.275
x=0.35
x=0.45
x=0.55
x=0.65
x=0.75
F_2^p + offset
Q^2 GeV^2
E665 data (f)
x=0.00089
x=0.00124
x=0.00175
x=0.00246
x=0.0037
x=0.0052
x=0.00693
x=0.00893
x=0.01225
F_2^p + offset
Q^2 GeV^2

Parton distributions in the proton

- GLR-MQ-ZSR offers a bridge to connect quark models of hadron and various non-perturbative effects on them with measured structure functions at high scale Q^2.



Parton distributions in the nuclei

* Add 2 free parameters for nuclear media effect. Fermi motion is considered.

Shadowing enhancement

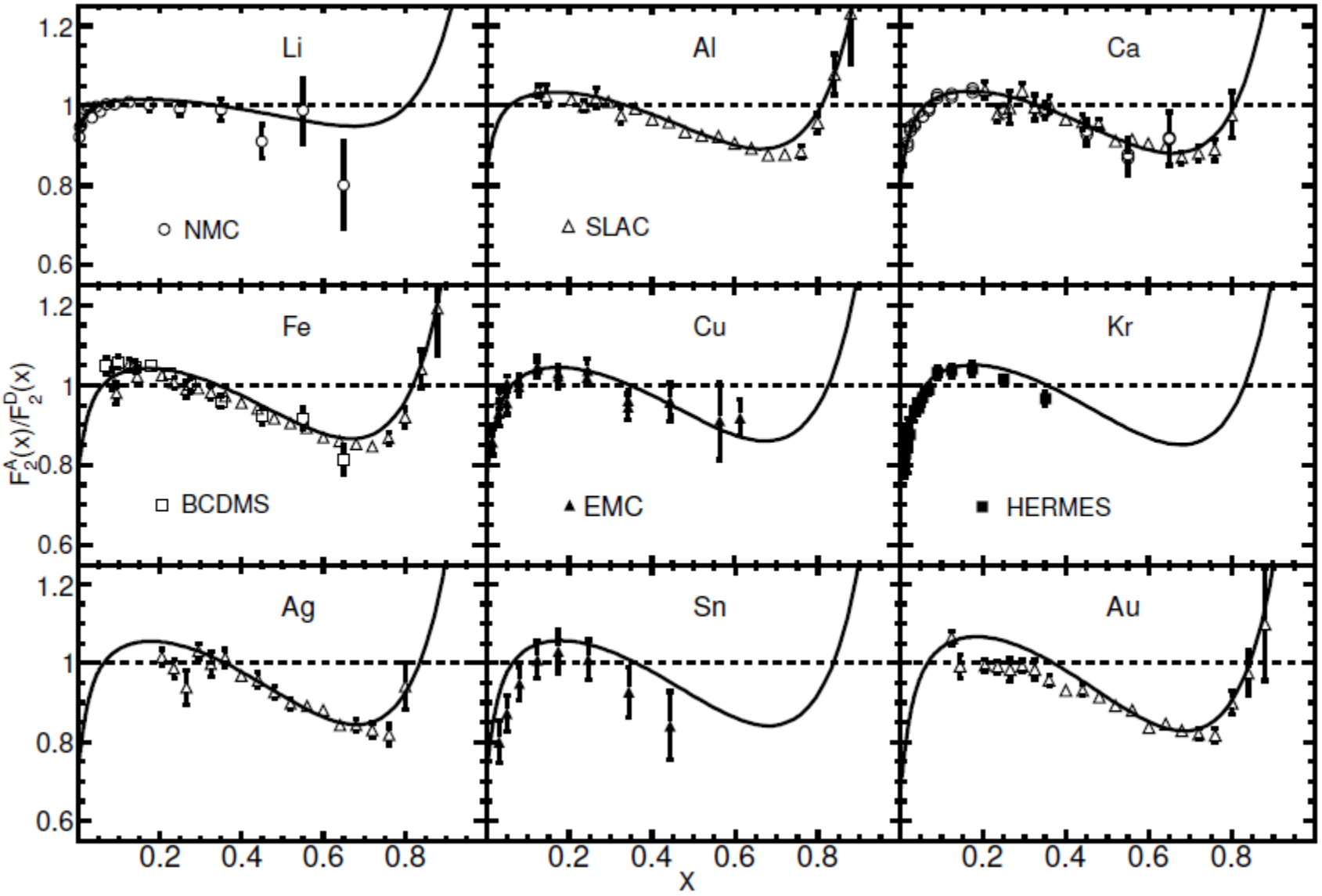
$$A_{eff} = 1 + \beta(A^{1/3} - 1)$$

Nucleon swelling

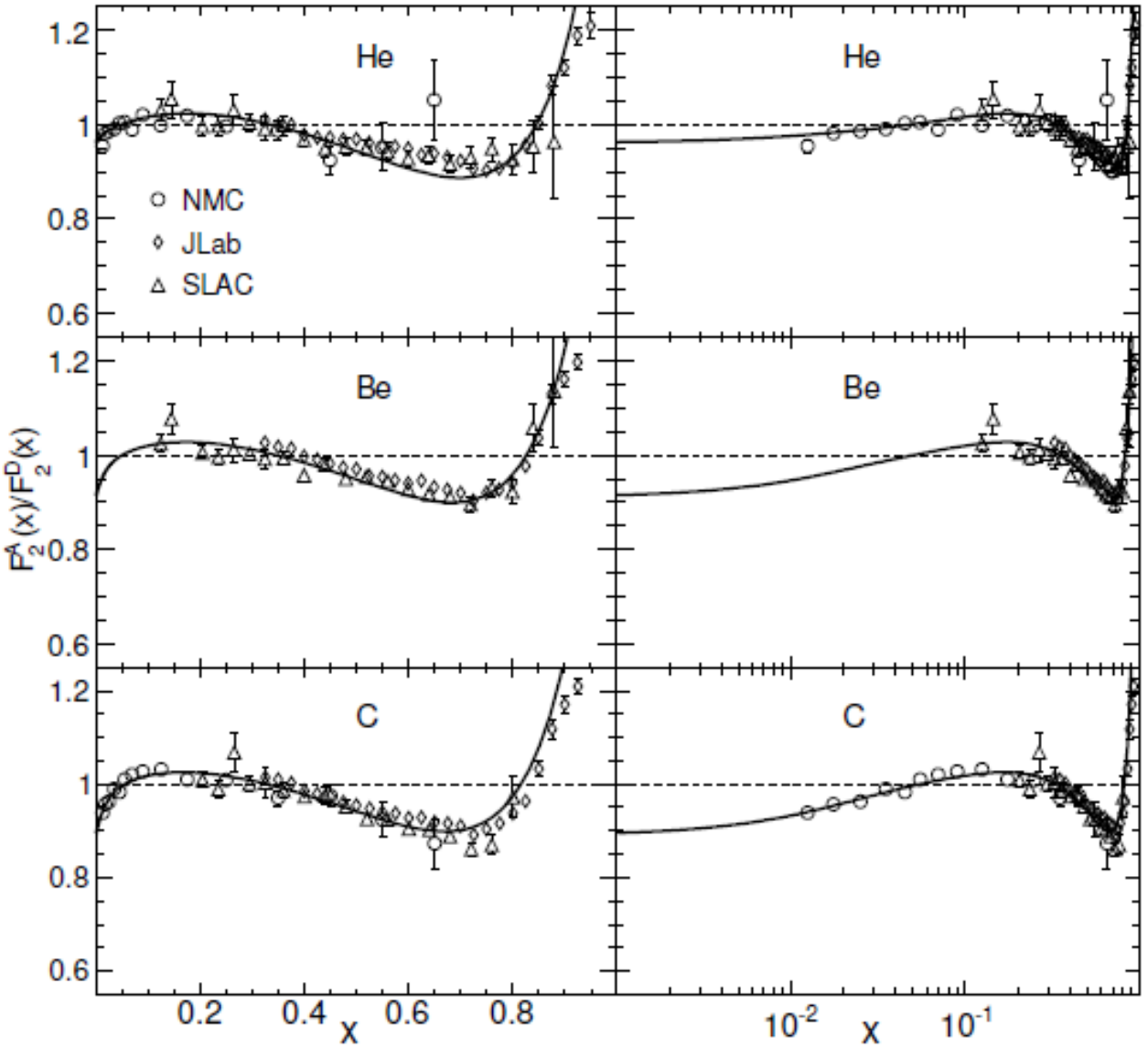
$$R_p/R_A \equiv \frac{1}{1+\delta_A}$$

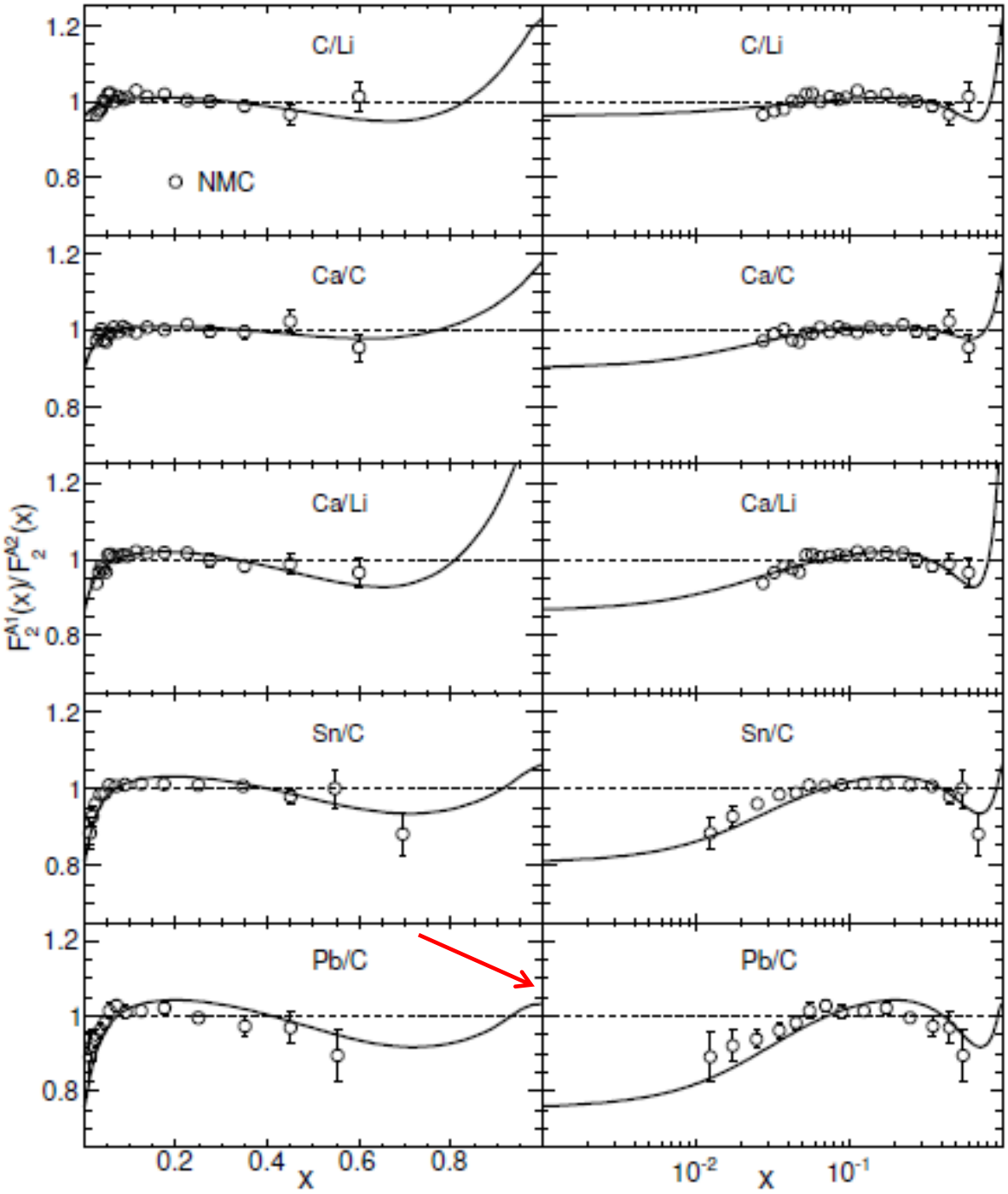
$$\delta_A = [1 - P_s(A)]\delta_0 + P_s(A)\delta_0/4$$

Parton distributions in the nuclei



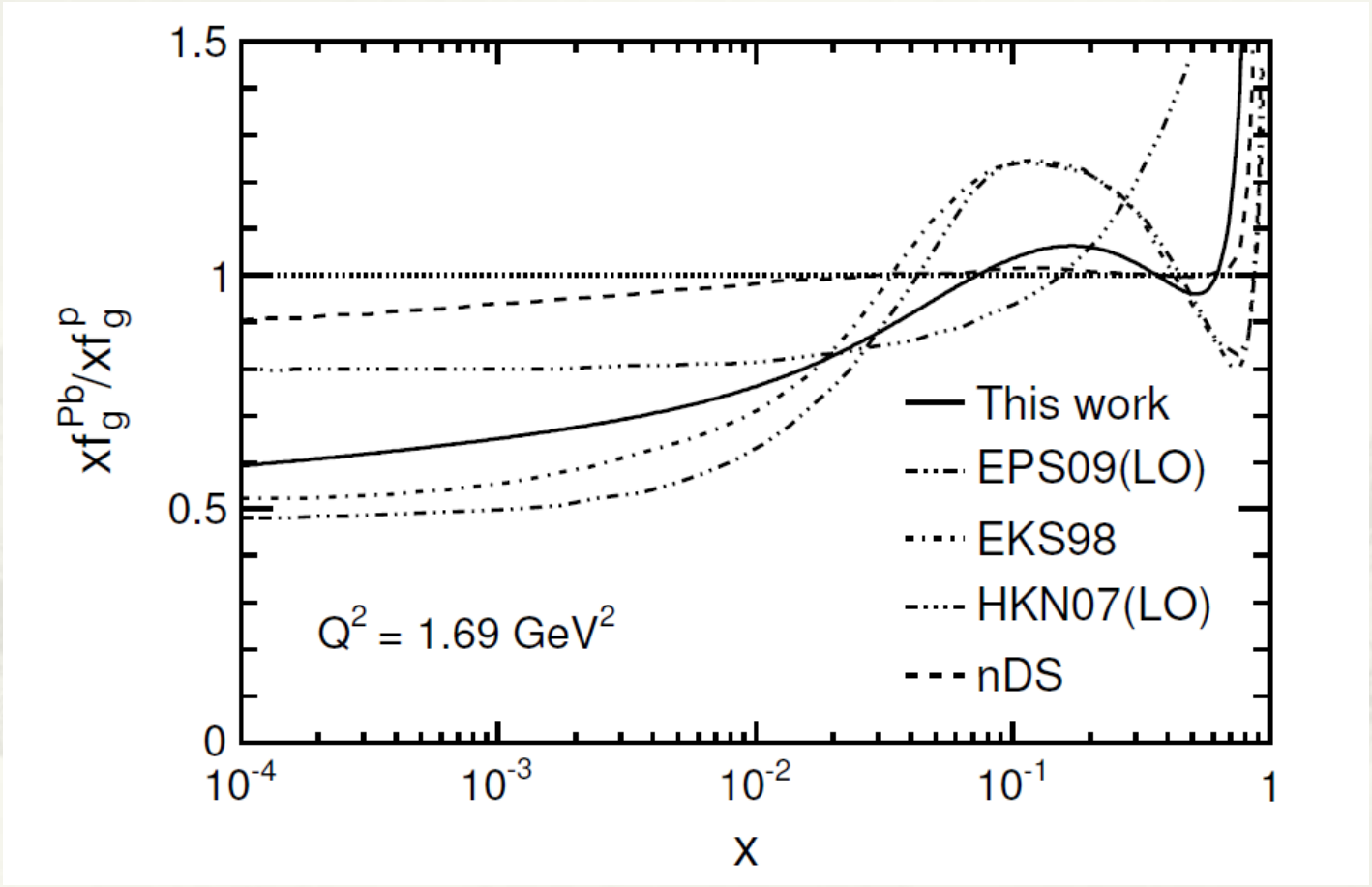
Parton distributions in the nuclei





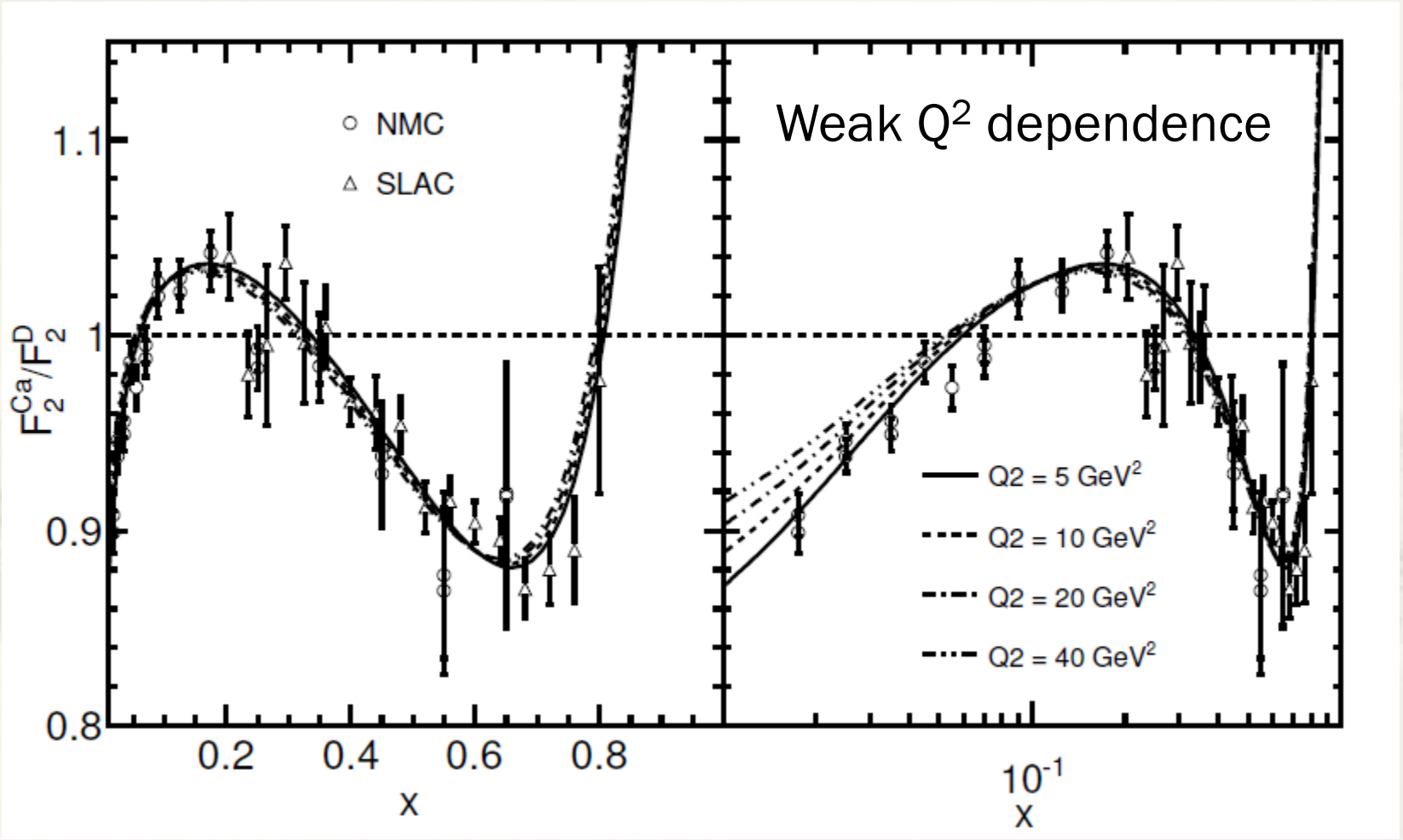
Weak short range correlation caused by fermi motion.

Parton distributions in the nuclei



The gluon is dynamically determined. The uncertainty is small.

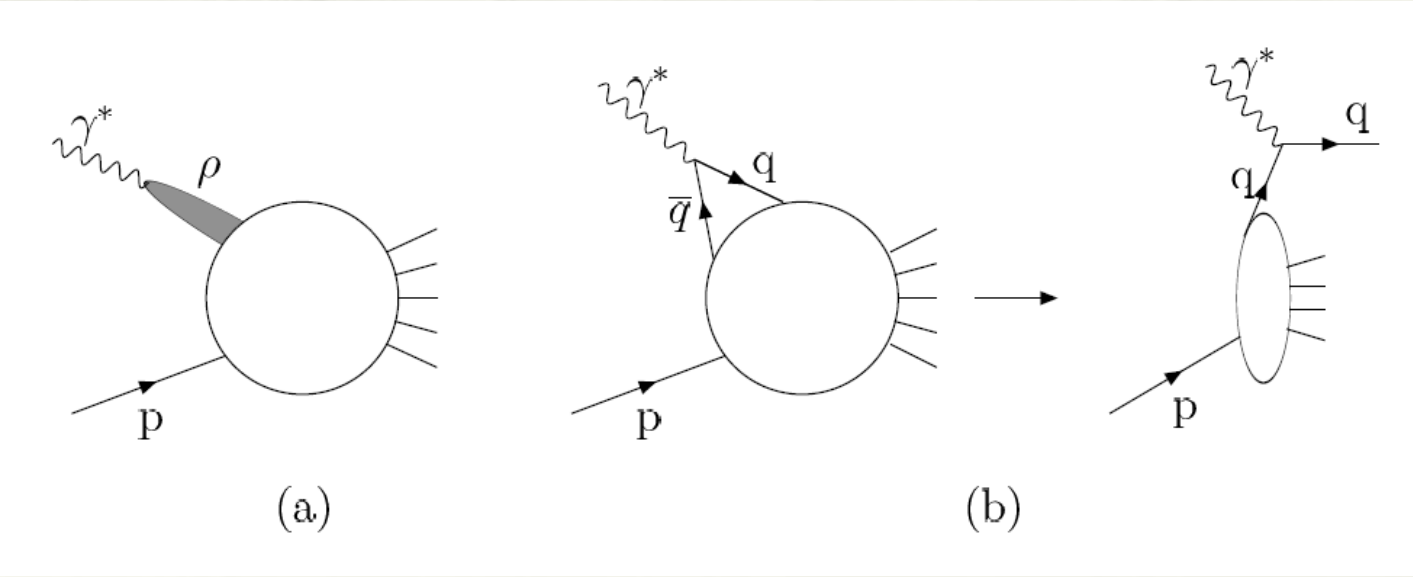
Parton distributions in the nuclei

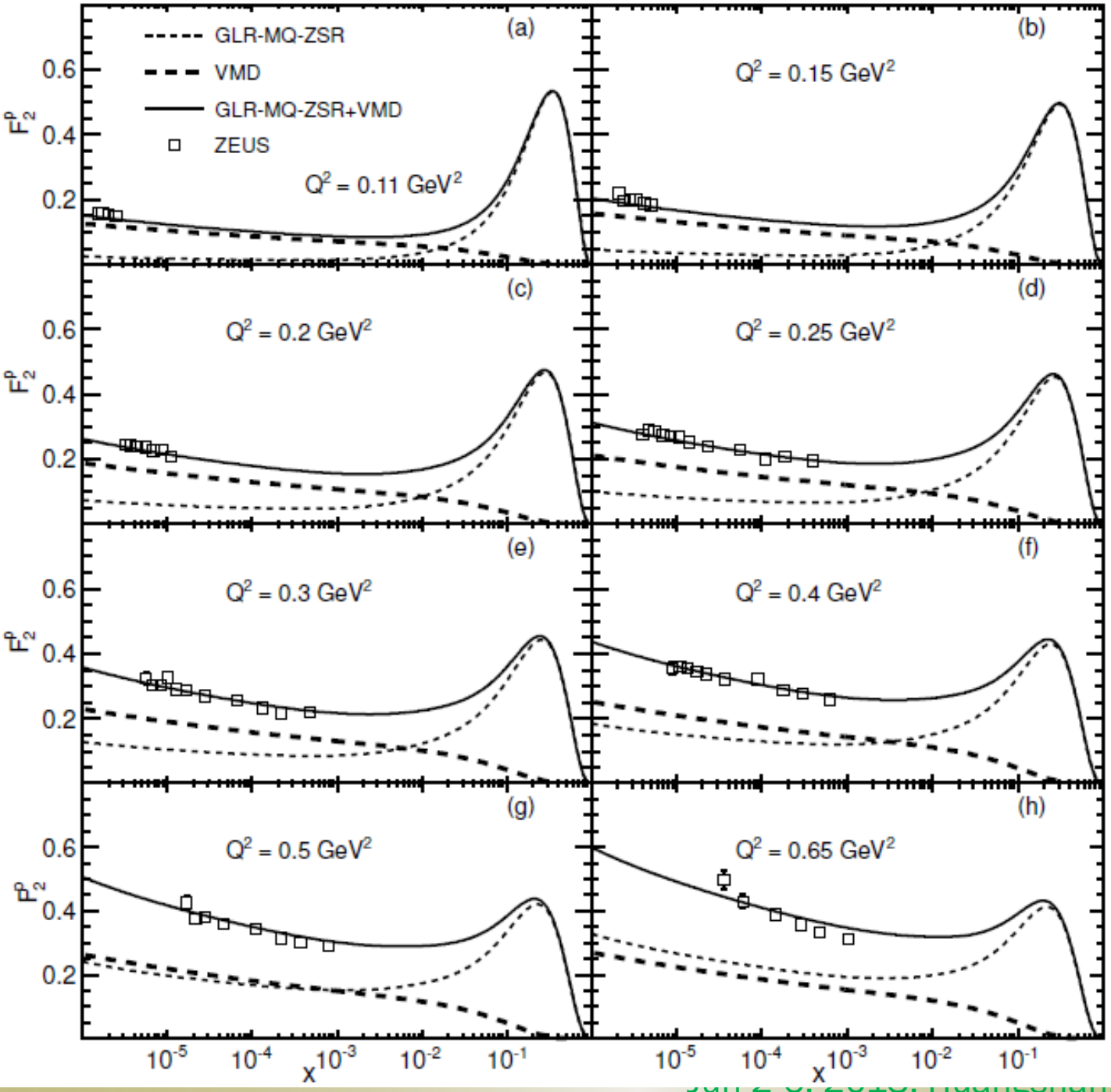


Quark saturation in low Q^2 range

* Add 1 parameter for hadron part in low Q^2 range.

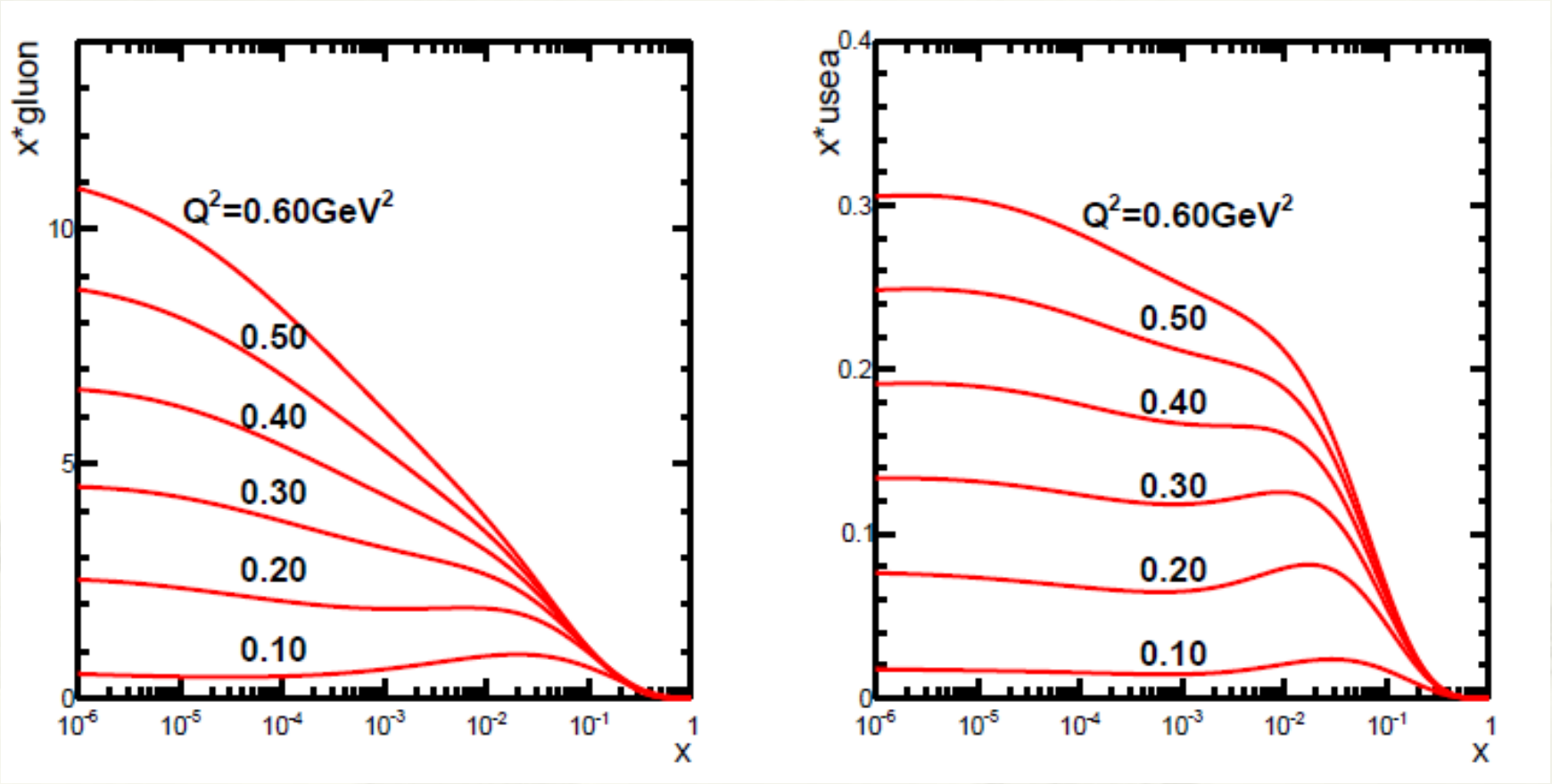
$$F_2^p(x,Q^2) = F_2^{parton}(x,Q^2) + F_2^{hadron}(x,Q^2)$$





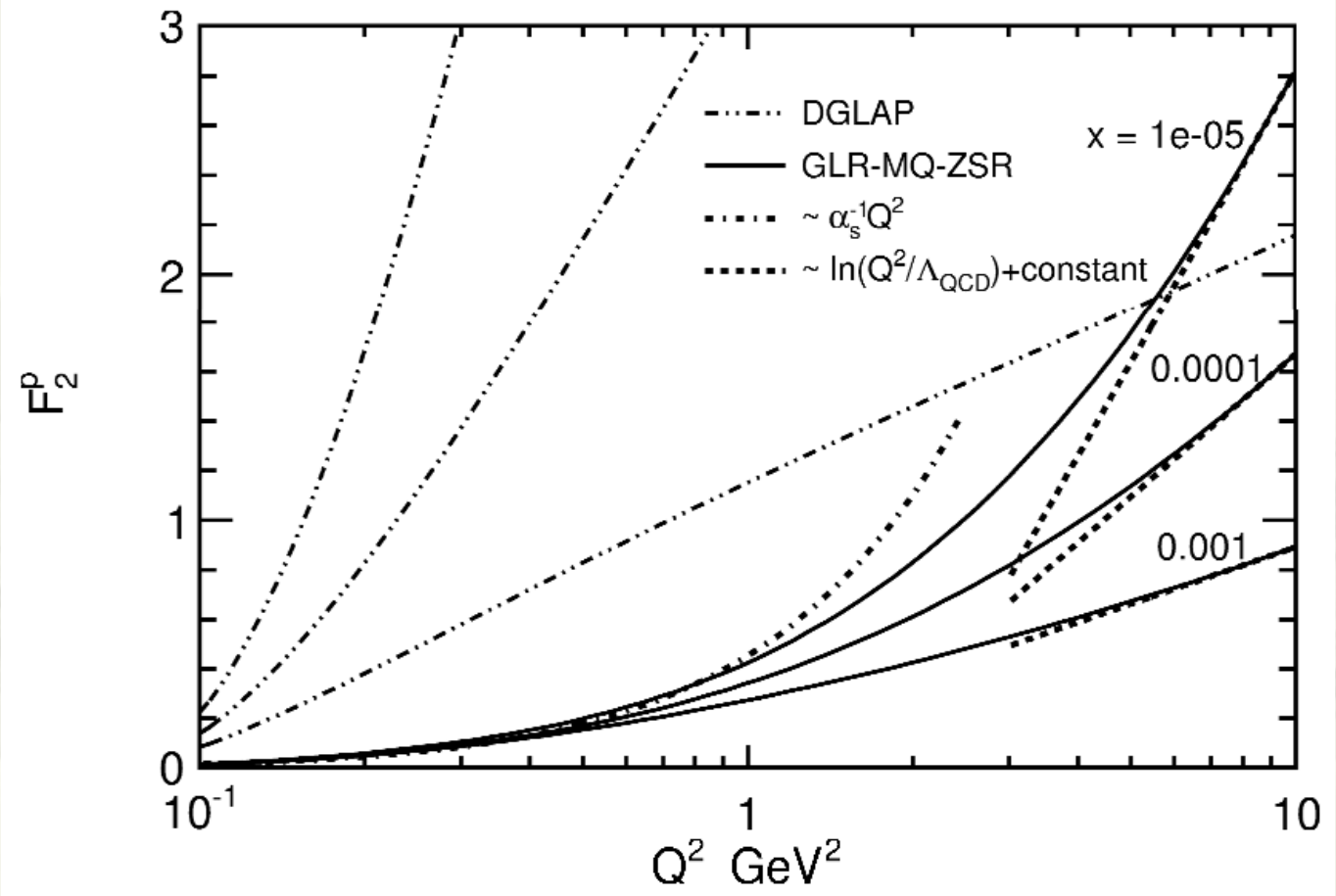
Fit good to experimental data.

Quark saturation in low Q^2 range

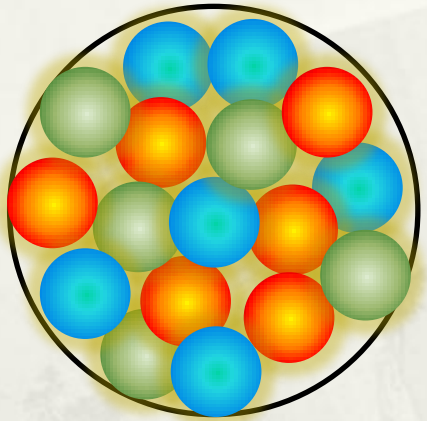


Quark distributions exhibit a flattish form at small x, while gluon distribution does not.

Quark saturation in low Q^2 range



Quark saturation in low Q^2 range

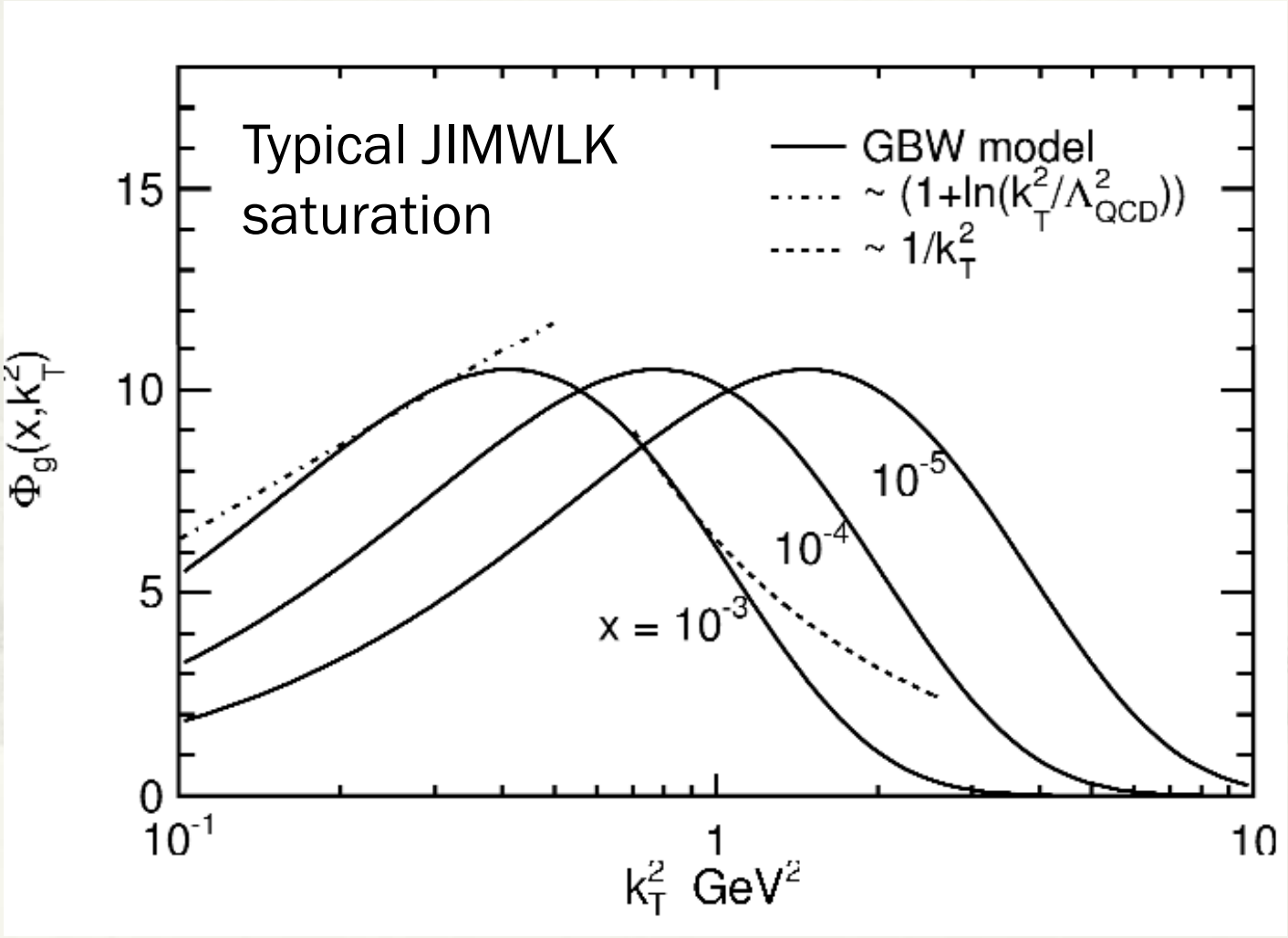


GLR-MQ-ZSR saturation,
Qs < 1 GeV, quark saturation.

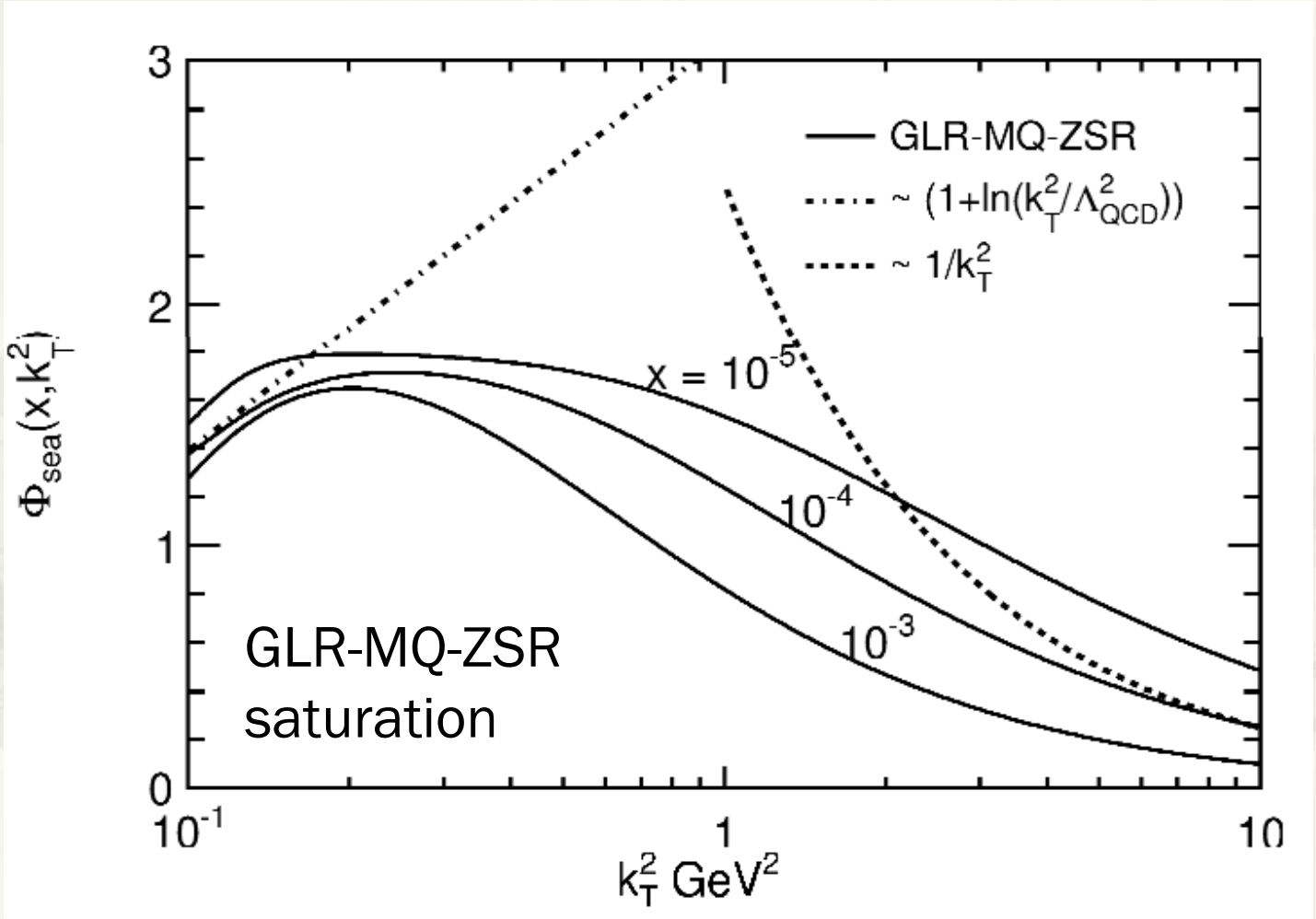
JIMWLK saturation,
Qs > 1 GeV, gluon saturation.

GLR-MQ-ZRS saturation has similar properties as JIMWLK saturation

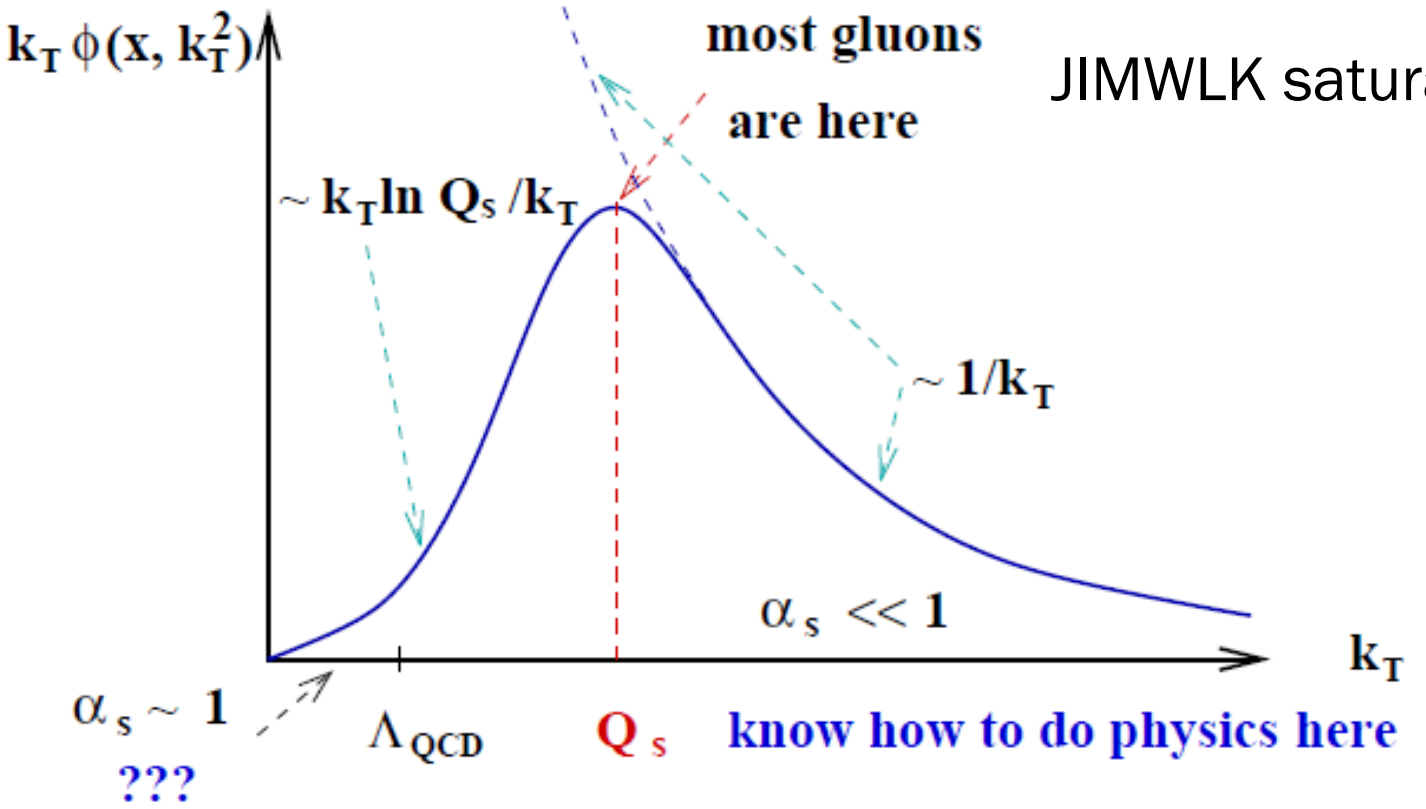
Quark saturation in low Q^2 range



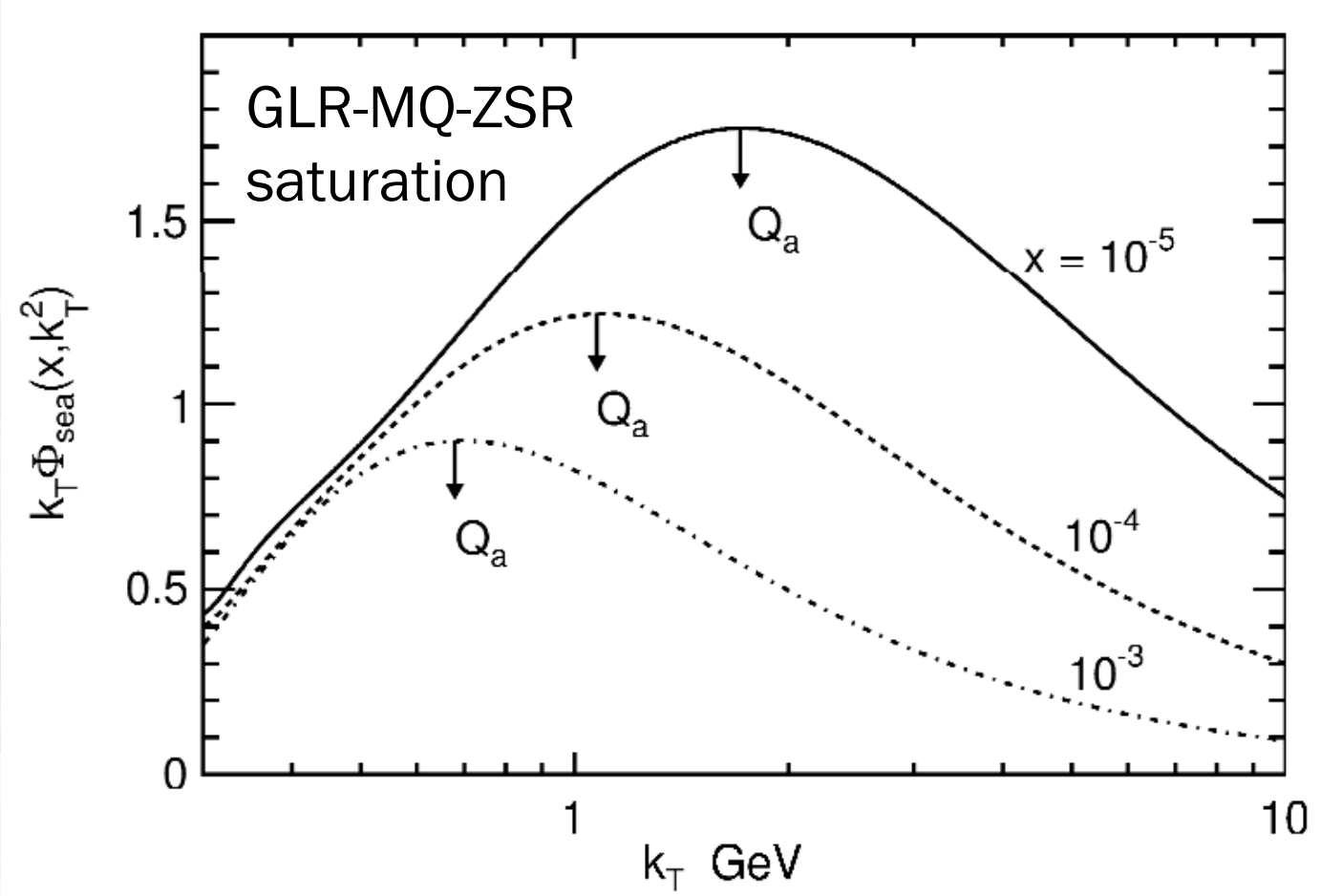
Quark saturation in low Q^2 range



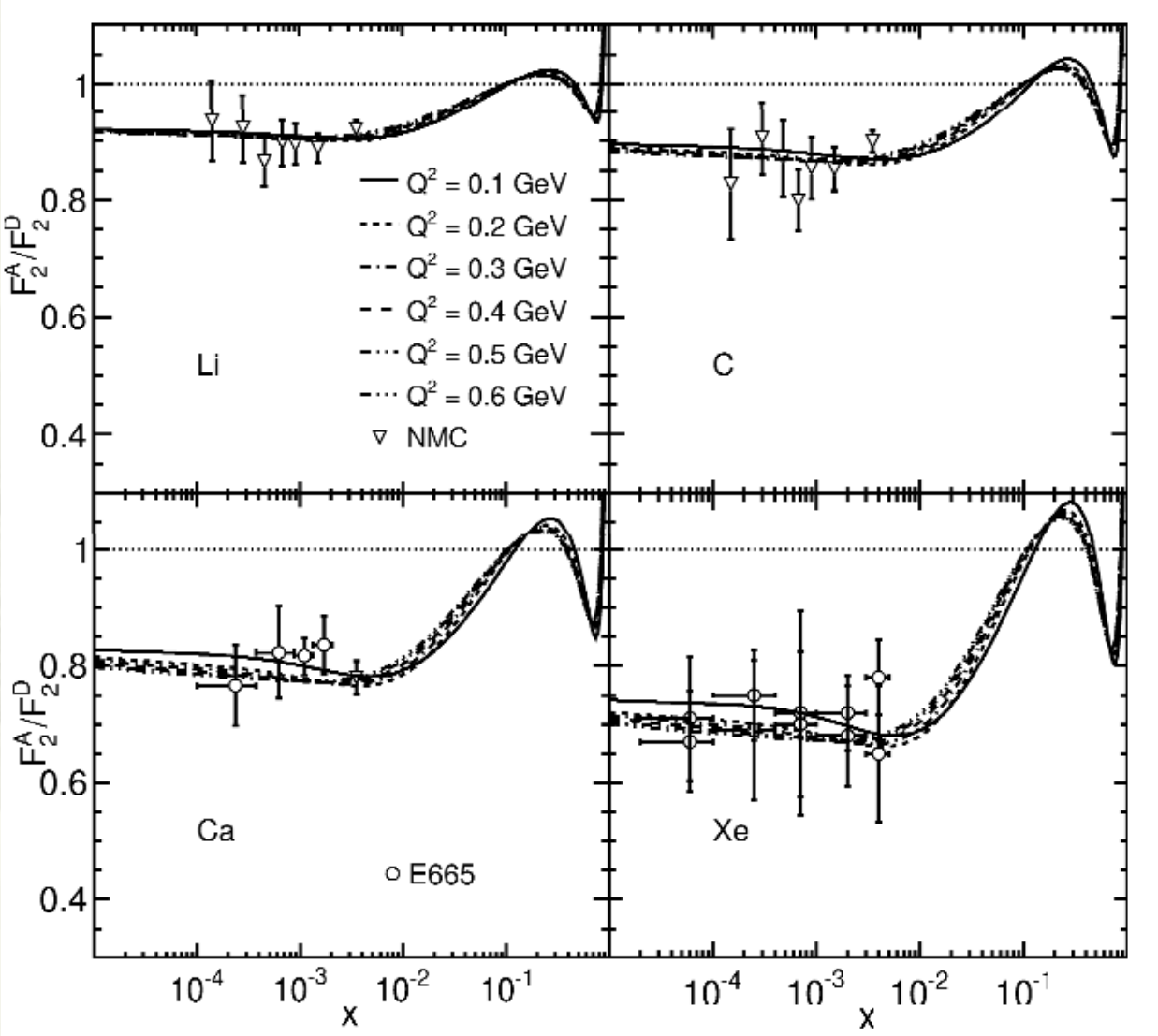
Gluon saturation



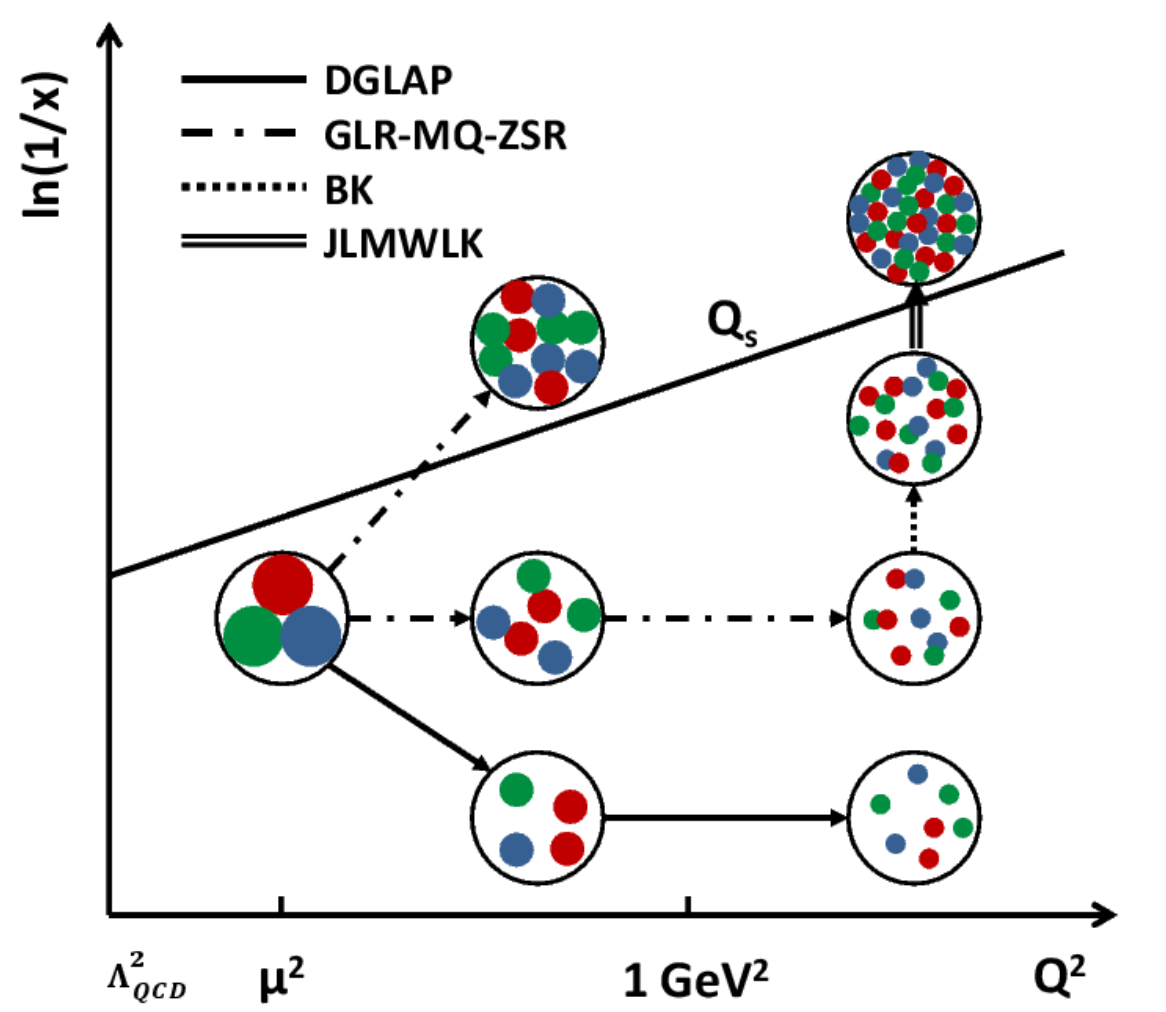
Quark saturation in low Q^2 range



Quark saturation in low Q^2 range



Evolution of parton distributions in different kinematic region



Next step

- PDF database for proton
- nPDF database for nuclei
- Spin-dependent PDF
- PDF for pion and kaon
- SRC
- Antishadowing
- TMD……

The end