Determination of light asymmetric sea in proton

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The 6th Workshop on Hadron Physics in China and Opportunities in US

Outline

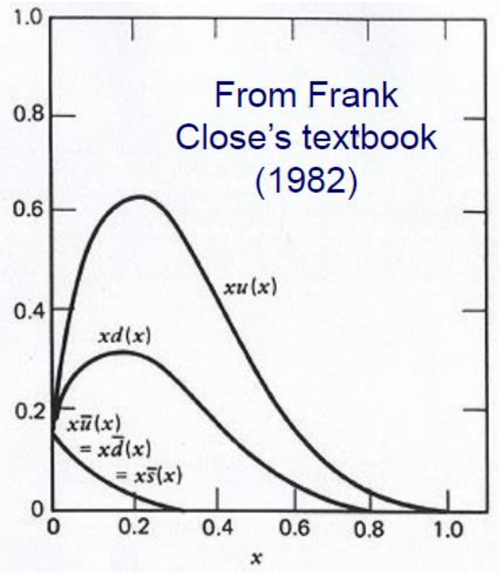
- Symmetric and asymmetric light flavor sea
- Extraction of asymmetric sea component
- A global analysis method
- Results
- Summary

Symmetric and asymmetric light flavor sea

- DGLAP equation for sea quarks is SU(3) flavor symmetric. If there is no initial sea distribution at very low scale, then light sea quarks from evolution (symmetric sea) are equal.

(The picture is from Peng's talk)

However the nucleon sea is found to be flavor dependent in experiment.



Symmetric and asymmetric light flavor sea

- Violation of Gottfried sum rule

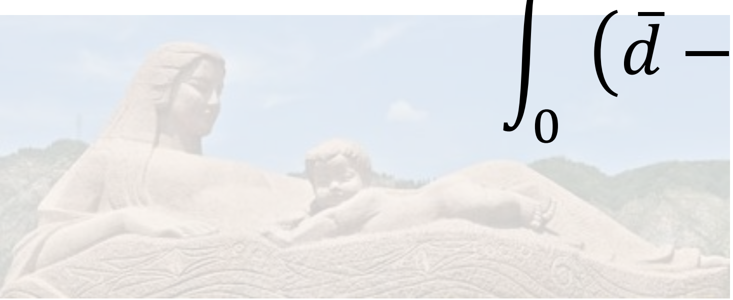
$$S_G = \frac{1}{3} + \frac{2}{3}\int_0^1 (\bar{u} - \bar{d})dx$$

For flavor-symmetric seas, $S_G = \frac{1}{3}$ (Gottfried sum rule, Phys. Rev. Lett. 18 (1967) 1174).

NMC measurement (Phys. Rev. Lett. 66 (1991) 2712, Phys. Rev. D 50 (1994) R1):

$$S_G = 0.235 \pm 0.026$$

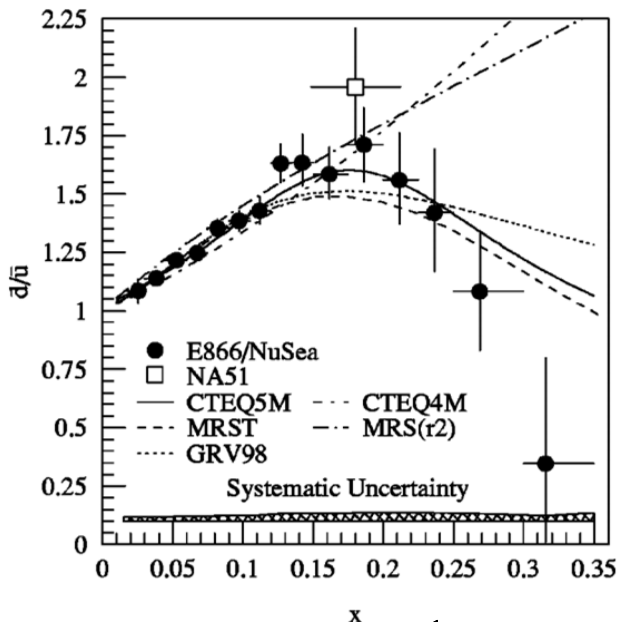
$$\int_0^1 (\bar{d} - \bar{u})dx = 0.148 \pm 0.039$$

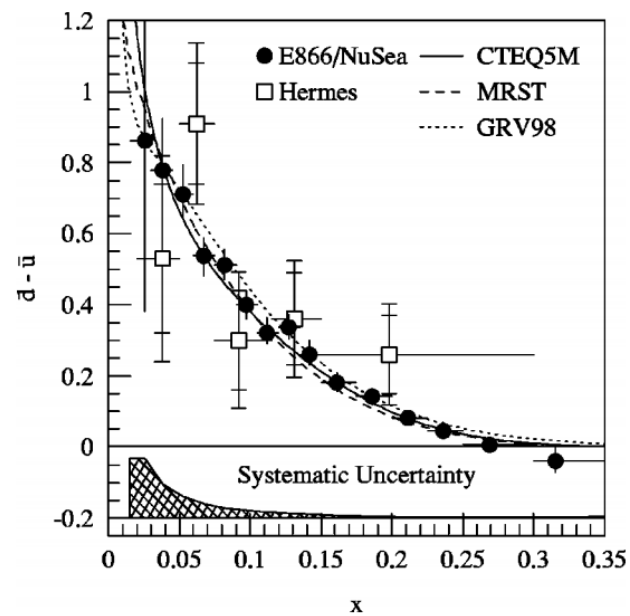


Symmetric and asymmetric light flavor sea

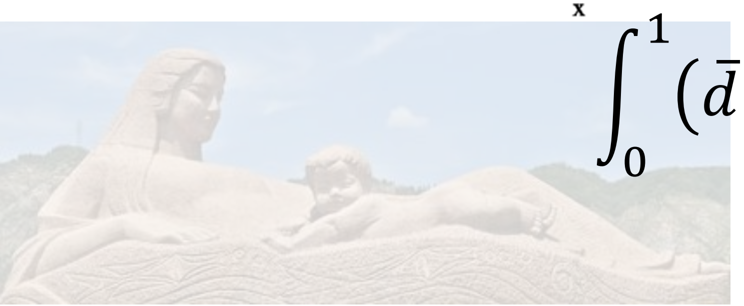
- $\bar{d}/\bar{u}$ asymmetry from Drell-Yan process

E866/NuSea Collaboration (Phys. Rev. D 64 (2001) 052002):



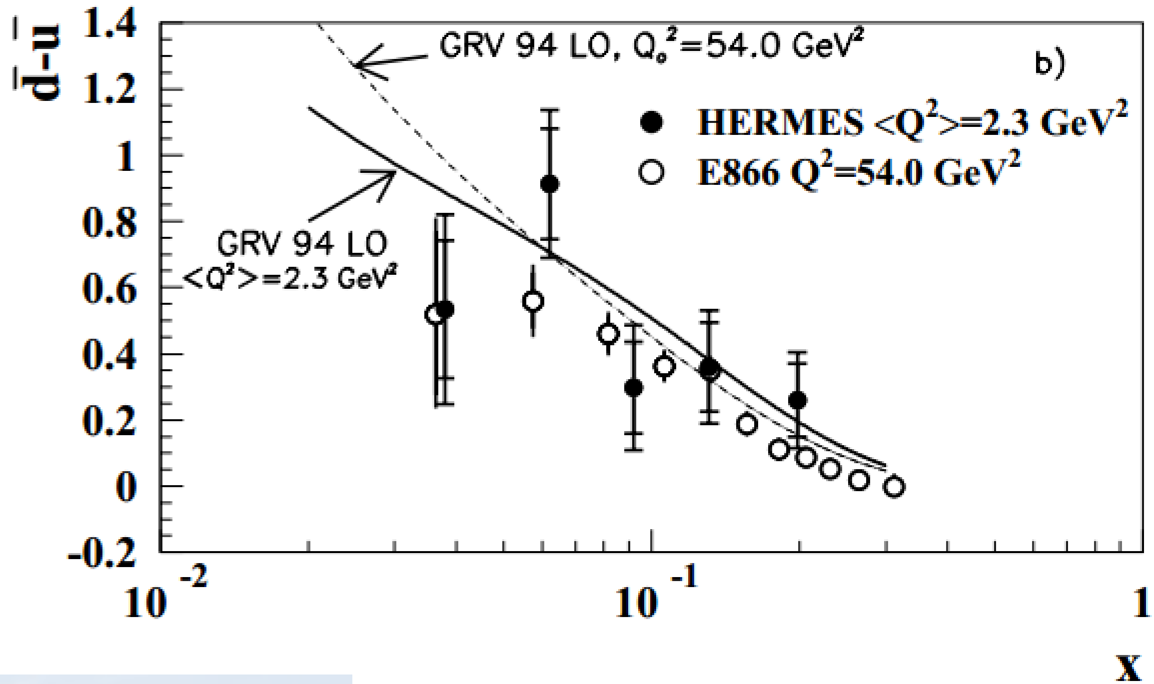


$$\int_0^1 (\bar{d} - \bar{u})dx = 0.118 \pm 0.012$$



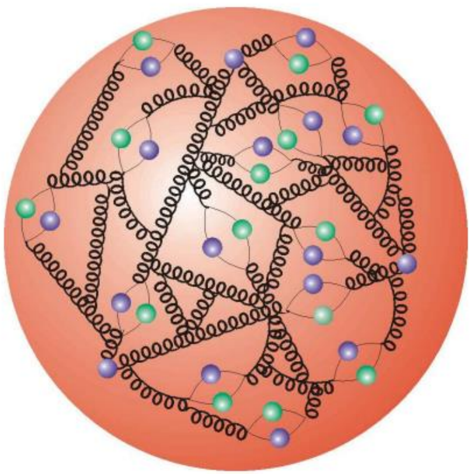
Symmetric and asymmetric light flavor sea

- $\bar{d} - \bar{u}$ asymmetry from semi-inclusive DIS



Symmetric and asymmetric light flavor sea

If the sea of quark-antiquark pairs is merely produced perturbatively from gluon splitting, then a large $\bar{d}/\bar{u}$ asymmetry is not expected.



other origin of sea except gluon splitting ?

There must be other source to the asymmetric sea quarks.

Symmetric and asymmetric light flavor sea

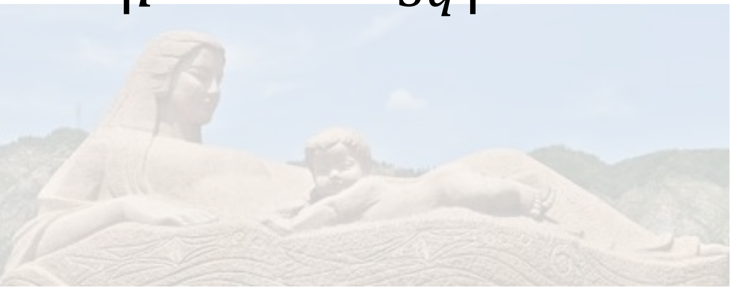
- Pauli blocking principle effect (Phys. Rev. D 15 (1977) 2590)

Two up valence quarks hinder the emission of $u\bar{u}$ compared to $d\bar{d}$ pairs in the proton.

- Valence-like intrinsic sea (Phys Lett B 93 (1980) 451, Phys. Rev. Lett. 106 (2011) 252002)

The intrinsic light sea should have larger probabilities.

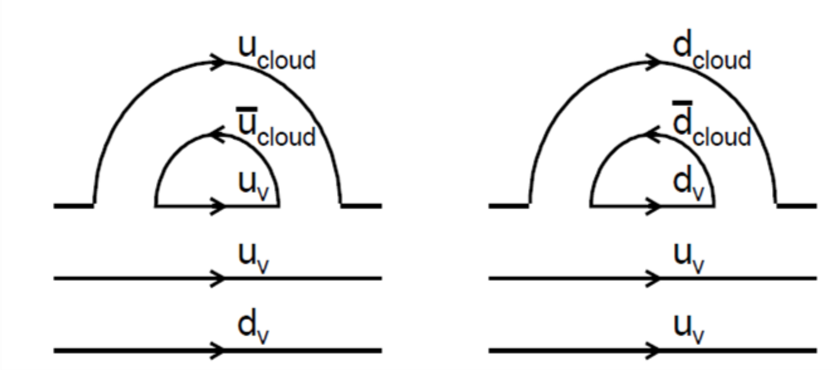
$$|p> = P_{3q}|uud> + P_{5q}|uud\bar{Q}Q> + \cdots$$



Symmetric and asymmetric light flavor sea

- Cloud sea (Mod. Phys. Lett. A 6 (1991) 271, Phys. Rev. D 60 (1999) 014004, Phys. Rev. D 59 (1999) 014033)

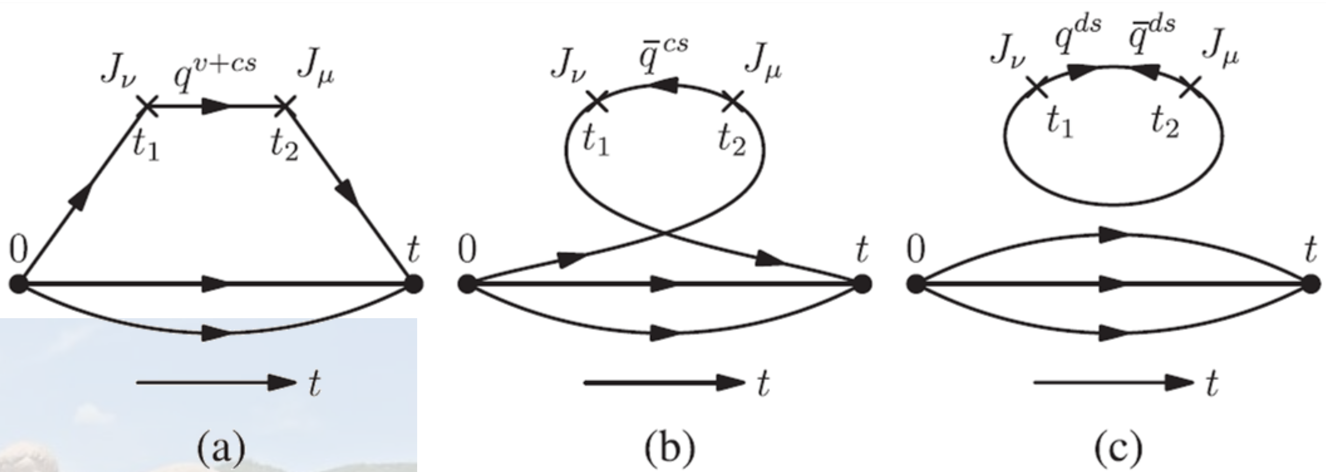
There are nonperturbative processes of nucleon dissociation into $\pi - N$ and $\pi - \Delta$. Here the process $p \to n + \pi^+$ is favored over $p \to \Delta^{++} + \pi^-$.



Symmetric and asymmetric light flavor sea

- Connected sea (Phys. Rev. Lett. 72 (1994) 1790, Phys. Rev. D 62 (2000) 074501, Phys. Rev. Lett.109 (2012) 252002)

According to the path-integral formalism of the hadronic tensor, the nucleon sea contains two distinct components called the connected sea (CS) and the disconnected sea (DS)



Symmetric and asymmetric light flavor sea

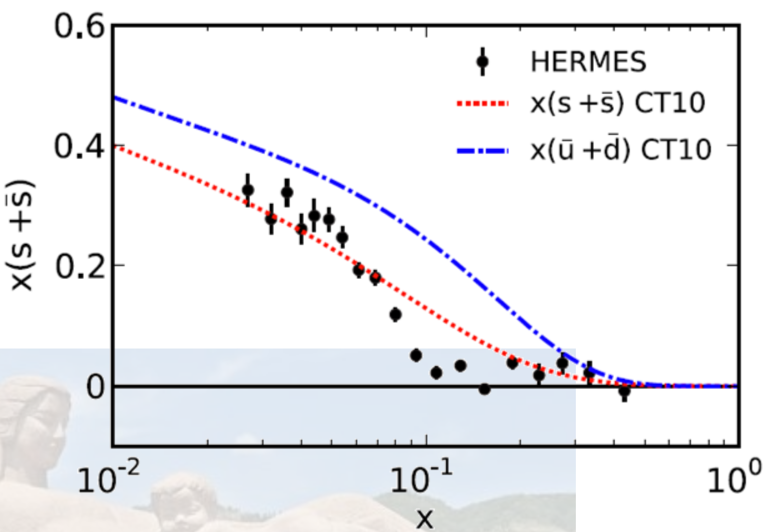
- asymmetric sea (intrinsic sea, cloud sea, CS)
- How large is the asymmetric light flavor sea actually?
- How to separate flavor asymmetric sea component from the symmetric part?

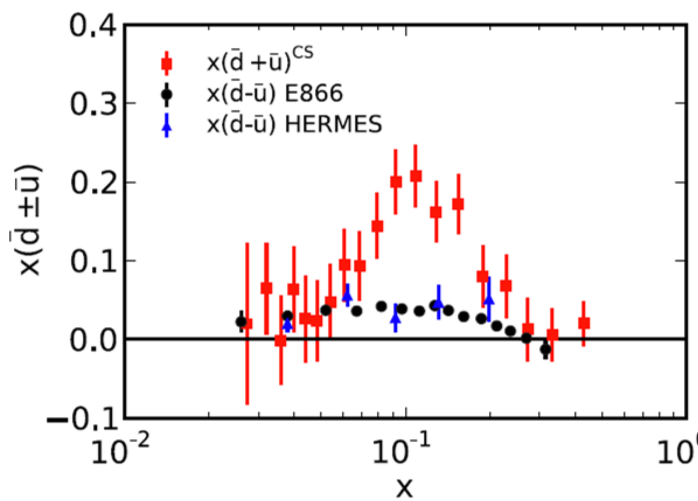
Extraction of asymmetric sea component

- (K.F. Liu et al., Phys. Rev. Lett.109 (2012) 252002)

$$\bar{u}^{\,cs}(x) + \bar{d}^{cs}(x) = \bar{u}(x) + \bar{d}(x) - \frac{1}{R}(s(x) + \bar{s}(x))$$

CT10 Lattice QCD HERMES exp.



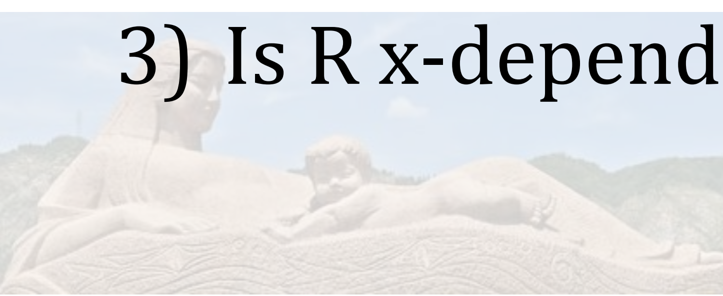


Extraction of asymmetric sea component

- (K.F. Liu et al., Phys. Rev. Lett.109 (2012) 252002)

some worries:

1) PDF varies from set to set.
2) extraction of strange quark distribution has big uncertainty from the fragmentation function. More over, strange quark also has intrinsic component.
3) Is R x-dependent?



Extraction of asymmetric sea component

- A model-independent way to separate asymmetric sea component from symmetric sea?
- Can we extract asymmetric light flavor sea only from experiment data?

Extraction of asymmetric sea component

The asymmetric sea always mixes with the symmetric sea at higher Q^2.

However the symmetric sea quarks and gluons naturally disappear in the initial distributions at very low Q^2. The nonperturbative input at some scale is just valence and asymmetric sea.

It is a naive and novel way separate asymmetric and symmetric sea.

arXiv:1404.0759

A global analysis method

- From valence moment evolution, we get the starting point at $Q_0^2 \approx \mu^2 = 0.064\ \mathrm{GeV}^2$.
- Natural input:

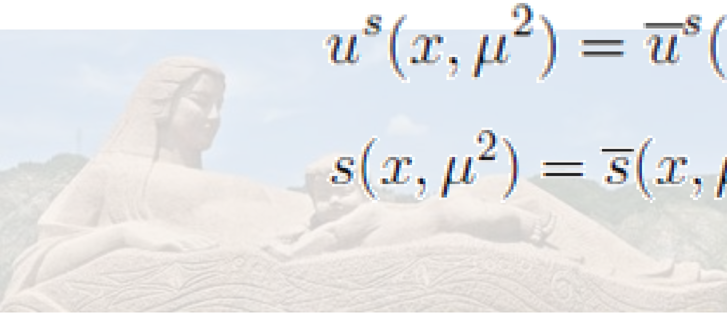
$$q^{NS}(x, Q^2) = [q^v(x, Q^2) + q^{as}(x, Q^2) + \overline{q}^{as}(x, Q^2)]$$

$$\int_0^1 dx u^{NS}(x, Q^2) = 2 + 2 < u^{as} >_1, \quad \int_0^1 dx d^{NS}(x, Q^2) = 1 + 2 < d^{as} >_1,$$

$$\int_0^1 dx x[u^{NS}(x, \mu^2) + d^{NS}(x, \mu^2)] = 1,$$

$$u^s(x, \mu^2) = \overline{u}^s(x, \mu^2) = 0, \quad d^s(x, \mu^2) = \overline{d}^s(x, \mu^2) = 0,$$

$$s(x, \mu^2) = \overline{s}(x, \mu^2) = 0, \quad g(x, \mu^2) = 0.$$



A global analysis method

From such low resolution scale, gluons and sea quarks from DGLAP evolution are too steep. Parton recombination corrections is needed.

- GLR-MQ@DGLAP equation: for gluon combination
- GLR-MQ-ZRS@DGLAP equation: extend to whole x region for all kinds of recombination.

(Nucl. Phys. B 551 (1999) 245 [arXiv:hep-ph/9809391], Nucl. Phys.B 559 (1999) 378 [arXiv:hep-ph/9907330v2], HEP & NP, 29 (2005) 109 [arXiv:hep-ph/0406213v3].)

We use ZRS@DGLAP equations for the evolution.

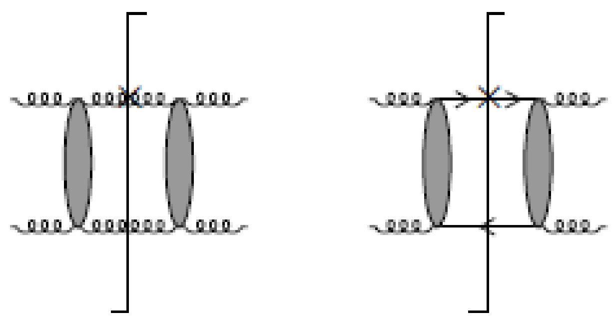
A global analysis method

- Simplified ZRS equations

$$Q^2\frac{dxq^{NS}(x,Q^2)}{dQ^2} = \frac{\alpha_s(Q^2)}{2\pi}P_{qq}\otimes q^{NS},$$

$$Q^2\frac{dxq^{s}(x,Q^2)}{dQ^2} = \frac{\alpha_s(Q^2)}{2\pi}[P_{qq}\otimes q^s + P_{qg}\otimes g]$$
$$-\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_x^{1/2}\frac{dy}{y}xP_{gg\to q}(x,y)[yg(y,Q^2)]^2$$
$$+\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_{x/2}^{x}\frac{dy}{y}xP_{gg\to q}(x,y)[yg(y,Q^2)]^2, (if\ x\le 1/2),$$

$$Q^2\frac{dxg(x,Q^2)}{dQ^2} = \frac{\alpha_s(Q^2)}{2\pi}[P_{gq}\otimes\Sigma + P_{gg}\otimes g]$$
$$-\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_x^{1/2}\frac{dy}{y}xP_{gg\to g}(x,y)[yg(y,Q^2)]^2$$
$$+\frac{\alpha_s^2(Q^2)}{4\pi R^2Q^2}\int_{x/2}^{x}\frac{dy}{y}xP_{gg\to g}(x,y)[yg(y,Q^2)]^2, (if\ x\le 1/2),$$



(a) $P_{gg\to g}$ (b) $P_{gg\to q}$

A global analysis method

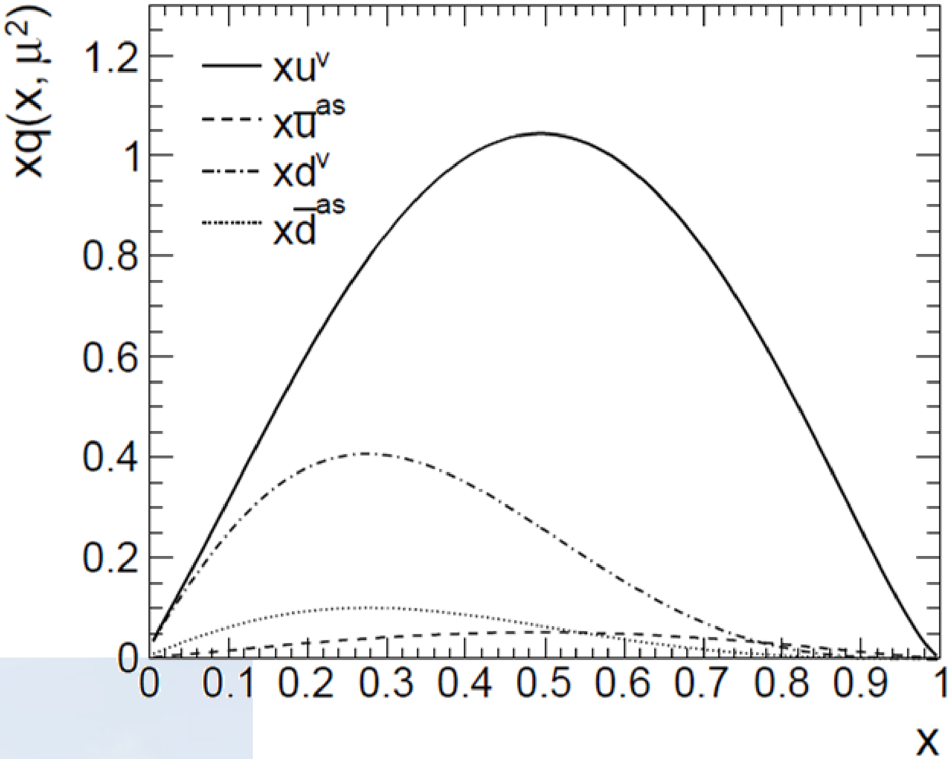
For a simple case, we make an assumption that the asymmetric sea is valence-like? What is asymmetric sea distribution takes the valence form?

$$q^{as}(x, \mu^2) = k \times q^{v}(x, \mu^2)$$

With this assumption, we obtained the non-perturbative input by a global fit to various experimental data.

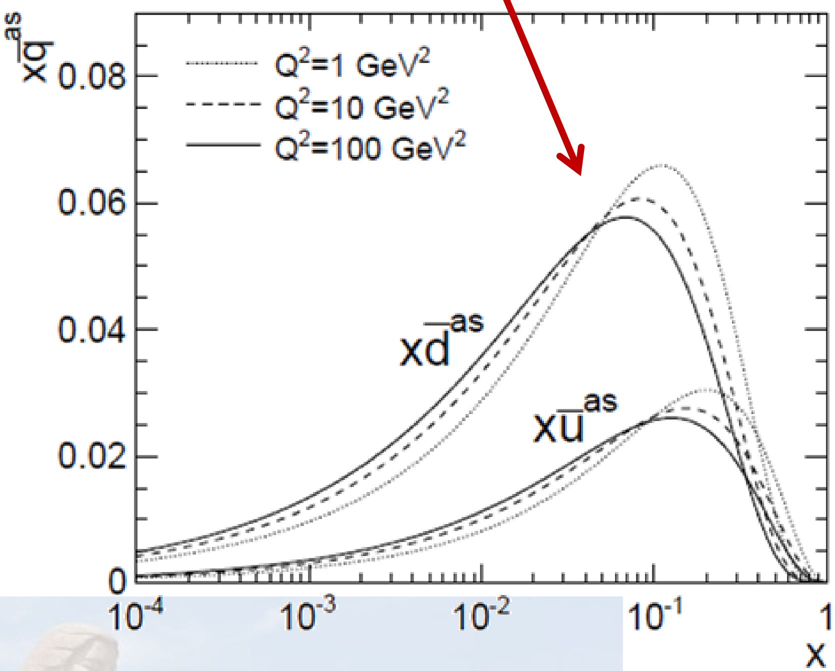
Results

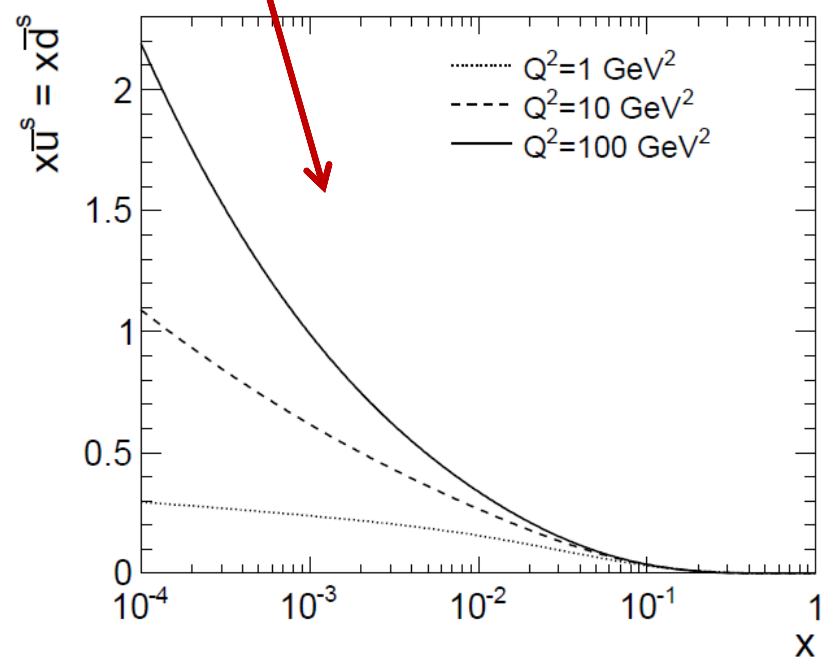
- The obtained initial nonperturbative input



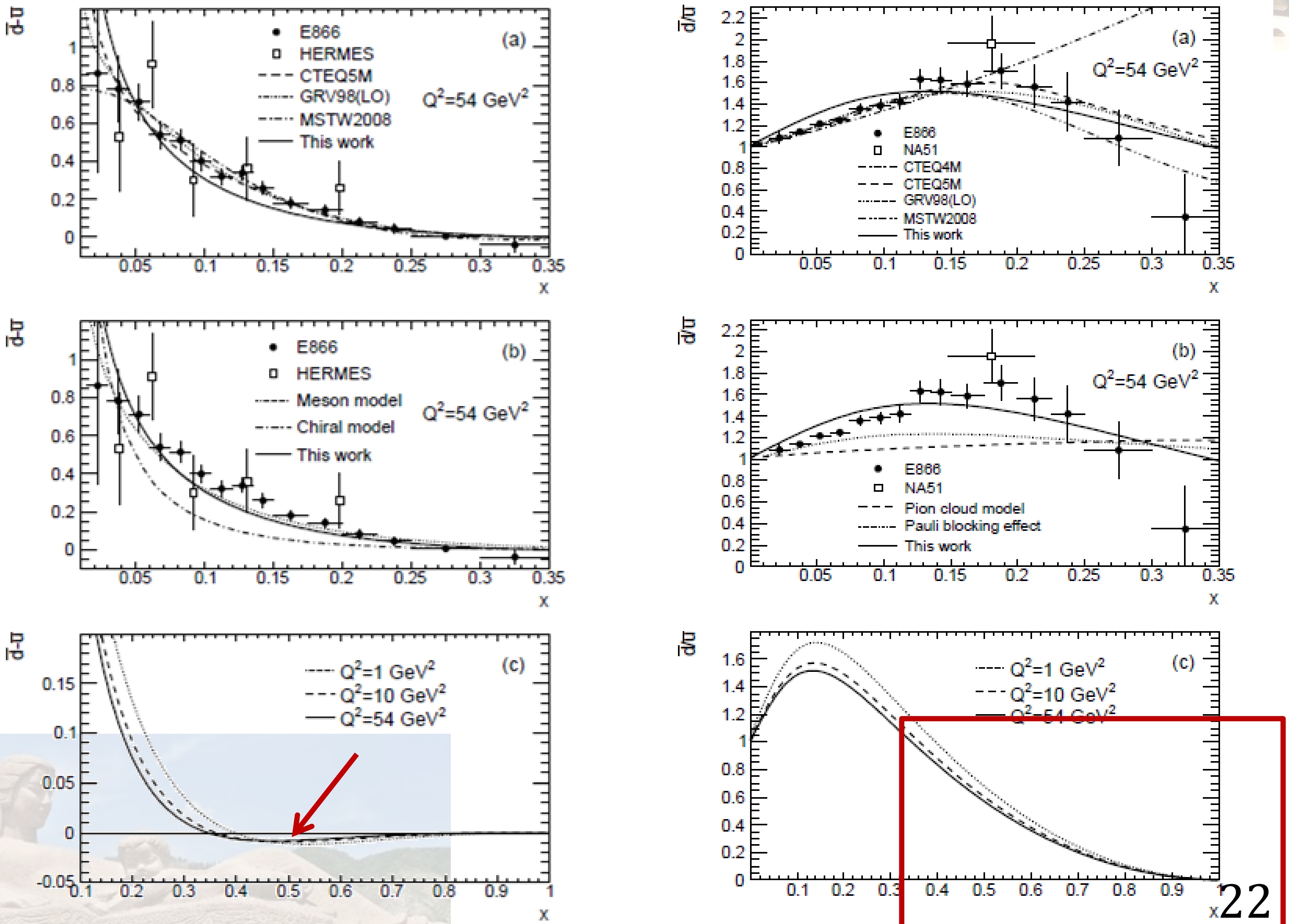
Results

- Asymmetric sea and symmetric sea





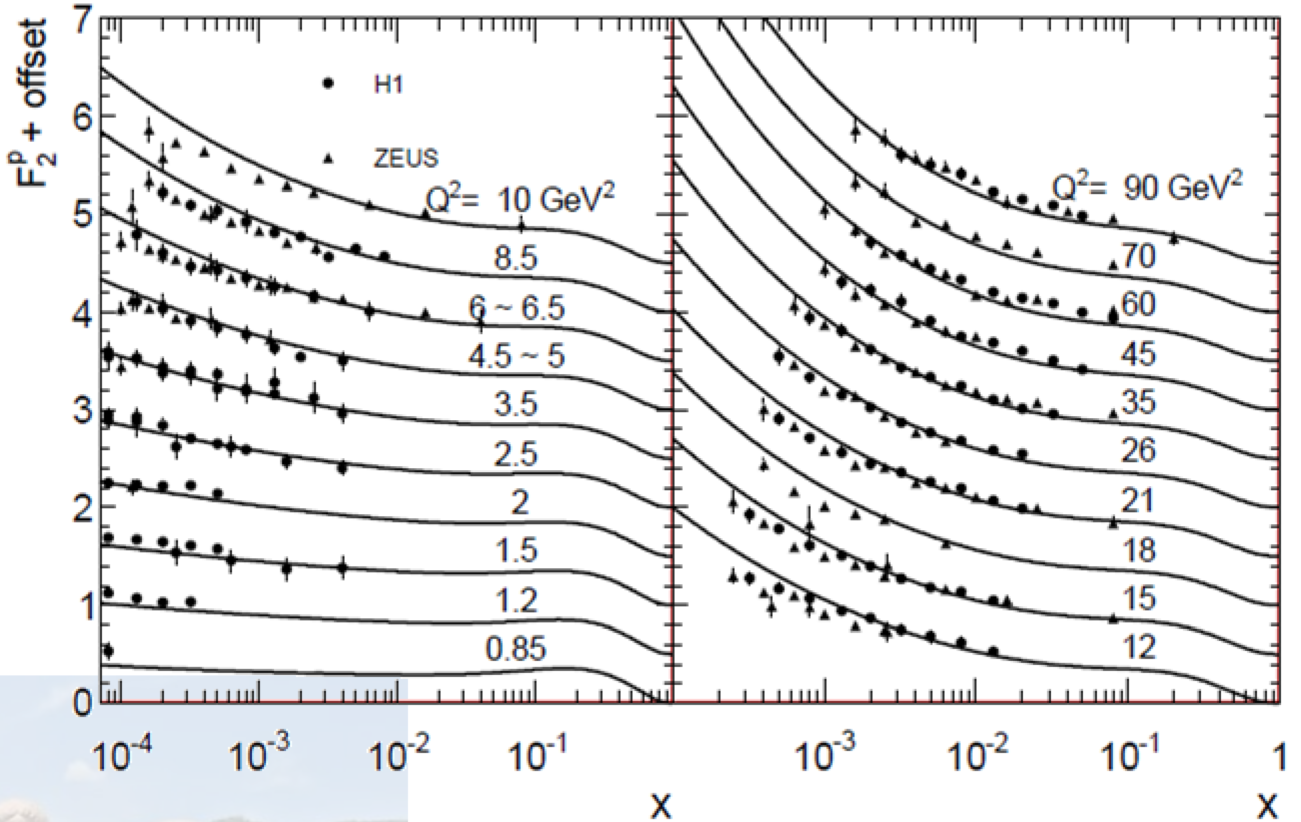
Results



d̄-ū
E866
HERMES
CTEQ5M
GRV98(LO)
MSTW2008
This work
(a)
Q²=54 GeV²
x
d̄/ū
E866
NA51
CTEQ4M
CTEQ5M
GRV98(LO)
MSTW2008
This work
(a)
Q²=54 GeV²
x
d̄-ū
E866
HERMES
Meson model
Chiral model
This work
(b)
Q²=54 GeV²
x
d̄/ū
E866
NA51
Pion cloud model
Pauli blocking effect
This work
(b)
Q²=54 GeV²
x
d̄-ū
Q²=1 GeV²
Q²=10 GeV²
Q²=54 GeV²
(c)
x
d̄/ū
Q²=1 GeV²
Q²=10 GeV²
Q²=54 GeV²
(c)
x

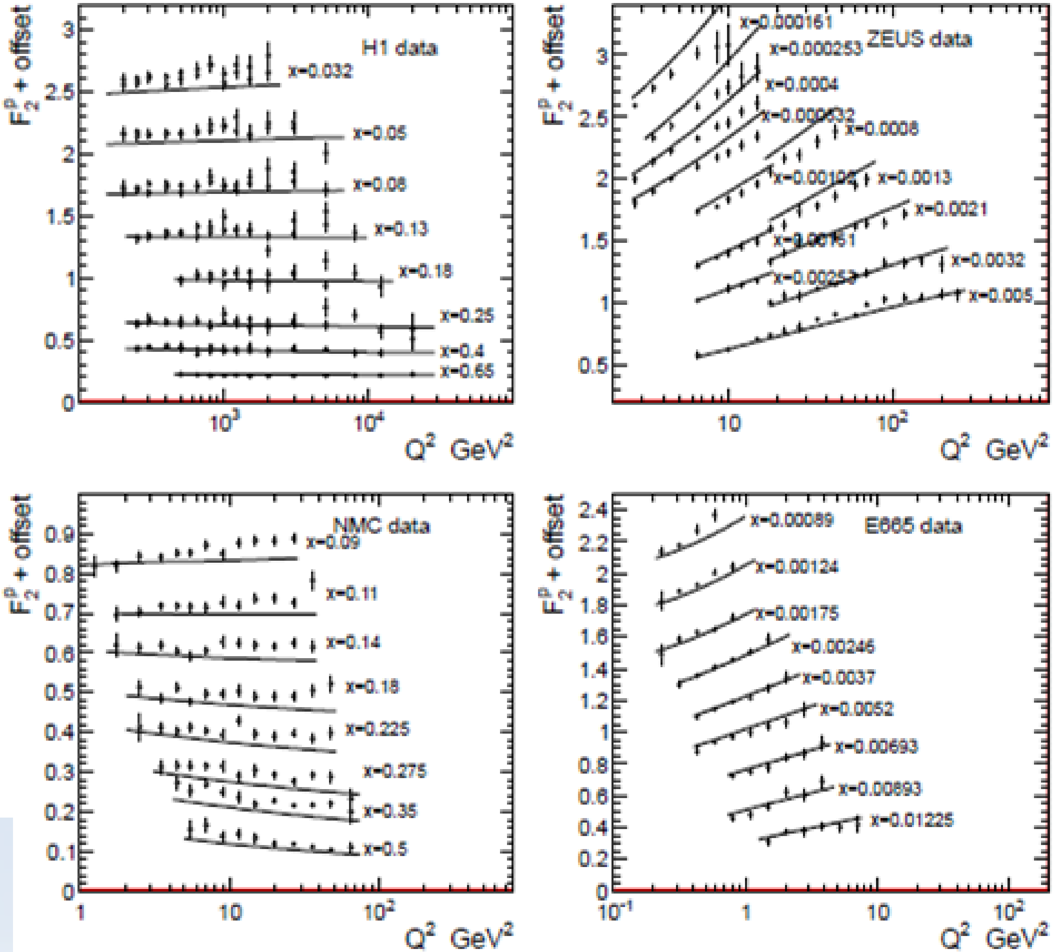
Results

- Compared to F_2 data



Results

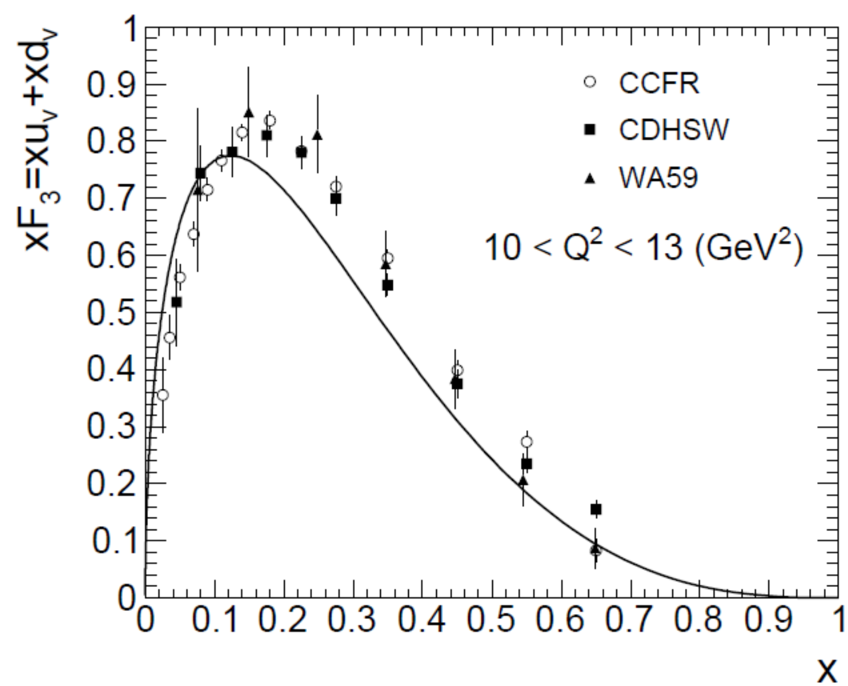
- Compared to F_2 data



Results

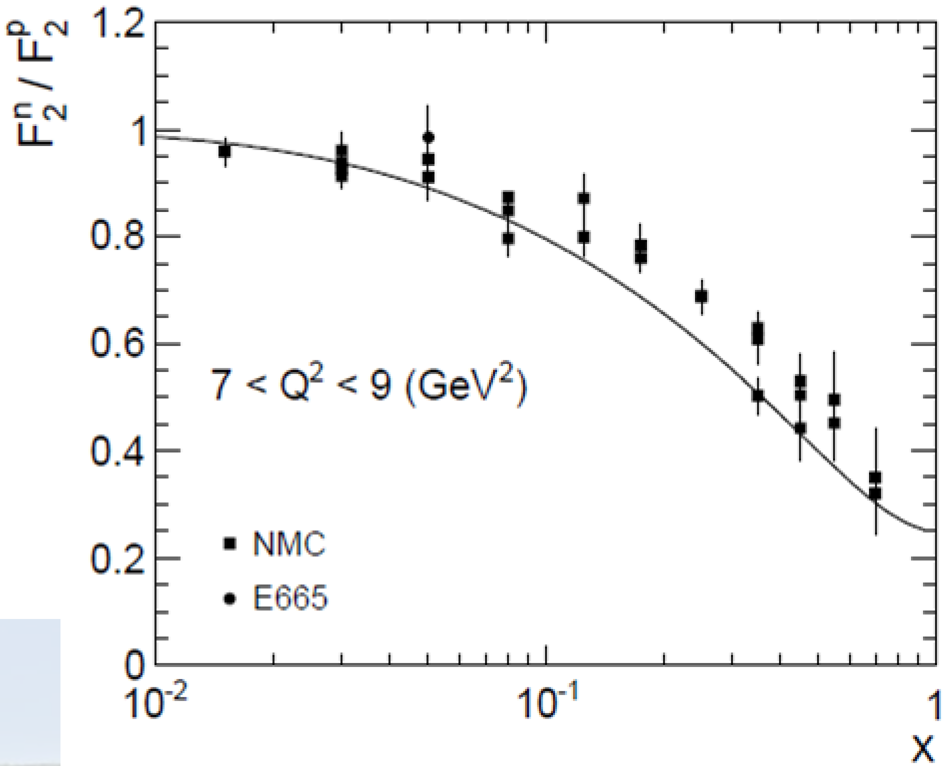
- Compared to F_3 data

The discrepancy may be due to the over strict assumption that asymmetric sea distribution takes valence input form exactly.



Results

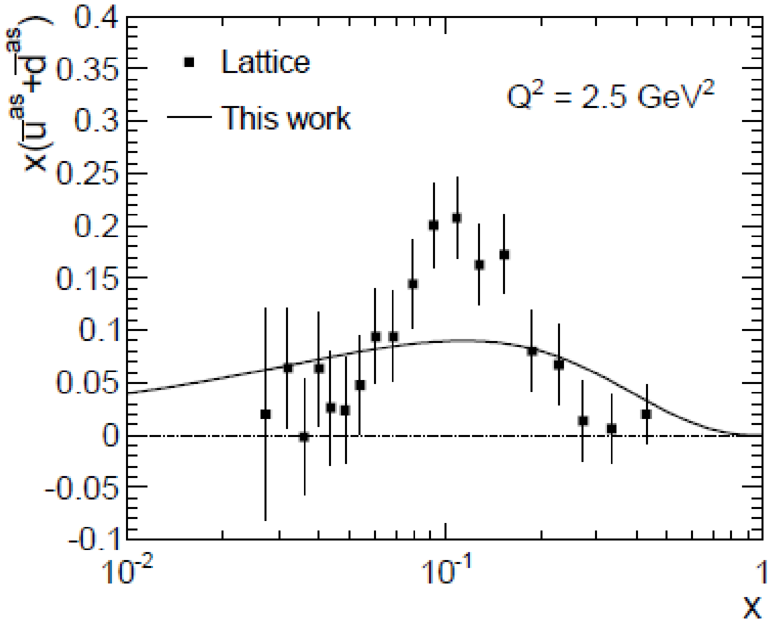
- F_2 ratio of neutron to proton



Results

- Compared to Liu's result

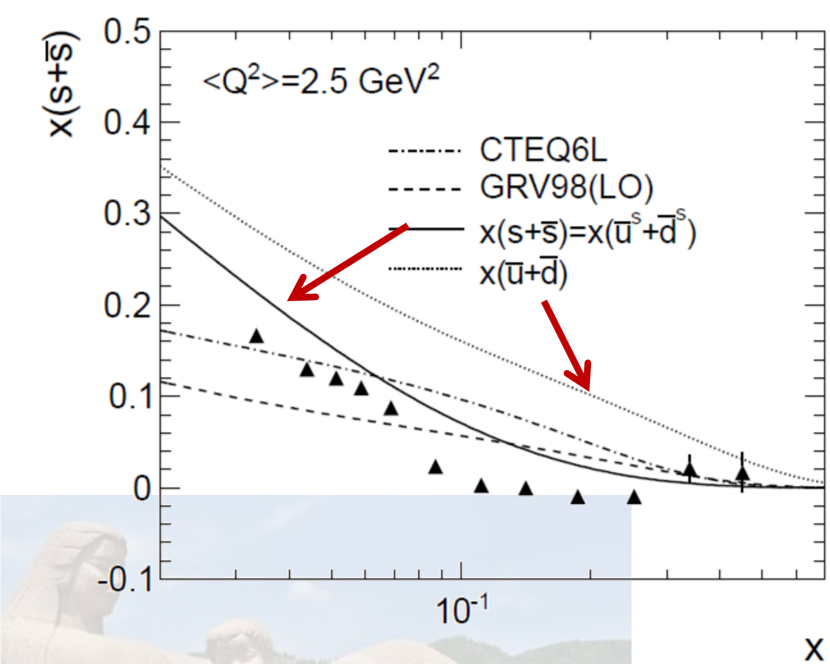
The peaks of both results are similar, however, the global analysis result shows a broader distribution.

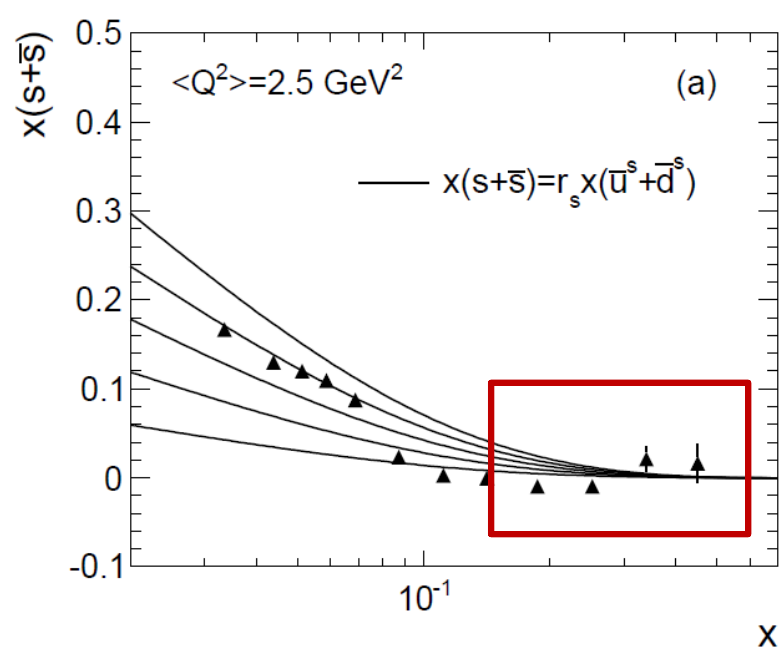


Results

- Strange quark distribution

We neglect intrinsic strange quark. Experiment data take from HERMES recent reevaluation. (Phys. Rev. D 89 (2014) 097101)





Summary

- Light flavor asymmetric sea component is extracted in a model-independent way.
- Valence-shape asymmetric sea approximation is basically acceptable.
- Strange sea quark distribution function resembles symmetric up and down quark distributions.

The end

Thank you for your attention!