Intrinsic Sea in the Proton

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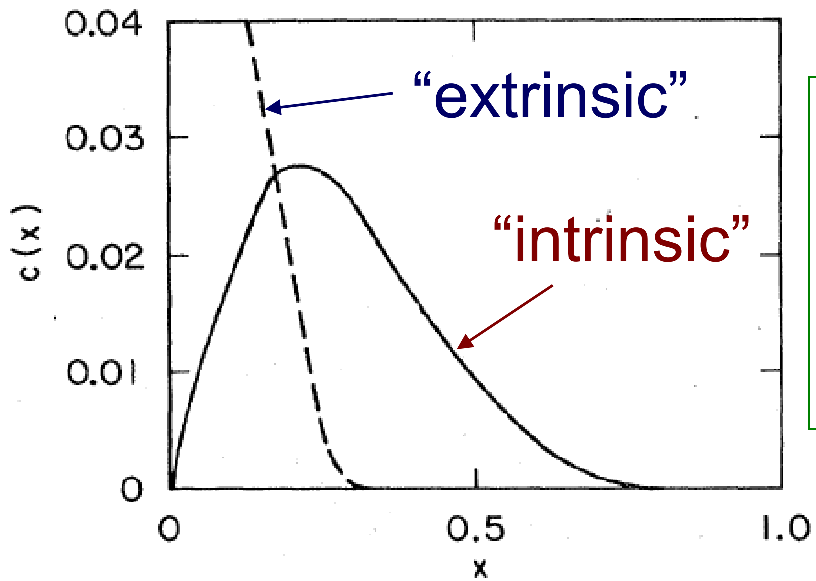
Search for the "intrinsic" quark sea

In 1980, Brodsky, Hoyer, Peterson, Sakai (BHPS) suggested the existence of "intrinsic" charm

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

The "intrinsic"-charm from $|uudc\bar{c}\rangle$ is "valence"-like and peak at large x unlike the "extrinsic" sea ($g \to c\bar{c}$)



The "intrinsic charm" in $|uudc\bar{c}\rangle$ can lead to large contribution to charm production at large x

A recent global fit by CTEQ-TEA to extract intrinsic-charm (JHEP02 (2018) 059)

CT14 intrinsic charm parton distribution functions from CTEQ-TEA global analysis

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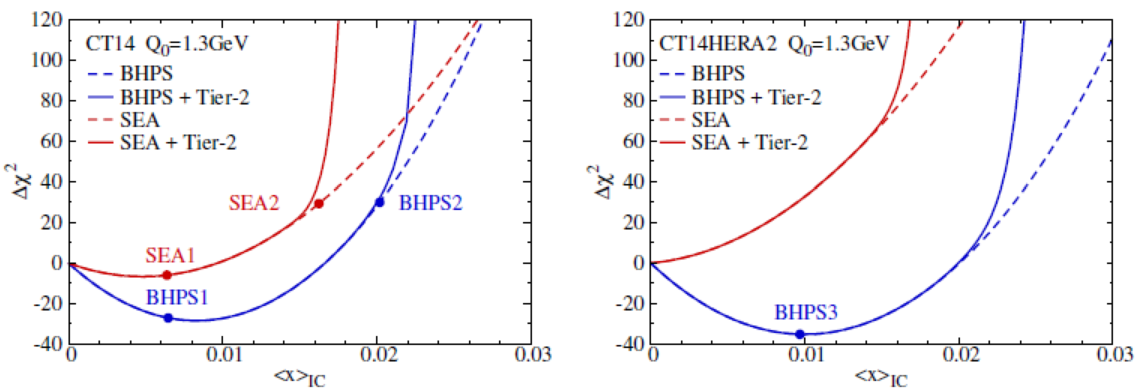


We see from figure 5 that large amounts of intrinsic charm are disfavored for all models under scrutiny. A mild reduction in χ^2, however, is observed for the BHPS fits, roughly at $\langle x \rangle_{\mathrm{IC}} = 1\%$, both in the CT14 and CT14HERA2 frameworks.

No conclusive evidence for intrinsic-charm (However, possible new evidence from LHC)

PHYSICAL REVIEW LETTERS **128,** 082001 (2022)

Study of Z Bosons Produced in Association with Charm in the Forward Region

R. Aaij *et al.*[*]
(LHCb Collaboration)

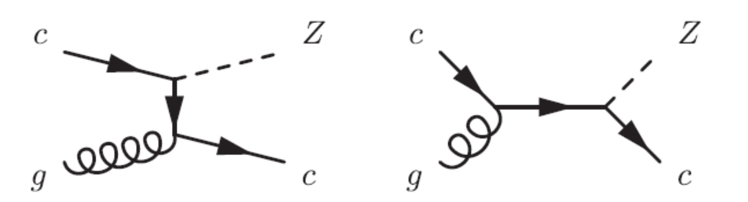
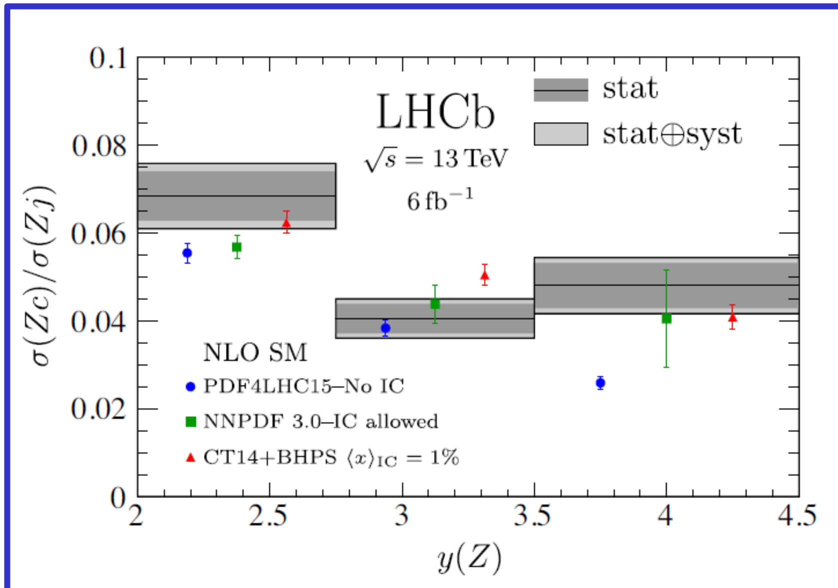


FIG. 1. Leading-order Feynman diagrams for $gc \to Zc$ production.



charm jets is determined in intervals of Z-boson rapidity in the range $2.0 < y(Z) < 4.5$. A sizable enhancement is observed in the forwardmost $y(Z)$ interval, which could be indicative of a valencelike intrinsic-charm component in the proton wave function.

"…However, conclusion about whether the proton contains valence-like intrinsic charm can only be drawn after incorporating these results into global PDF analyses"

Article

Evidence for intrinsic charm quarks in the proton

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The NNPDF Collaboration*

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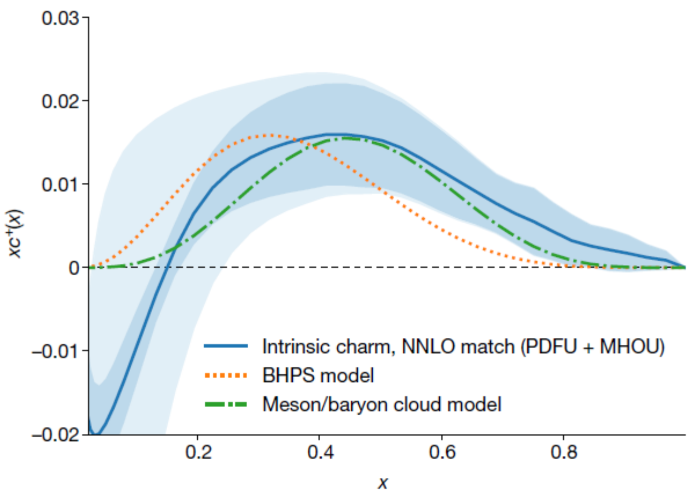


The theory of the strong force, quantum chromodynamics, describes the proton in terms of quarks and gluons. The proton is a state of two up quarks and one down quark bound by gluons, but quantum theory predicts that in addition there is an infinite number of quark–antiquark pairs. Both light and heavy quarks, whose mass is respectively smaller or bigger than the mass of the proton, are revealed inside the proton in high-energy collisions. However, it is unclear whether heavy quarks also exist as a part of the proton wavefunction, which is determined by non-perturbative dynamics and accordingly unknown: so-called intrinsic heavy quarks[1]. It has been argued for a long time that the proton could have a sizable intrinsic component of the lightest heavy quark, the charm quark. Innumerable efforts to establish intrinsic charm in the proton[2] have remained inconclusive. Here we provide evidence for intrinsic charm by exploiting a high-precision determination of the quark–gluon content of the nucleon[3] based on machine learning and a large experimental dataset. We disentangle the intrinsic charm component from charm–anticharm pairs arising from high-energy radiation[4]. We establish the existence of intrinsic charm at the 3-standard-deviation level, with a momentum distribution in remarkable agreement with model predictions[1,5]. We confirm these findings by comparing them to very recent data on *Z*-boson production with charm jets from the Large Hadron Collider beauty (LHCb) experiment[6].

However, see Guzzi et al. (2211.01387) for another view

SIDIS with charm production at JLab22 would be very interesting

Search for the lighter “intrinsic” quark sea

In collaboration with Wen-Chen Chang, Academia Sinica

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

No conclusive experimental evidence
for intrinsic-charm

Are there experimental evidences for the intrinsic

$| uudu\bar{u}\rangle, | uudd\bar{d}\rangle, | uuds\bar{s}\rangle$ 5-quark states ?

$$P_{5q} \sim 1 / m_Q^2$$

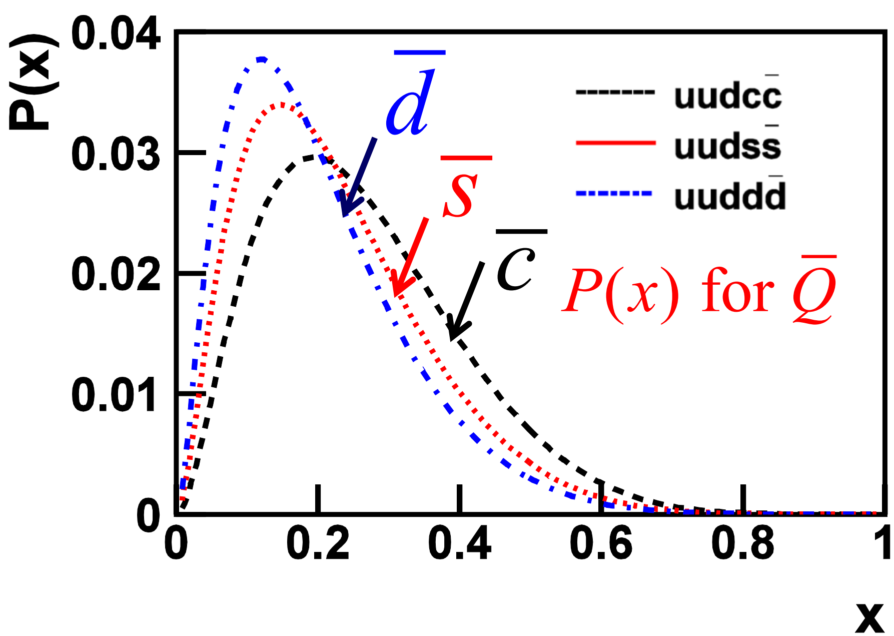
The 5-quark states for lighter
quarks have larger probabilities!

x-distribution for "intrinsic" light-quark sea

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

Brodsky et al. (BHPS) give the following probability for quark *i* (mass m_i) to carry momentum x_i

$$P(x_1, \cdots, x_5) = N_5 \delta(1 - \sum_{i=1}^{5} x_i)[m_p^2 - \sum_{i=1}^{5} \frac{m_i^2}{x_i}]^{-2}$$



In the limit of large mass for quark Q (charm):

$$P(x_5) = \frac{1}{2}\tilde{N}_5 x_5^2[(1 - x_5)(1 + 10x_5 + x_5^2) - 2x_5(1 + x_5)ln(1/x_5)]$$

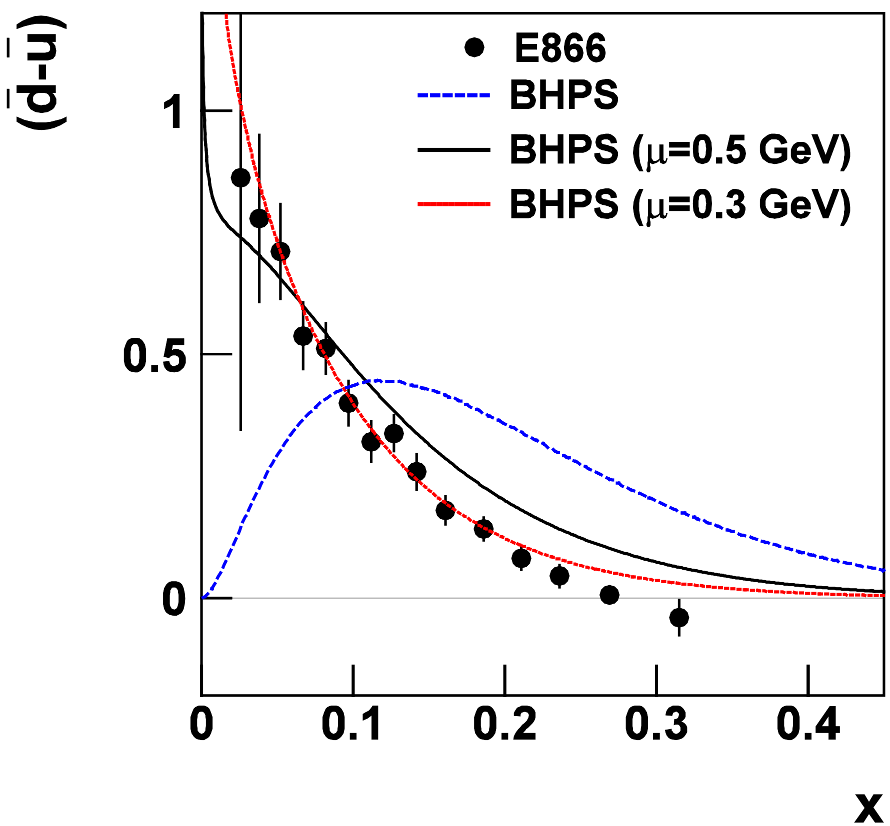
One can calculate $P(x)$ for antiquark $\bar{Q}$ ($\bar{c}, \bar{s}, \bar{d}$) numerically

How to separate the "intrinsic sea" from the "extrinsic sea"?

- Select experimental observables which have no contributions from the "extrinsic sea"

$$\bar{d}-\bar{u} \text{ has no contribution from extrinsic sea } (g \rightarrow \bar{q}q)$$
$$\text{and is sensitive to "intrinsic sea" only}$$

Comparison between the $\bar{d}(x)-\bar{u}(x)$ data with the intrinsic-sea model



(W. Chang and JCP , PRL 106, 252002)

The data are in good agreement with the BHPS model after evolution from the initial scale μ to $Q^2=54$ GeV^2

The difference in the two 5-quark components can also be determined

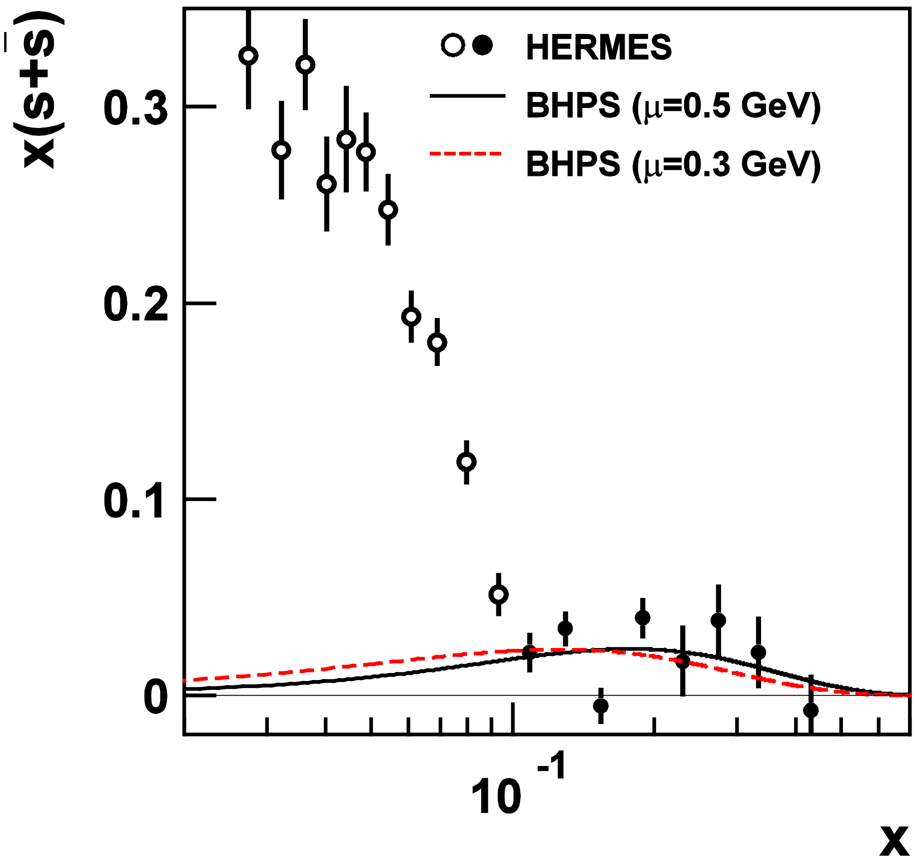
$$P_5^{uudd\bar{d}} - P_5^{uudu\bar{u}} = 0.118$$

How to separate the “intrinsic sea” from the “extrinsic sea”?

- “Intrinsic sea” and “extrinsic sea” are expected to have different x-distributions
  - Intrinsic sea is “valence-like” and is more abundant at larger x
  - Extrinsic sea is more abundant at smaller x

An example is the $s(x)+\bar{s}(x)$ distribution

Comparison between the $s(x)+\bar{s}(x)$ data with the intrinsic 5-q model



(W. Chang and JCP, PL B704,197)

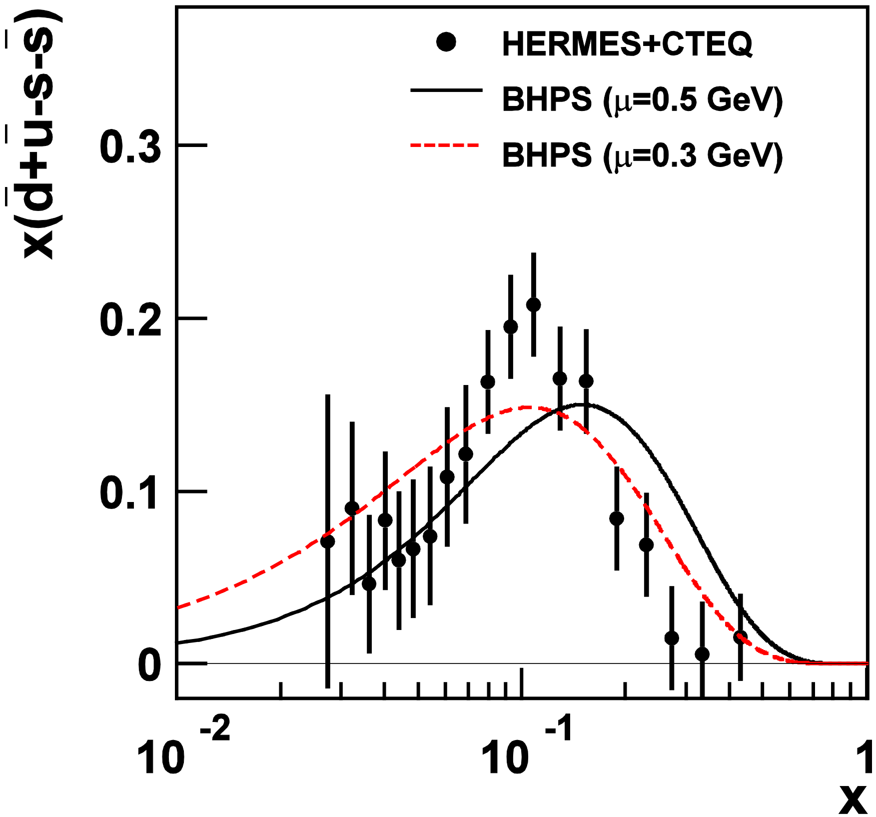
$s(x)+\bar{s}(x)$ from HERMES kaon SIDIS data at $\langle Q^2 \rangle = 2.5\ \text{GeV}^2$

Assume $x > 0.1$ data are dominated by intrinsic sea (and $x < 0.1$ are from QCD sea)

This allows the extraction of the intrinsic sea for strange quarks

$$P_5^{uuds\bar{s}} = 0.024$$

Comparison between the $\bar{u}(x)+\bar{d}(x)-s(x)-\bar{s}(x)$ data with the intrinsic 5-q model



(W. Chang and JCP, PL B704, 197)

$\bar{d}(x)+\bar{u}(x)$ from CTEQ6.6

$s(x)+\bar{s}(x)$ from HERMES

$$\bar{u}+\bar{d}-s-\bar{s}$$

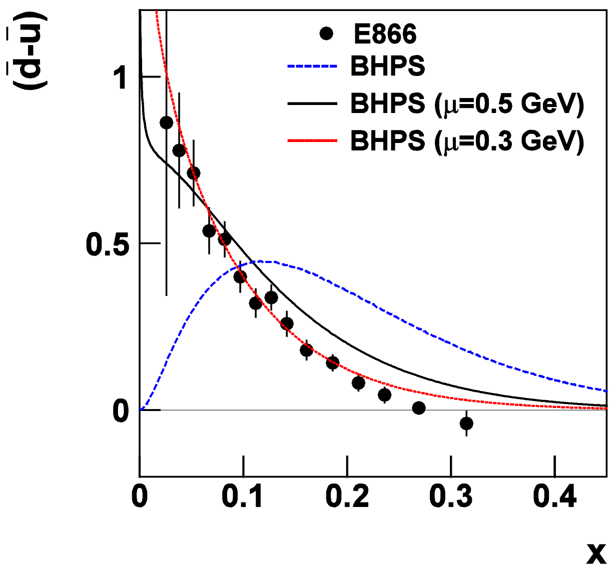
$$\sim P_5^{uudu\bar{u}}+P_5^{uudd\bar{d}}-2P_5^{uuds\bar{s}}$$

(not sensitive to extrinsic sea)

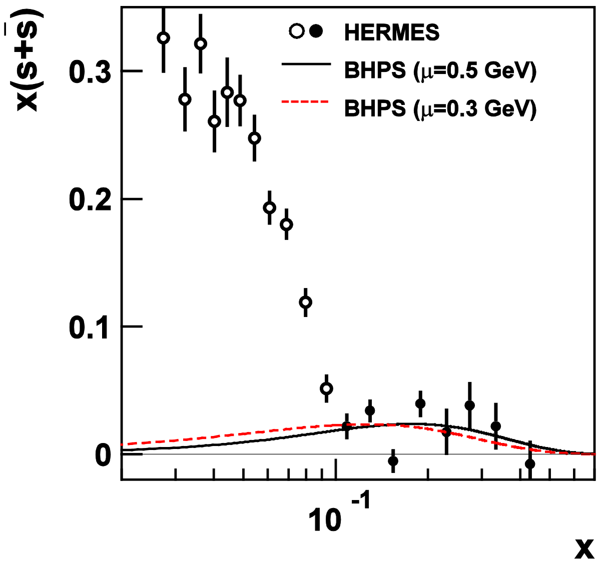
A valence-like distribution peaking at $x \sim 0.1$ is observed

$$P_5^{uudu\bar{u}}+P_5^{uudd\bar{d}}-2P_5^{uuds\bar{s}}=0.314$$

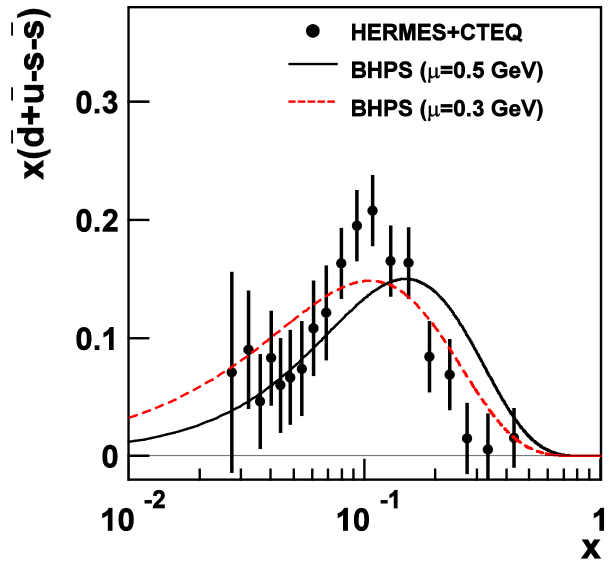
Extraction of the various five-quark components for light quarks



$$P_5^{uudd\bar{d}} - P_5^{uudu\bar{u}} = 0.118$$



$$P_5^{uuds\bar{s}} = 0.024$$

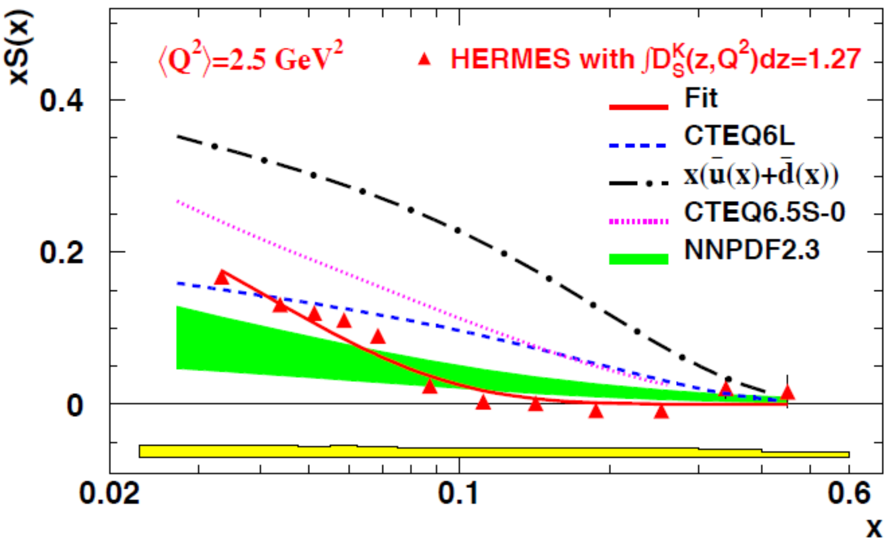


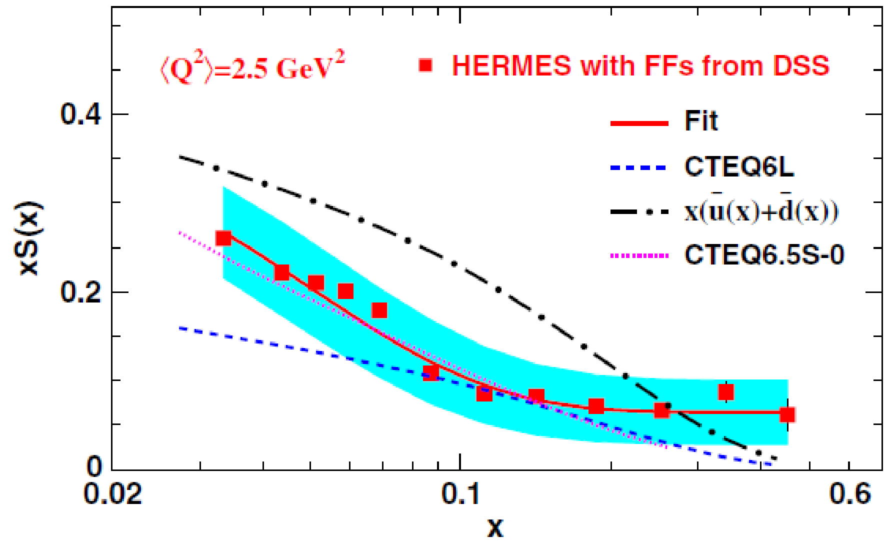
$$P_5^{uudu\bar{u}} + P_5^{uudd\bar{d}} - 2P_5^{uuds\bar{s}} = 0.314$$

$$P_5^{uudd\bar{d}} = 0.240; \;\; P_5^{uudu\bar{u}} = 0.122; \;\; P_5^{uuds\bar{s}} = 0.024$$

Later HERMES result on $xS(x)$

PHYSICAL REVIEW D **89**, 097101 (2014)





xS(x) obtained with HERMES kaon fragmentation function

xS(x) obtained with DSS kaon fragmentation function

Extraction of xS(x), and intrinsic strange-quark sea, from SIDIS depends sensitively on the kaon fragmentation functions

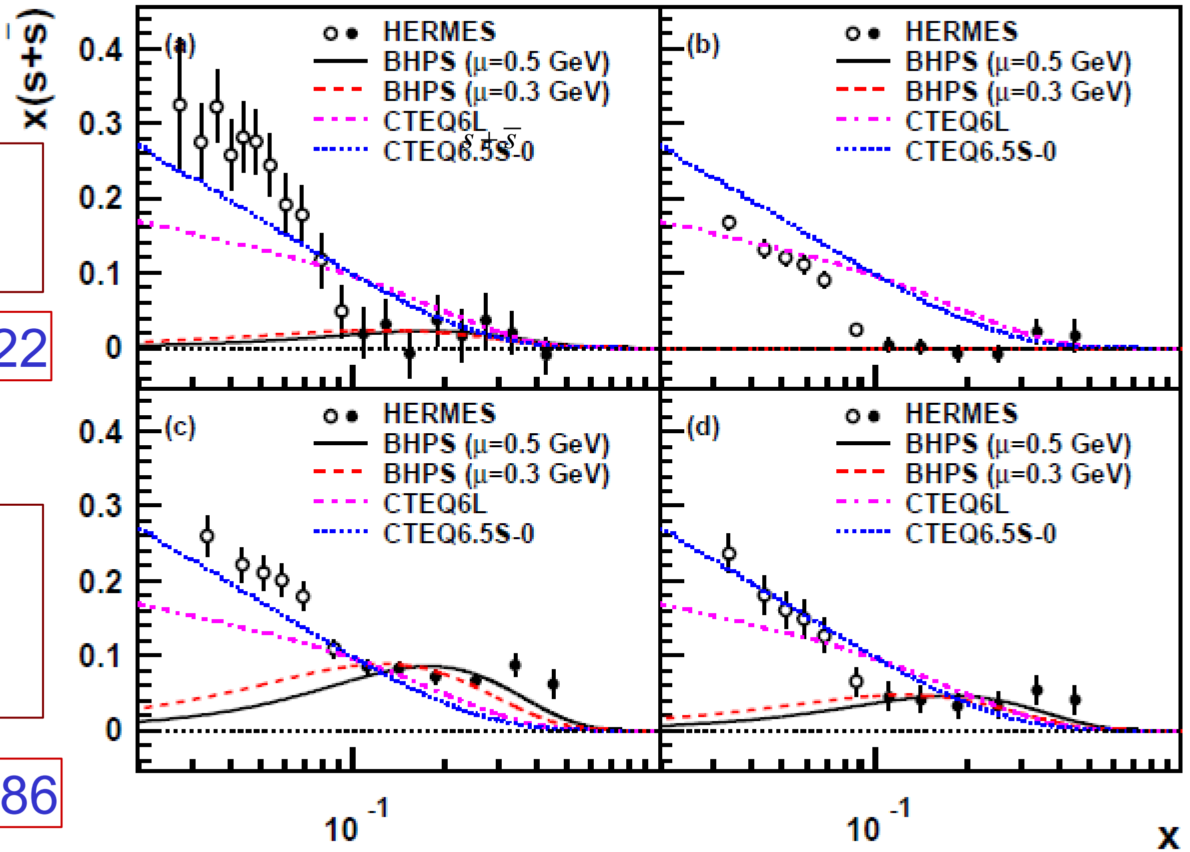
Dependence of $s+\bar{s}$ extraction on the kaon fragmentation functions

2008 HERMES

$P_5^{uuds\bar{s}}$=0.022

2014 HERMES DSS FF

$P_5^{uuds\bar{s}}$=0.086



2014 HERMES

$P_5^{uuds\bar{s}}$=0.00

2014 HERMES Intermediate FF

$P_5^{uuds\bar{s}}$=0.046

Wen-Chen Chang and JCP, PRD 92, 054020 (2015)

Need more SIDIS kaon production data at JLab22

Summary

- Evidences for the existence of "intrinsic" light-quark seas $(\bar{u}, \bar{d}, \bar{s})$ in the nucleons.
- Clear evidence for intrinsic charm remains to be found.
- SIDIS with charm-meson production at JLab22 might provide new input for intrinsic charm.
- New measurements for the strange-quark distributions at fixed-target energies are needed.
- Future SIDIS with kaon production at JLab22 could provide crucial new information on intrinsic strange sea.