Five-Quark Components of the Proton from Drell-Yan and Semi-Inclusive DIS

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In collaboration with Wen-Chen Chang

Outline

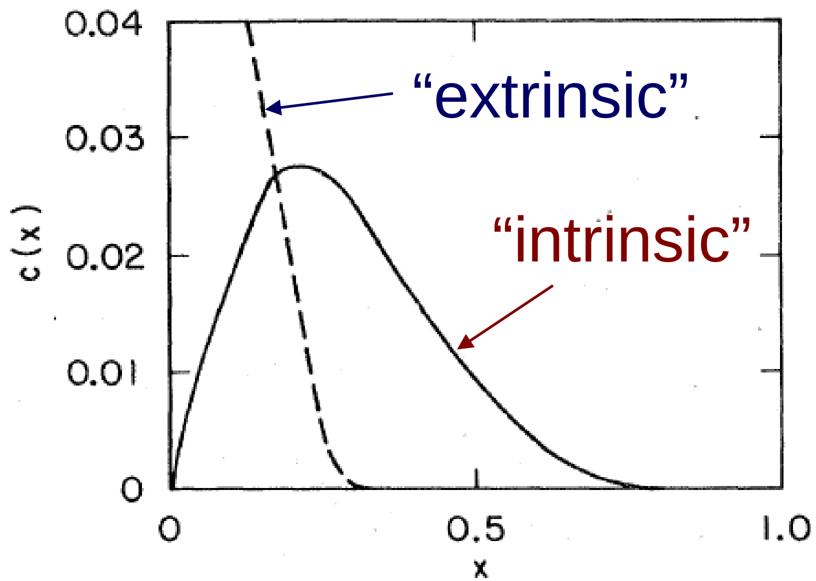
- Search for “intrinsic charm” in the nucleons
- Evidence for “intrinsic” up, down, and strange sea in the nucleons from Drell-Yan and semi-inclusive DIS experiments
- Extraction of five-quark components of the nucleons
- Implication for intrinsic charm and future experiments

Search for the "intrinsic" quark sea

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

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

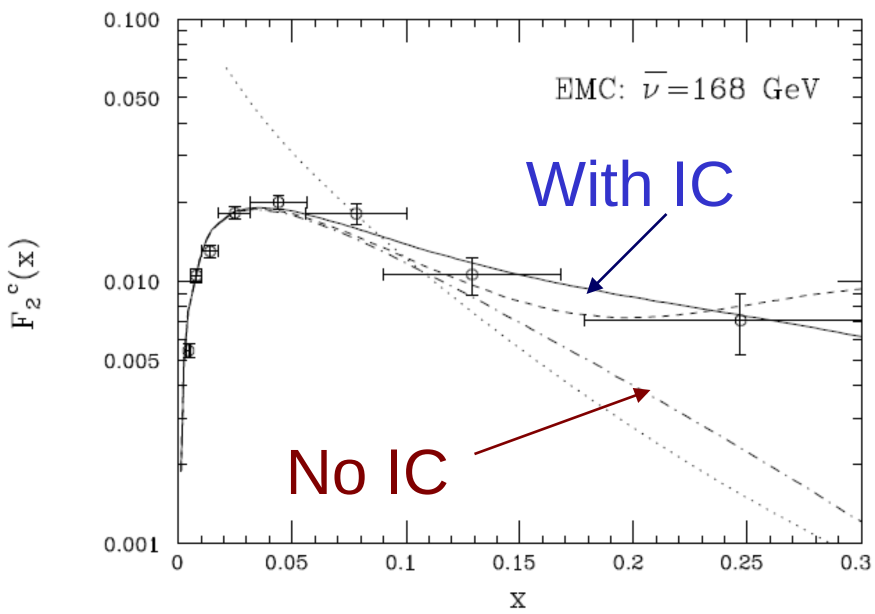
The "intrinsic"-charm from $|uudc\bar{c}\rangle$ is "valence"-like and peak at large x unlike the "extrinsic" sea ($g \to c\bar{c}$)



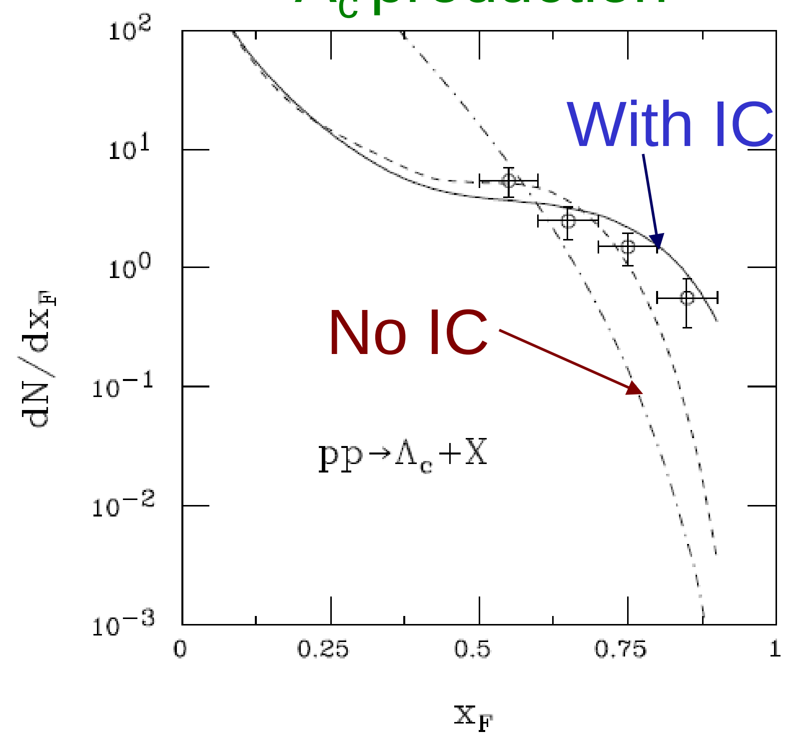
The $|uudc\bar{c}\rangle$ intrinsic-charm can lead to large contribution to charm production at large x

Evidence for the "intrinsic" charm (IC)

DIS data



Λ_c production



Gunion and Vogt (hep-ph/9706252)

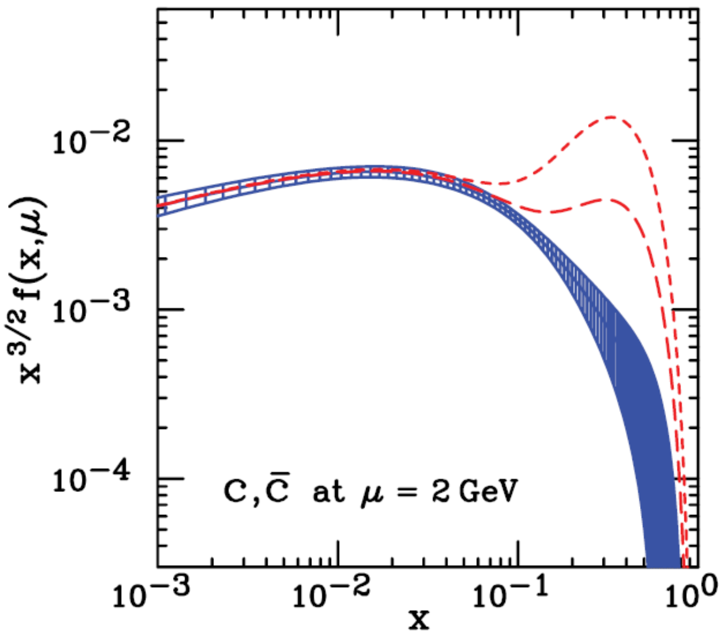
(Evidence is subjected to the uncertainties of charmed-quark parametrization in the PDF)

A global fit by CTEQ to extract intrinsic-charm

PHYSICAL REVIEW D 75, 054029 (2007)

Charm parton content of the nucleon

J. Pumplin,[1,*] H. L. Lai,[1,2,3] and W. K. Tung[1,2]



Blue band corresponds to CTEQ6 best fit, including uncertainty

Red curves include intrinsic charm of 1% and 3% (χ^2 changes only slightly)

We find that the range of IC is constrained to be from zero (no IC) to a level 2 – 3 times larger than previous model estimates. The behaviors of typical charm distributions within this range are described, and their implications for hadron collider phenomenology are briefly discussed.

No conclusive evidence for intrinsic-charm

Search for the lighter "intrinsic" quark sea

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

No conclusive experimental evidence
for intrinsic-charm so far

Are there experimental evidences for the intrinsic

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

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

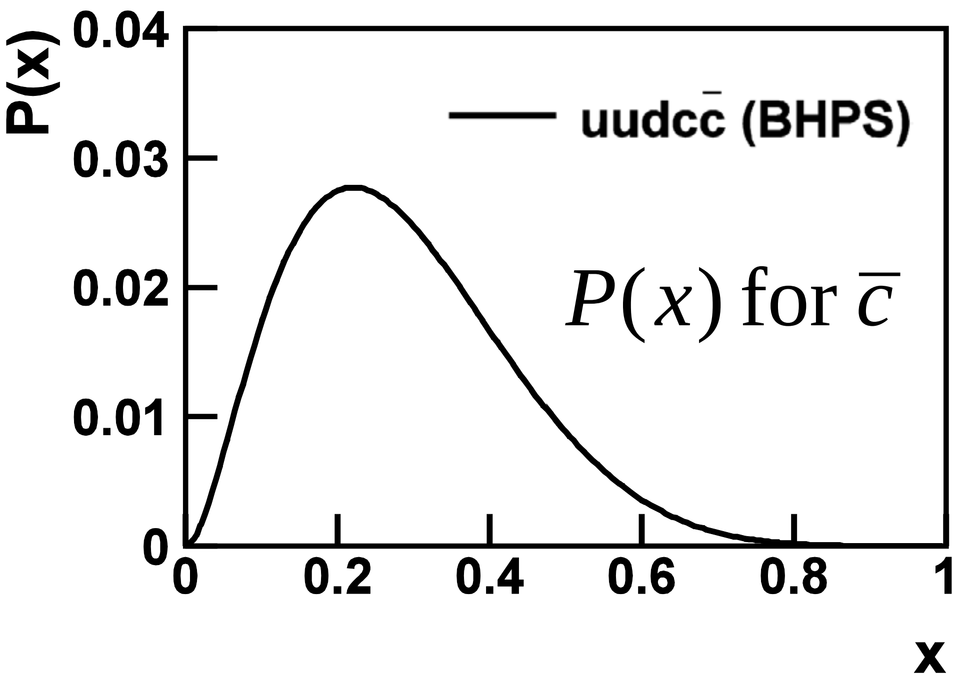
The 5-quark states for lighter
quarks have larger probabilities!

x-distribution for "intrinsic" charm

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

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):

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

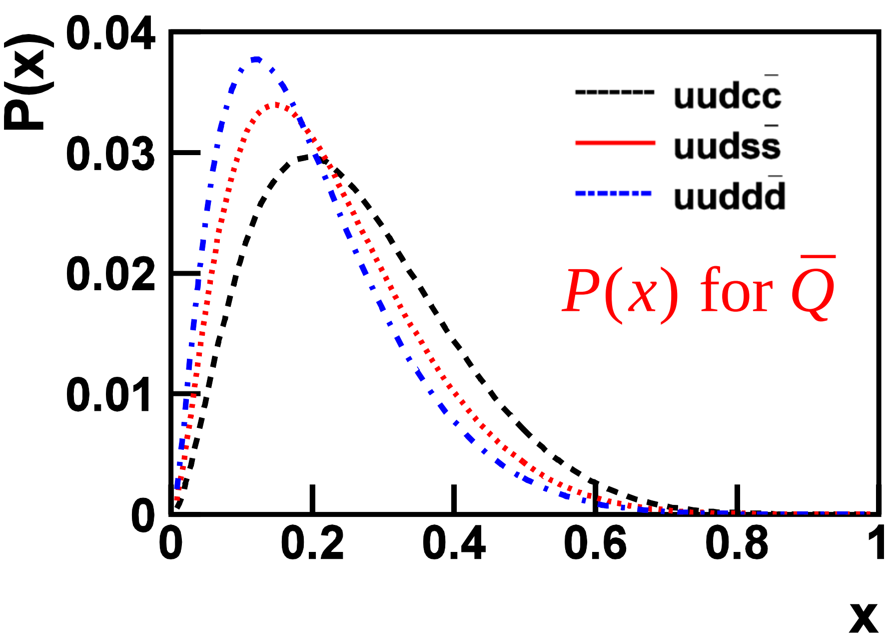
An analytical expression for *P(x)* is obtained

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

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



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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”
- “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*

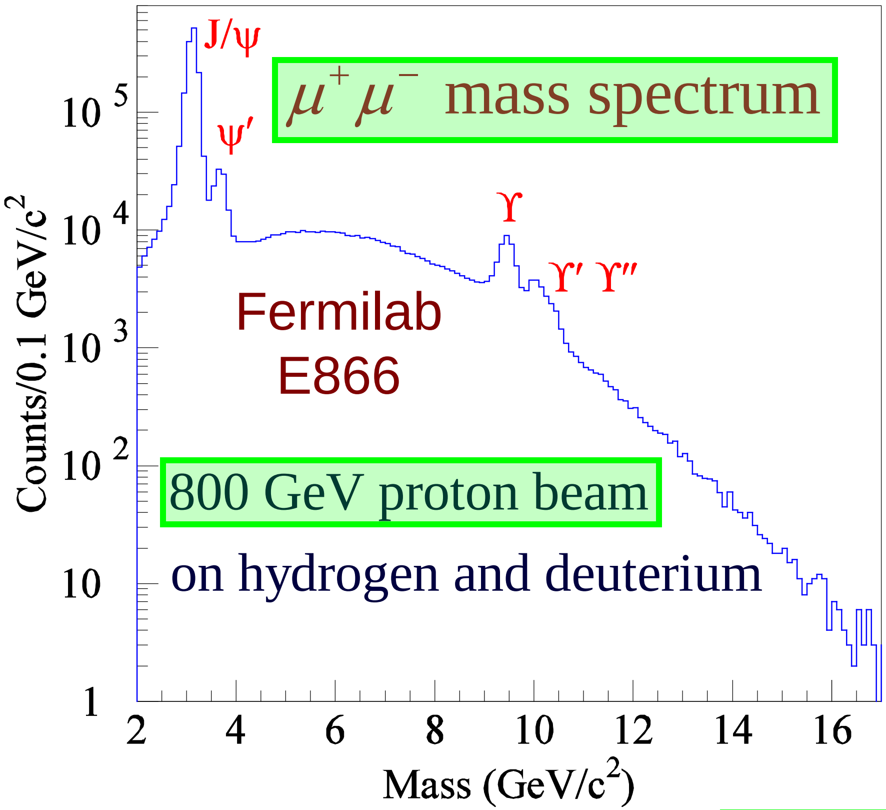
How to separate the "intrinsic sea" from the "extrinsic sea"?

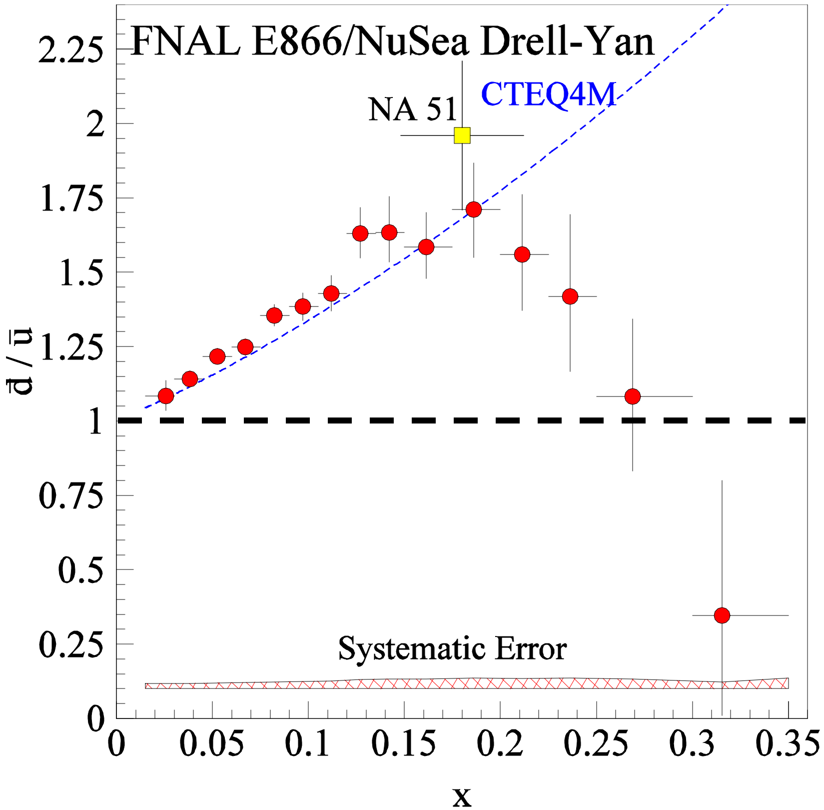
- Select experimental observables which have no contributions from the "extrinsic sea"

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

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

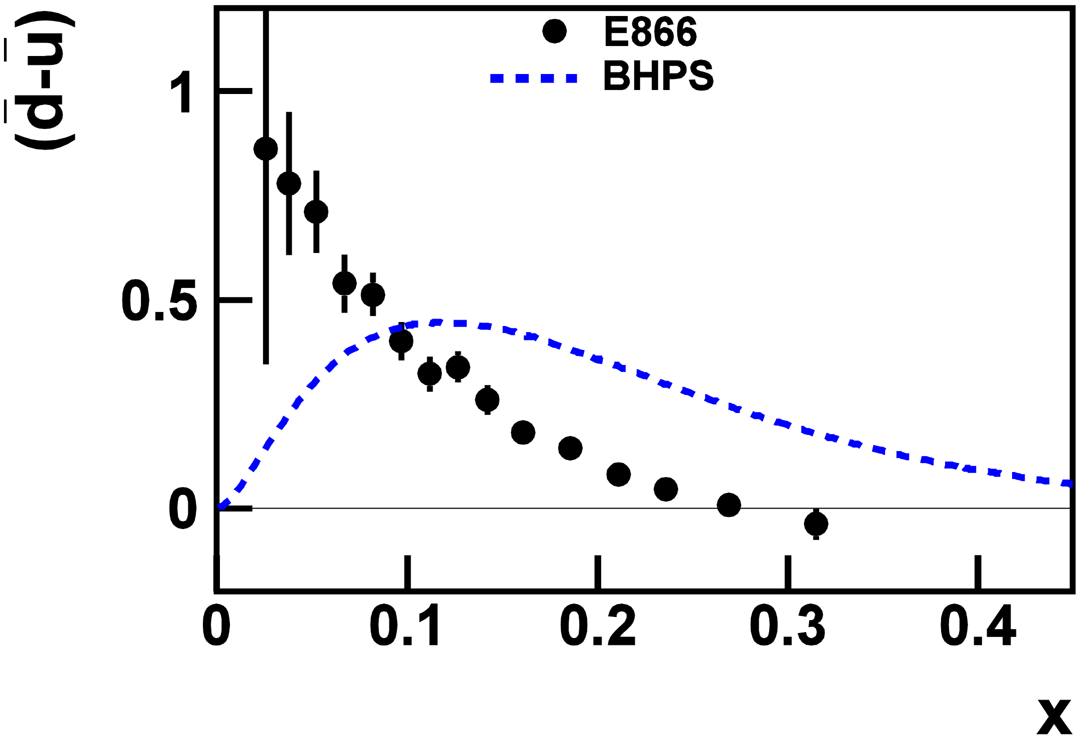
$$\left(\frac{d^2\sigma}{dx_1 dx_2}\right)_{D.Y.} = \frac{4\pi\alpha^2}{9sx_1x_2}\sum_a e_a^2\left[q_a(x_1)\bar{q}_a(x_2)+\bar{q}_a(x_1)q_a(x_2)\right]$$





$at\ \ x_1 > x_2:$ Drell-Yan: $\sigma^{pd}/2\sigma^{pp} \sim \frac{1}{2}(1+\bar{d}(x_2)/\bar{u}(x_2))$

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

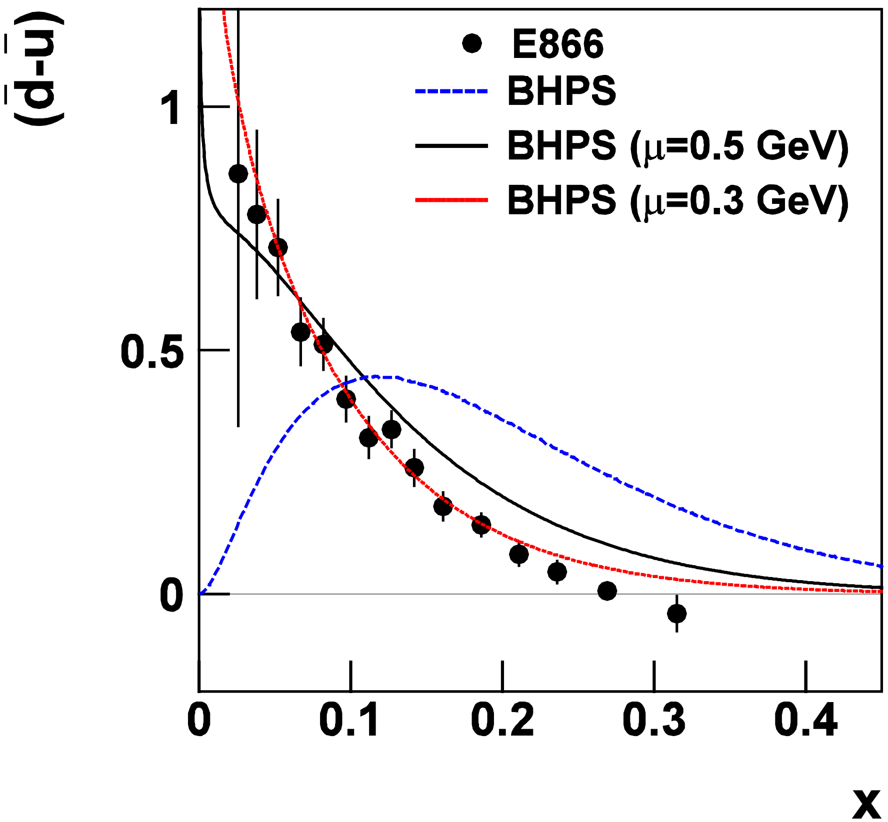


The data have very different shape compared to the BHPS 5-q model

E866 data measured at $\langle Q^2 \rangle = 54\ \mathrm{GeV}^2$

Need to evolve the 5-q model prediction from the initial scale μ to Q^2=54 GeV^2

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



(W. Chang and JCP , PRL 106, 252002 (2011))

The data are in good agreement with the 5-q 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

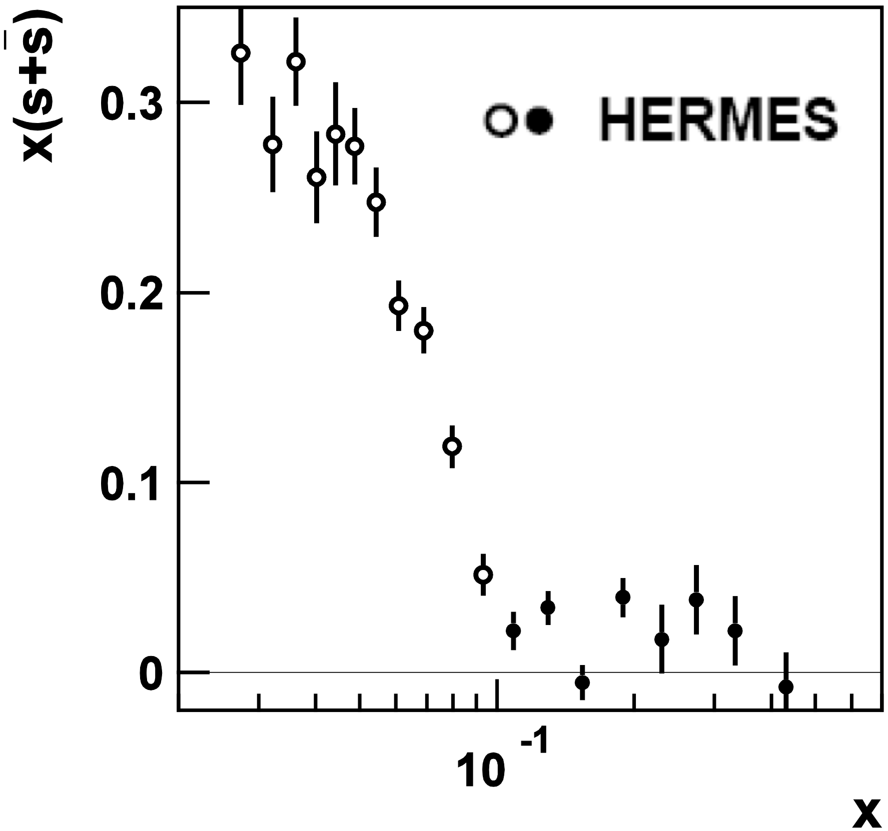
$$P_5^{uudd\bar{d}} - P_5^{uudu\bar{u}} = 0.118$$

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

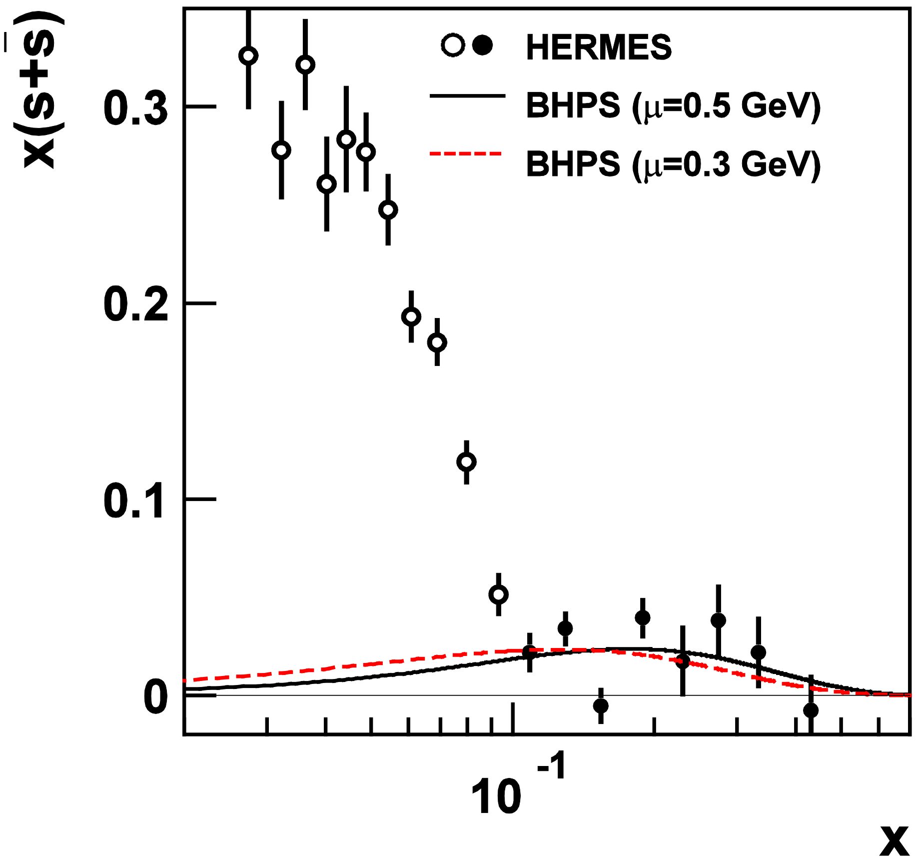


$s(x)+\bar{s}(x)$ from HERMES kaon SIDIS data at $\langle Q^2 \rangle = 2.5\ \mathrm{GeV}^2$

The data appear to consist of two different components (intrinsic and extrinsic?)

HERMES collaboration, Phys. Lett. B666, 446 (2008)

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



(W. Chang and JCP, PL B704, 197(2011))

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

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

This allows the extraction of the intrinsic sea for strange quarks

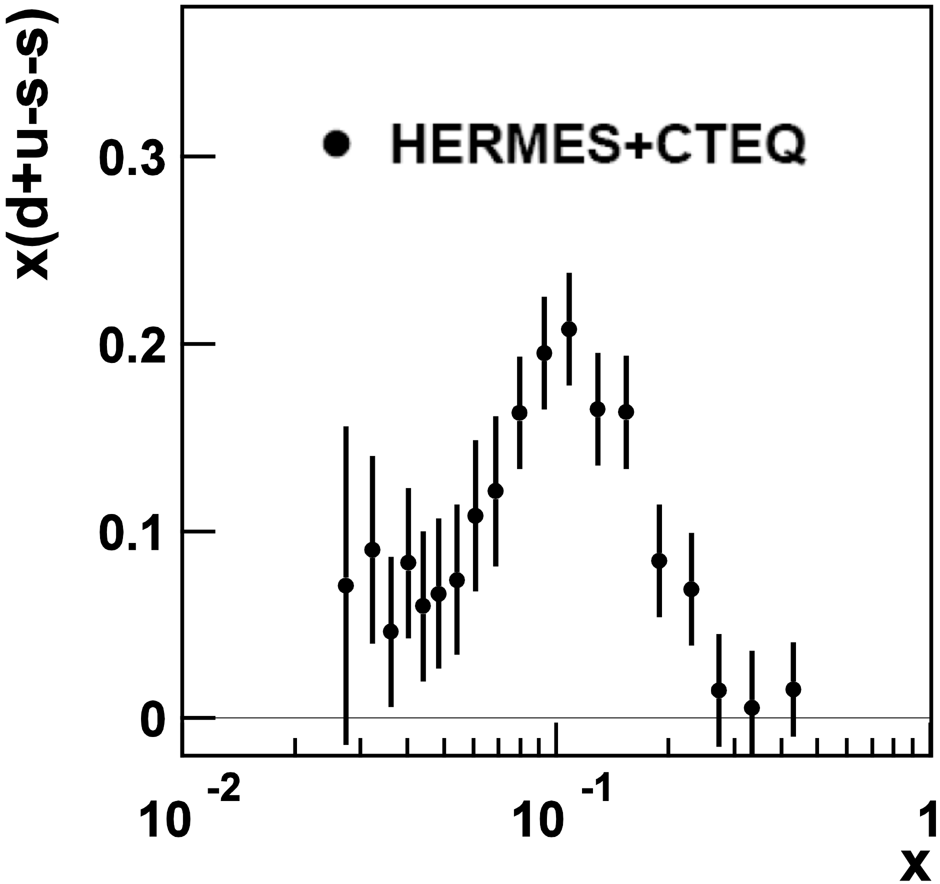
$$P_5^{uuds\bar{s}} = 0.024$$

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

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

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

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



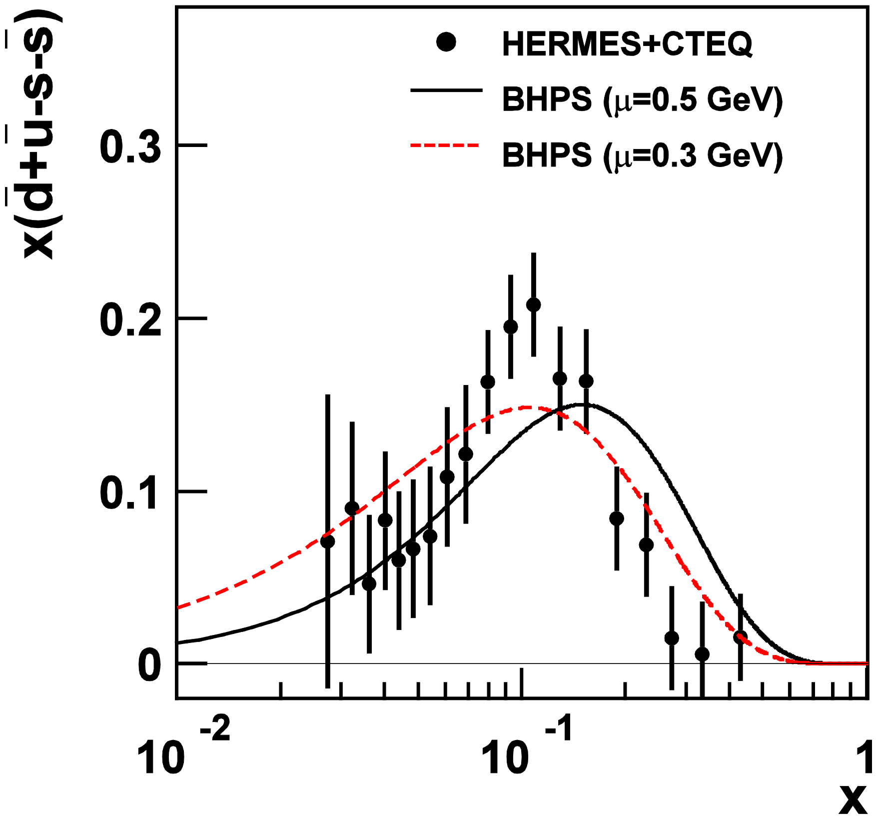
$\bar{d}(x)+\bar{u}(x)$ from CTEQ6.6

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

> $\bar{u}+\bar{d}-s-\bar{s}$ has no contribution from extrinsic sea

A valence-like *x*-distribution is observed

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



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

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

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

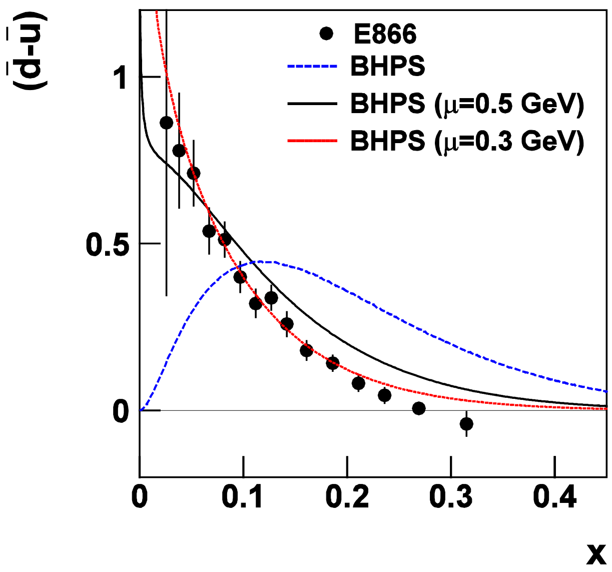
$$\sim P_5^{uudu\bar{u}}+P_5^{uudd\bar{d}}-2P_5^{uuds\bar{s}}$$

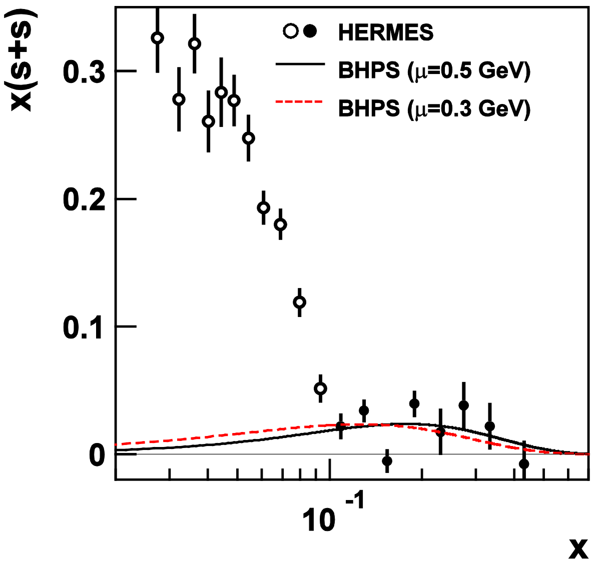
(not sensitive to extrinsic sea)

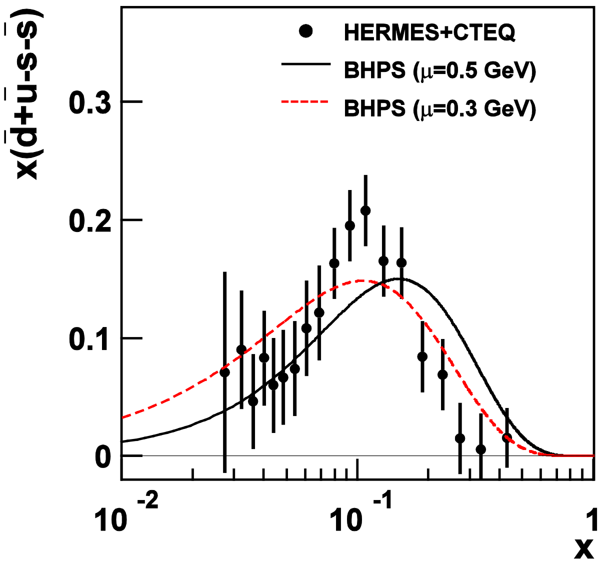
(W. Chang and JCP, PL B704, 197(2011))

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

Extraction of the various five-quark components for light quarks







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

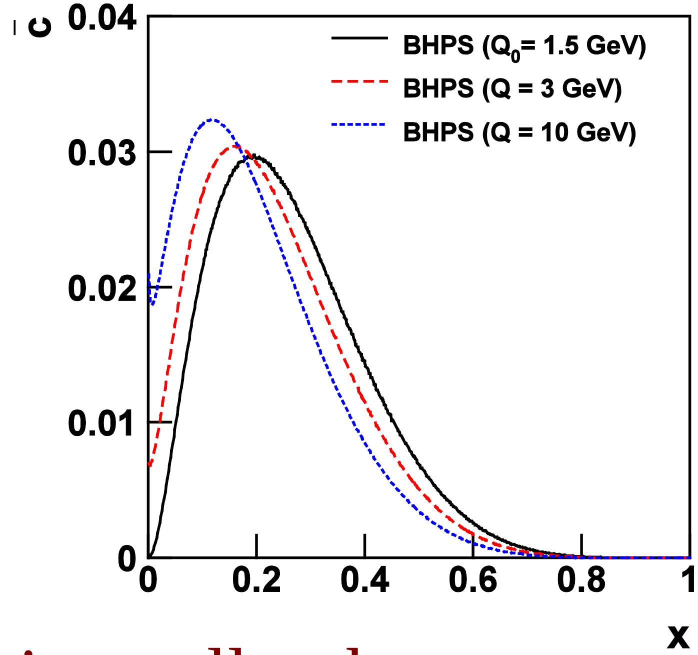
$P_5^{uuds\bar{s}} = 0.024$

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

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

Possible implications on the intrinsic charm

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



Assuming

$$P_5^{uudQ\bar{Q}} \sim 1/m_Q^2$$

then

$$P_5^{uudc\bar{c}} \sim 0.1 P_5^{uuds\bar{s}} \sim 0.003$$

- Probability of intrinsic-charm is smaller than expected
- Evolution would shift the intrinsic-charm distribution to smaller-x

Future Prospect (Theoretical)

- Intrinsic sea for hyperons and mesons?
- Intrinsic gluons in the nucleons (Hoyer and Roy)?
- Connection between the 5-quark model and the meson-cloud model and lattice QCD calculations?
- Spin-dependent observables of intrinsic sea?

Future Prospect (Experimental)

- dbar-ubar is being measured for large *x* region at the Fermilab E906 Drell-Yan experiment.
- Kaon production in SIDIS at COMPASS and 12 GeV Jlab/EIC for additional information on s and s-bar?
- Kaon-induced Drell-Yan at COMPASS for probing s and s-bar?
- Open-charm production at forward rapidity at RHIC and LHC.
- J/ψ production at forward x_F in p-A collision.

Conclusion

- Existing data on the sea-quark distributions are consistent with the presence of intrinsic light-quark sea.
- Probabilities for the intrinsic *u*, *d*, and *s* quarks can be determined from data which are not sensitive to extrinsic sea.
- Evidence for intrinsic charm remains to be better established with more accurate data (due to smaller probability for the intrinsic charm).