Fixed-Target Dimuon Experiments at Fermilab with Proton Beams

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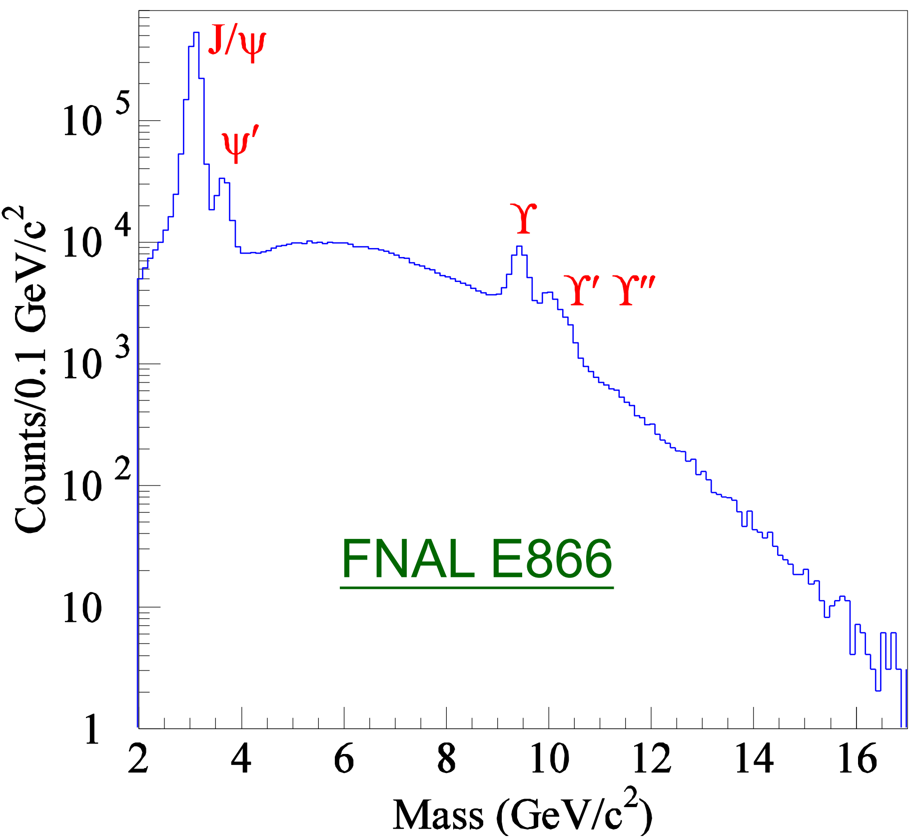
ECT* Workshop on "Physics at A Fixed Target ExpeRiment (AFTER) using the LHC beams"
Trento, Feb. 3-13, 2013

Outline

- Highlights from the Fermilab dimuon experiments
- Physics opportunities at AFTER with dilepton experiments

Dilepton production in hadron-hadron collision

$p + p(d) \rightarrow \mu^+\mu^- x$ *at 800 GeV/c*



Two components in the dilepton mass spectrum

(a) Continuum: Drell-Yan process

- Electromagnetic process
- Quark - antiquark annihilation

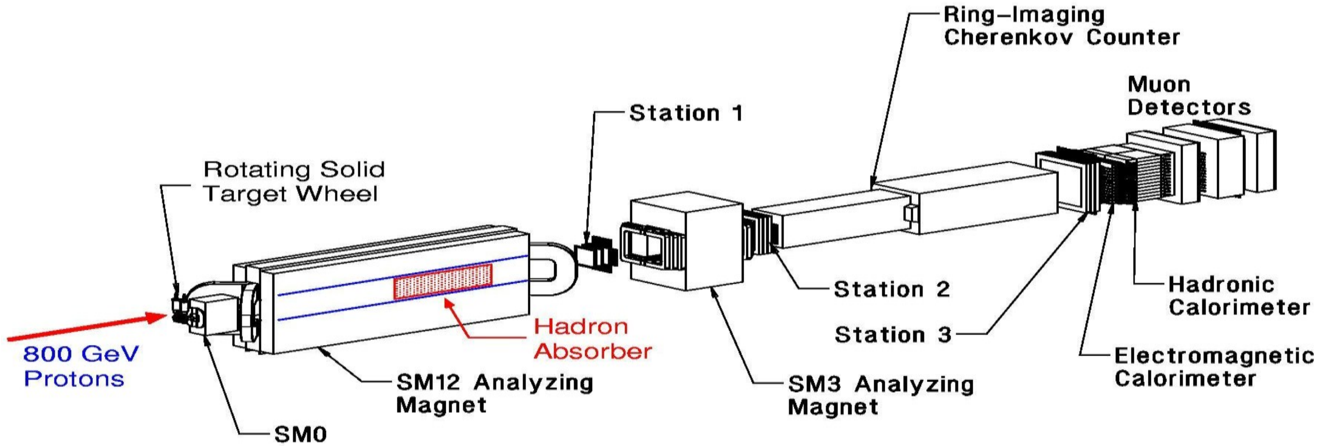
(b) Vector mesons: J/ψ, Y

- Strong interaction
- Gluon - gluon fusion

  (quark - antiquark annihilation)

Fermilab Dimuon Spectrometer

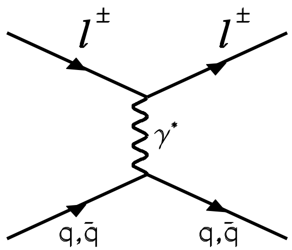
(E605 / 772 / 789 / 866 / 906)

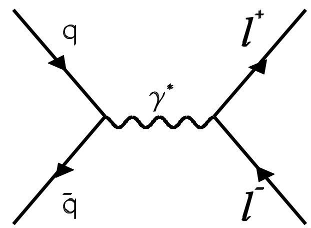


1) Fermilab E772 (proposed in 1986 and completed in 1988)
   "Nuclear Dependence of Drell-Yan and Quarkonium Production"
2) Fermilab E789 (proposed in 1989 and completed in 1991)
   "Search for Two-Body Decays of Heavy Quark Mesons"
3) Fermilab E866 (proposed in 1993 and completed in 1996)
   "Determination of $\bar{d}\,/\,\bar{u}$ Ratio of the Proton via Drell-Yan"
4) Fermilab E906 (proposed in 1999, run started in 2012)
   "Drell-Yan with the FNAL Main Injector"

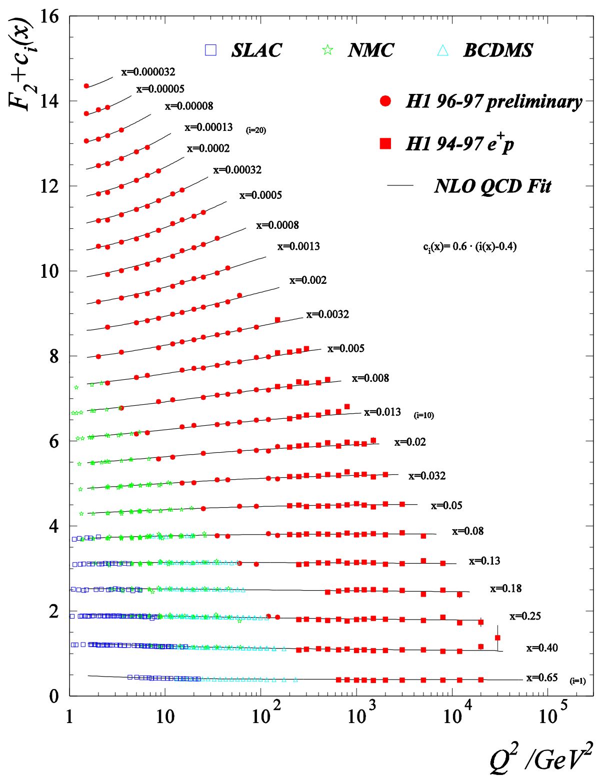
Complimentality between DIS and Drell-Yan

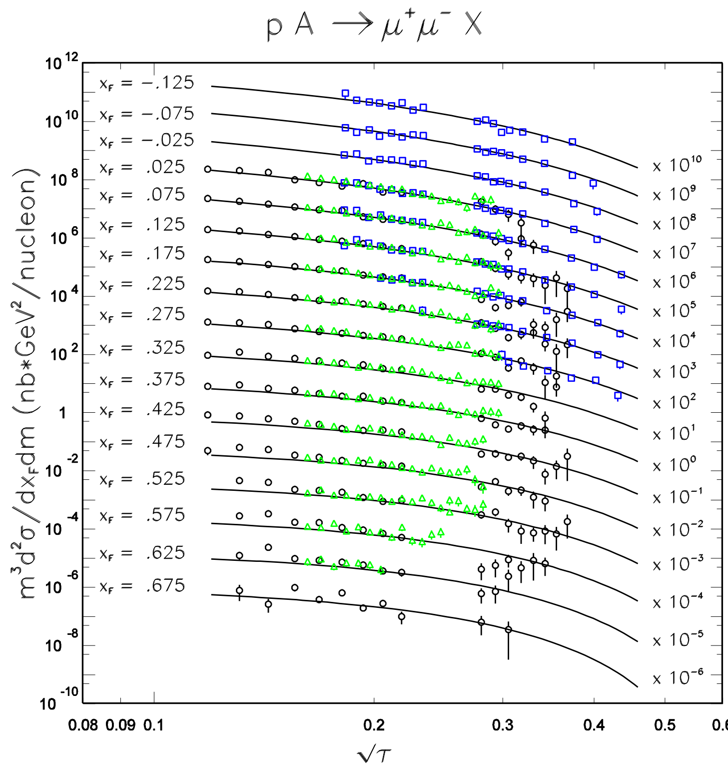
DIS





Drell-Yan



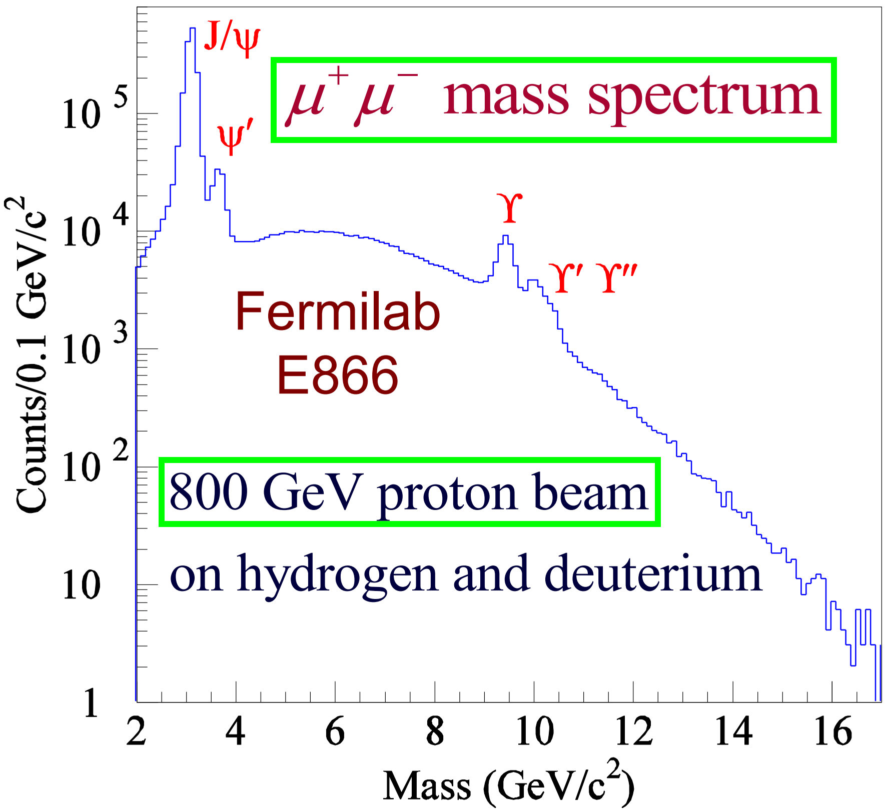


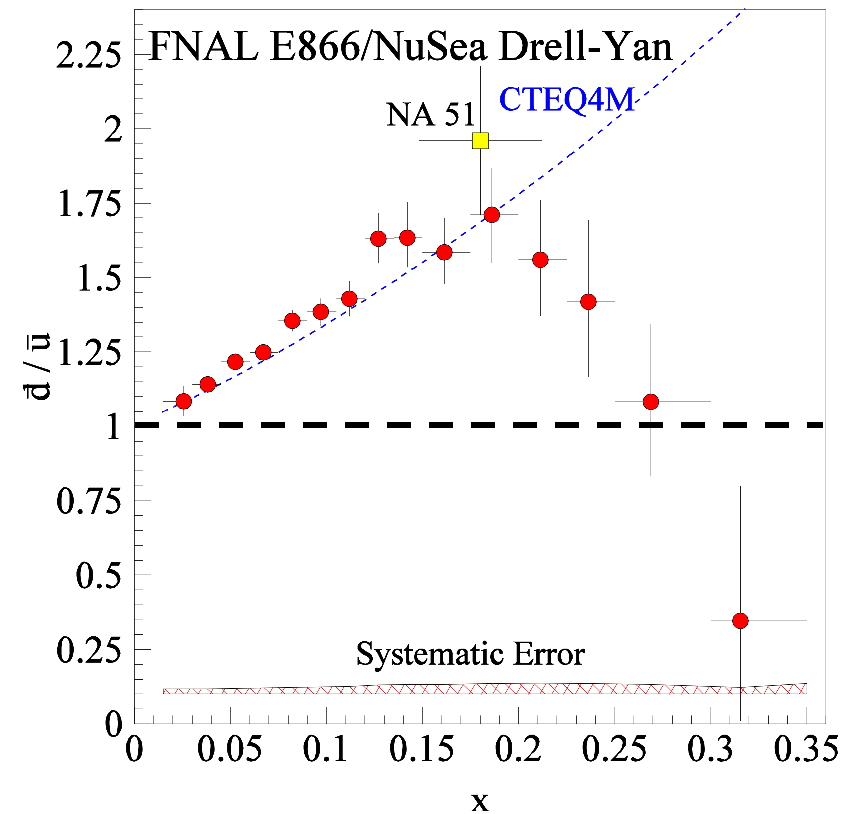
McGaughey, Moss, JCP, Ann.Rev.Nucl. Part. Sci. 49 (1999) 217

Both DIS and Drell-Yan process are tools to probe the quark and antiquark structure in hadrons (factorization, universality)

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

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

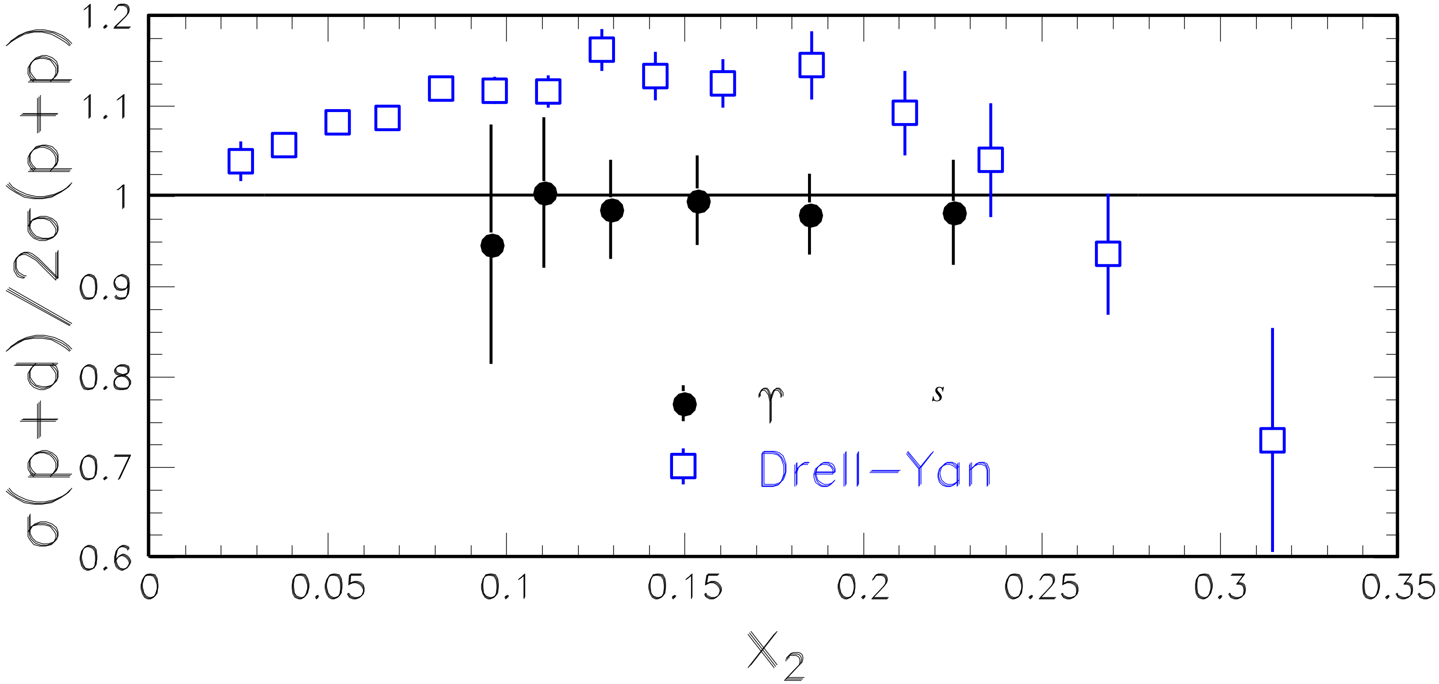




at $x_1 > x_2$: Drell-Yan: $\sigma^{pd}/2\sigma^{pp} \sim \frac{1}{2}\left(1+\bar{d}(x_2)/\bar{u}(x_2)\right)$

Gluon distributions in proton versus neutron?

$$\text{E866 data}: \sigma(p+d \rightarrow \Upsilon X)/2\sigma(p+p \rightarrow \Upsilon X)$$



Lingyan Zhu et al., PRL, 100 (2008) 062301 (arXiv: 0710.2344)

$$Drell-Yan: \quad \sigma^{pd}/2\sigma^{pp} \simeq [1+\bar{d}(x)/\bar{u}(x)]/2$$

$$J/\Psi, \Upsilon: \quad \sigma^{pd}/2\sigma^{pp} \simeq [1+g_n(x)/g_p(x)]/2$$

If gluon distributions in proton and neutron are different, then charge-symmetry is violated at the partonic level

Charge Symmetry Violation in PDF?

- Charge symmetry : rotation around isospin axis I_y by 180°

  $p \leftrightarrow n \quad u \leftrightarrow d \quad \bar{u} \leftrightarrow \bar{d} \quad (u_p = d_n;\ \bar{u}_p = \bar{d}_n\ etc.)$

- Charge symmetry in PDF is generally assumed, but not tested

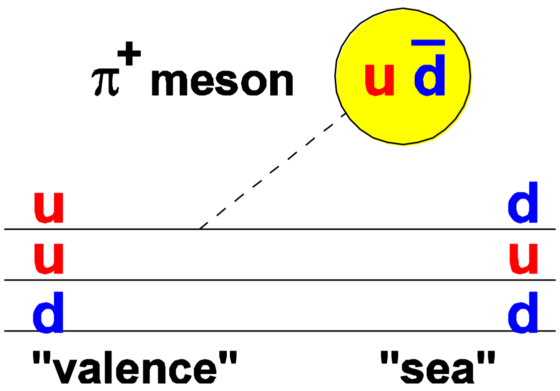
  A comparison of F_2^{ν} with F_2^{γ} shows upper limit of CS breaking of 5 – 10% (Londergan and Thomas, hep-ph/0407247)

- The NuTeV anomaly in the Weinberg angle could be partly explained by charge symmetry violation (Londergan and Thomas, PL B558 (2003) 132)

See recent review of Charge Symmetry violation:
Londergan, Peng, and Thomas (Rev. Mod. Phy. **82 (2010) 2009**)

Origins of $\bar{u}(x) \neq \bar{d}(x)$?

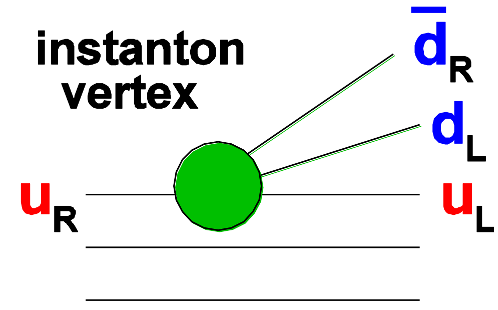
Meson Cloud Models



Chiral-Quark Soliton Model

- nucleon = chiral soliton
- expand in 1/*Nc*
- Quark degrees of freedom in a pion mean-field

Instantons



Theory: Thomas, Miller, Kumano, Ma, Londergan, Henley, Speth, Hwang, Melnitchouk, Liu, Cheng/Li, etc.

(For reviews, see Speth and Thomas (1997), Kumano (hep-ph/9702367), Garvey and Peng (nucl-ex/0109010))

Theses models also have implications on

- asymmetry between $s(x)$ and $\bar{s}(x)$
- flavor structure of the polarized sea

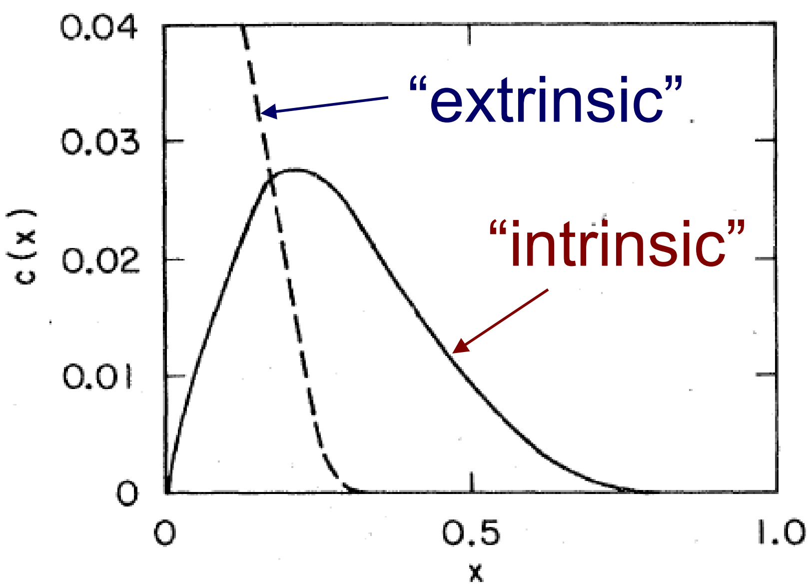
Meson cloud has significant contributions to sea-quark distributions

Implications on the "intrinsic" quark sea

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

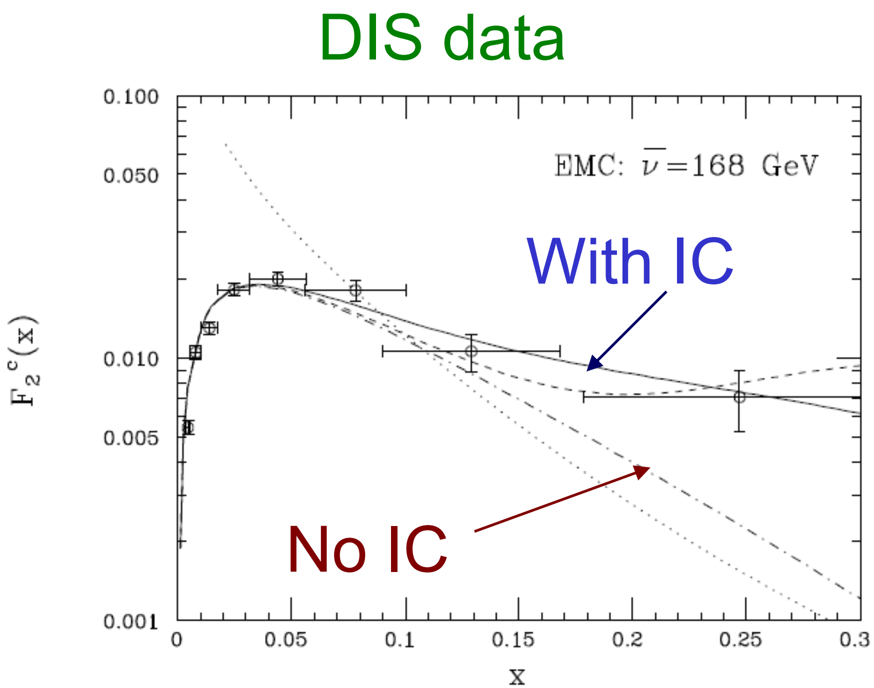
$$|p\rangle = P_{3q}\,|uud\rangle + P_{5q}\,|uudQ\bar{Q}\rangle + \cdots\cdots$$

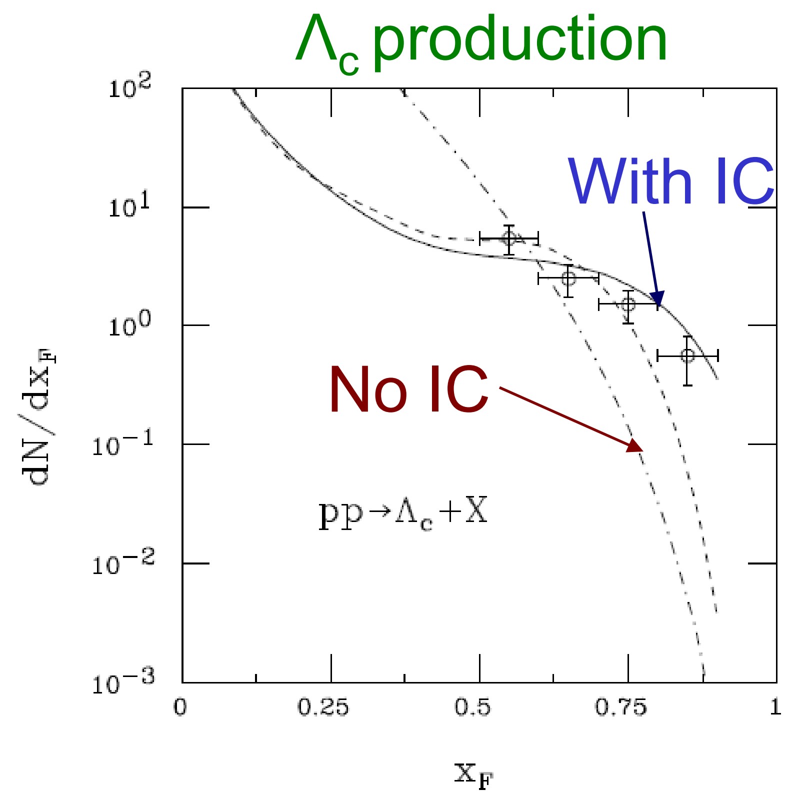
The "intrinsic"-charm from $|uudc\bar{c}\rangle$ is "valence"-like and peak at large x unlike the "extrinsic" sea ($g \to c\bar{c}$)



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

Evidence for the "intrinsic" charm (IC)





Gunion and Vogt (hep-ph/9706252)

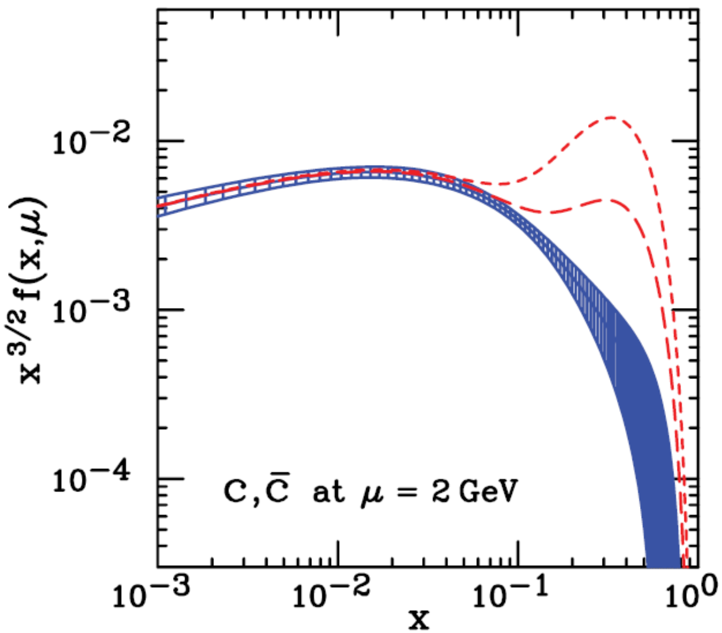
(Evidence is subjected to the uncertainties of charmed-quark parametrization in the PDF)

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!

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

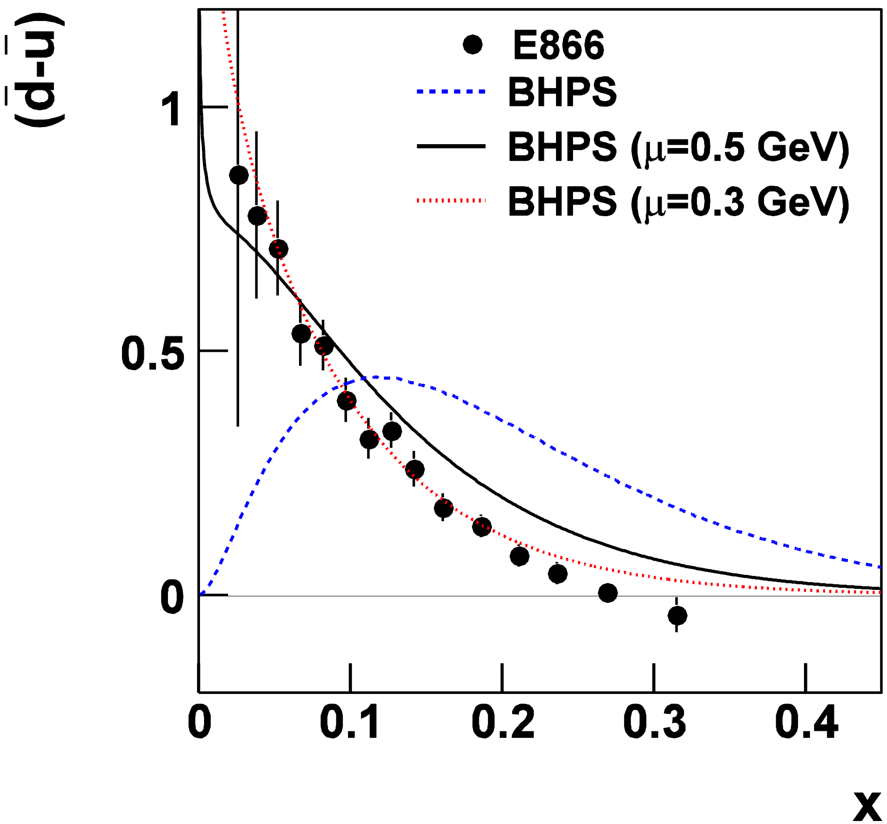
How to separate the “intrinsic sea” from the “extrinsic sea”?

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

$$\bar{d} - \bar{u} \text{ has no contribution from extrinsic sea } (g \rightarrow \bar{q} q)$$

$$\text{and is sensitive to "intrinsic sea" only}$$

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



The data are in good agreement with the 5-q model after evolution from the initial scale μ to Q^2=54 GeV^2

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

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

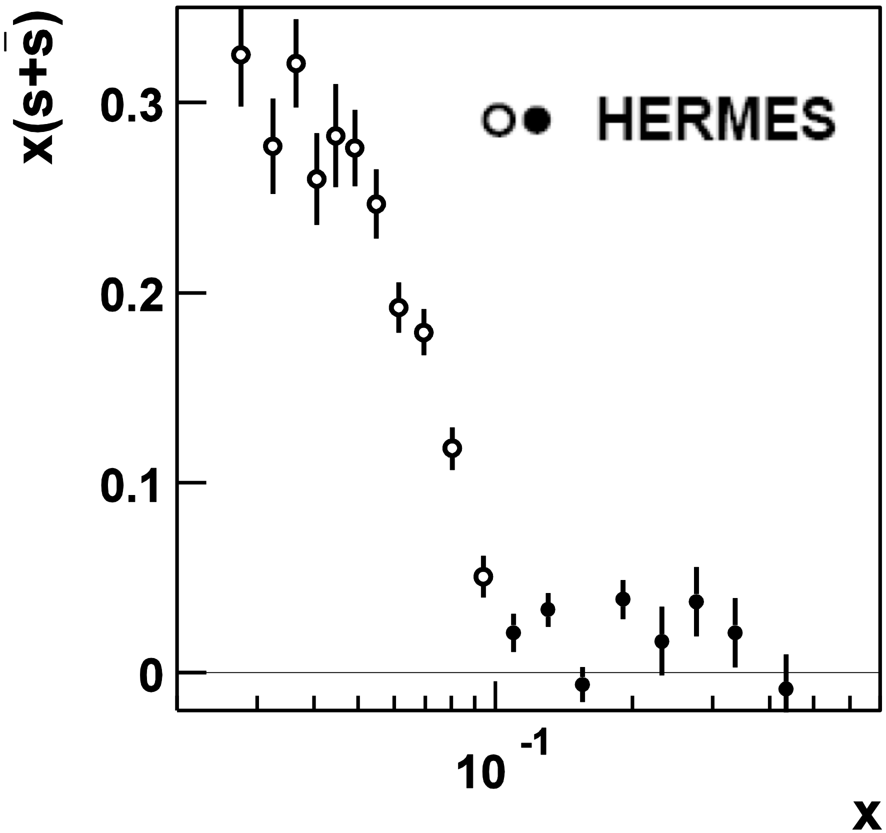
$$P_5^{uudd\bar{d}} - P_5^{uudu\bar{u}} = 0.118$$

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

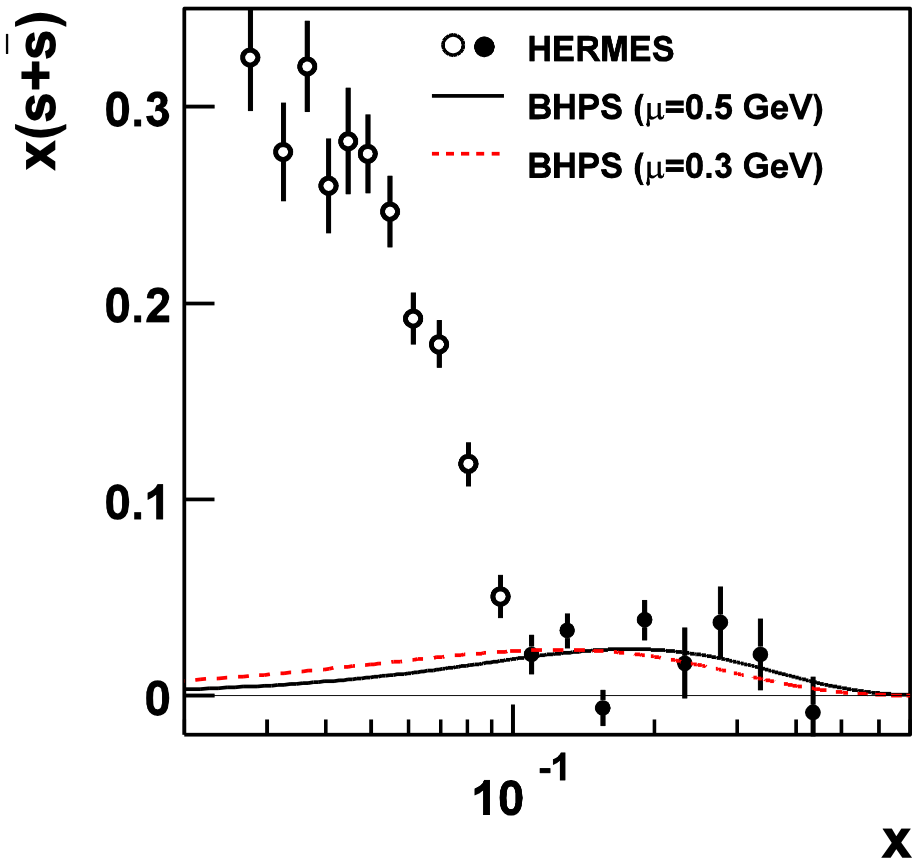


$s(x)+\bar{s}(x)$ from HERMES kaon SIDIS data at $\langle Q^2\rangle = 2.5\ \mathrm{GeV}^2$

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

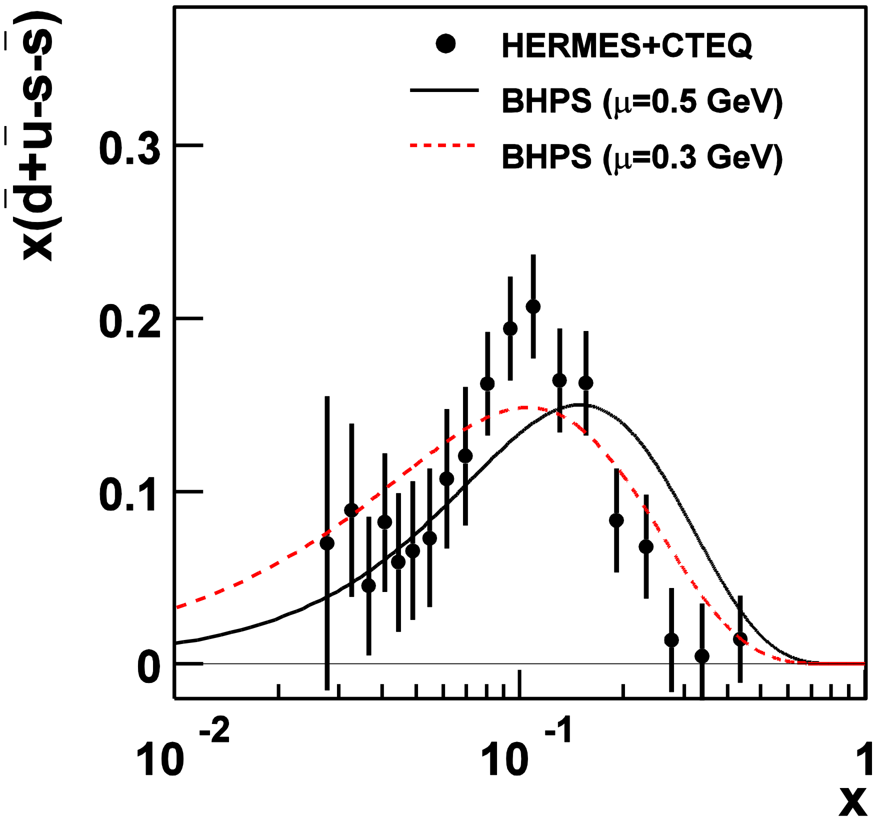
$$P_5^{uuds\bar{s}} = 0.024$$

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

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

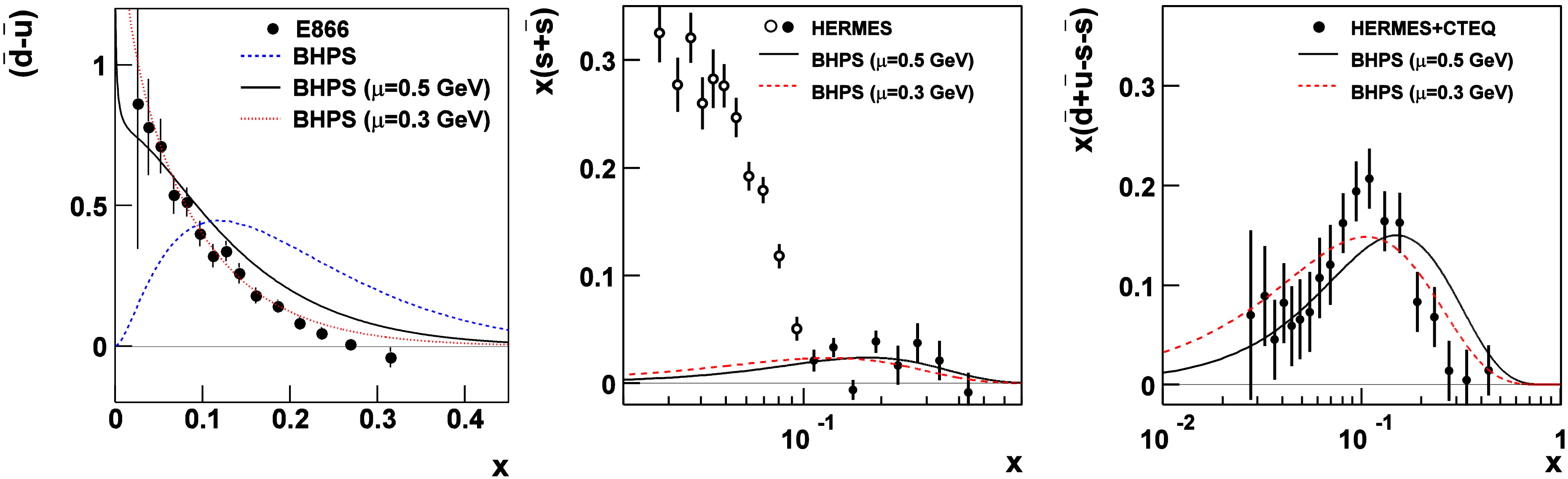
$$\sim P_5^{uudu\bar{u}}+P_5^{uudd\bar{d}}-2P_5^{uuds\bar{s}}$$

(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



$P_5^{uudd\bar{d}} - P_5^{uudu\bar{u}} = 0.118$ $\qquad P_5^{uuds\bar{s}} = 0.024$ $\qquad P_5^{uudu\bar{u}} + P_5^{uudd\bar{d}} - 2P_5^{uuds\bar{s}} = 0.314$

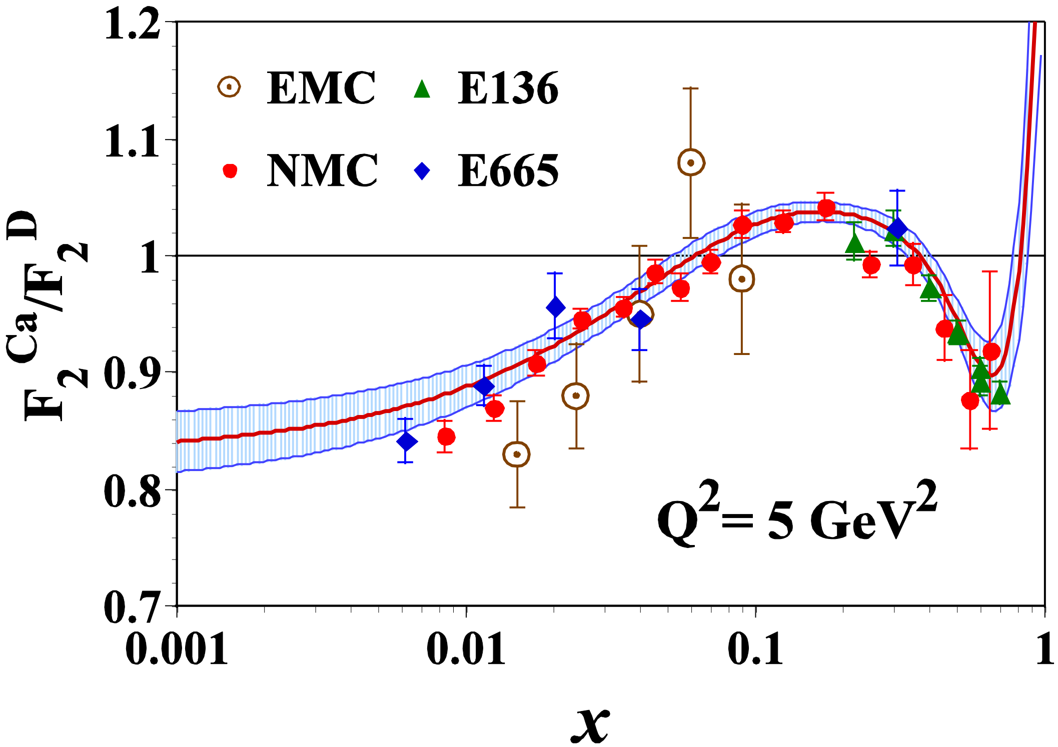
$$P_5^{uudd\bar{d}} = 0.240;\ P_5^{uudu\bar{u}} = 0.122;\ P_5^{uuds\bar{s}} = 0.024$$

Future Prospect (Experimental)

- Kaon production in SIDIS at COMPASS and 12 GeV Jlab/EIC for more information on s and s-bar?
- Kaon-induced Drell-Yan at COMPAS for probing s and s-bar?
- Open-charm and open-beauty production at forward rapidity at LHC to search for intrinsic charm and beauty.
- J/ψ and Upsilon production at forward x_F to search for intrinsic charm and beauty at AFTER?

Modification of Parton Distributions in Nuclei

EMC effect observed in DIS

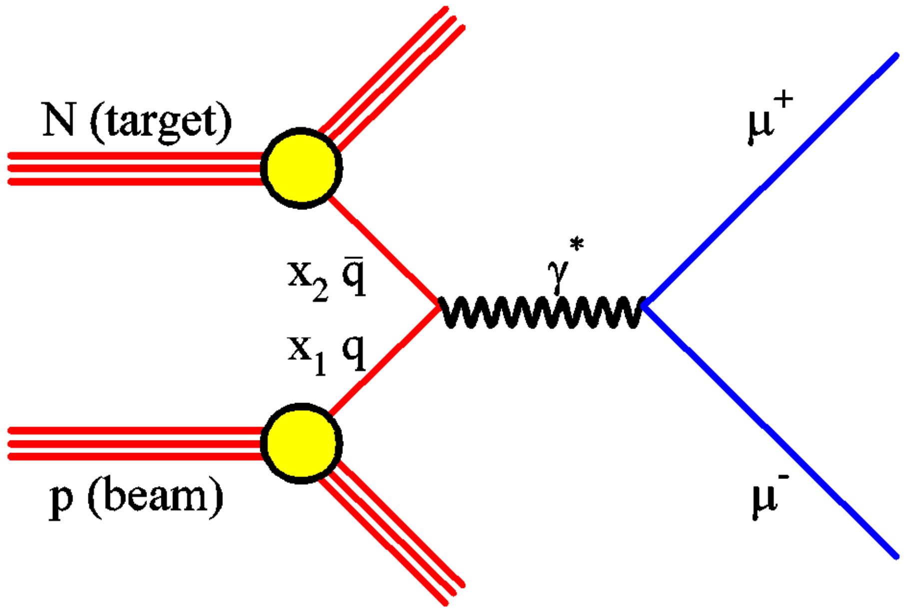


(Ann. Rev. Nucl. Part. Phys., Geesaman, Sato and Thomas)

F_2 contains contributions from quarks and antiquarks

How are the antiquark distributions modified in nuclei?

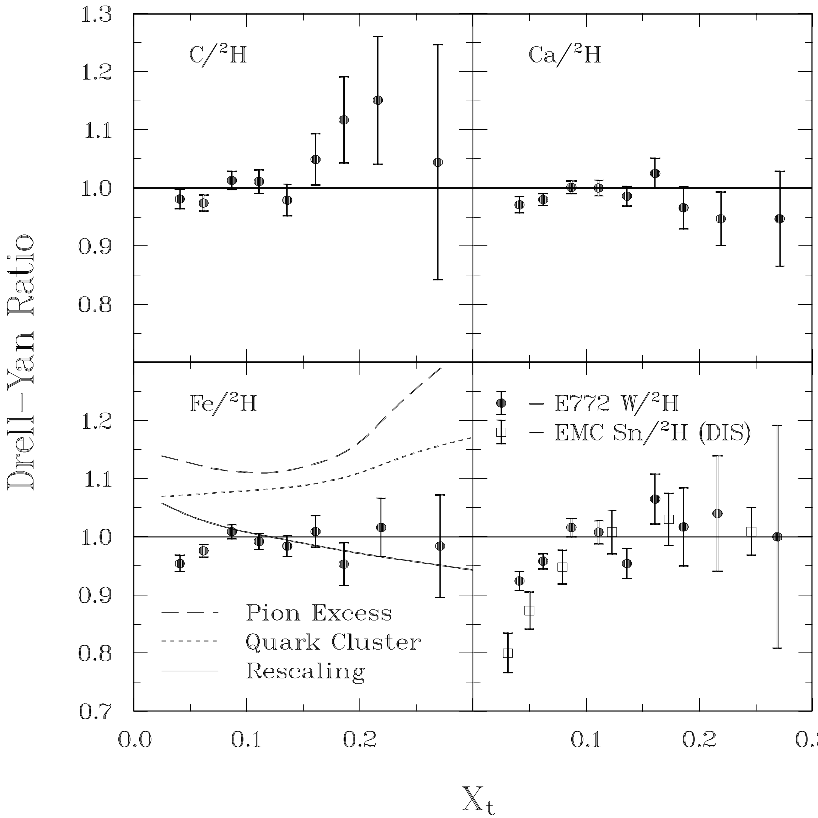
Drell-Yan on nuclear targets

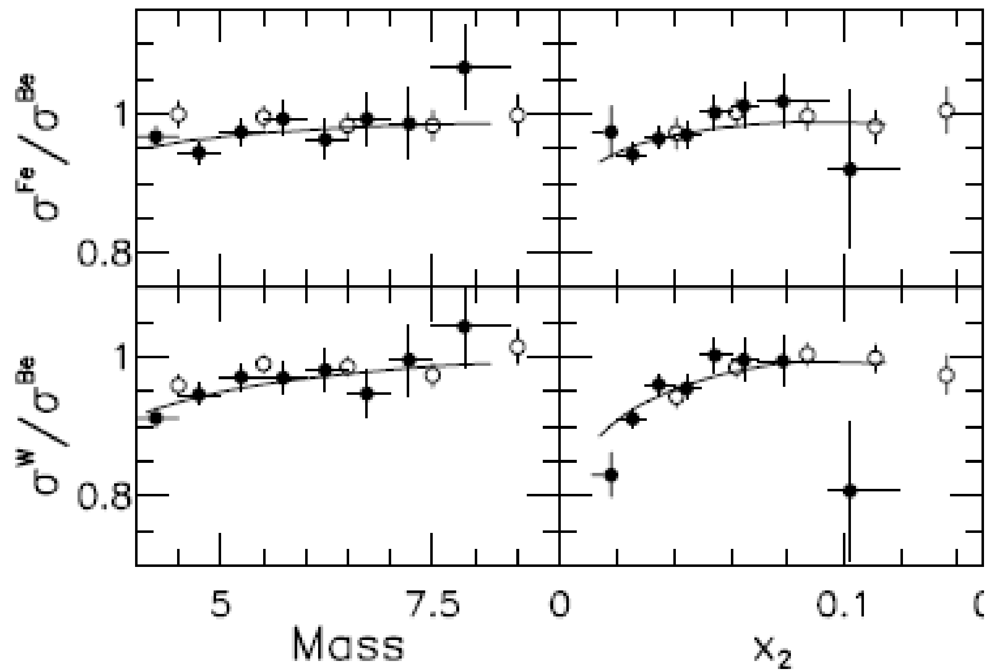


$$\frac{\sigma^{pA}}{\sigma^{pd}} \approx \frac{\bar{u}_A(x)}{\bar{u}_N(x)}$$

The x-dependence of $\bar{u}_A(x)/\bar{u}_N(x)$ can be directly measured

Drell-Yan on nuclear targets





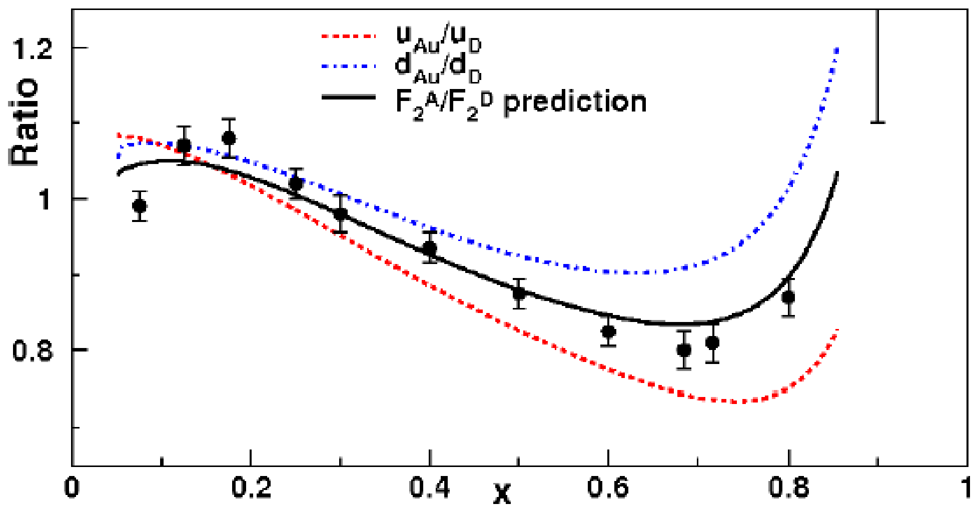
PRL 64 (1990) 2479

PRL 83 (1999) 2304

No evidence for enhancement of antiquark in niclei !?

LHC (AFTER) can explore antiquark shadowing/saturation in nuclei at small x

Flavor dependence of the EMC effects ?



Isovector mean-field generated in Z≠N nuclei can modify nucleon's *u* and *d* PDFs in nuclei

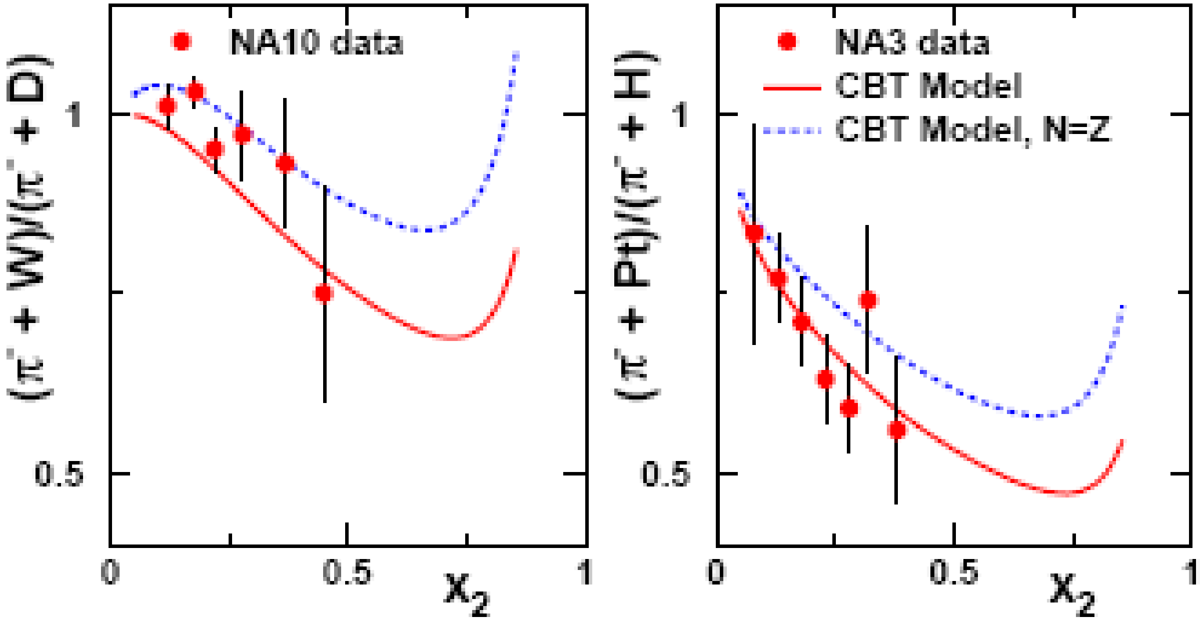
Cloet, Bentz, and Thomas, arXiv:0901.355
(see also Kumano et al.)

How can one check this prediction?

- SIDIS (Semi-inlusive DIS) and PVDIS (Parity-violating DIS)
- Pion-induced Drell-Yan

Pion-induced Drell-Yan and the flavor-dependent EMC effect

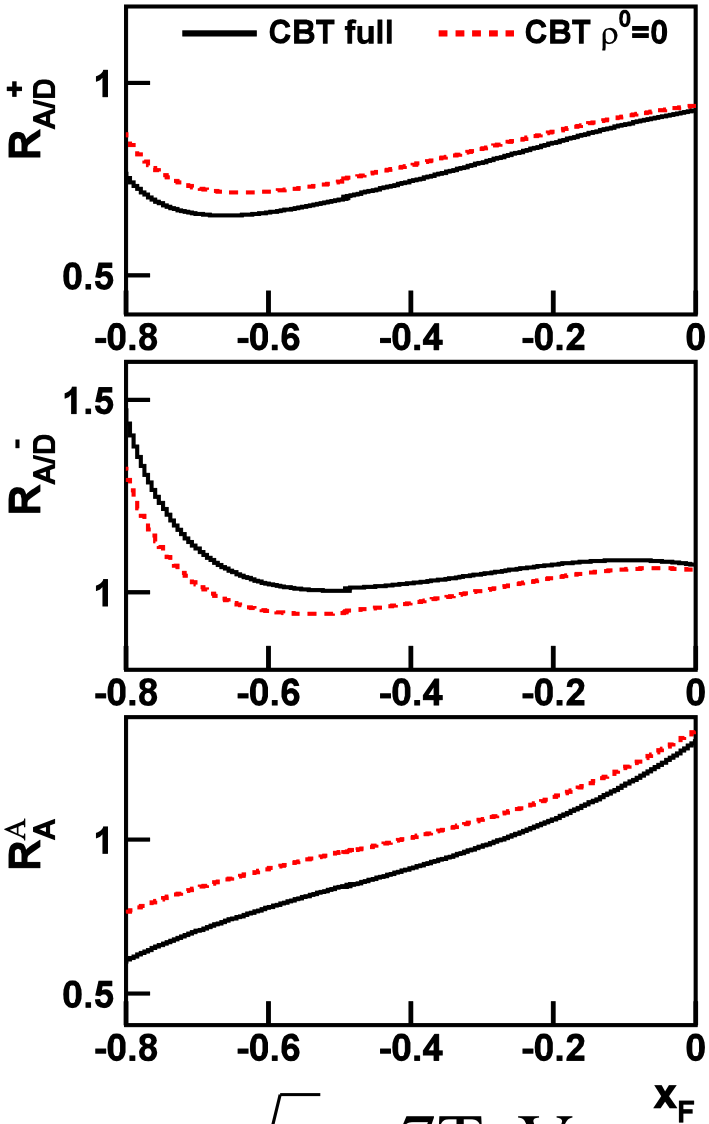
$$\frac{\sigma^{DY}(\pi^- + A)}{\sigma^{DY}(\pi^- + D)} \approx \frac{u_A(x)}{u_D(x)}$$



Red (blue) curves correspond to flavor-dependent (independent) EMC

(D. Dutta, JCP, Cloet, Gaskell, arXiv: 1007.3916)

W-production at LHC and the flavor-dependent EMC effect



$\sqrt{s} = 7\text{TeV}$

$$R^+_{A/D} \equiv \frac{d\sigma(p+A \to W^+ + x)}{d\sigma(p+D \to W^+ + x)} \approx \frac{u_A(x_2)}{u_D(x_2)}$$

$$R^-_{A/D} \equiv \frac{d\sigma(p+A \to W^- + x)}{d\sigma(p+D \to W^- + x)} \approx \frac{d_A(x_2)}{d_D(x_2)}$$

$$R^{\pm}_A \equiv \frac{d\sigma(p+A \to W^+ + x)}{d\sigma(p+A \to W^- + x)} \approx \frac{\bar{d}_p(x_1)}{\bar{u}_p(x_1)} \frac{u_A(x_2)}{d_A(x_2)}$$

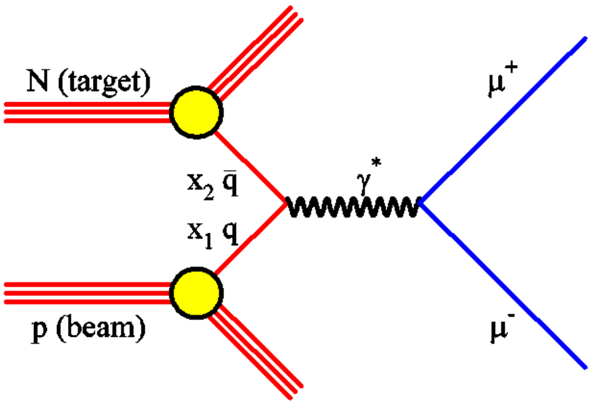
(Chang, Cloet, Dutta, JCP, 1109.3108)

Pb beam at AFTER is ideal for exploring the negative x_F region

Can one measure $\bar{d}/\bar{u}$ in nuclei?

The Drell-Yan Proce

$$pN \rightarrow \mu^+ \mu^- X$$



Drell-Yan ratios for p-A /p-d :

$$\frac{2\sigma^{pA}}{A\sigma^{pd}} \approx \frac{2}{A}\frac{Z + N\bar{d}/\bar{u}}{1+\bar{d}/\bar{u}}$$

Assuming dbar/ubar = 1.5 for the nucleons at x=0.15, then the above ratios are:

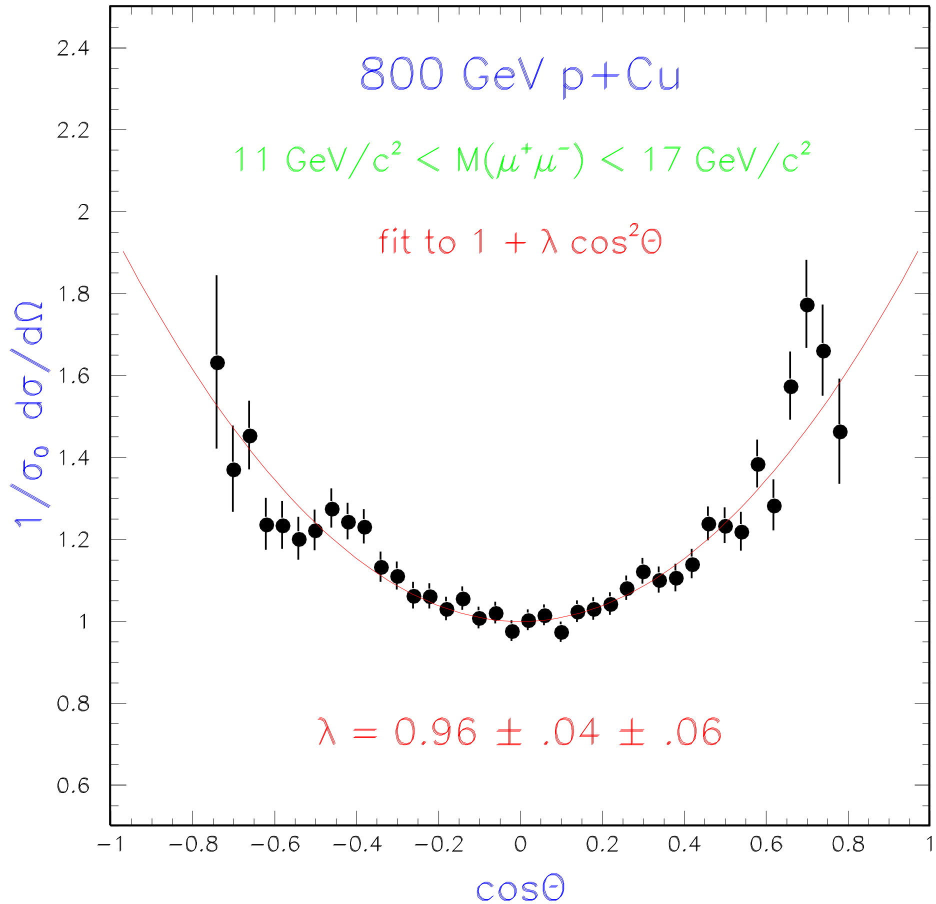
1.0 for ^{40}Ca, 1.042 for ^{208}Pb

Could probably be measured at AFTER

Dilepton angular distribution

Decay Angular Distribution of "naïve" Drell-Yan:

$$\frac{d\sigma}{d\Omega} = \sigma_0 (1 + \cos^2 \theta)$$



Data from Fermilab E772

Polarization of J/Ψ and Υ

- Decay angular distribution in the quarkonium rest frame

$$\frac{d\sigma}{d\Omega} \sim 1 + \lambda \cos^2\theta$$

  * Transverse : σ_T ; helicity: ± 1; $\lambda = 1$
  * Longitudinal : σ_L ; helicity: 0; $\lambda = -1$
  * Unpolarized : $\sigma_T = 2\sigma_L$; helicity: $0, \pm 1$; $\lambda = 0$

- $\lambda = \dfrac{\sigma_T - 2\sigma_L}{\sigma_T + 2\sigma_L} = (1 - 2\sigma_L/\sigma_T)/(1 + 2\sigma_L/\sigma_T)$

- σ_L/σ_T depends on the color - spin states of the $Q\bar{Q}$ pair :

State:	$^3S_1^{(1)}$	$^1S_0^{(8)}$	$^3P_J^{(8)}$	$^3S_1^{(8)}$
σ_L/σ_T :	$1/3.4$	$1/2$	$1/6$	$0/1$

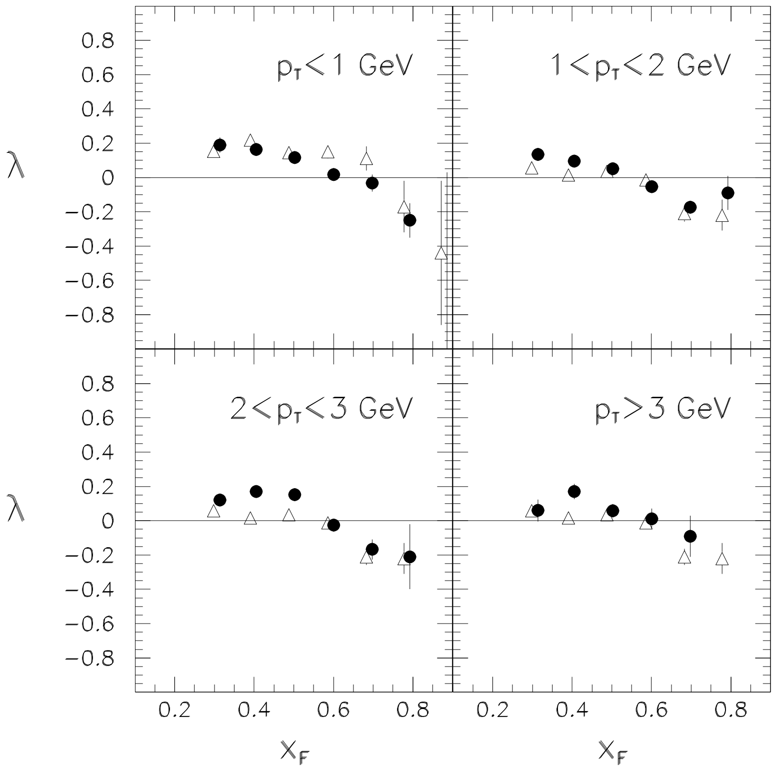
- Polarization of $Q\bar{Q}$ is sensitive to the production mechanism

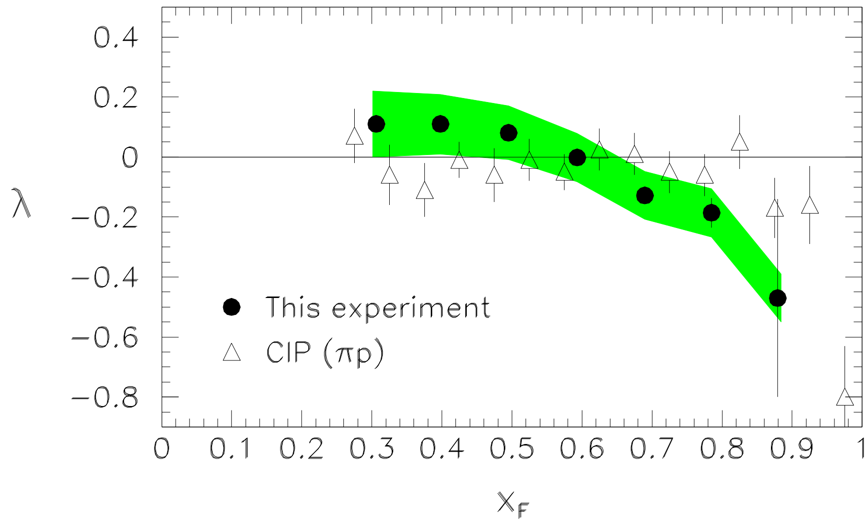
Polarization of J/Ψ in p + Cu Collision

$d\sigma/d\Omega \sim 1 + \lambda \cos^2\theta$

(λ=1: transversely polarized, λ = -1: longitudinally polarized λ = 0, unpolarized)

E866 data





hep-ex/030801

λ is small, but nonzero

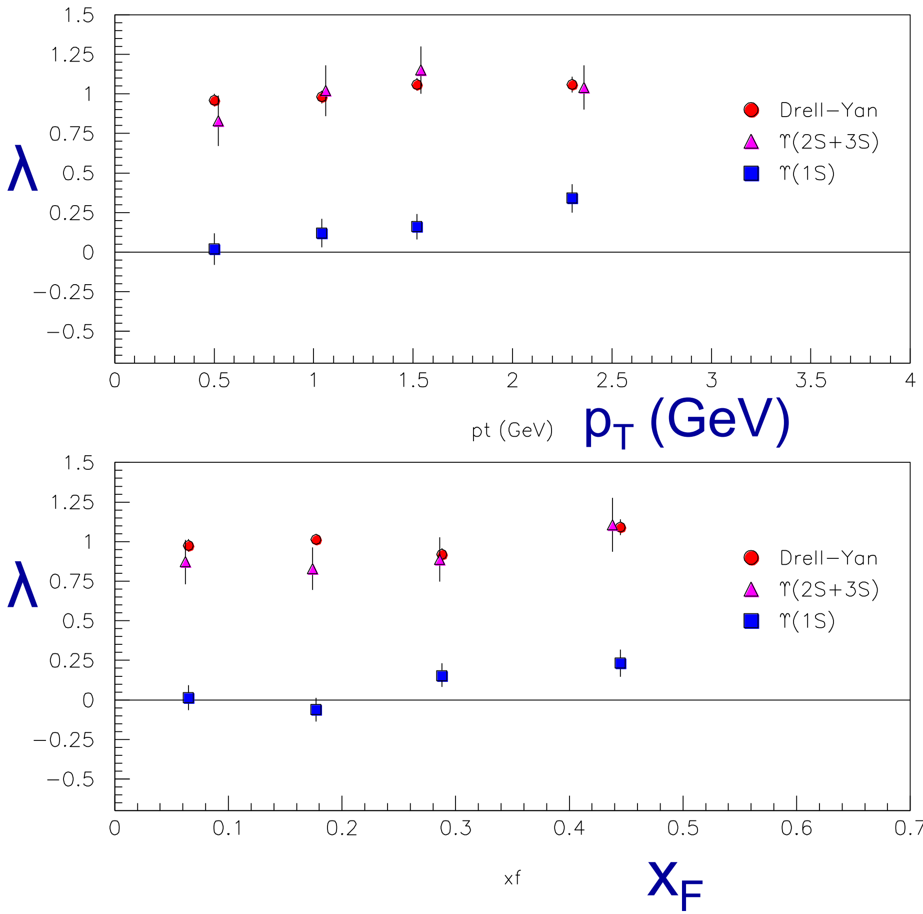
λ becomes negative at large x_F

No strong p_T dependence for λ

Polarization of Y(1S),Y(2S+3S)

p + Cu →Y + x (E866 beam-dump data)

λ for D-Y, Y(1S), Y(2S+3S)



Brown et al. PRL 86, 2529 (2001)

D-Y is transversely polarized

Y(1S) is slightly polarized (like J/Ψ)

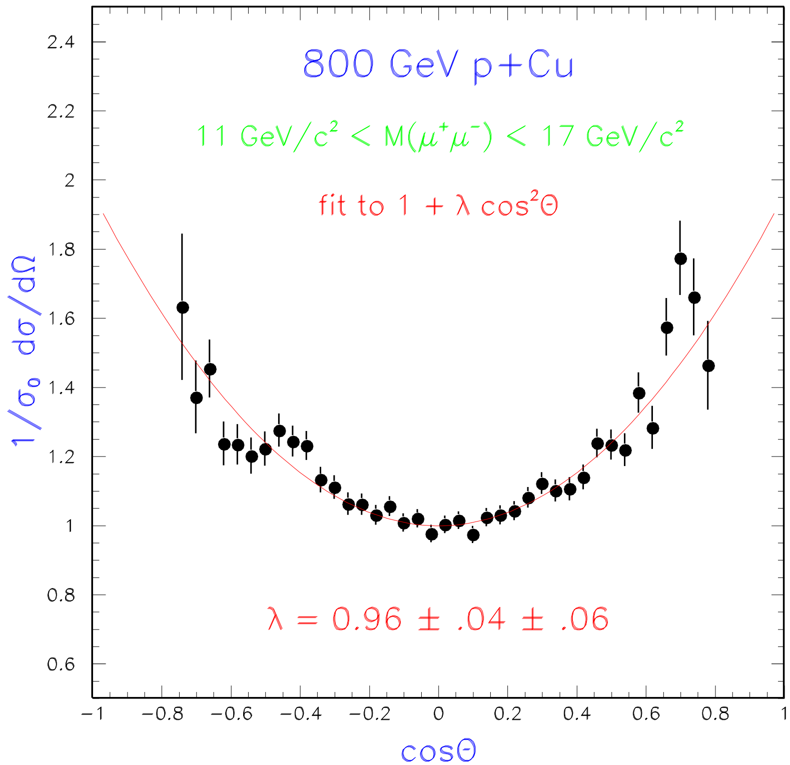
Y(2S+3S) is transversely polarized!

Measurement of Upsilon polarization in p+p and p+d at AFTER would be very interesting (nuclear dependence?)

Parity violation in Drell-Yan?

Forward-backward asymmetry in decay angular distribution of Drell-Yan:

$$\frac{d\sigma}{d\Omega} = \sigma_0 (1 + a\cos\theta + b\cos^2\theta)$$



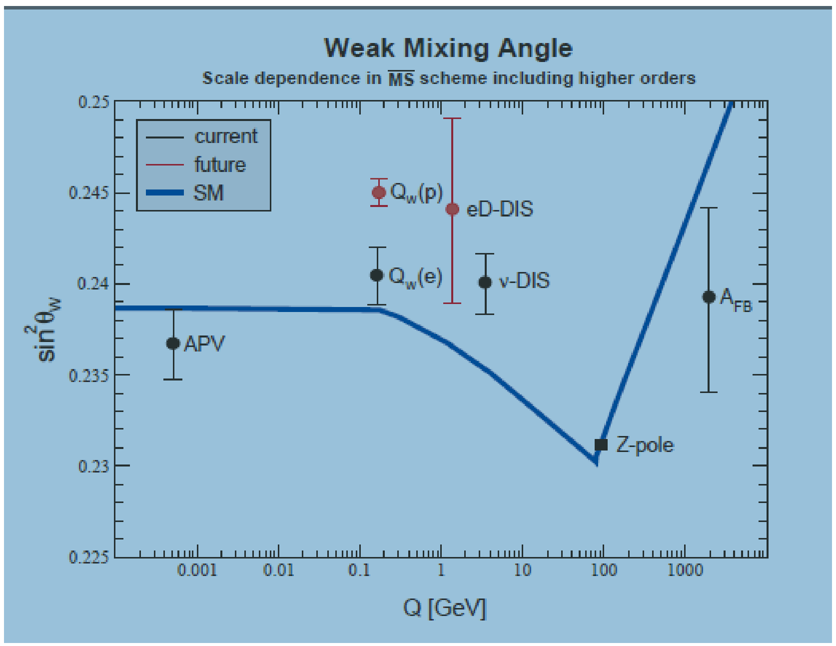
Interference between γ and Z^0 diagrams can lead to non-zero parity-violating $\cos\theta$ term

Parity violation in D-Y can probe Weinberg angles at low Q^2

Parity violation in Drell-Yan?

Forward-backward asymmetry in decay angular distribution of Drell-Yan:

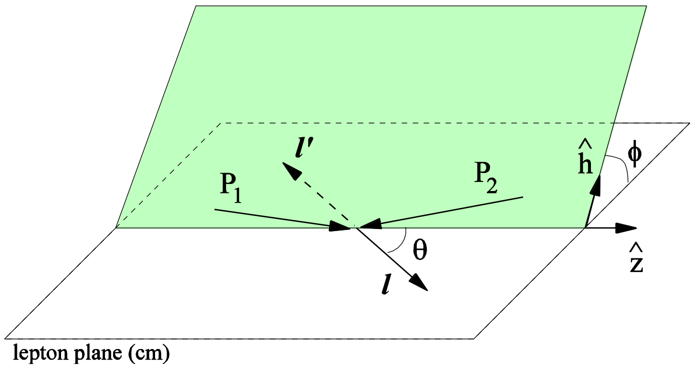
$$\frac{d\sigma}{d\Omega} = \sigma_0 (1 + \boxed{a \cos\theta} + b \cos^2 \theta)$$



Interference between γ and Z^0 diagrams can lead to non-zero parity-violating $\cos\theta$ term

Parity violation in D-Y can probe Weinberg angles at low Q^2 (Never been studied yet)

Drell-Yan decay angular distributions



Θ and Φ are the decay polar and azimuthal angles of the μ^+ in the dilepton rest-frame

Collins-Soper frame

A general expression for Drell-Yan decay angular distributions:

$$\left(\frac{1}{\sigma}\right)\left(\frac{d\sigma}{d\Omega}\right)=\left[\frac{3}{4\pi}\right]\left[1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi\right]$$

λ can differ from 1, but should satisfy $1-\lambda=2\nu$ (Lam-Tung)

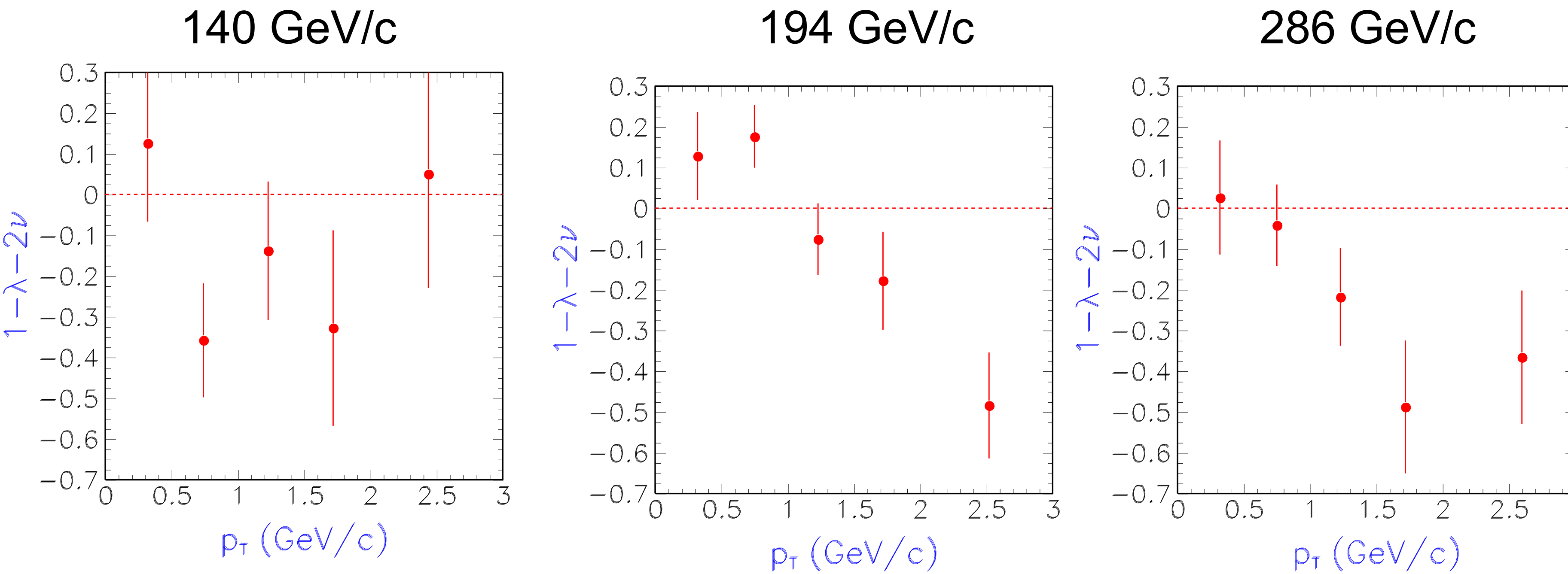
– Reflect the spin-1/2 nature of quarks

(analog of the Callan-Gross relation in DIS)

– Insensitive to QCD - corrections

Decay angular distributions in pion-induced Drell-Yan

Is the Lam-Tung relation violated?

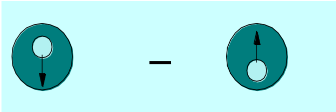


Data from NA10 (Z. Phys. 37 (1988) 545)

Violation of the Lam-Tung relation suggests new mechanisms with non-perturbative origin

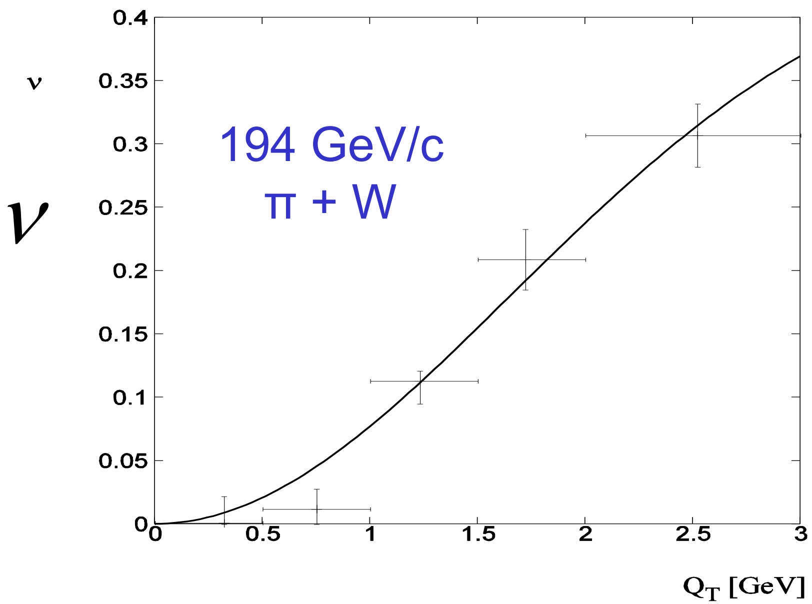
- $q-\bar{q}$ spin correlation in QCD color field (Nachtmann et al.)

Boer-Mulders function $h_1^{\perp}$



- $h_1^{\perp}$ represents a correlation between quark's k_T and transverse spin in an unpolarized hadron
- $h_1^{\perp}$ is a time-reversal odd, chiral-odd TMD parton distribution
- $h_1^{\perp}$ can lead to an azimuthal cos(2ϕ) dependence in Drell-Yan

$$\left(\frac{1}{\sigma}\right)\left(\frac{d\sigma}{d\Omega}\right)=\left[\frac{3}{4\pi}\right]\left[1+\lambda\cos^2\theta+\mu\sin 2\theta\cos\phi+\frac{\nu}{2}\sin^2\theta\cos 2\phi\right]$$

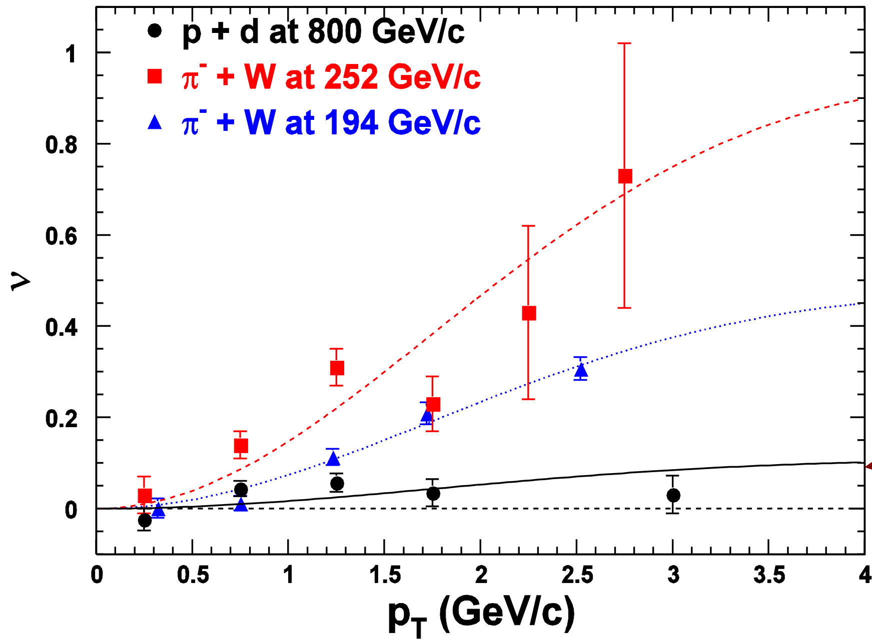


Boer, PRD 60 (1999) 014012

- Observation of large cos(2Φ) dependence in Drell-Yan with pion beam
- $\nu \propto h_1^{\perp}(x_q)h_1^{\perp}(x_{\bar{q}})$
- B-M functions have same signs for pion and nucleon

Azimuthal cos2Φ Distribution in p+p and p+d Drell-Yan

E866 Collab., Lingyan Zhu et al.,
PRL 99 (2007) 082301; PRL 102 (2009) 182001



Small ν is observed for p+d and p+p D-Y

With Boer-Mulders function $h_1^{\perp}$:

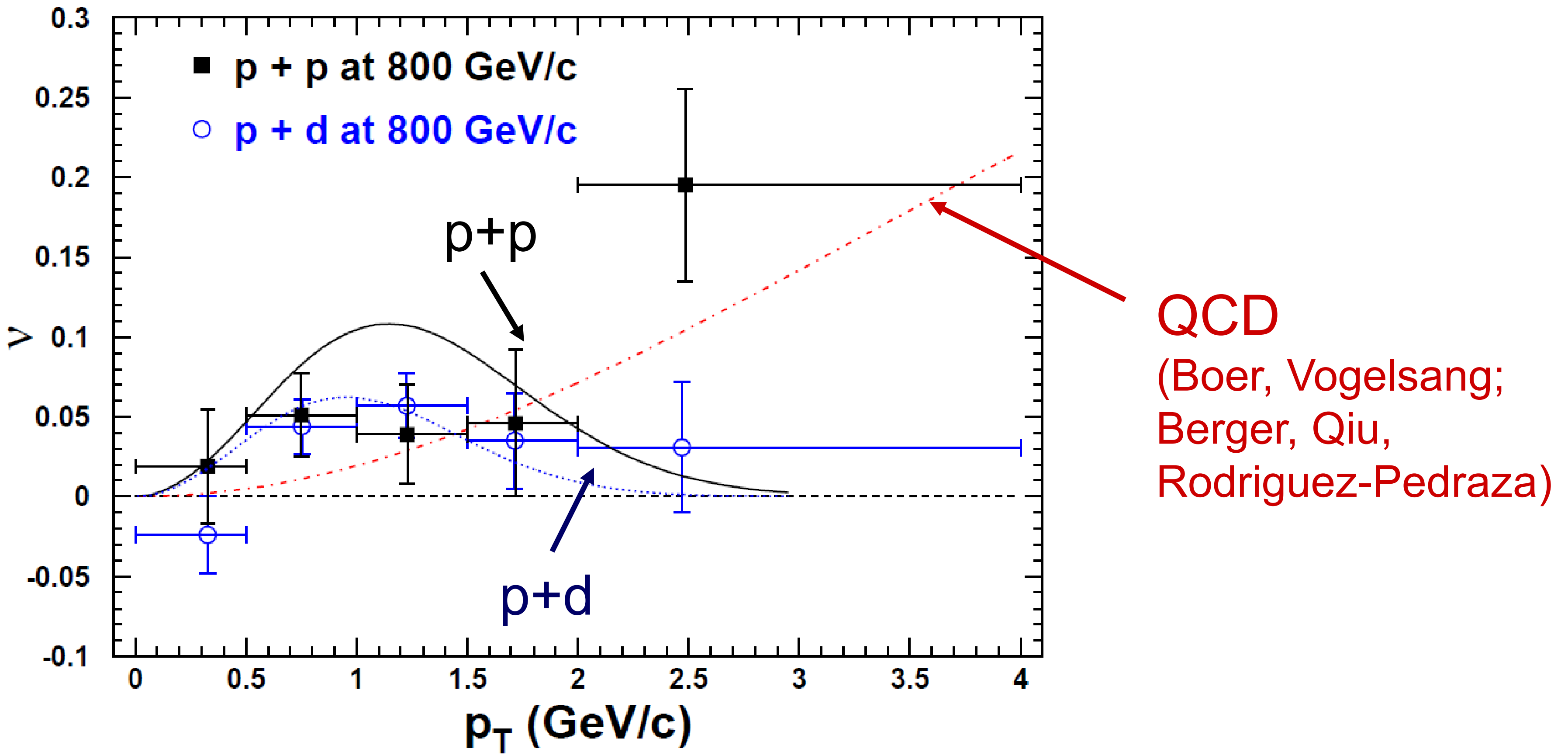
$\nu(\pi^- W \rightarrow \mu^+\mu^- X) \sim$ [valence $h_1^{\perp}(\pi)$] * [valence $h_1^{\perp}(p)$]

$\nu(pd \rightarrow \mu^+\mu^- X) \sim$ [valence $h_1^{\perp}(p)$] * [sea $h_1^{\perp}(p)$]

Sea-quark BM functions are much smaller than valence quarks

Results on cos2Φ Distribution in p+p Drell-Yan

L. Zhu et al., PRL 102 (2009) 182001



Data at larger p_T (from AFTER) would be very interesting

Nuclear modification of spin-dependent PDF?

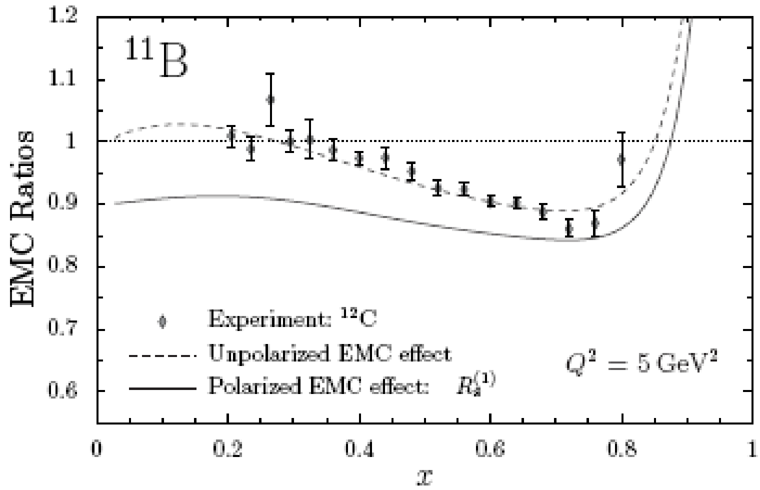


Figure 7: EMC ratios for ^{11}B. The experimental data refer to ^{12}C.

EMC effect for $g_1(x)$

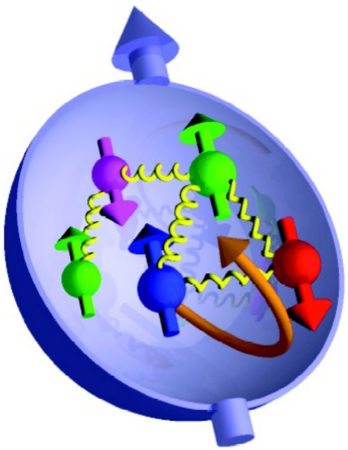
Bentz, Cloet, Thomas et al., arXiv:0711.0392

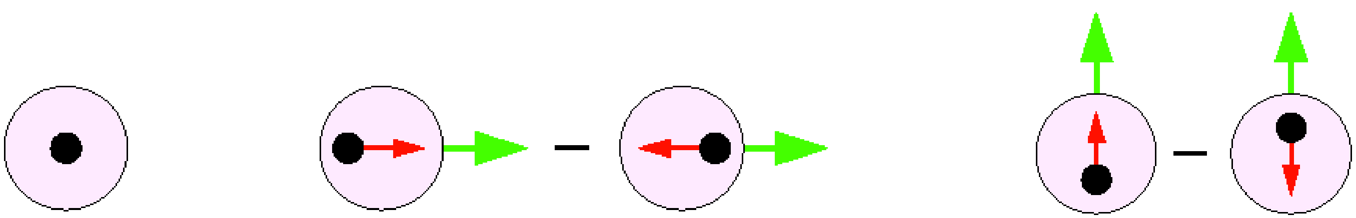
Remains to be tested by experiments

Measure the nuclear modification of Boer-Mulders functions with Drell-Yan ?
(only unpolarized Drell-Yan is required)

Polarized Drell-Yan with polarized proton beam?

- Polarized Drell-Yan experiments have never been done before
- Provide unique information on the quark (antiquark) spin





$q(x)$ $\Delta q(x)$ $h_1(x)$

Quark helicity distribution

Quark transversity distribution

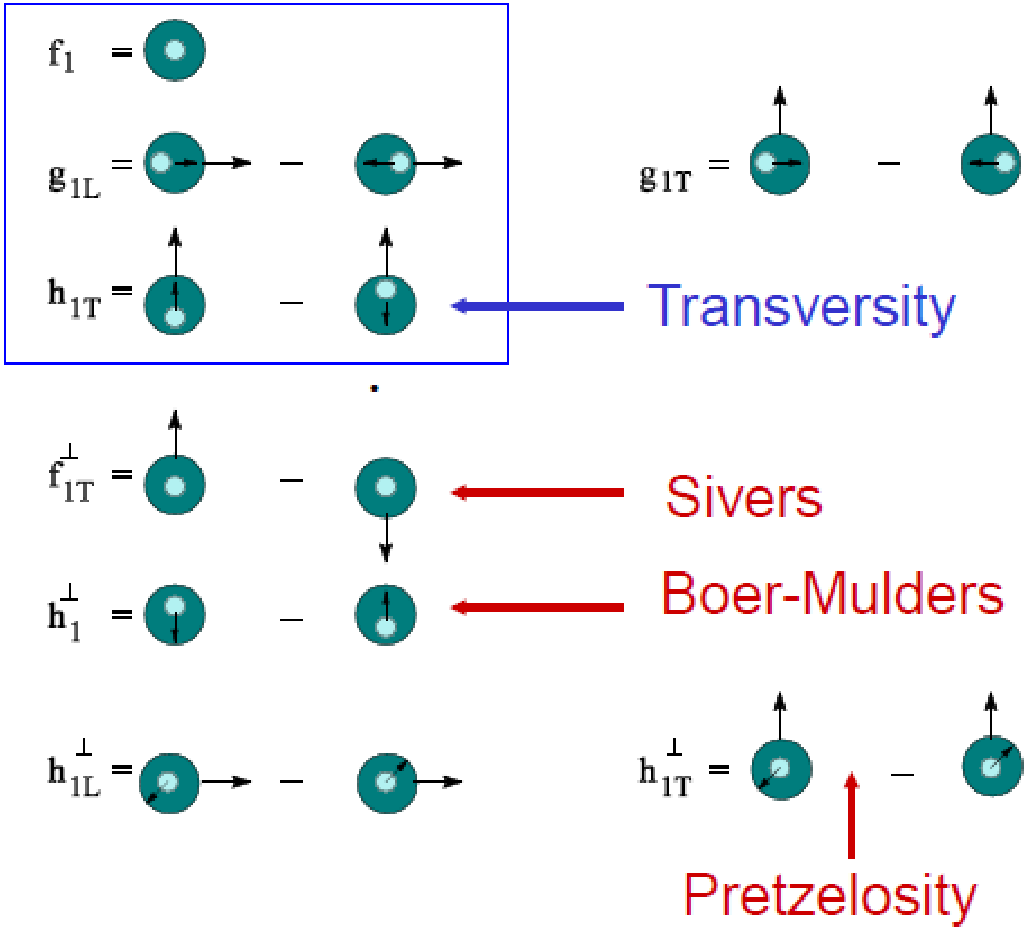
Drell-Yan and Transverse Momentum Dependent (TMD) Quark Distributions

Leading-Twist Quark Distributions

(A total of eight distributions)

Three would remain after $k_\perp$ integration

The other five are transverse momentum ($k_\perp$) dependent (TMD)



Transversity and Transverse Momentum Dependent PDFs are also probed in Drell-Yan

a) Boer-Mulders functions:

- Unpolarized Drell-Yan: $d\sigma_{DY} \propto h_1^{\perp}(x_q) h_1^{\perp}(x_{\bar{q}}) \cos(2\phi)$

b) Sivers functions:

- Single transverse spin asymmetry in polarized Drell-Yan:

$$A_N^{DY} \propto f_{1T}^{\perp}(x_q) f_{\bar{q}}(x_{\bar{q}})$$

c) Transversity distributions:

- Double transverse spin asymmetry in polarized Drell-Yan:

$$A_{TT}^{DY} \propto h_1(x_q) h_1(x_{\bar{q}})$$

- Drell-Yan does not require knowledge of the fragmentation functions
- T-odd TMDs are predicted to change sign from DIS to DY (Boer-Mulders and Sivers functions)

Remains to be tested experimentally!

Outstanding questions to be addressed by future Drell-Yan experiments

- Does Sivers function change sign between DIS and Drell-Yan?
- Does Boer-Mulders function change sign between DIS and Drell-Yan?
- Are all Boer-Mulders functions alike (proton versus pion Boer-Mulders functions)
- Flavor dependence of TMD functions
- Independent measurement of transversity with Drell-Yan

Can be studied at COMPASS, RHIC, FAIR, LHC,JPARC, JINR, etc

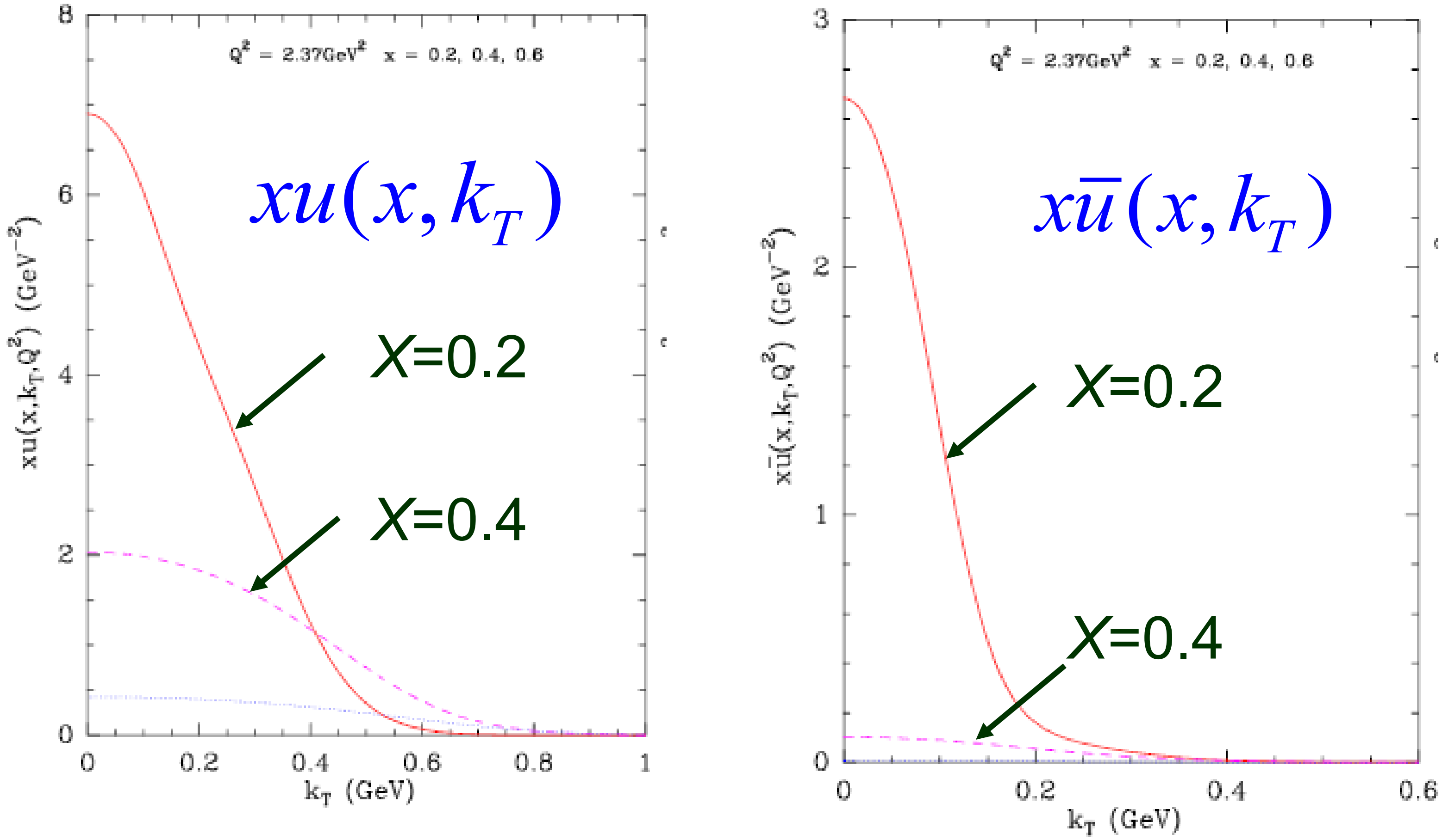
What do we know about the quark and gluon intrinsic transverse momentum distributions?

- Does the quark k_T distribution depend on x?
- Do valence quarks and sea quarks have different k_T distributions?
- Do u and d quarks have the same k_T distribution?
- Do nucleons and mesons have different quark k_T distribution?
- Do gluons have k_T distribution different from quarks?

- Important for extracting the TMD parton distributions
- Interesting physics in its own right

Flavor and x-dependent k_T-distributions?

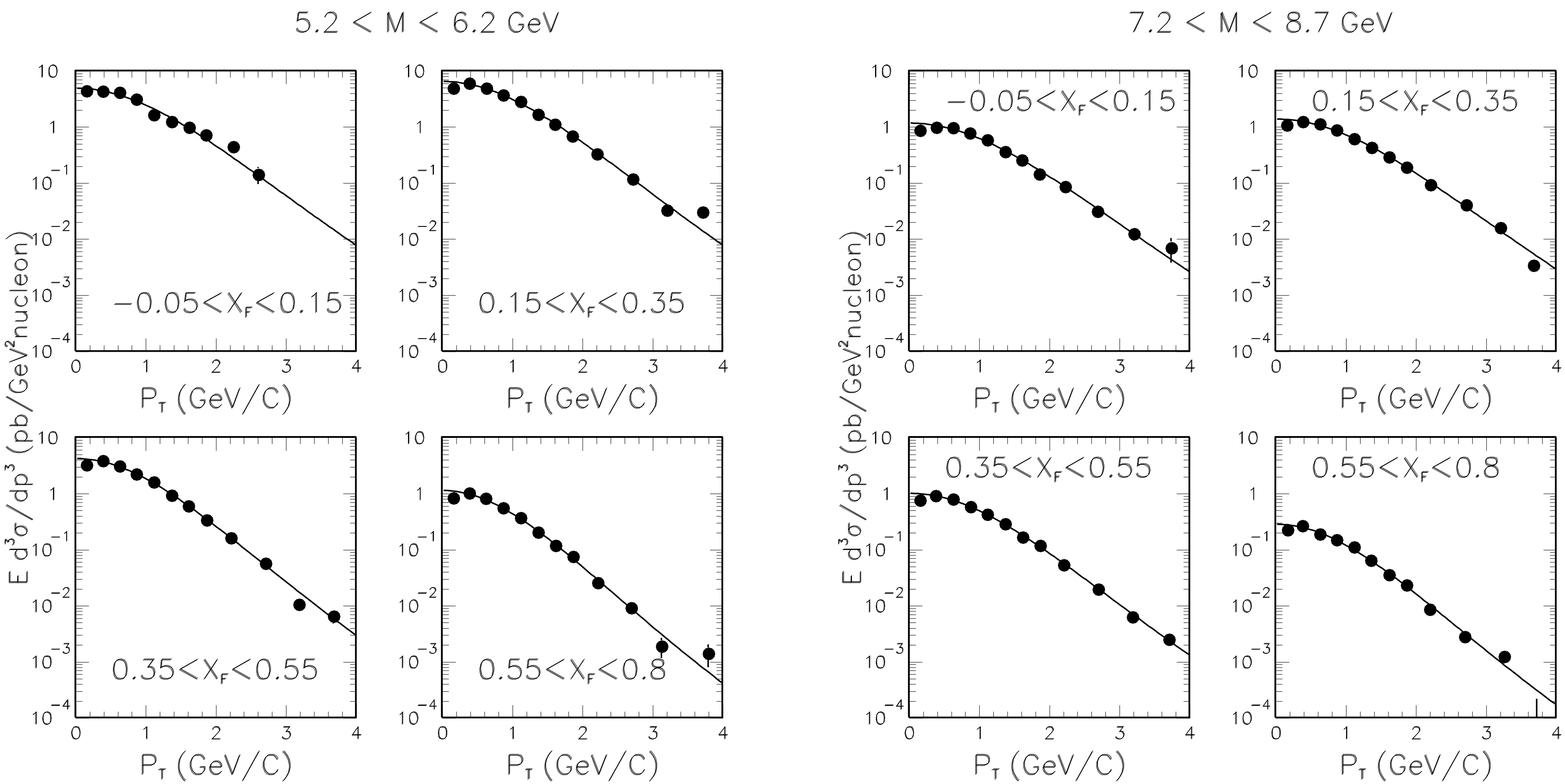
(Bourrely, Buccella, Soffer, arXiv:1008.5322)



- $\langle k_T \rangle$ increases when x increases
- $\langle k_T \rangle$ for sea quarks is smaller than for valence quarks

Test of possible *x*-dependent k_T-distributions

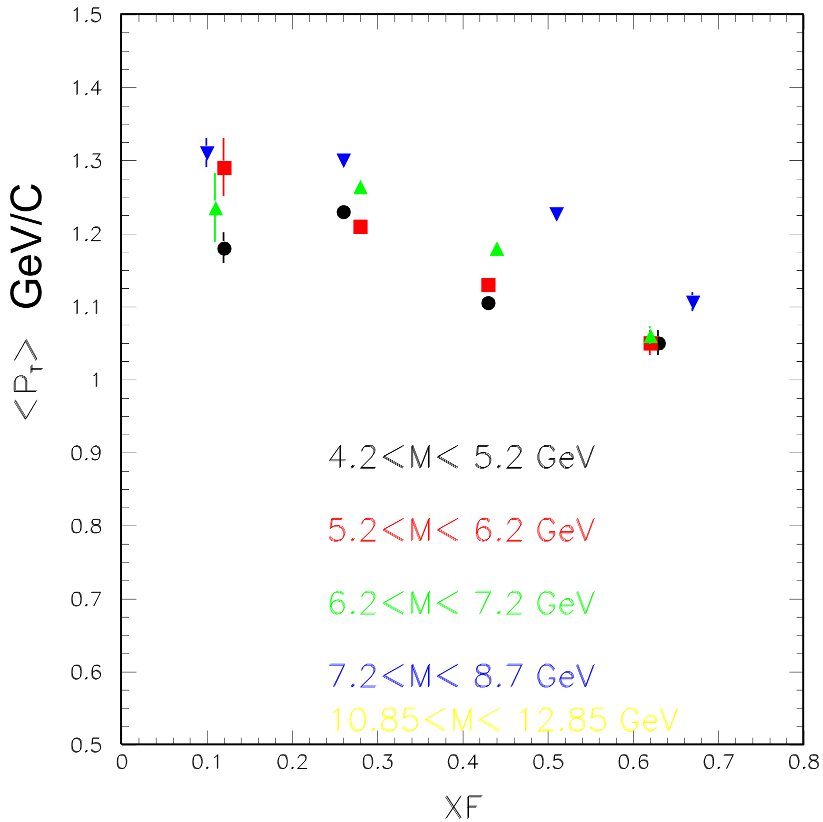
E866 p+d D-Y data (800 GeV beam)

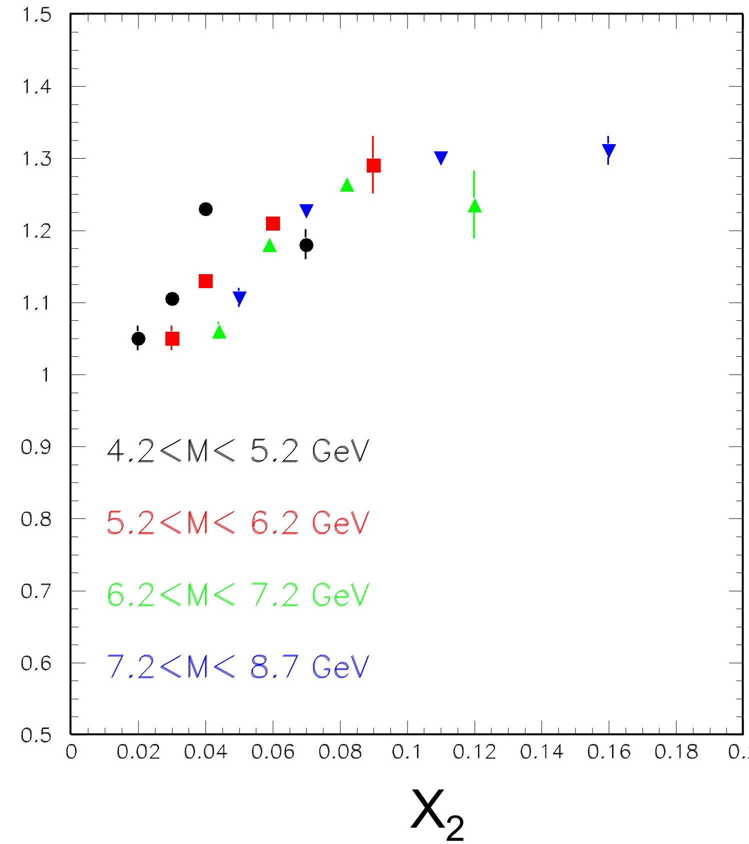


Data from thesis of J. Webb

Possible *x*-dependent k_T-distributions

E866 p+d D-Y data (800 GeV beam)





$\langle p_T \rangle$ scale with x_2 ?

Analysis is ongoing (A. Ghalsasi, E. McClellan,JCP)

Would be very interesting to have new data at AFTER

Summary

- The Drell-Yan process is a powerful experimental tool complimentary to the DIS for exploring quark structures in nucleons and nuclei.
- A rich physics program in Drell-Yan and quarkonium production can be pursued at AFTER.

There must be physics AFTER Higgs