Chiral Dynamics, August 6 – 10, Jefferson Lab

Alexei Prokudin

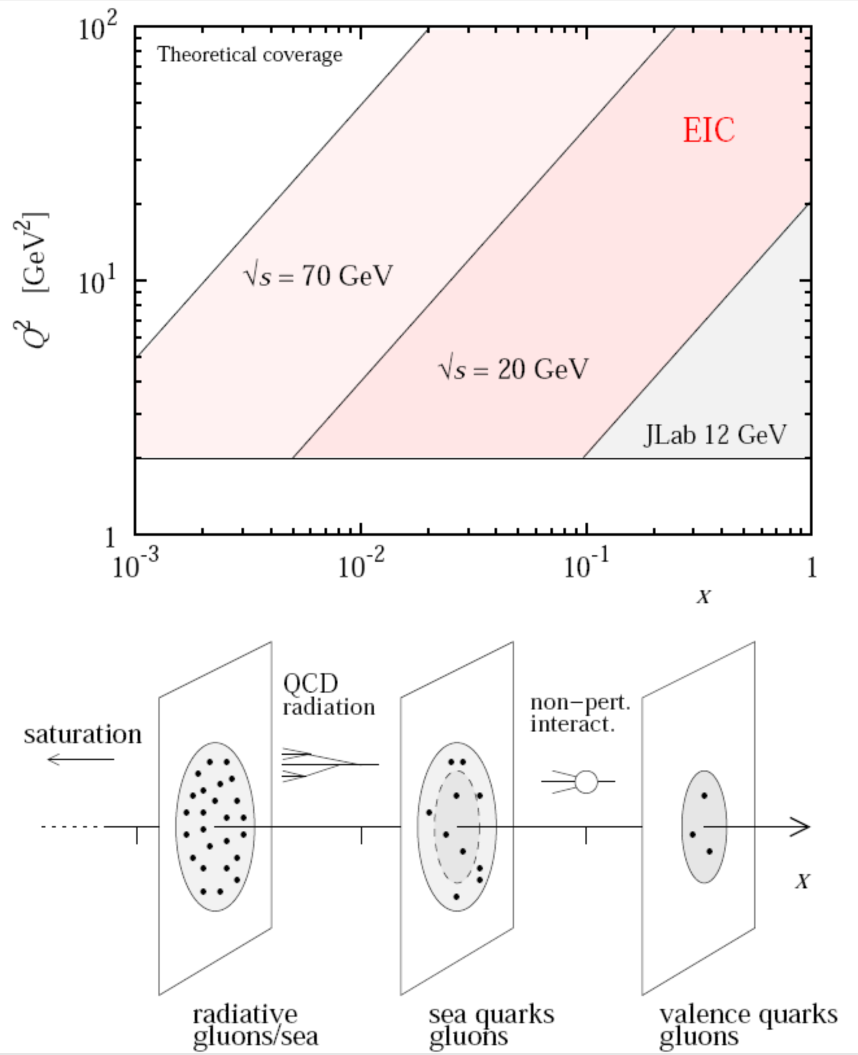
Jefferson Lab

Transversity parton distribution

Jefferson Lab

EXPLORING THE NATURE OF MATTER

Nucleon landscape



Plot courtesy of Christian Weiss

Nucleon is a many body dynamical system of quarks and gluons

Changing x we probe different aspects of nucleon wave function

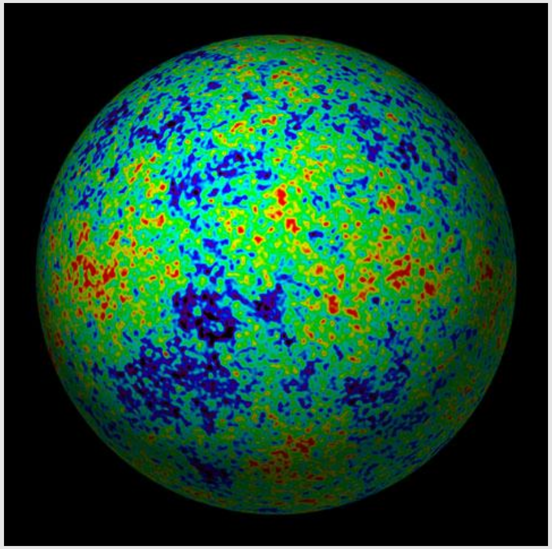
How partons move and how they are distributed in space is one of the future directions of development of nuclear physics

Technically such information is encoded into Generalised Parton Distributions and Transverse Momentum Dependent distributions

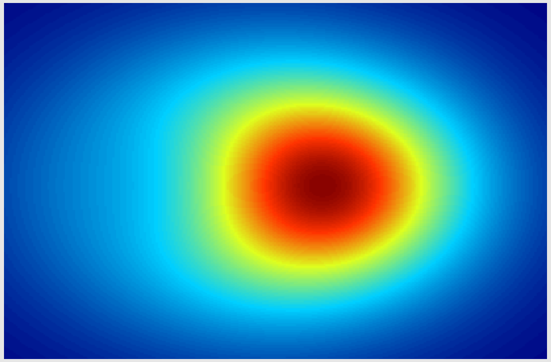
See talk by Christian Weiss

These distributions are also referred to as 3D (three-dimensional) distributions

Fundamental knowledge from 3D distributions



Cosmic Microwave Background is the source of information on history of our universe, inflation, distribution of matter, dark matter etc



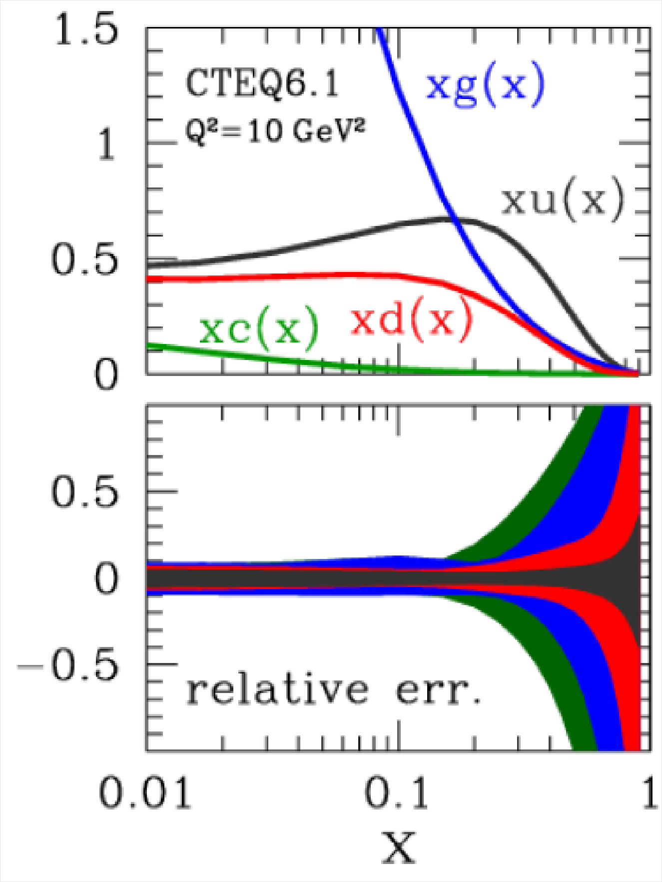
3 Dimensional partonic picture gives us insights on the dynamics of the confined system of quarks and gluons.

It also gives information on fundamental properties of the nucleon

Spin is one of these properties

Hadron tomography

Conventional inclusive processes are sensitive to longitudinal momentum fraction of hadron momenta, they give no information on spatial or momentum 3D distribution of partons

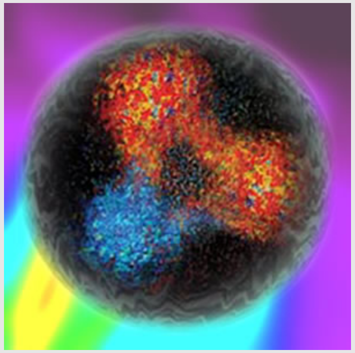


Good knowledge of
Parton
Distribution
Functions (PDFs)
is acquired at HERA

However large-x behavior has still large uncertainties
Data from JLab 12 will be important

Wigner distribution

Our goal is to understand 3 dimensional distributions of partons,
How they move, where they are located inside a nucleon



Wigner distribution (1933) is a possibility

$$W(\mathbf{p},\mathbf{r}) = \int d^3\eta\, e^{i\,\mathbf{p}\eta}\psi^*(\mathbf{r}+\eta/\mathbf{2})\psi(\mathbf{r}-\eta/\mathbf{2})$$

It gives both position and momenta

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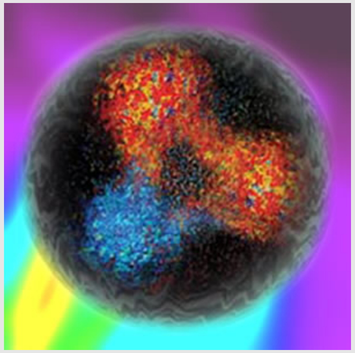

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Can it be measured?

Wigner distribution

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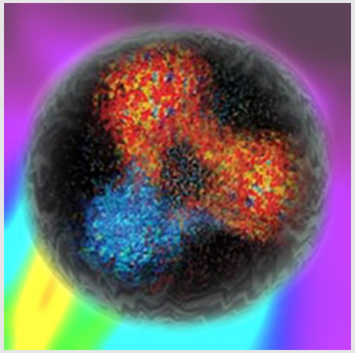

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$$W(\mathbf{p},\mathbf{r}) = \int d^3\eta\, e^{i\,\mathbf{p}\eta}\psi^*(\mathbf{r}+\eta/\mathbf{2})\psi(\mathbf{r}-\eta/\mathbf{2})$$

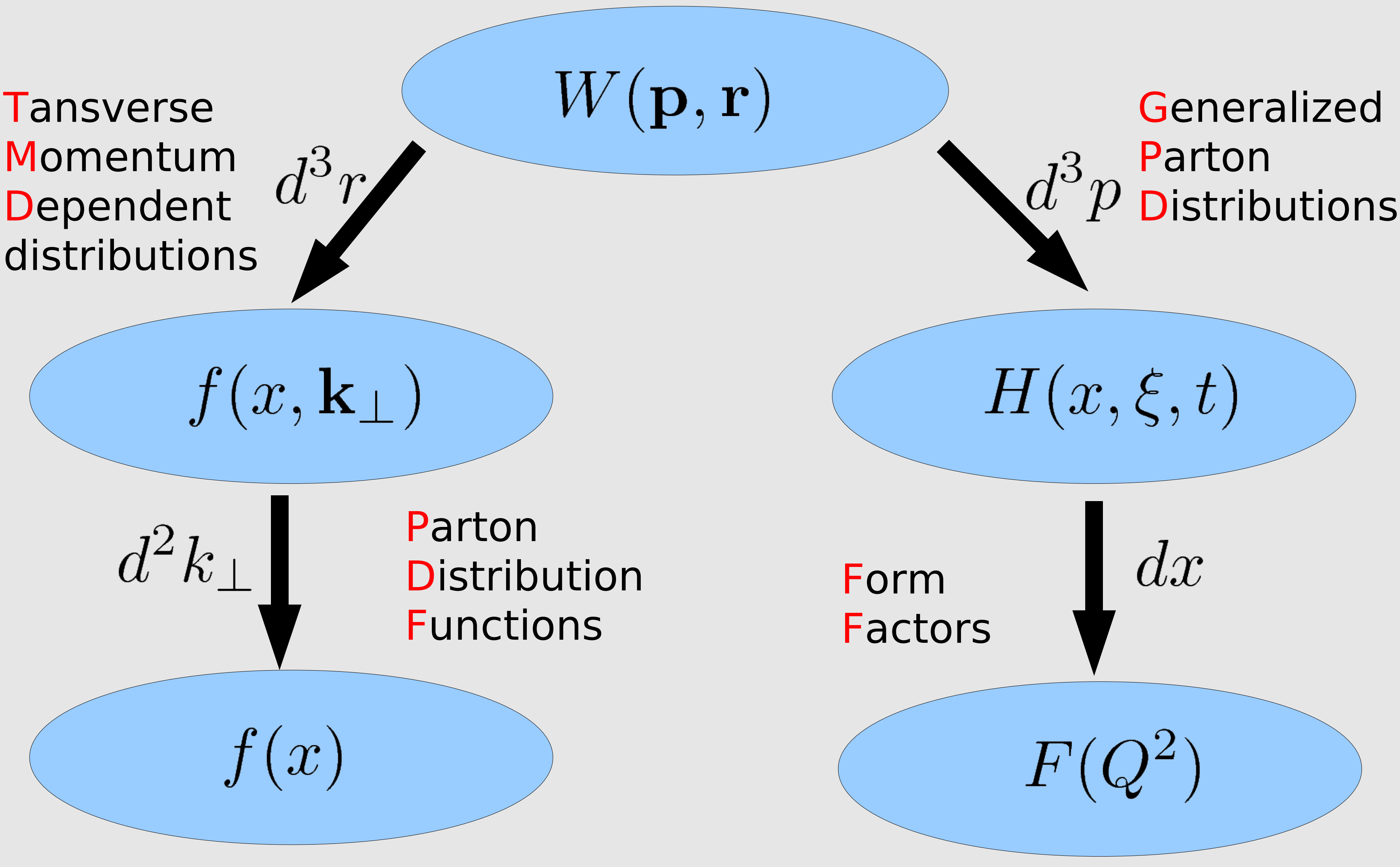
It gives both position and momenta

Can it be measured? PROBABLY NOT!

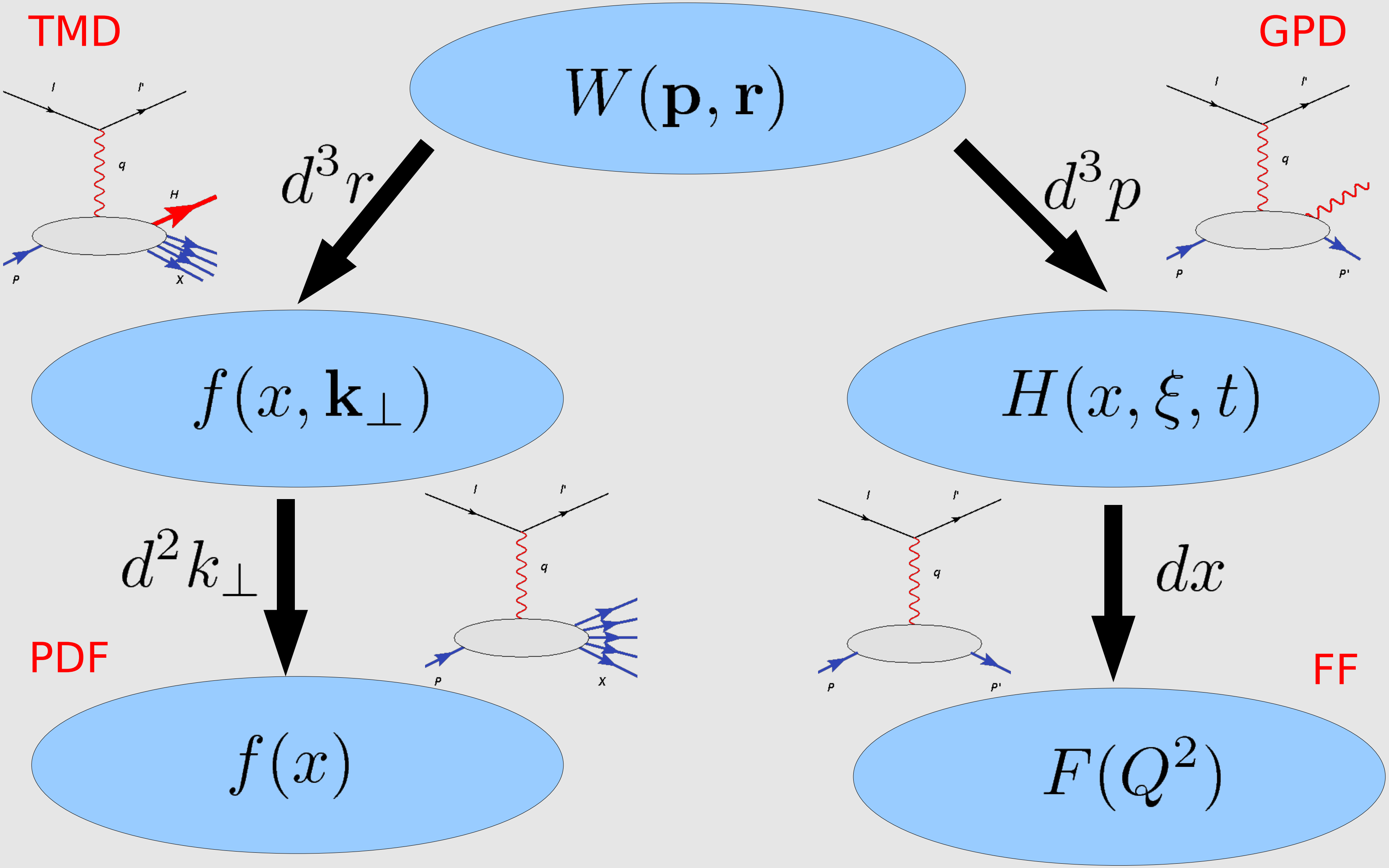
$$\Delta p \Delta r \geq \hbar/2$$

No simultaneous knowledge on position and momenta

Wigner distribution

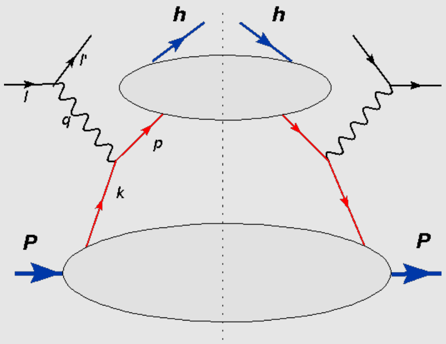


Wigner distribution



Transverse Momentum Dependent distributions

SIDIS



$$\mathbf{l} + \mathbf{P} \rightarrow \mathbf{l}' + \mathbf{h} + \mathbf{X}$$

If produced hadron has low transverse momentum

$$P_{hT} \sim \Lambda_{QCD} << Q$$

it will be sensitive to quark transverse momentum $k_\perp$

TMD factorization

Ji, Ma, Yuan (2002)
Collins (2011)

GAUGE INVARIANT

$$\Phi_{ij}(x, \mathbf{k}_\perp) = \int \frac{d\xi^-}{(2\pi)} \frac{d^2\xi_\perp}{(2\pi)^2} e^{ixP^+\xi^- - i\mathbf{k}_\perp \xi_\perp} \langle P, S_P | \bar{\psi}_j(0) \mathcal{U}(\mathbf{0}, \xi) \psi_i(\xi) | P, S_P \rangle$$

Transverse Momentum Dependent distributions

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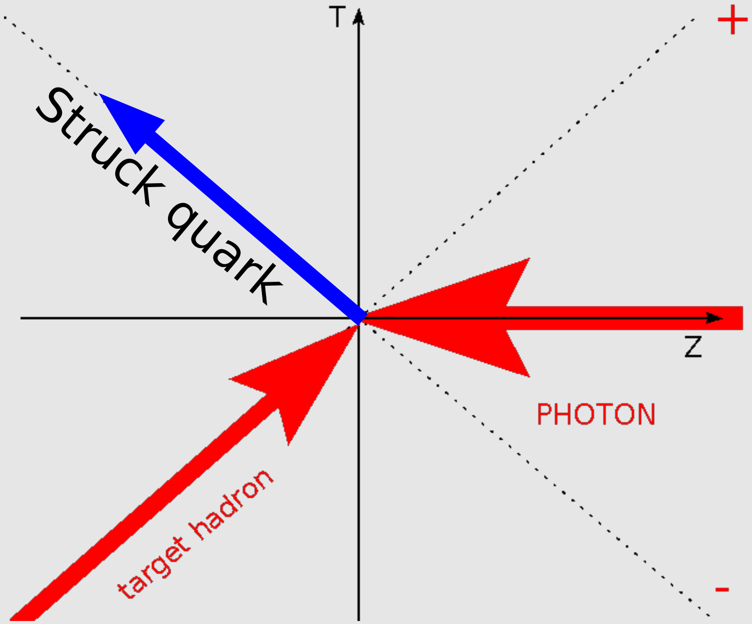
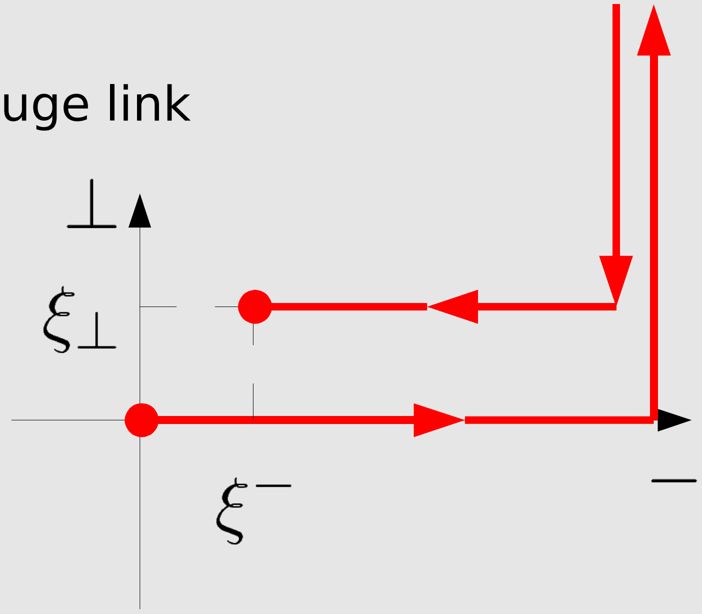
SIDIS in IMF:



Gauge link



$$\mathcal{U}(a,b;n) = e^{-ig\int_a^b d\lambda n\cdot A_\alpha(\lambda n)t_\alpha}$$

Ensures guage invariance of the distribuion

TMDs

N \ q	U	L	T
U	f_1		$h_1^\perp$
L		g_1	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	h_1 $h_{1T}^\perp$

8 functions in total (at leading Twist)

Each represents different aspects of partonic structure

Each function is to be studied

Kotzinian (1995), Mulders, Tangerman (1995), Boer, Mulders (1998)

Twist-2 collinear PDFs

Quark-quark correlator can be decomposed by means of
3 Parton Distributions Functions (PDF) in collinear (kt integrated) case

$$\Phi(x;P,S) = \frac{1}{2}\left\{ f_1(x)\ \not{P} + S_L g_1(x)\gamma_5\ \not{P} + \frac{1}{2} h_1(x)\gamma_5 [\not{S}_T, \not{P}] \right\}$$

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Unpolarised PDF

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Unpolarised PDF

Helicity distribution

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Unpolarised PDF

Helicity distribution

Transversity distribution

Unpolarised PDFs

Good knowledge of
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Parton
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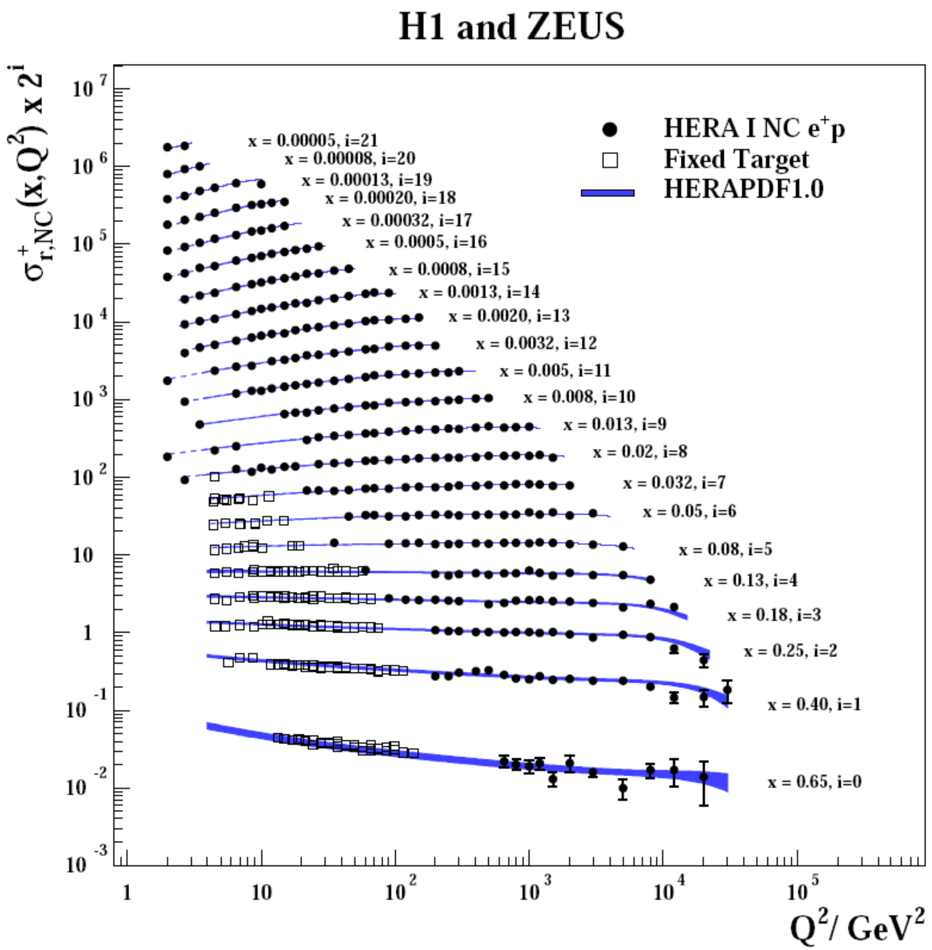

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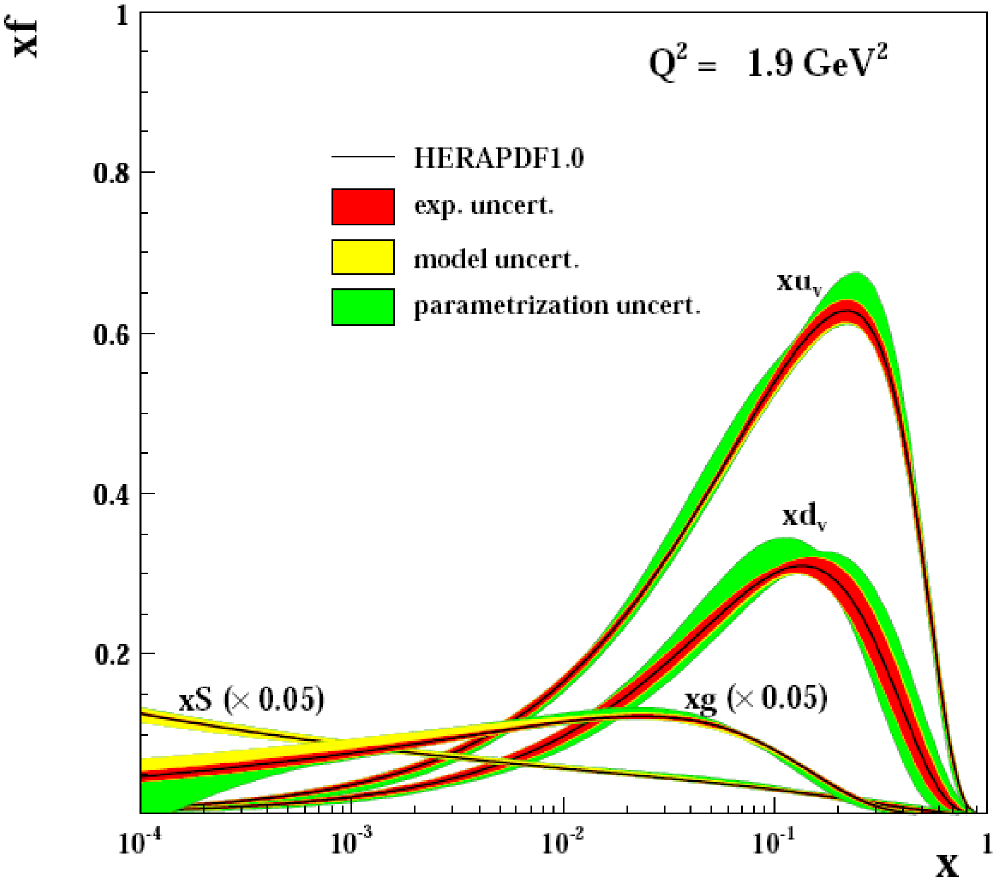
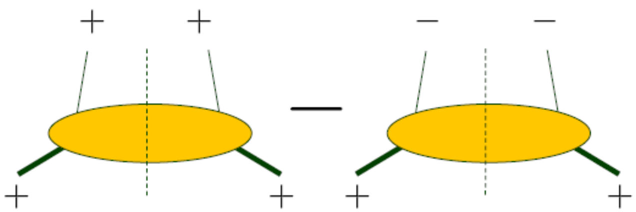
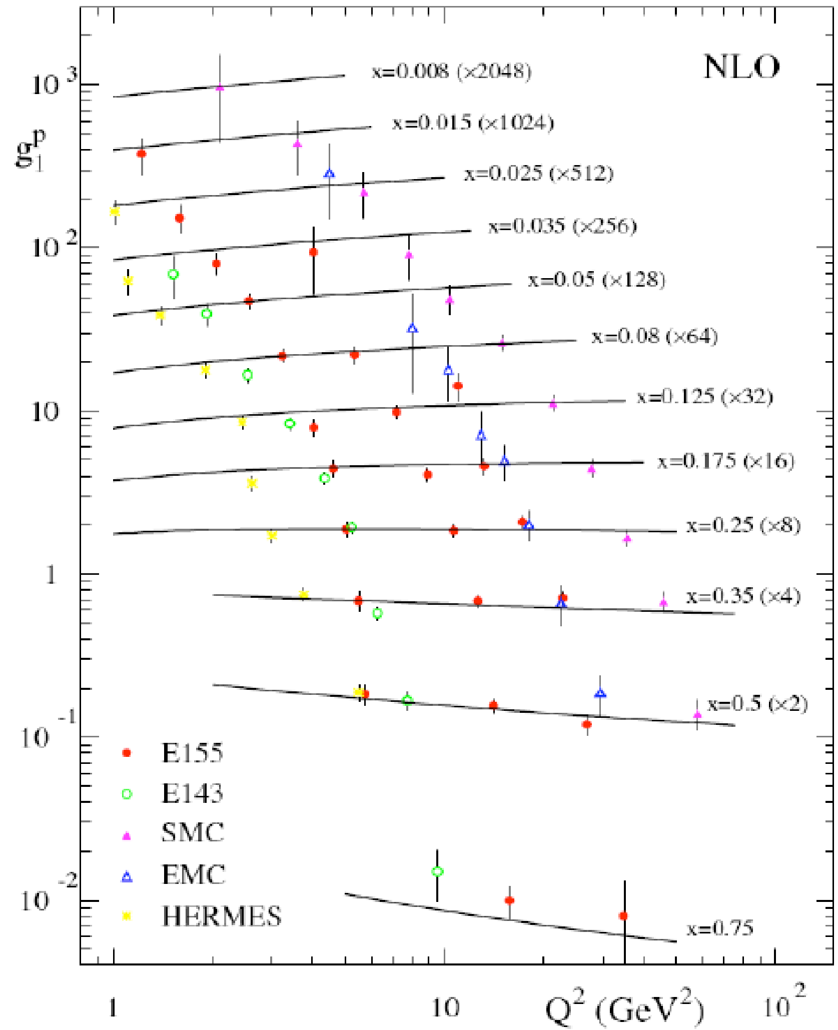


g_1

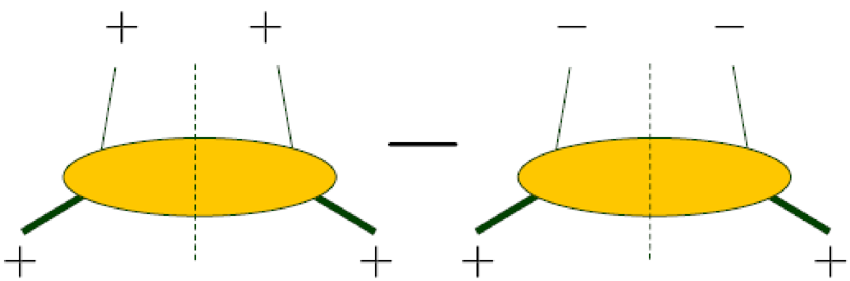
Helicity distributions

Helicity distributions are well known

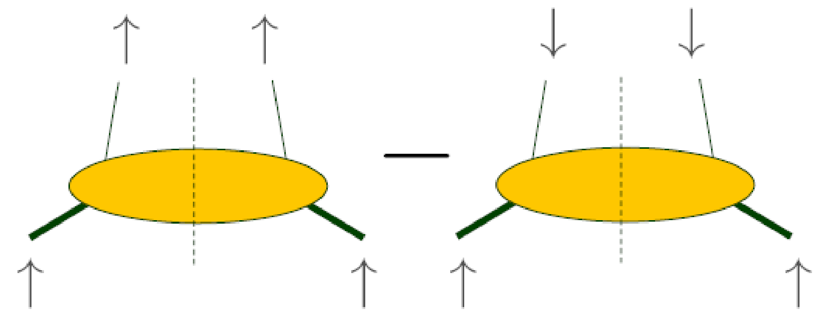




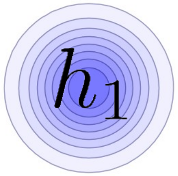
Helicity distribution



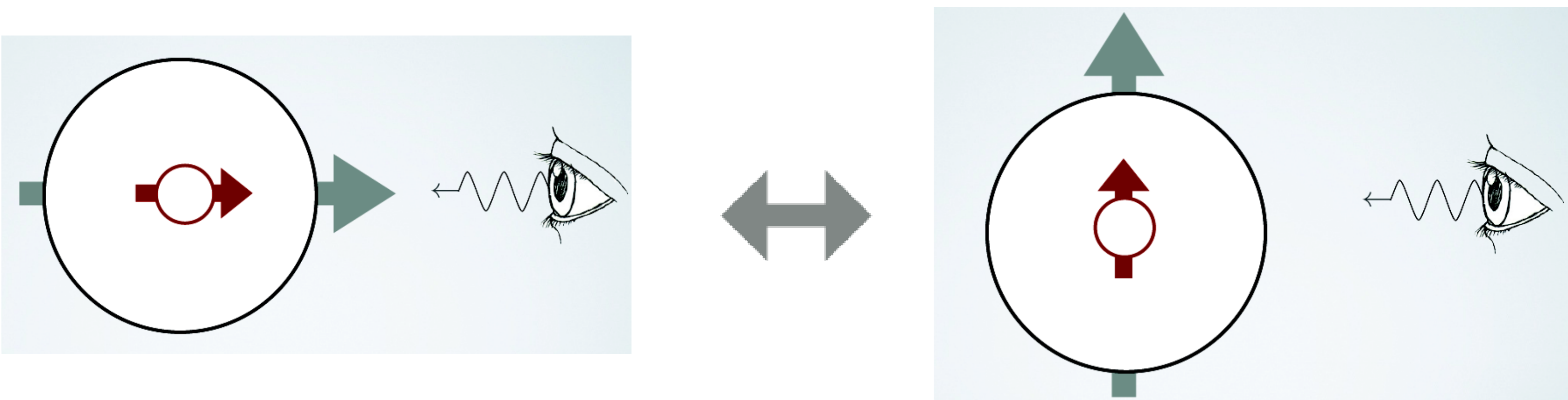
Transversity distribution



Distribution of transversely polarised quarks inside transversely polarised nucleon

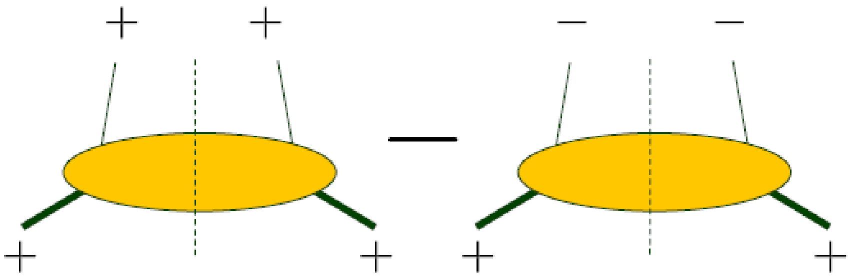


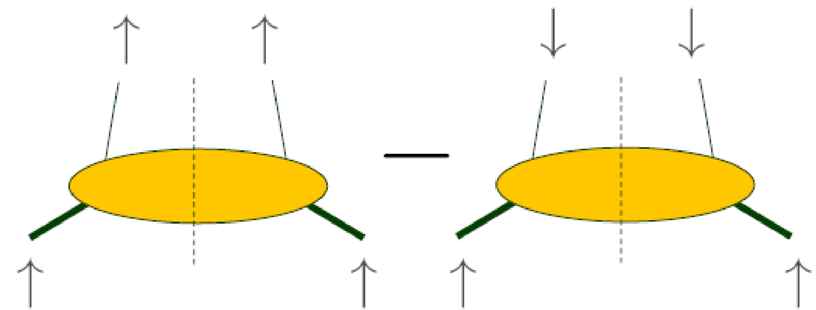
Helicity distribution   Transversity distribution



Boost and rotation do not commute → helicity and transversity are different and difference a relativistic effect

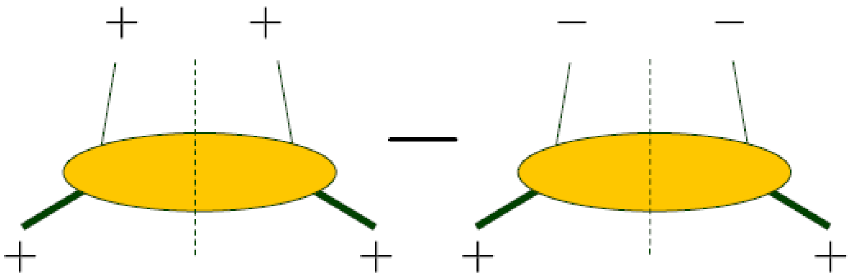
Helicity distribution   Transversity distribution

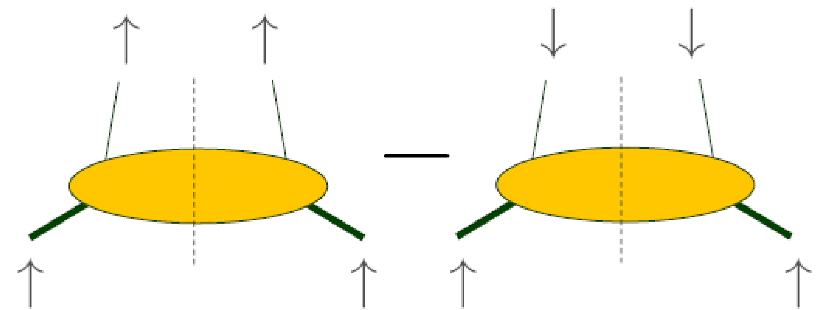




2005: first data on transversity

Helicity distribution   Transversity distribution



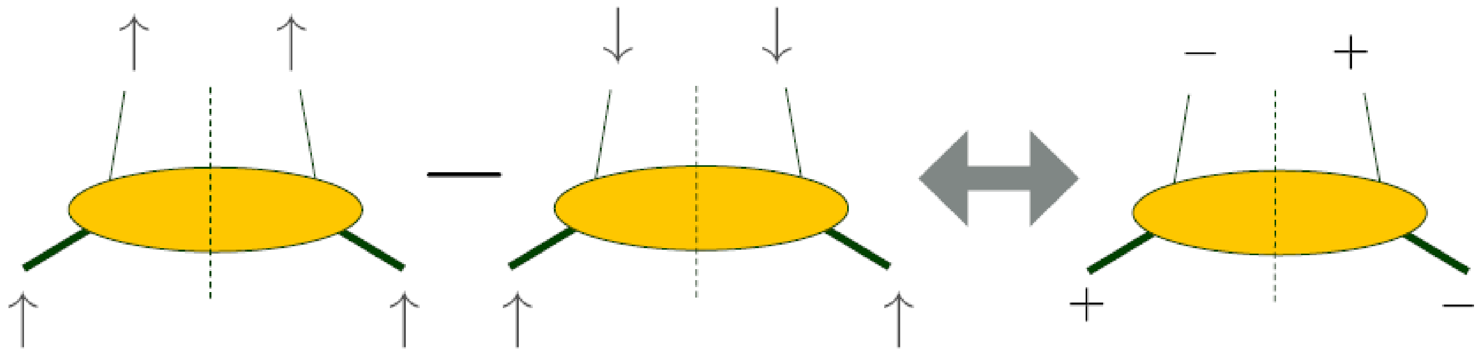


2005: first data on transversity

2012: hundred points from HERMES and COMPASS

Why it is difficult to measure transversity distribution?

Transversity in helicity basis $|\uparrow,\downarrow\rangle = \frac{1}{\sqrt{2}}(|+\rangle \pm i|-\rangle)$



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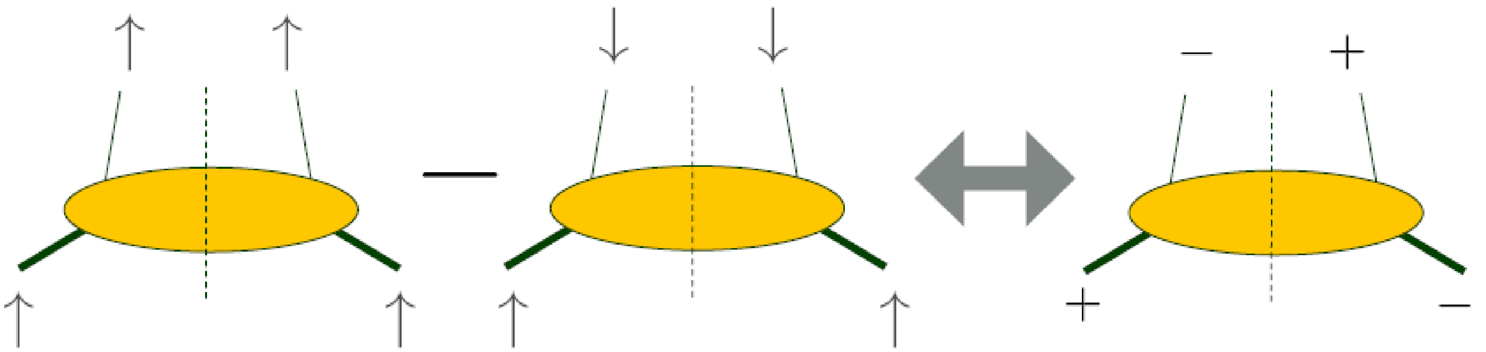
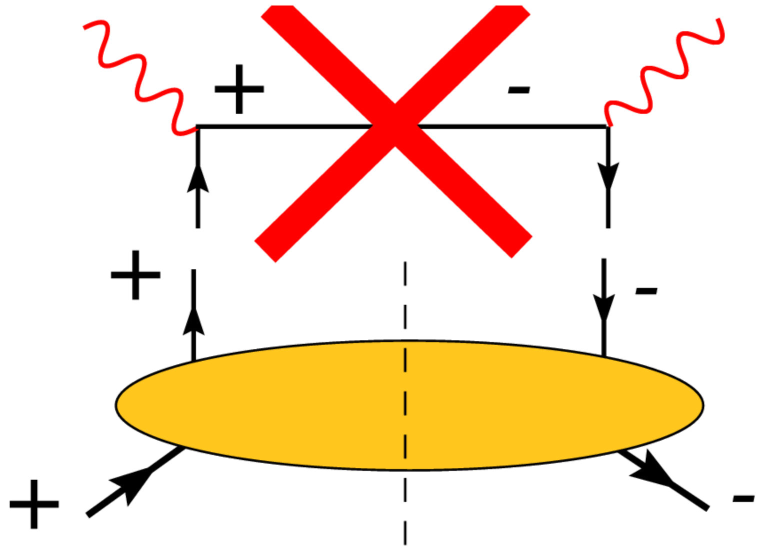


Chiral Odd!

Transversity distribution

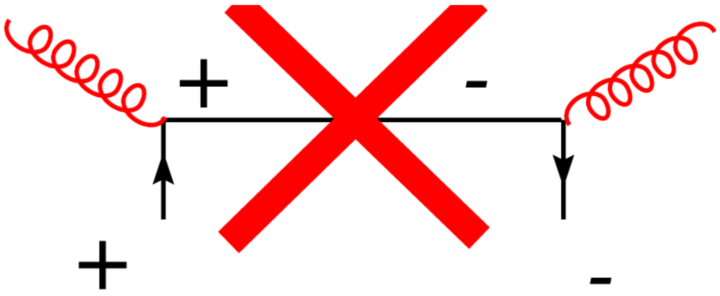
Chiral Odd: it cannot be measured in Deep Inelastic Scattering process



Needs another chiral odd function to be measured

Transversity distribution

QCD Evolution: no gluon contribution in the evolution



$h_1(x, Q^2)$ is suppresed at low x

JLab 12 is an ideal place to measure transversity → as JLab explores high x region

Transversity distribution

Bounds on transversity distribution: The Soffer Bound

$$|h_1(x)| \leq \frac{1}{2}\left(f_1(x) + g_1(x)\right)$$

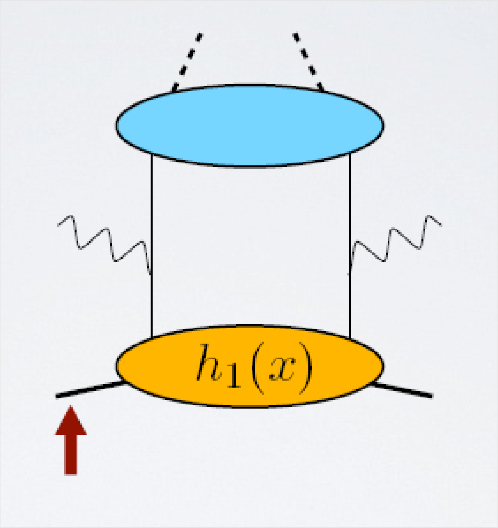
Valid at LO QCD, Barone 97, Bourelly et al 98

Valid at NLO QCD, Vogelsang 98

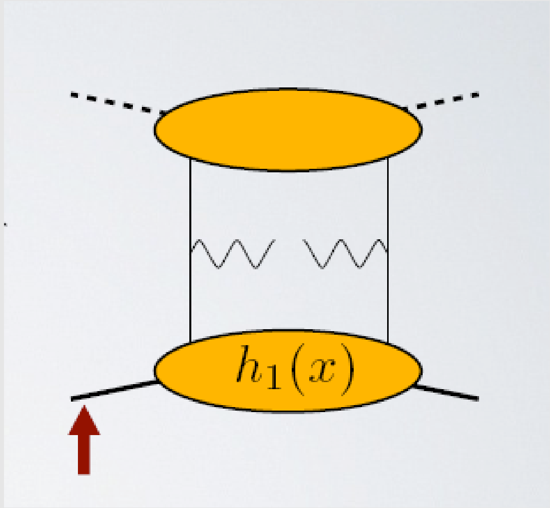
Transversity how to measure?

Transversity needs another chiral odd function to be measured

Semi Inclusive DIS (SIDIS)



Drell-Yan



Transversity how to measure?

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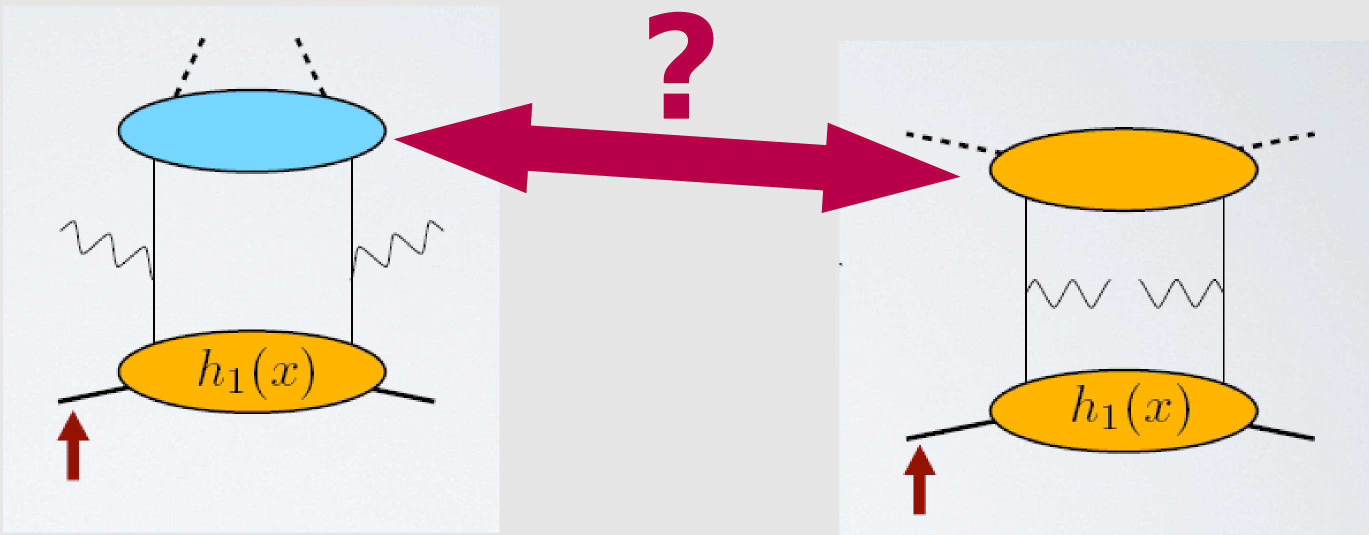
Semi Inclusive DIS (SIDIS) **Drell-Yan**



Collins fragmentation function

$$H_1^{\perp}(z, p_{\perp})$$

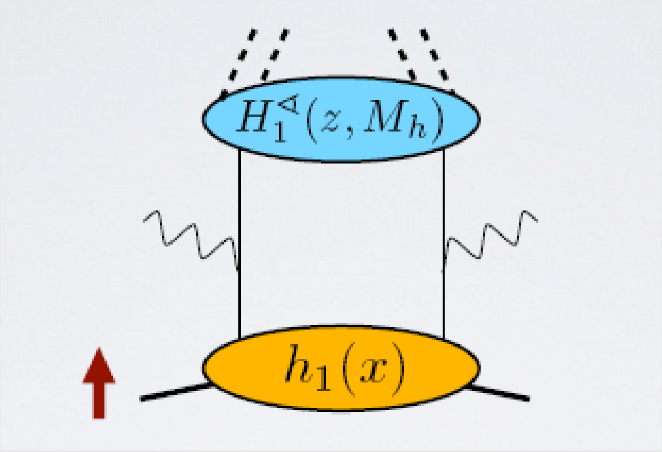
Transversity or Boer-Mulders function

$$h_1(x) \qquad h_1^{\perp}(x, k_{\perp})$$

Transversity how to measure?

Another way to measure transversity is via dihadron fragmentation functions

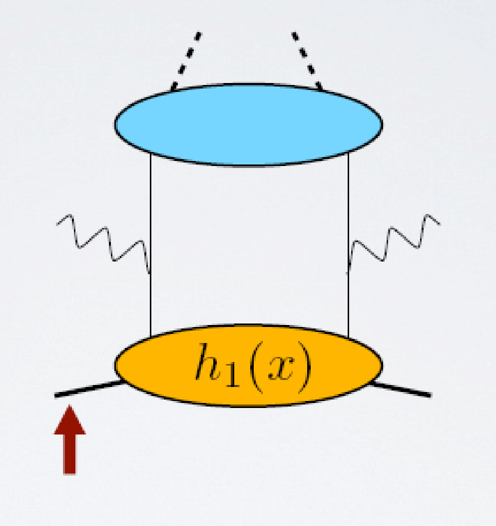
SIDIS



Dihadron fragmentation function

$$H_1^{\sphericalangle}(z, M_h)$$

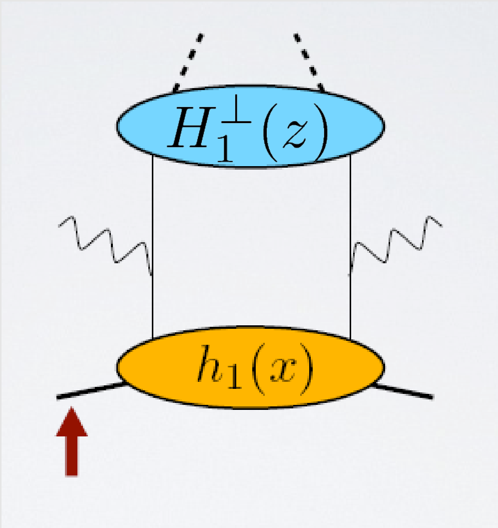
Transversity from SIDIS



First extraction in 2007, Anselmino et al 07

$$A_{UT}^{\sin(\Phi_h+\Phi_S)} \propto \frac{\sum e_q^2 h_1^q \otimes H_1^{\perp q}}{\sum e_q^2 f_1^q \otimes D_1^q}$$

Transversity from SIDIS



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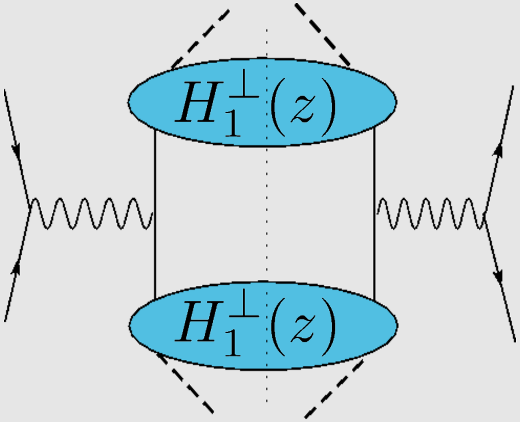
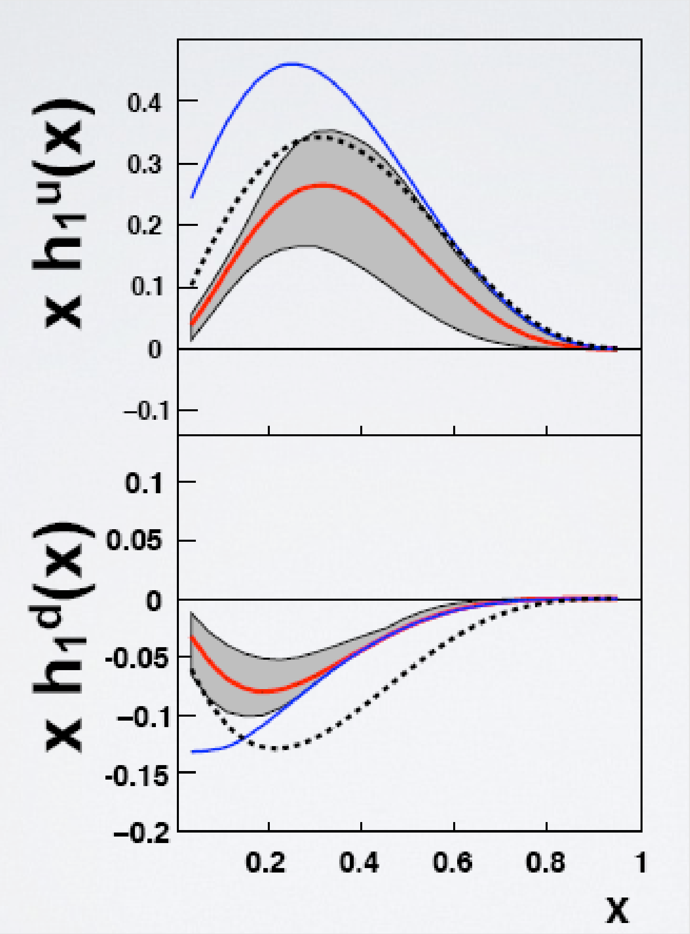
Two unknowns, transversity $h_1(x)$
Collins Fragmentation Function $H_1^\perp(z)$

Fortunatelly information on $H_1^\perp(z)$ is available from e^+e^-



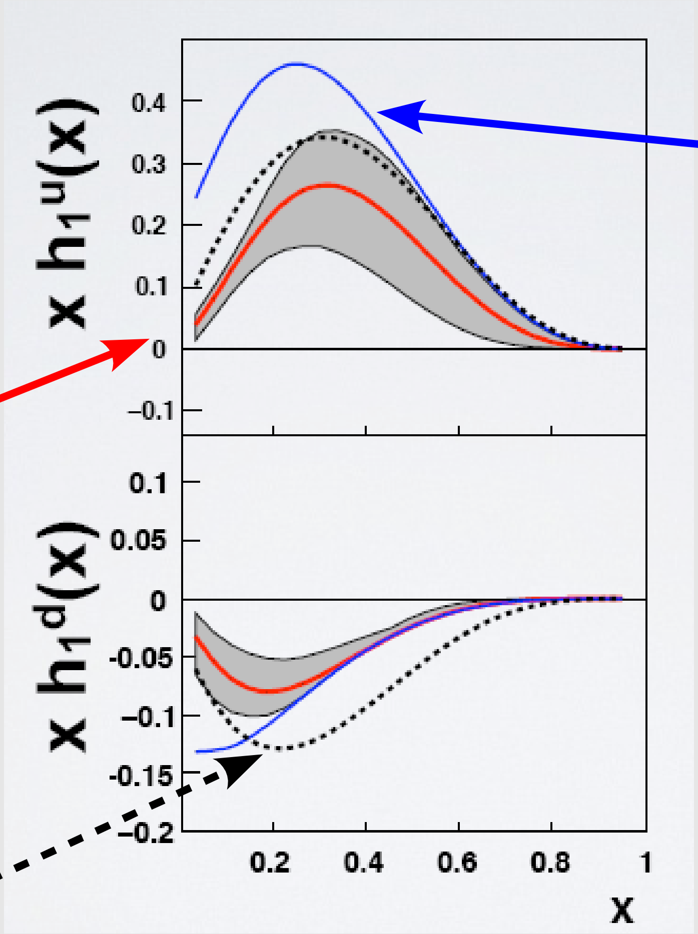
$$A_{e^+e^-} \propto \frac{\sum e_q^2 H_1^{\perp q} \otimes H_1^{\perp \bar{q}}}{\sum e_q^2 D_1^q \otimes D_1^{\bar{q}}}$$

Transversity



Anselmino et al 09

Transversity



Soffer Bound

Transversity

Helicity

Anselmino et al 09

Comparison with models

1 - Barone et al., (1997)
2 - Soffer et al., (2002)
3 - Korotkov et al., (2001)
4 - Schweitzer et al., (2001)
5 - Wakamatzu, (2007)
6 - Pasquini et al., (2005)
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8 - Bacchetta et al., (2008)
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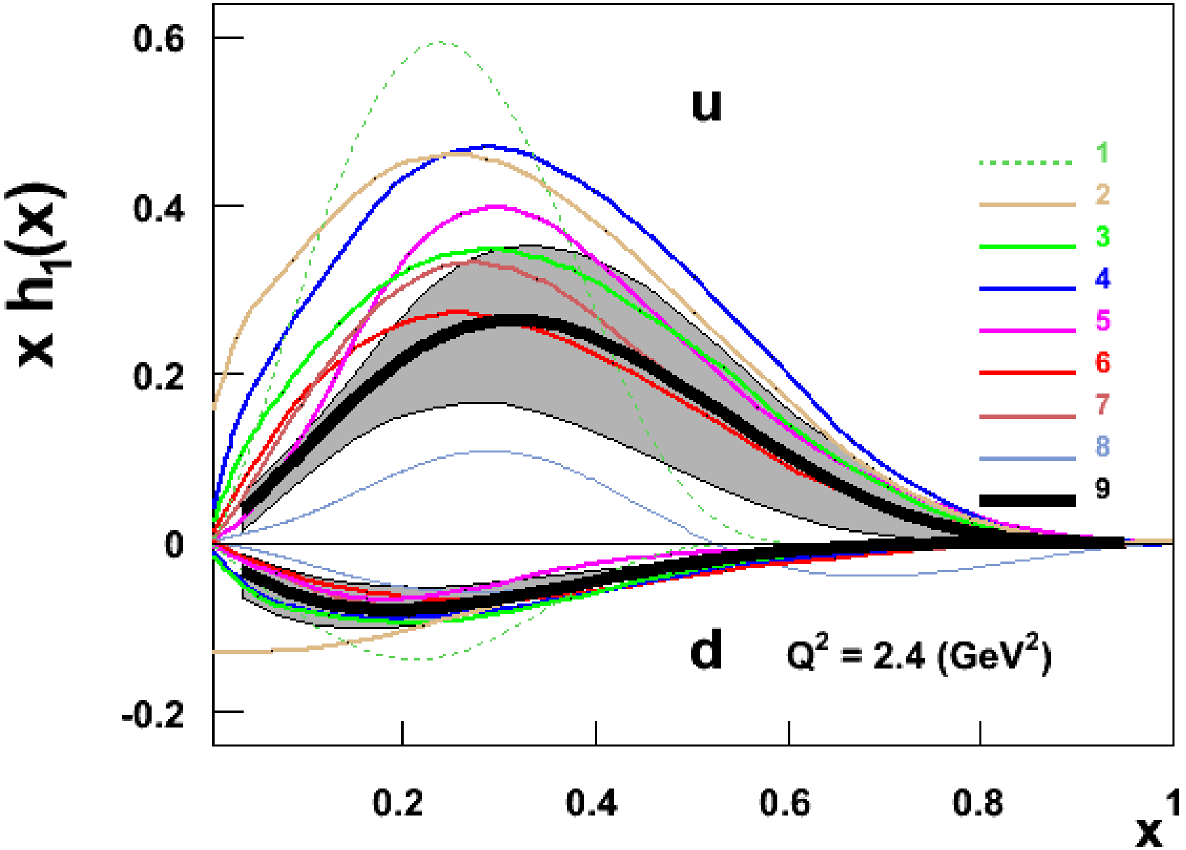

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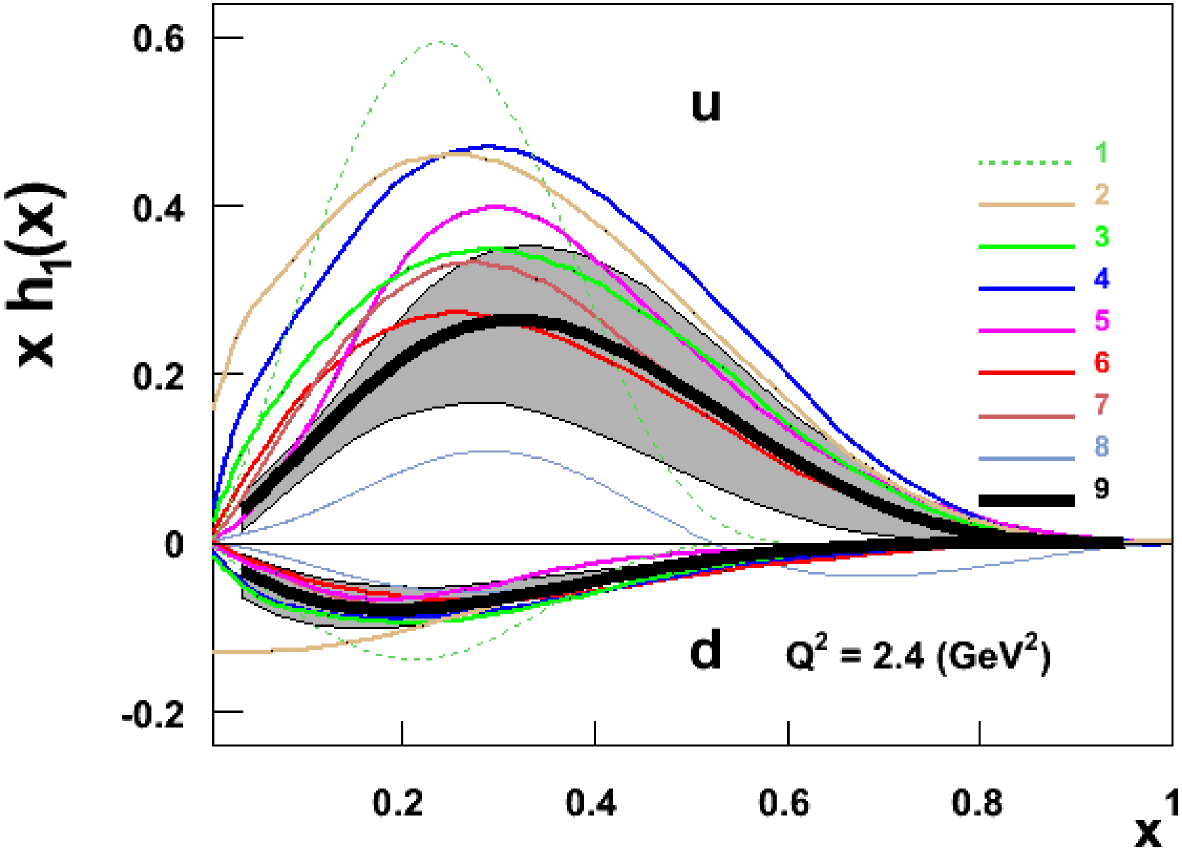

Good agreement with models in sign and size of transversity.

High uncertainty especially in high-x region

Tensor charge

Transversity is the only source of information on tensor charge

$$\delta q = \int_0^1 dx (h_1^q(x) - h_1^{\bar{q}}(x))$$

Fundamental quantity, as fundamental as vector or axial charges

Caveat: no sum rules

Tensor charge

$\delta u = 0.54^{+0.09}_{-0.22}$, $\delta d = -0.23^{+0.09}_{-0.16}$

1 - Anselmino et al., Nucl.Phys.Proc.Suppl. (2009)
2 - Cloet, Bentz and Thomas, Phys.Lett.B (2008)
3 - Wakamatsu, Phys.Lett.B (2007)
4 - Gockeler et al., Phys.Lett.B (2005)
5 - He and Ji, Phys. Rev. D (1995)
6 - Pasquini et al, Phys. Rev. D (2007)
7 - Gamberg and Goldstein, Phys. Rev. Lett. (2001)

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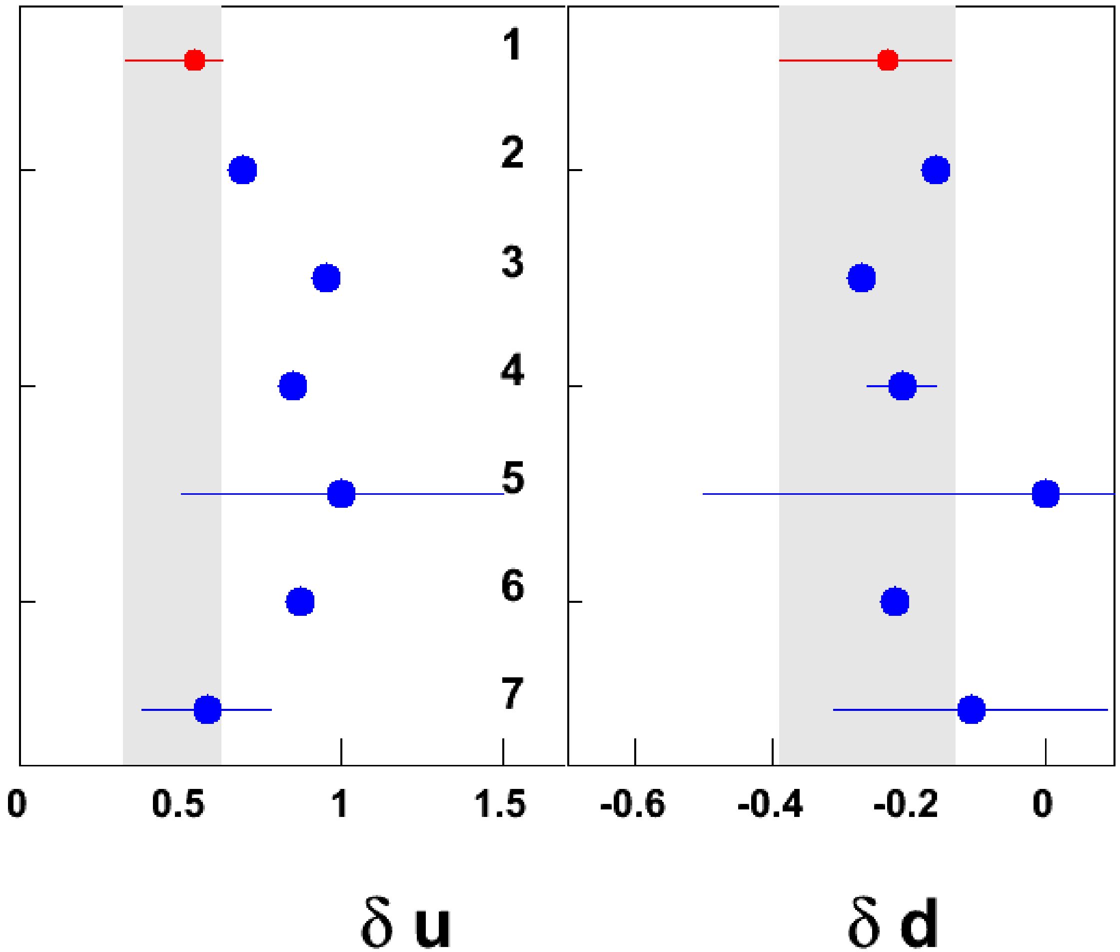

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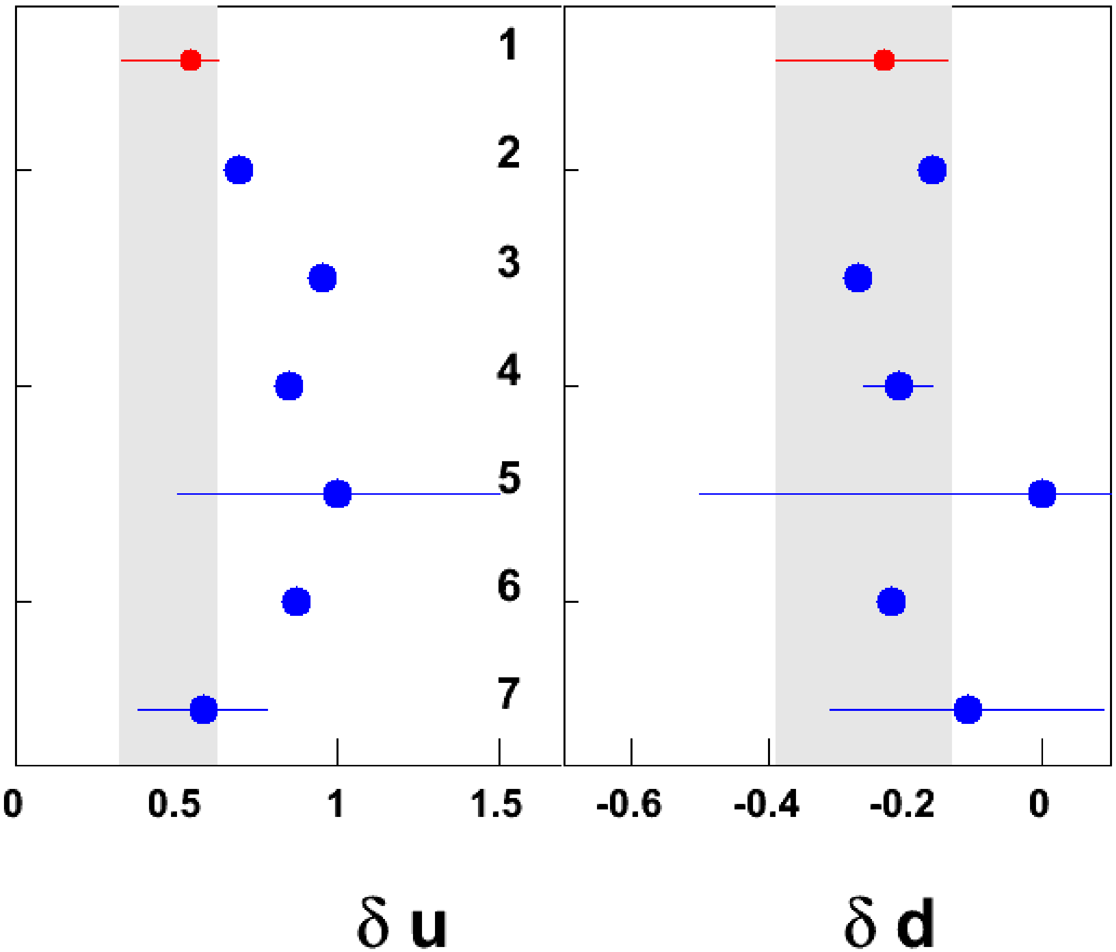


Precision is not enough to discriminate among different calculations

Tensor vs axial charges

$$\Delta q = \int_0^1 dx (g_1^q(x) + g_1^{\bar{q}}(x)) \qquad \delta q = \int_0^1 dx (h_1^q(x) - h_1^{\bar{q}}(x))$$

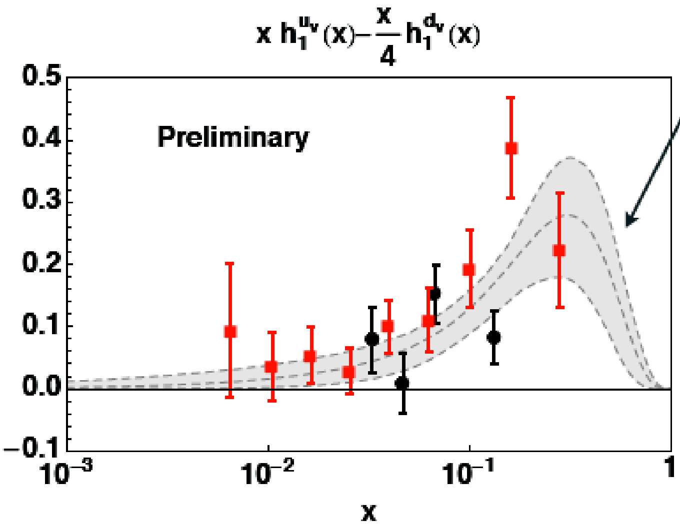
	Axial, DSSV	Tensor, Anselmino
u	0.82	0.54
d	-0.45	-0.23
s	-0.11	0
sum	0.26	0.39

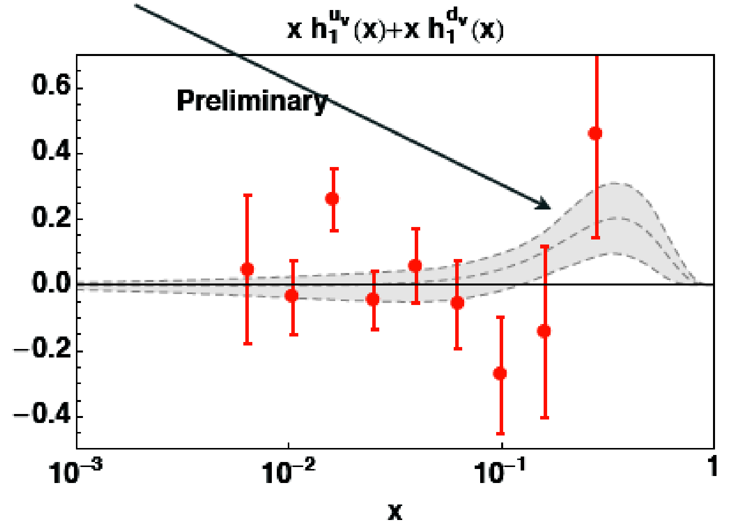
$$Q = 1\ , 0.9(\mathrm{GeV})$$

DSSV: De Florian, Sassot, Stratmann, Vogelsang (2008)

Transversity from dihadron fragmentation

Torino's fit Anselmino et al 09

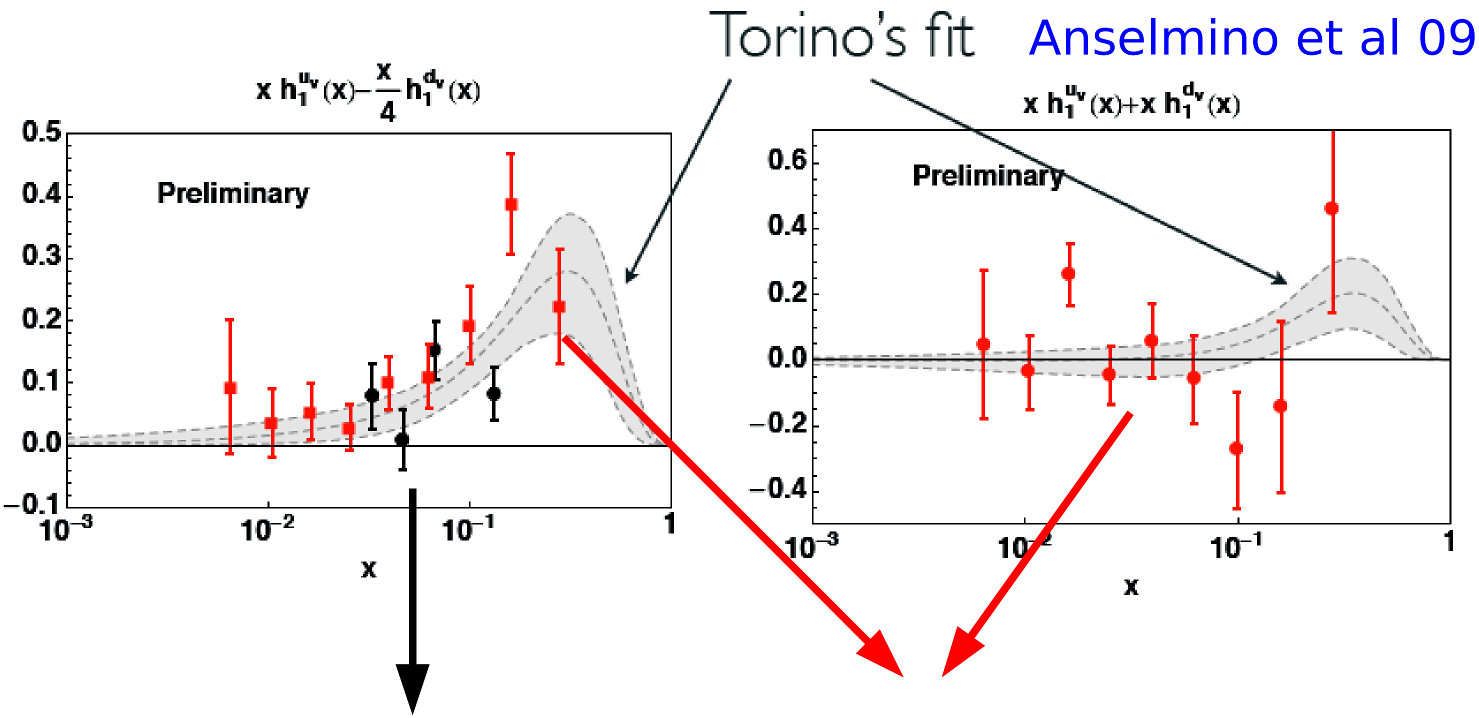




Bacchetta et al. PRL 107,012001 (2011)

Bacchetta et al.,arXiv:1206.1836

Transversity from dihadron fragmentation



Bacchetta et al. PRL 107,012001 (2011)

Bacchetta et al.,arXiv:1206.1836

Good qualitative agreement of two methods of extraction

What do we expect from JLab 12?

12 GeV approved experiments

	Hall A	Hall B	Hall C	Hall D	Total
The Hadron Spectra as Probes of QCD (GluEx & heavy baryon and meson spectroscopy)		1		1	2
The Transverse Structure of the Hadrons (elastic and transition form factors)	4	3	2		9
The Longitudinal Structure of the Hadrons (Unpolarized and polarized parton distributions)	2	2	5		9
The 3D Structure of the Hadrons (GPDs and TMDs)	5	10	3		18
Hadrons and Cold Nuclear Matter	3	2	6		11
Low-Energy Tests of the Standard Model and Fundamental Symmetries	2			1	3
Total	**16**	**18**	**16**	**2**	**52**

See talk by Bob McKeown

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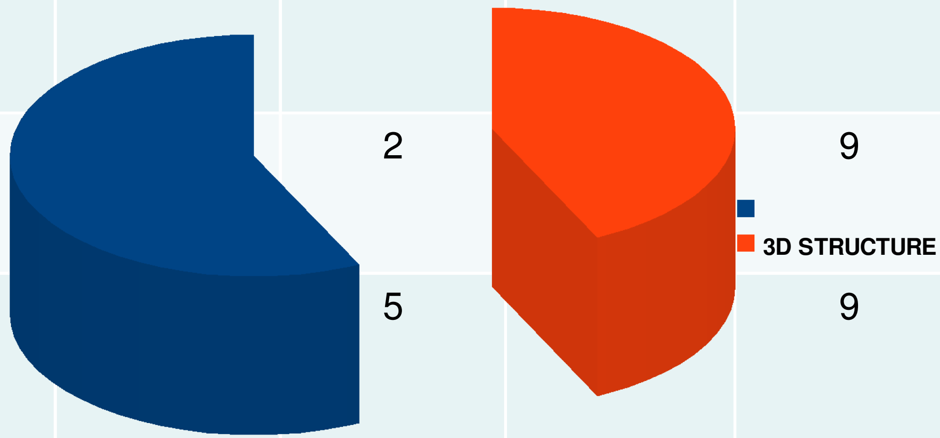
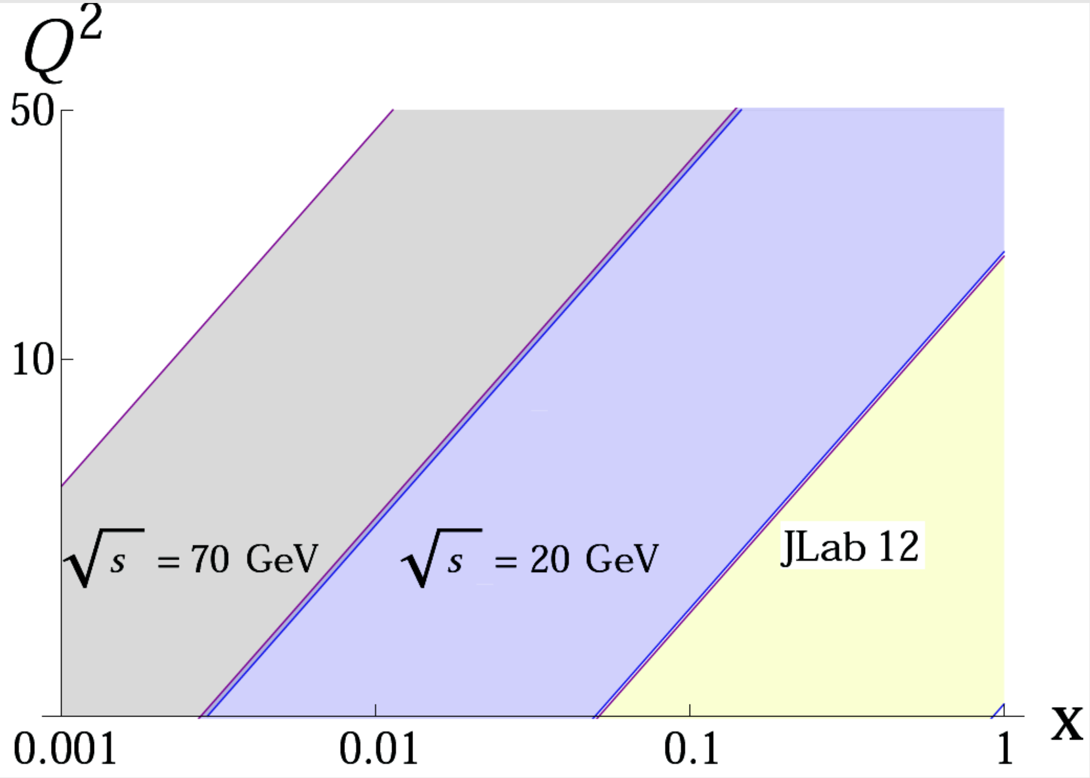


>30% is dedicated to 3D structure!

See talk by Bob McKeown

Kinematics

Kinematics $Q^2 \simeq sxy$



JLab 12 and future Electron Ion Collider are complimentary

Kinematics

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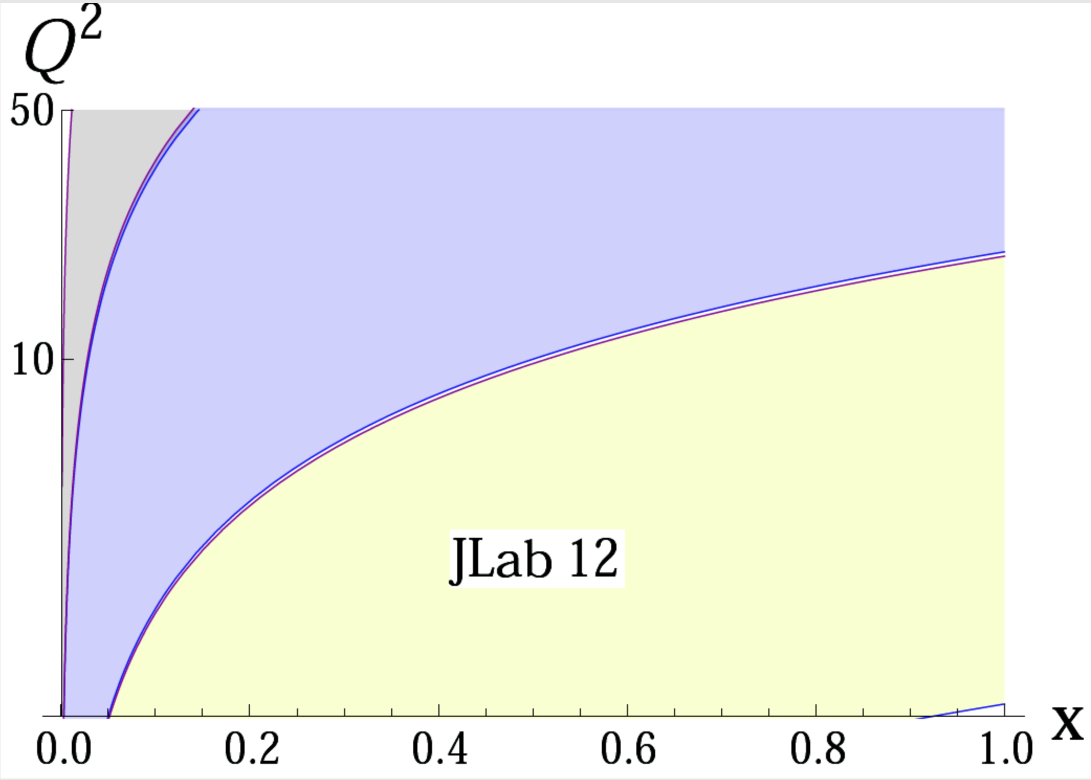
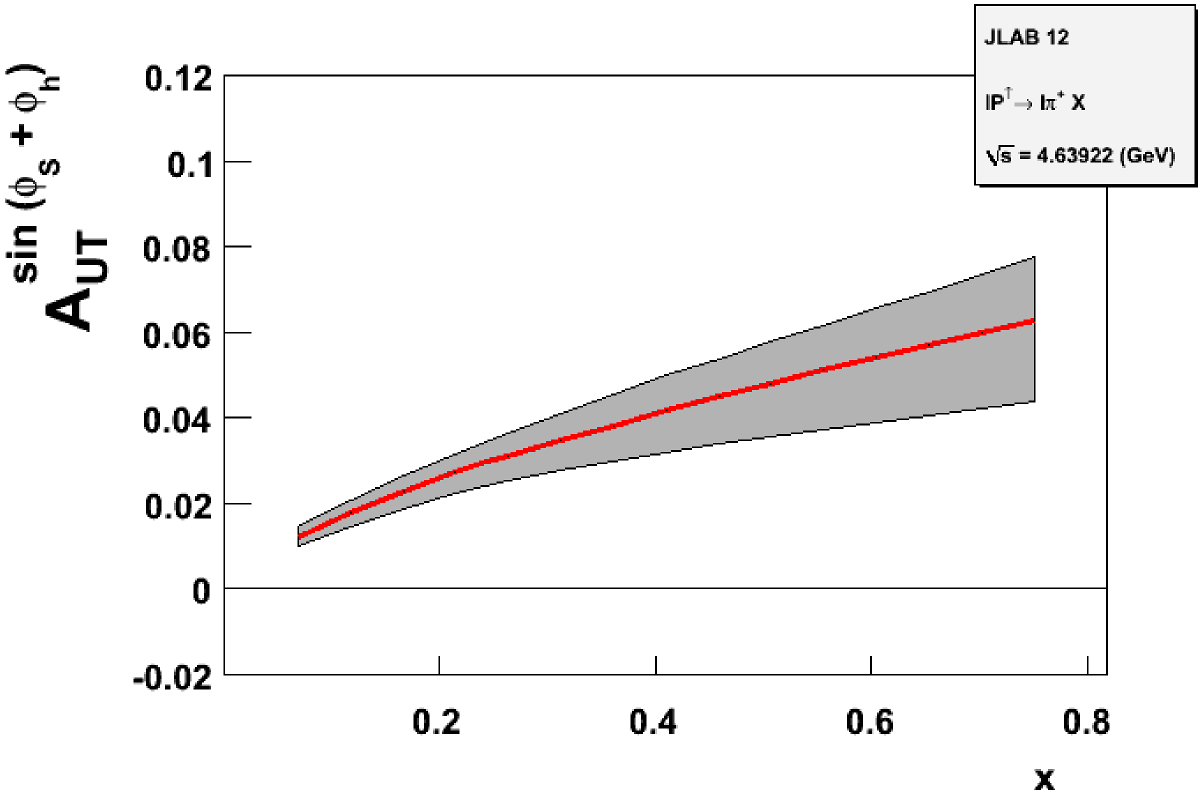


JLab 12 and future Electron Ion Collider are complimentary

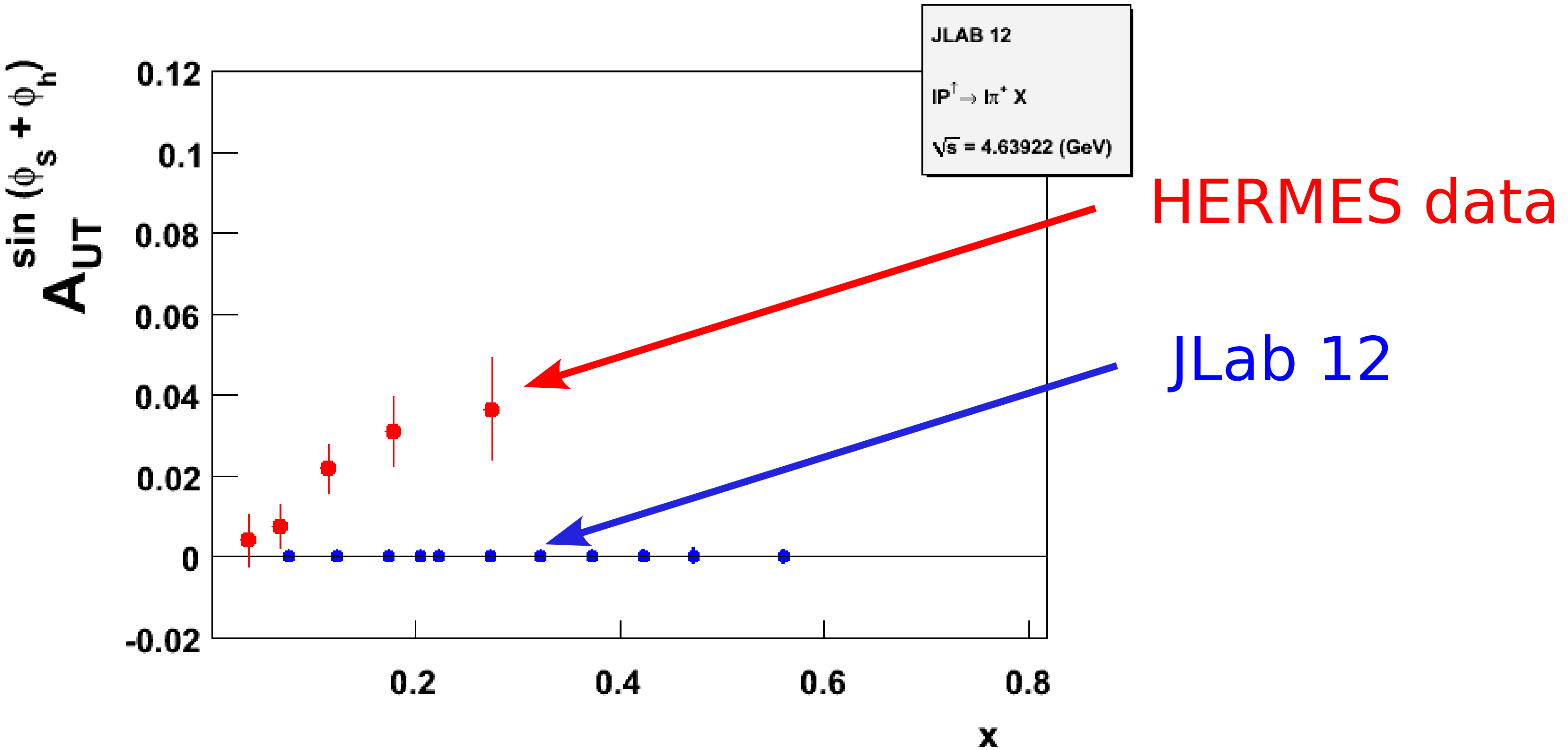
JLab and EIC are going to provide fine 4D binning of the data.

What do we expect at JLab?



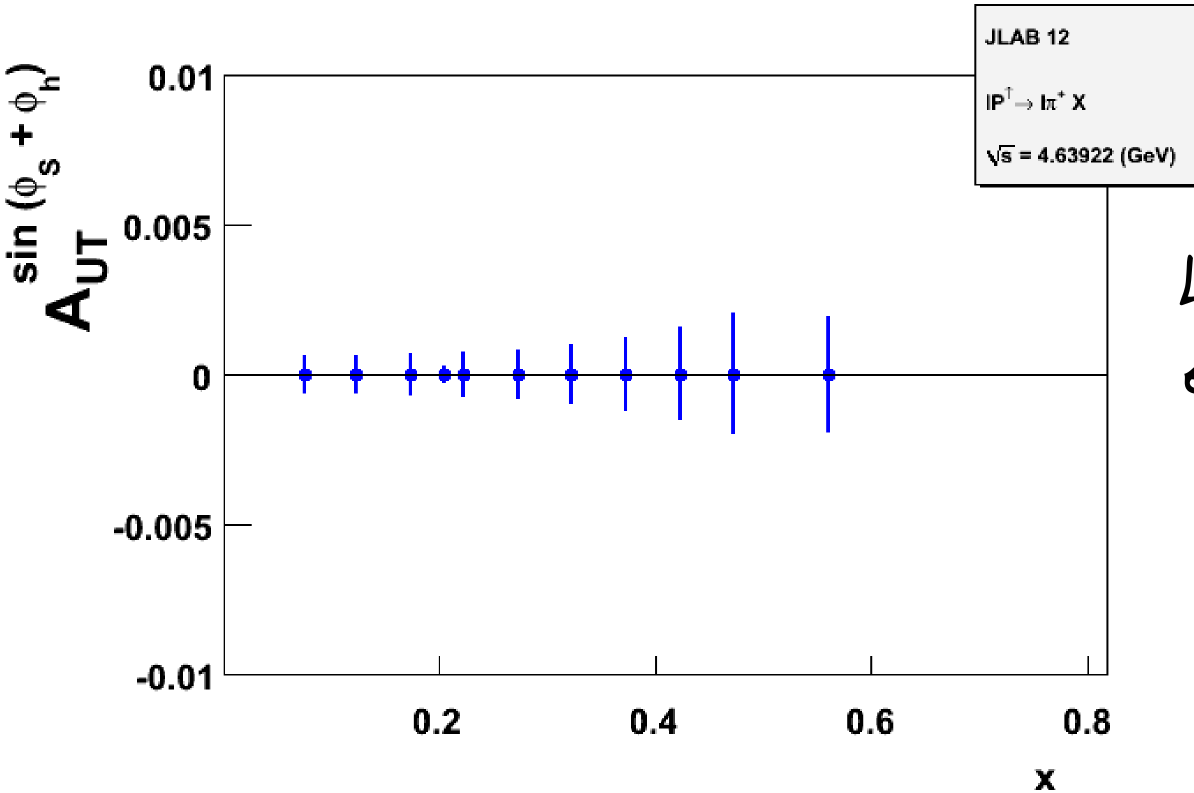
Prediction for JLab 12 kinematics based on Anselmino et al 09

What do we expect at JLab?



Estimates of experimental error for JLab 12

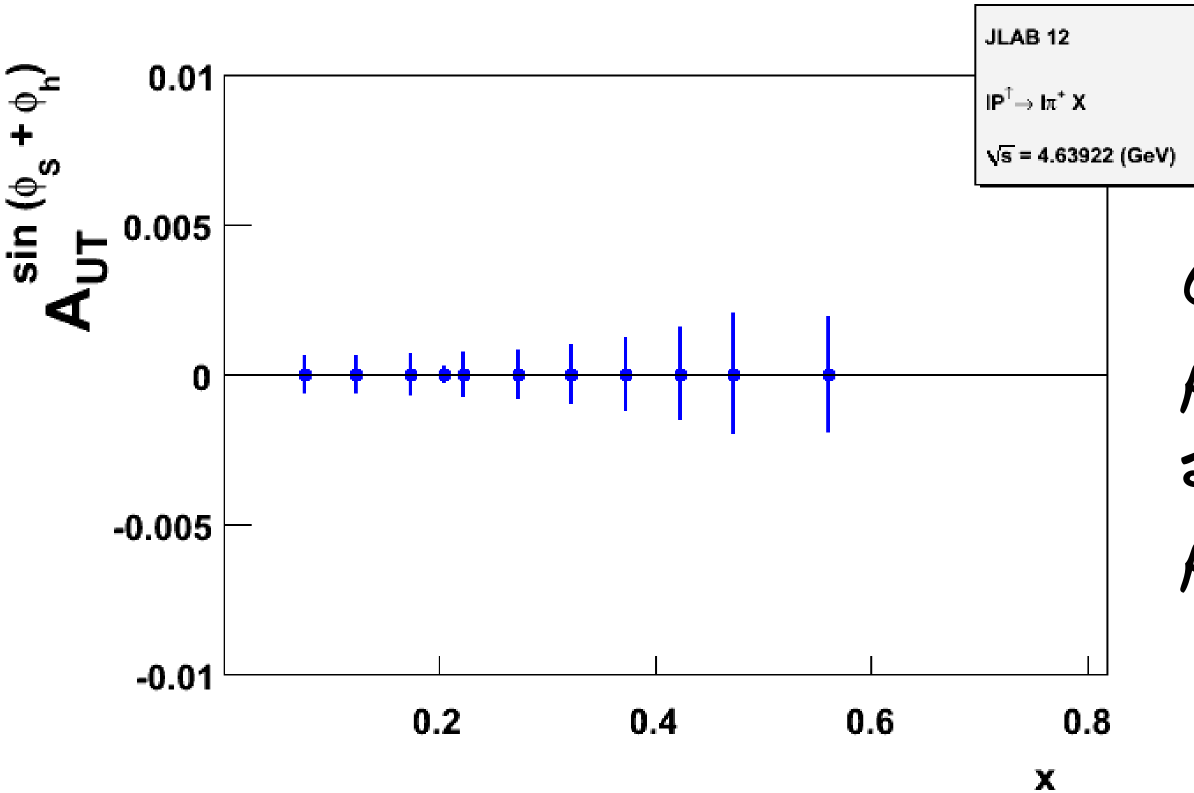
What do we expect at JLab?



Less than 0.25 % error!

Estimates of experimental error for JLab 12

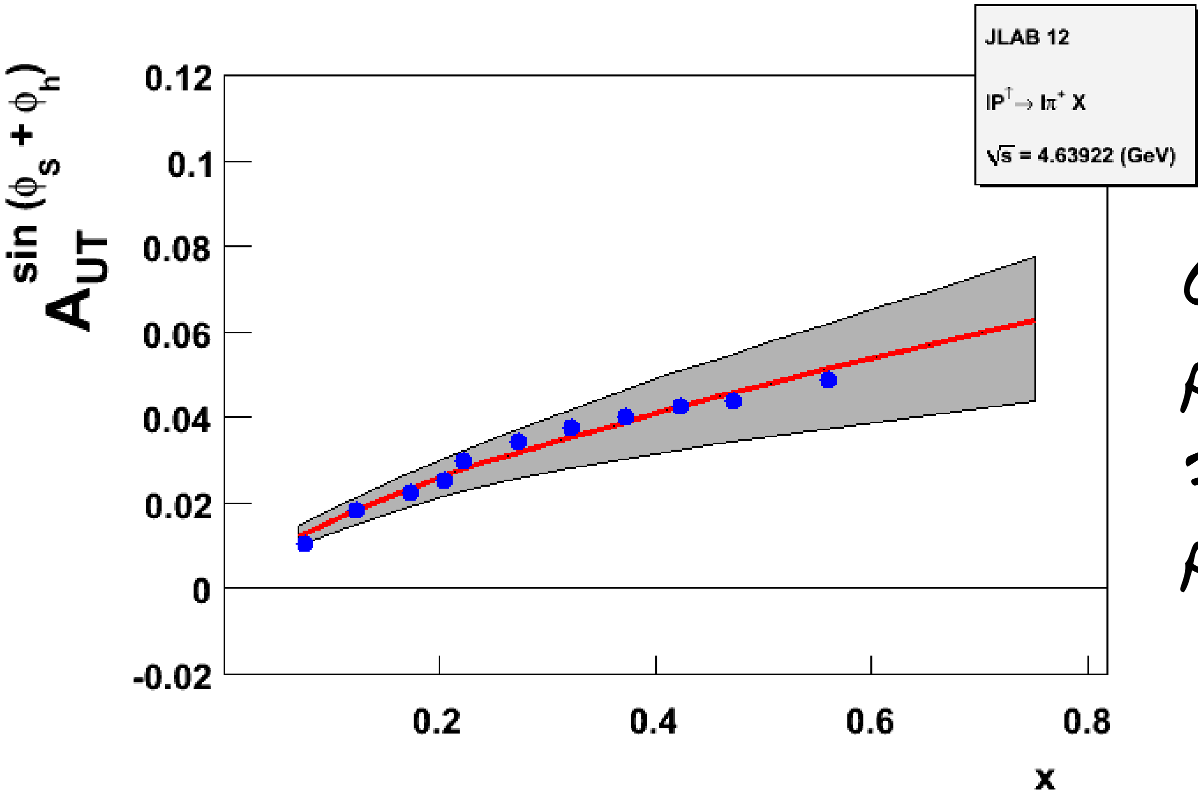
Generate pseudo-data



Generate pseudodata around our predictions

Estimates of experimental error for JLab 12

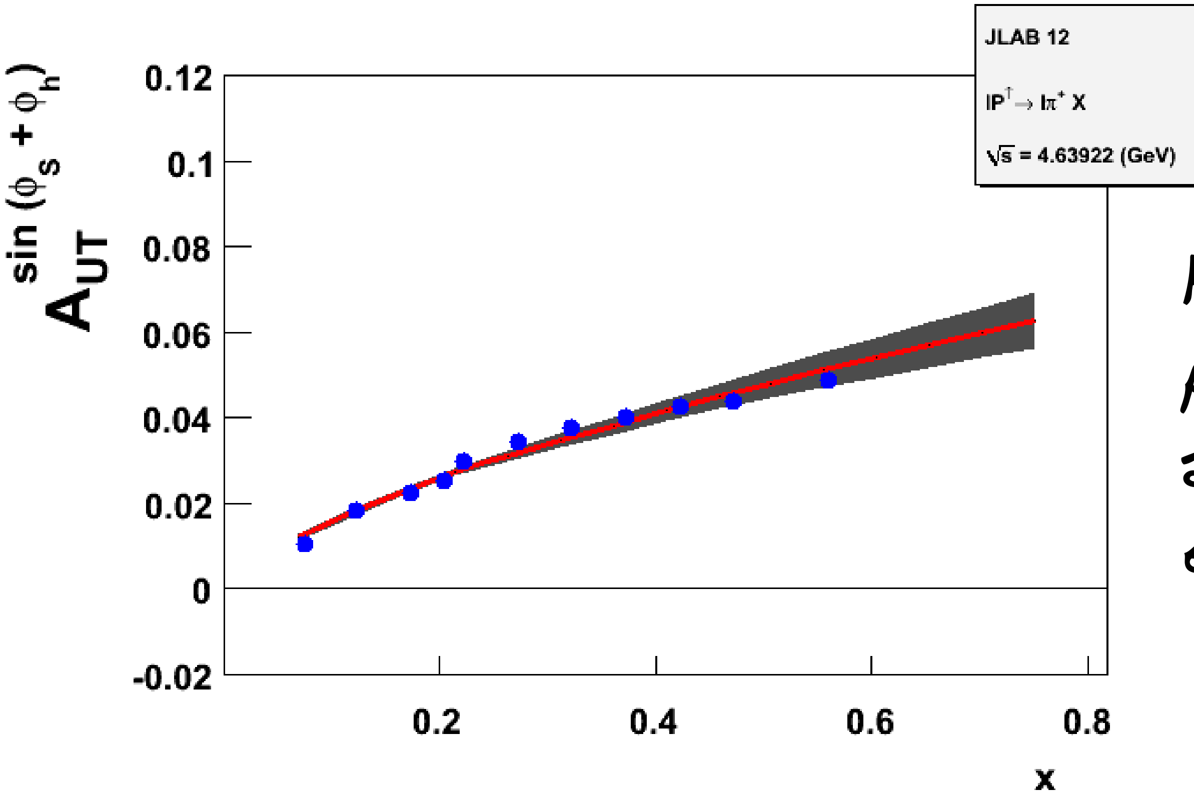
Generate pseudo-data



Generate pseudodata 1-σ around our predictions

Based on Anselmino et al 09

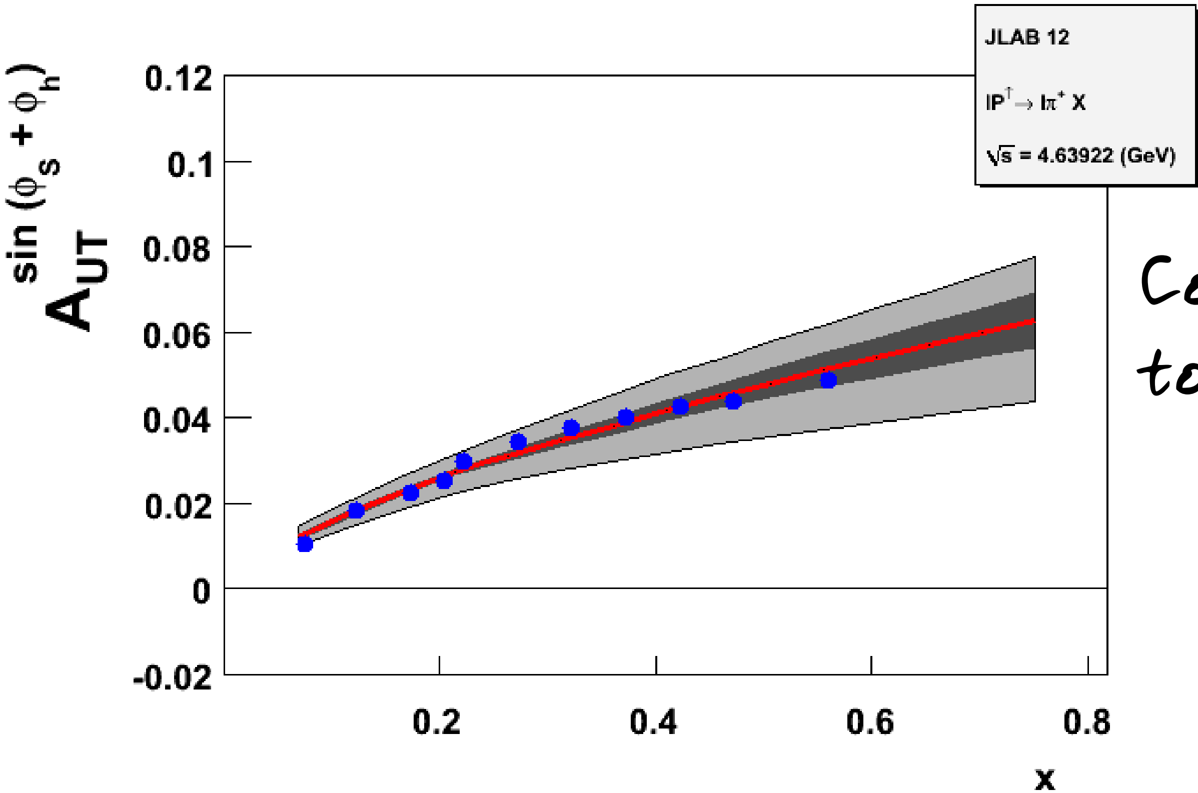
Fit the pseudo-data



Fit the pseudodata and estimate the error

Based on Anselmino et al 09

Generate pseudo-data



Compare the error to the existing one

Based on Anselmino et al 09

Tensor charge

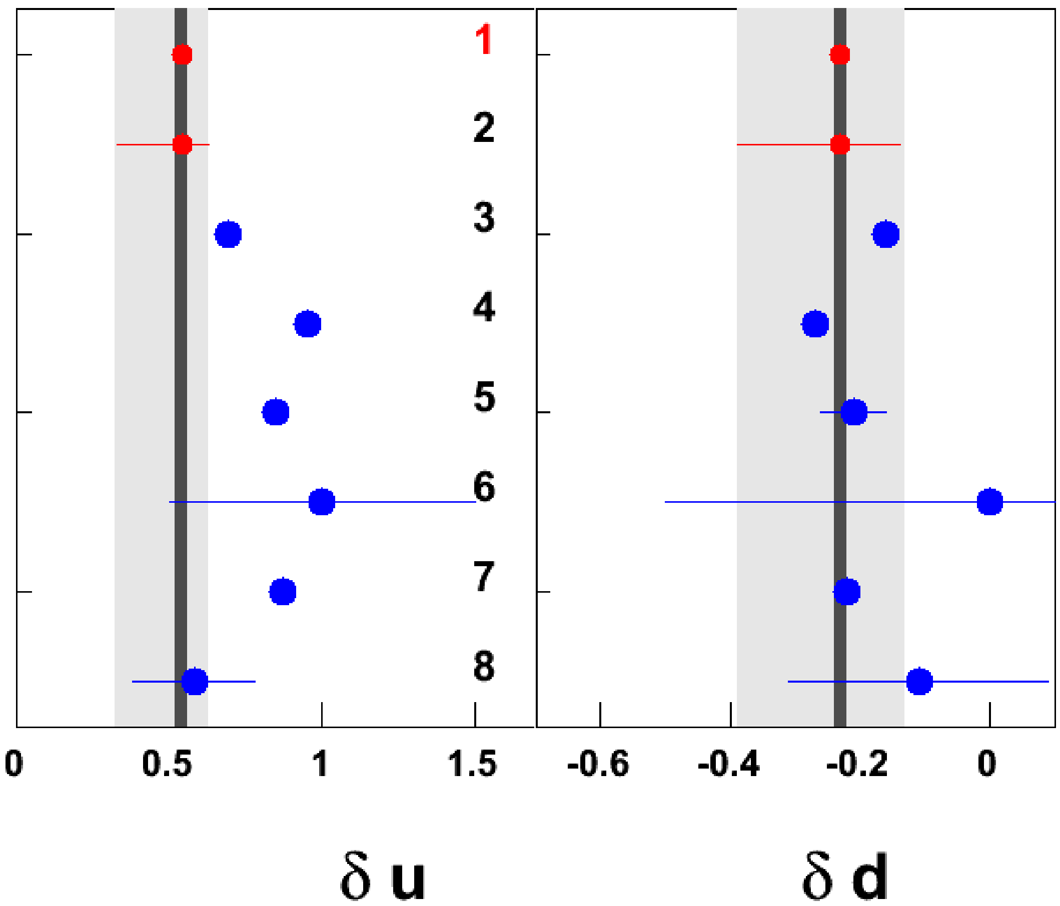
1 - JLab 12
2 - Anselmino et al., Nucl.Phys.Proc.Suppl. (2009)
3 - Cloet, Bentz and Thomas, Phys.Lett.B (2008)
4 - Wakamatsu, Phys.Lett.B (2007)
5 - Gockeler et al., Phys.Lett.B (2005)
6 - He and Ji, Phys. Rev. D (1995)
7 - Pasquini et al, Phys. Rev. D (2007)
8 - Gamberg and Goldstein, Phys. Rev. Lett. (2001)

$$\delta q = \int_0^1 dx \left(h_1^q(x) - h_1^{\bar{q}}(x) \right)$$

$$\delta u = 0.54^{+0.09}_{-0.22},\ \delta d = -0.23^{+0.09}_{-0.16}$$

JLab 12 Proton and He^3 targets

$$\delta u = 0.54^{+0.02}_{-0.02},\ \delta d = -0.23^{+0.01}_{-0.01}$$



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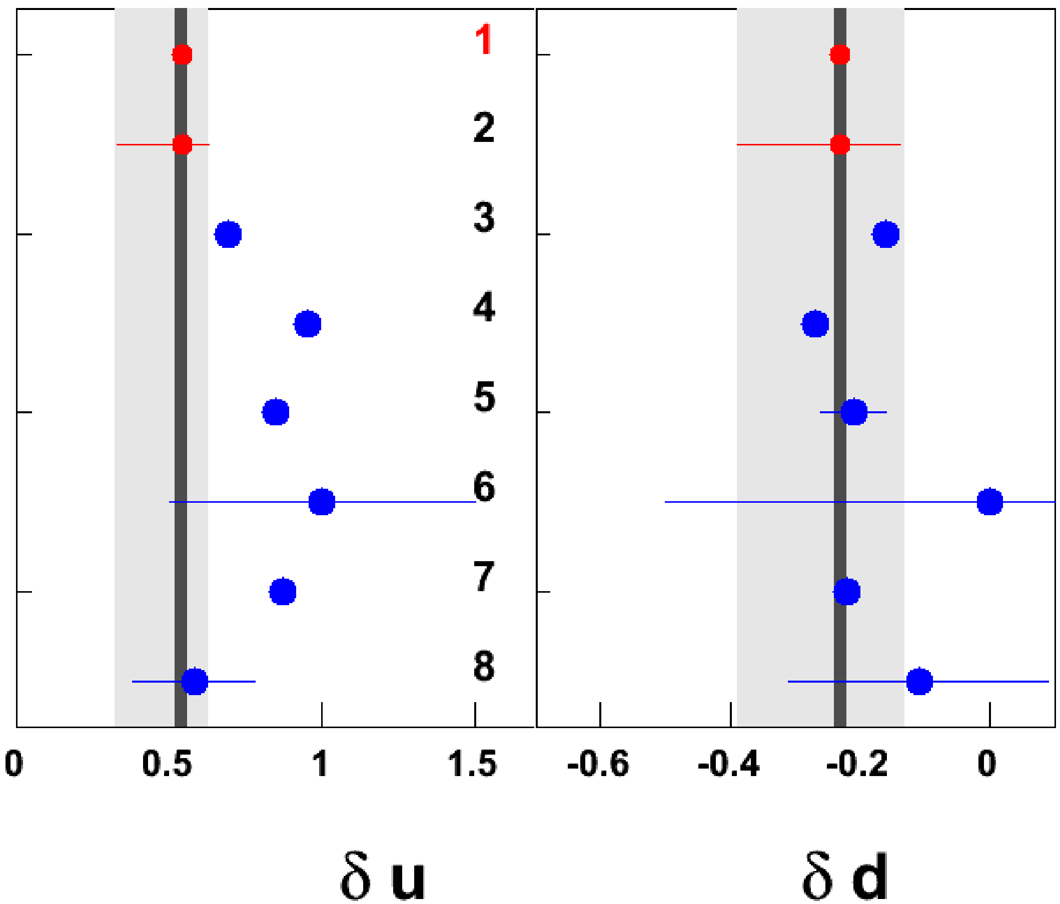


Enough precision to discriminate among models!

CONCLUSIONS

~~CONCLUSIONS~~

Message

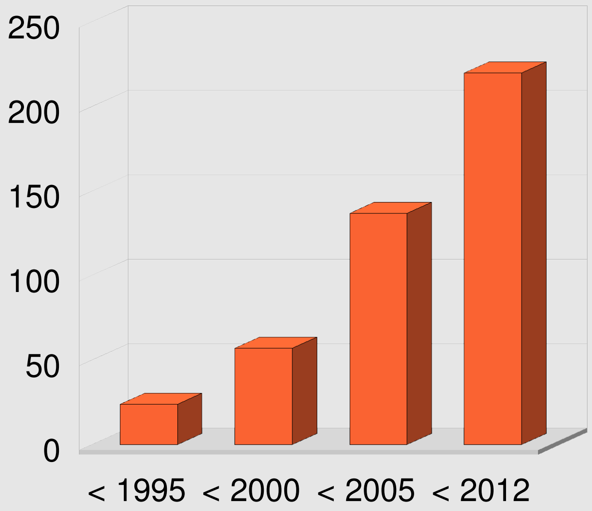
~~CONCLUSIONS~~ Message

- Transversity has clear operator structure

$$\langle \bar{q}\gamma^+\gamma^1\gamma_5 q\rangle$$

- Transversity is equally important part of the nucleon structure as the other two leading twist distributions

- Title “transversity” in the literature



- JLab 12 promises unprecedented accuracy $\pm 5\%$