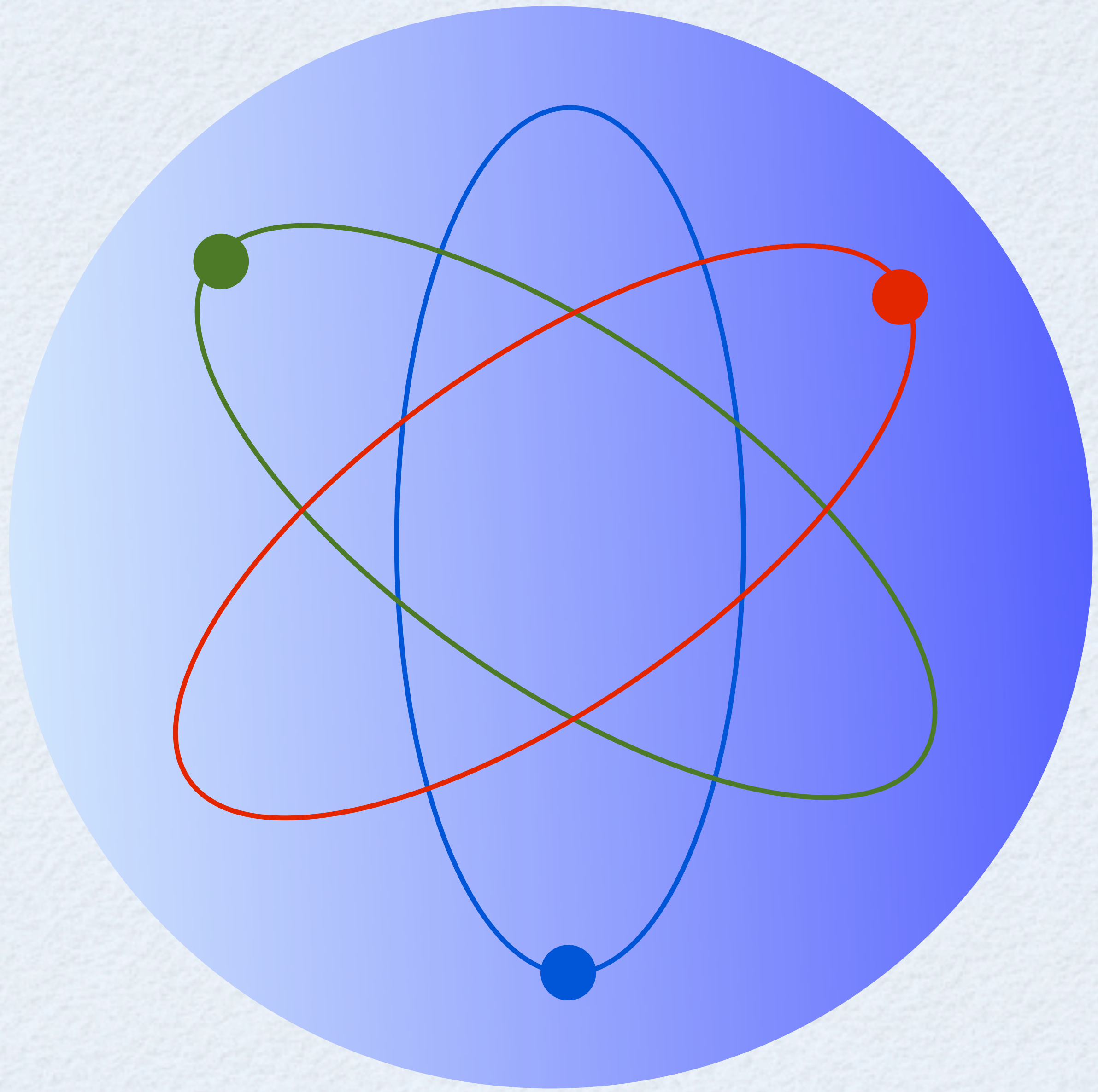
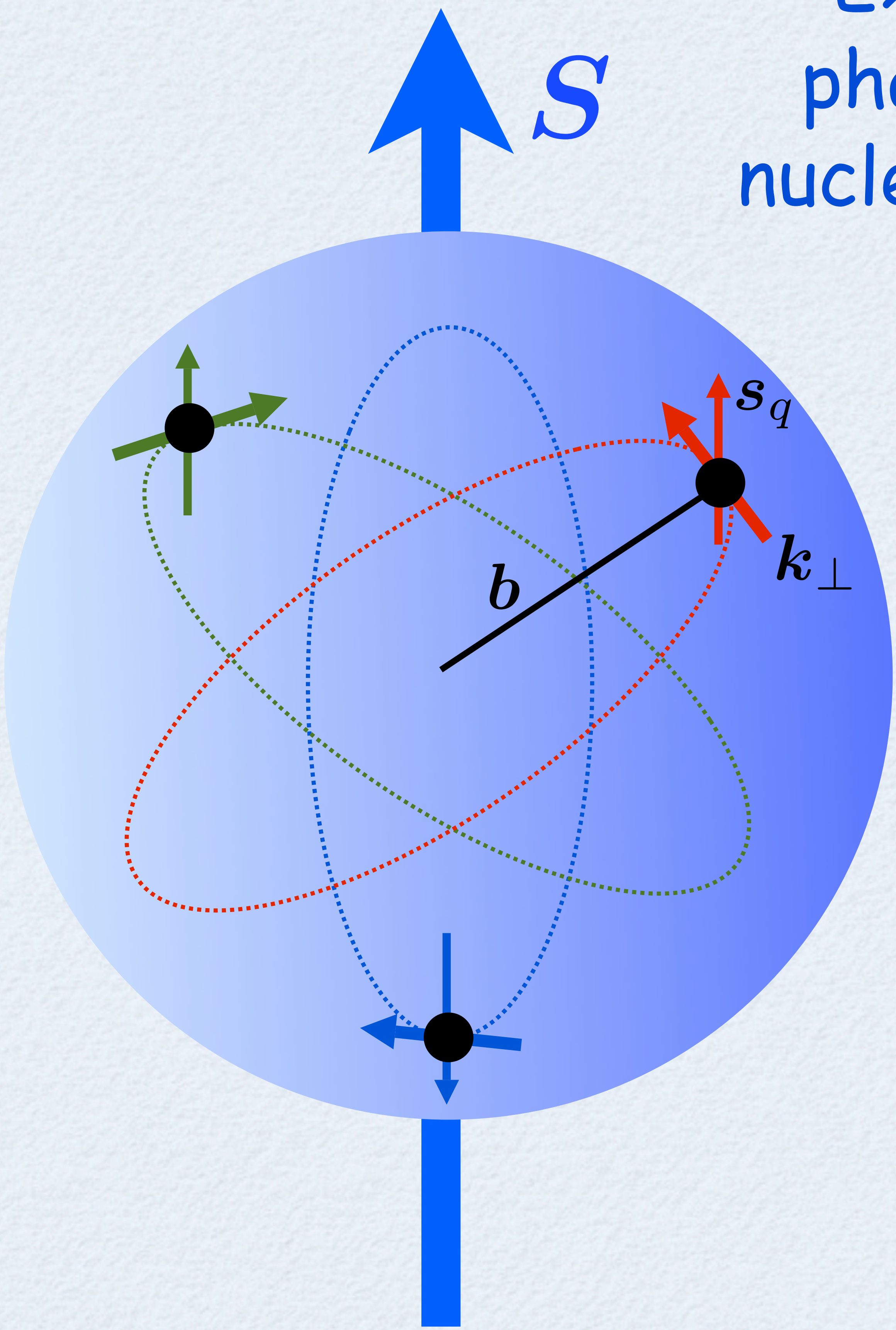
Studying the hadron structure in Drell-Yan reactions - concluding remarks



Mauro Anselmino, Torino University & INFN

26-27 April 2010 CERN

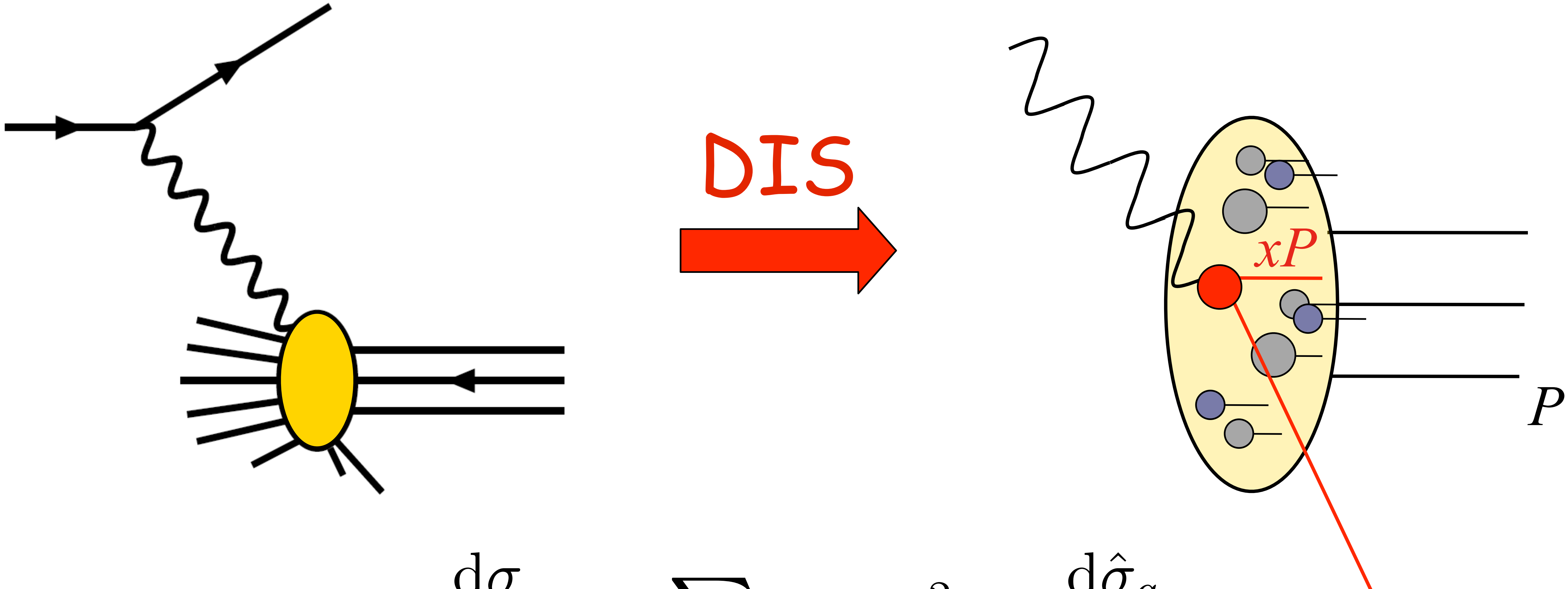
Exploring the 3-dimensional phase-space structure of the nucleon with Drell-Yan processes



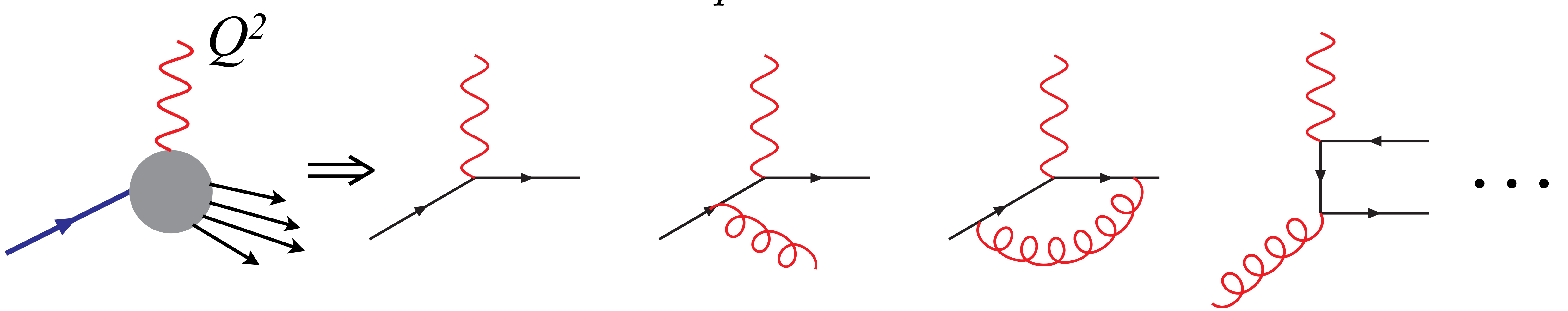
phase-space (**k**-**b**) distribution of partons in nucleons; parton intrinsic motion; spin-$k_\perp$ correlations? orbiting quarks?

information encoded in GPDs and TMDs (exclusive and inclusive processes)

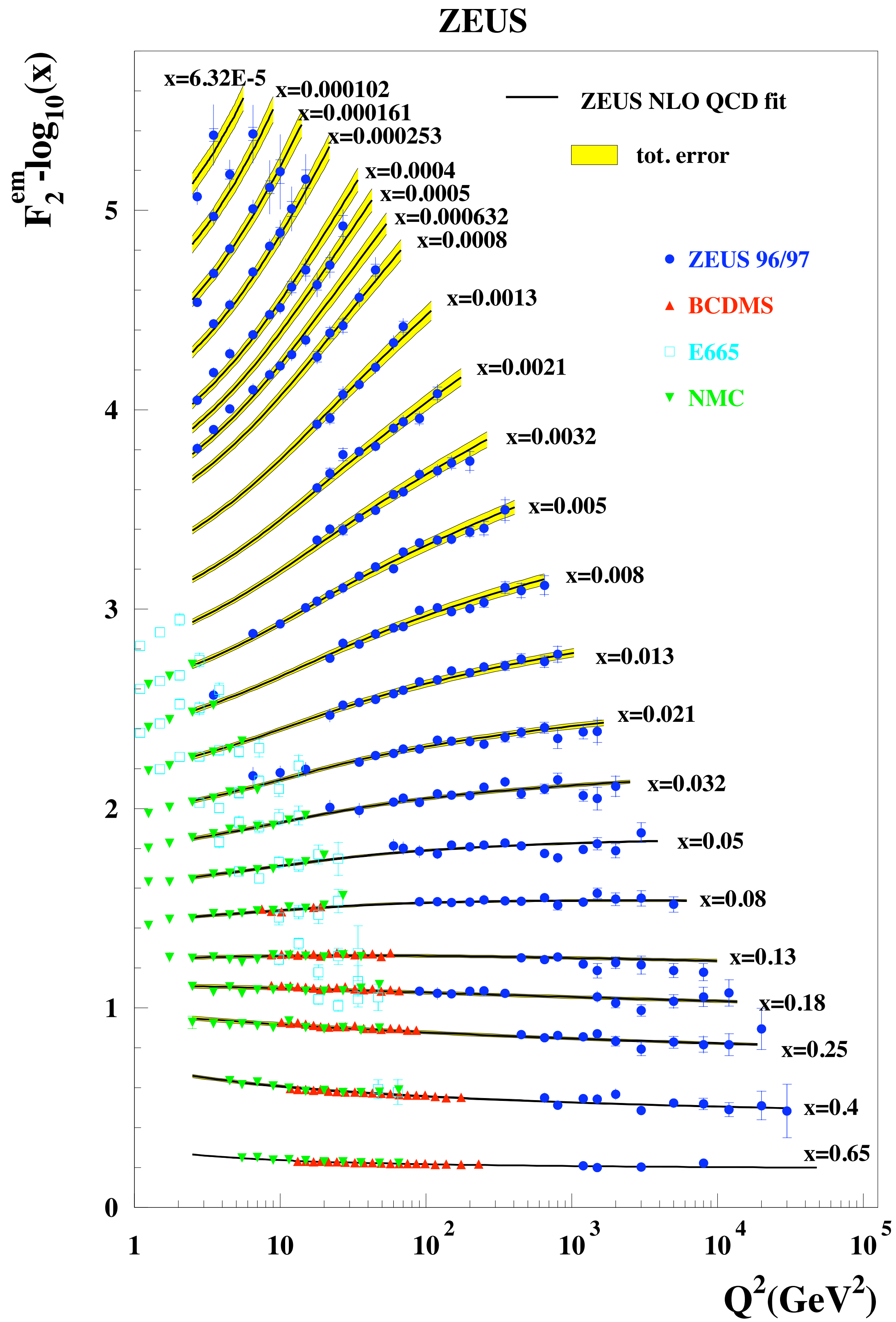
Usual way of exploring the nucleon structure: collinear QCD parton model



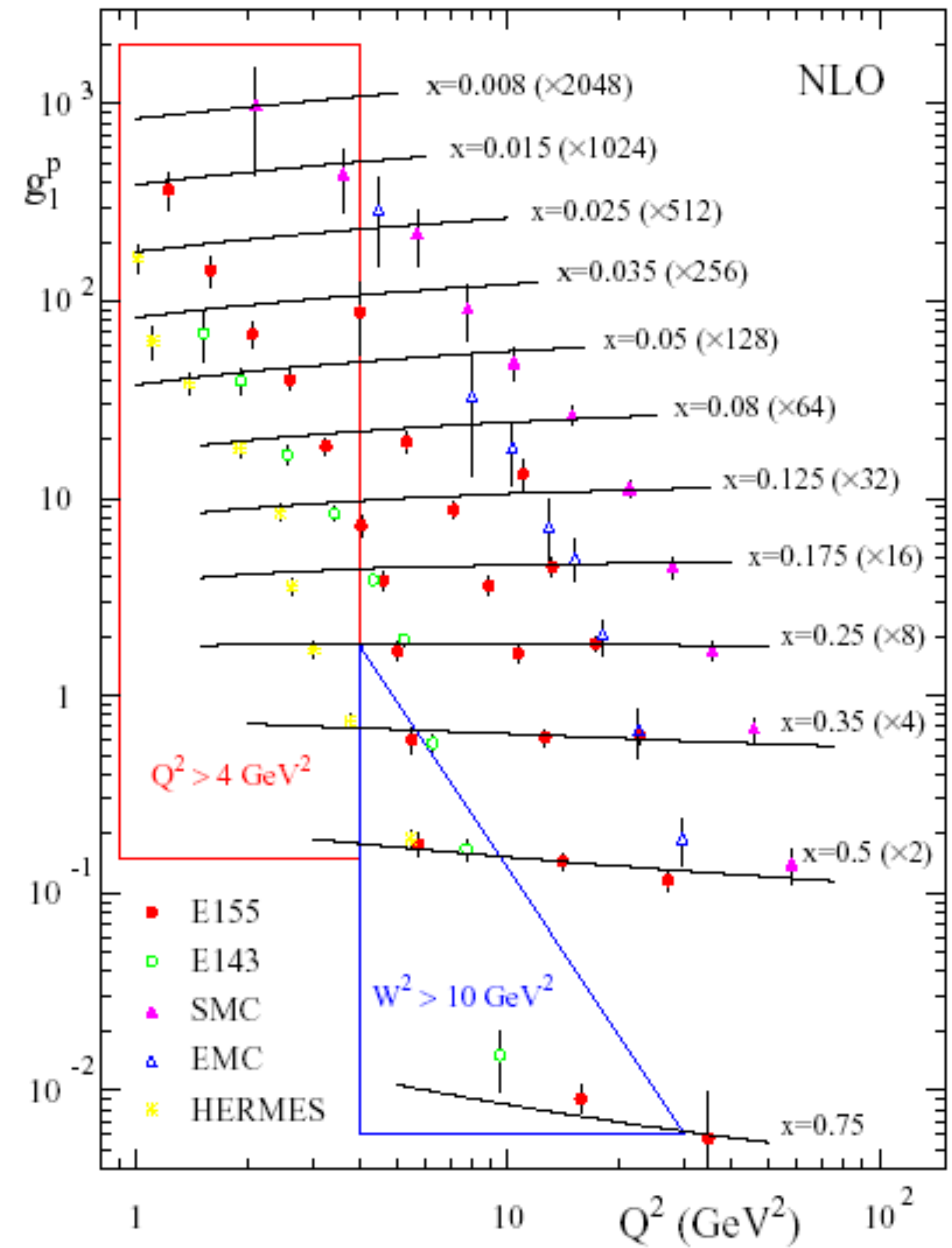
$$\frac{\mathrm{d}\sigma}{\mathrm{d}x\,\mathrm{d}Q^2} = \sum_q q(x, Q^2) \otimes \frac{\mathrm{d}\hat{\sigma}_q}{\mathrm{d}Q^2}$$



great success, but essentially x and Q^2 degrees of freedom ....

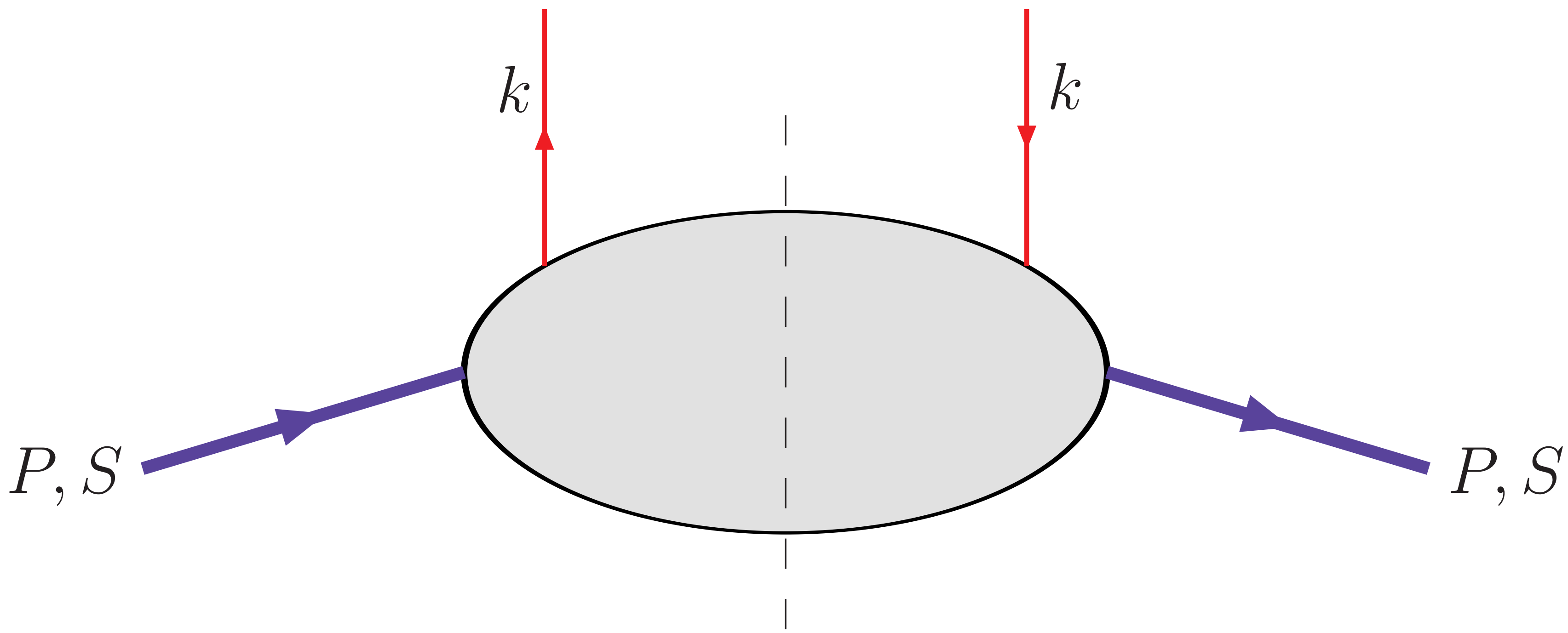


$$F_2 = \sum_q x\, q(x, Q^2)$$



$$g_1 = \frac{1}{2} \sum_q e_q^2\, \Delta q(x, Q^2)$$

The nucleon, as probed in DIS, in collinear configuration: 3 distribution functions



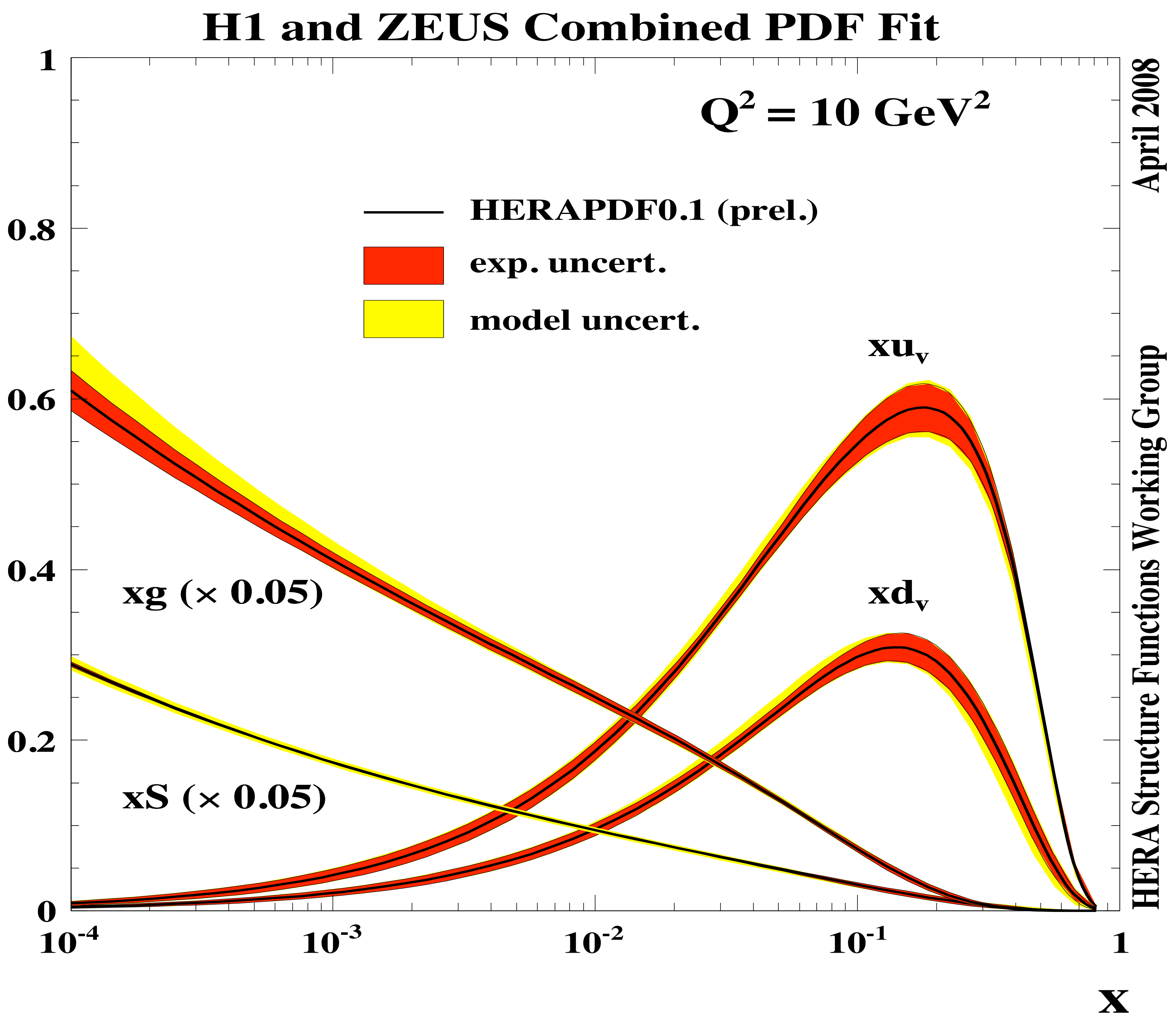
Correlator:

$$\Phi_{ij}(k;P,S) = \sum_X \int \frac{\mathrm{d}^3\boldsymbol{P}_X}{(2\pi)^3\,2E_X}(2\pi)^4\,\delta^4(P-k-P_X)\langle PS|\overline{\Psi}_j(0)|X\rangle\langle X|\Psi_i(0)|PS\rangle$$
$$= \int \mathrm{d}^4\,\xi\,e^{ik\cdot\xi}\langle PS|\overline{\Psi}_j(0)\Psi_i(\xi)|PS\rangle$$

$$\Phi(x,S) = \frac{1}{2}\left[f_1(x)\not{n}_+ + S_L\,g_{1L}(x)\gamma^5\not{n}_+ + h_{1T}\,i\sigma_{\mu\nu}\gamma^5 n_+^\mu S_T^\nu\right]$$

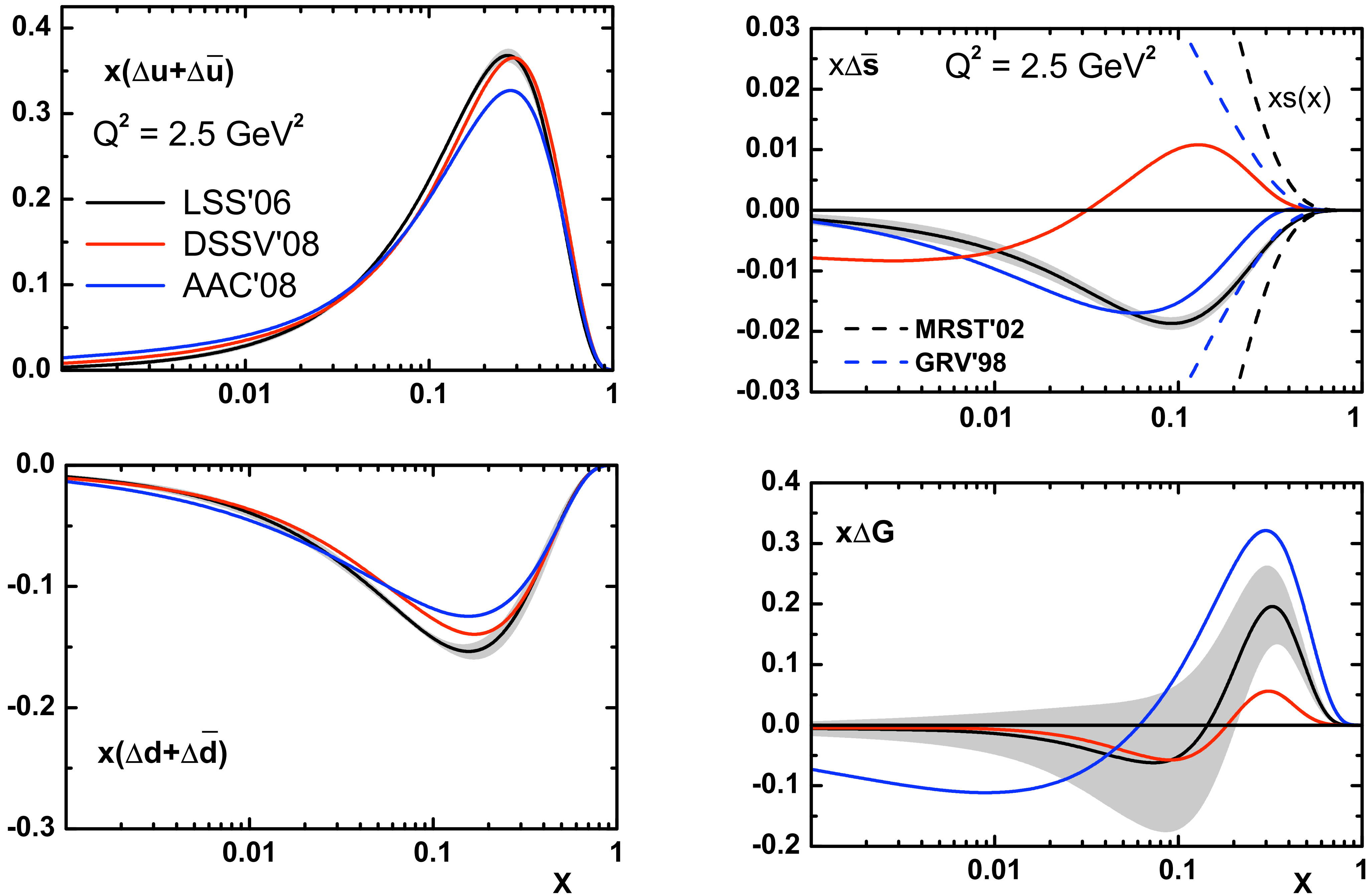
$f_1(x)$: q $\quad g_{1L}(x)$: Δq $\quad h_{1T}$: $\Delta_T q$

integrated parton distribution functions, PDF



$$q(x,Q^2) = f_1^q(x,Q^2) = \int d^2\boldsymbol{k}_\perp \, f_1^q(x,k_\perp^2;Q^2)$$

integrated helicity distributions

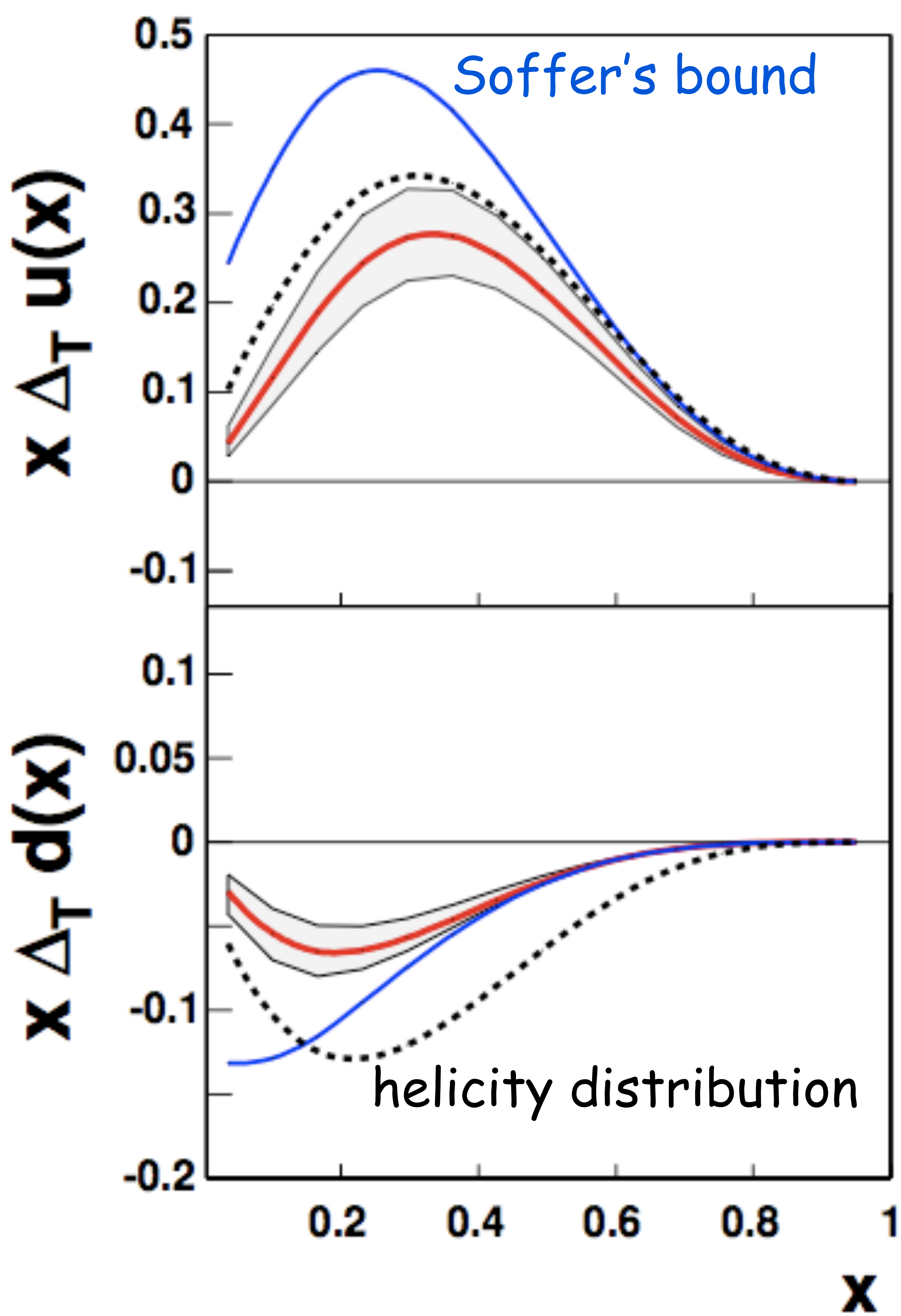


E. Leader, A. Sidorov and D.B. Stamenov

$$\Delta q(x, Q^2) = g_1^q(x, Q^2) = \int \mathrm{d}^2\boldsymbol{k}_\perp \, g_{1L}^q(x, k_\perp^2; Q^2)$$

transversity distributions

M.A., M. Boglione, U. D'Alesio, A. Kotzinian, S. Melis, F. Murgia, A. Prokudin, C. Türk



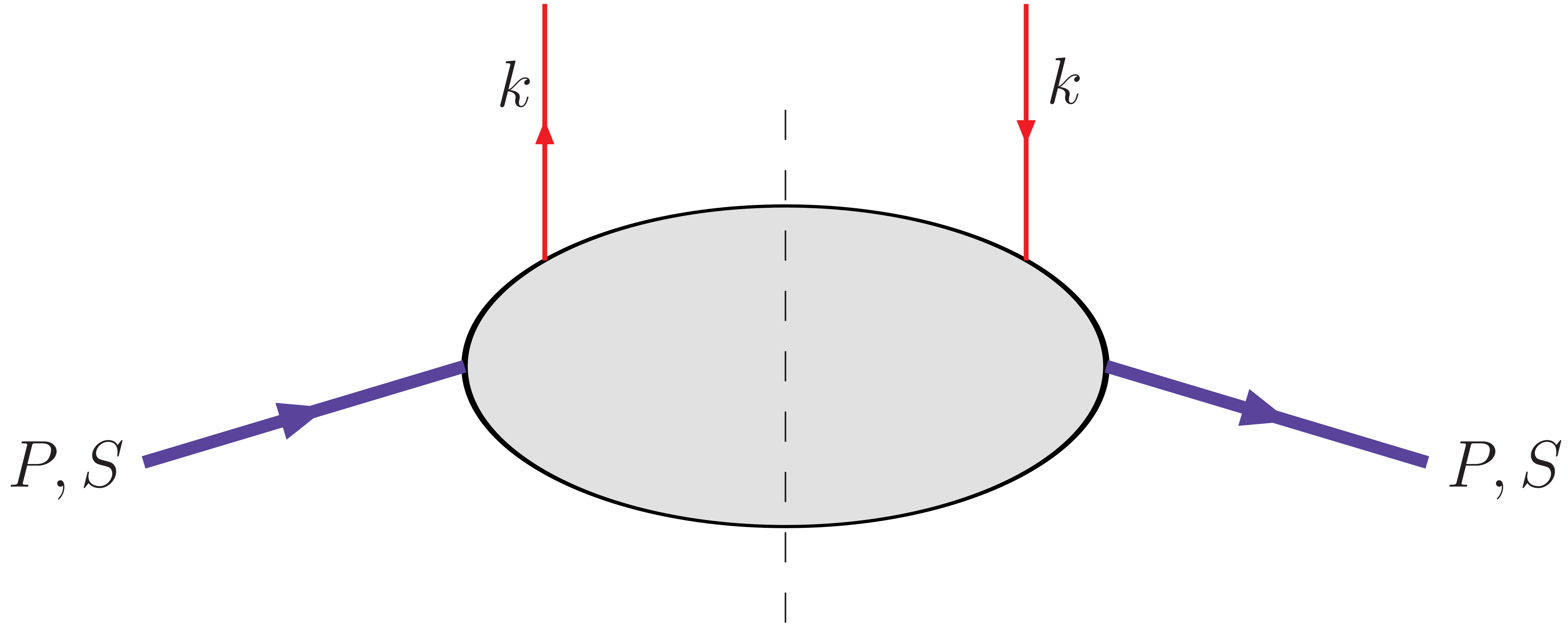
$$\Delta_T q(x, Q^2) = h_1^q(x, Q^2)$$

Extraction from SIDIS (HERMES, COMPASS-D) + e^+e^- (Belle) data, $h_1 \otimes H_1^{\perp}$

new probes and concepts to explore the nucleon structure

TMDs - Transverse Momentum Dependent
(distribution and fragmentation functions)

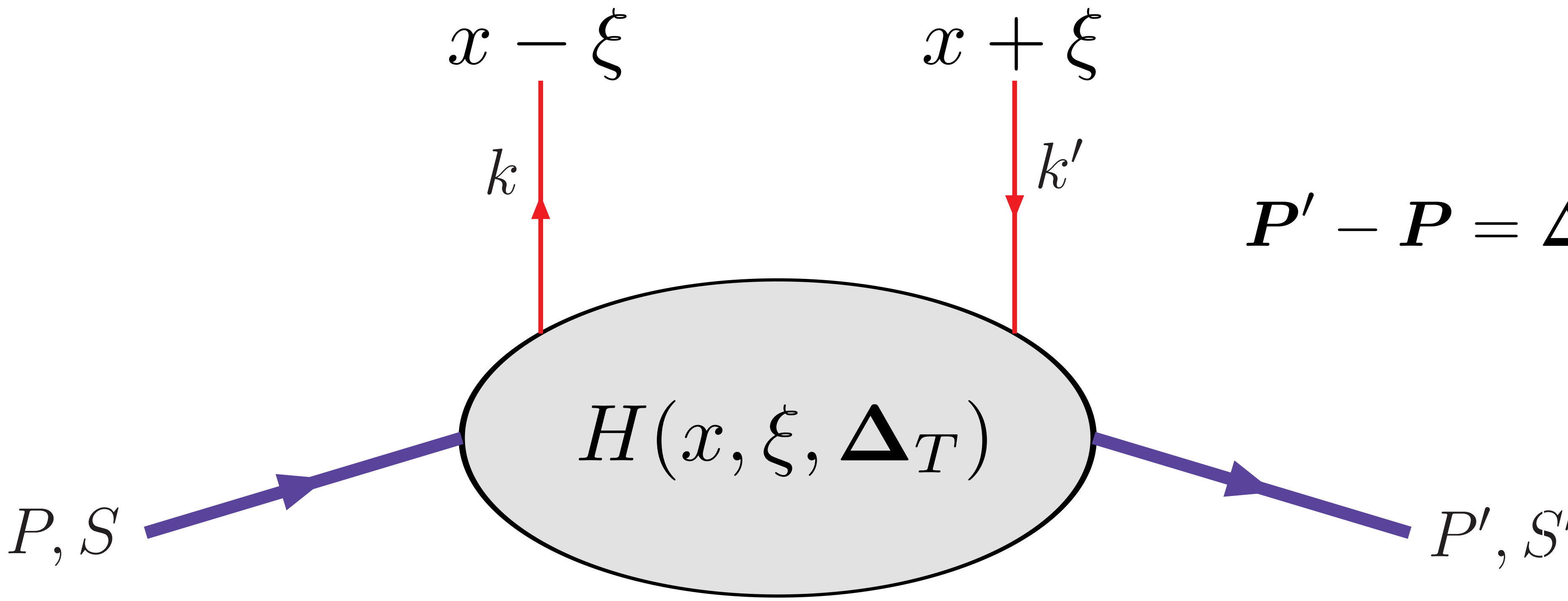
(polarized) SIDIS and Drell-Yan,
spin asymmetries in inclusive
(large p_T) NN processes



$$f_{a/p}(x, \boldsymbol{k}_\perp; \boldsymbol{s}_a, \boldsymbol{S})$$

GPDs - Generalized Partonic Distributions

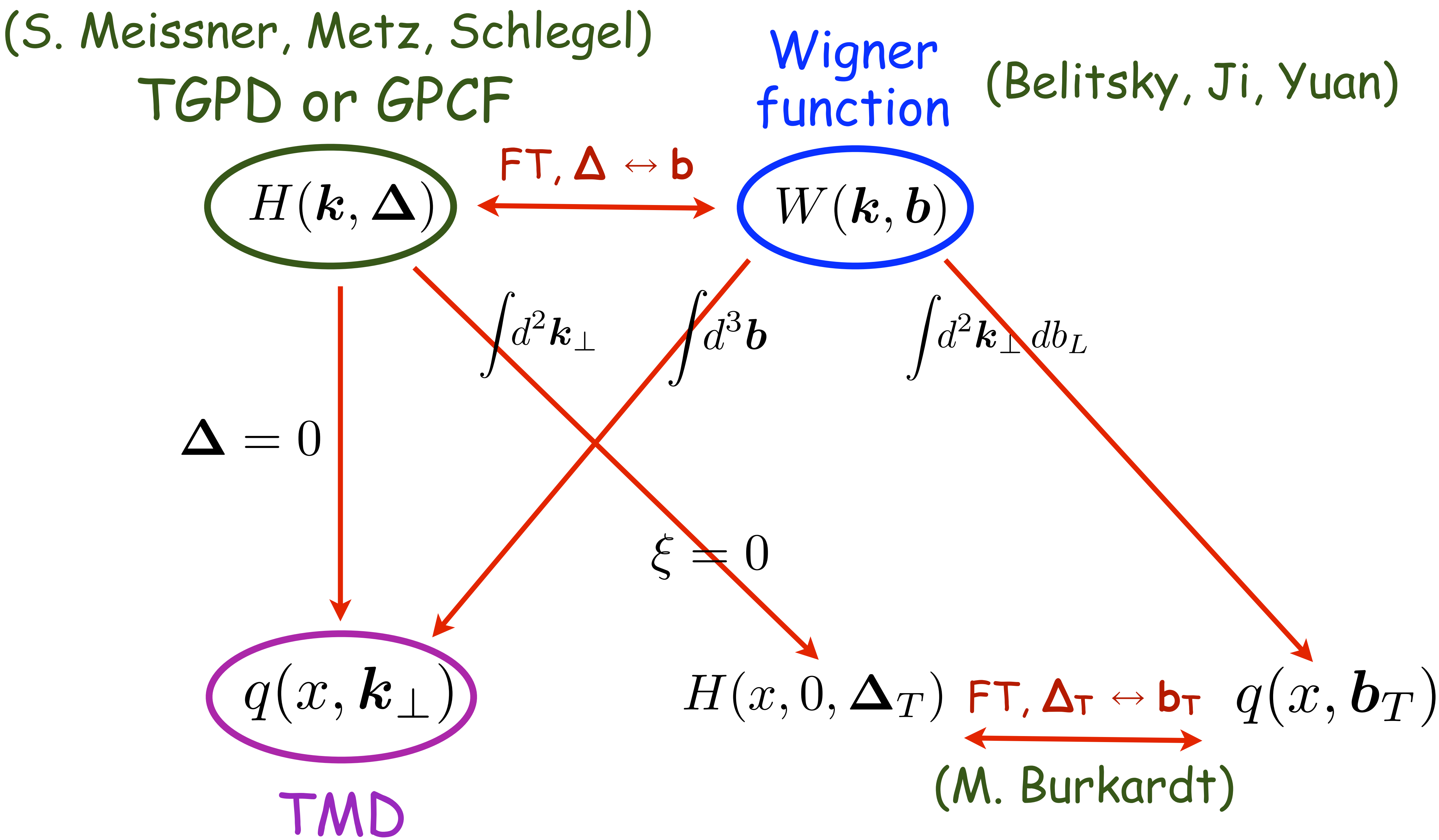
exclusive processes in leptonic and hadronic interactions



$\boldsymbol{P}' - \boldsymbol{P} = \boldsymbol{\Delta}$

$$q(x, \boldsymbol{b}_T) = \int \frac{d^2\boldsymbol{\Delta}_T}{(2\pi)^2} H_q(x, 0, -\boldsymbol{\Delta}_T^2) e^{-i\,\boldsymbol{b}_T \cdot \boldsymbol{\Delta}_T}$$

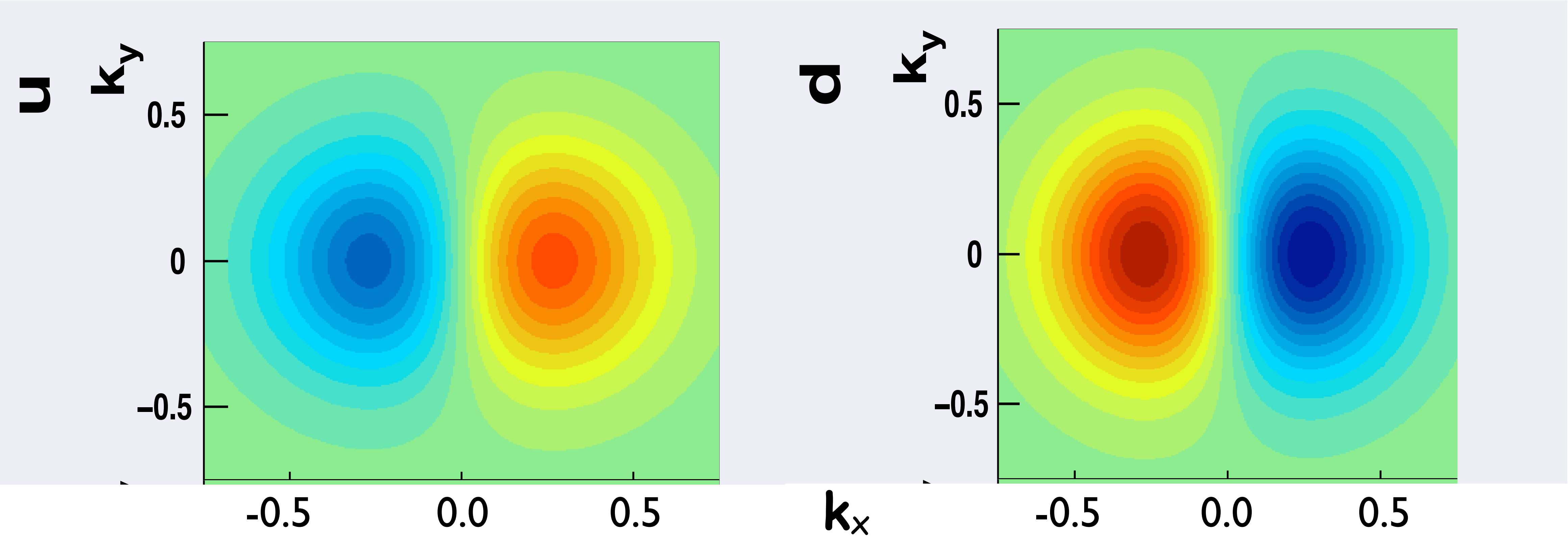
phase-space parton distribution, $W(\boldsymbol{k}, \boldsymbol{b})$



$$\int d^2\boldsymbol{k}_\perp \, H(\boldsymbol{k}, \boldsymbol{\Delta}) = H(x, \xi, \boldsymbol{\Delta}_T)$$

$$q(x, \boldsymbol{k}_\perp)$$

Sivers u and d quark densities in transverse momentum space

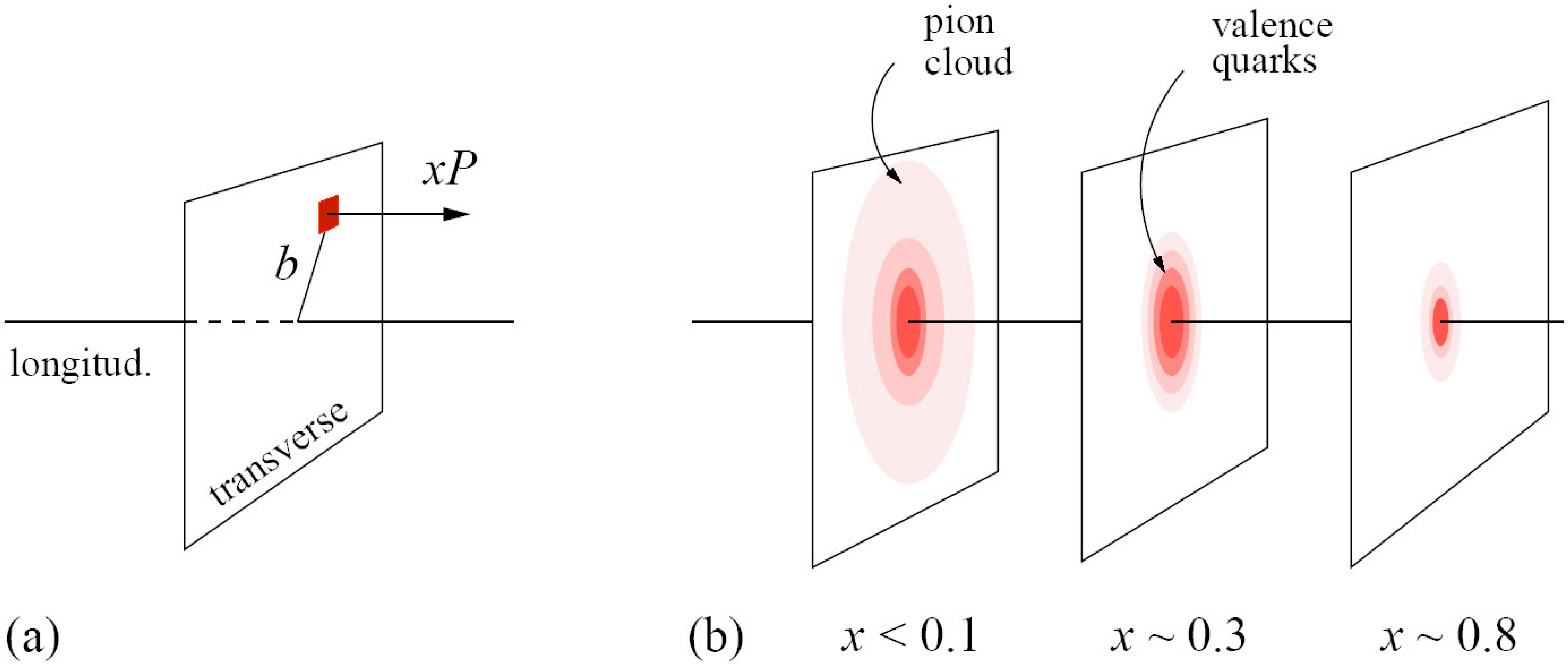


proton moving into the screen, polarization along y-axis

blue: less quarks red: more quarks $x = 0.2$ k in GeV/c

courtesy of A. Prokudin

$$q(x, \boldsymbol{b}_T)$$

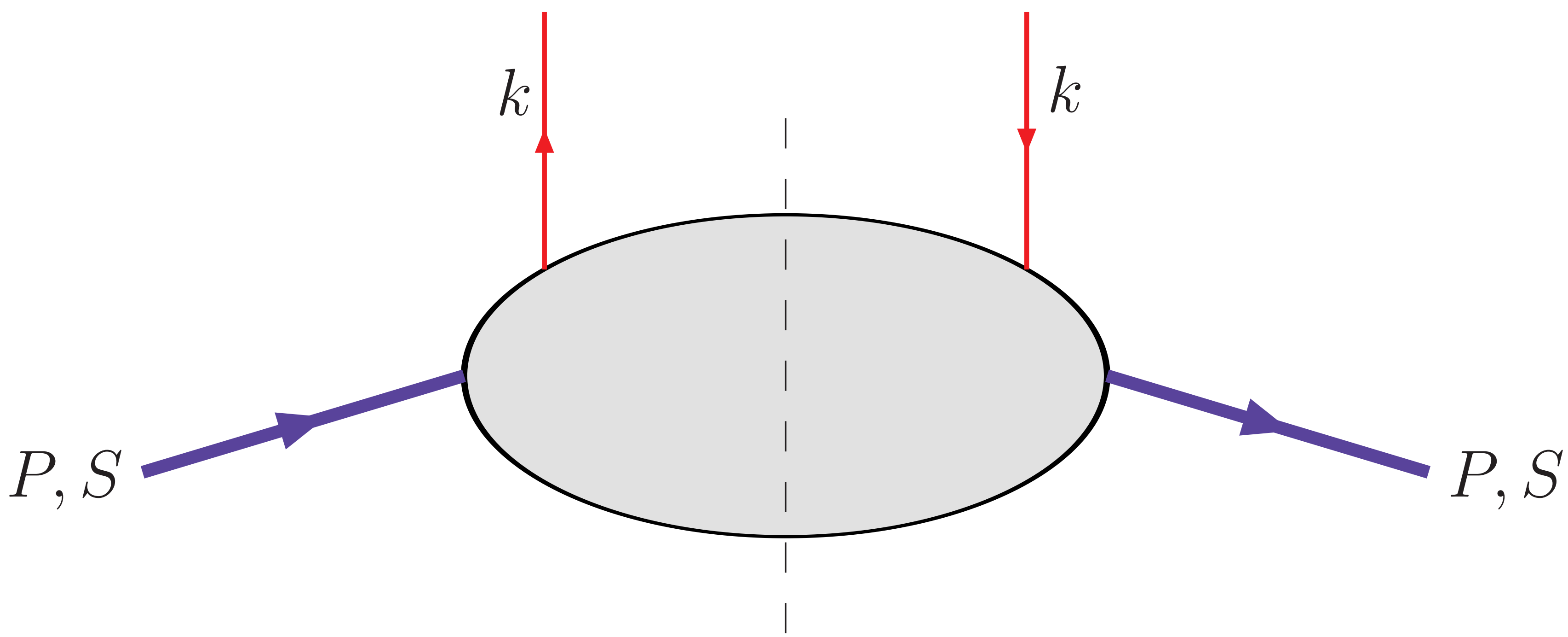


femtophotography or tomography
of the nucleon

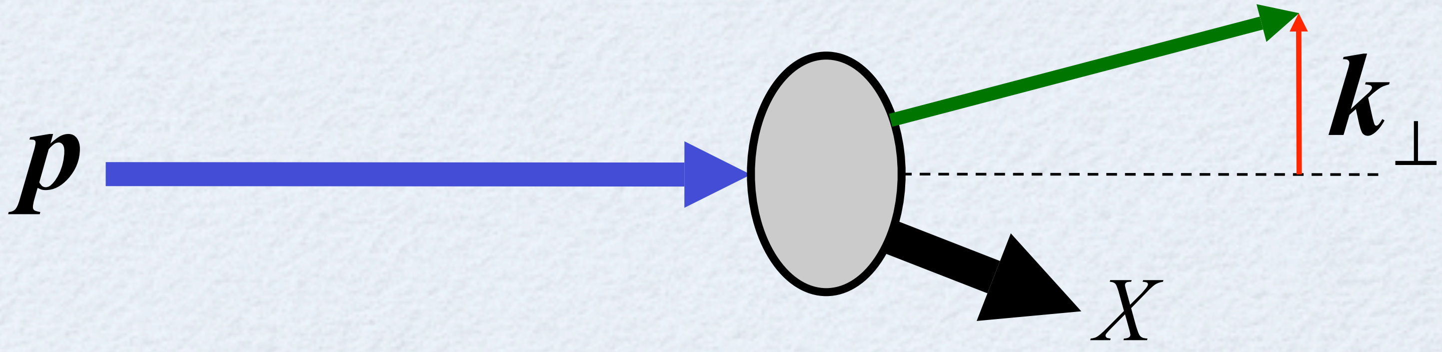
courtesy of C. Weiss

TMDs: the leading-twist correlator, with intrinsic $k_\perp$, contains 8 independent functions .....

$$\Phi(x, \boldsymbol{k}_\perp) = \frac{1}{2}\Big[f_1 \not{n}_+ + f_{1T}^\perp \frac{\epsilon_{\mu\nu\rho\sigma}\gamma^\mu n_+^\nu k_\perp^\rho S_T^\sigma}{M} + \Big(S_L g_{1L} + \frac{\boldsymbol{k}_\perp \cdot \boldsymbol{S}_T}{M} g_{1T}^\perp\Big)\gamma^5 \not{n}_+$$
$$+ h_{1T} i\sigma_{\mu\nu}\gamma^5 n_+^\mu S_T^\nu + \Big(S_L h_{1L}^\perp + \frac{\boldsymbol{k}_\perp \cdot \boldsymbol{S}_T}{M} h_{1T}^\perp\Big)\frac{i\sigma_{\mu\nu}\gamma^5 n_+^\mu k_\perp^\nu}{M}$$
$$+ h_1^\perp \frac{\sigma_{\mu\nu} k_\perp^\mu n_+^\nu}{M}\Big]$$

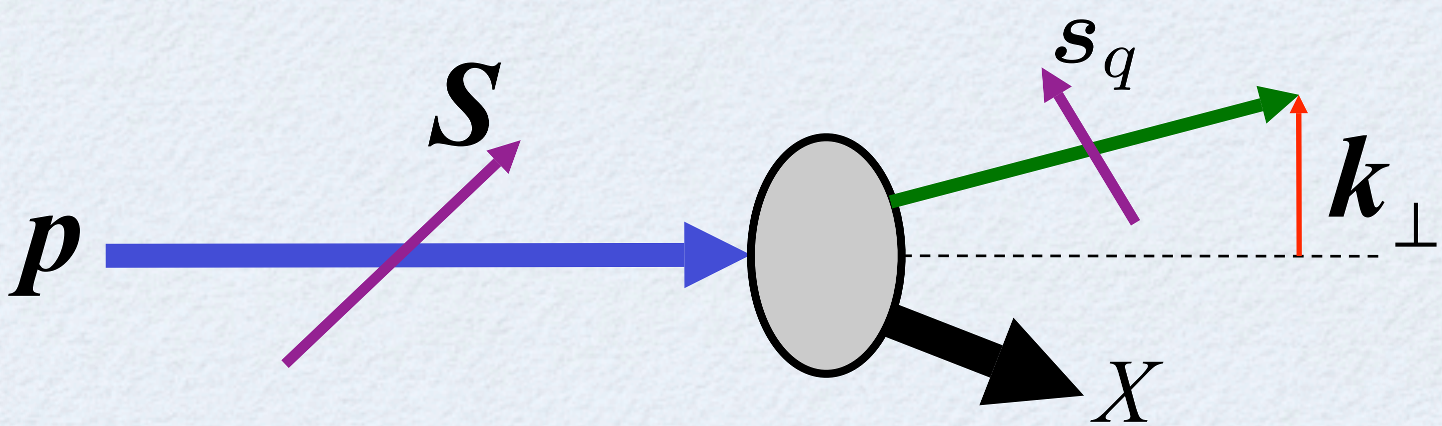


... with partonic interpretation



$$f_1^q(x, k_\perp^2) \qquad\qquad q(x) = f_1^q(x) = \int \mathrm{d}^2\boldsymbol{k}_\perp\, f_1^q(x, k_\perp^2)$$

several spin-k⊥ correlations in TMDs: $f_q(x, \boldsymbol{k}_\perp; \boldsymbol{s}_q, \boldsymbol{S})$



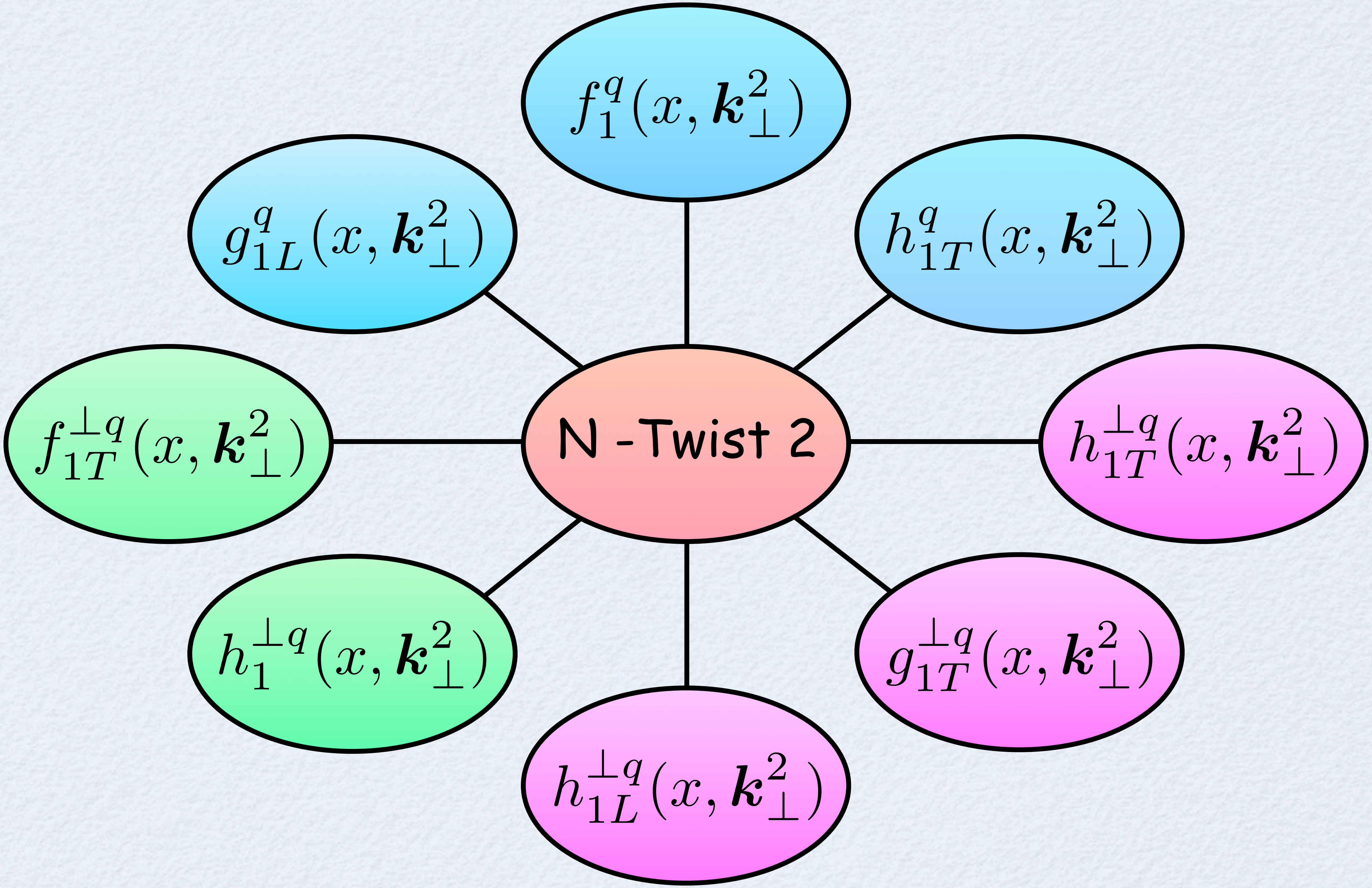
$\boldsymbol{S}\cdot(\boldsymbol{p}\times\boldsymbol{k}_\perp)$ — "Sivers effect"

$\boldsymbol{s}_q\cdot(\boldsymbol{p}\times\boldsymbol{k}_\perp)$ — "Boer-Mulders effect"

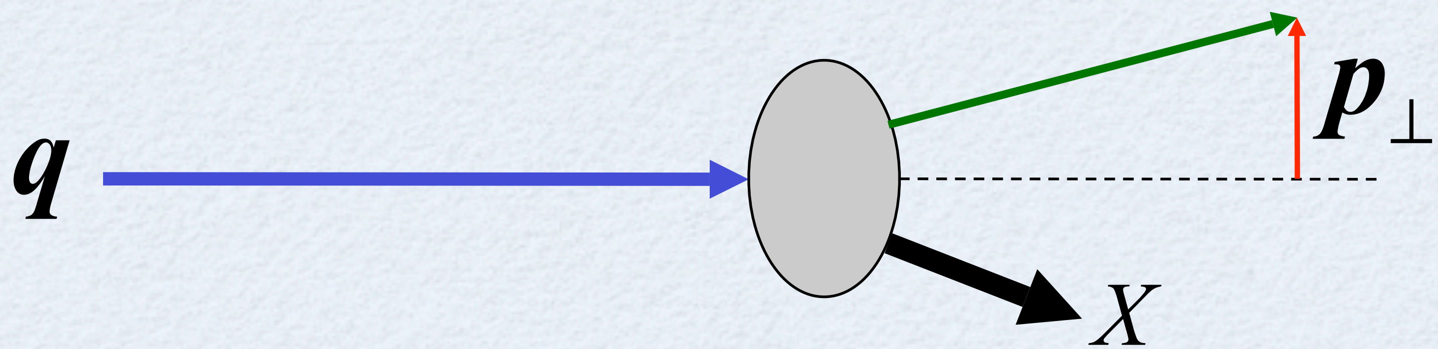
$\boldsymbol{S}\cdot\boldsymbol{s}_q$

$\cdots$

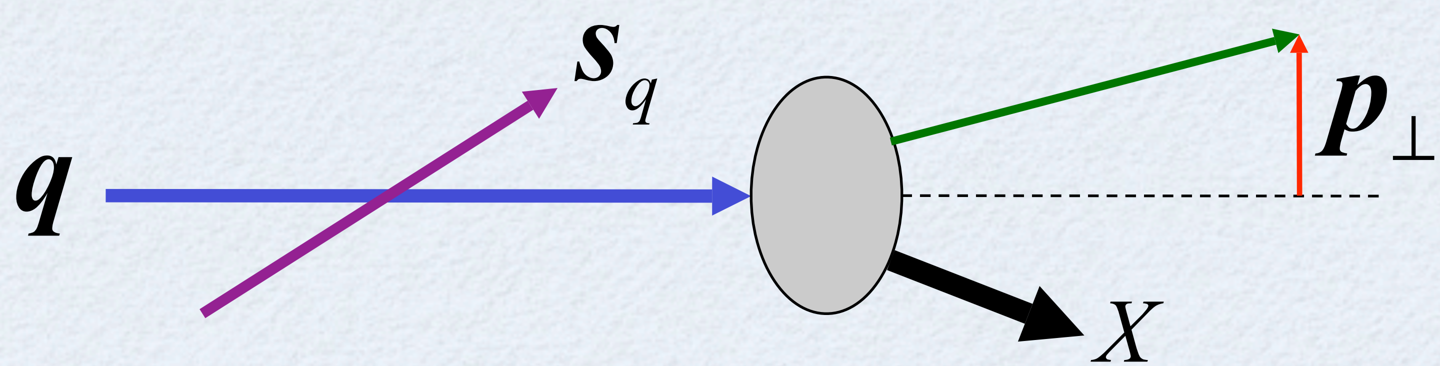
The nucleon at twist-2,



similar spin-$p_\perp$ correlations in fragmentation process (case of final spinless hadron)



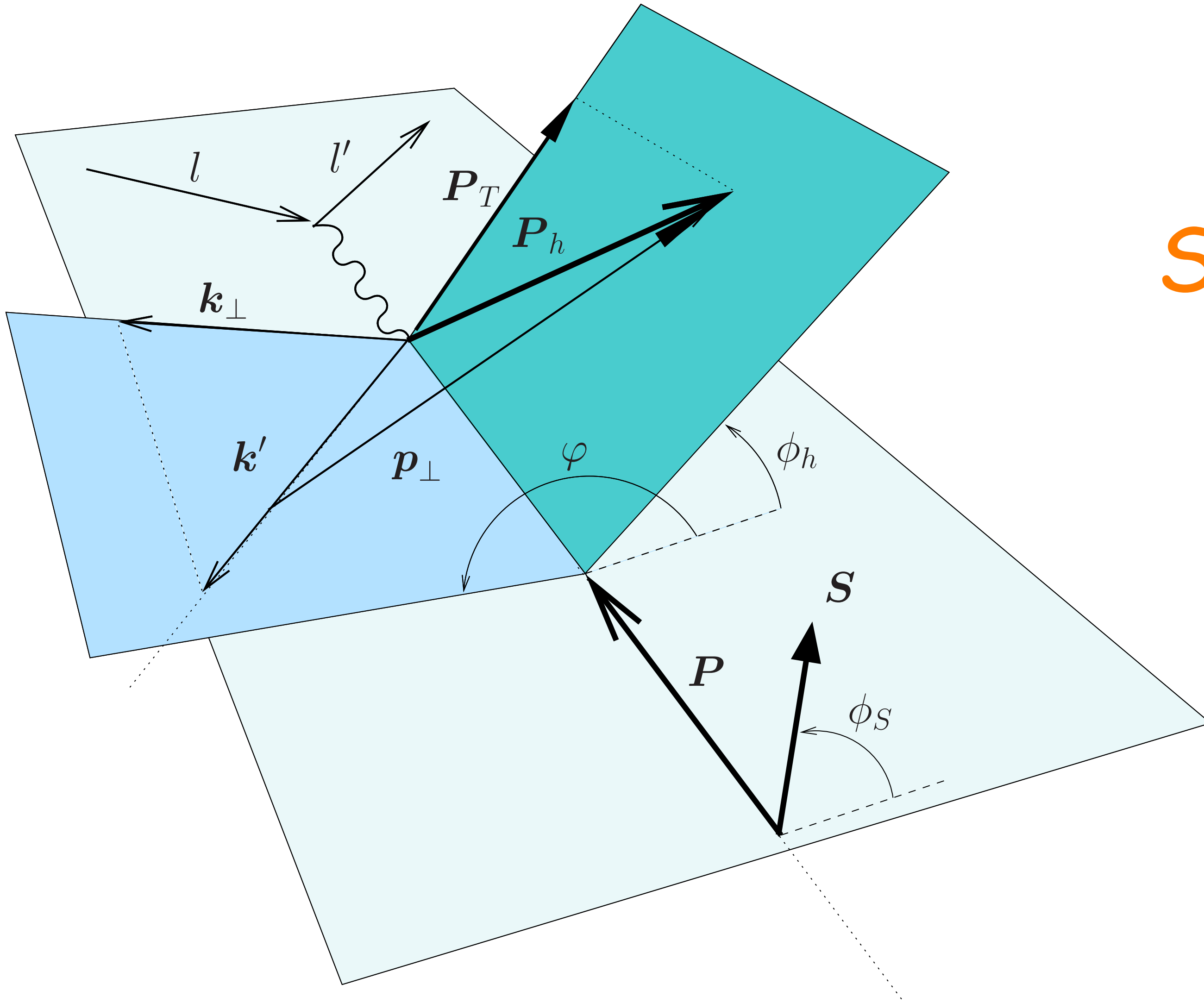
$$D_1^q(x, \boldsymbol{p}_\perp^2)$$



$$\boldsymbol{s}_q \cdot (\boldsymbol{p}_q \times \boldsymbol{p}_\perp)$$

"Collins effect"

$$\begin{aligned} D_q(z, \boldsymbol{p}_\perp; \boldsymbol{s}_q) &= D_1^q(z, \boldsymbol{p}_\perp^2) + \frac{1}{2} \Delta^N D_{h/q^\uparrow}(z, \boldsymbol{p}_\perp^2)\, \boldsymbol{s}_q \cdot (\hat{\boldsymbol{p}}_q \times \hat{\boldsymbol{p}}_\perp) \\ &= D_1^q(z, \boldsymbol{p}_\perp^2) + \frac{p_\perp}{z M_h} H_1^{\perp q}(z, \boldsymbol{p}_\perp^2)\, \boldsymbol{s}_q \cdot (\hat{\boldsymbol{p}}_q \times \hat{\boldsymbol{p}}_\perp) \end{aligned}$$



usual 3-dimensional probe of nucleons: SIDIS in parton model with intrinsic motion

$$d^6\sigma \equiv \frac{d^6\sigma^{\ell p^\uparrow \to \ell h X}}{dx_B\, dQ^2\, dz_h\, d^2\boldsymbol{P}_T\, d\phi_S}$$

$$\boldsymbol{p}_\perp \simeq \boldsymbol{P}_T - z_h\, \boldsymbol{k}_\perp$$

factorization holds at large Q^2, and $P_T \approx k_\perp \approx \Lambda_{\rm QCD}$

Two scales: $P_T^2 \ll Q^2$

$$d\sigma^{\ell p \to \ell h X} = \sum_q f_q(x, \boldsymbol{k}_\perp; Q^2) \otimes d\hat{\sigma}^{\ell q \to \ell q}(y, \boldsymbol{k}_\perp; Q^2) \otimes D_q^h(z, \boldsymbol{p}_\perp; Q^2)$$

Collins, Soper, Ji, J.P. Ma, Yuan, Qiu, Vogelsang, Collins, Metz,...

general azimuthal structure of SIDIS cross-section

(with leading-twist TMDs)

$$\frac{d\sigma}{d\phi} = F_{UU} + \cos(2\phi)\, F_{UU}^{\cos(2\phi)} + \frac{1}{Q}\,\cos\phi\, F_{UU}^{\cos\phi} + \lambda\,\frac{1}{Q}\,\sin\phi\, F_{LU}^{\sin\phi}$$
$$+\; S_L \left\{ \sin(2\phi)\, F_{UL}^{\sin(2\phi)} + \frac{1}{Q}\,\sin\phi\, F_{UL}^{\sin\phi} + \lambda \left[F_{LL} + \frac{1}{Q}\,\cos\phi\, F_{LL}^{\cos\phi} \right] \right\}$$
$$+\; S_T \left\{ \sin(\phi-\phi_S)\, F_{UT}^{\sin(\phi-\phi_S)} + \sin(\phi+\phi_S)\, F_{UT}^{\sin(\phi+\phi_S)} + \sin(3\phi-\phi_S)\, F_{UT}^{\sin(3\phi-\phi_S)} \right.$$
$$+\; \frac{1}{Q} \left[\sin(2\phi-\phi_S)\, F_{UT}^{\sin(2\phi-\phi_S)} + \sin\phi_S\, F_{UT}^{\sin\phi_S} \right]$$
$$\left. +\; \lambda \left[\cos(\phi-\phi_S)\, F_{LT}^{\cos(\phi-\phi_S)} + \frac{1}{Q} \left(\cos\phi_S\, F_{LT}^{\cos\phi_S} + \cos(2\phi-\phi_S)\, F_{LT}^{\cos(2\phi-\phi_S)} \right) \right] \right\}$$

many spin asymmetries

$$d\sigma(\boldsymbol{S}) \neq d\sigma(-\boldsymbol{S})$$

$F_{S_B S_T}^{(\dots)}$ contain the TMDs

Kotzinian, **NP B441** (1995) 234

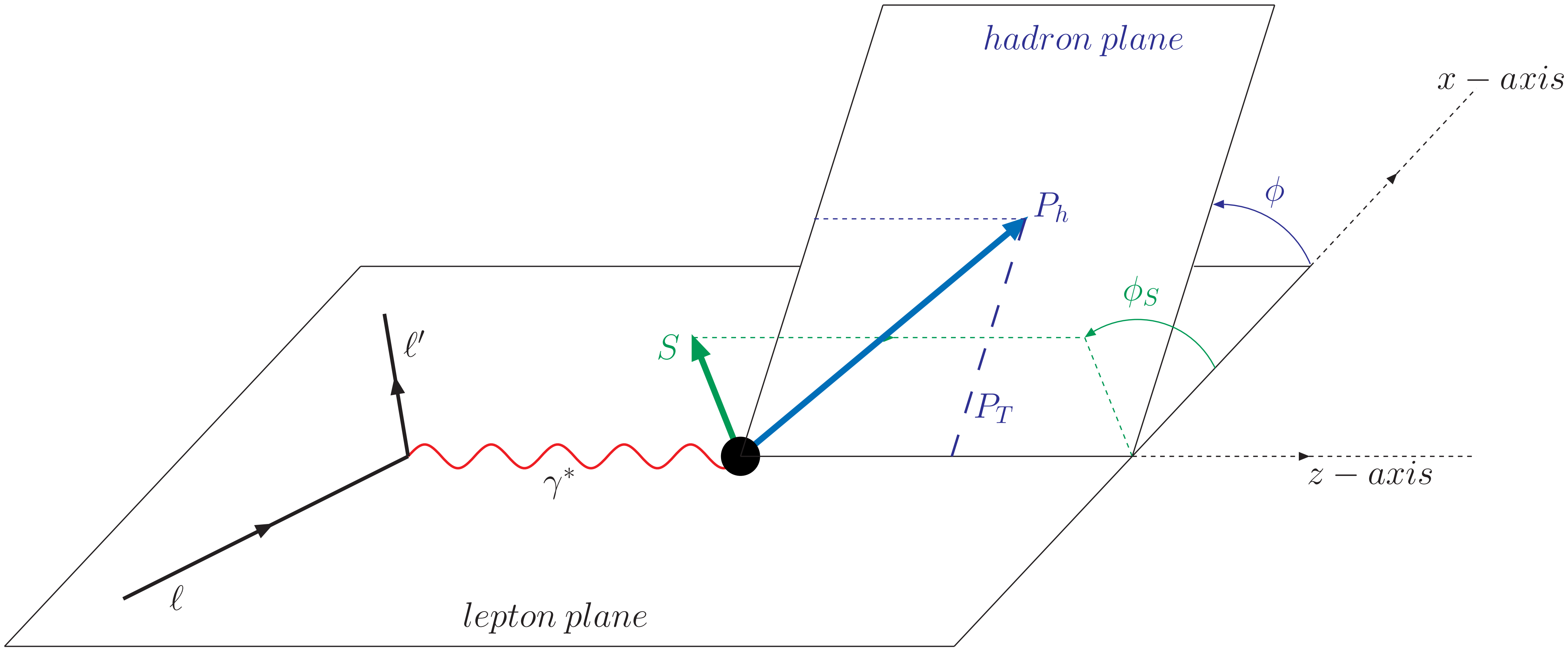
Mulders and Tangermann, **NP B461** (1996) 197

Boer and Mulders, **PR D57** (1998) 5780

Bacchetta et al., **PL B595** (2004) 309

Bacchetta et al., **JHEP 0702** (2007) 093

Anselmino et al., in preparation



$$F_{UU} \sim \sum_a e_a^2 f_1^a \otimes D_1^a \qquad F_{LT}^{\cos(\phi-\phi_S)} \sim \sum_a e_a^2 g_{1T}^{\perp a} \otimes D_1^a$$

$$F_{LL} \sim \sum_a e_a^2 g_{1L}^a \otimes D_1^a \qquad F_{UT}^{\sin(\phi-\phi_S)} \sim \sum_a e_a^2 f_{1T}^{\perp a} \otimes D_1^a$$

chiral-even TMDs

$$F_{UU}^{\cos(2\phi)} \sim \sum_a e_a^2 h_1^{\perp a} \otimes H_1^{\perp a} \qquad F_{UT}^{\sin(\phi+\phi_S)} \sim \sum_a e_a^2 h_{1T}^a \otimes H_1^{\perp a}$$

$$F_{UL}^{\sin(2\phi)} \sim \sum_a e_a^2 h_{1L}^{\perp a} \otimes H_1^{\perp a} \qquad F_{UT}^{\sin(3\phi-\phi_S)} \sim \sum_a e_a^2 h_{1T}^{\perp a} \otimes H_1^{\perp a}$$

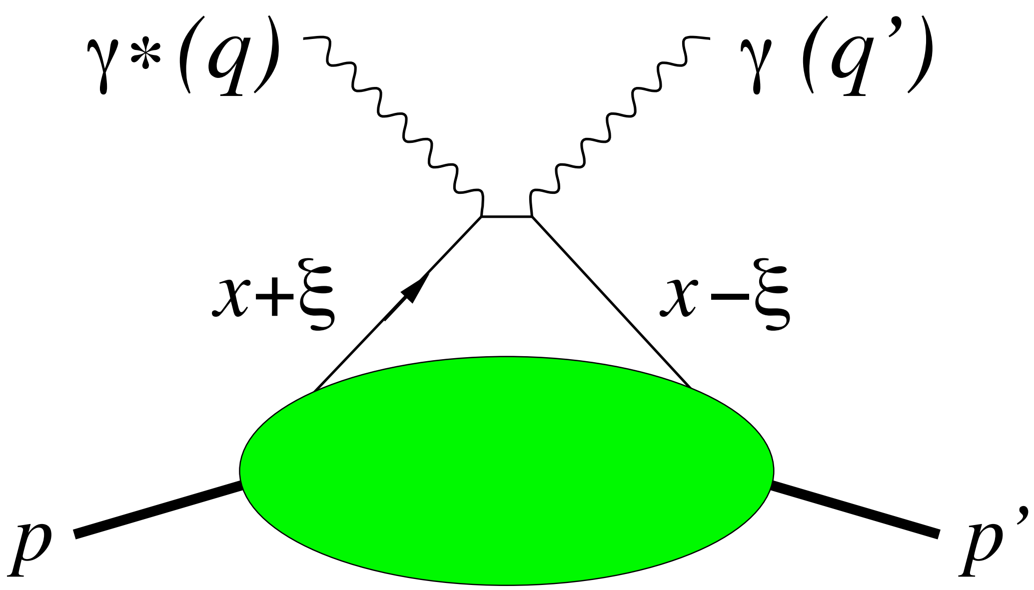
chiral-odd TMDs

talks by A. Kotzinian, S. Melis

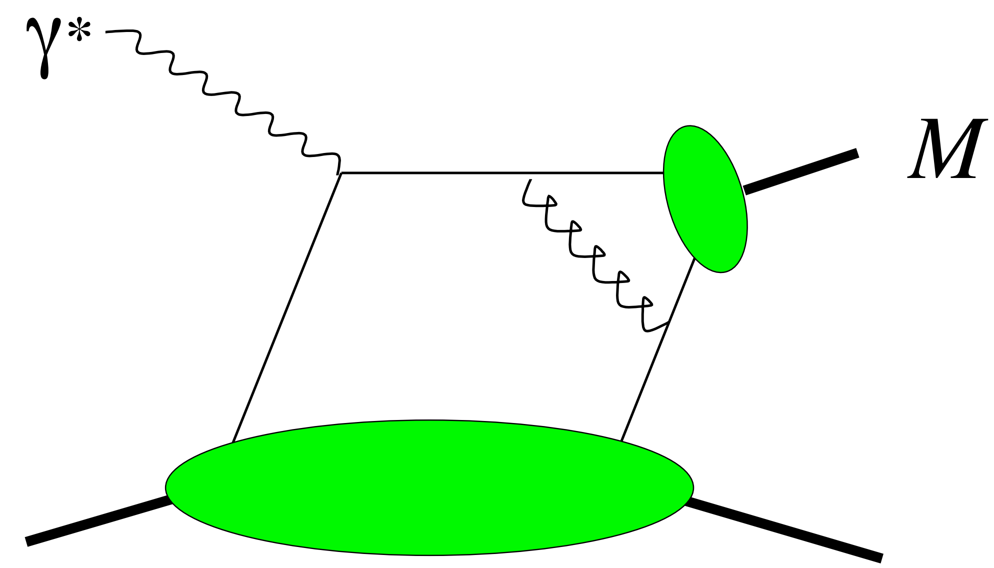
GPDs (8 independent ones)

(recover partonic distributions in the forward limit)

$$H, E, \tilde{H}, \tilde{E}; H_T, E_T, \tilde{H}_T, \tilde{E}_T(x, \xi, t)$$



DVCS

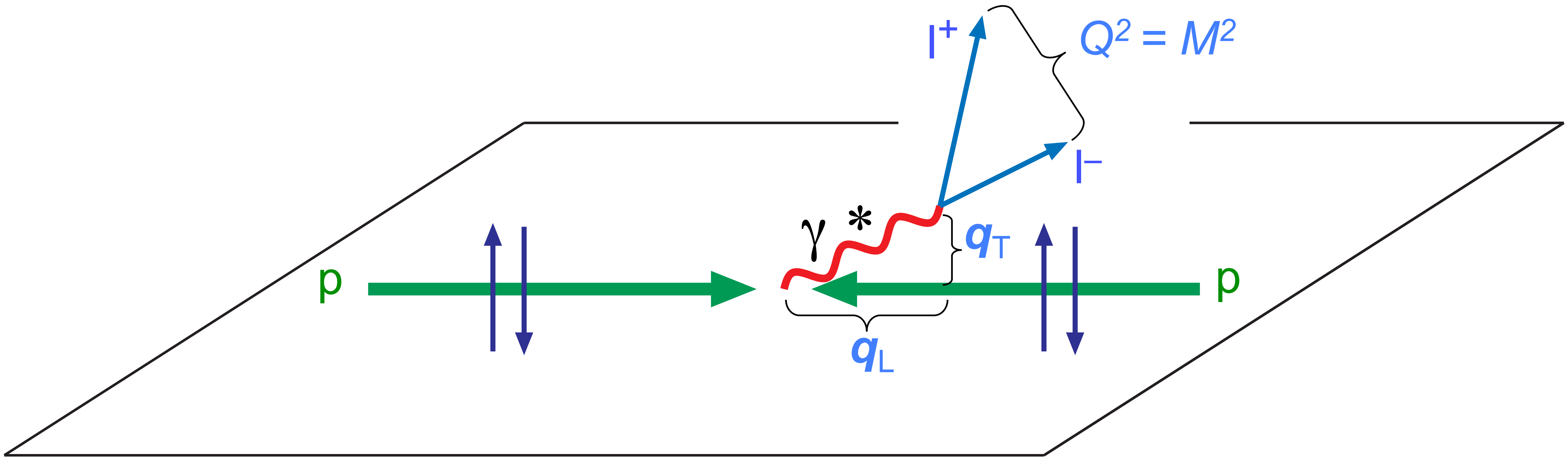


hard meson production

exclusive leptonic processes. More possibilities with Drell-Yan production

talk by B. Pire

Drell-Yan processes - TMDs



factorization holds, two scales, M^2, and $q_T \ll M$

$$d\sigma^{D-Y} = \sum_a f_q(x_1, \boldsymbol{k}_{\perp 1}; Q^2) \otimes f_{\bar{q}}(x_2, \boldsymbol{k}_{\perp 2}; Q^2)\, d\hat{\sigma}^{q\bar{q}\to\ell^+\ell^-}$$

direct product of TMDs
no fragmentation process

talks by D. Boer, W. Vogelsang

cross-section: most general pp leading-twist expression

S. Arnold, A. Metz and M. Schlegel, arXiv:0809.2262 [hep-ph]

M. Schlegel talk

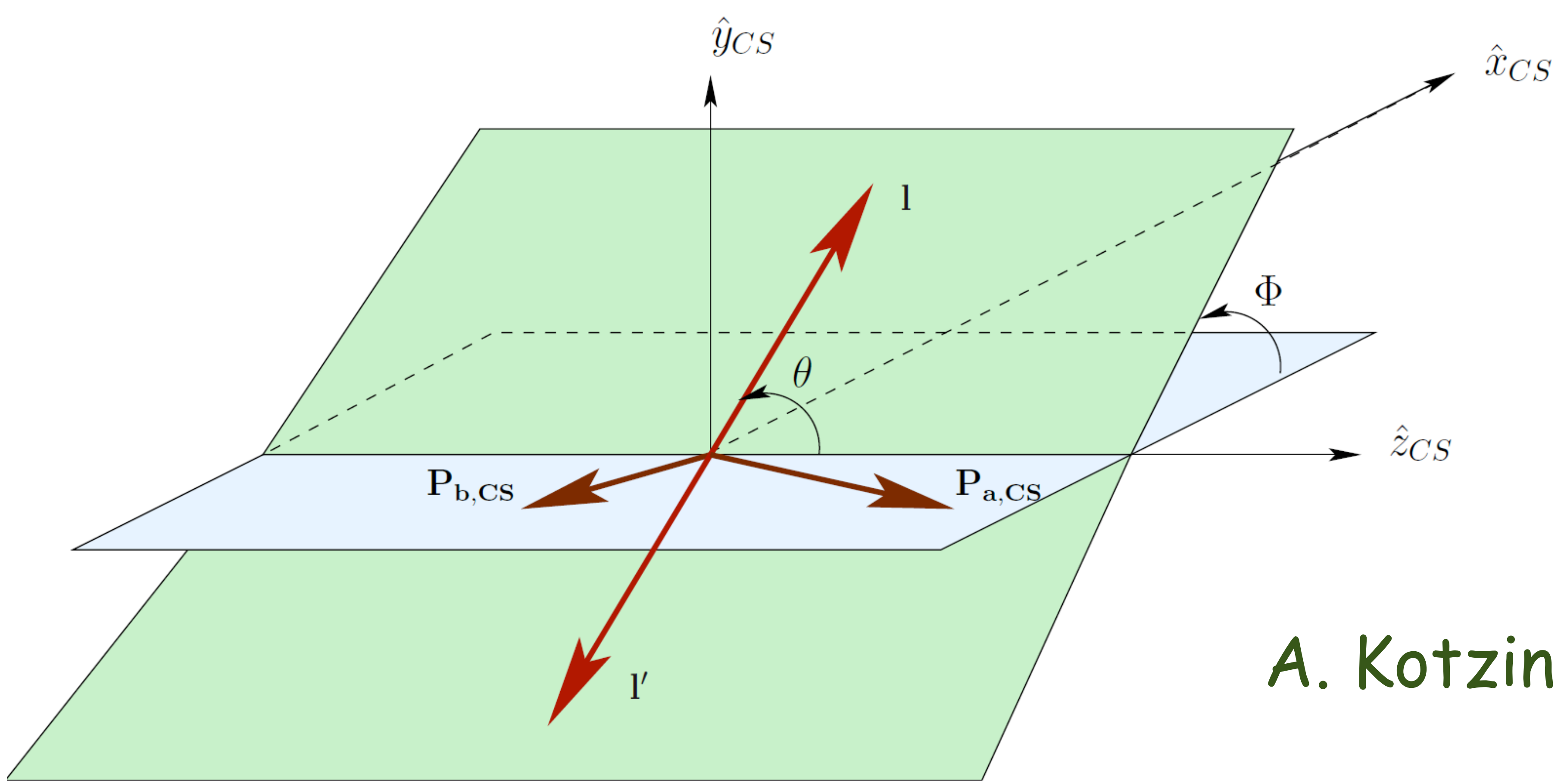
$$
\begin{aligned}
\frac{d\sigma}{d^4q\, d\Omega} = \frac{\alpha_{em}^2}{F\, q^2} \times
&\Big\{ \Big((1+\cos^2\theta)\, F_{UU}^1 + (1-\cos^2\theta)\, F_{UU}^2 + \sin 2\theta \cos\phi\, F_{UU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UU}^{\cos 2\phi} \Big) \\
&+ S_{aL} \Big(\sin 2\theta \sin\phi\, F_{LU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{LU}^{\sin 2\phi} \Big) \\
&+ S_{bL} \Big(\sin 2\theta \sin\phi\, F_{UL}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UL}^{\sin 2\phi} \Big) \\
&+ |\vec{S}_{aT}| \Big[\sin\phi_a \Big((1+\cos^2\theta)\, F_{TU}^1 + (1-\cos^2\theta)\, F_{TU}^2 + \sin 2\theta \cos\phi\, F_{TU}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TU}^{\cos 2\phi} \Big) \\
&\qquad + \cos\phi_a \Big(\sin 2\theta \sin\phi\, F_{TU}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TU}^{\sin 2\phi} \Big) \Big] \\
&+ |\vec{S}_{bT}| \Big[\sin\phi_b \Big((1+\cos^2\theta)\, F_{UT}^1 + (1-\cos^2\theta)\, F_{UT}^2 + \sin 2\theta \cos\phi\, F_{UT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{UT}^{\cos 2\phi} \Big) \\
&\qquad + \cos\phi_b \Big(\sin 2\theta \sin\phi\, F_{UT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{UT}^{\sin 2\phi} \Big) \Big] \\
&+ S_{aL}\, S_{bL} \Big((1+\cos^2\theta)\, F_{LL}^1 + (1-\cos^2\theta)\, F_{LL}^2 + \sin 2\theta \cos\phi\, F_{LL}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{LL}^{\cos 2\phi} \Big) \\
&+ S_{aL}\, |\vec{S}_{bT}| \Big[\cos\phi_b \Big((1+\cos^2\theta)\, F_{LT}^1 + (1-\cos^2\theta)\, F_{LT}^2 + \sin 2\theta \cos\phi\, F_{LT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{LT}^{\cos 2\phi} \Big) \\
&\qquad + \sin\phi_b \Big(\sin 2\theta \sin\phi\, F_{LT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{LT}^{\sin 2\phi} \Big) \Big] \\
&+ |\vec{S}_{aT}|\, S_{bL} \Big[\cos\phi_a \Big((1+\cos^2\theta)\, F_{TL}^1 + (1-\cos^2\theta)\, F_{TL}^2 + \sin 2\theta \cos\phi\, F_{TL}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TL}^{\cos 2\phi} \Big) \\
&\qquad + \sin\phi_a \Big(\sin 2\theta \sin\phi\, F_{TL}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TL}^{\sin 2\phi} \Big) \Big] \\
&+ |\vec{S}_{aT}|\, |\vec{S}_{bT}| \Big[\cos(\phi_a+\phi_b) \Big((1+\cos^2\theta)\, F_{TT}^1 + (1-\cos^2\theta)\, F_{TT}^2 + \sin 2\theta \cos\phi\, F_{TT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, F_{TT}^{\cos 2\phi} \Big) \\
&\qquad + \cos(\phi_a-\phi_b) \Big((1+\cos^2\theta)\, \bar{F}_{TT}^1 + (1-\cos^2\theta)\, \bar{F}_{TT}^2 + \sin 2\theta \cos\phi\, \bar{F}_{TT}^{\cos\phi} + \sin^2\theta \cos 2\phi\, \bar{F}_{TT}^{\cos 2\phi} \Big) \\
&\qquad + \sin(\phi_a+\phi_b) \Big(\sin 2\theta \sin\phi\, F_{TT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, F_{TT}^{\sin 2\phi} \Big) \\
&\qquad + \sin(\phi_a-\phi_b) \Big(\sin 2\theta \sin\phi\, \bar{F}_{TT}^{\sin\phi} + \sin^2\theta \sin 2\phi\, \bar{F}_{TT}^{\sin 2\phi} \Big) \Big] \Big\}
\end{aligned}
$$

Drell-Yan

48 structure functions ...

Case of one polarized nucleon only

$$\frac{d\sigma}{d^4q\,d\Omega} = \frac{\alpha^2}{\Phi\, q^2}\Big\{(1+\cos^2\theta)\,F_U^1 + (1-\cos^2\theta)\,F_U^2 + \sin 2\theta\cos\phi\,F_U^{\cos\phi} + \sin^2\theta\cos 2\phi\,F_U^{\cos 2\phi}$$
$$+\ S_L\left(\sin 2\theta\sin\phi\,F_L^{\sin\phi} + \sin^2\theta\sin 2\phi\,F_L^{\sin 2\phi}\right)$$
$$+\ S_T\Big[\left(F_T^{\sin\phi_S} + cos^2\theta\,\tilde{F}_T^{\sin\phi_S}\right)\sin\phi_S + \sin 2\theta\,\Big(\sin(\phi+\phi_S)\,F_T^{\sin(\phi+\phi_S)}$$
$$+\ \sin(\phi-\phi_S)\,F_T^{\sin(\phi-\phi_S)}\Big)$$
$$+\ \sin^2\theta\left(\sin(2\phi+\phi_S)\,F_T^{\sin(2\phi+\phi_S)} + \sin(2\phi-\phi_S)\,F_T^{\sin(2\phi-\phi_S)}\right)\Big]\Big\}$$

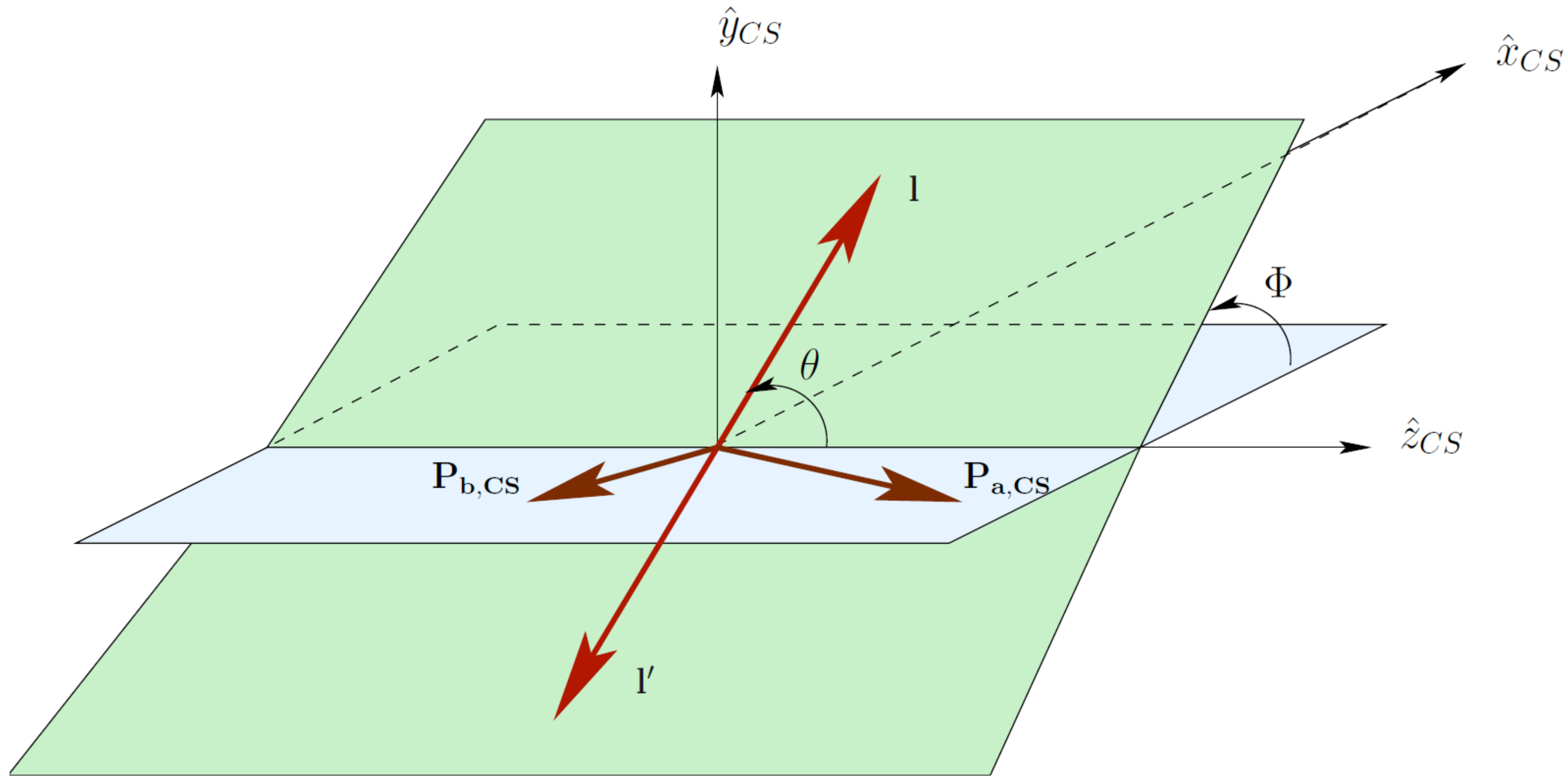


Collins-Soper frame

A. Kotzinian, M. Schlegel

Unpolarized cross section already very interesting

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

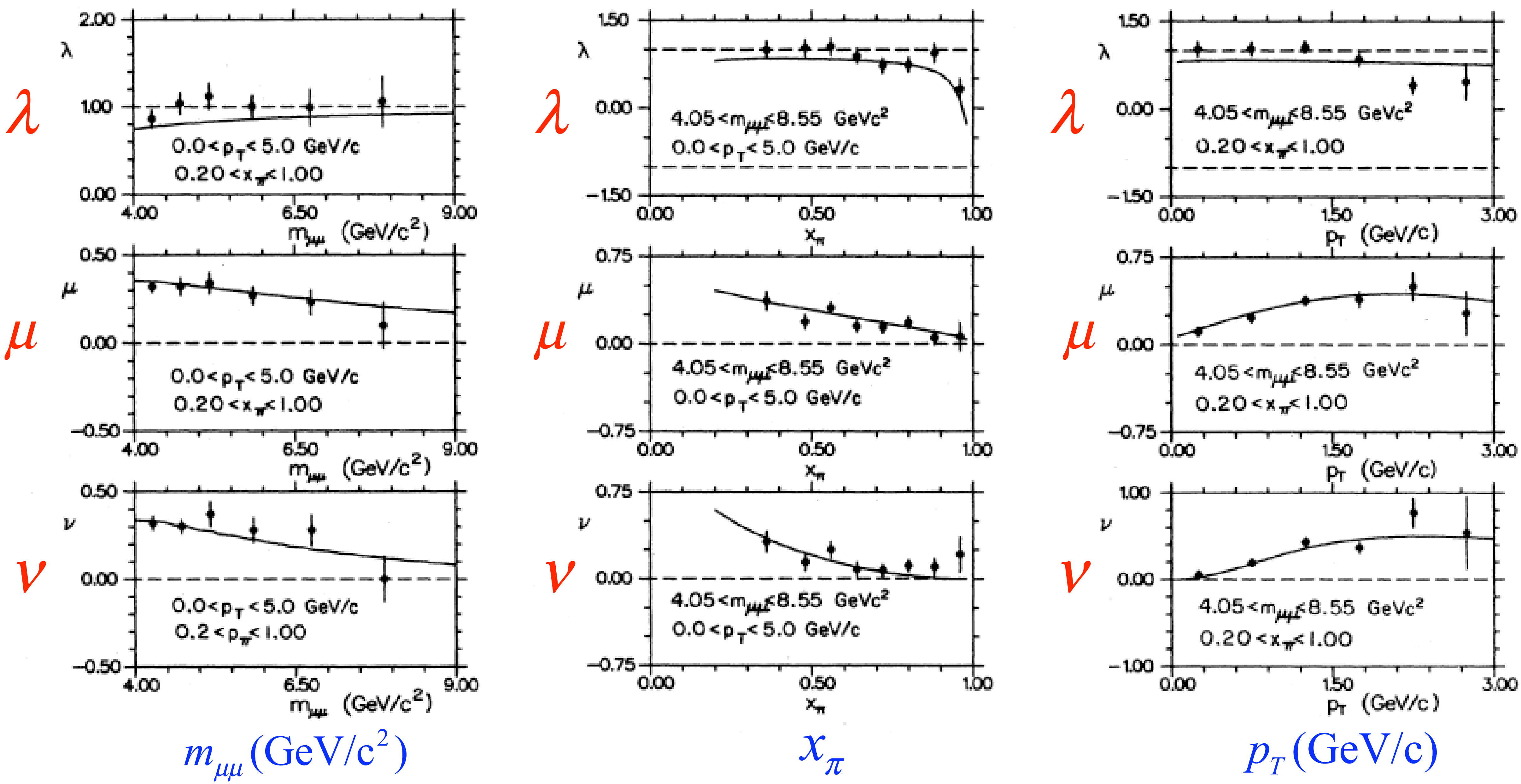


Collins-Soper frame

naive collinear parton model: $\lambda = 1 \quad \mu = \nu = 0$

Decay angular distributions in pion-induced Drell-Yan

E615 Data 252 GeV $\pi^- + W$ Phys. Rev. D 39 (1989) 92



$$\lambda \neq 1 \quad \mu, \nu \neq 0 \quad 1 - \lambda - 2\nu \neq 0$$

(valence quarks ?)

(talk by P. Reimer)

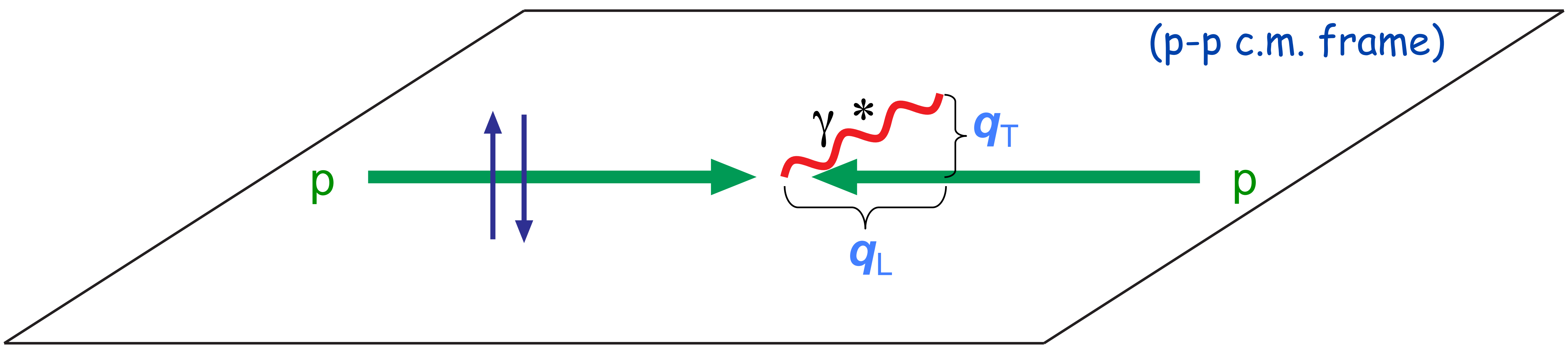
Sivers effect in D-Y processes

By looking at the $d^4\sigma/d^4q$ cross section one can single out the Sivers effect in D-Y processes

$$d\sigma^{\uparrow} - d\sigma^{\downarrow} \propto \sum_q \Delta^N f_{q/p^{\uparrow}}(x_1, \boldsymbol{k}_{\perp}) \otimes f_{\bar{q}/p}(x_2) \otimes d\hat{\sigma}$$

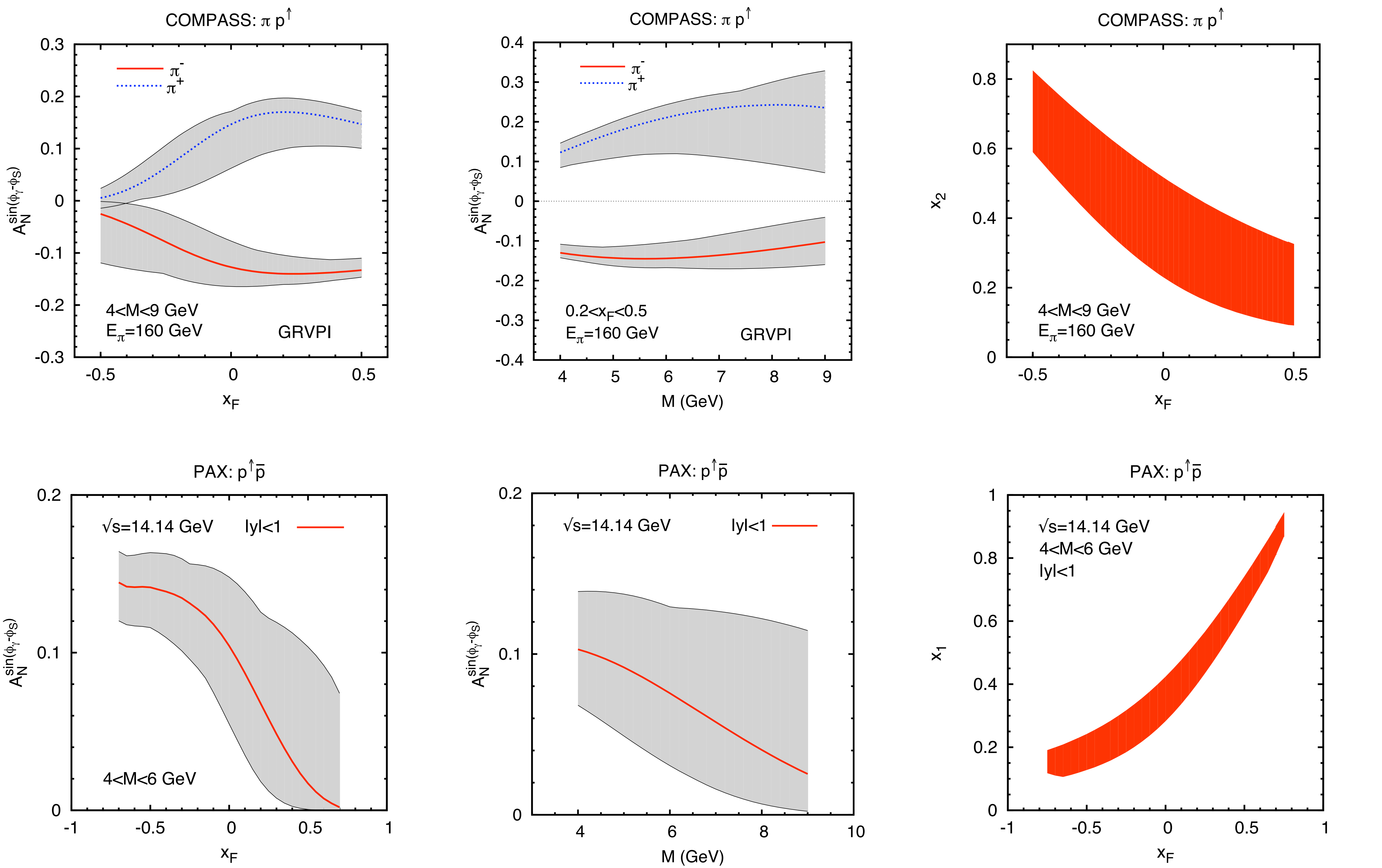
$q = u, \bar{u}, d, \bar{d}, s, \bar{s}$

$$A_N^{\sin(\phi_S - \phi_\gamma)} \equiv \frac{2\int_0^{2\pi} d\phi_\gamma \, [d\sigma^{\uparrow} - d\sigma^{\downarrow}] \, \sin(\phi_S - \phi_\gamma)}{\int_0^{2\pi} d\phi_\gamma \, [d\sigma^{\uparrow} + d\sigma^{\downarrow}]}$$

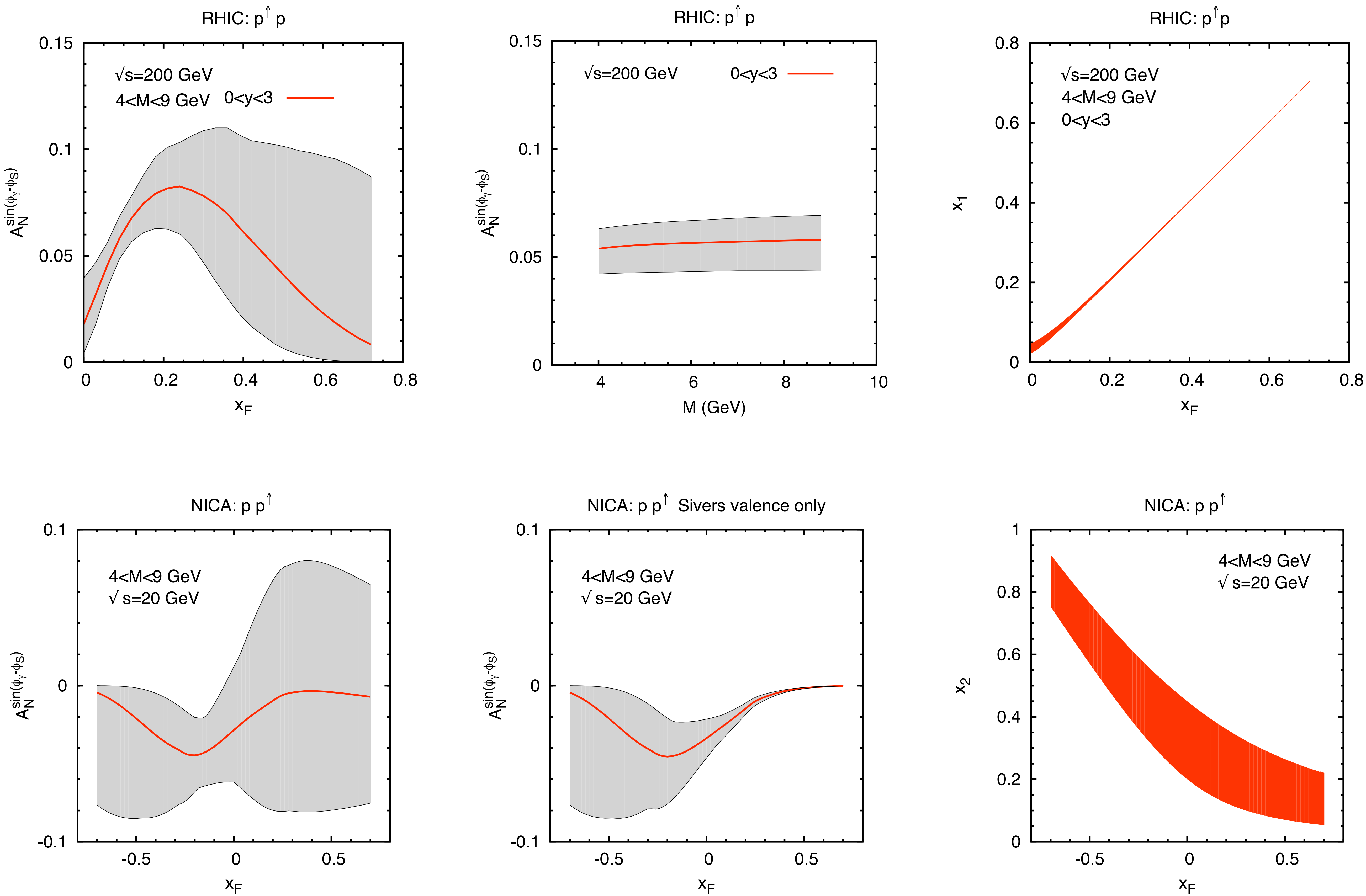


Predictions for A_N

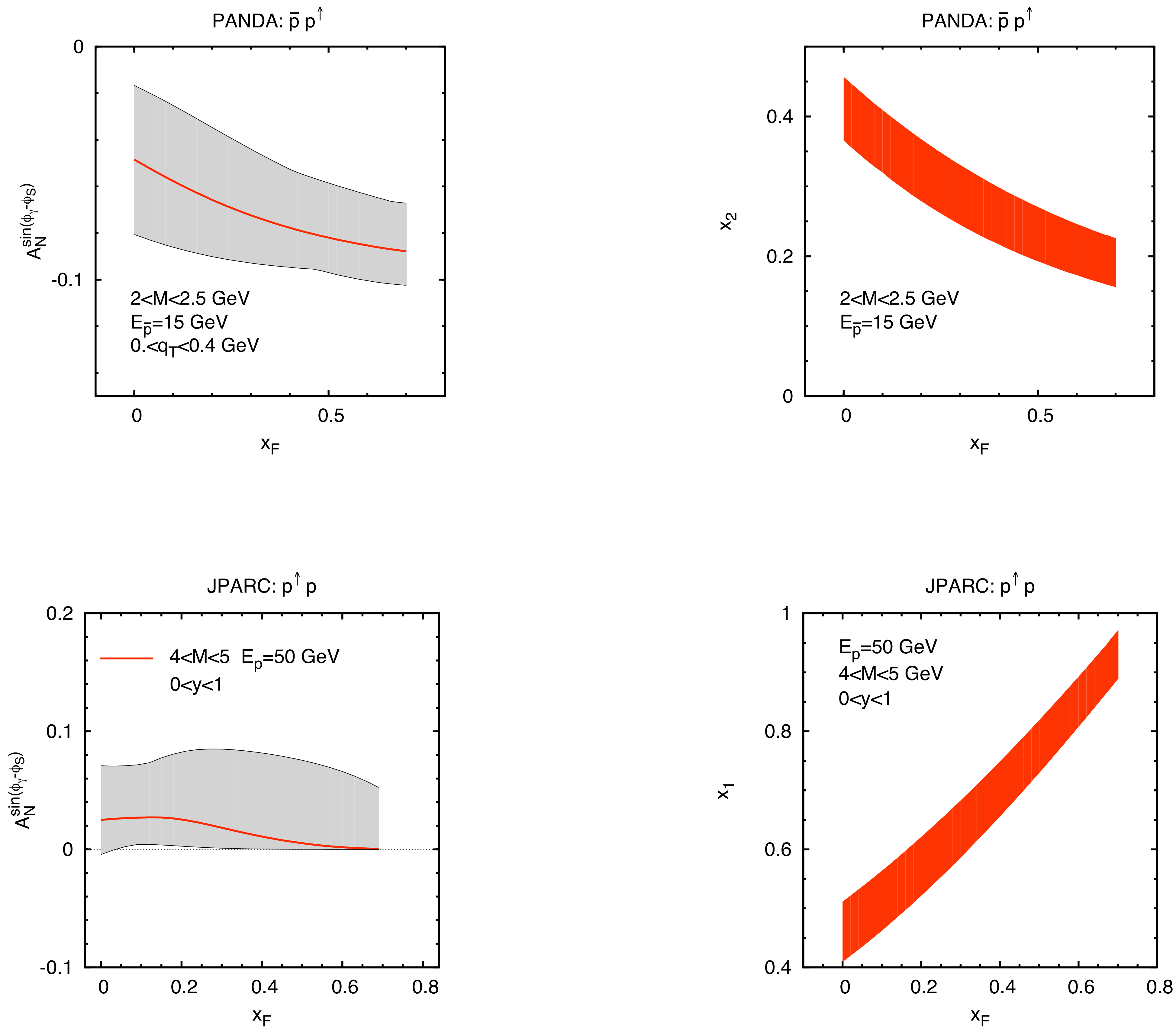
Sivers functions as extracted from SIDIS data, **with opposite sign**



M.A., M. Boglione, U. D'Alesio, S. Melis, F. Murgia, A. Prokudin, e-Print: arXiv:0901.3078



RHIC: p↑ p
√s=200 GeV
4<M<9 GeV
0<y<3
$A_N^{\sin(\phi_\gamma-\phi_S)}$
x_F
RHIC: p↑ p
√s=200 GeV
0<y<3
$A_N^{\sin(\phi_\gamma-\phi_S)}$
M (GeV)
RHIC: p↑p
√s=200 GeV
4<M<9 GeV
0<y<3
x_1
x_F
NICA: p p↑
4<M<9 GeV
√ s=20 GeV
$A_N^{\sin(\phi_\gamma-\phi_S)}$
x_F
NICA: p p↑ Sivers valence only
4<M<9 GeV
√ s=20 GeV
$A_N^{\sin(\phi_\gamma-\phi_S)}$
x_F
NICA: p p↑
4<M<9 GeV
√ s=20 GeV
x_2
x_F

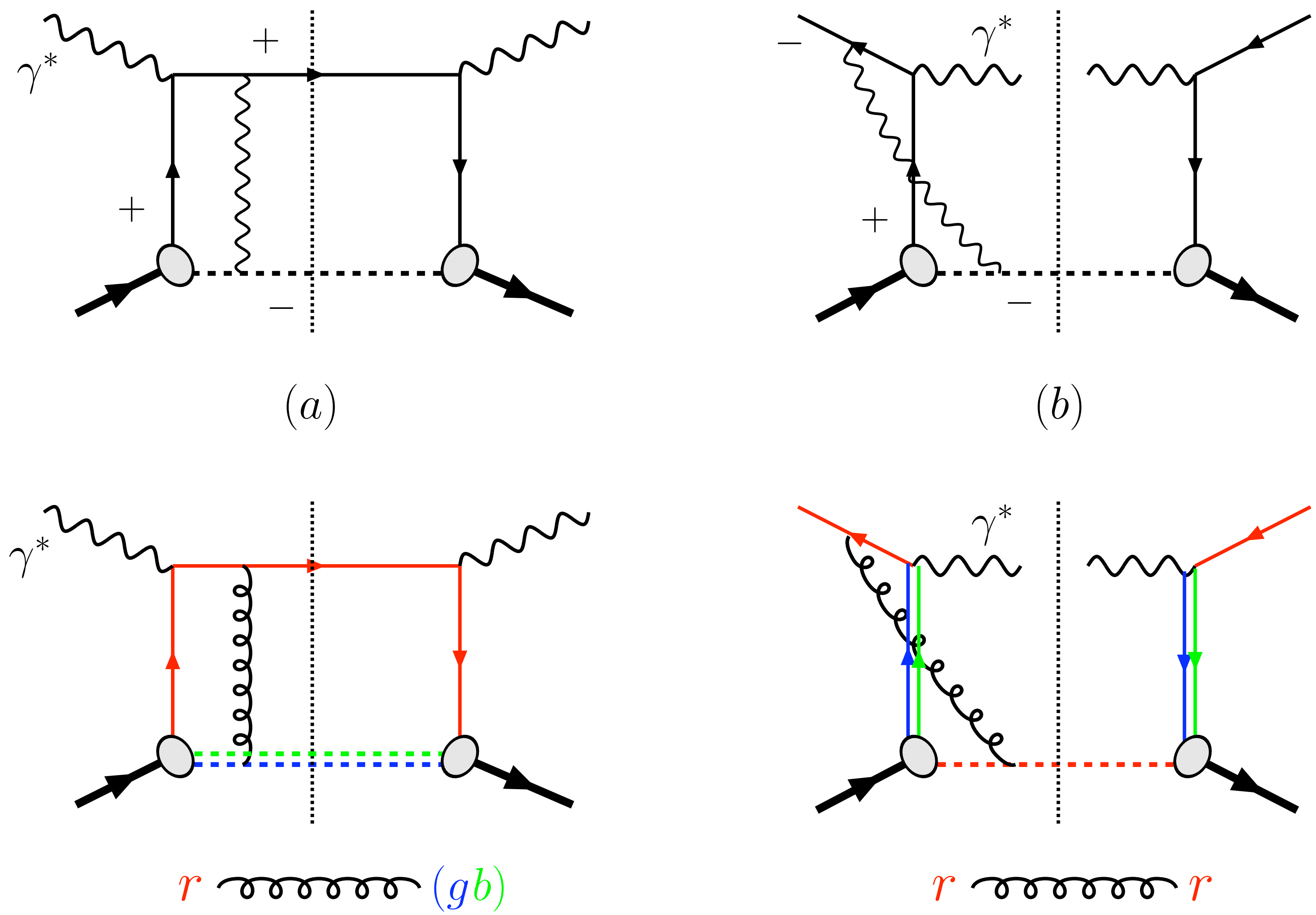

PANDA: $\bar{p}\, p^{\uparrow}$
$A_N^{\sin(\phi_\gamma-\phi_S)}$
2<M<2.5 GeV
$E_{\bar{p}}$=15 GeV
0.<q_T<0.4 GeV
x_F
PANDA: $\bar{p}\, p^{\uparrow}$
x_2
2<M<2.5 GeV
$E_{\bar{p}}$=15 GeV
x_F
JPARC: $p^{\uparrow}\, p$
$A_N^{\sin(\phi_\gamma-\phi_S)}$
4<M<5 E_p=50 GeV
0<y<1
x_F
JPARC: $p^{\uparrow}\, p$
x_1
E_p=50 GeV
4<M<5 GeV
0<y<1
x_F

Crucial role of gauge-links in TMDs

Brodsky, Hwang, Schmidt; Collins; Belitsky, Ji, Yuan; Boer, Mulders, Pijlman

process-dependence of Sivers functions

DIS: "attractive"



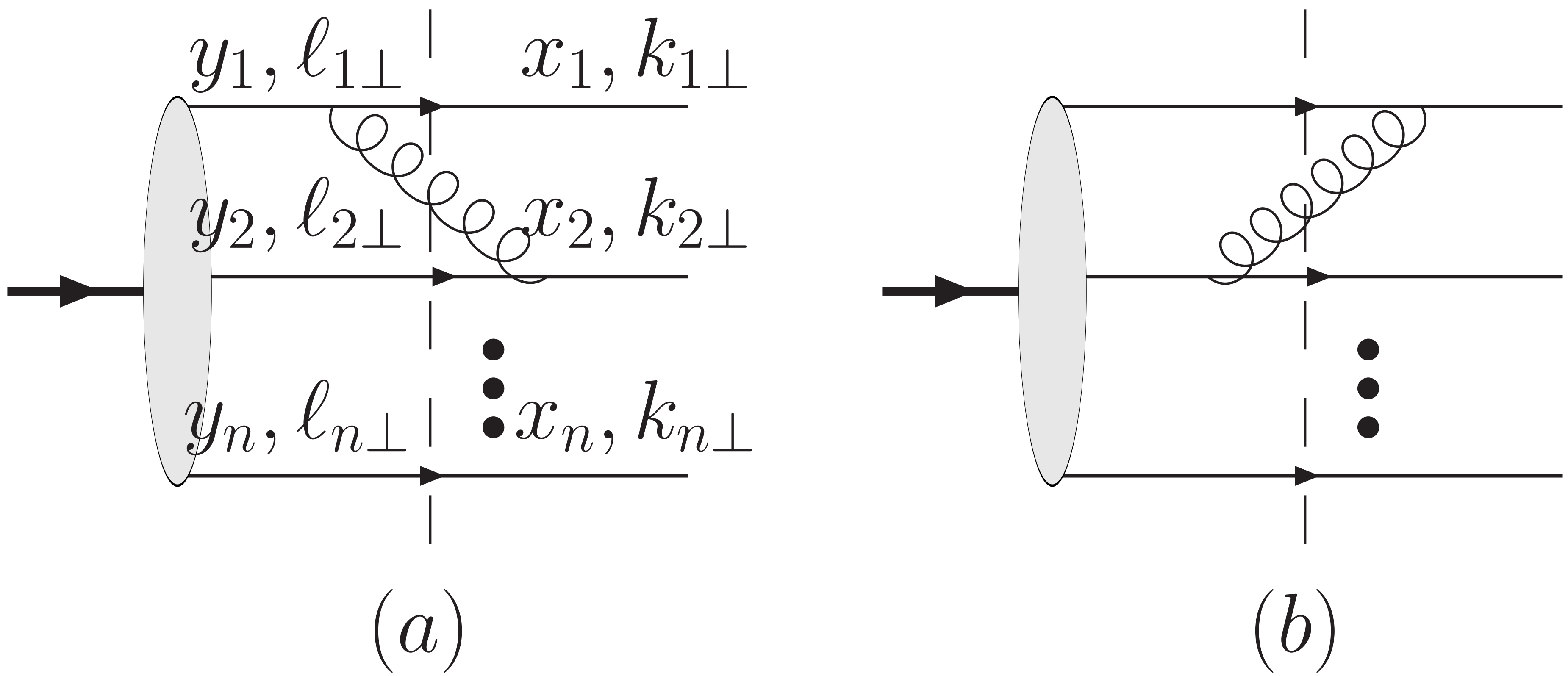
D-Y: "repulsive"

$$[f_{1T}^{q\perp}]_{\mathrm{SIDIS}} = -[f_{1T}^{q\perp}]_{\mathrm{DY}}$$

Talks by D. Boer, A. Bacchetta, round table

Sivers function from light-front wave function

Brodsky, Pasquini, Xiao, Yuan, arXiv:1001.1163
Pasquini, Yuan, arXiv:1001.5398



in all models one has:

$$[f_{1T}^{q\perp}]_{\rm SIDIS} = -[f_{1T}^{q\perp}]_{\rm DY}$$

whatever the reason, check it!

see also Hwang, arXiv:1003.0867 - incorporation of final state interactions into the light-cone wave function

The dream experiment, D-Y with polarized antiprotons

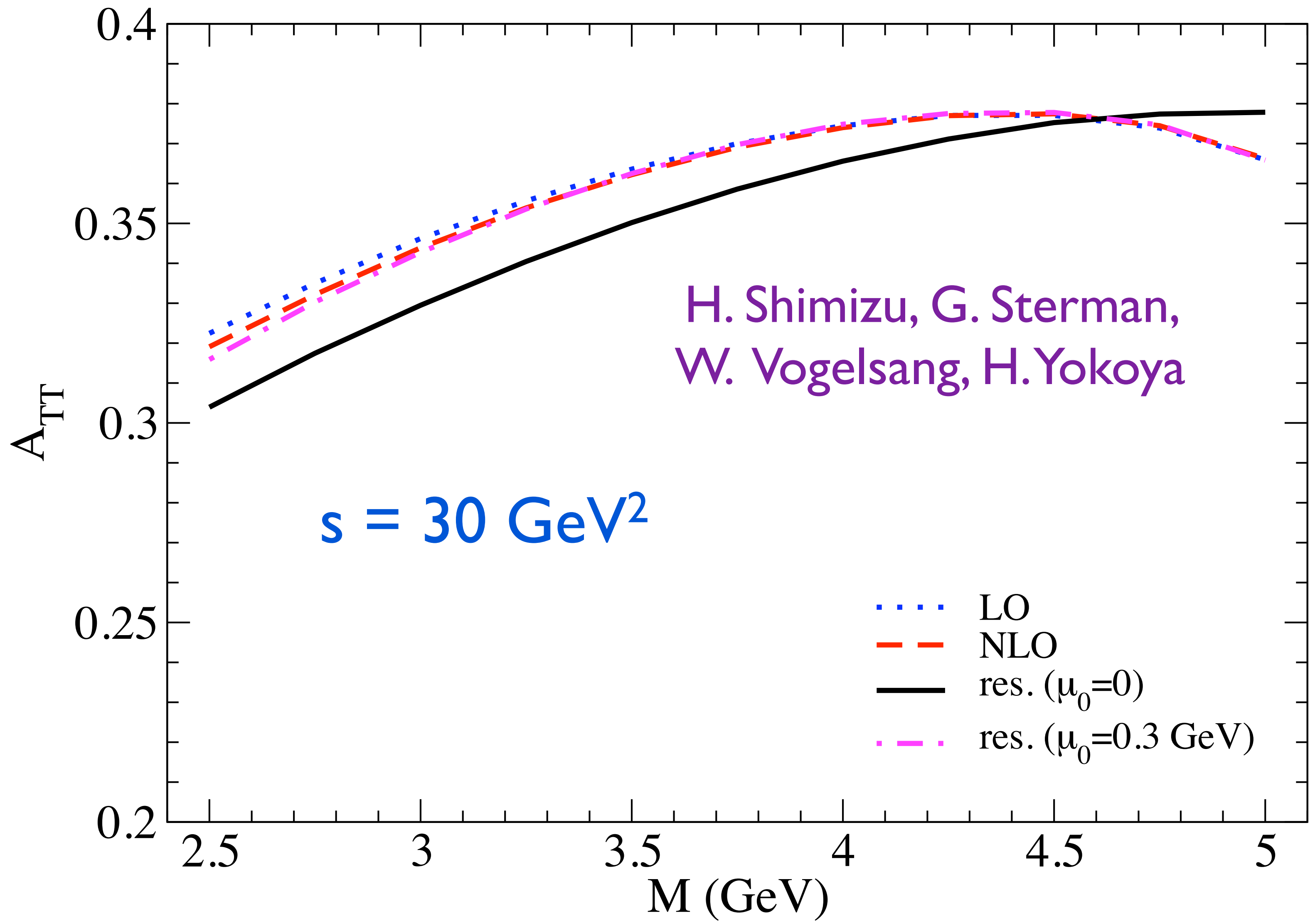
measure transversity via double spin asymmetry A_{TT}

PAX proposal: hep-ex/0505054

M.A., V. Barone, A. Drago, N. Nikolaev

$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}}$$

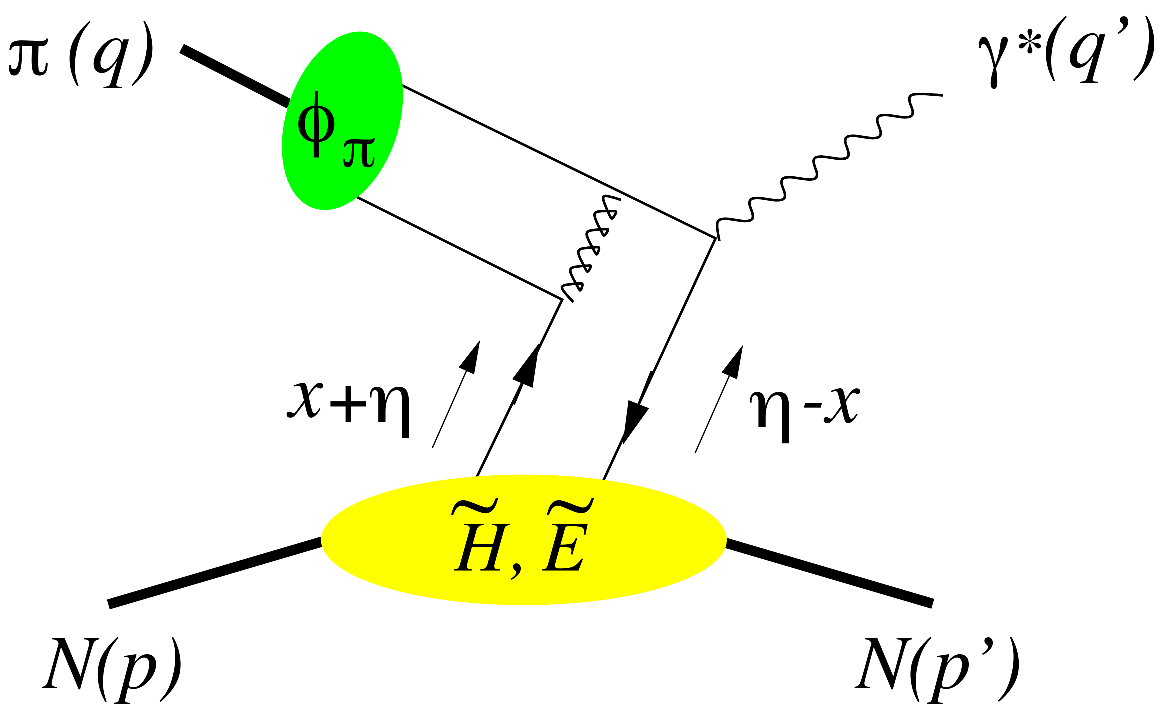
$$\hat{a}_{TT} = \frac{\sin^2\theta}{1+\cos^2\theta}\,\cos(2\varphi)$$

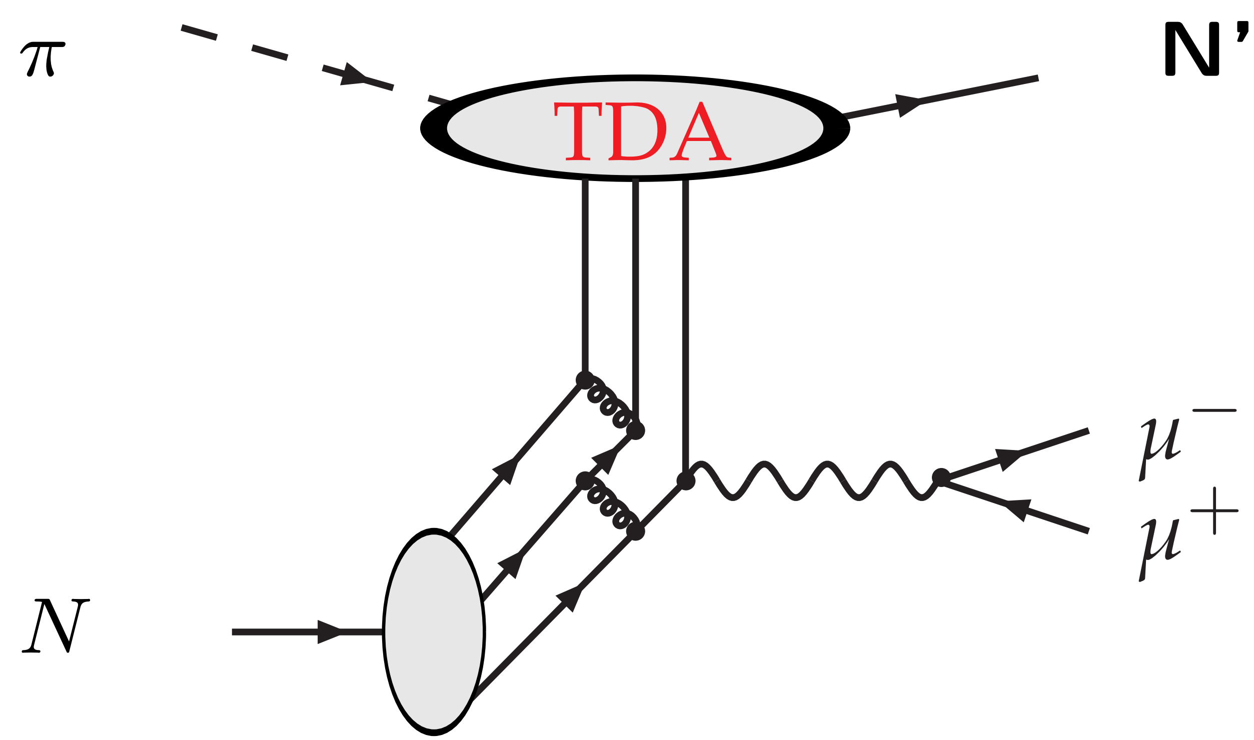


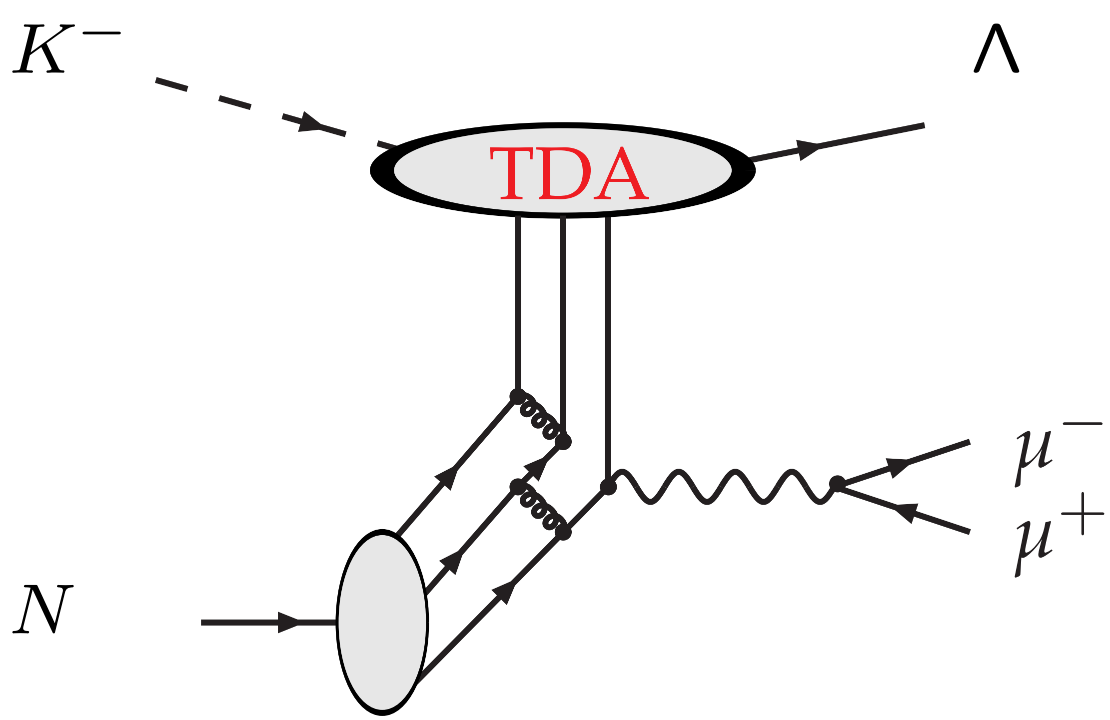
$$A_{TT} \equiv \frac{d\sigma^{\uparrow\uparrow} - d\sigma^{\uparrow\downarrow}}{d\sigma^{\uparrow\uparrow} + d\sigma^{\uparrow\downarrow}} \simeq \hat{a}_{TT}\,\frac{\sum_q e_q^2\, h_{1q}(x_1)\, h_{1q}(x_2)}{\sum_q e_q^2\, q(x_1)\, q(x_2)}$$

talk by P. Lenisa, W. Vogelsang

Drell-Yan processes - GPDs and TDAs







exclusive limits of Drell-Yan processes

(B. Pire)

Conclusions

3-dimensional exploration of nucleon has just started:

collect as much data as possible and try to reconstruct the nucleon phase-space structure

Drell-Yan processes are cleanest probe

ideal machines:

x-range including the valence region,

Q^2, M^2 high enough to control higher-twist corrections

P_T, Q_T ranges large enough to see transition from TMDs to collinear factorization

plenty of challenging theoretical issues....

many thanks to the organizers!