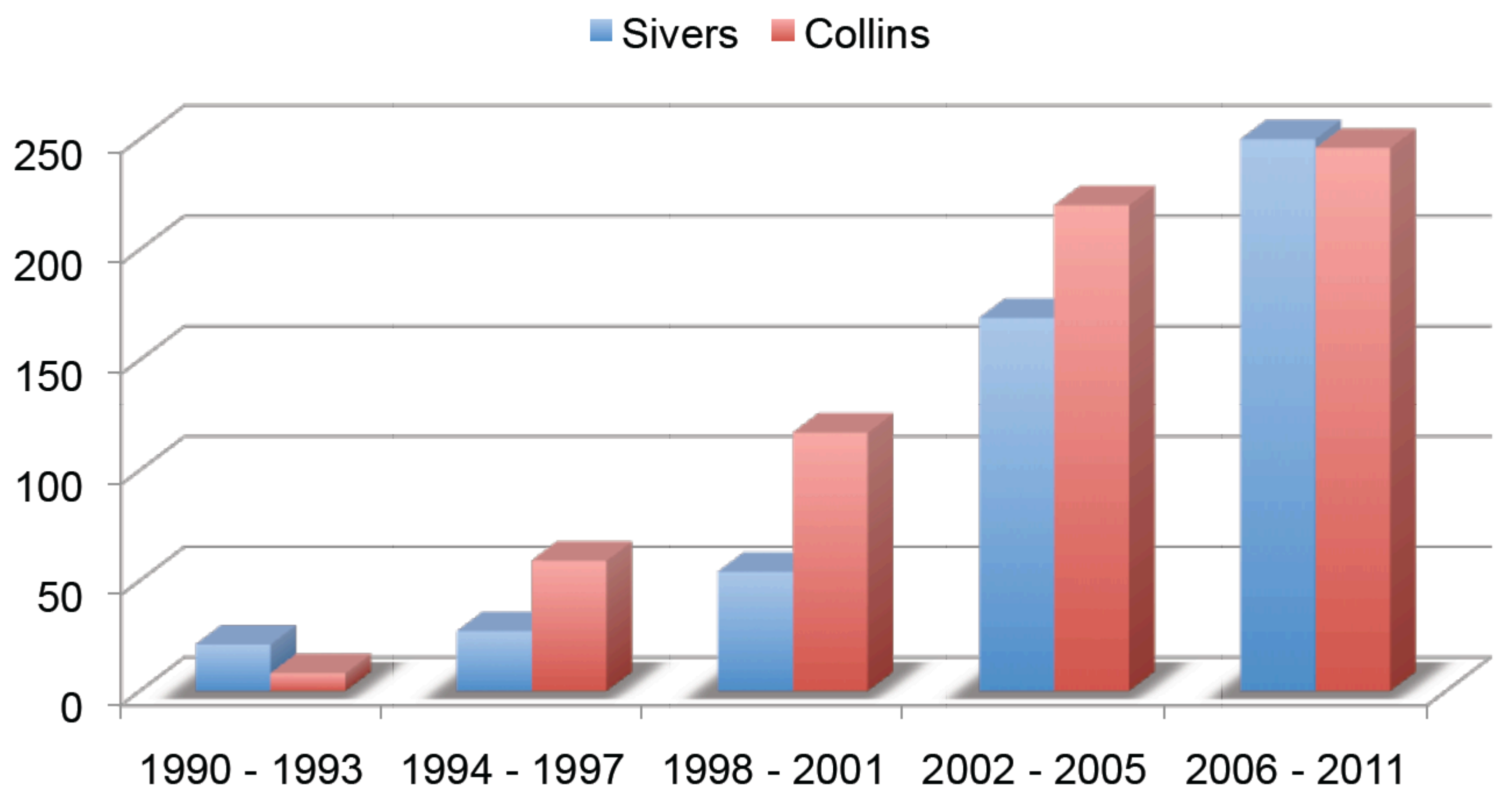
# Transverse-Spin Physics: Highlights and News

Werner Vogelsang
Tübingen University

Veli Losinj, 29.08.2011

- Remarkable development of this field:
  from
  The sidelines in strong interaction physics
  to
  Center stage in our efforts to figure out QCD




Courtesy of Z. Kang, shown at 2011 RHIC Users meeting

- Numerous exciting new developments over past ~3 years
- Continue to get new insights and face new puzzles
- A lot of progress in advancing theory framework
- Have uncovered connections to other areas of QCD

Will touch on a few aspects of this
(with a strong theory and personal bias)

- Particular boost by INT program on the Electron Ion Collider (EIC)

**Organizers:**
Daniel Boer
KVI, University of Groningen
D.Boer@rug.nl

Markus Diehl
DESY
markus.diehl@desy.de

Richard Milner
MIT
milner@mit.edu

Raju Venugopalan
Brookhaven National Laboratory
raju@quark.phy.bnl.gov

Werner Vogelsang
University of Tübingen
werner.vogelsang@uni-tuebingen.de

**Program Coordinator:**
Inge Dolan
inge@phys.washington.edu
(206) 685-4286

Talks online

Application form

Exit report

Friends of the INT

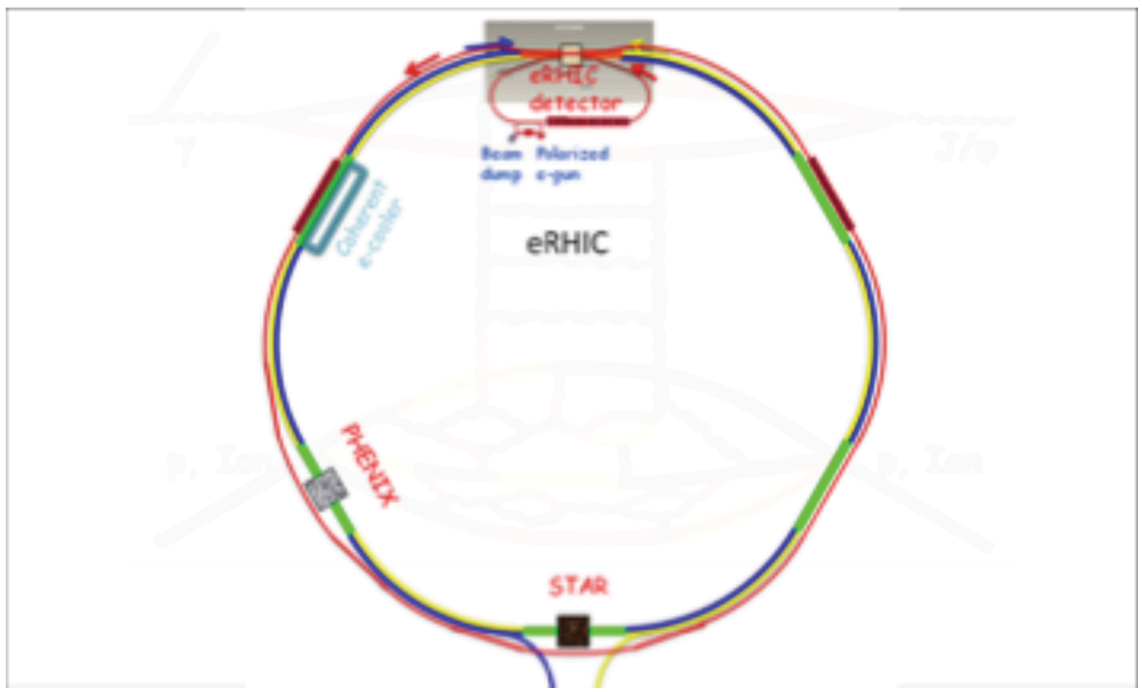
Obtain an INT preprint number

INT homepage

Gluons and the quark sea at high energies: distributions, polarization, tomography

September 13 to November 19, 2010

Report from the INT program "Gluons and the quark sea at high energies: distributions, polarization, tomography"



The EIC Science case: a report on the joint BNL/INT/JLab program

Gluons and the quark sea at high energies:
distributions, polarization, tomography

arXiv:1108.1713v1 [nucl-th]

Institute for Nuclear Theory, University of Washington, USA
September 13 to November 19, 2010

Editors:

D. Boer, Universiteit Groningen, The Netherlands
M. Diehl, Deutsches Elektronen-Synchroton DESY, Germany
R. Milner, Massachusetts Institute of Technology, USA
R. Venugopalan, Brookhaven National Laboratory, USA
W. Vogelsang, Universität Tübingen, Germany

# 1 The spin and flavor structure of the proton
Stratmann

# 2 Three-dimensional structure of the proton and nuclei: transverse momentum
Hasch, Yuan

# 3 Three-dimensional structure of the proton and nuclei: spatial imaging
Burkardt, Guzey, Sabatie

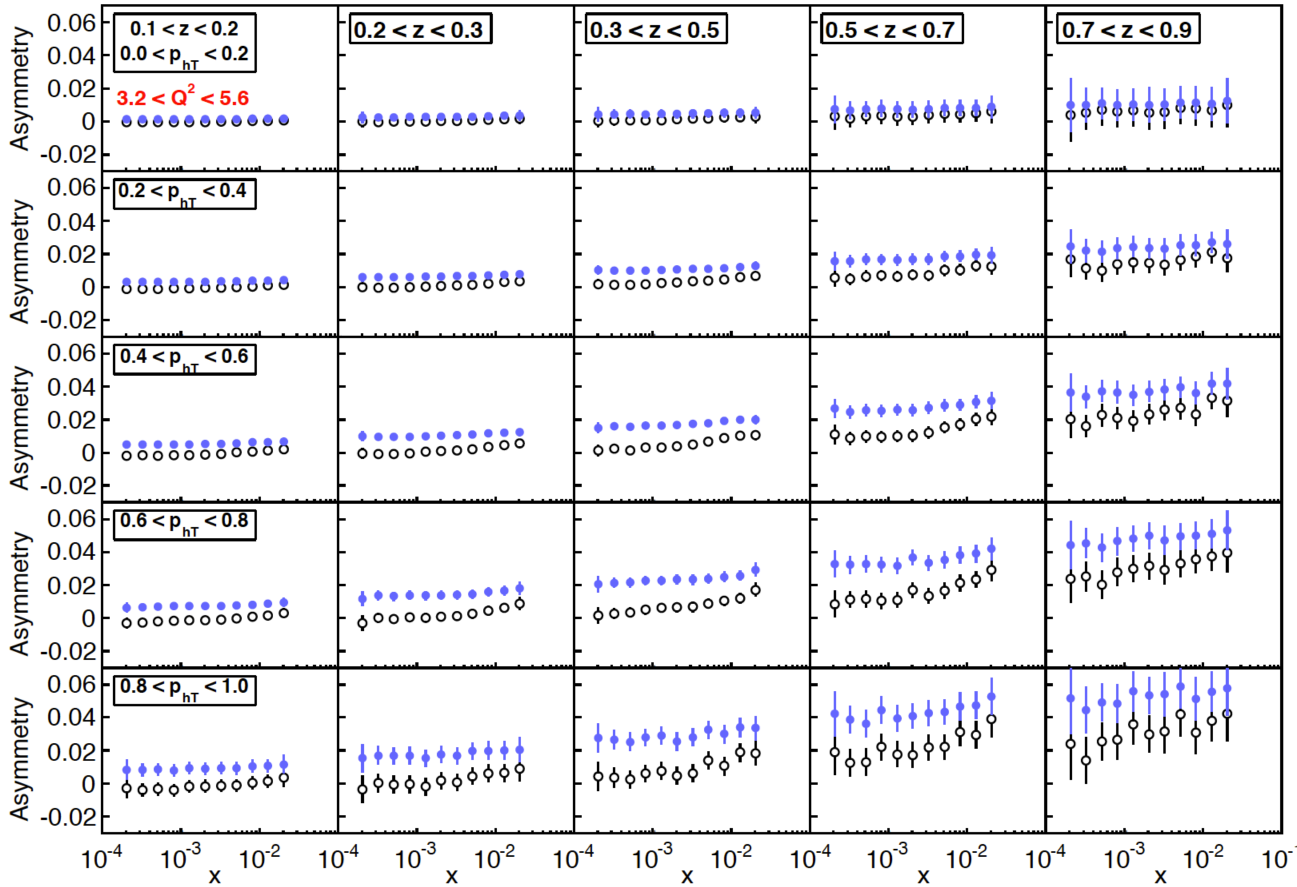
# 4 Input from lattice QCD
Hasch, Yuan

# 5 QCD matter under extreme conditions
Accardi, Lamont, Marquet

# 6 Electroweak physics
Kumar, Li, Marciano

# 7 Experimental aspects
Aschenauer, Ent

# Sivers projections for EIC:

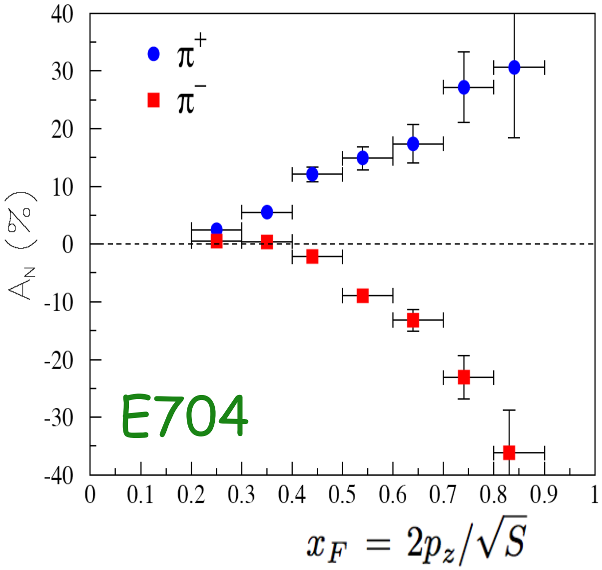


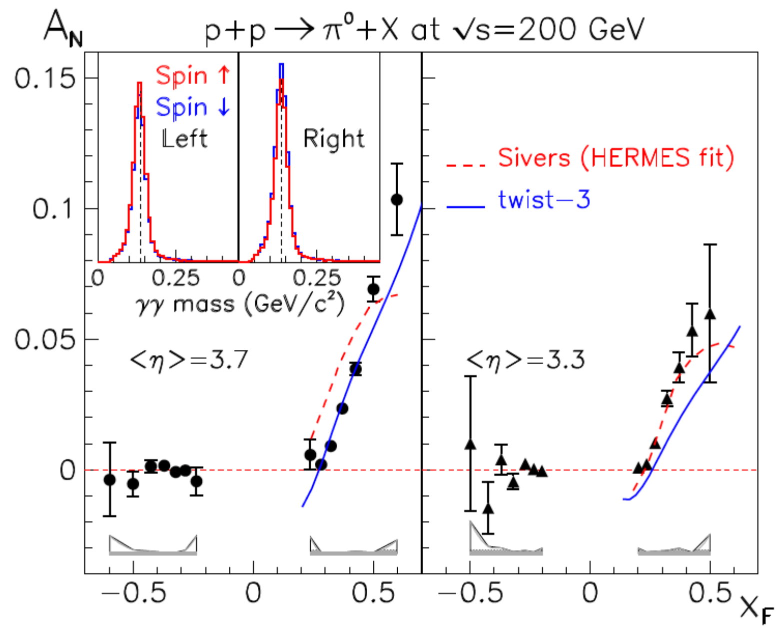

$$\pi^+, \quad \sqrt{s} = 140\,\mathrm{GeV}, \quad 4/\mathrm{fb}$$

# Outline:

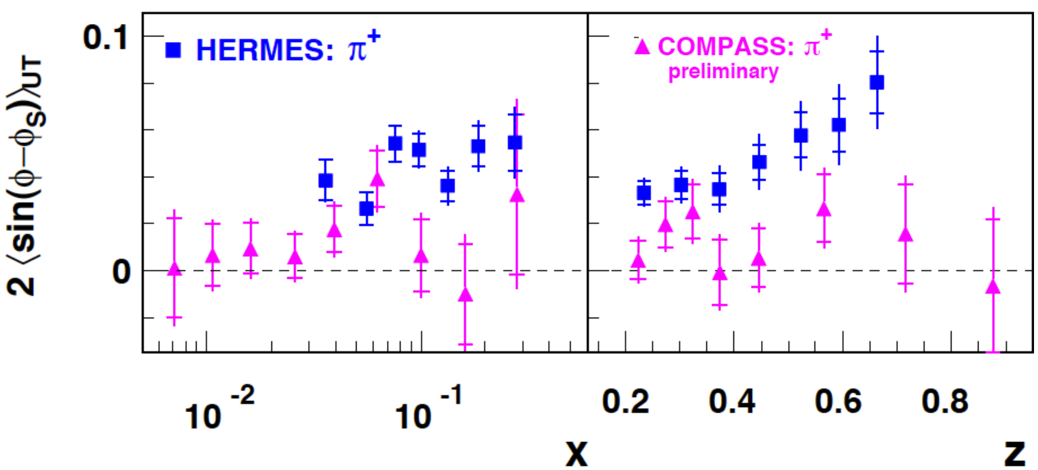
- Single-spin and azimuthal asymmetries
  - TMDs, twist-3 correlations
  - factorization, evolution, resummation
  - role of gluon distributions
  - ramifications for other areas
- Other things I am looking forward to at Transversity 2011
- Conclusions

# Single-spin & azimuthal asymmetries

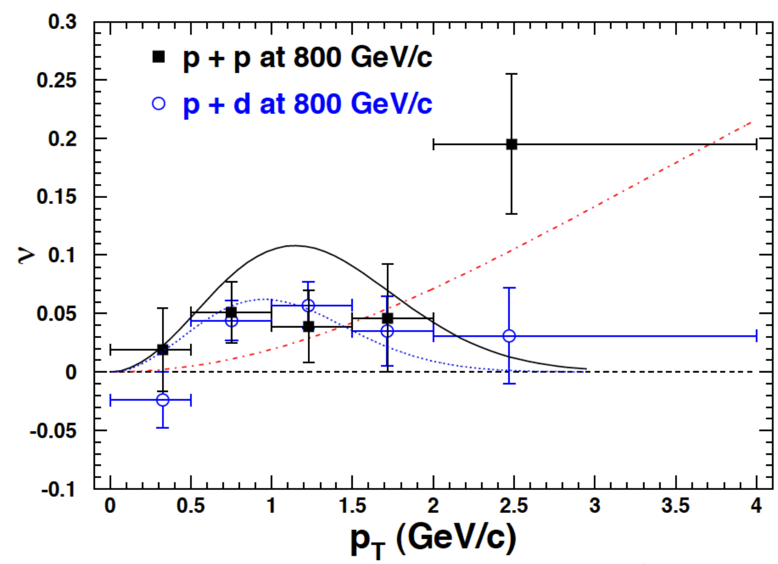



STAR



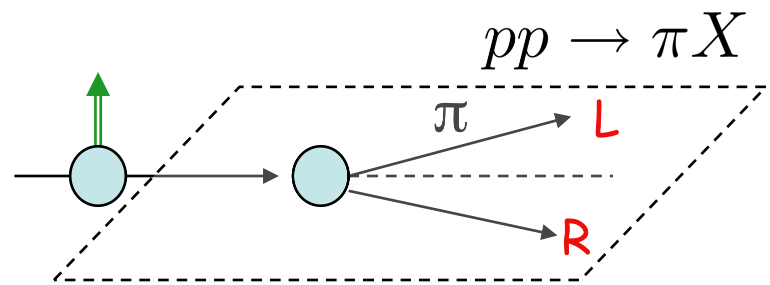

HERMES, COMPASS,
JLab



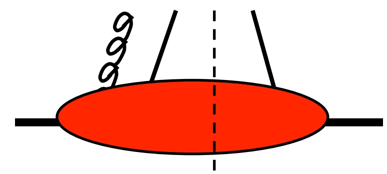

E866/NuSea

**Distinguish:**

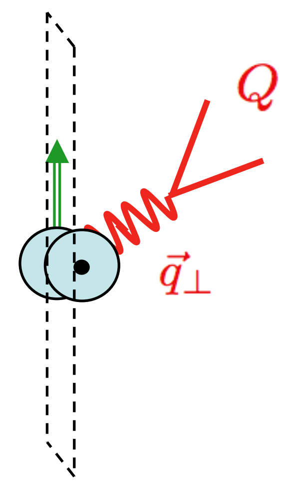
- *single-inclusive* processes




  - single large scale $p_\perp$
  - power-suppressed ~$1/p_\perp$ in QCD
  - collinear factorization, e.g. $T_F(x,y)$
  - phase in hard scattering



- *two-scale* processes: small & measured $q_\perp \ll Q$




  - SIDIS at HERMES,COMPASS
  - TMD factorization holds only for simplest observables
  - crucial role of gauge links

- quark TMD correlator

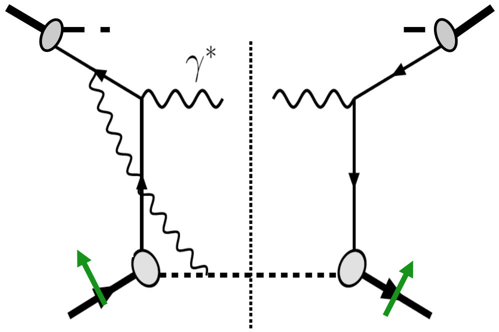
$$\Phi^q_{ij}(x,\boldsymbol{k}_\perp,\boldsymbol{S})_\eta = \int \frac{dz^- d^2 z_\perp}{(2\pi)^3}\, e^{ik\cdot z} \langle \boldsymbol{P},\boldsymbol{S}\,|\,\bar\psi^q_j(0)\,\mathcal{W}_\eta(0,z)\,\psi^q_i(z)\,|\boldsymbol{P},\boldsymbol{S}\rangle\Big|_{z^+=0}$$

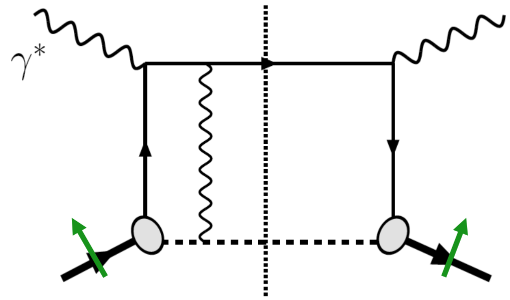
- leading-power TMDs

$$\begin{aligned}
\frac{1}{2}\,\mathrm{tr}\left[\gamma^+\,\Phi^q(x,\boldsymbol{k}_\perp,\boldsymbol{S})\right] &= f^q_1(x,k_\perp) - \frac{\varepsilon^{jk}\,k^j_\perp\,S^k_T}{M}\,f^{\perp q}_{1T}(x,k_\perp)\\
\frac{1}{2}\,\mathrm{tr}\left[\gamma^+\gamma_5\,\Phi^q(x,\boldsymbol{k}_\perp,\boldsymbol{S})\right] &= S_L\,g^q_{1L}(x,k_\perp) + \frac{\boldsymbol{k}_\perp\cdot\boldsymbol{S}_T}{M} g^q_{1T}(x,k_\perp)\\
\frac{1}{2}\,\mathrm{tr}\left[i\sigma^{j+}\gamma_5\,\Phi^q(x,\boldsymbol{k}_\perp,\boldsymbol{S})\right] &= S^j_T\,h^q_1(x,k_\perp) + S_L\,\frac{k^j_\perp}{M}\,h^{\perp q}_{1L}(x,k_\perp)\\
&+ \frac{(k^j_\perp\,k^k_\perp - \frac{1}{2}\,\boldsymbol{k}^2_\perp\,\delta^{jk})S^k_T}{M^2}\,h^{\perp q}_{1T}(x,k_\perp) + \frac{\varepsilon^{jk}\,k^k_\perp}{M}\,h^{\perp q}_1(x,k_\perp)
\end{aligned}$$

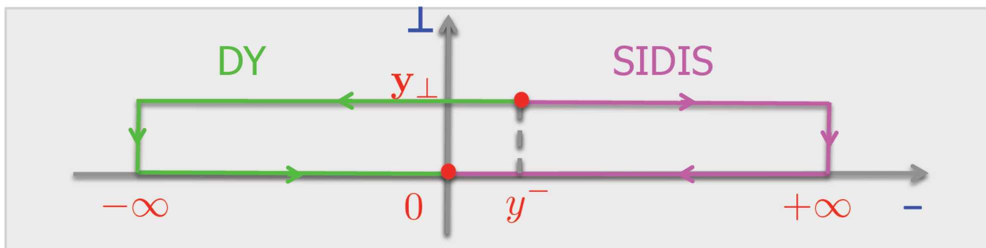
- extensive phenomenology Anselmino,D'Alesio,Murgia,Prokudin,Schlegel,...
- most of the TMDs involve orbital angular momentum: Spin-orbit corr., "lensing", 3D imaging (-> models) Burkardt
- $f^{\perp q}_{1T}$, $h^{\perp q}_1$ have particularly interesting physics

- gauge link determined by hard process and its color flow




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




- central quest for our field: verify consequence

$$\left(f_{1T}^{\perp q}\right)_{\mathrm{DY}} = - \left(f_{1T}^{\perp q}\right)_{\mathrm{DIS}}$$

- goes beyond “just” check of TMD factorization
- strong motivation for Drell-Yan-type experiments

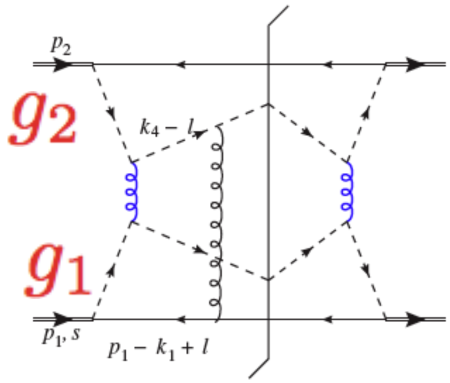
AnDY, COMPASS, E906,W bosons at RHIC

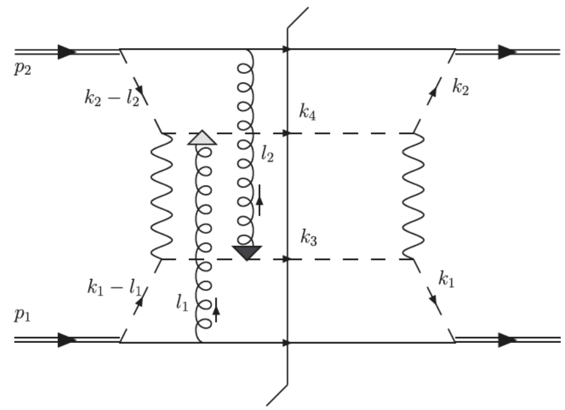
Barone et al., Anselmino et al., Yuan,WV, Schlegel et al., Kang,Qiu, Metz,Zhou

**News**

## No TMD factorization for general QCD hard scattering !

Bomhof, Mulders, Pijlman; Collins, Qiu; Mulders,Rogers




- gauge links in parton distributions "know" about full hard process

  $\longrightarrow$ loss of universality

- even "generalized factorization" does not hold Mulders,Rogers
- Dynamics! QM interplay of probe and structure
- a lot to learn from phenomenological studies of fact. breaking
- wider ramifications for strong-interaction physics

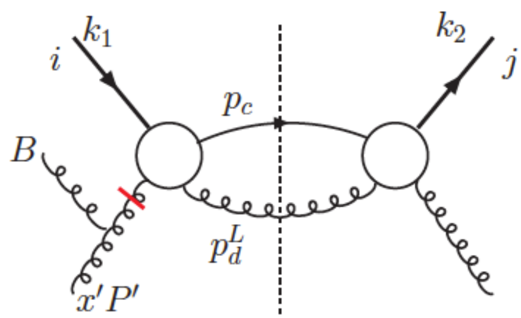
- Twist-3 collinear correlator, e.g.

$$\tilde{\Phi}^{\mu}_{\alpha\beta}(x,x_1) = \int \frac{dy^-}{2\pi}\frac{dy_1^-}{2\pi} e^{-ixP^+y^-} e^{i(x_1-x)P^+y_1^-} \langle P,S|\bar{\psi}_\beta(y^-) g F_+^{\mu}(y_1^-)\psi_\alpha(0)|P,S\rangle$$

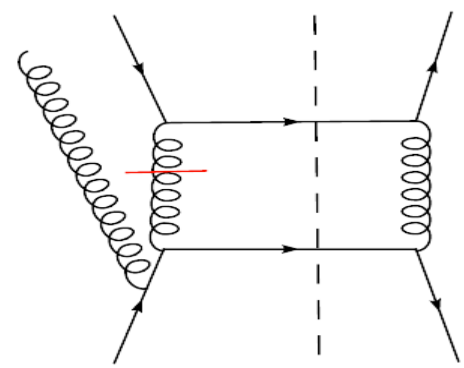
$$= \frac{M}{2}\left\{\underbrace{T_F(x,x_1)}\epsilon_\perp^{\nu\mu}S_{\perp\nu}\not{p} + \underbrace{T_F^{(\sigma)}(x,x_1)} i\gamma_\perp^\mu \not{p} + \ldots\right\}_{\alpha\beta}$$

Efremov, Teryaev, Qiu, Sterman, Kanazawa, Koike, …

- accessible in $A_N$ for inclusive processes such as $pp \to \pi X$




soft-gluon pole
$T_F(x,x)$



soft-fermion pole
$T_F(x,0)$

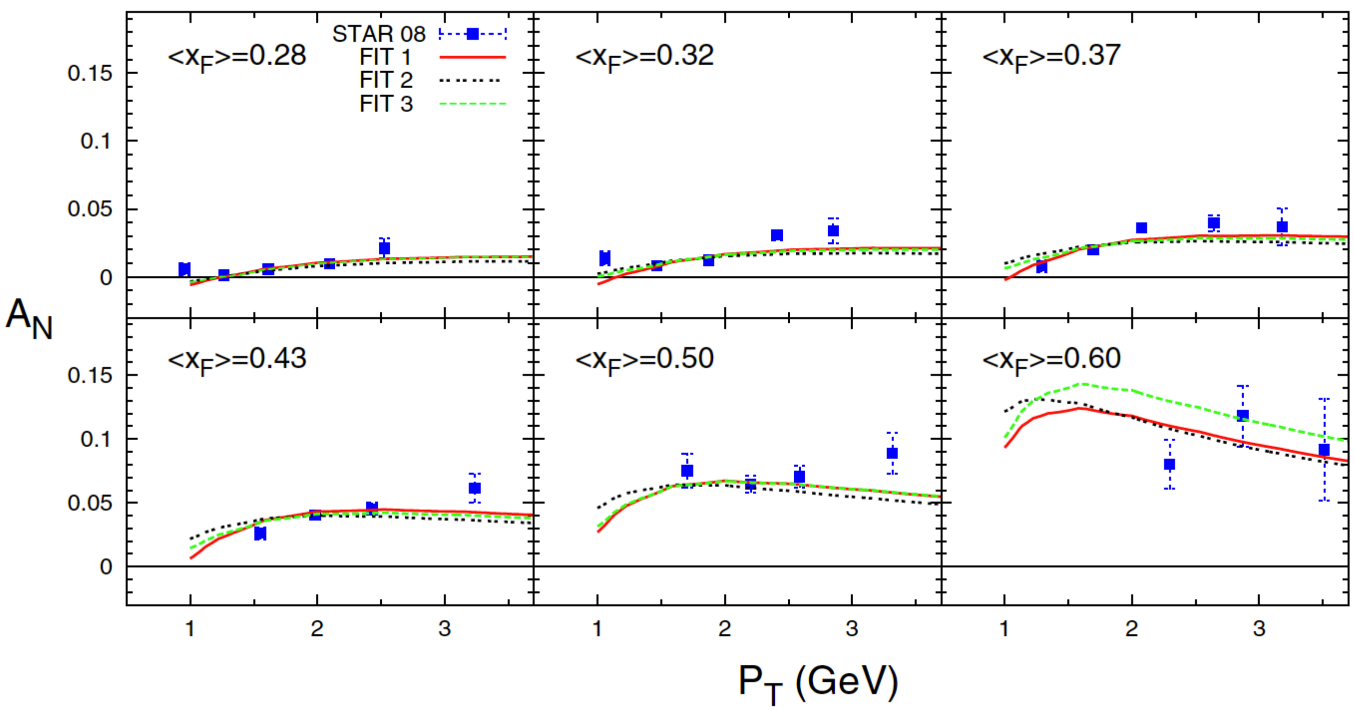
- factorization and universality

**News**

# Most complete (to date) analysis of $pp \to \pi X$ data

Kanazawa, Koike

- better description of $p_T$ dependence through interplay of SGP and SFP contributions



# We have learned that TMDs and twist-3 functions are closely related

- at operator level:

Boer, Mulders, Pijlman
Ma, Wang

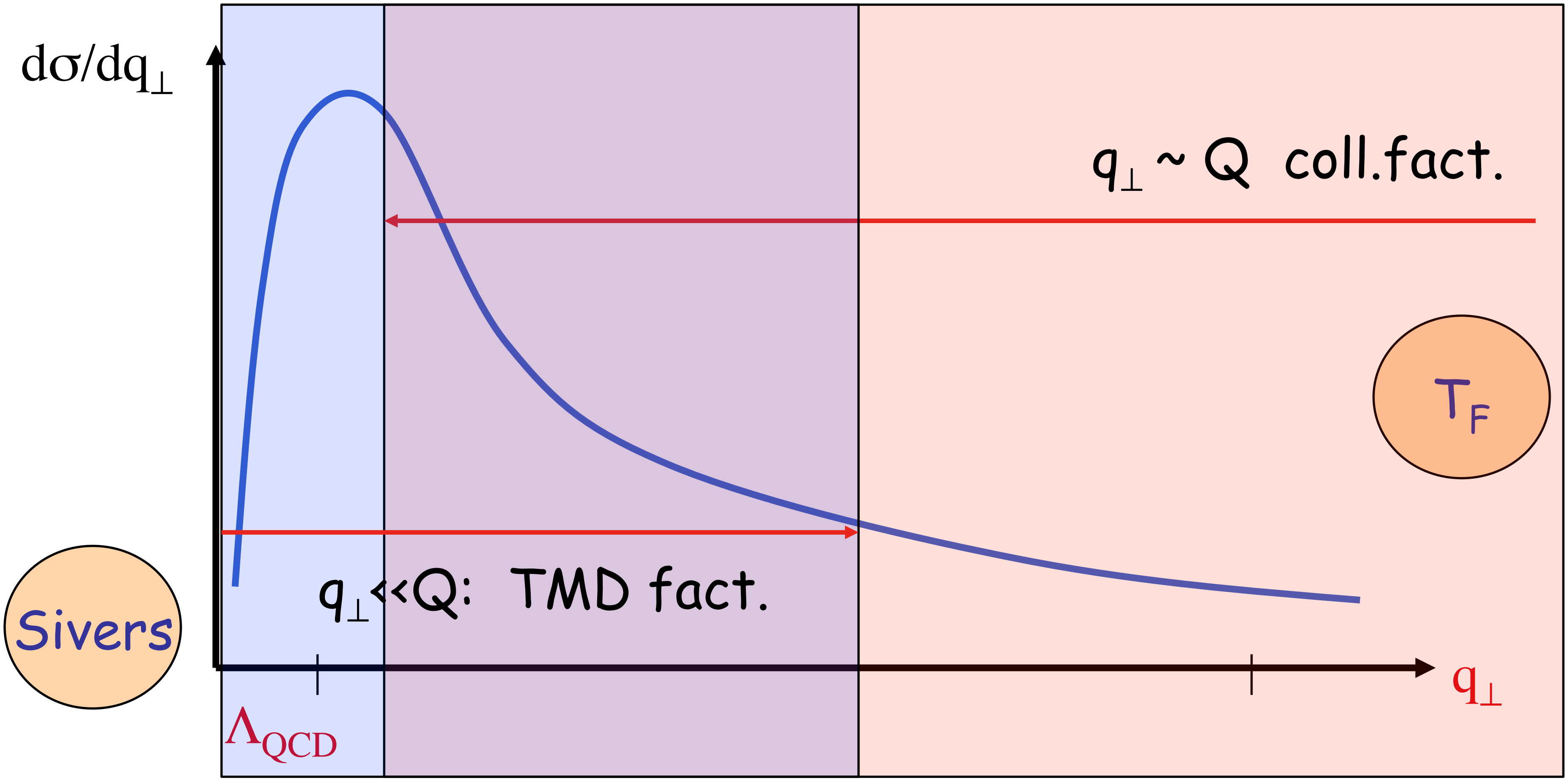
$$T_F(x,x) = -\int \frac{d^2\vec{k}_\perp}{2\pi}\frac{\vec{k}_\perp^2}{M^2}\left(f_{1T}^\perp(x,k_\perp)\right)_{\rm DIS}$$

$$T_F^{(\sigma)}(x,x) = -\int \frac{d^2\vec{k}_\perp}{2\pi}\frac{\vec{k}_\perp^2}{M^2}\left(h_1^\perp(x,k_\perp)\right)_{\rm DIS}$$

(caveat: renormalization)

- r.h.s. realized by $q_T$ moments of cross sections
- it means we can use SIDIS and RHIC data jointly

- at level of a physical process:




$\Lambda_{QCD} \ll q_\perp \ll Q$ same physics

Verified to 1-loop

Ji, Qiu,WV,Yuan; Koike,WV,Yuan
Zhou,Yuan,Liang
Bacchetta,Boer,Diehl,Mulders

News

# A sign puzzle ?

Kang, Qiu, Yuan, WV
Gamberg, Kang
Boer
Kang, Prokudin

- previous twist-3 calculations of pion $A_N$ had incorrect sign
- as a result, signs of extracted $T_F$ functions to be reversed
- use

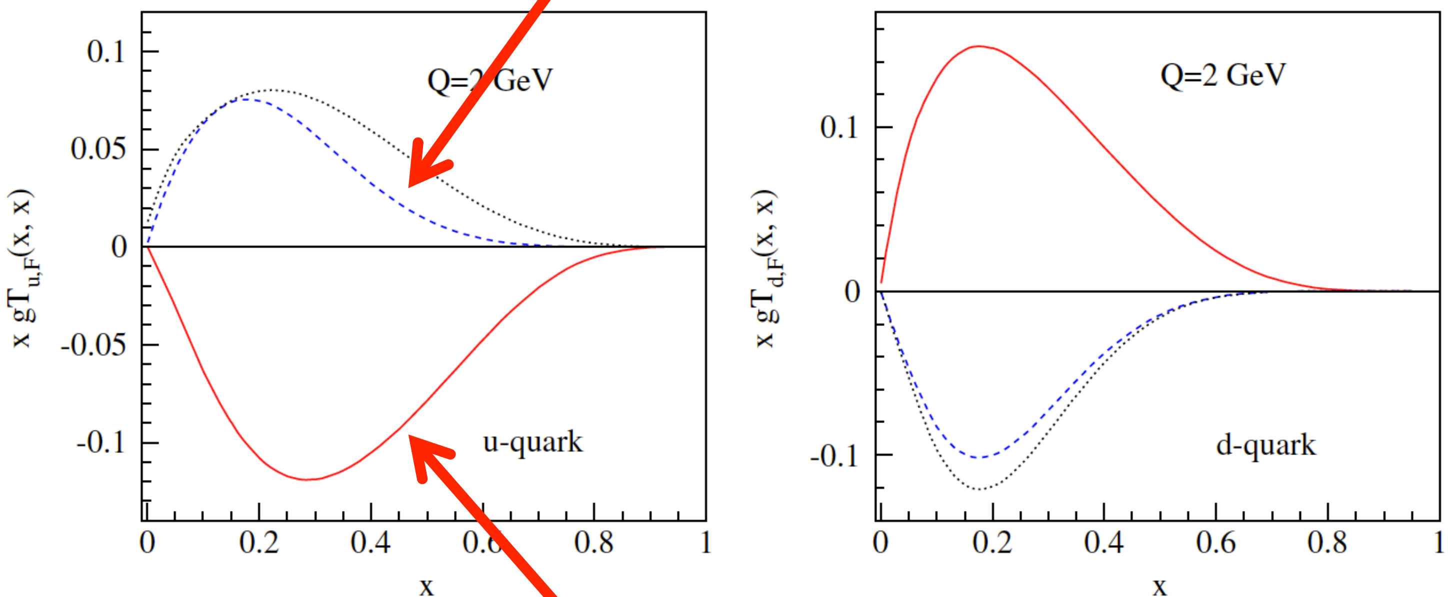
$$T_F(x,x) = -\int \frac{d^2\vec{k}_\perp}{2\pi} \frac{\vec{k}_\perp^2}{M^2} \left(f_{1T}^\perp(x,k_\perp)\right)_{\text{DIS}}$$

with Sivers functions extracted from SIDIS

Anselmino et al.

- and compare...

from $-\int \frac{d^2\vec{k}_\perp}{2\pi} \frac{\vec{k}_\perp^2}{M^2} \left(f_{1T}^{\perp}(x,k_\perp)\right)_{\rm DIS}$




Kang,Qiu,Yuan,WV

$T_F(x,x)$ from pp

- basic observation:

SIDIS $\pi^+$ : *final-state* interaction

$pp \to \pi^+ X$ : *initial-state* interaction dominates in $ug \to ug$

## A puzzle? What are the implications?

Possibly: inconsistency in QCD formalism for single-spin

More likely, one of the following:

- Collins-type effect dominates in $pp \to \pi X$

- Sivers fct. mostly constrained at $k_\perp \sim \Lambda_{QCD}$
  maybe "Gaussian" large- $k_\perp$ produces different sign?

$$- \int \frac{d^2\vec{k}_\perp}{2\pi} \frac{\vec{k}_\perp^2}{M^2} \left( f_{1T}^\perp(x, k_\perp) \right)_{\rm DIS}$$

Also: UV renormalization

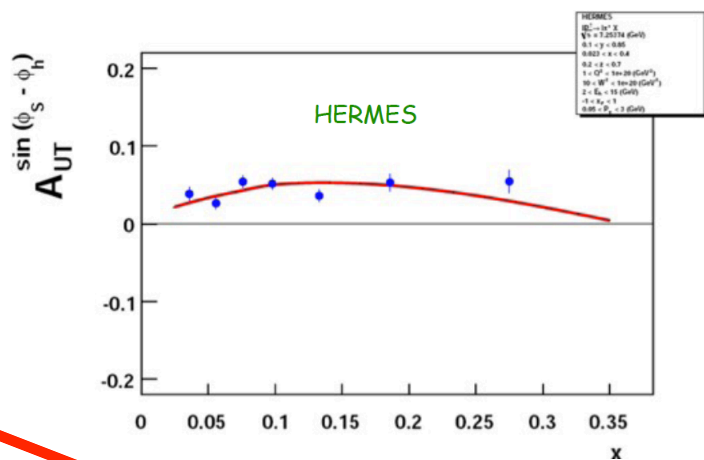
-> map out $k_\perp$ dependence in experiment!

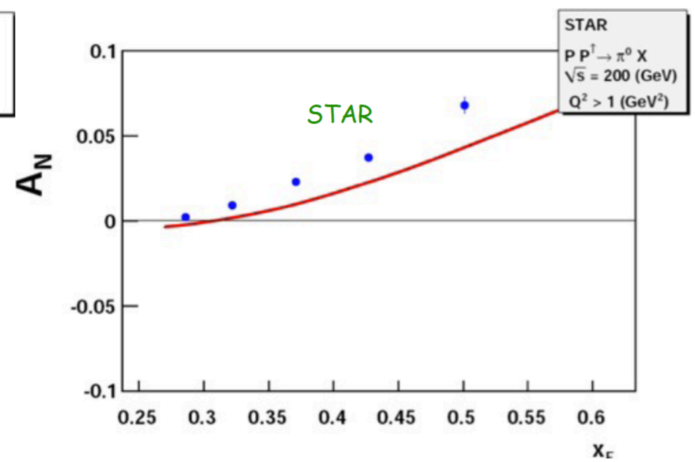
- Perhaps $T_F(x,x)$ has node in x?

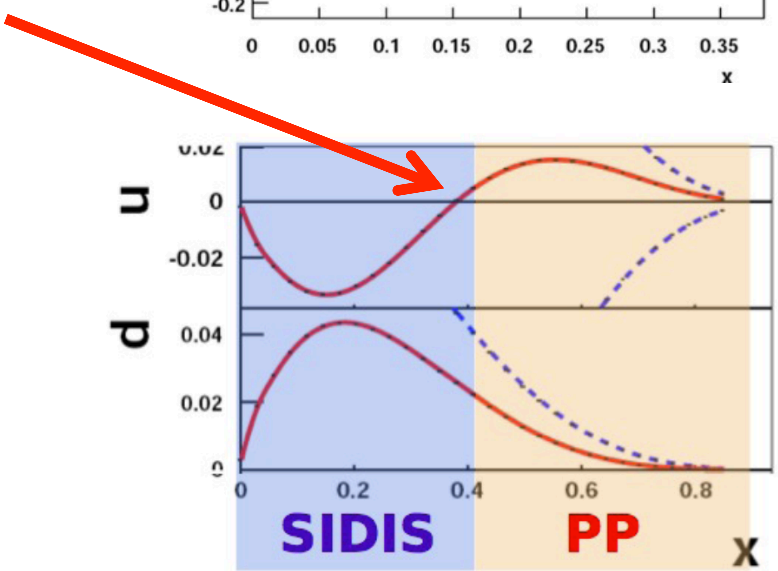
Boer
Kang, Prokudin

joint fit to SIDIS and pp data:

Kang, shown at RHIC Users meeting 2011



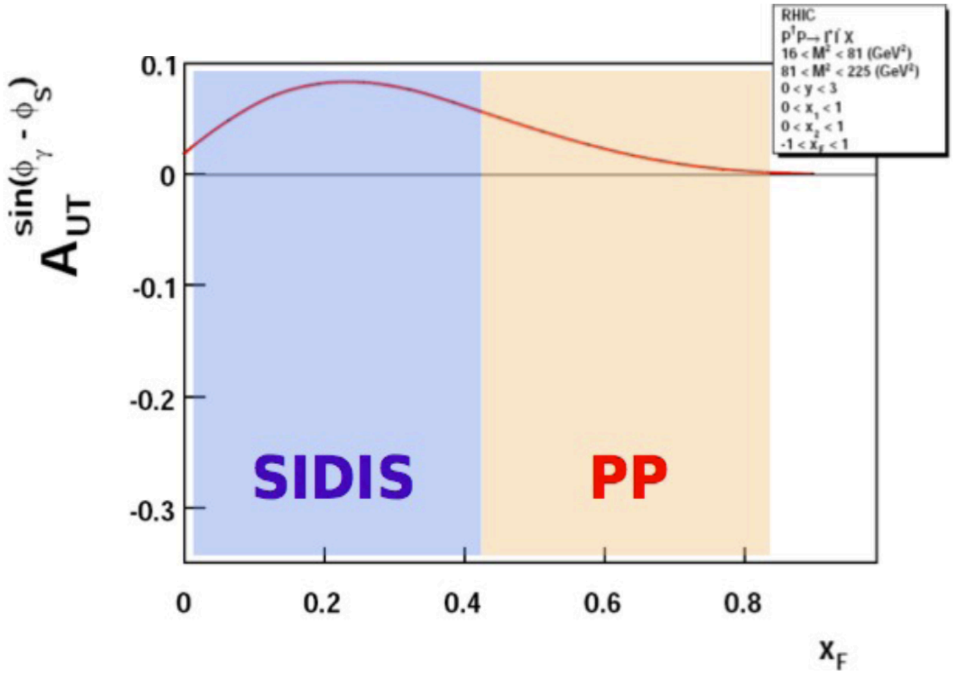



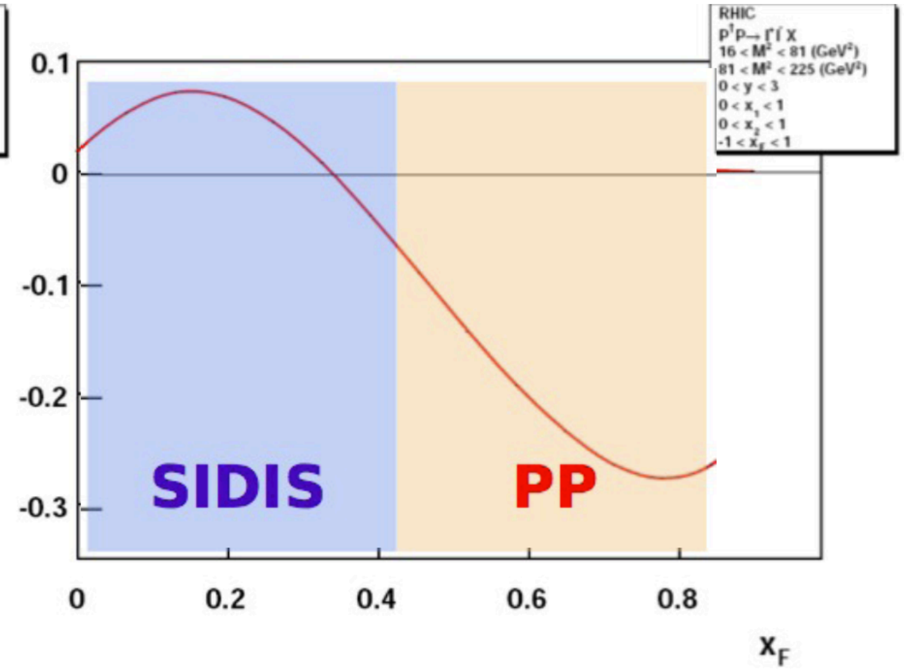

(conflict with BRAHMS data?)

# Has ramifications for DY spin asymmetry:

Kang, Prokudin




w/o node




with node

Strengthens case for study of DY "sign change" !

Twist-3 calculation is the only known consistent framework for describing $A_N$ for $pp \to \pi X$ in pQCD

- a "hybrid" TMD/Twist-3 model: Gamberg,Kang D'Alesio,Gamberg,Kang, Murgia,Pisano

  Use TMDs (Sivers) and factorization, but with proper IS and FS interactions included.
  Reproduces most of Twist-3 terms, but has more.

- how much to be learned from it ?

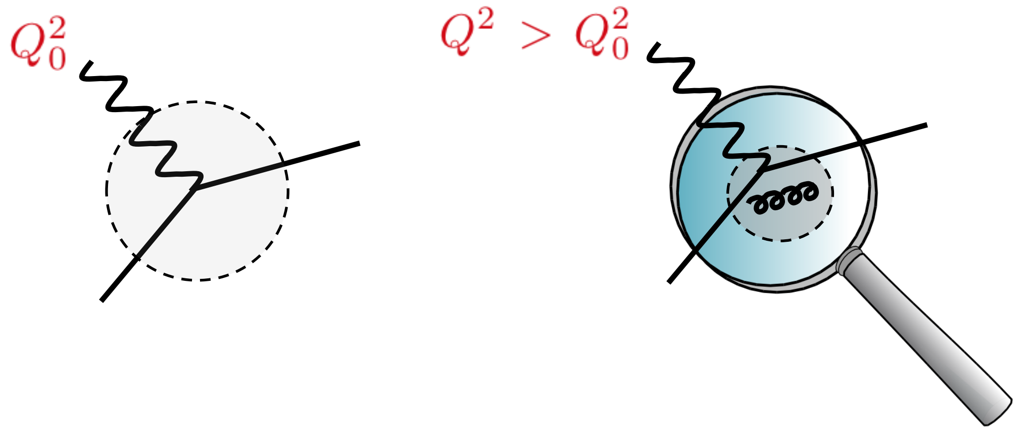
**News**

## QCD corrections to single-spin observables

Mert Aybat,Rogers
Kang,Xiao,Yuan
Kang,Qiu
Yuan,WV
Braun,Manashov,Pirnay
Zhou,Yuan,Liang
Kang

- takes this field to new level
- crucial for future physics at an EIC
- closely tied to definitions of TMDs and twist-3 fcts., evolution, factorization, universality

- Like ordinary pdfs, twist-3 correlation functions are scale dependent: $T_F(x, x, Q^2)$




$$\left(\alpha_s \log \frac{Q}{Q_0}\right)^k$$

- DGLAP type evolution:

Kang,Qiu
Yuan,WV
Braun,Manashov,Pirnay

$$\frac{\partial T_F(x,x,\mu_F)}{\partial \ln \mu_F^2} = \frac{\alpha_s}{2\pi}\int_x^1 \frac{d\xi}{\xi}\left\{P_{qq}(z)\, T_F(\xi,\xi,\mu_F)\right.$$

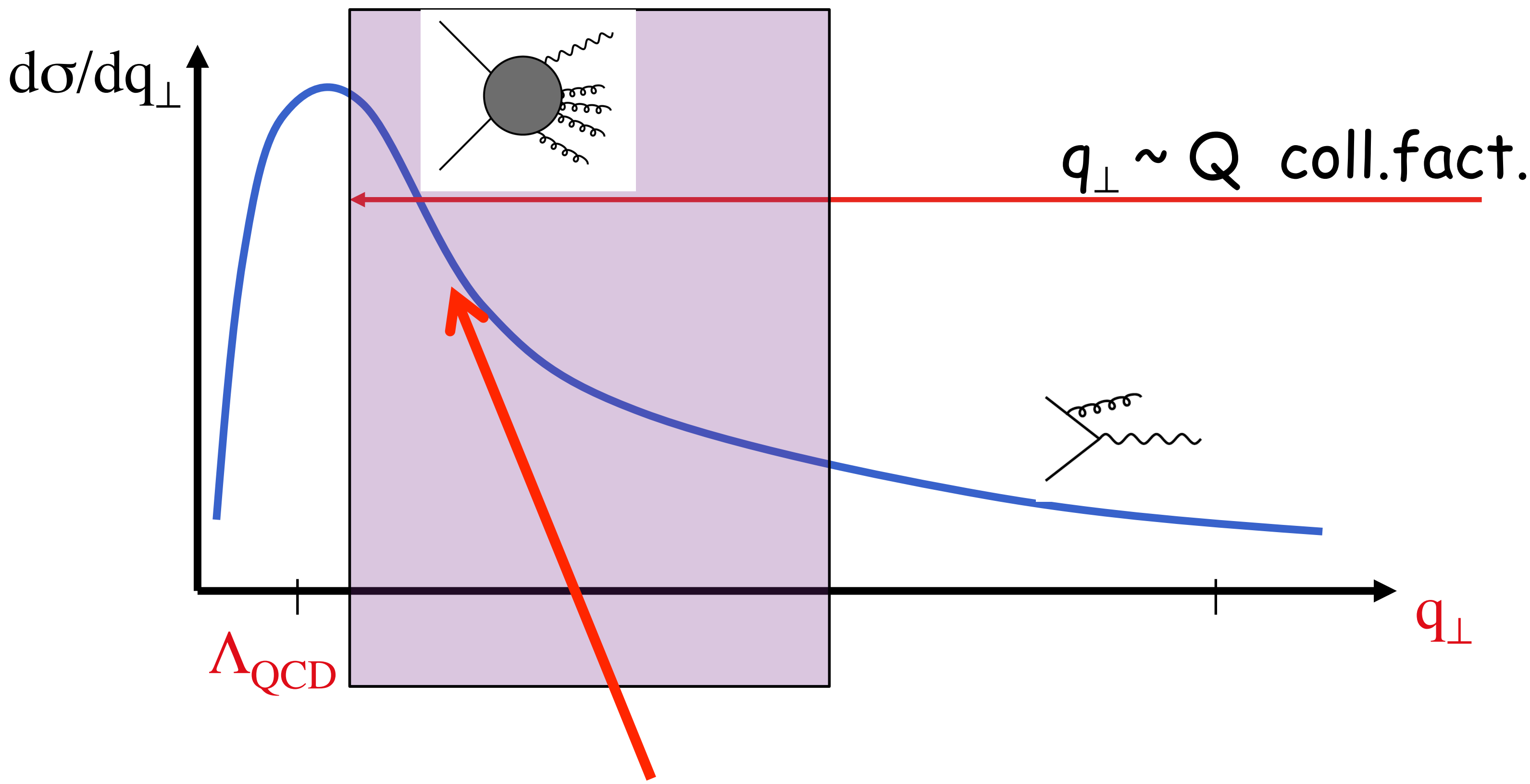
$$\left. + \frac{C_A}{2}\left[\frac{1+z^2}{1-z}\left[T_{q,F}(\xi,x,\mu_F) - T_{q,F}(\xi,\xi,\mu_F)\right] + z\, T_{q,F}(\xi,x,\mu_F)\right] + \ldots\right\}$$

- N.B.: various calculations not in complete agreement

- Full NLO of Drell-Yan single-spin asymmetry — Yuan,WV

  (would be great to have for $pp \to \pi X$ ...)

- Evolution for TMDs ?




well-known feature: emergence of Sudakov logarithms

$$\alpha_s^k \, \frac{\log^{2k-1}\left(\frac{Q^2}{q_\perp^2}\right)}{q_\perp^2}$$

- can be resummed to all orders in strong coupling

(e.g. Drell-Yan, simplified) Collins,Soper,Sterman;...

$$\frac{d\sigma}{d^2q_\perp} \sim \sigma_0 \int d^2b\, \mathrm{e}^{-i\vec{b}\cdot\vec{q}_\perp}\, q(x_1,1/b) \otimes \bar{q}(x_2,1/b)\, \mathrm{e}^{\underbrace{-\frac{C_F}{\pi}\int_{1/b^2}^{Q^2}\frac{dk_\perp^2}{k_\perp^2}\left(\alpha_s(k_\perp^2)\log\frac{Q^2}{k_\perp^2}+\ldots\right)}_{\text{Sudakov exponent}}}$$

- idea: re-organize in terms of simple TMD-like formula

$$\frac{d\sigma}{dq_\perp^2} \sim \sigma_0 \int d^2k_{\perp,1} \int d^2k_{\perp,2}\, F(x_1,k_{\perp,1},Q)\, \bar{F}(x_2,k_{\perp,2},Q)\, \delta^{(2)}(\vec{k}_{\perp,1}+\vec{k}_{\perp,2}-\vec{q}_\perp)$$

Mert Aybat,Rogers

- this gives the evolution of TMDs

- requires a number of developments, such as

  convenient definition of TMDS

  treatment of light-cone divergences

Collins (Cherednikov, Stefanis)

- final result:

$$\tilde{F}_{f/P}(x, \mathbf{b}_T; \mu, \zeta_F) = \overbrace{\sum_j \int_x^1 \frac{d\hat{x}}{\hat{x}} \tilde{C}_{f/j}(x/\hat{x}, b_*; \mu_b^2, \mu_b, g(\mu_b)) f_{j/P}(\hat{x}, \mu_b)}^{A \text{ collinear piece}}$$
$$\times \overbrace{\exp\left\{\ln\frac{\sqrt{\zeta_F}}{\mu_b}\tilde{K}(b_*; \mu_b) + \int_{\mu_b}^{\mu}\frac{d\mu'}{\mu'}\left[\gamma_F(g(\mu'); 1) - \ln\frac{\sqrt{\zeta_F}}{\mu'}\gamma_K(g(\mu'))\right]\right\}}^{B \text{ ~ Sudakov}}$$
$$\times \overbrace{\exp\left\{g_{j/P}(x, b_T) + g_K(b_T)\ln\frac{\sqrt{\zeta_F}}{\sqrt{\zeta_{F,0}}}\right\}}^{C \text{ non-perturbative piece}},$$

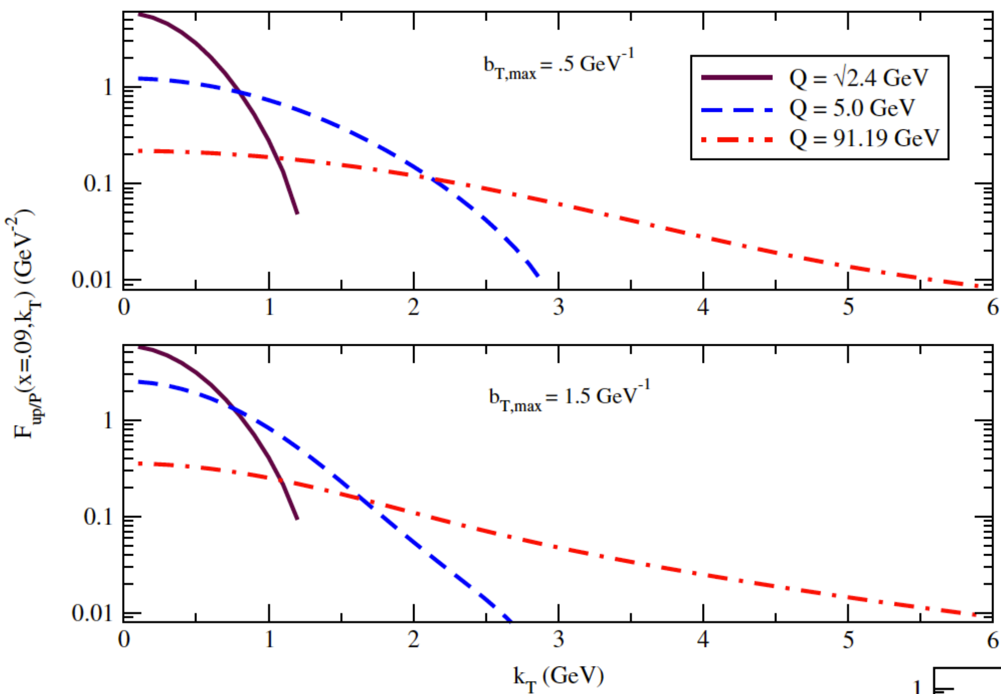
Mert Aybat,Rogers

- Note, separation of non-perturbative piece into “intrinsic” and “extrinsic” not so clear. Depends on large-b prescription.
- Appealing! (at the end of the day can use original CSS)

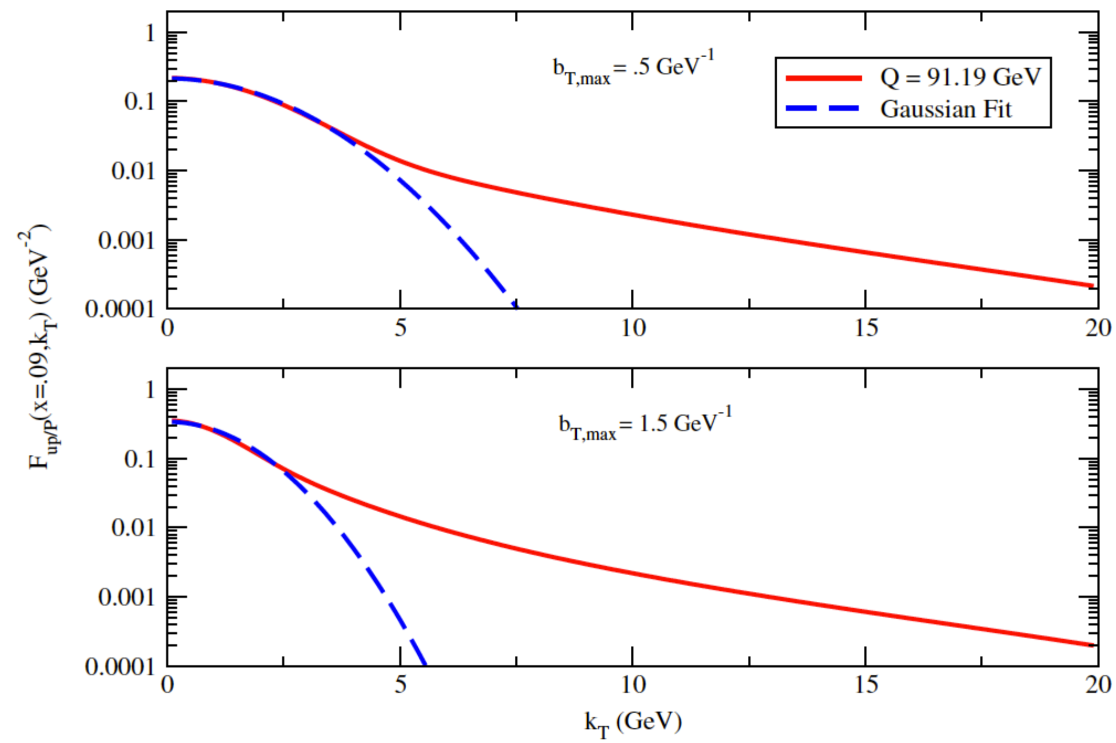
Koike, Nagashima,WV

Mert Aybat,Rogers

evolution of unpolarized TMDs




comparison to Gaussian:



The latest:

- TMD resummation for single-spin asymmetries

Kang,Xiao,Yuan

- uses CSS formalism, starting from explicit NLO calc.
- same Sudakov exponent as for spin-averaged case
- result involves $T_F(x,x)$
- important applications at EIC

News

# Study of gluon distributions

Boer,Brodsky,Mulders,Pisano
Metz,Zhou
Qiu,Schlegel,WV
Beppu,Koike,Tanaka,Yoshida

- again, a topic also for the EIC
- have wider relevance: small-x, Higgs

- gluons & spin: focus is presently on helicity $\Delta g(x)$

- for inclusive single-spin asym.: triple-gluon correlations

- complete classification:

Beppu,Koike,Tanaka,Yoshida

$$O^{\alpha\beta\gamma}(x_1,x_2) = -g(i)^3 \int \frac{d\lambda}{2\pi} \int \frac{d\mu}{2\pi} e^{i\lambda x_1} e^{i\mu(x_2-x_1)} \langle pS| d_{bca} F_b^{\beta n}(0) F_c^{\gamma n}(\mu n) F_a^{\alpha n}(\lambda n)|pS\rangle$$

$$N^{\alpha\beta\gamma}(x_1,x_2) = -g(i)^3 \int \frac{d\lambda}{2\pi} \int \frac{d\mu}{2\pi} e^{i\lambda x_1} e^{i\mu(x_2-x_1)} \langle pS| i f_{bca} F_b^{\beta n}(0) F_c^{\gamma n}(\mu n) F_a^{\alpha n}(\lambda n)|pS\rangle$$

- for example, photon production in pp:

$$
\begin{aligned}
E_\gamma \frac{d\sigma}{d^3q} &= \frac{4\alpha_{em}\alpha_s M_N \pi}{S} \sum_a \int \frac{dx'}{x'} f_a(x') \int \frac{dx}{x} \delta(\hat{s}+\hat{t}+\hat{u}) \varepsilon^{qpnS_\perp} \frac{1}{\hat{u}} \\
&\times \left[ \delta_a \left( \frac{d}{dx} O(x,x) - \frac{2O(x,x)}{x} + \frac{d}{dx} O(x,0) - \frac{2O(x,0)}{x} \right) \right. \\
&\left. - \frac{d}{dx} N(x,x) + \frac{2N(x,x)}{x} + \frac{d}{dx} N(x,0) - \frac{2N(x,0)}{x} \right] \left( \frac{1}{N} \frac{\hat{s}^2+\hat{u}^2}{\hat{s}\hat{u}} \right)
\end{aligned}
$$

- contribution to $pp \to \pi X$ would be very interesting !

- gluon TMDs originally studied in   Mulders,Rodrigues '01
- correlator

$$\Gamma_{\mu\nu;\lambda\eta}(x,\vec{k}_T) = \int \frac{dz^-\, d^2z_T}{(2\pi)^3 x P^+}\, \mathrm{e}^{ik\cdot z}\, \langle P,S|\, F^{\alpha}_{\mu\nu}(0)\, \mathcal{W}^{\alpha\beta}[0\,;\,z]\, F^{\beta}_{\lambda\eta}(z)\, |P,S\rangle \Big|_{z^+=0}$$

- leading terms

"Boer Mulders"

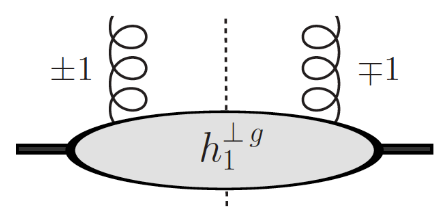
$$\Gamma_U^{+i;+j}(x,\vec{k}_T) = \frac{\delta^{ij}}{2}\, f_1^g + \frac{k_T^i k_T^j - \frac{1}{2}\vec{k}_T^2\delta^{ij}}{2M^2}\, h_1^{\perp g}$$

Sivers

$$\Gamma_T^{+i;+j}(x,\vec{k}_T) = -\frac{\delta^{ij}}{2}\, \frac{\epsilon_T^{rs} k_T^r S_T^s}{M}\, f_{1T}^{\perp g} + \frac{i\epsilon_T^{ij}}{2}\, \frac{\vec{k}_T\cdot\vec{S}_T}{M}\, g_{1T}^{\perp g}$$

$$+ \frac{S_T^{\{i}\epsilon_T^{j\}r}k_T^r + k_T^{\{i}\epsilon_T^{j\}r}S_T^r}{8M}\, h_{1T}^g + \frac{k_T^{\{i}\epsilon_T^{j\}r}k_T^r}{4M^2}\, \frac{\vec{k}\cdot\vec{S}_T}{M}\, h_{1T}^{\perp g}$$

- $h_1^{\perp g}$: gluons with *linear* polarization in unpolarized hadron   (T-even, ΔL=2)



Possibilities for measurement of $h_1^{\perp g}$ :

- heavy-flavor leptoproduction $ep \to eQ\bar{Q}X$

  factorization should hold -> EIC

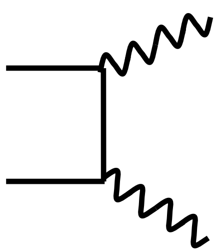
  Boer,Brodsky, Mulders,Pisano

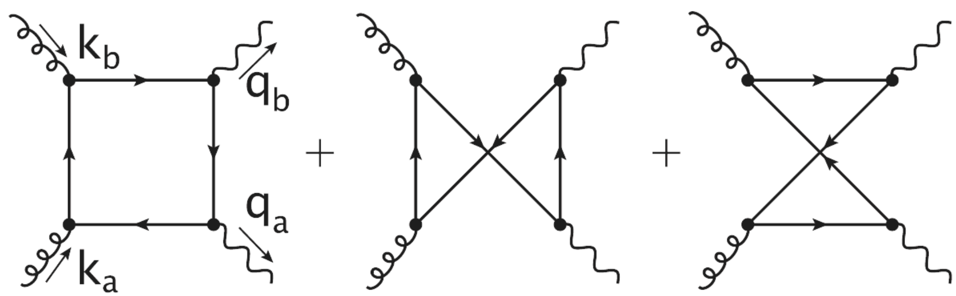
- heavy-flavor hadroproduction $pp \to Q\bar{Q}X$

  factorization breaking expected from IS, FS interactions

- double-photon production $pp \to \gamma\gamma X$

  Qiu,Schlegel,WV

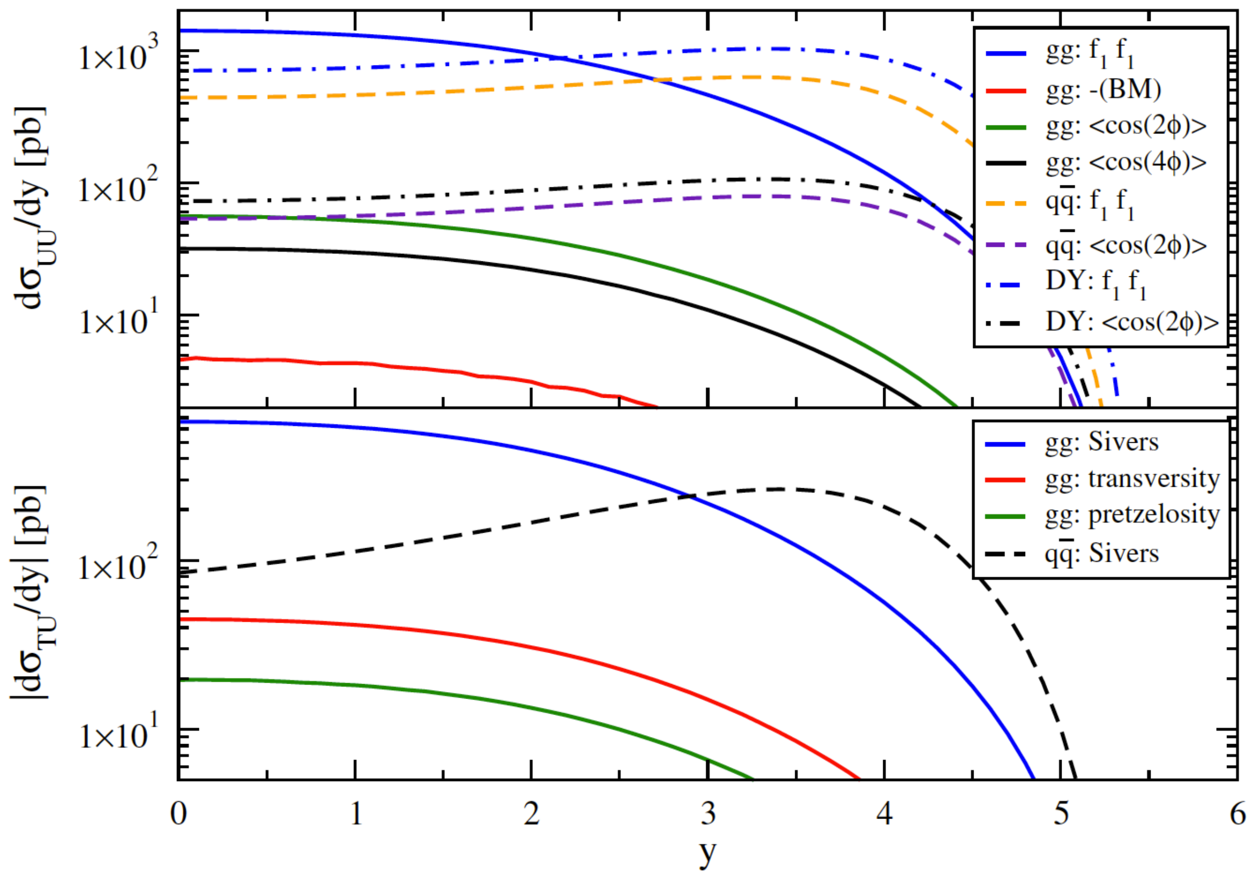





"Drell-Yan like" gauge links -> factorizes (?)

# RHIC $\sqrt{s} = 500\,\mathrm{GeV}$

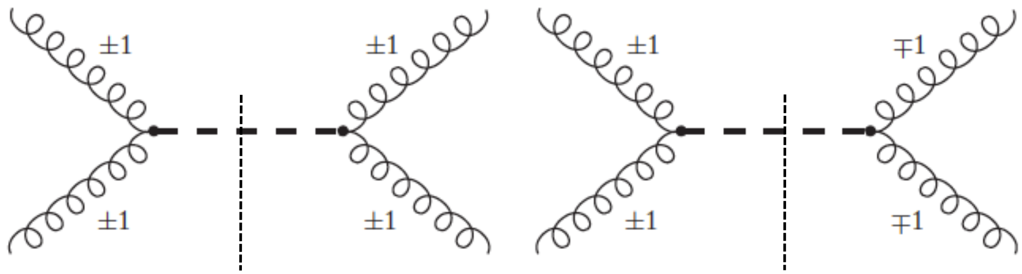
(assuming Gaussians with saturated positivity bounds)




Qiu,Schlegel,WV

- $h_1^{\perp g}$ may contibute to Higgs production !

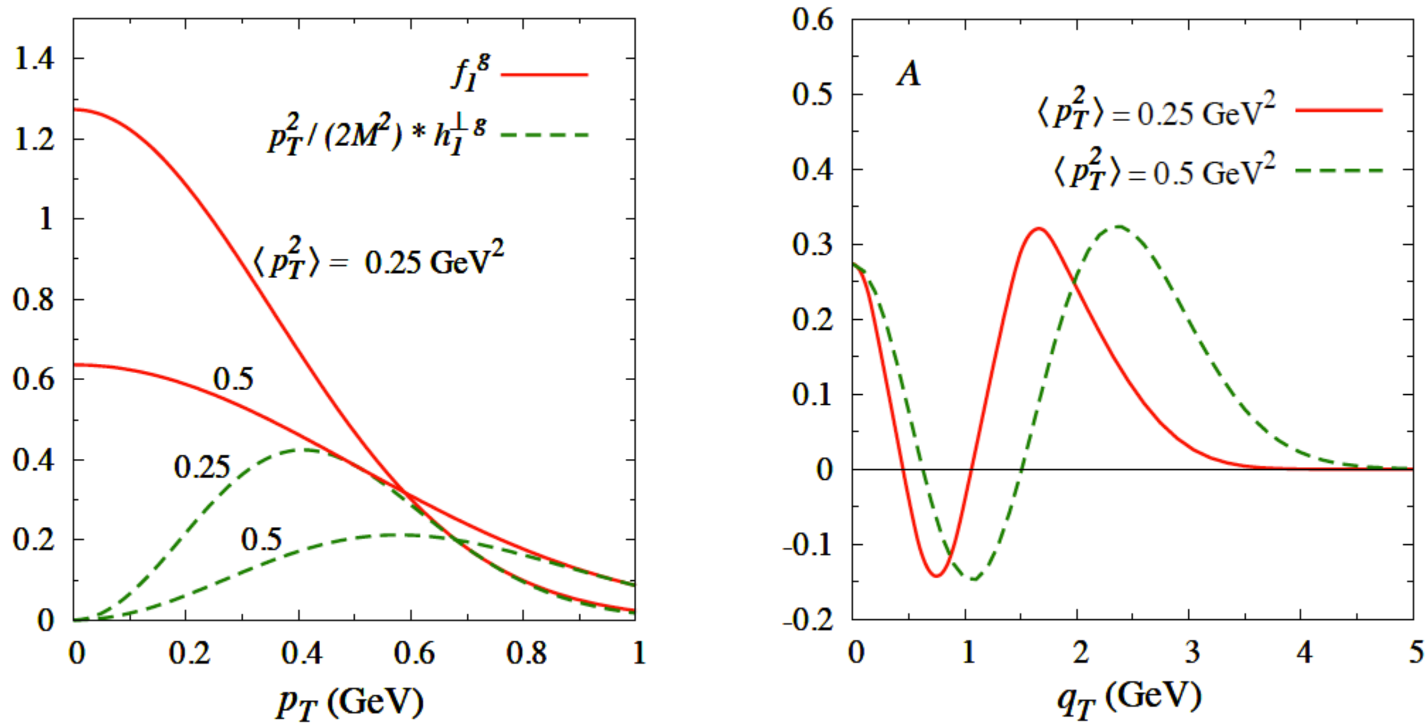
Boer,den Dunnen, Pisano,Schlegel,WV (in prep.)




distinguishes parity of Higgs:

Higgs = scalar: $\sigma \propto \mathcal{C}\left[f_1^g\, f_1^g\right] + \mathcal{C}\left[w_H\, h_1^{\perp g}\, h_1^{\perp g}\right]$

Higgs = pseudoscalar: $\sigma \propto \mathcal{C}\left[f_1^g\, f_1^g\right] - \mathcal{C}\left[w_H\, h_1^{\perp g}\, h_1^{\perp g}\right]$




$$A = \frac{\mathcal{C}[w_H\, h_1^{\perp g}\, h_1^{\perp g}]}{\mathcal{C}[f_1^g\, f_1^g]}$$

- could make significant non-perturbative contribution to perturbative resummation

Sun,Xiao,Yuan (in prep.)
Also: Catani,Grazzini
Nadolsky,Balazs,Berger,Yuan

- relevance reduced when decay & background taken into acc.

# Other things I am looking forward to at Transversity 2011

News

- spin sum rule / orbital angular momentum: a long-standing debate

$$J_{QCD} = \boldsymbol{S}^q + \boldsymbol{L}^q + \boldsymbol{S}^g + \boldsymbol{L}^g$$

$$\boldsymbol{S}^q = \int \psi^\dagger \frac{1}{2} \boldsymbol{\Sigma} \psi \, d^3x,$$

$$\boldsymbol{L}^q = \int \psi \, \boldsymbol{x} \times (\boldsymbol{p} - g \, \boldsymbol{A}) \, \psi \, d^3x,$$

$$\boldsymbol{S}^g = \int \boldsymbol{E}^a \times \boldsymbol{A}^a_{phys} \, d^3x,$$

$$\boldsymbol{L}^g = \int E^{aj} \, (\boldsymbol{x} \times \nabla) \, A^{aj}_{phys} \, d^3x + g \int \psi^\dagger \, \boldsymbol{x} \times \boldsymbol{A}_{phys} \psi \, d^3x$$

$$A^\mu_{phys}(x) \rightarrow U(x) \, A^\mu_{phys}(x) \, U^{-1}(x),$$

$$A^\mu_{pure}(x) \rightarrow U(x) \left( A^\mu_{pure}(x) - \frac{i}{g} \, \partial^\mu \right) U^{-1}(x)$$

Recently:
**Wakamatsu**
Chen et al.
Leader

There are many observables that are sensitive to OAM.
Question is connection to spin sum rule

News

Sivers <-> OAM in a quantitative way ?

Bacchetta,Radici

- combines:
  - Ji's expression for $J_q$ in terms of GPDs
  - connection between moment of $f_{1T}^{\perp}$ and GPD $\mathcal{E}$ (Burkardt's lensing idea)
  - joint fit of SIDIS Sivers asymmetries and magnetic moments

- OAM from Wigner distributions ?

Lorce,Pasquini

$$\rho^{[\Gamma]}(\vec{b}_\perp, \vec{k}_\perp, x, \vec{S}) \equiv \int \frac{d^2\Delta_\perp}{(2\pi)^2} \left\langle p^+, \frac{\vec{\Delta}_\perp}{2}, \vec{S} \right| \hat{W}^{[\Gamma]}(\vec{b}_\perp, \vec{k}_\perp, x) \left| p^+, -\frac{\vec{\Delta}_\perp}{2}, \vec{S} \right\rangle$$

$$\ell_z^q = \int dx d^2k_\perp d^2b_\perp (\vec{b}_\perp \times \vec{k}_\perp)_z \rho^{[\gamma^+]q}(\vec{b}_\perp, \vec{k}_\perp, x, \vec{e}_z)$$

- the latest on transversity (dihadron fragmentation)

Bacchetta,Courtoy,Radici

- experimental data

- and a lot more !

Enjoy

Transversity 2011 !