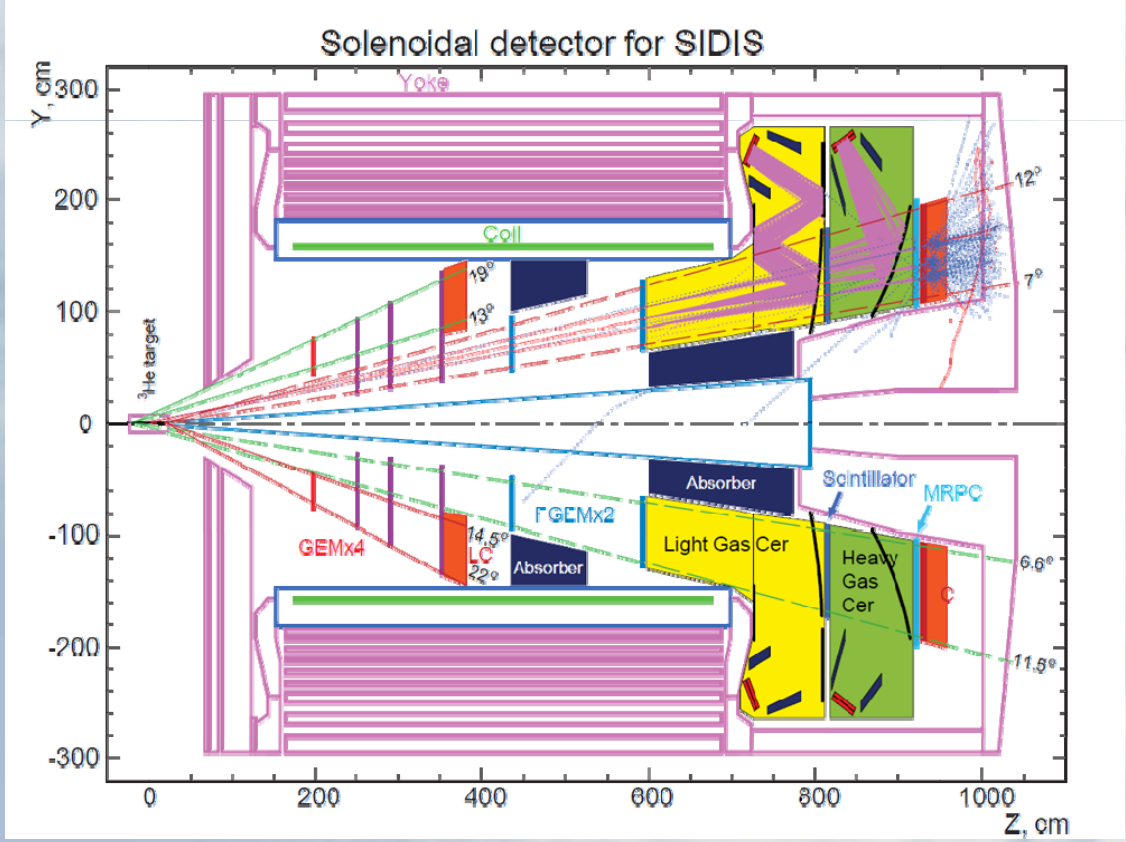
Physics Opportunities with SSA at SoLID with Transverse Polarized ^{3}He



Xin Qian

KRL

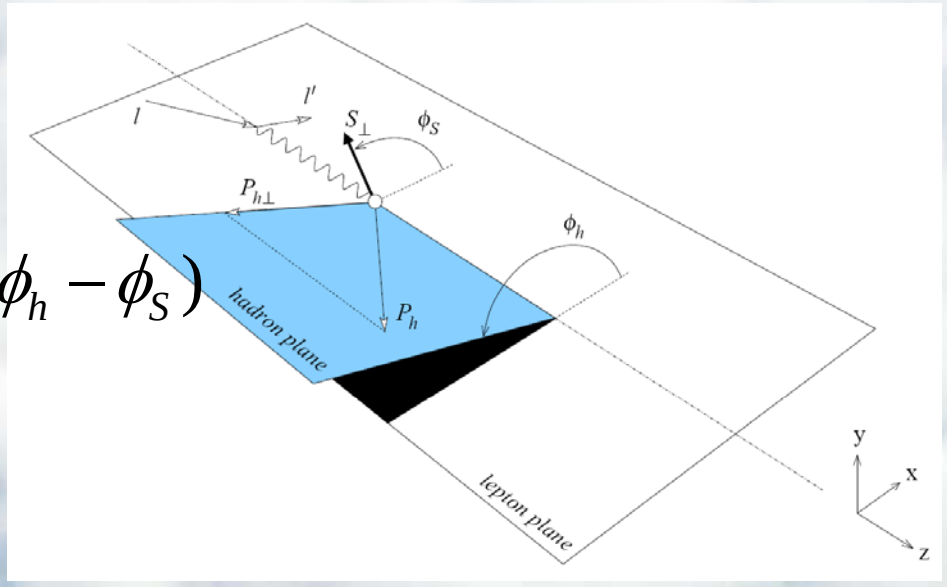
Caltech

Measure Collins, Sivers and Pretzlosity Asymmetries on Neutron for pions

$$A_{UT}(\varphi_h^l, \varphi_S^l) = \frac{1}{P}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}$$

$$= A_{UT}^{Collins} \sin(\phi_h + \phi_S) + A_{UT}^{Sivers} \sin(\phi_h - \phi_S)$$

$$+ A_{UT}^{Pretzelosity} \sin(3\phi_h - \phi_S)$$



UT: **U**npolarized lepton + **T**ransversely polarized nucleon

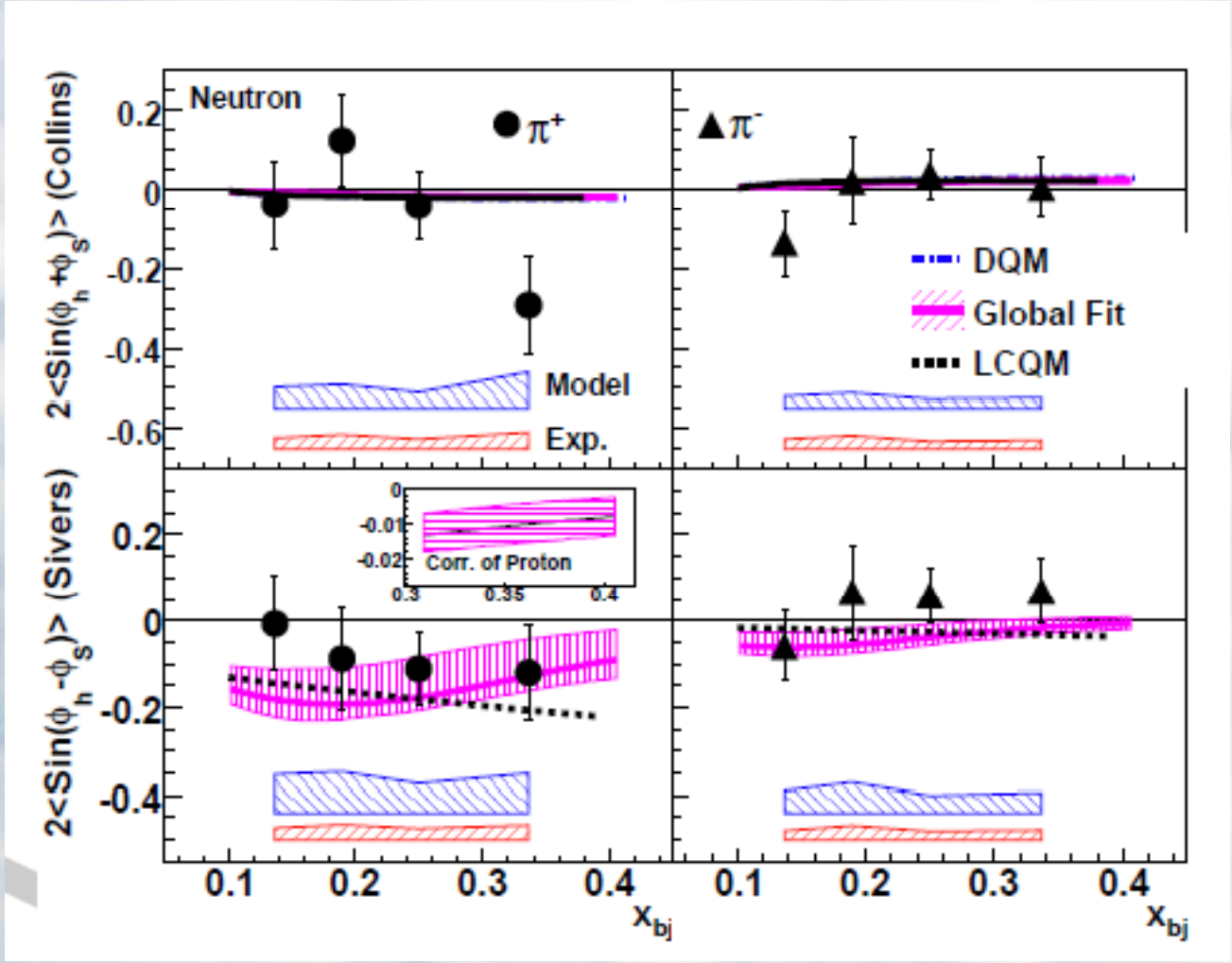
$$A_{UT}^{Collins} \propto \langle \sin(\phi_h + \phi_S) \rangle_{UT} \propto h_1 \otimes H_1^{\perp}$$ Transversity

$$A_{UT}^{Sivers} \propto \langle \sin(\phi_h - \phi_S) \rangle_{UT} \propto f_{1T}^{\perp} \otimes D_1$$

$$A_{UT}^{Pretzelosity} \propto \langle \sin(3\phi_h - \phi_S) \rangle_{UT} \propto h_{1T}^{\perp} \otimes H_1^{\perp}$$

Results of 6 GeV Experiment

- Large Collins asymmetry at large x for π^+?
- Negative Sivers asymmetries for π^+
- Significant contribution from model due to limited angular coverage.

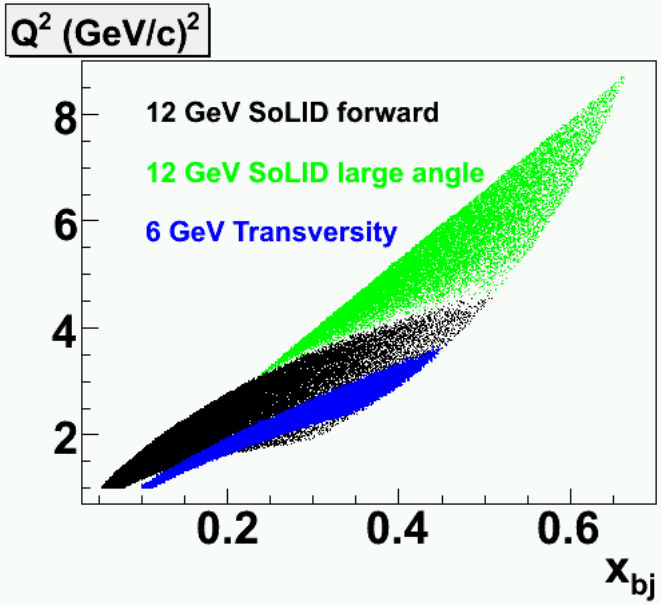


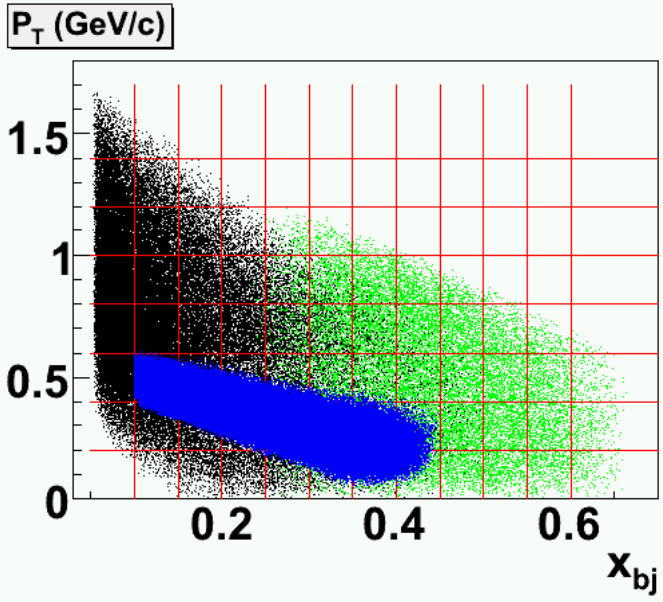
Huge improvement in azimuthal angular coverage with SoLID.
Large stat. enable multi-term fitting with SoLID.

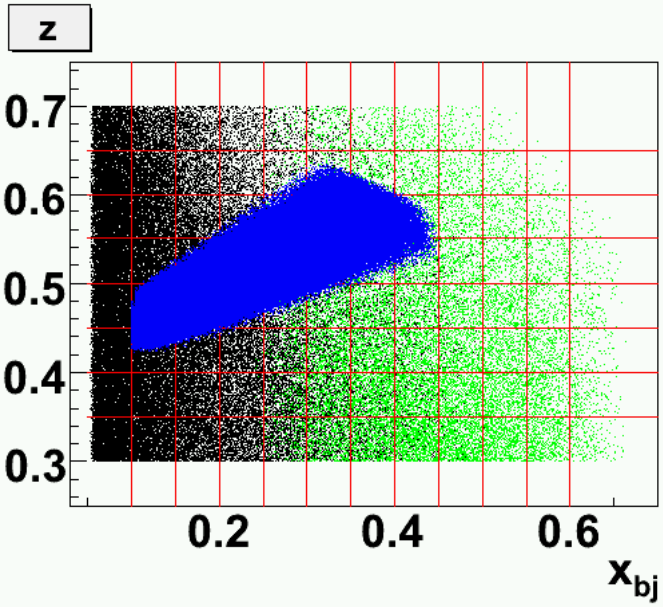
Phase Space (much large z coverage)

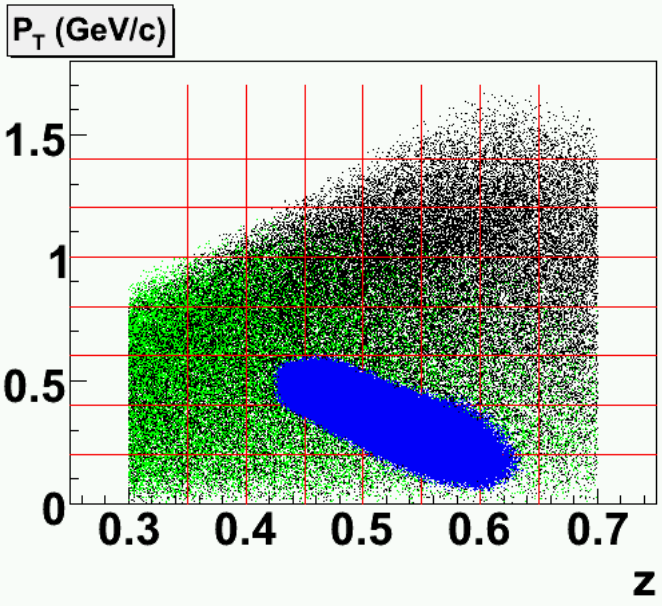
Low z: for target fragmentation analysis

High z: for exclusive channel, nuclear effect

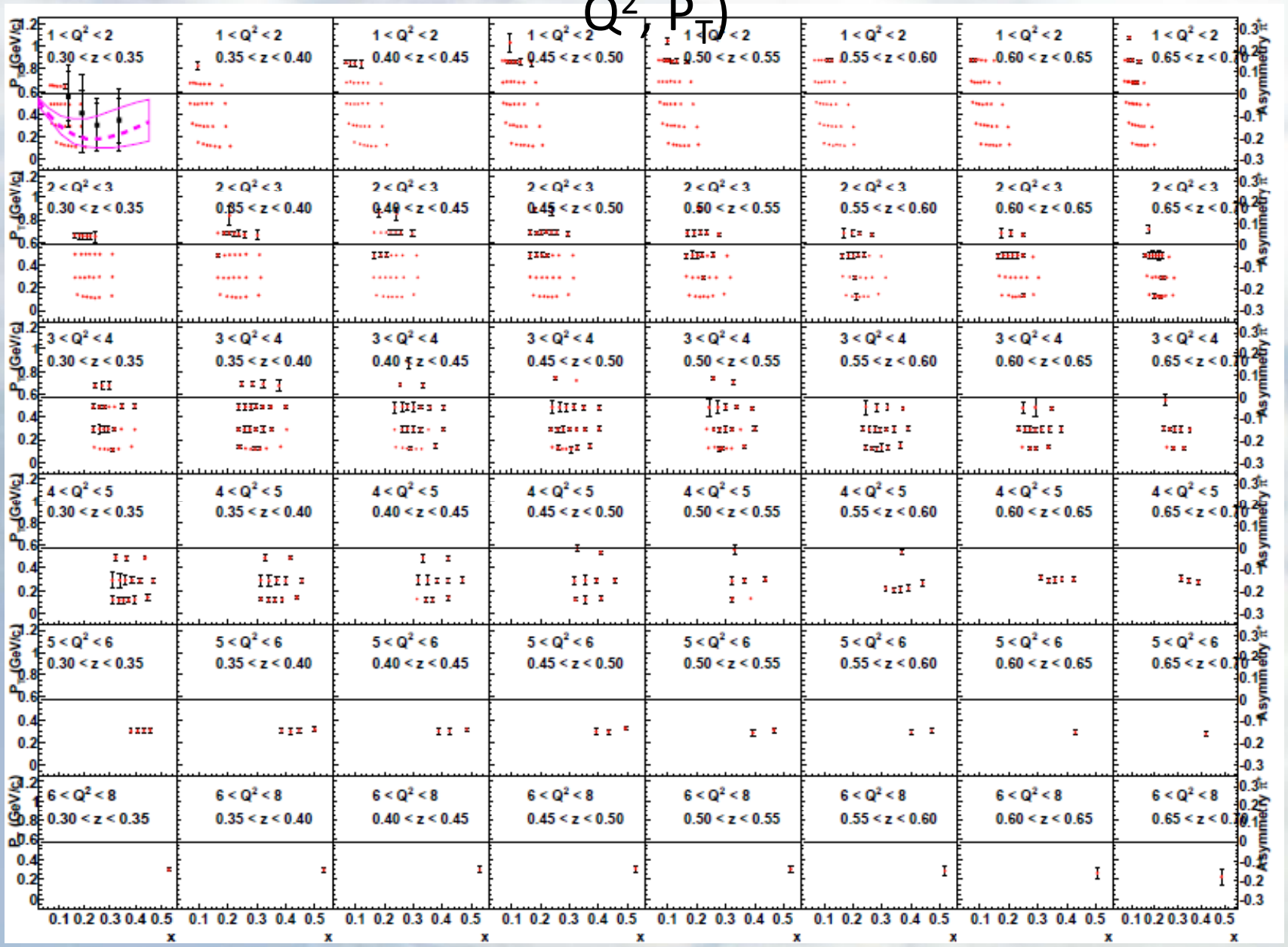




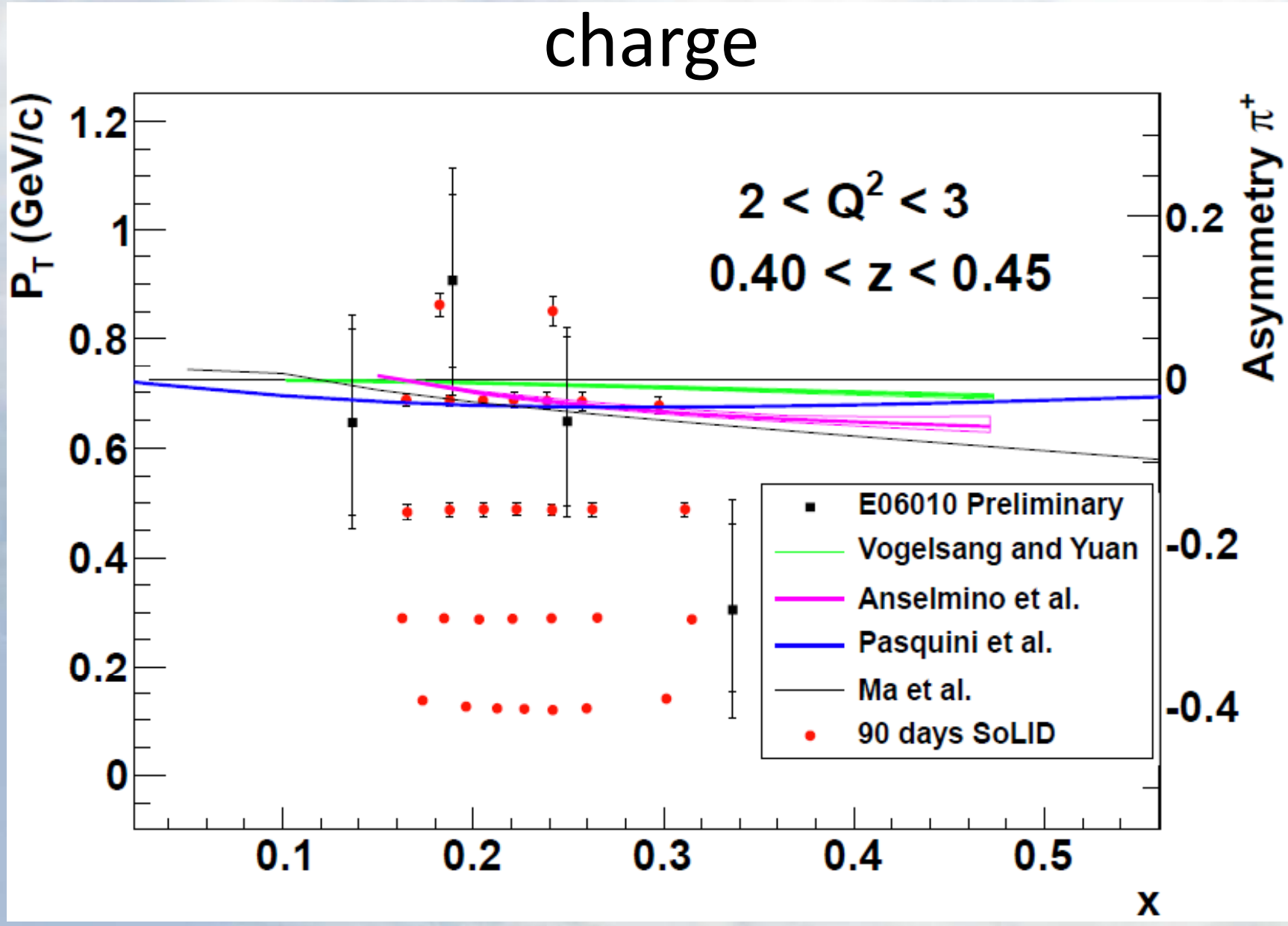




Map Collins, Sivers and Pretzlosity asymmetries in a 4-D (x, z, Q^2, P_T)



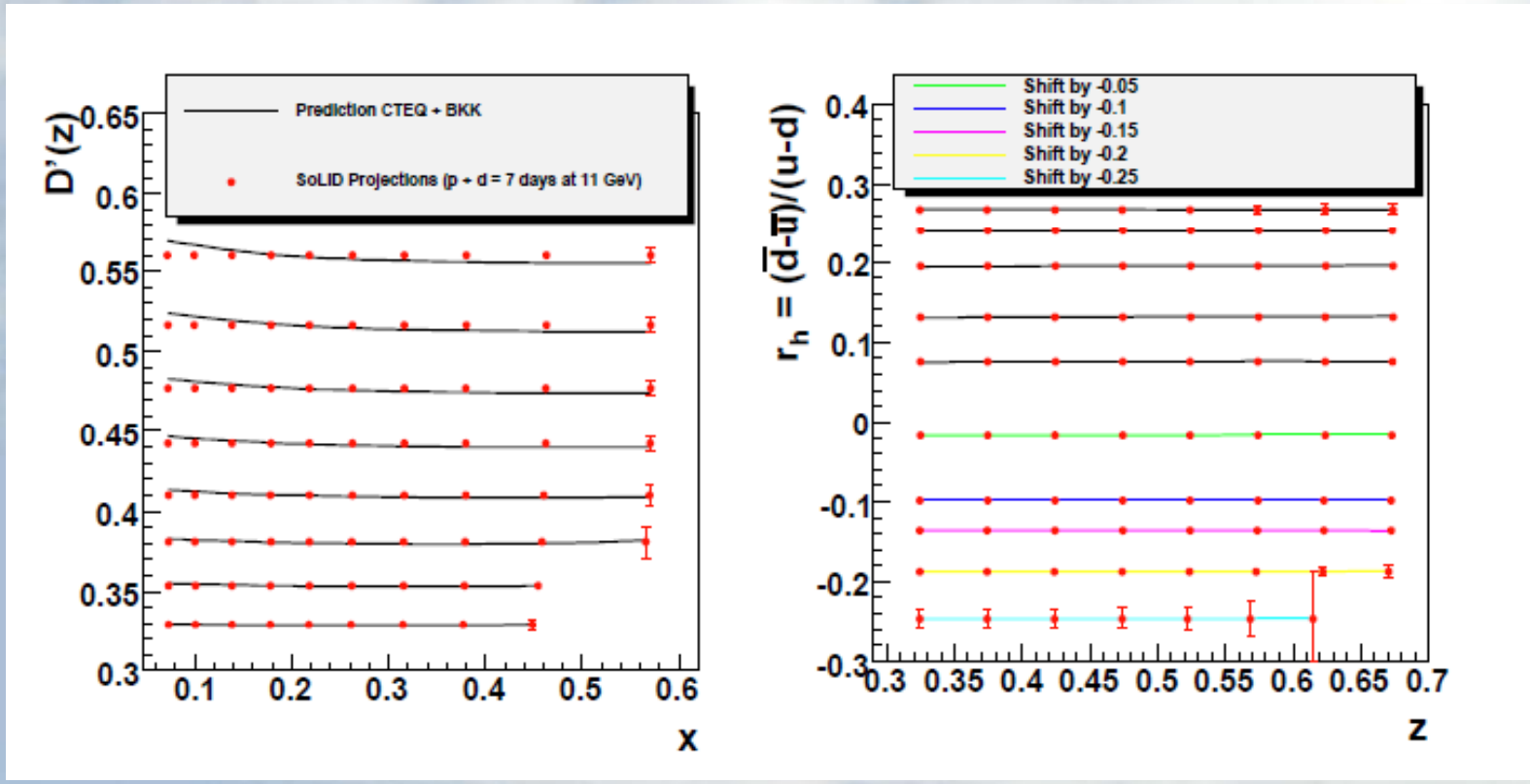
10% Measurement on d quark tensor charge



What else?

– With proton/deuteron/^{3}He unpolarized data in a large phase space coverage.

- Understand SIDIS process itself (Factorization , P_T dependence)
- Understand the Nuclear effect in the light nuclei.

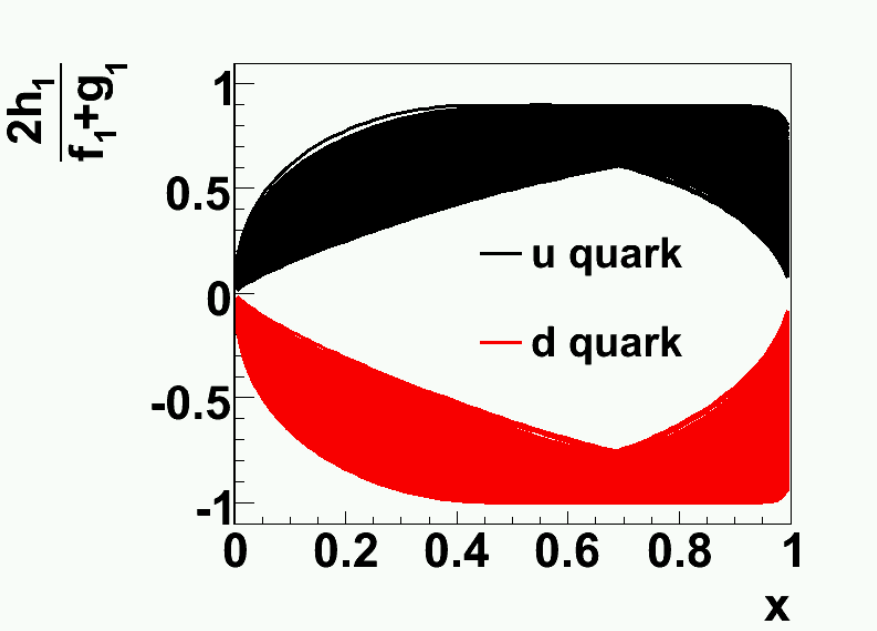


Transversity: Soffer Bound Violation?

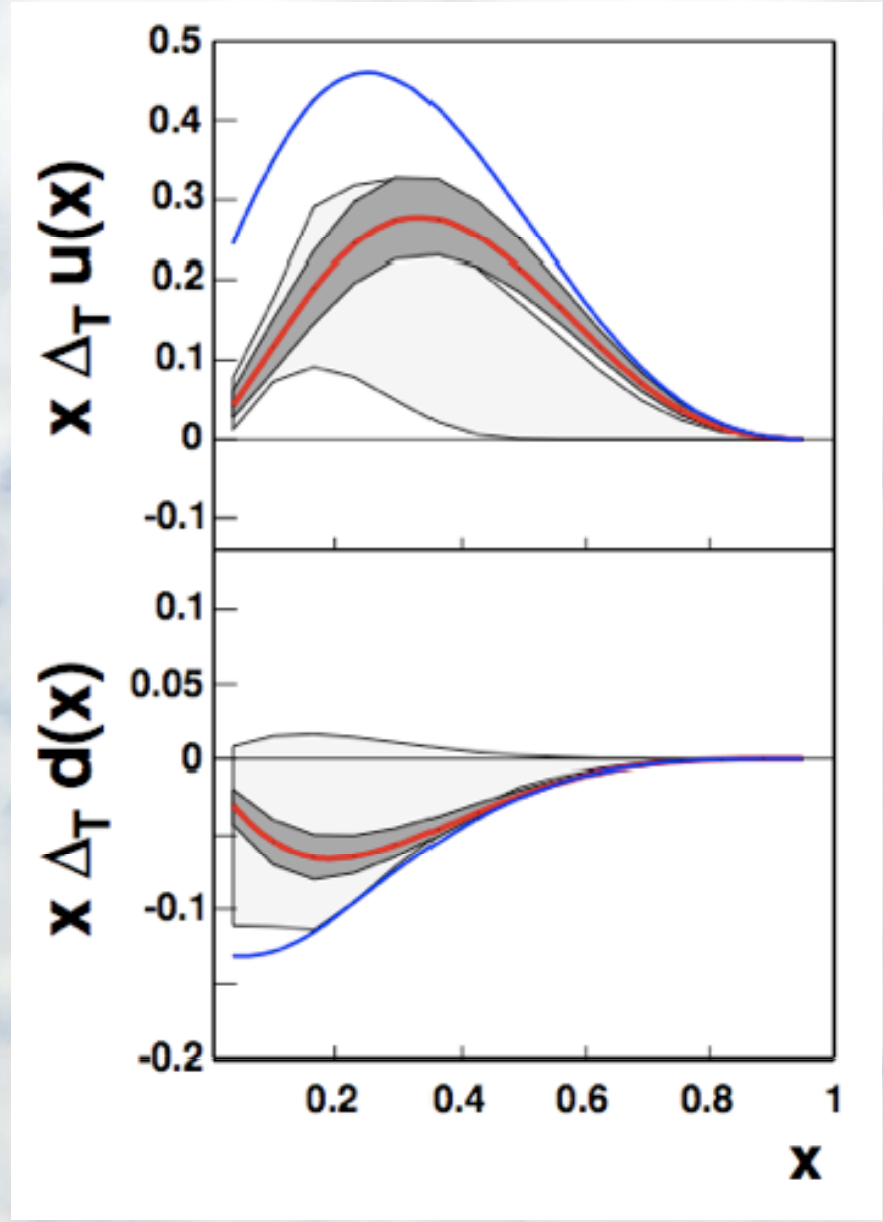
- Soffer bound: $|h_{1T}| <= (f_1+g_{1L})/2$
  - PRL 74, 1292 (1995).
- NLO QCD evolution will not break Soffer bound, if it is satisfied at one scale.
  - Phys.Rev. D57 (1998) 1886
- Doubts has been casted on this inequality
  - J. P. Alston: arxiv:0810.0871, also spin08 talk
    - "…Soffer bound on transversity is not a valid fact of QCD…"
    - Understand QCD confinement through study of spin effect.

Current Knowledge (Torino)

$$\frac{2h_1}{f_1+g_1} = Nx^{\alpha}(1-x)^{\beta}\frac{(\alpha+\beta)^{\alpha+\beta}}{\alpha^{\alpha}\beta^{\beta}}$$



Close to the bound, bound is required in the fit. As N_d = -1, current fitting favors a result violating the bound. (arxiv:0812.4366)



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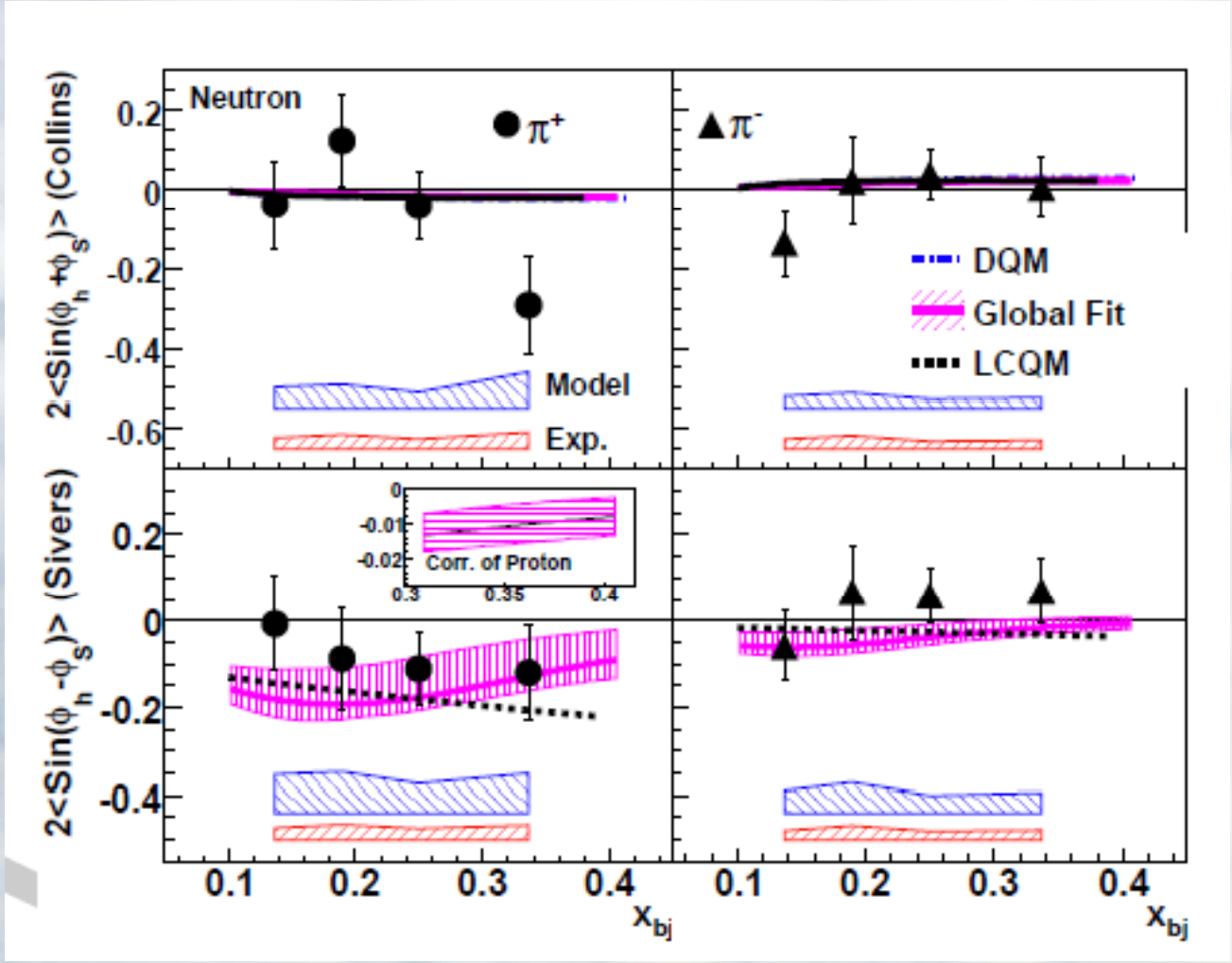


Huge improvement in azimuthal angular coverage with SoLID.
Large stat. enable multi-term fitting with SoLID.

Test Violation of Soffer Bound

- Precision measurement of Collins asymmetry at large x can provide an unique opportunity to test Soffer's bound.

- Transversity Distribution:
  - Possible sign change in x dependence?
  - Possible sign change in k_T dependence?
  - 10% measurement of d quark tensor charge.

Pretzlosity Asymmetry

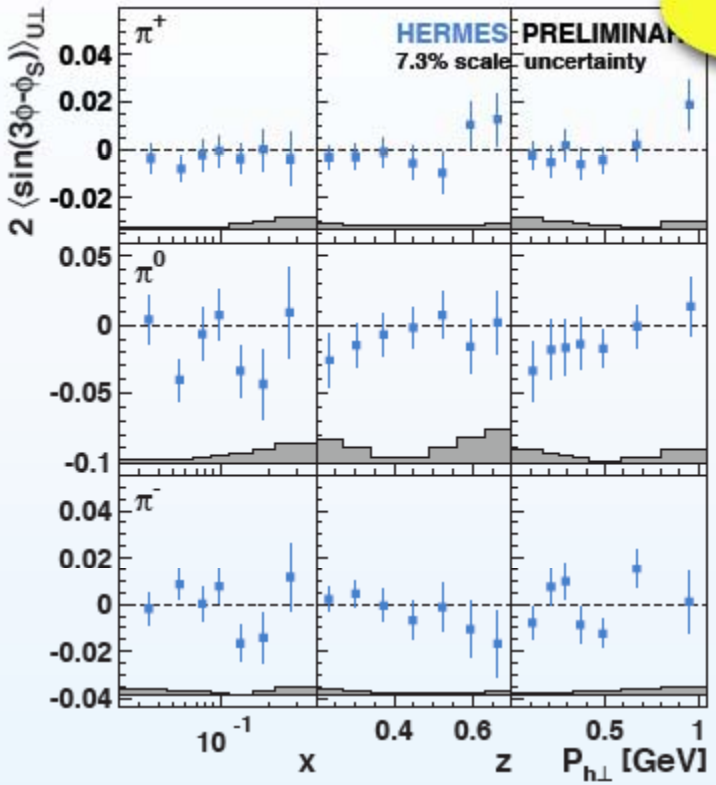
- Non-zero Pretzlosity require interference of LCWFs different by 2 units of OAM.
- Direct measurement of relativistic effect of quark?
  - PRD 78, 114024 (2008)
- Direct measurement of OAM?
  - PRD 58, 096008 (1998)
- Spin densities, deformation of nucleon shape etc

Zero so far from Experiments!

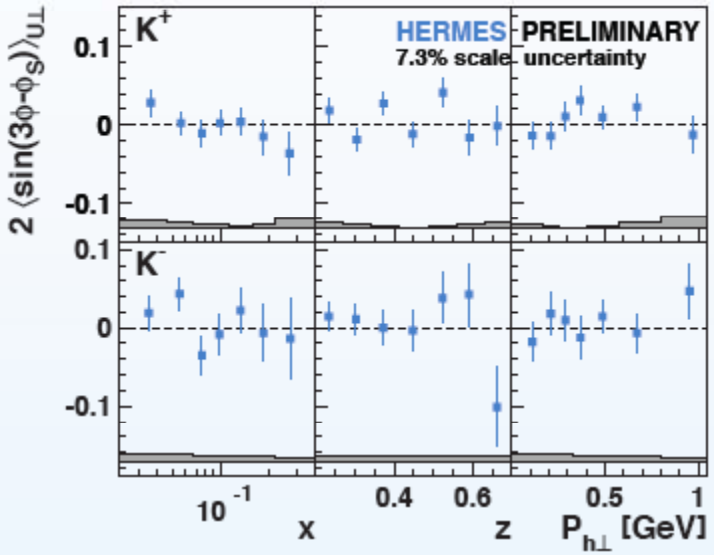
❹ The $\langle \sin(3\phi - \phi_S) \rangle_{U\perp}$ Fourier component:

sensitive to pretzelosity!

zero

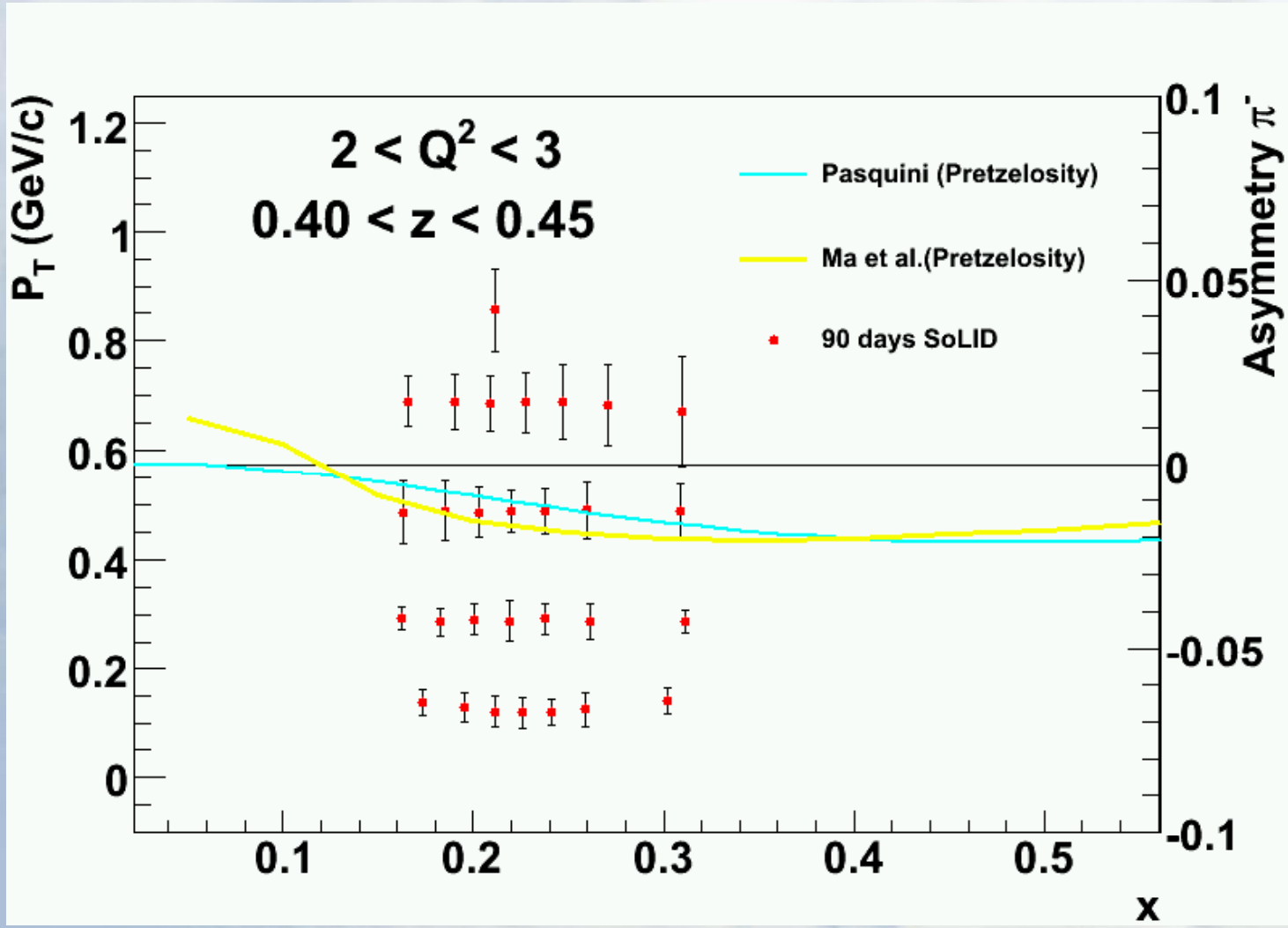


suppressed w.r.t. Collins and Sivers amplitudes



NEW

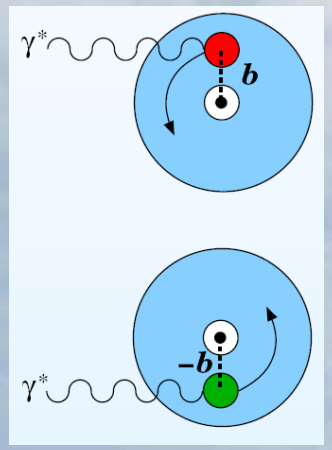
First non-zero Pretzlosity Assymetry at SoLID?

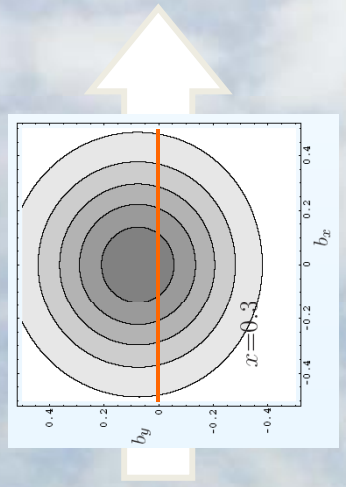


Rich Physics in Sivers Function

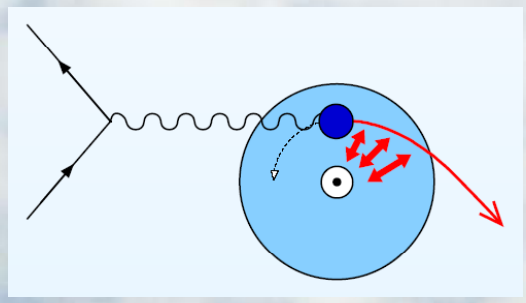
- Correlation between nucleon **spin** with quark **orbital angular momentum**

$$A^{Sivers} = f_{1T}^{\perp} \otimes D_1$$

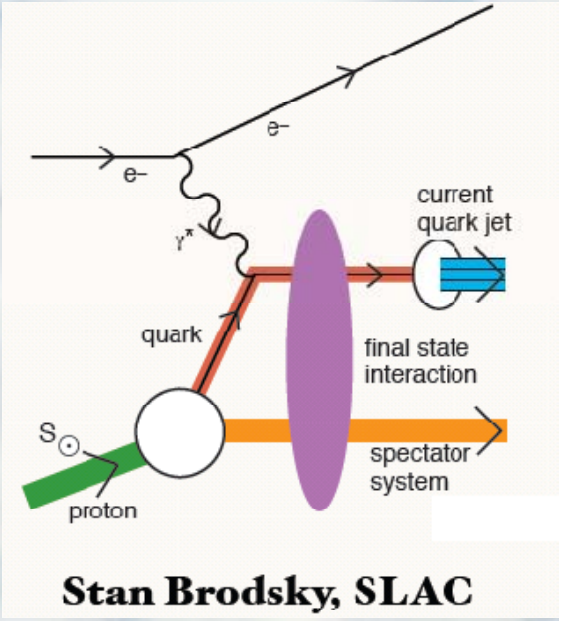




$u_X\,(x,\boldsymbol{b}_\perp)$



Burkhardt : chromodynamic lensing

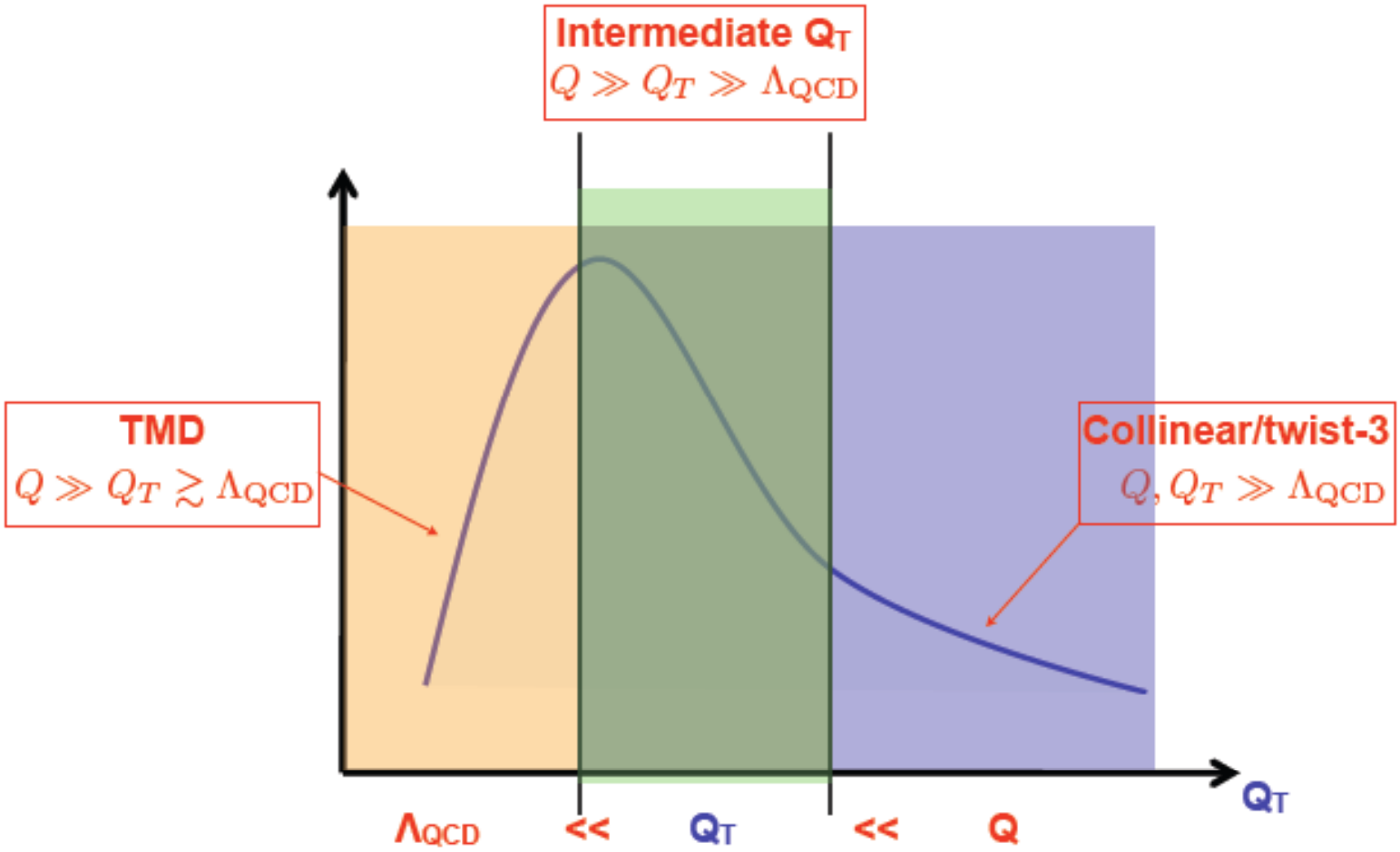


$$f_{1T}^{\perp q}\Big|_{SIDIS} = -\,f_{1T}^{\perp q}\Big|_{D-Y}$$

Important test for Factorization

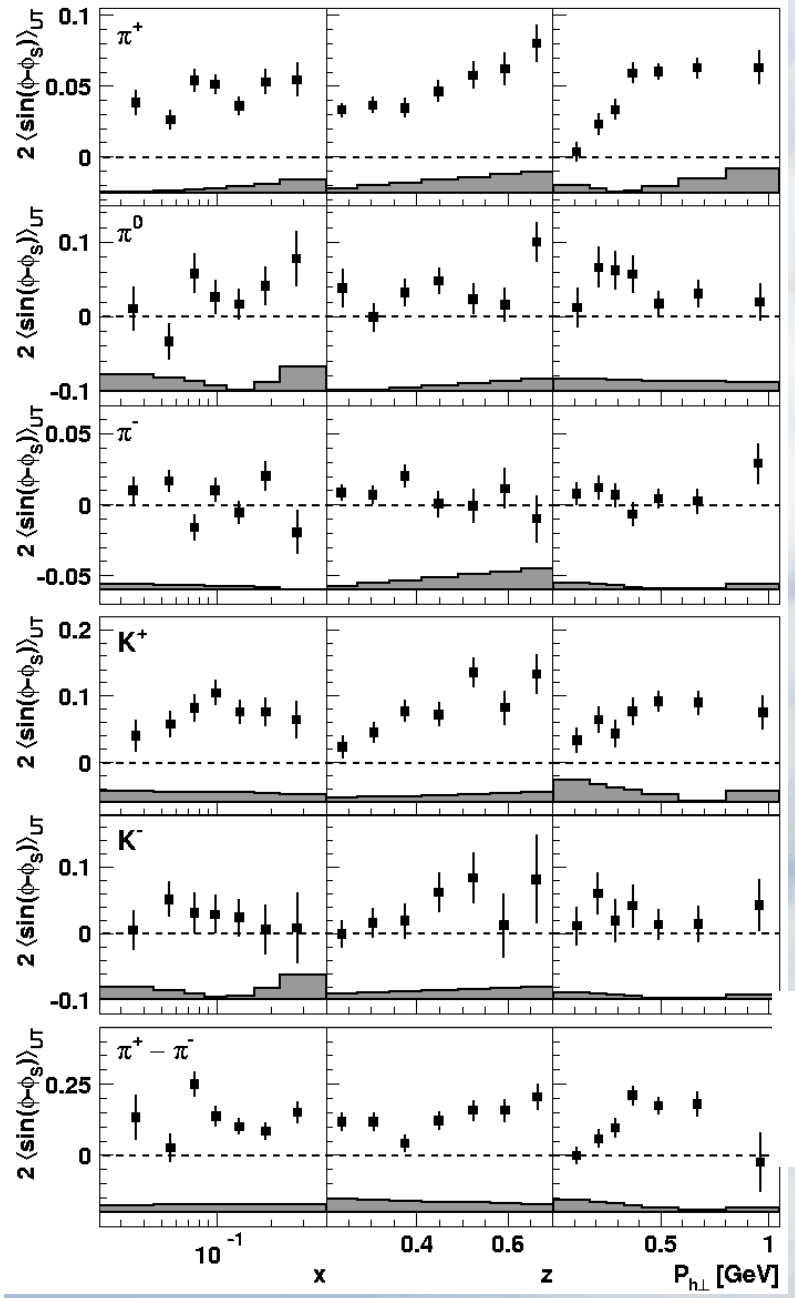
Final-State-Interaction

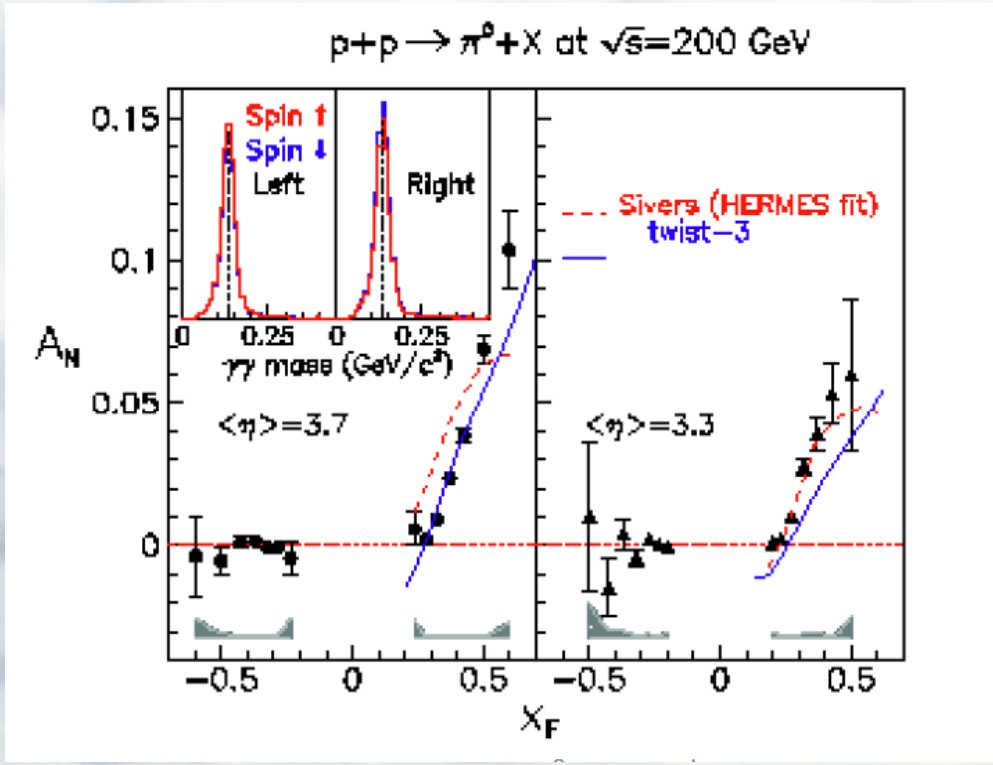
A unified picture for Drell-Yan (leading Q_T/Q)



Physics at medium P_T

Sivers vs. Twist-3





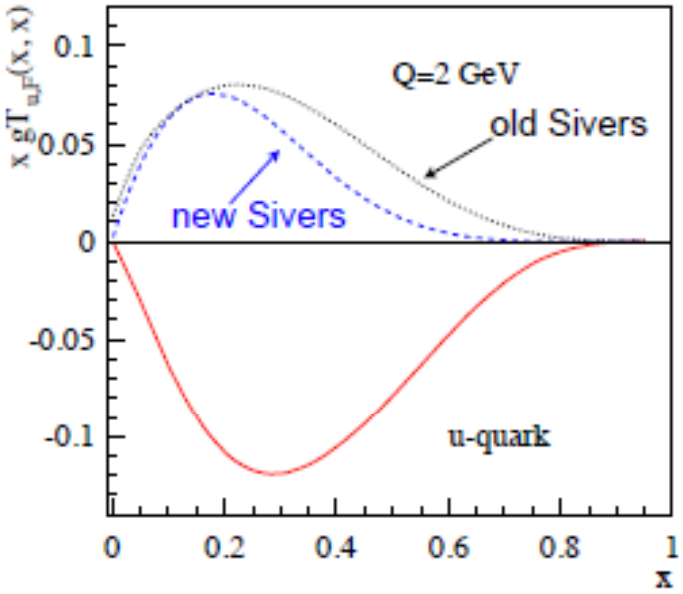
$$gT_{q,F}(x,x) = -\int d^2k_\perp \frac{|k_\perp|^2}{M} f_{1T}^{\perp q}(x,k_\perp^2)|_{\text{SIDIS}}$$

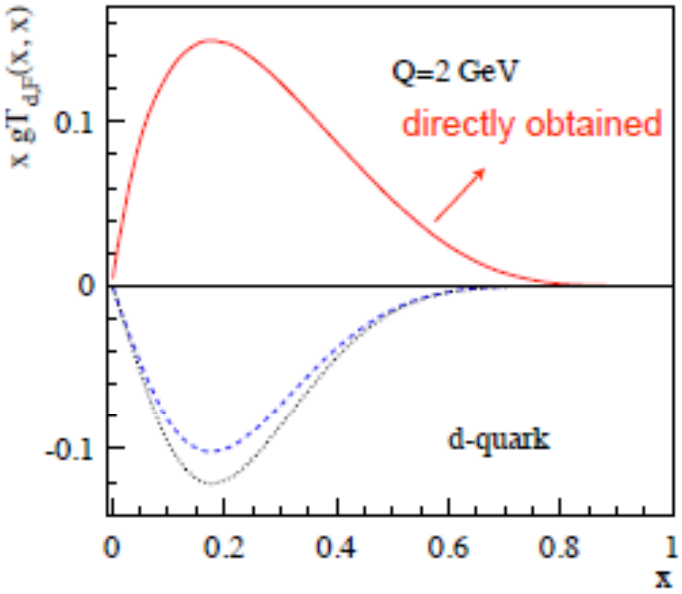
PRL 97 082002 (2006)

SIDIS

Sign Mismatch?

- ETQS function could be directly obtained from the global fitting of inclusive hadron production in hadronic collisions



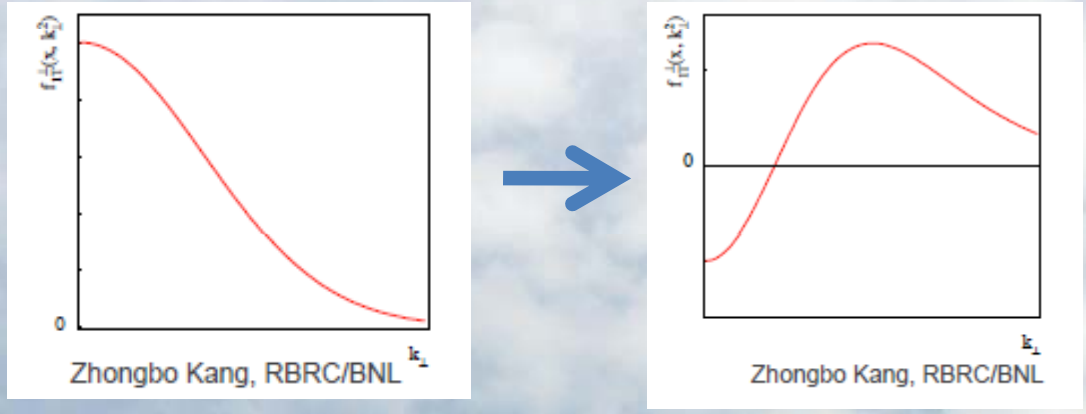


- directly obtained ETQS functions for both u and d quarks are opposite in sign to those indirectly obtained from the kt-moment of the quark Sivers function - "a sign mismatach"

- From Z. B. Kang

Is there a problem?

- Kang, Qiu, Vogelsang and Yuan: arxiv: 1103.1591
  - k_T dependence of Sivers function?



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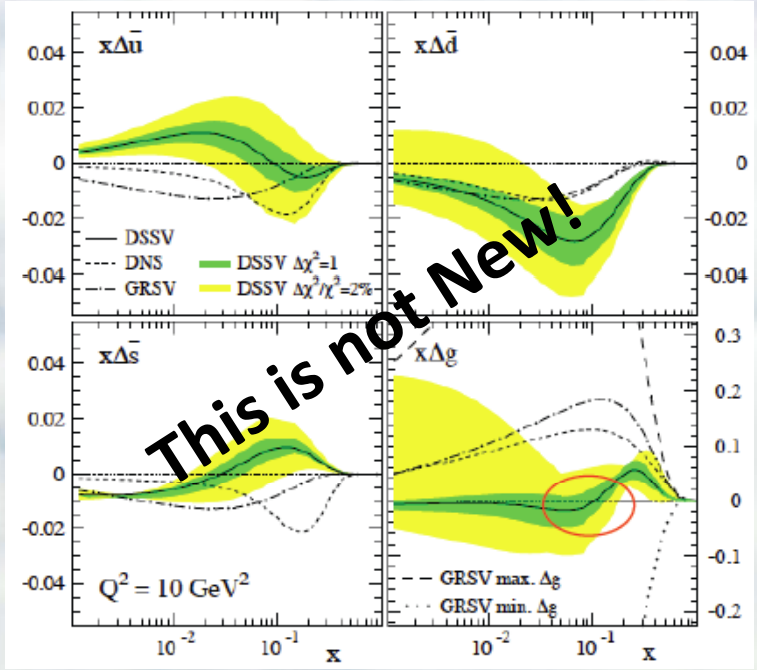


  - A node in x, sign change of Sivers function at large x? (A. Prokudin)
  - Complications in A_N (PDF vs. FF)
- SoLID can provide some inputs to this "puzzle"!

Opportunities of P_T Weighted Asymmetry

$P_{h\perp}$ weighted Spin Asymmetries help to resolve the convolution into a simple product of moments of TMDS Mulders 95,Boer 97, Kotzinian 97

$v(P_{h\perp}) \propto P_{h\perp}^n$

$$\begin{aligned} \mathcal{C}[v(P_{h\perp})wfD] &= \int_0^\infty d^2\mathbf{P}_{\mathbf{h}\perp}\, v(P_{h\perp})\mathcal{C}[v(P_{h\perp})wfD] \\ &= \mathbf{f^{(k)}(x)\, D^{(m)}(z)\, U^{(0)}} + \ldots \end{aligned}$$

Moments are defined as

$$f^{(k)}(x) \equiv \int d^2\boldsymbol{p}_T \left(\frac{\boldsymbol{p}_T^2}{2M^2}\right)^k f(x, \boldsymbol{p}_T^2)$$

$$D^{(m)}(z) \equiv \int d^2\boldsymbol{K}_T \left(\frac{\boldsymbol{K}_T^2}{2z^2M_h^2}\right)^m D(z, \boldsymbol{K}_T^2)\,.$$

- Large Contribution from large P_T
- Experiment always have limited range in P_T
- From A. Prokudin

We need a weight that regularize high $P_{h\perp}$. This can be achieved by Bessel function weighting – product of Fourier transfom of TMDs at some certain transverse distance $\mathcal{R}$ appear Boer, Gamberg, Musch, AP 2010 in preparation $P_{h\perp}^n \to J_n(P_{h\perp}\mathcal{R})$ (idea of Berni Musch)

$$\begin{aligned}\hat{\mathcal{C}}[J_n(P_{h\perp}\mathcal{R})wfD] &= \int_0^\infty d^2\mathbf{P_{h\perp}} J_n(P_{h\perp}\mathcal{R})\mathcal{C}[wfD] \\ &= \tilde{\mathbf{f}}^{(\mathbf{k})}(\mathbf{x},\mathbf{z}^2\mathcal{R}^2)\,\tilde{\mathbf{D}}^{(\mathbf{m})}(\mathbf{z},\mathcal{R}^2)\,\tilde{\mathbf{U}}^{(0)}(\mathcal{R}^2)\end{aligned}$$

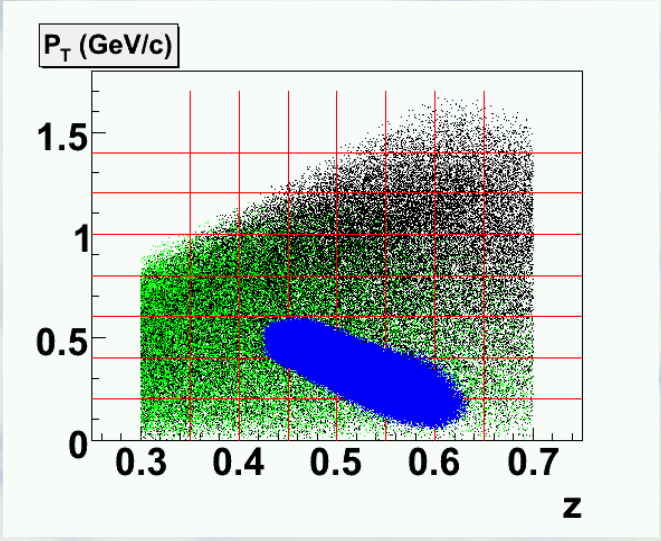
Fourier transformed TMDs are defined as

$$\begin{aligned}\tilde{f}^a(x,\boldsymbol{\mathcal{R}}_T^2) &\equiv \int d^2\boldsymbol{p}_T\; e^{i\boldsymbol{p}_T\cdot\boldsymbol{\mathcal{R}}_T}\; f^a(x,\boldsymbol{\mathcal{R}}_T^2) \\ \tilde{f}^{a(n)}(x,\boldsymbol{\mathcal{R}}_T^2) &\equiv \left(\tfrac{2}{M^2}\right)^n (\partial_{\boldsymbol{\mathcal{R}}_T^2})^n\; \tilde{f}^a(x,\boldsymbol{\mathcal{R}}_T^2)\end{aligned}$$

- Such method will give k_T dependence of TMD

$$A_{UT}^{J\sin(\phi_h-\phi_S)} = \frac{\int dP_T\, J(P_T) A_{UT}^{\sin(\phi_h-\phi_S)} \cdot \sigma_{UU}}{\int dP_T \sigma_{UU}}$$

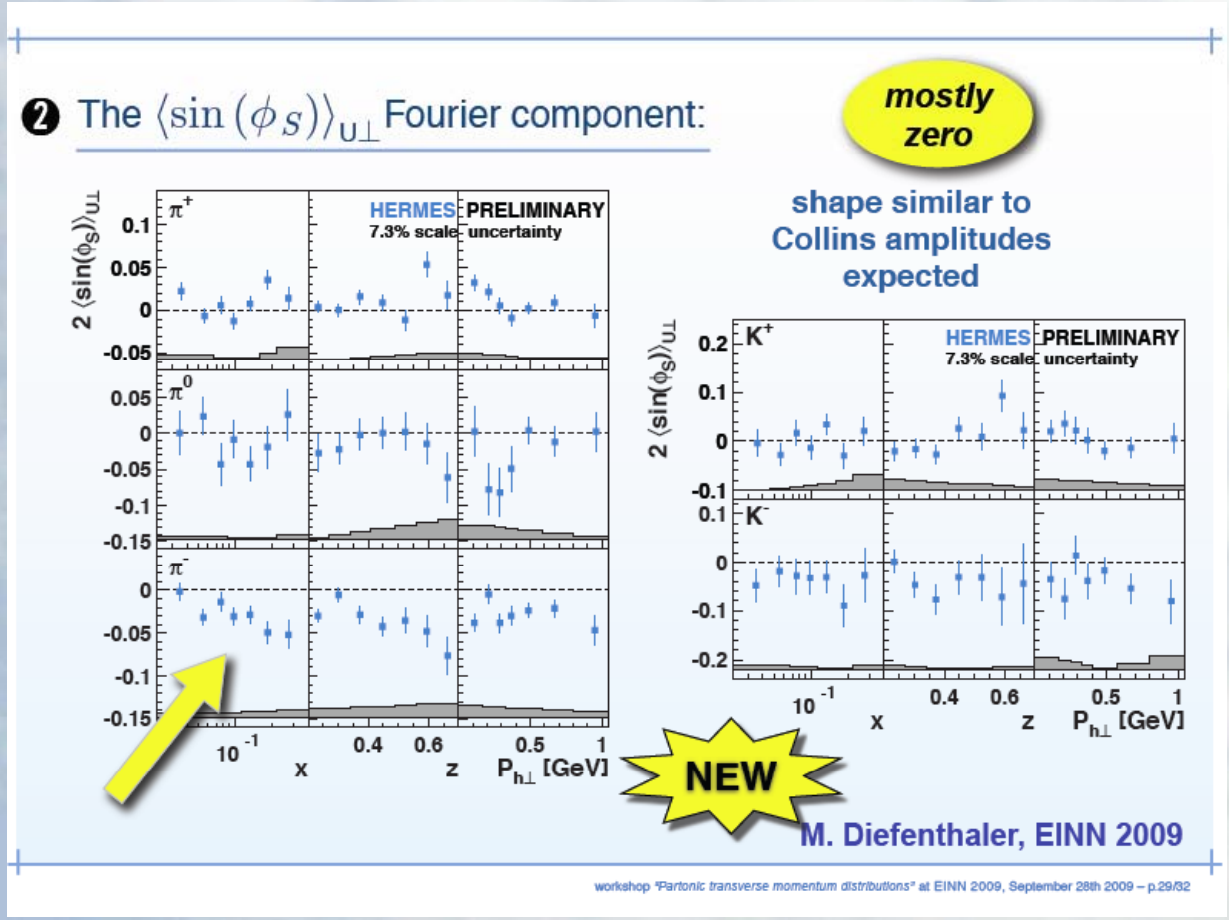
Require measurements on both asymmetry and unpolarized cross section.



What about Higher Twist?

$$LT :< \sin(\phi_h + \phi_S) >, < \sin(3\phi_h - \phi_S) >, < \sin(\phi_h - \phi_S) >$$

$$NLT :< \sin(\phi_S) >, < \sin(2\phi_h - \phi_S) >$$

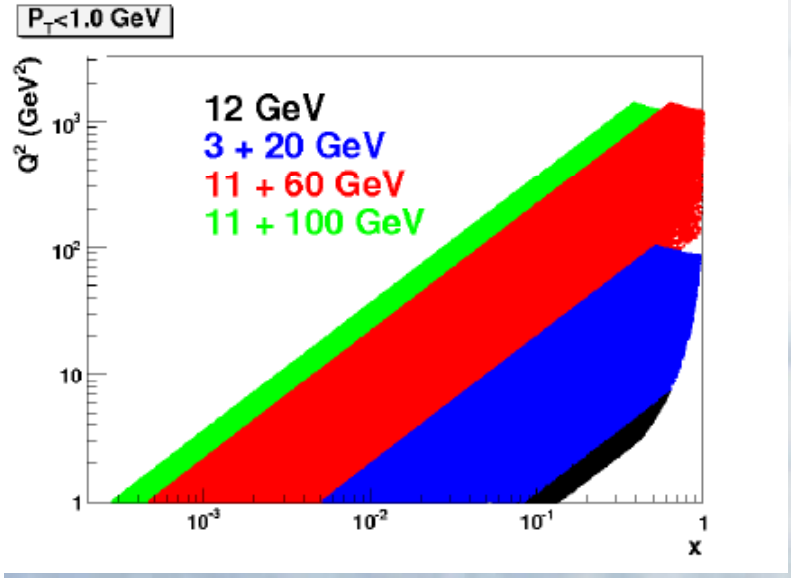


Summary

- Goals of SoLID:
  - 4-D mapping of TSSA
  - Test SIDIS factorization, PT dependence at JLab12
- Selected topics covered in this talk.
  - Test Soffer bound of transversity distribution!
  - Non-zero pretzlosity?!
  - Search for Sign change in x or k_T dependence of Sivers function!
  - PT weighted asymmetry.
  - Higher Twist measurements.
- Acknowledgement: A. Prokudin, B. Musch

Bright Future for TMDs

- Golden channel of Electron-Ion Collider



Dream!