TMD evolution for Collins asymmetries in e^+e^- annihilation and SIDIS

Peng Sun

LBNL

in collaboration with Kang, Prokudin and Yuan

arXiv:1410.4877

Outlines

- Energy evolution in TMD factorization
- Collins asymmetry in e^+e^- annihilation and SIDIS
- Summary

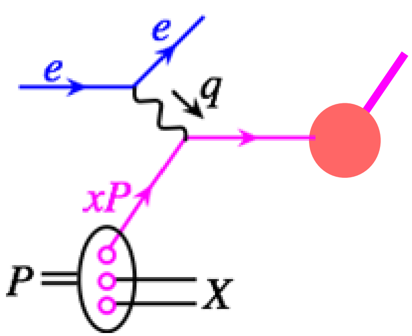
Why do we need QCD evolution?

TMD factorization is applicable in case two different scales are observed in processes such as SIDIS, Drell-Yan, W/Z production in hadron-hadron collisions. Kinematical regime: $Q_T \ll Q$

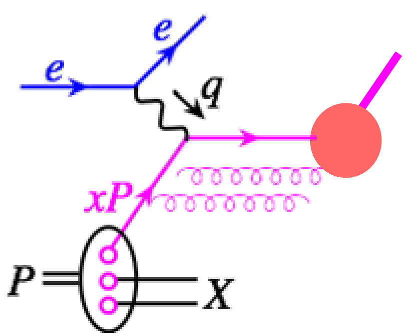
For SIDIS Q_T is transverse momentum of final parton

And Q is the invariant mass of virtual photon

Double and Single logarithms will appear order by order in perturbative calculations



$f(x)$



$f(x, k_\perp; Q)$

$$\left(\alpha_s \ln^{2} \frac{Q^2}{Q_T^2}\right)^n$$

$$\left(\alpha_s \ln \frac{Q^2}{\mu^2}\right)^n$$

TMD evolution in TMD parton distributions

With CSS evolution equation, evolution starts from $\mu_b = c/b,\ c = 2e^{-\gamma_E}$

$$\tilde{f}(x,b;Q) = \tilde{f}(x,b;\mu_b)e^{-S_{pert}(b)}$$

where

$$\tilde{f}(x,b;Q) = \int d^2k_\perp e^{-ik_\perp b} f(x,k_\perp;Q)$$

$$S^{PT}(b) = \int_{\mu_b}^{Q} \frac{d\mu}{\mu}\left(A \ln\frac{Q^2}{\mu^2} + B\right)$$ Perturbative Sudakov factor

$$A = \sum_{n=1}\left(\frac{\alpha_s}{\pi}\right)^n A^{(n)} \qquad B = \sum_{n=1}\left(\frac{\alpha_s}{\pi}\right)^n B^{(n)}$$

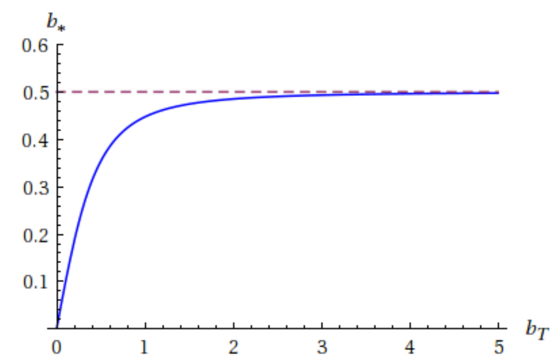
Calculation is perturbative, valid only in region $b \ll 1/\Lambda_{QCD}$

Fourier transform in momentum space involves non-perturbative region

$$f(x, k_\perp; Q) = \int_0^\infty \frac{bdb}{2\pi} J_0(k_\perp b) \tilde{f}(x, b; Q)$$

Non perturbative region needs to be treated.
Common method b* prescription

$$b_* = \frac{b}{\sqrt{1 + b^2/b_{max}^2}}$$



$$\tilde{f}(x, b; Q) = \tilde{f}(x, b_*; c/b_*) e^{-S_{pert}(b_*)} e^{-S_{NP}(b)}$$

Non perturbative Sudakov factor

$$S_{\rm NP}^{\rm SIDIS}(Q,b) = g_2 \ln\left(\frac{b}{b_*}\right) \ln\left(\frac{Q}{Q_0}\right) + \left(\frac{g_1}{2} + g_3 \left(\frac{x_0}{x_B}\right)^{\lambda} + \frac{g_h}{z_h^2}\right) b^2$$

A new non-perturabtive Sudakov factor is used. Where x_0=0.01, Q_0^2=2.4GeV^2, and λ =0.2

g_1 , g_2 and g_3 are free parameters, from the fitting of Drell-Yan processes, and g_h is from SIDIS

In our fit, we choose b_{max}=1.5GeV^{-1}

$$\tilde{f}^{j}(x, b_*; c/b_*) = \sum_{j'=q,g} \int_x^1 \frac{d\hat{x}}{\hat{x}} C_{j/j'}\left(\frac{x}{\hat{x}}, b_*; c/b_*\right) f^{j'}(x; c/b_*)$$

$$C = \sum_{n=1} \left(\frac{\alpha_s}{\pi}\right)^n C^{(n)}$$

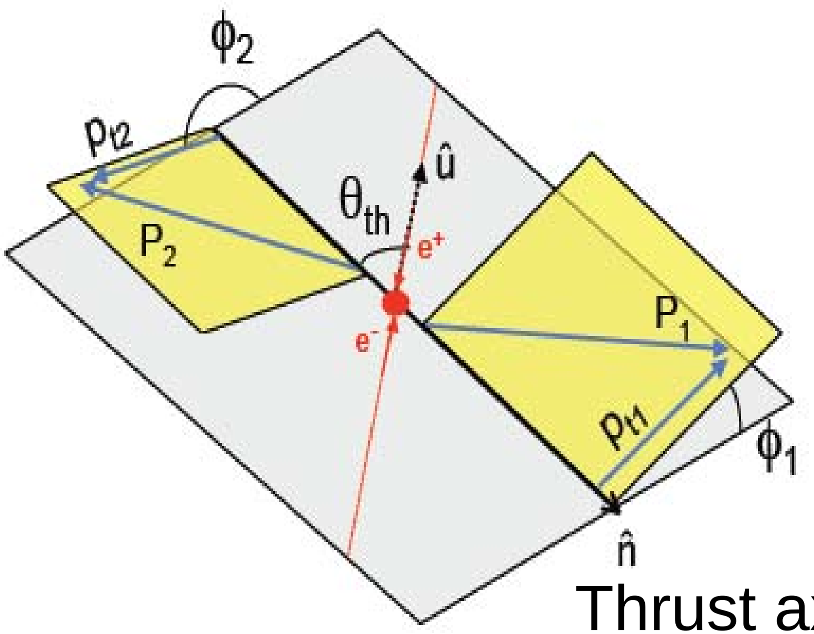
Wilson coefficient

Collinear PDF

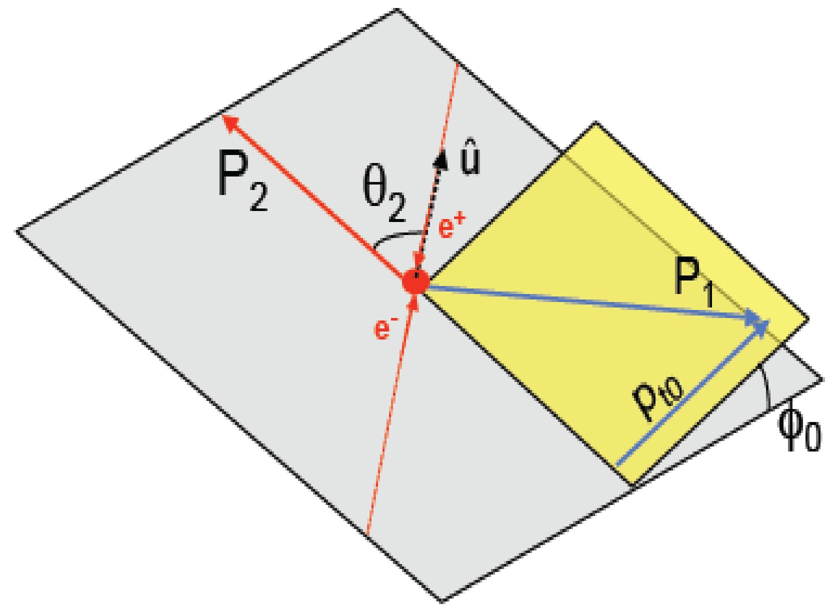
transversity is related to a twist-2 colinear PDF

Collins function is related to twist-3 collinear PDF

Collins asymmetries in $e^+e^- \rightarrow hh+X$



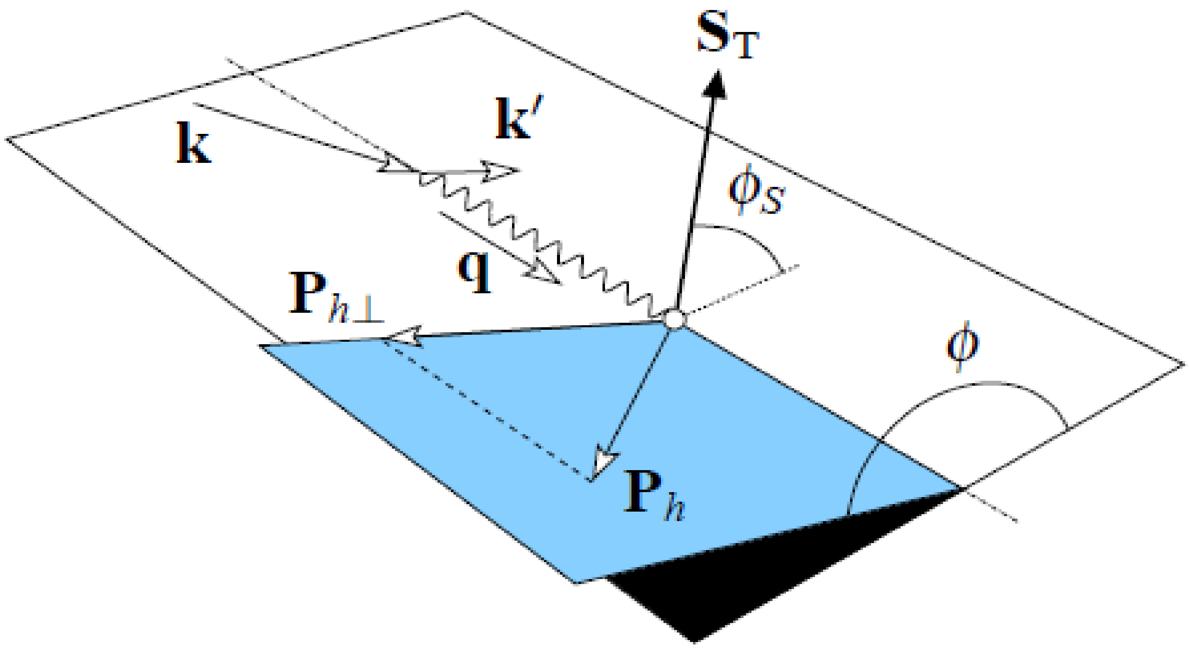
Thrust axis



A_{12} A_0

The Collins asymmetries is proportional to $\cos(\phi_1+\phi_2)$ or $\cos(2\phi_0)$

Collins asymmetries in SIDIS



The Collins asymmetries is proportional to $\sin(\phi+\phi_S)$

Transversity and Collins FF

Kang-Prokudin-Sun-Yuan 2014

Parametrizations: $$h_1^q(x, Q_0) \propto N_q^h x^{a_q}(1-x)^{b_q} \frac{1}{2}\left(f_1(x, Q_0) + g_1(x, Q_0)\right)$$

Transversity

Favoured and unfavoured Collins FF

$$\hat{H}_{fav}^{(3)}(z, Q_0) = N_u^c z^{\alpha_u}(1-z)^{\beta_u} D_{\pi^+/u}(z, Q_0)$$

$$\hat{H}_{unf}^{(3)}(z, Q_0) = N_d^c z^{\alpha_d}(1-z)^{\beta_d} D_{\pi^+/d}(z, Q_0)$$

Total 13 parameters: $N_u^h, N_d^h, a_u, a_d, b_u, b_d, N_u^c, N_d^c, \alpha_u, \alpha_d, \beta_d, \beta_u, g_c$

SIDIS data used: HERMES, COMPASS, JLAB – 140 points

e+e- data used: BELLE, BABAR including P_T dependence – 122 points

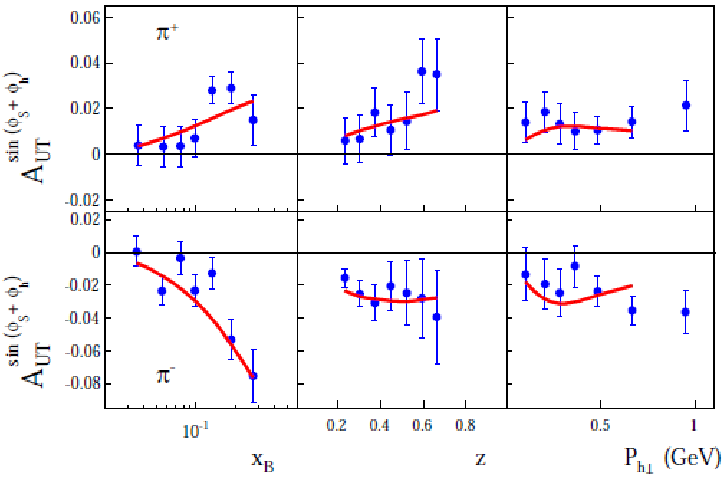
$$\chi^2_{min}/n_{d.o.f} = 0.89$$

Transversity and Collins FF

Kang-Prokudin-Sun-Yuan 2014

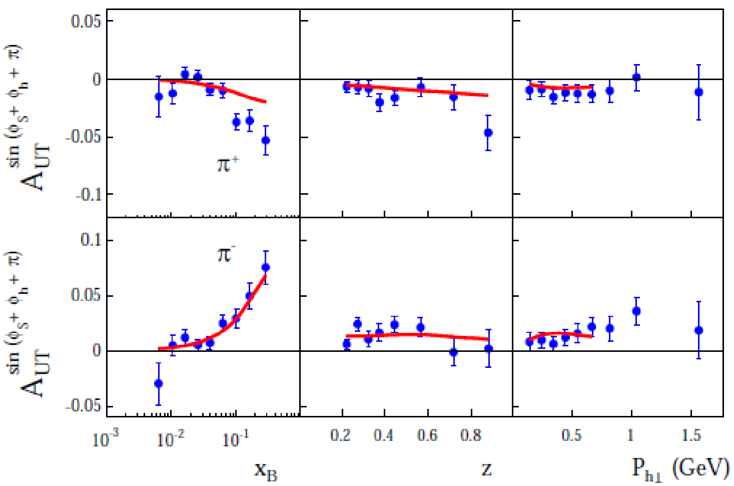
$$\ell P \to \pi^{\pm} X$$

HERMES



$$1 \lesssim \langle Q^2 \rangle \lesssim \ 6 \ \mathrm{GeV}^2$$

COMPASS



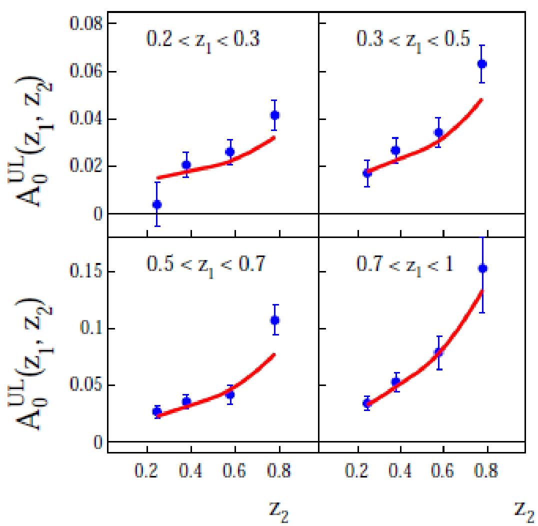
$$1 \lesssim \langle Q^2 \rangle \lesssim \ 21 \ \mathrm{GeV}^2$$

Transversity and Collins FF

Kang-Prokudin-Sun-Yuan 2014

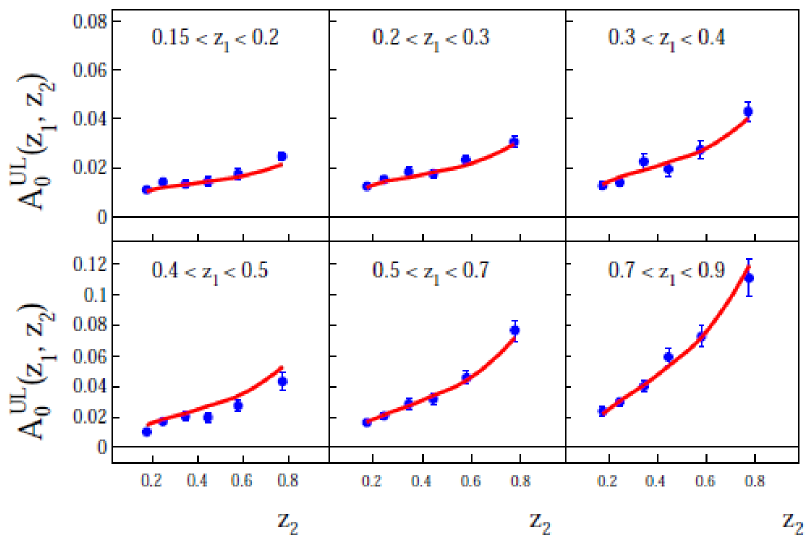
$$e^+e^- \to \pi\pi X$$

BELLE



$Q^2 = 110\ \mathrm{GeV}^2$

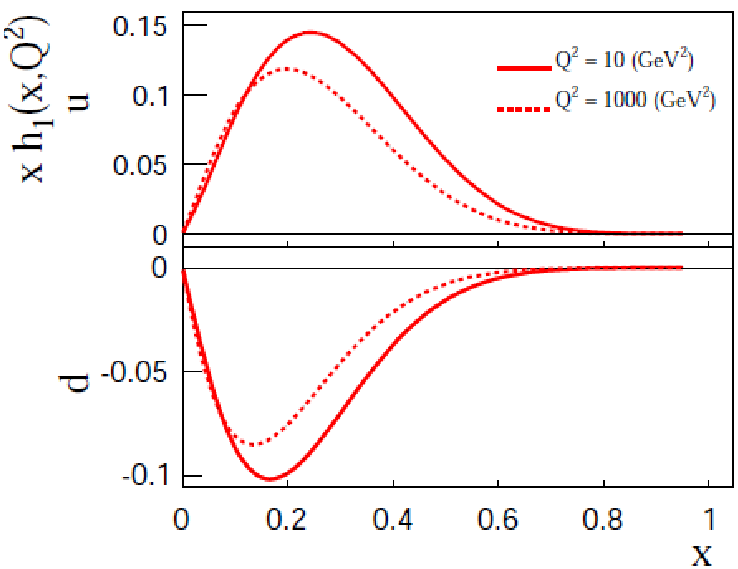
BABAR



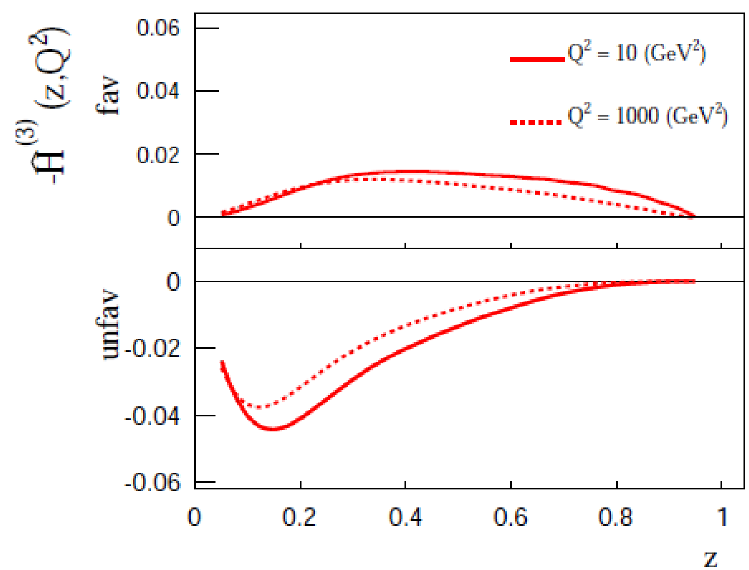
$Q^2 = 110\ \mathrm{GeV}^2$

Transversity and Collins FF Kang-Prokudin-Sun-Yuan 2014

Transversity



Collins



Positive u and negative d transversity

Positive favoured and negative unfavoured Collins FF

Compatible with LO extraction Anselmino et al 2009

Transversity and Collins FF

Kang-Prokudin-Sun-Yuan 2014

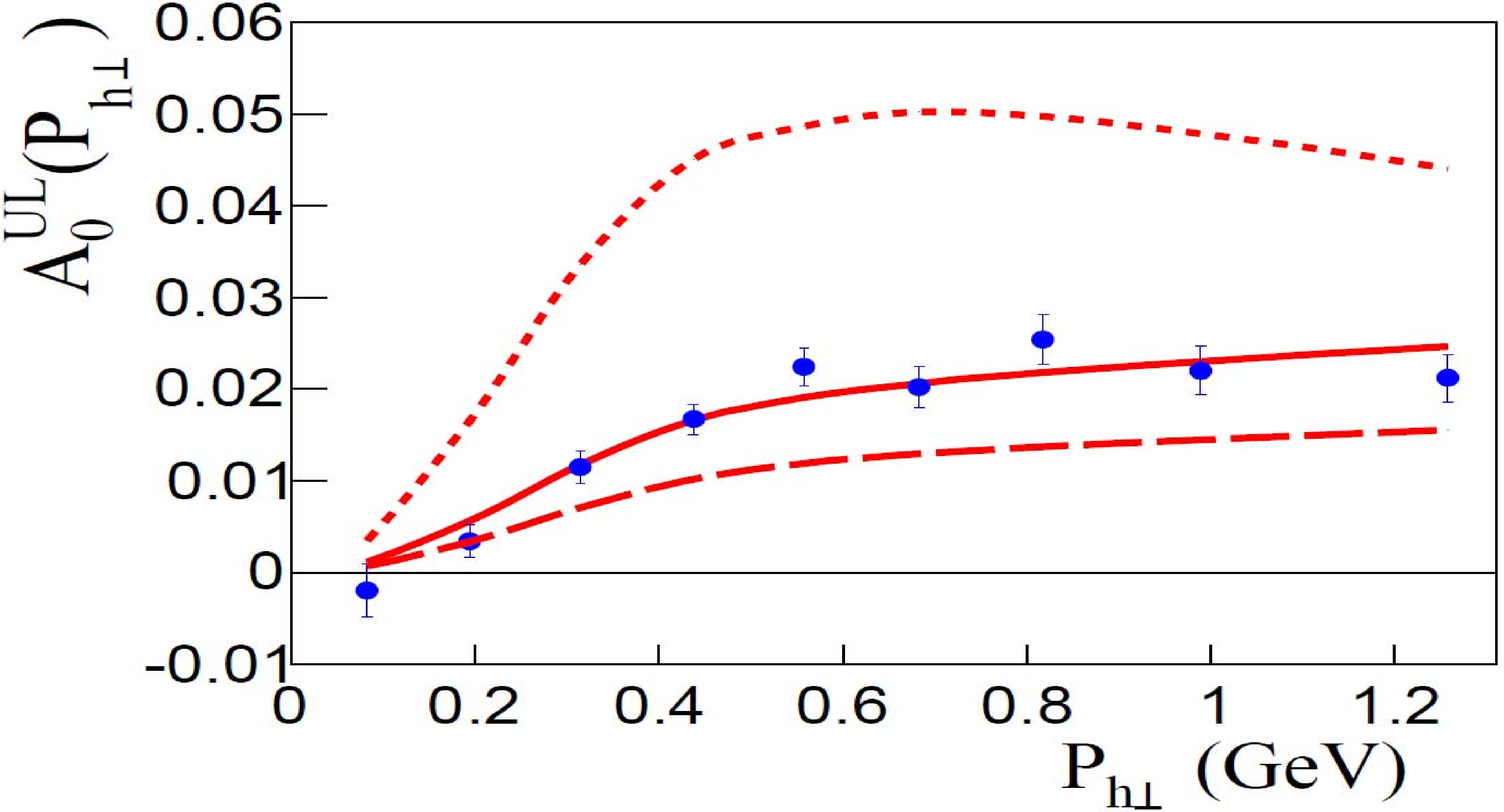
What are evolution effects?

$$e^+e^- \to \pi\pi X$$

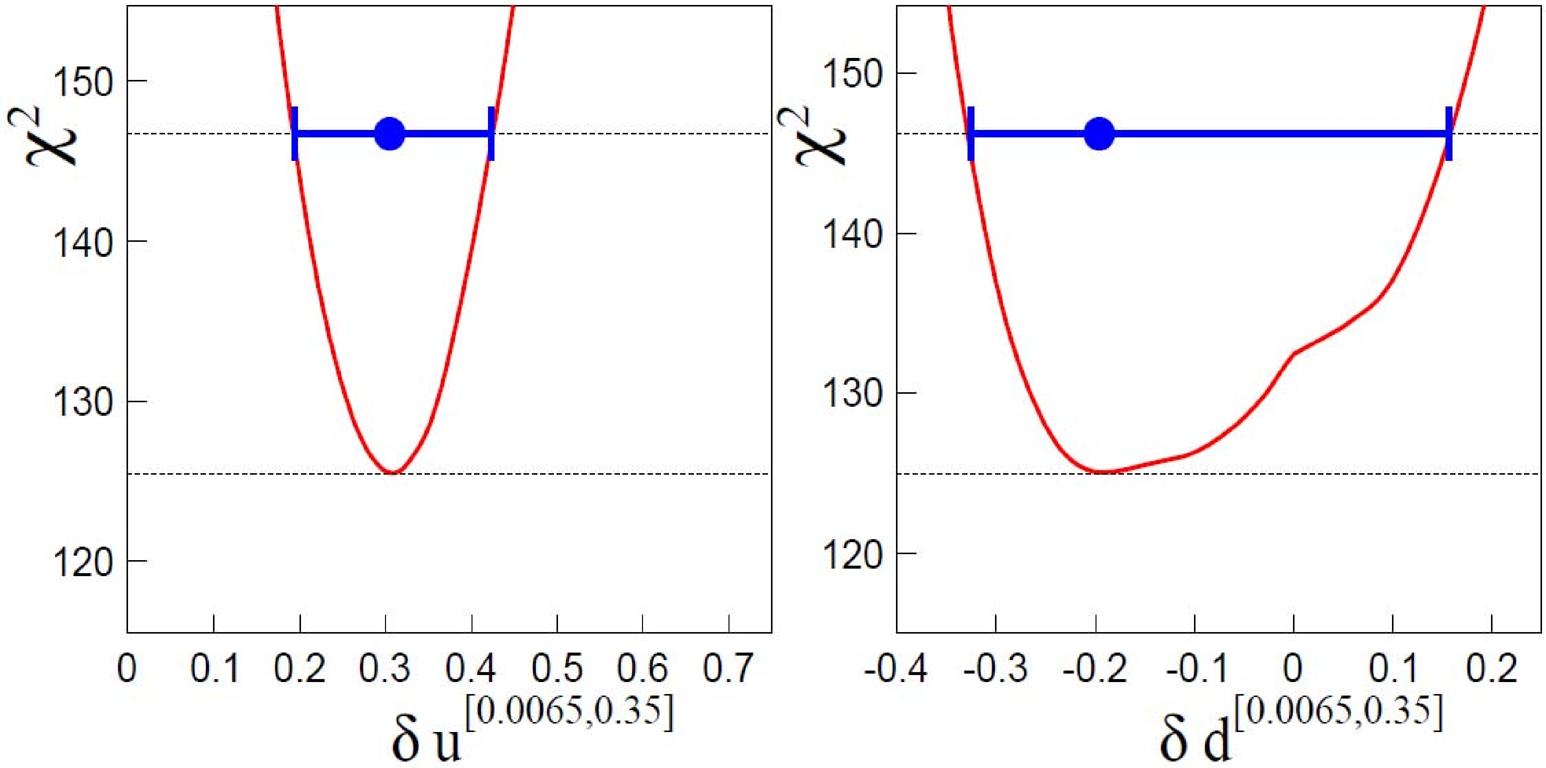
No evolution:

$Q^2 = 2.4\ \mathrm{GeV}^2$

No A_2



Scan δq for transversity



$$\delta u^{[0.0065,0.35]} = +0.30^{+0.12}_{-0.11}$$

$$\delta d^{[0.0065,0.35]} = -0.20^{+0.35}_{-0.13}$$

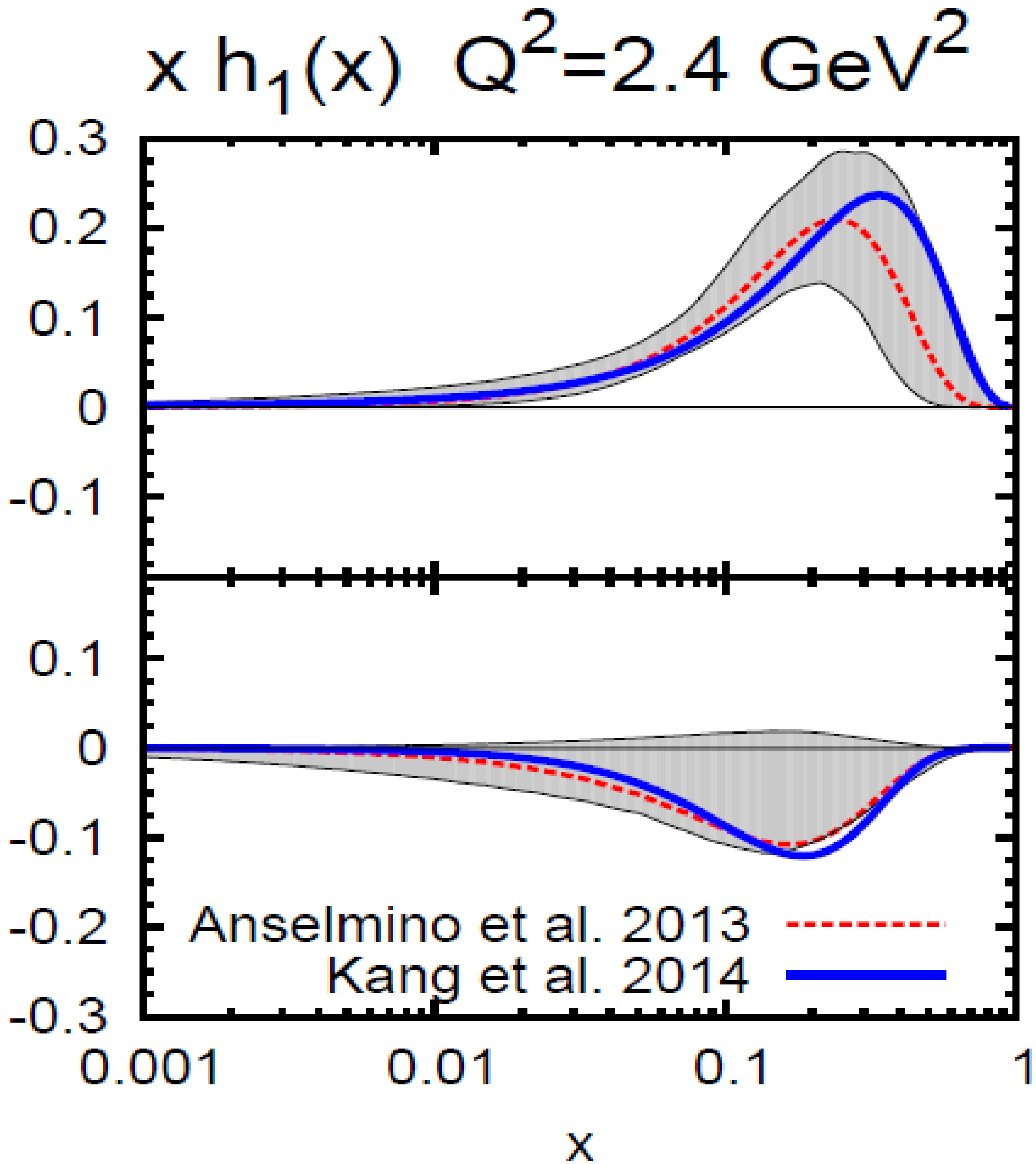
$$\delta q^{[x_{\min},x_{\max}]}\,(Q^2) \equiv \int_{x_{\min}}^{x_{\max}} dx\, h_1^q(x,Q^2)$$

at $Q^2 = 10\ \mathrm{GeV}^2$

Summary

- TMD evolution is studied for the Collins effects in e^+e^- annihilation and SIDIS
- Collins functions and transversity are fitted from the existing data at BELLE , BABAR, JLAB, COMPASS and HERMES with CSS resummation scheme

Thank you very much!



x h_1(x) Q^2=2.4 GeV^2
0.3
0.2
0.1
0
-0.1
u
0.1
0
-0.1
-0.2
-0.3
d
Anselmino et al. 2013
Kang et al. 2014
0.001
0.01
0.1
1
x

Approaches to TMD evolution

Collins-Soper-Sterman (CSS) resummation framework

Collins-Soper-Sterman 1985
ResBos: C.P. Yuan, P. Nadolsky
Qiu-Zhang 1999, Vogelsang tetc...
Kang-Xiao-Yuan 2011, Sun-Yuan 2013
Prokudin-Kang-Sun-Yuan 2014

"New" Collins approach

Collins 2011
Aybat-Rogers 2011,
Aybat-Collins-Rogers-Qiu, 2012
Aybat-Prokudin-Rogers 2012
Anselmino-Boglione-Melis 2012
Prokudin-Bacchetta 2013
Echevarria-Idilbi-Kang-Vitev 2014

Soft Collinear Effective Theory (SCET)

Echevarria-Idilbi-Schafer-Scimemi 2012
D'Alesio-Echevarria-Melis-Scimemi 2014