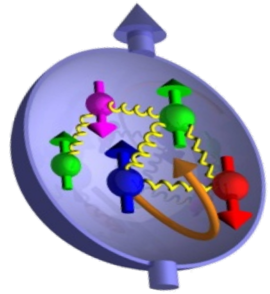


Transverse Spin Physics at SpinQuest

Ming Liu

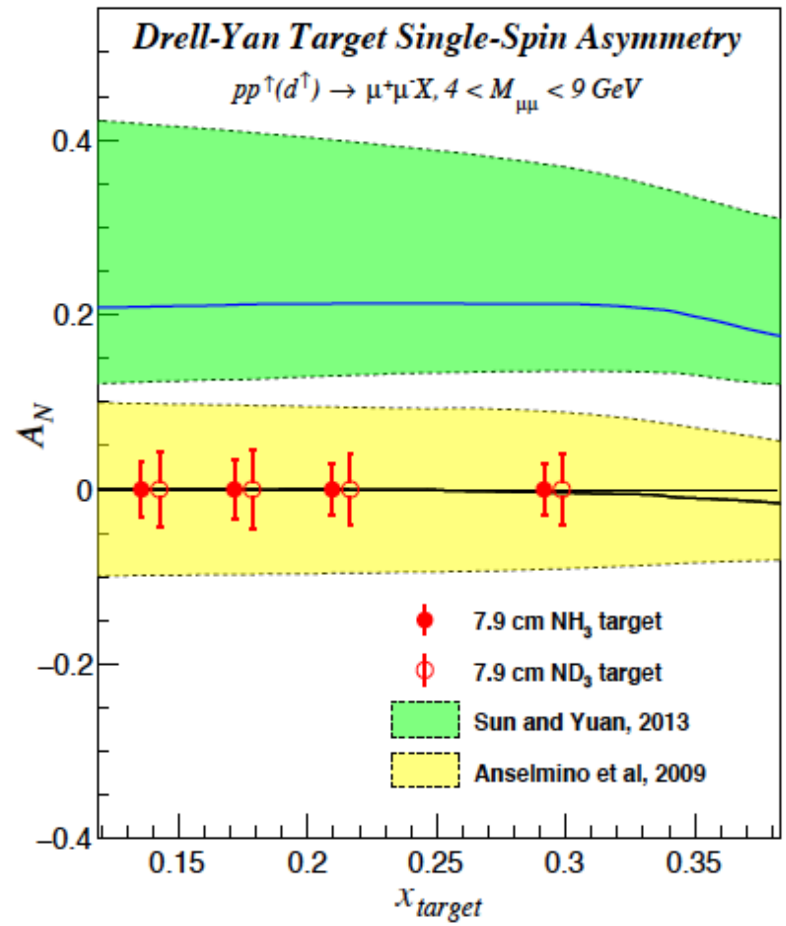
LANL

3/07/2019

E1039 Collaboration Meeting

Outline

- Recent highlights
  - RHIC,COMPASS et al
- E1039 opportunities
  - Sea quark Sivers at high-x
    - ubar & dbar
  - Gluon Sivers at high-x
  - Other topics
    - Transversity distributions …
- Trigger optimization
  - J/Psi
  - Open charm

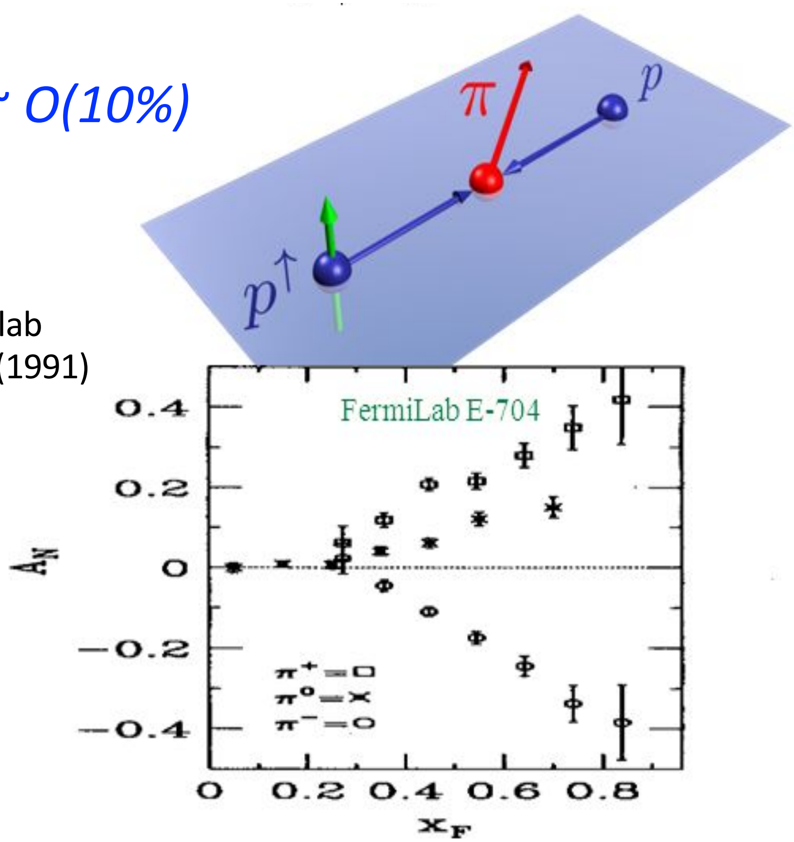


Large TSSA Challenge: TMD Physics

Large Transverse Single Spin Asymmetry (TSSA) in forward hadron production persists up to top RHIC energy.

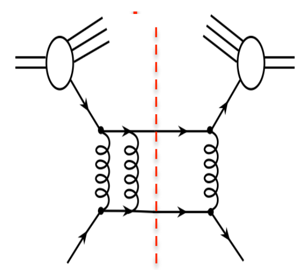
A_N ~ *O(10%)*

Fermilab
E704 (1991)



Kane, Pumplin, Repko (1978)

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$



$$\propto \alpha_s \frac{m_q}{p_T}$$

$$A_N^{(pred.)} \sim 0$$

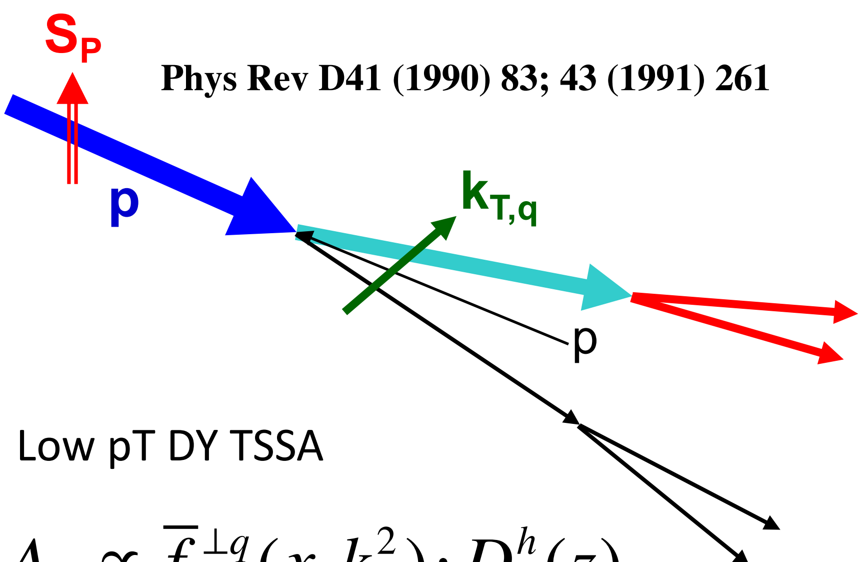
Probe the Underlying Physics via Hard Scatterings

TMD vs Collinear Twist-3 Factorizations

(i) Sivers mechanism:

correlation proton spin & parton k_T

Phys Rev D41 (1990) 83; 43 (1991) 261



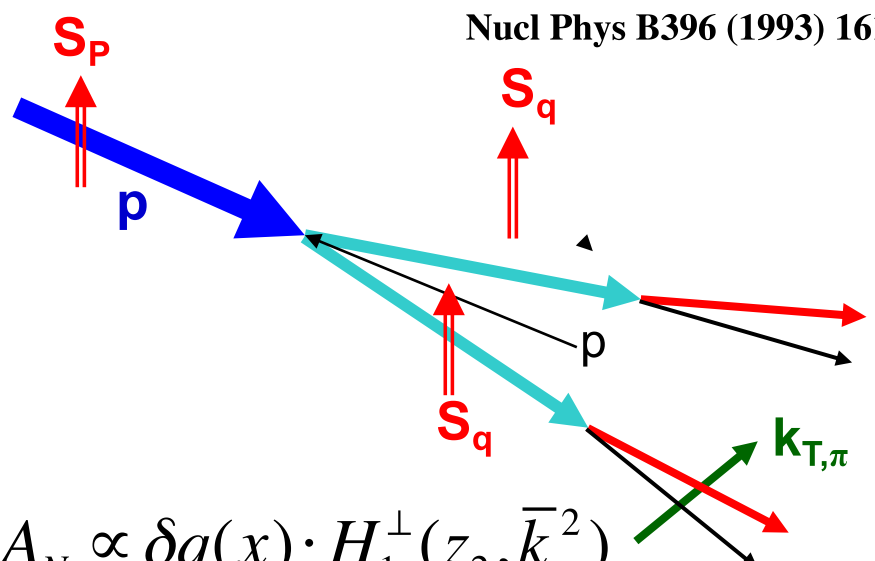
Low pT DY TSSA

$$A_N \propto \overline{f}_{1T}^{\perp q}(x, k_\perp^2) \cdot D_q^h(z)$$

(ii) Collins mechanism:

Transversity × spin-dep fragmentation

Nucl Phys B396 (1993) 161



$$A_N \propto \delta q(x) \cdot H_1^\perp(z_2, \overline{k}_\perp^2)$$

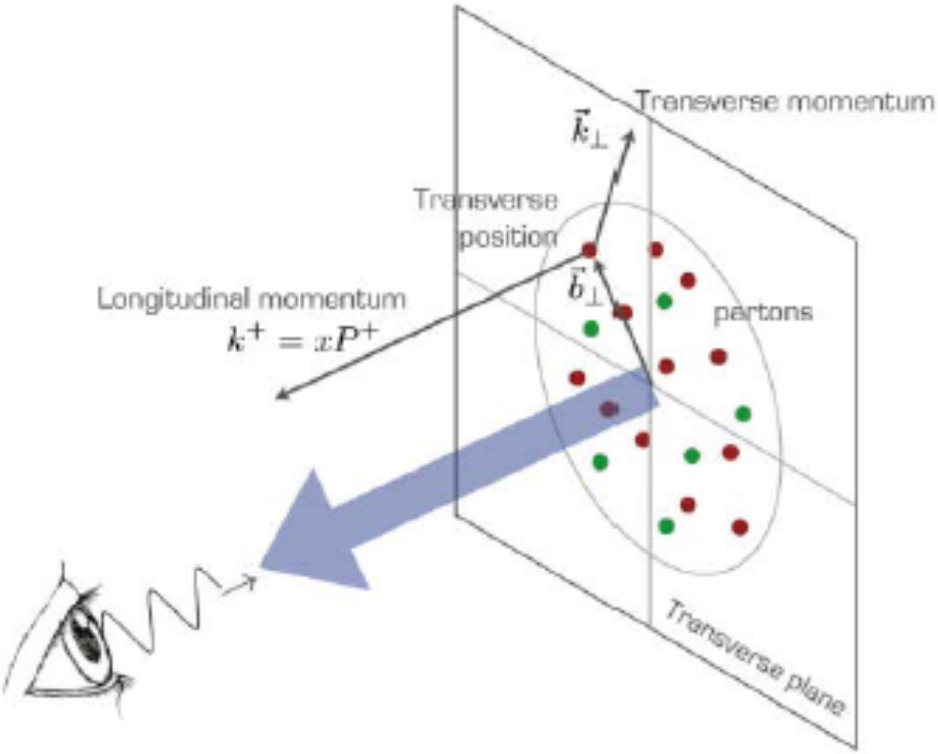
Collinear Twist-3 (RHIC, Fermilab):

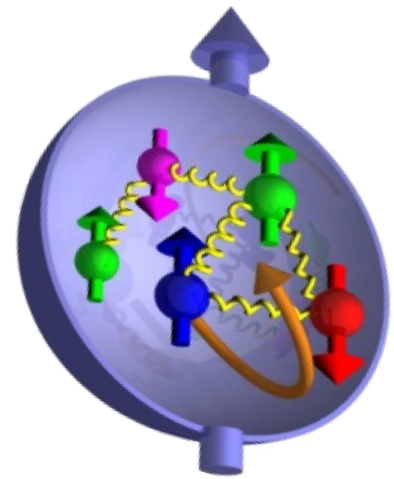
quark-gluon/gluon-gluon correlation

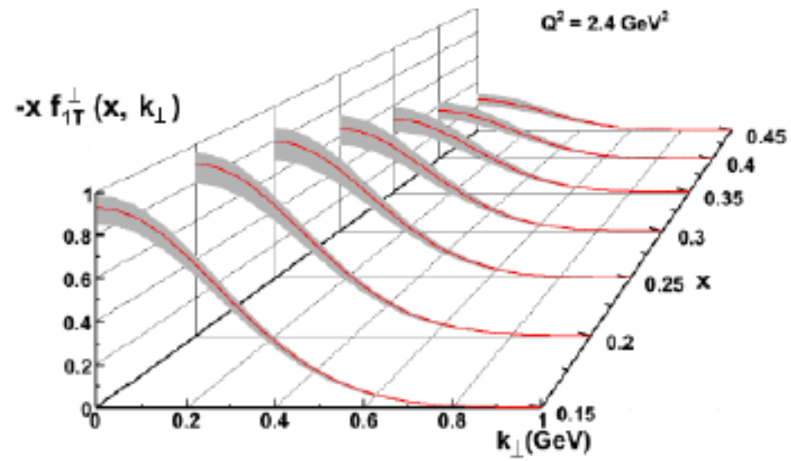
for hadron production @E1039

Nucleon Structure and TMD

from Alessandro Bacchetta







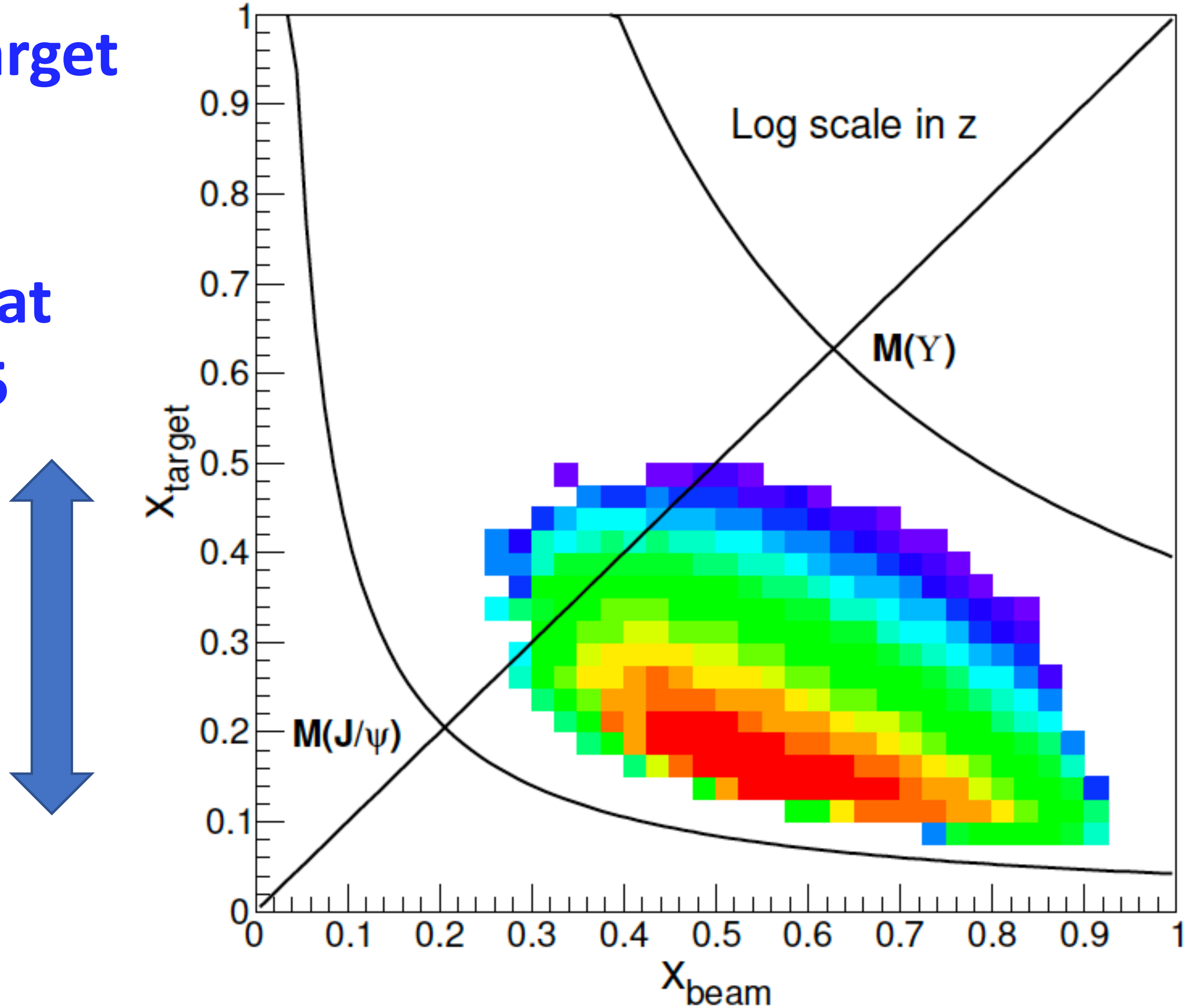
TMD: $f(x, k_T)$

Sivers functions, quark transversity etc.

E1039 Dimuon Acceptance

Polarized target coverage:

Sea quarks at x = 0.1~ 0.5

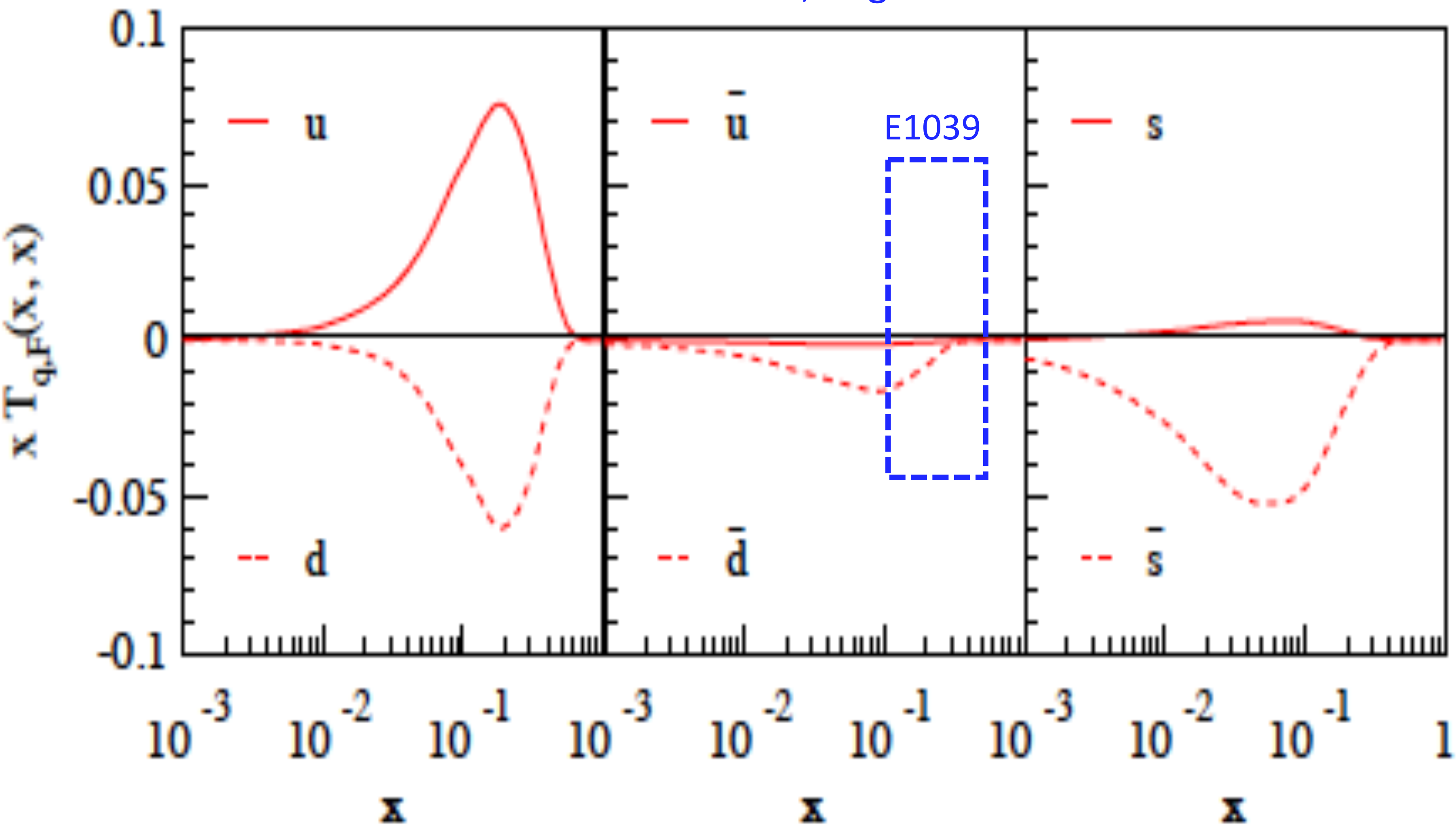


Sivers: Global Fits w/ TMD Evolution

Large TSSA from valence quarks

Sivers fits: small ubar, large dbar

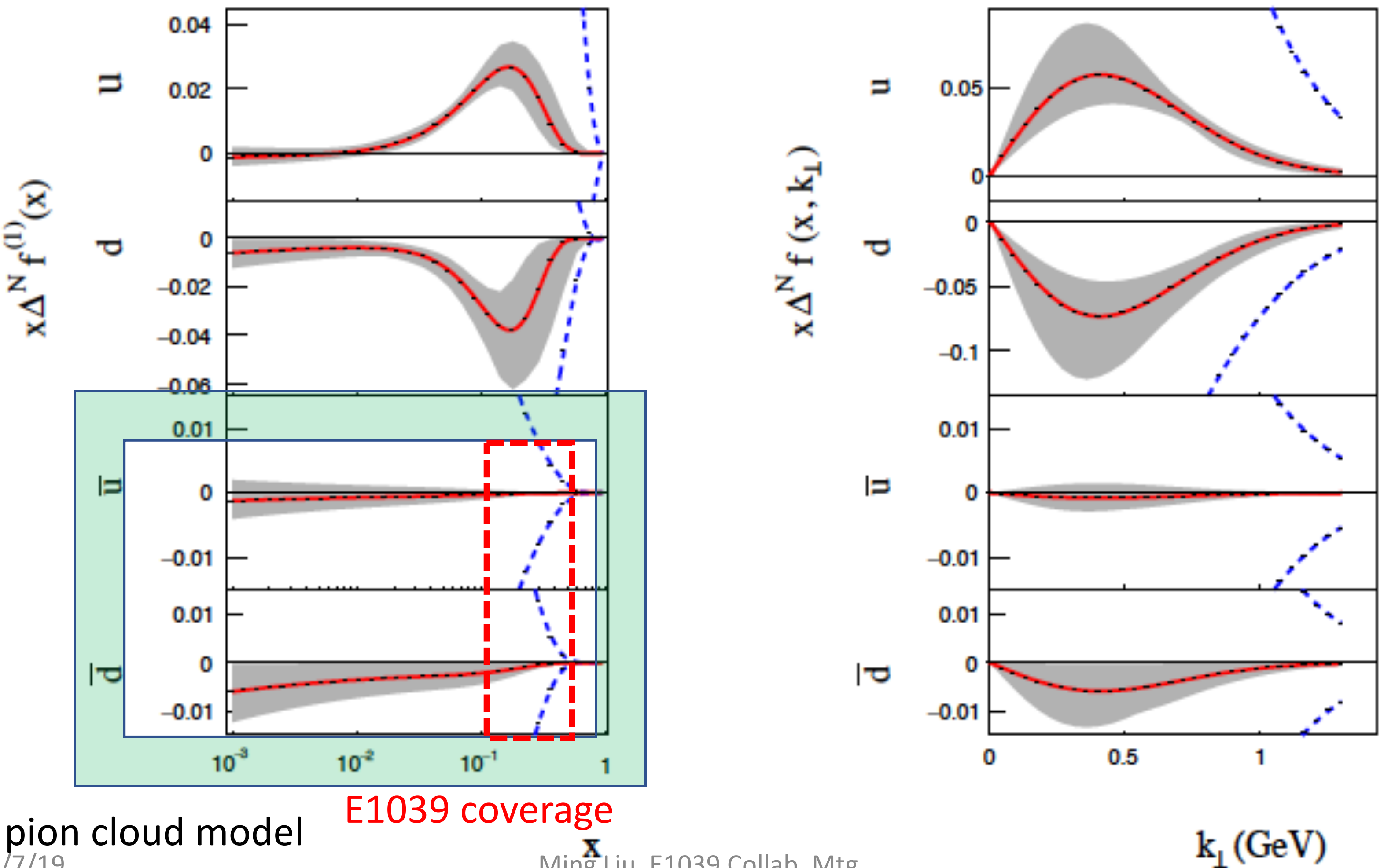
Kang et al, 1401.5078



Sivers Functions from Global Fits – Quarks

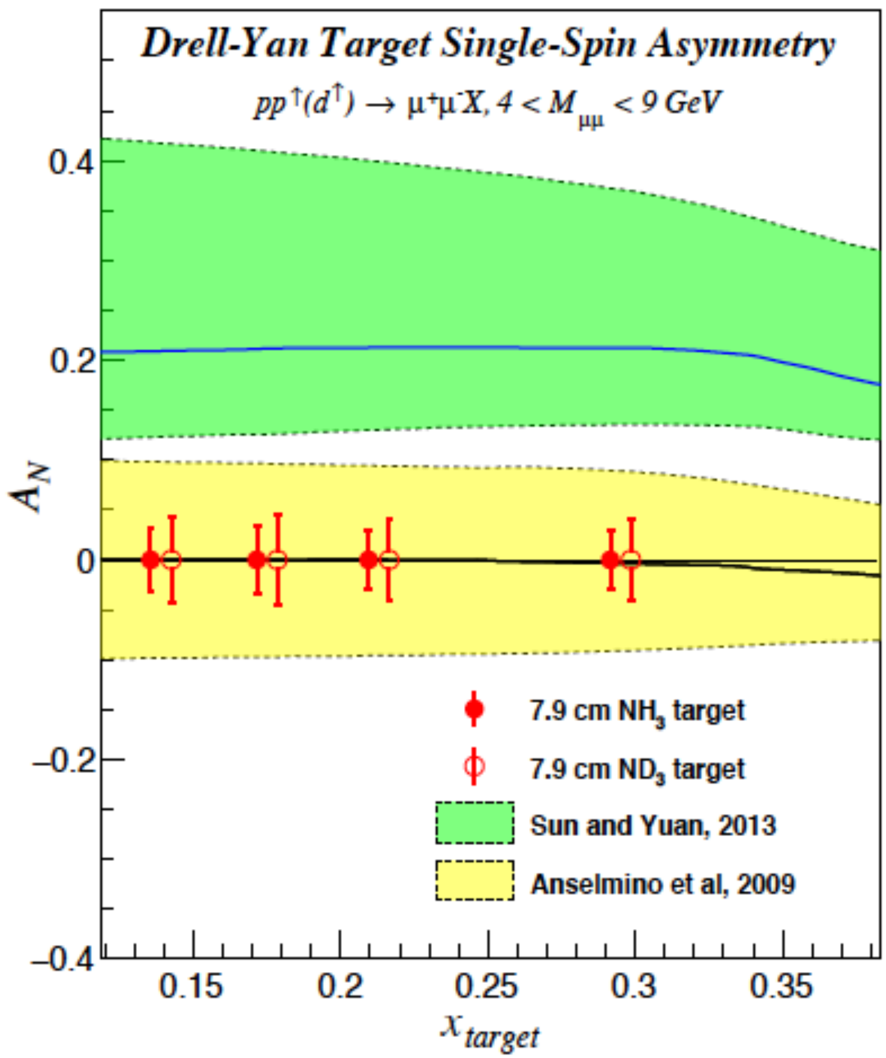
- Sea Quark Sivers poorly constrained, but small

1612.06413, M. Anselmino et al



- Test pion cloud model

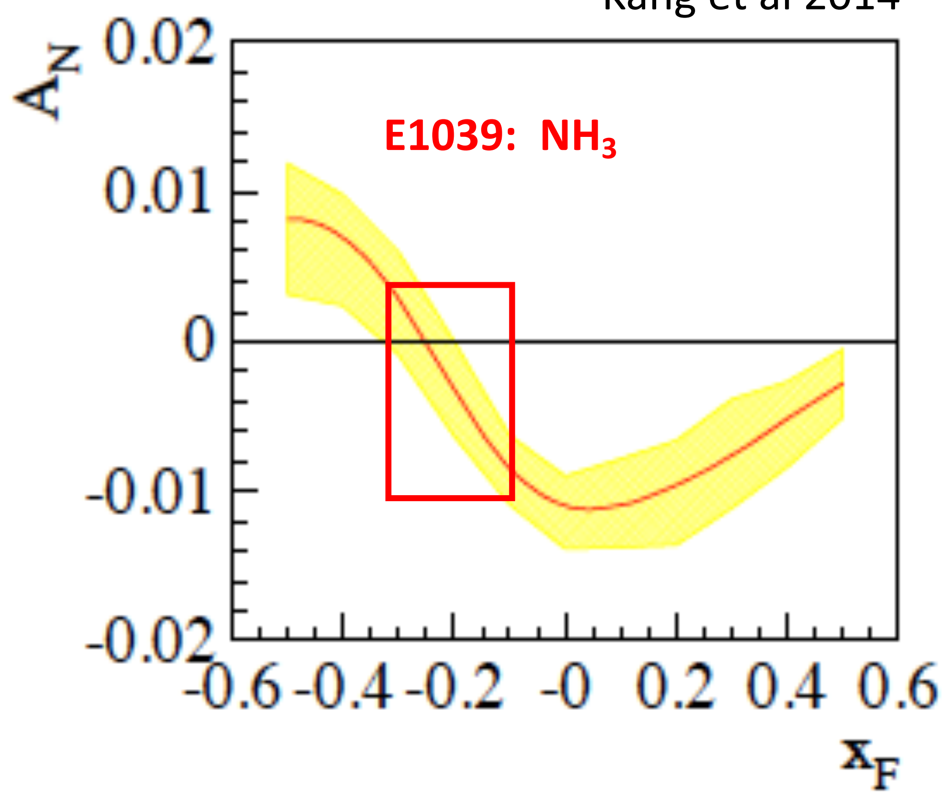
E1039 DY A_N Sensitivity



Control of systematic errors for high precision measurements

- ND_3
- NH_3

Kang et al 2014



E1039 Polarized Targets and TSSA

$$A_{\mathrm{meas}} = \underbrace{f \cdot P_{\mathrm{T}}}_{\sim 0.1} \cdot A_{\mathrm{phy}}$$

~ 0.1

~ 0.01

A_{meas} ~ 0.001

Material	Dens.	Dilution Factor	Packing Frac	<Pol>	Inter. Length
NH_3	.867 g/cm^3	.176	.60	80%	5.3 %
ND_3	1.007 g/cm^3	.3	.60	32%	5.7%

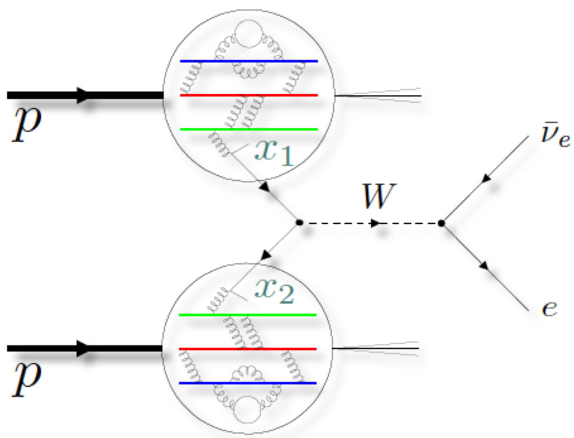
Table 1: *Parameters for the polarized target*

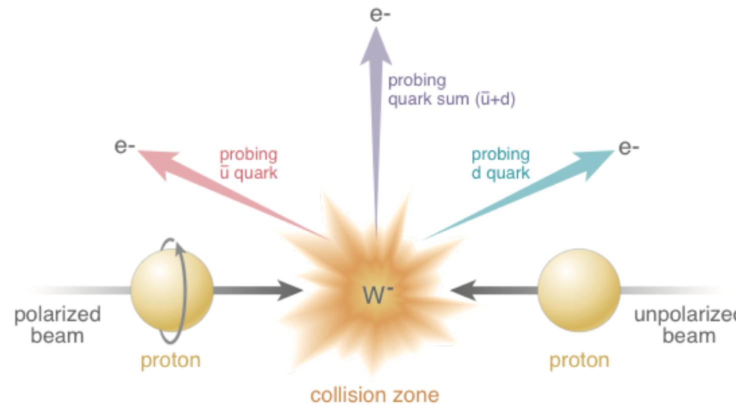
x_2 bin	$< x_2 >$	NH_3 ($p^\uparrow$)		ND_3 ($d^\uparrow$)		$n^\uparrow$
		N	ΔA (%)	N	ΔA (%)	ΔA(%)
0.10 - 0.16	0.139	5.0×10^4	3.2	5.8×10^4	4.3	5.4
0.16 - 0.19	0.175	4.5×10^4	3.3	5.2×10^4	4.6	5.7
0.19 - 0.24	0.213	5.7×10^4	2.9	6.6×10^4	4.1	5.0
0.24 - 0.60	0.295	5.5×10^4	3.0	6.4×10^4	4.1	5.1

Table 4: *Event yield and statistical precision of the A_N measurement in each of the x_2 bins for the NH_3 ($p^\uparrow$) and ND_3 ($d^\uparrow$) targets, and the deduced A_N measurement precision for polarized n.*

Sea Quarks Probed at RHIC 500GeV p+p

$$q(x_1) + \bar{q}'(x_2) \rightarrow W^{\pm} \rightarrow e^{\pm} + \nu(\bar{\nu})$$





$A_N(W^+) \sim$ $\left(\Delta^N f_{u/p^\uparrow} \otimes f_{\bar{d}/p} + \underline{\Delta^N f_{\bar{d}/p^\uparrow}} \otimes f_{u/p}\right)$

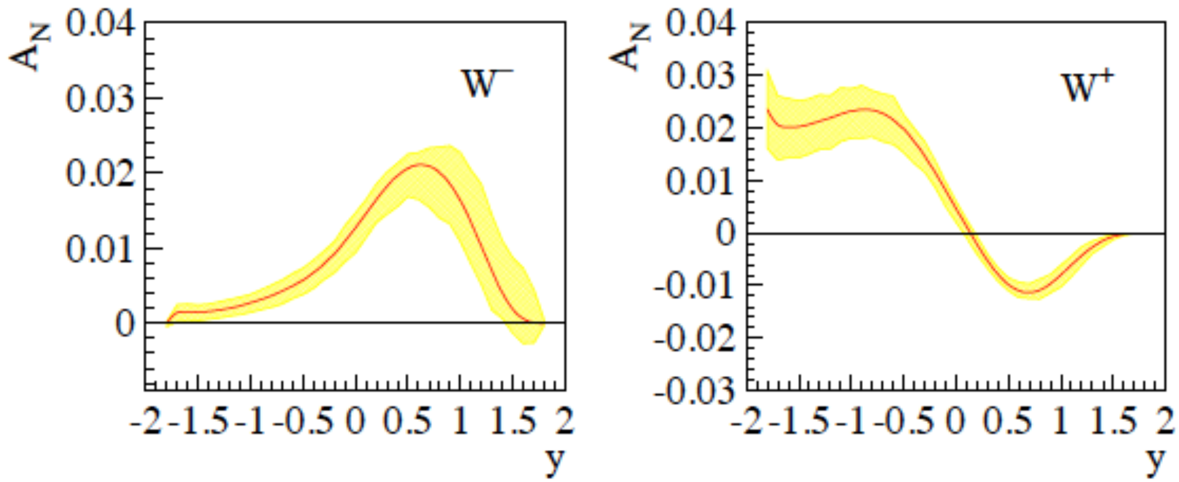
$A_N(W^-) \sim$ $\left(\underline{\Delta^N f_{\bar{u}/p^\uparrow}} \otimes f_{d/p} + \Delta^N f_{d/p^\uparrow} \otimes f_{\bar{u}/p}\right)$

Sensitive to flavor identified (sea)quarks' Sivers functions

<x>_RHIC ~ 0.15

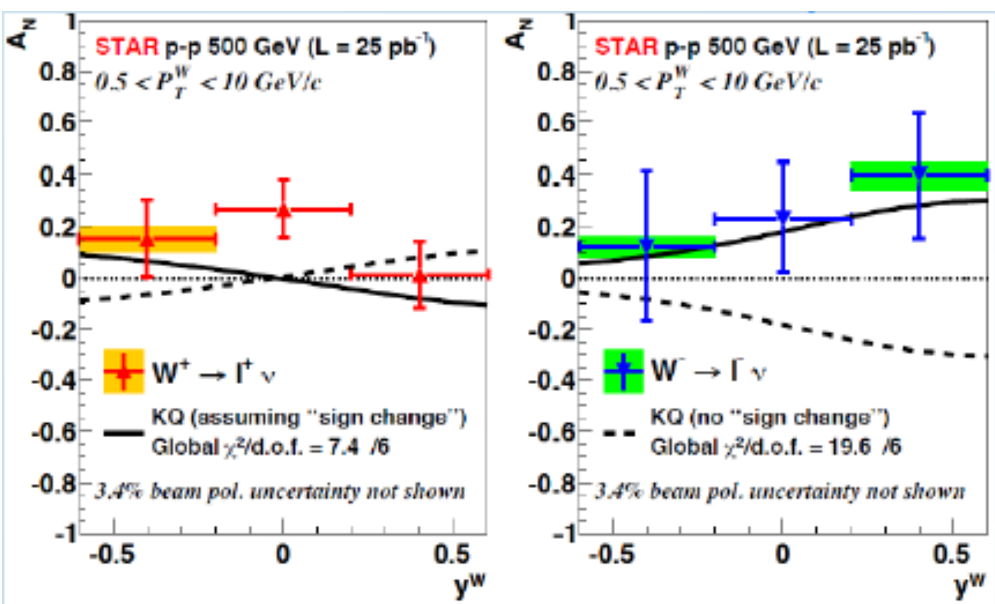
RHIC W$^{+/-}$ TSSA: Sea Quark Sivers

QCD Evolution included, Kang et al, 2014



QCD evolution:
reduces the amplitude

Anselmino et al 2016



RHIC data:
Statistically limited, ~0(10%)

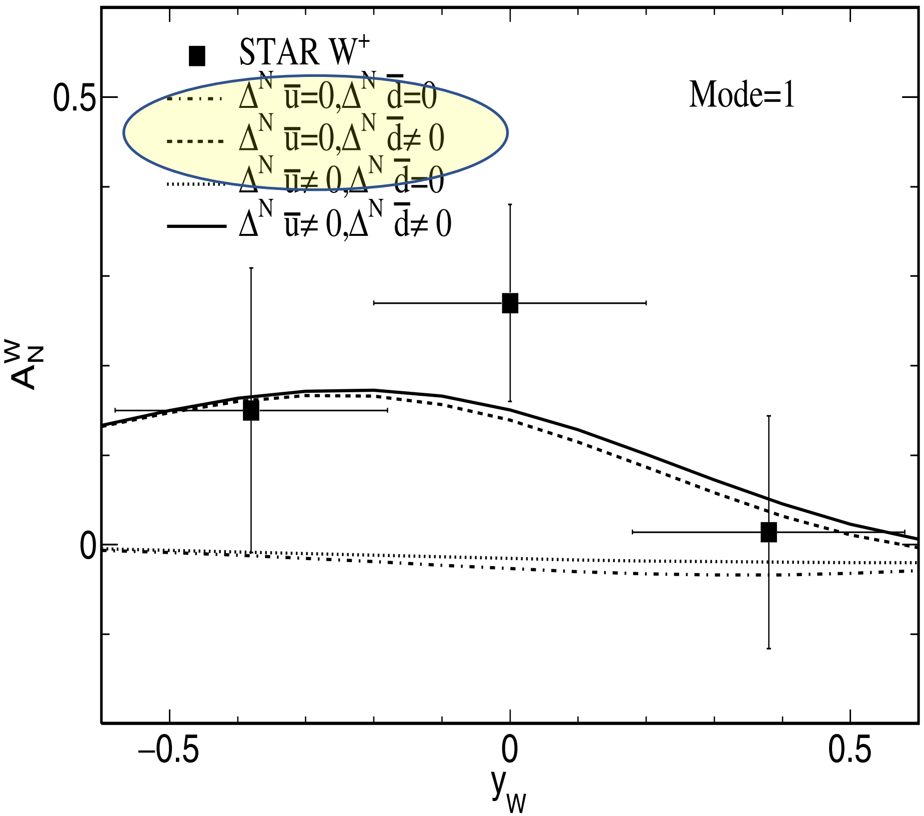
E1039:
- lower Q^2
- Better statistics, ~O(1%)

Sea Quark Sivers Effects: RHIC $W^{+/-}$ A_N

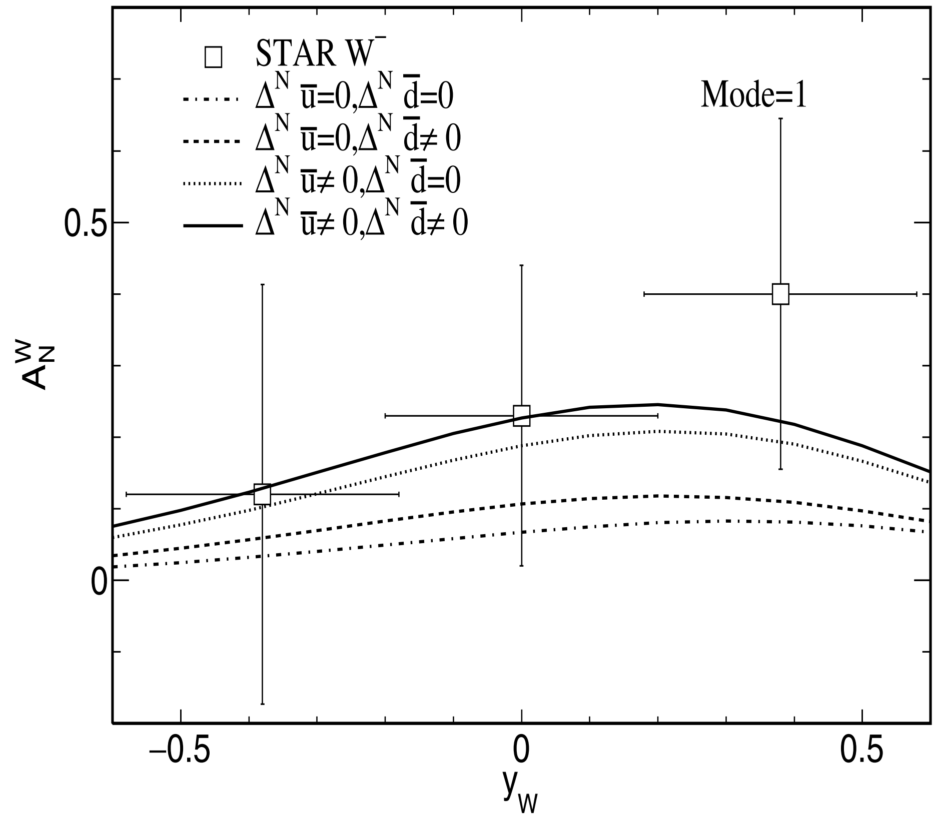
Favors non-zero d-bar Sivers:
~ pion cloud picture

Slightly prefer to have good d-bar data (ND_3) from E1039 first

F. Tian et al. / Nuclear Physics A 968 (2017) 379–390



(b) $A^N_{W^+}$.



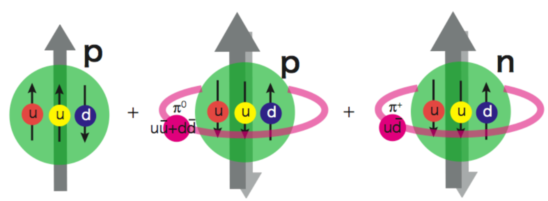
(a) $A^N_{W^-}$.

SeaQuest/E1039 Projected Drell-Yan A_N

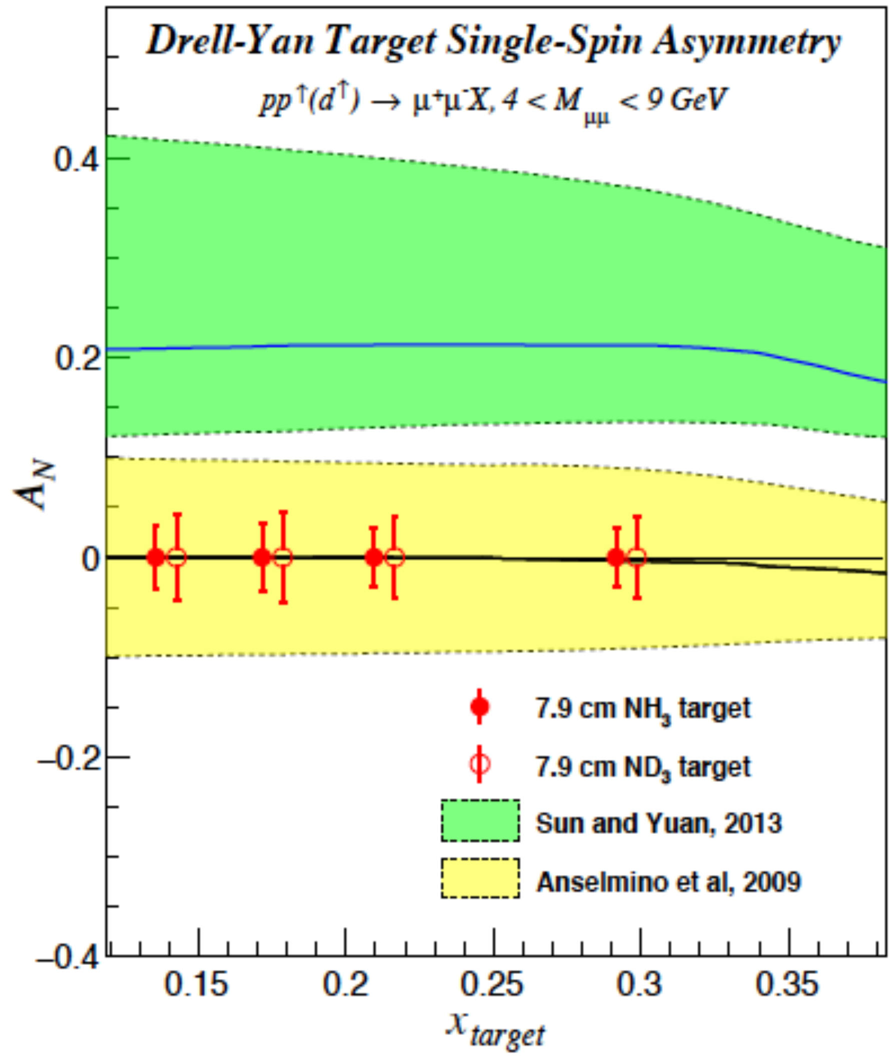
Sea quark Sivers:

$$A_N^{DY} \propto \frac{u(x_b)\cdot f_{1T}^{\perp,\bar{u}}(x_t)}{u(x_b)\cdot \bar{u}(x_t)}$$

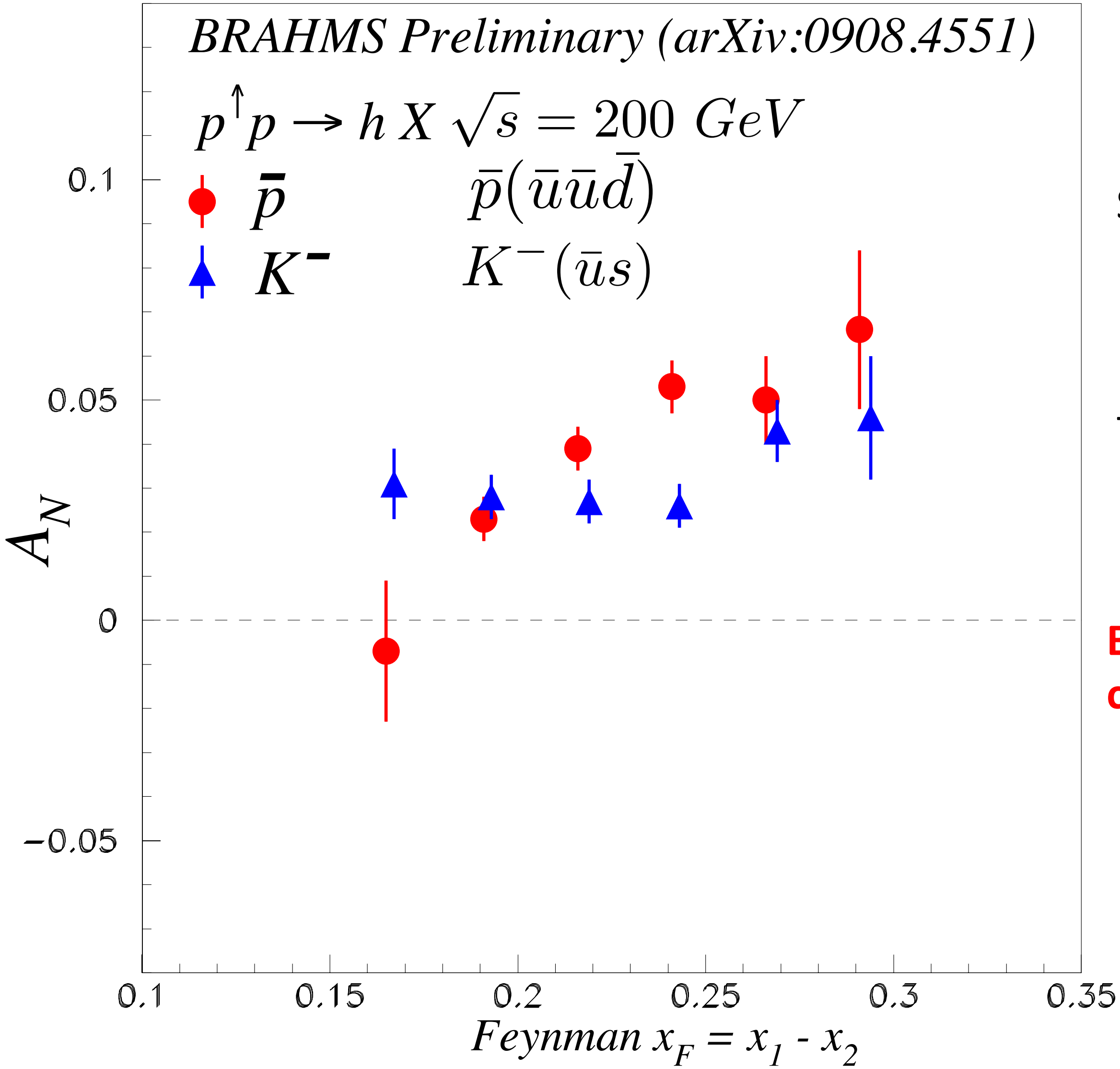
Pion cloud model:



Prefer to use ND_3 for “d-bar” Sivers



Non-Vanishing Sea Quark Sivers Distribution ?

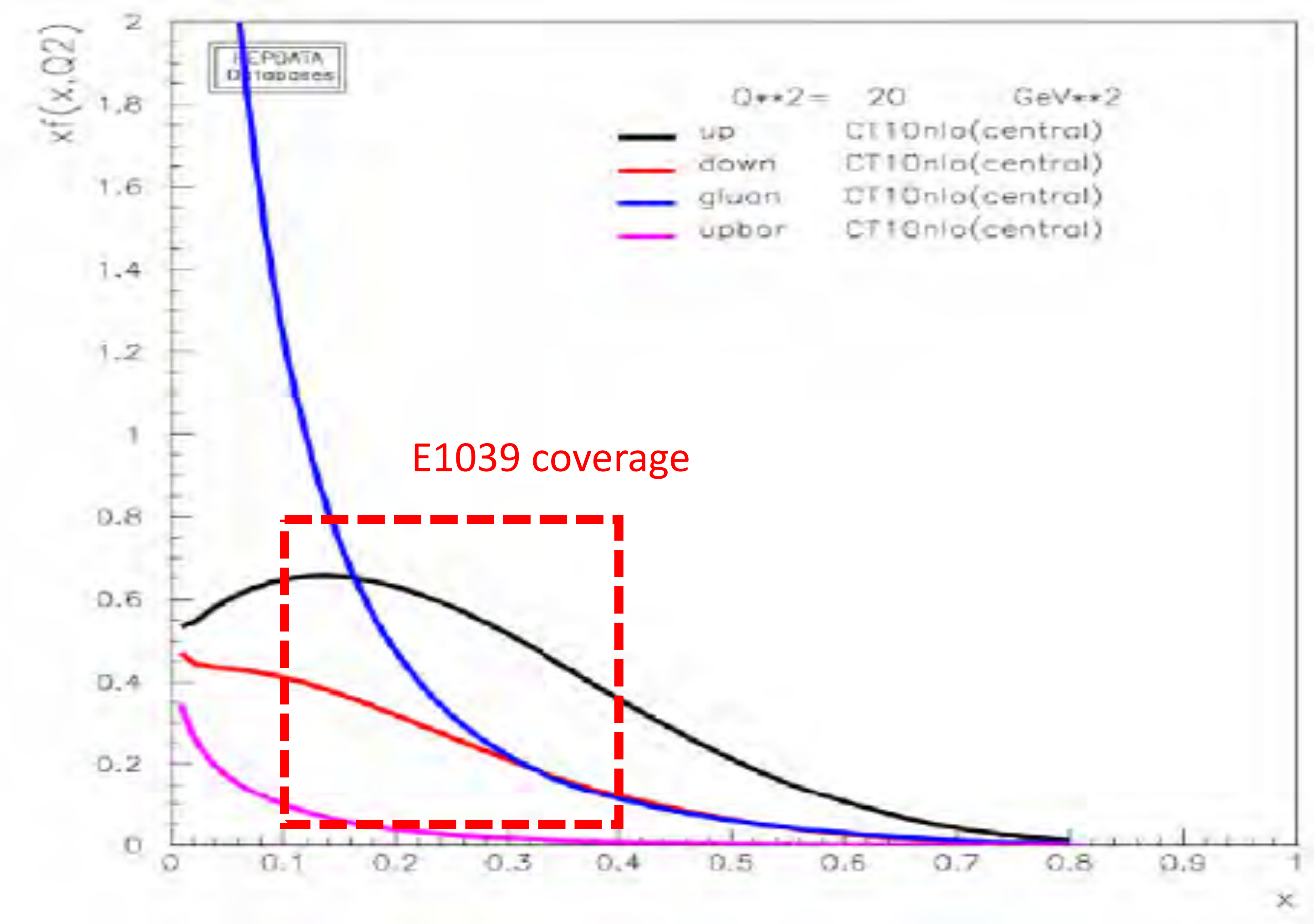


Sea quark generates left-right bias ?

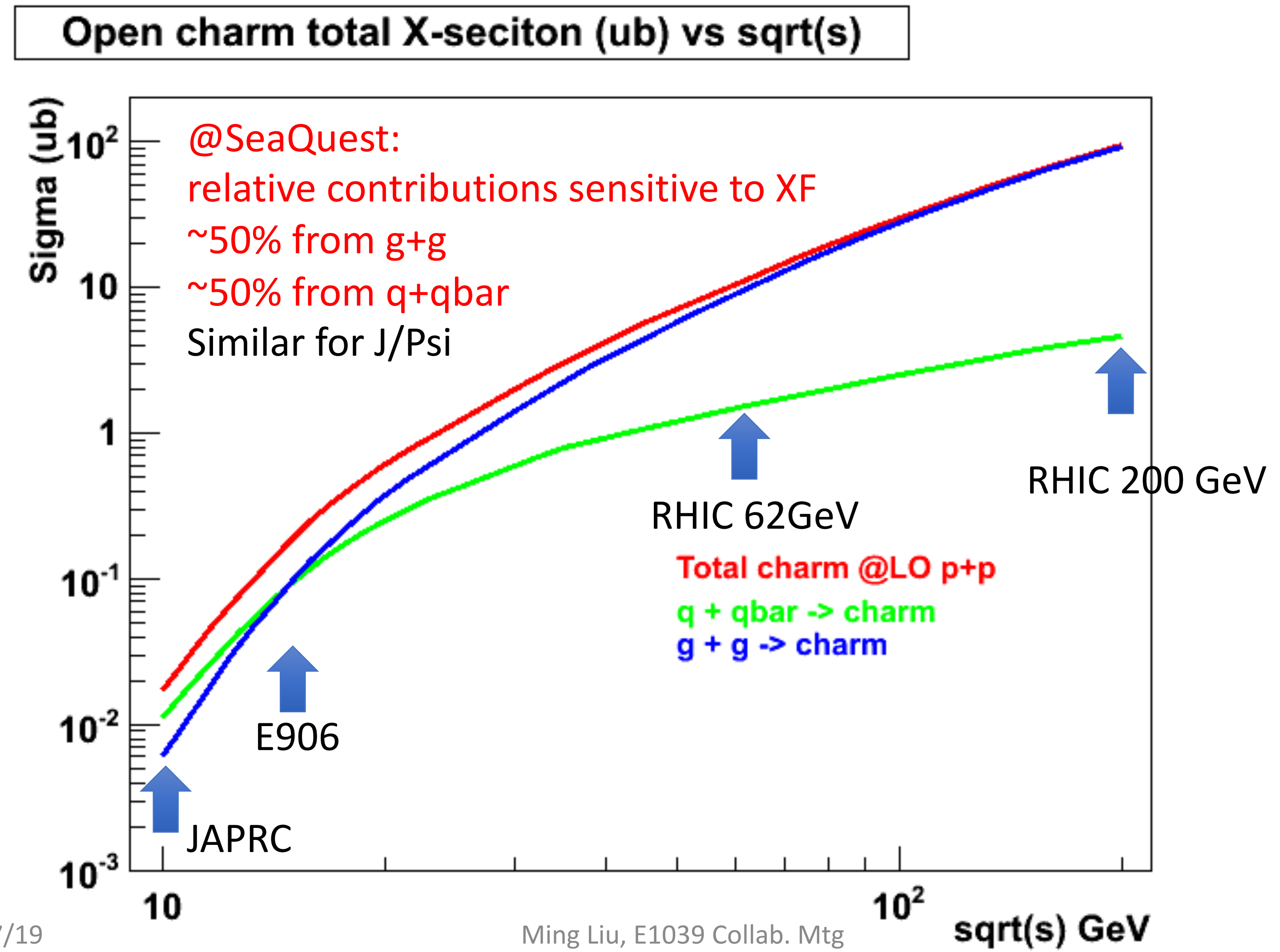
Left-right bias generated through fragmentation process ?

But the asymmetry from sea-quark could not be very large

Study Gluon Sivers at high-x
- a lot of gluons but poorly known!



Open Charm Production in p+p at LO - access gluon distribution



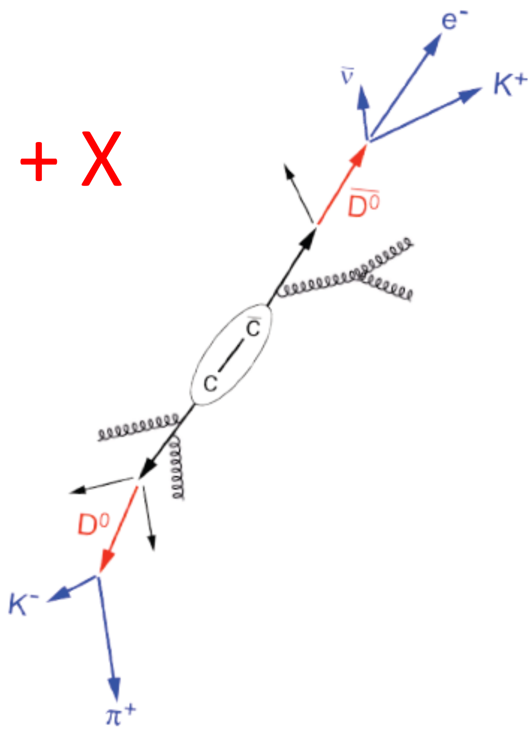
Gluon Sivers from a Model Fit

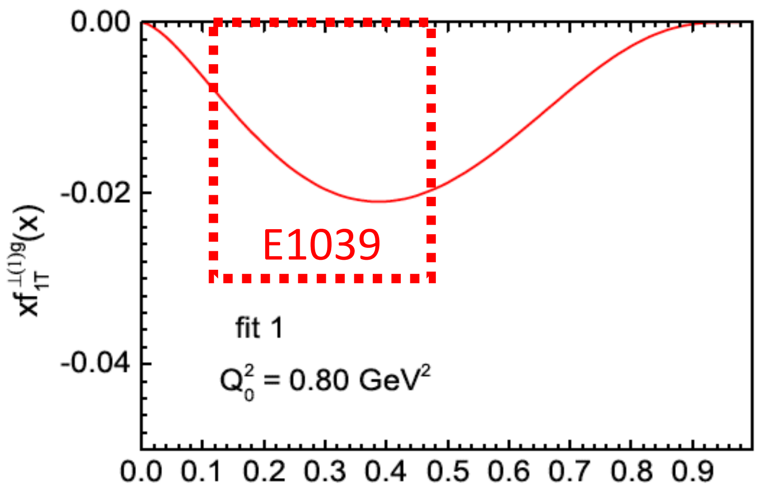
1611.00125 Z. Lu & B.Q. Ma

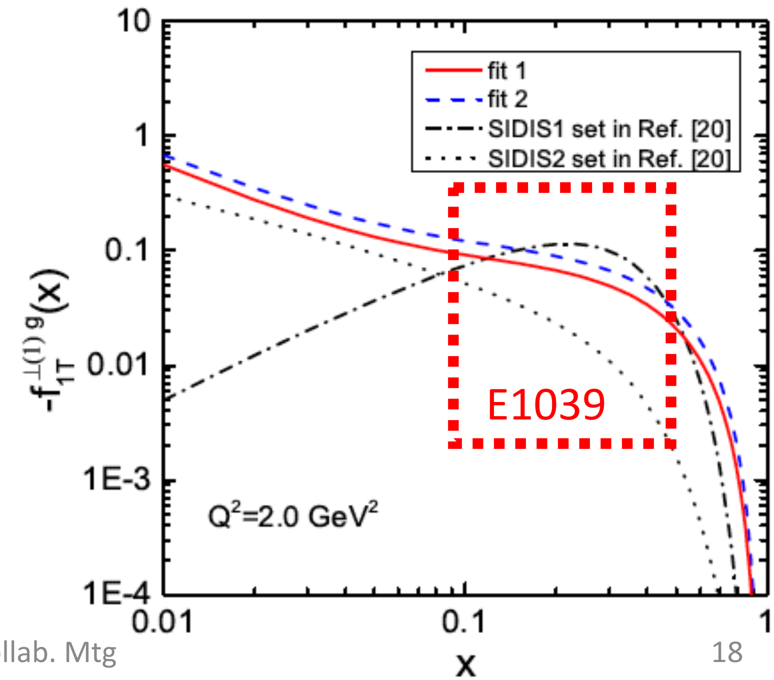
- Possible large gluon Sivers
- E1039 coverage:

  x =0.1 ~ 0.4

D -> mu + X







Open Charm TSSA in Twist-3 Approach

Factorized formula for D-meson production

Qiu, 2010

- Same factorized formula for both subprocesses:

$$E_{P_h}\frac{d\Delta\sigma}{d^3P_h}\Big|_{q\bar{q}\to c\bar{c}} = \frac{\alpha_s^2}{S}\sum_q \int\frac{dz}{z^2}D_{c\to h}(z)\int\frac{dx'}{x'}\phi_{\bar{q}/B}(x')\int\frac{dx}{x}\sqrt{4\pi\alpha_s}\left(\frac{\epsilon^{P_h s_T n\bar{n}}}{z\tilde{u}}\right)\delta\left(\tilde{s}+\tilde{t}+\tilde{u}\right)$$
$$\times\left[\left(T_{q,F}(x,x)-x\frac{d}{dx}T_{q,F}(x,x)\right)H_{q\bar{q}\to c}(\tilde{s},\tilde{t},\tilde{u})+T_{q,F}(x,x)\mathcal{H}_{q\bar{q}\to c}(\tilde{s},\tilde{t},\tilde{u})\right],$$

$$E_{P_h}\frac{d\Delta\sigma}{d^3P_h}\Big|_{gg\to c\bar{c}} = \frac{\alpha_s^2}{S}\sum_{i=f,d}\int\frac{dz}{z^2}D_{c\to h}(z)\int\frac{dx'}{x'}\phi_{g/B}(x')\int\frac{dx}{x}\sqrt{4\pi\alpha_s}\left(\frac{\epsilon^{P_h s_T n\bar{n}}}{z\tilde{u}}\right)\delta\left(\tilde{s}+\tilde{t}+\tilde{u}\right)$$
$$\times\left[\left(T_G^{(i)}(x,x)-x\frac{d}{dx}T_G^{(i)}(x,x)\right)H^{(i)}_{gg\to c}(\tilde{s},\tilde{t},\tilde{u})+T_G^{(i)}(x,x)\mathcal{H}^{(i)}_{gg\to c}(\tilde{s},\tilde{t},\tilde{u})\right],$$

- Hard parts:

$$H_{q\bar{q}\to c}=H^I_{q\bar{q}\to c}+H^F_{q\bar{q}\to c}\left(1+\frac{\tilde{u}}{\tilde{t}}\right)\qquad H^{(i)}_{gg\to c}=H^{I(i)}_{gg\to c}+H^{F(i)}_{gg\to c}\left(1+\frac{\tilde{u}}{\tilde{t}}\right)$$

All $\mathcal{H}_{q\bar{q}\to c}$ and $\mathcal{H}^{I(i)}_{gg\to c}$ and $\mathcal{H}^{F(i)}_{gg\to c}$ vanish as $m_c^2\to 0$

- Hard parts change sign for $T_G^{(d)}(x,x)$ when $c\to\bar{c}$

$$H^{(f)}_{gg\to\bar{c}}=H^{(f)}_{gg\to c},\qquad H^{(d)}_{gg\to\bar{c}}=-H^{(d)}_{gg\to c},$$
$$\mathcal{H}^{(f)}_{gg\to\bar{c}}=\mathcal{H}^{(f)}_{gg\to c},\qquad \mathcal{H}^{(d)}_{gg\to\bar{c}}=-\mathcal{H}^{(d)}_{gg\to c}.$$

Twist-3
-Quark-gluon
-Tri-gluon

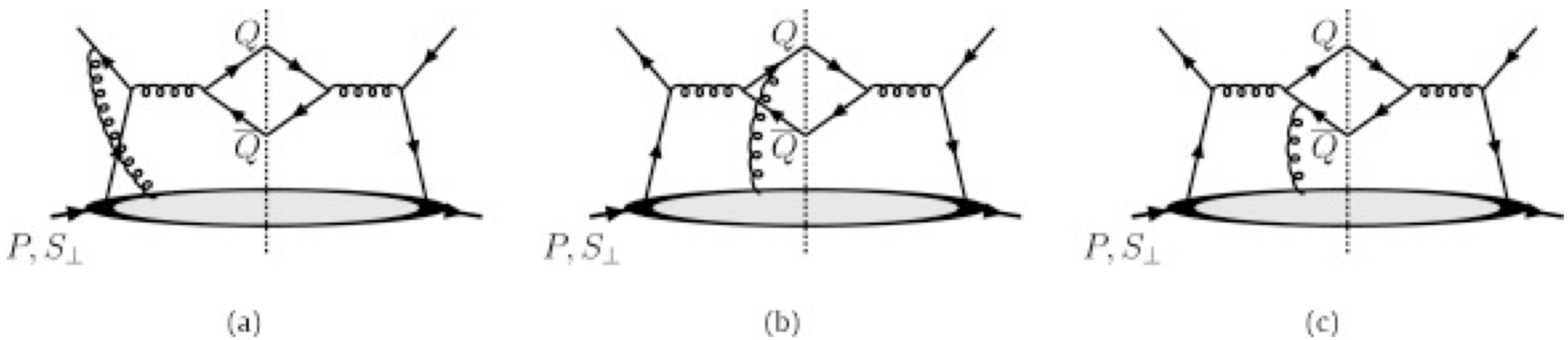
Heavy Quark TSSA @Fermilab

Twist-3 quark-gluon correlation functions

- Different color factors for charm and anti-charm A_N

$$q+\bar{q}\to c\bar{c}$$

F. Yuan and J. Zhou PLB 668 (2008) 216-220

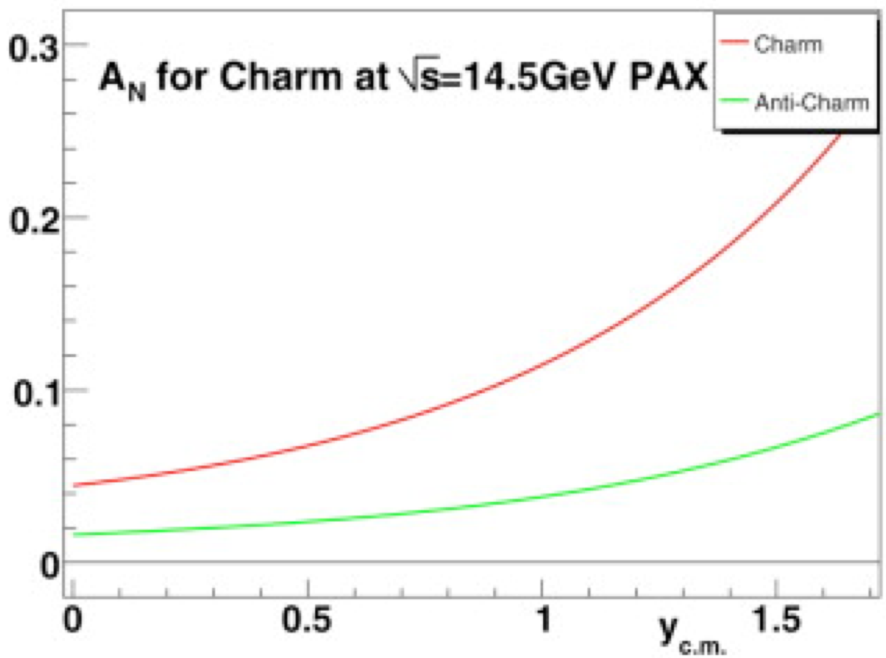


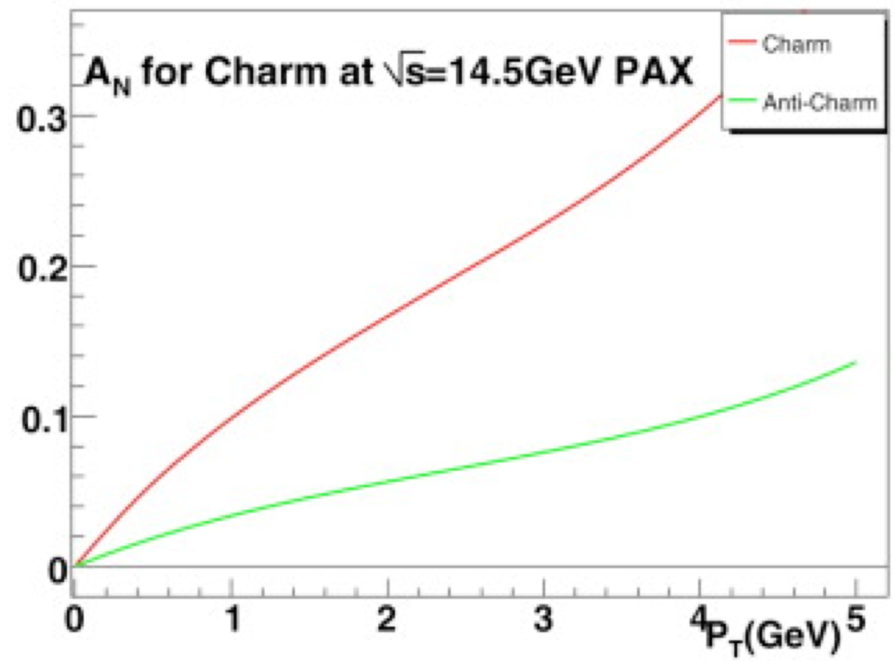
Initial state	Charm	anti-Charm
$\sim \frac{1}{2N_C^2}$	$\sim \frac{N_C^2-2}{2N_C^2}$	$\sim \frac{2}{2N_C^2}$

Open Charm TSSA at Low Energy

$$A_N : q + \bar{q} \rightarrow c(\bar{c}) + X$$

GSI: p+pbar. (similar energy of E1039)

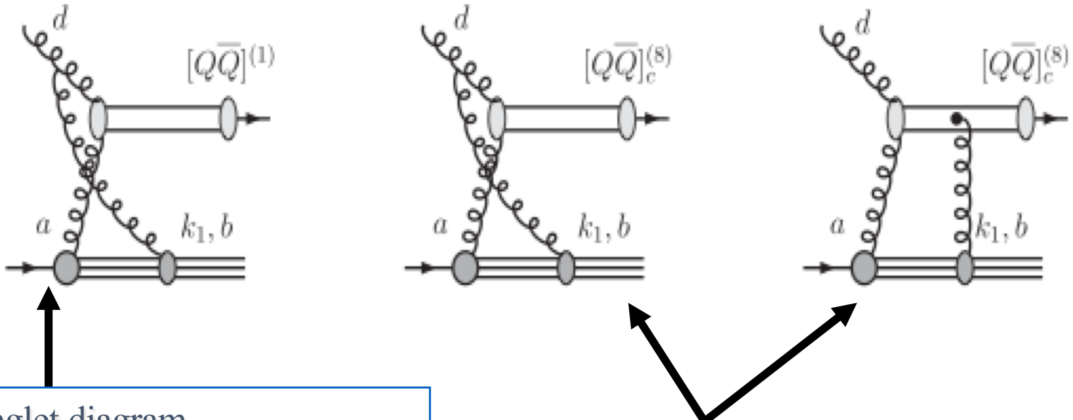




J/ψ A_N

- J/ψ A_N is sensitive to the production mechanisms
  - Assuming a non-zero gluon Sivers function, in pp scattering, J/ψ A_N vanishes if the pair are produced in a color-octet model but survives in the color-singlet model

F. Yuan, PRD 78, 014024(2008)

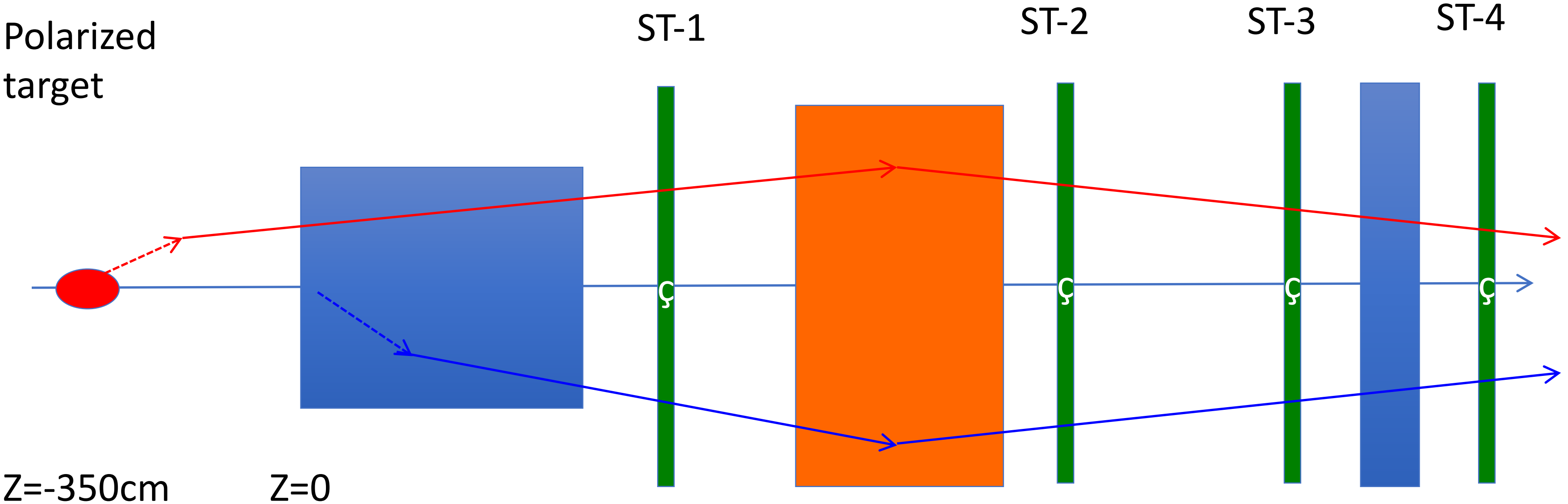


One color-singlet diagram
— no cancellation, asymmetry generated by the initial state interaction, $A_N \neq 0$

Two color-octet diagrams
— cancellation between initial and final state interactions, no asymmetry A_N=0

Single & Dimuon Triggers:

Target-Dump Separation with DP trigger detectors? (dZ~30cm)



1. Tag: single muons from pi/K decays
   - from target and beam dump
2. Trigger: single muons
   - high statistic single muons to provide positive A_N signals

- Low pZ events preferred (more "valence origin" hadrons), trigger optimization required;
- High pZ events are more sensitive to gluon and sea-quark Sivers

Summary

- Sea quark Sivers
  - D-bar (ND3)
  - Ubar (NH3)

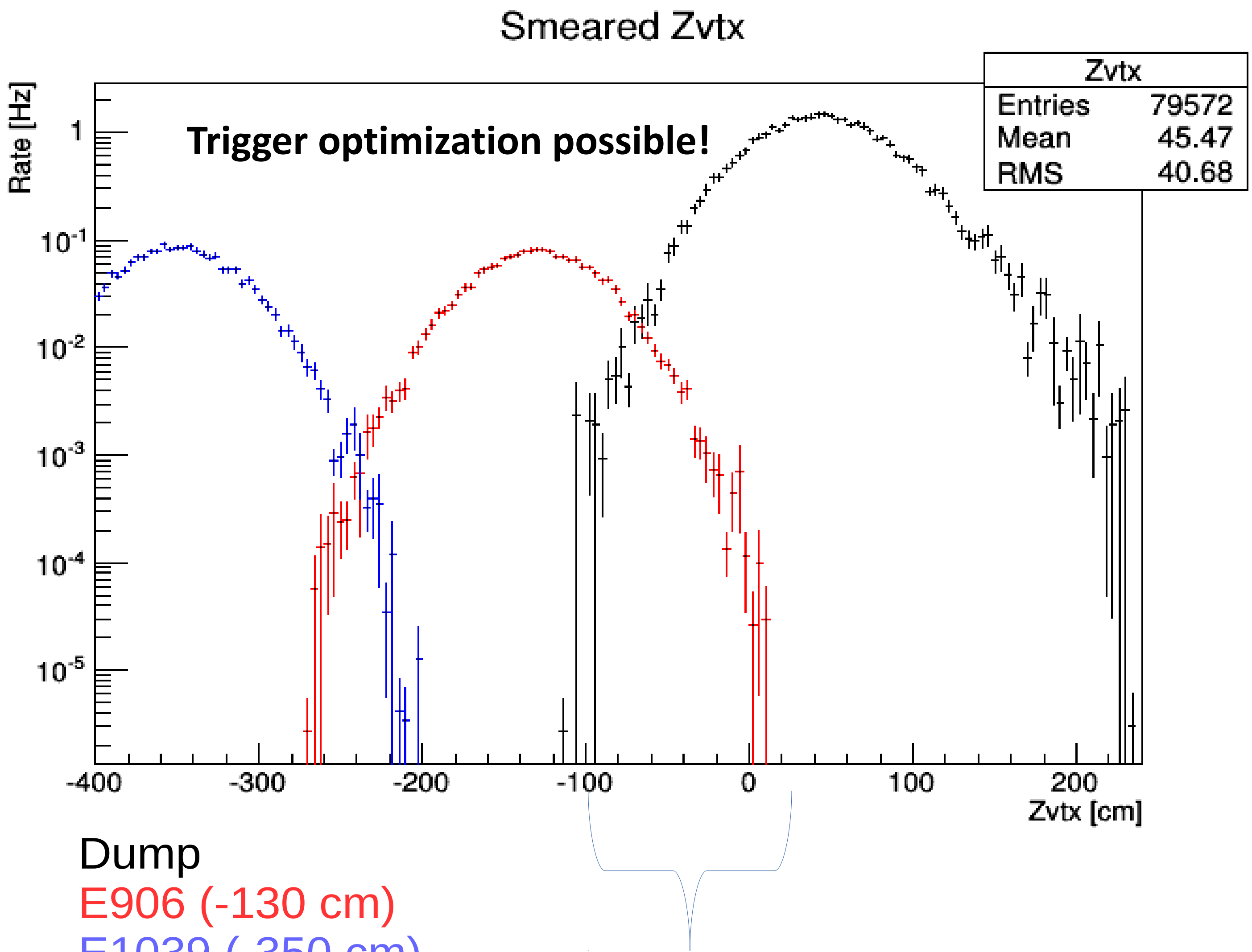
- Gluon Sivers
  - Open charm
  - J/Psi
- Triggers optimization
  - Target and dump separation

Expected TSSA small -- > a lot of statistics required, important to trigger on signals from the target

Backup slides

Target and Beam Dump Event Separation

target at upstream: Z=-3.5m



Dump

E906 (-130 cm)

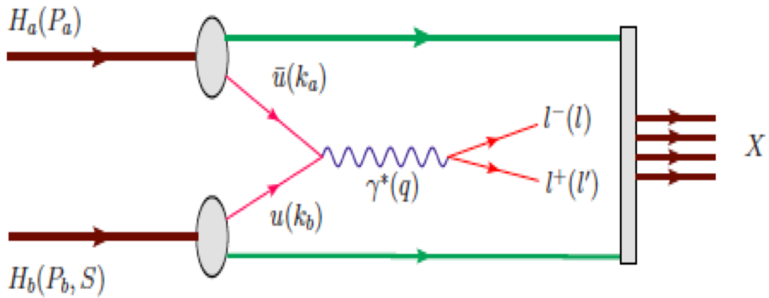
E1039 (-350 cm)

Drell-Yan A_N from COMPASS Polarized Target

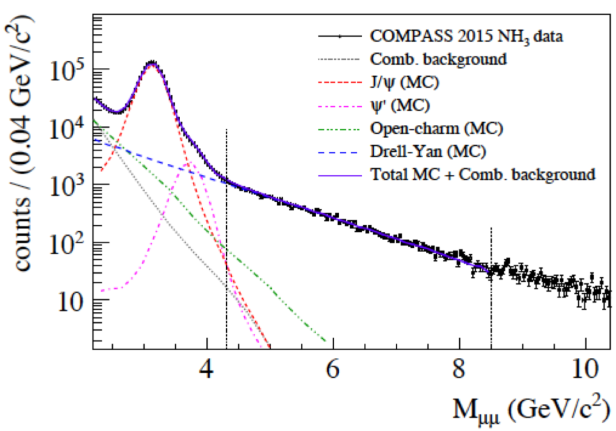
M. Quaresma's talk

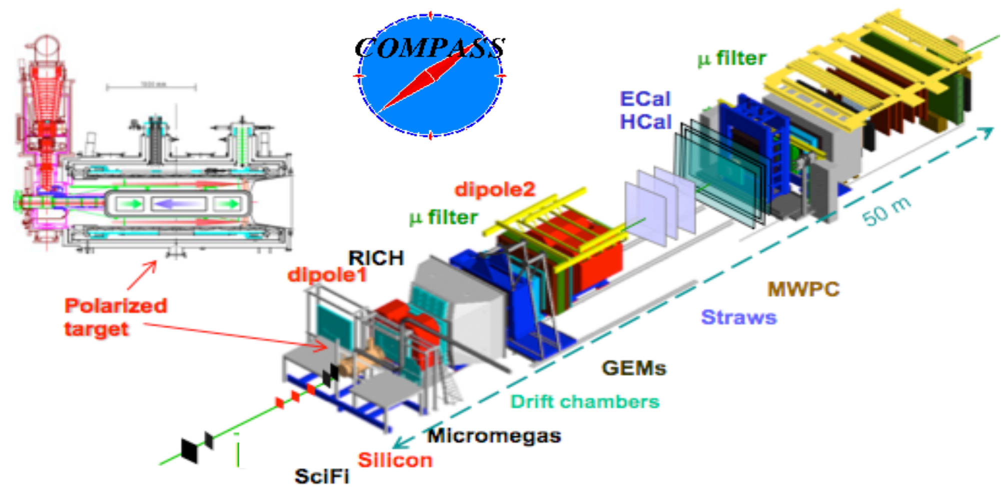
Beam: π^-
190GeV

Polarized
Proton target



- J/ψ (NH_3) **~1.5M**
- HM DY (NH_3) **~35K**

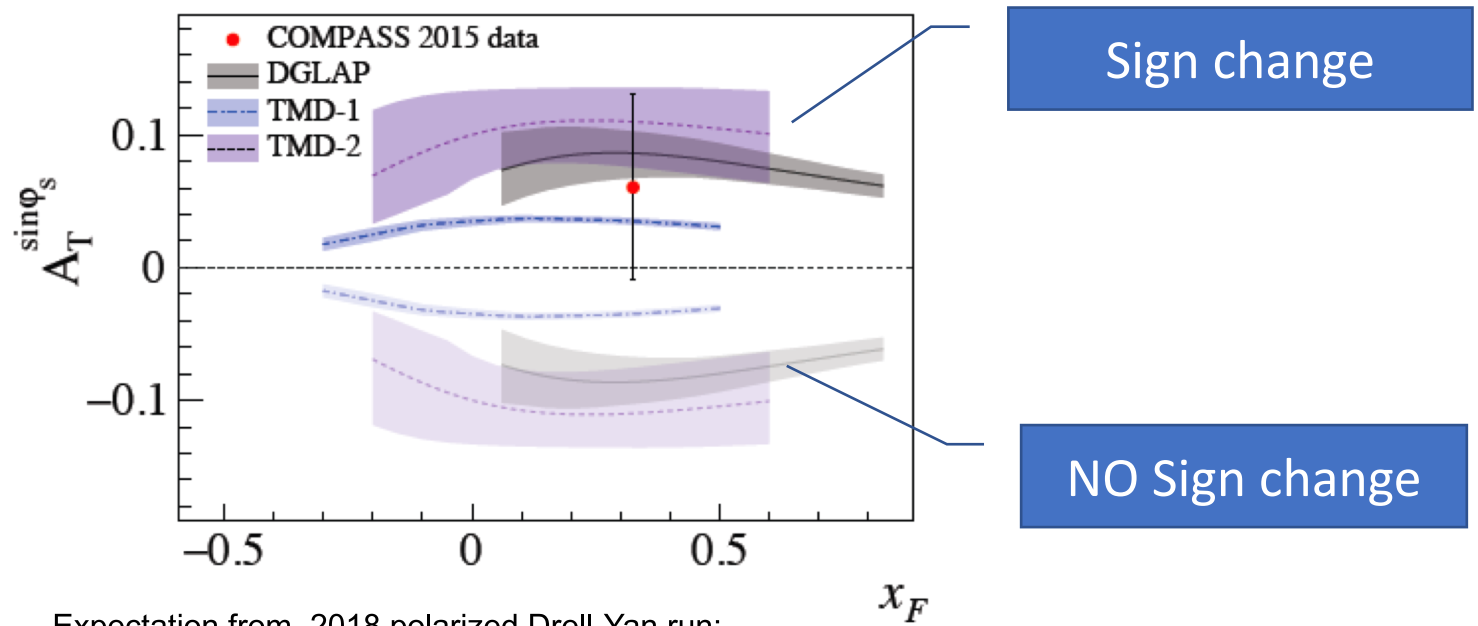




COMPASS Drell-Yan Run 2015 Results

PRL 119, 112002 (2017) PHYSICAL REVIEW LETTERS week ending 15 SEPTEMBER 2017

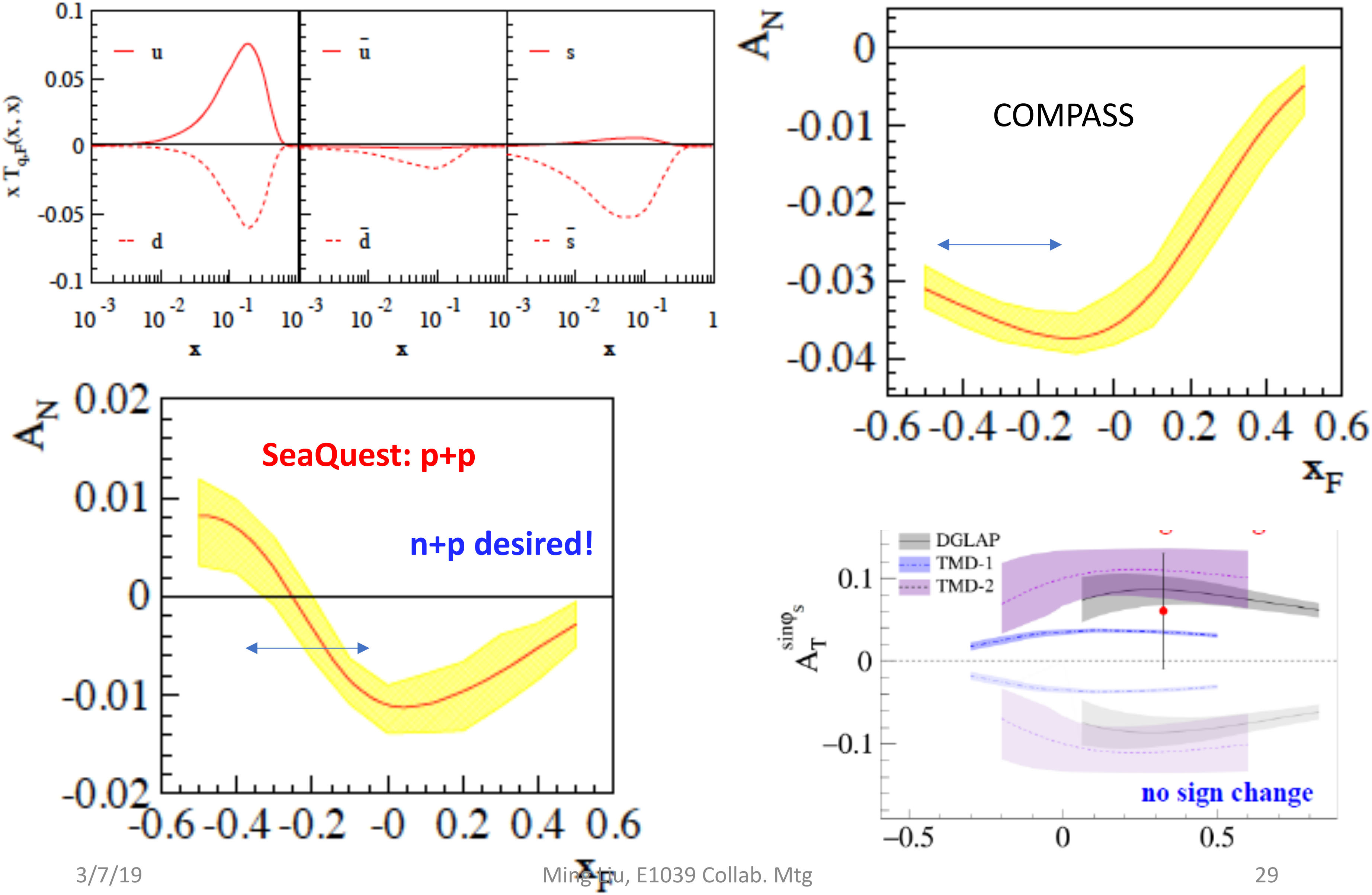
First Measurement of Transverse-Spin-Dependent Azimuthal Asymmetries in the Drell-Yan Process



Expectation from 2018 polarized Drell-Yan run:
Verification of the sign change by reducing of the error by a factor of ~1.5.

Drell-Yan Sivers Asymmetries

Kang et al, 1401.5078



Open Charm via high pT Single muons?

- Open charm cross section
  - Test NLO pQCD framework
- Open charm TSSA
  - test pQCD twist-3 framework

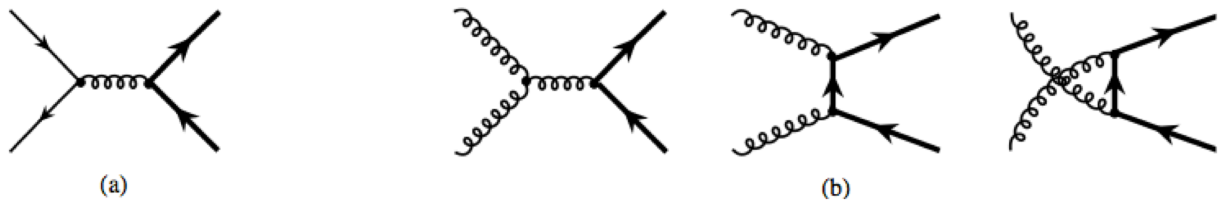
- High pT single muon trigger
- Target and dump separation

TSSA in Heavy Quark Production in p+p

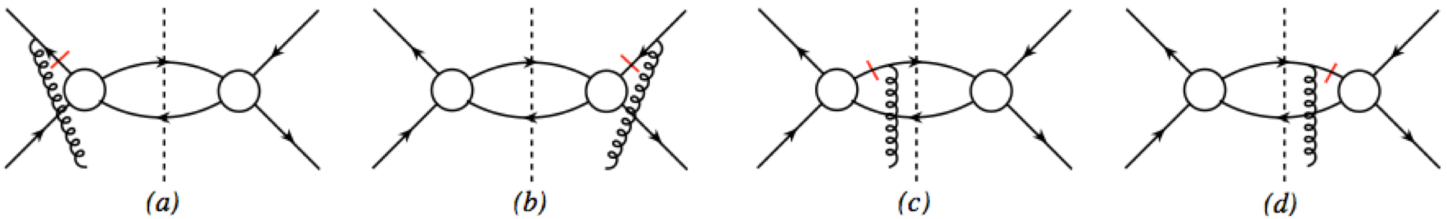
Kang, Qiu, Vogelsang, Yuan, PRD 2008

D-meson production in hadronic collisions

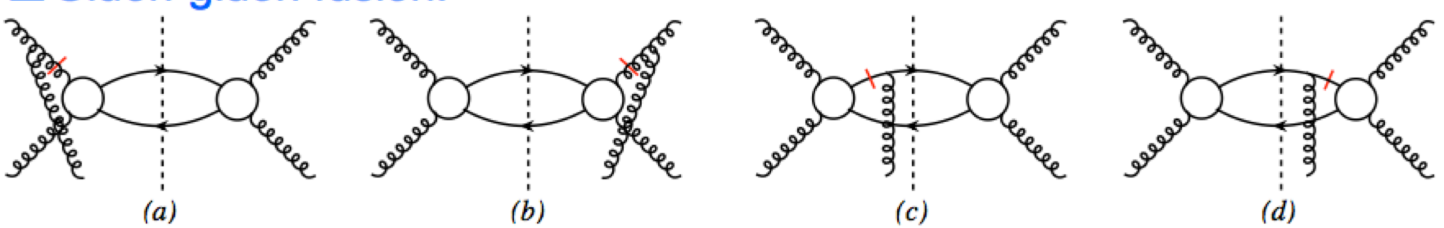
- Two partonic subprocesses:



- Quark-antiquark annihilation:



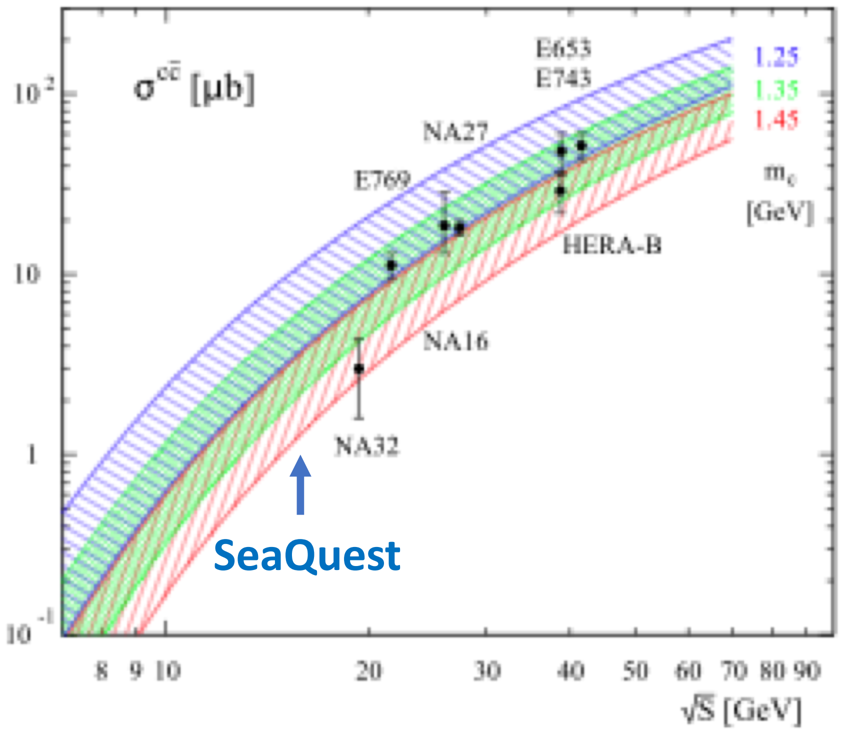
- Gluon-gluon fusion:



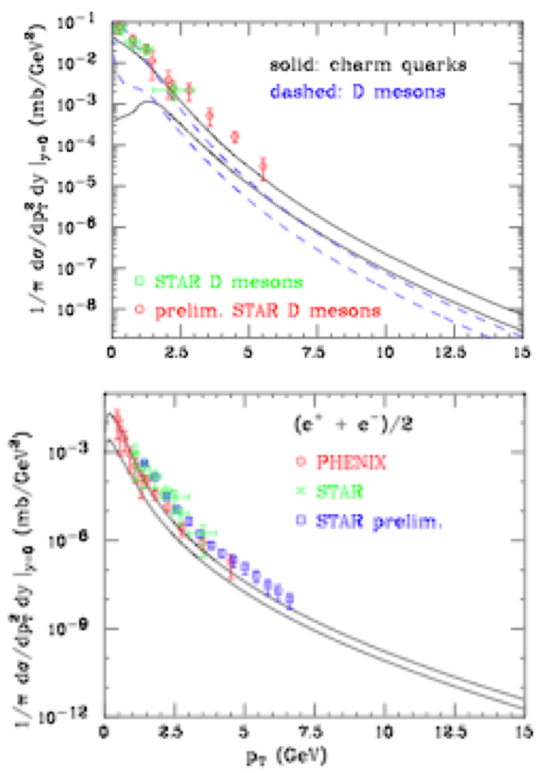
More on Open Charm Production

- Fixed targets vs NLO
- Collider mode @RHIC

EPJ C 52, 987 (2007) J. Riedl, A. Schafer, M. Stratmann



PRL 95, 122001 (2005) M. Cacciari, P. Nason, R. Vogt

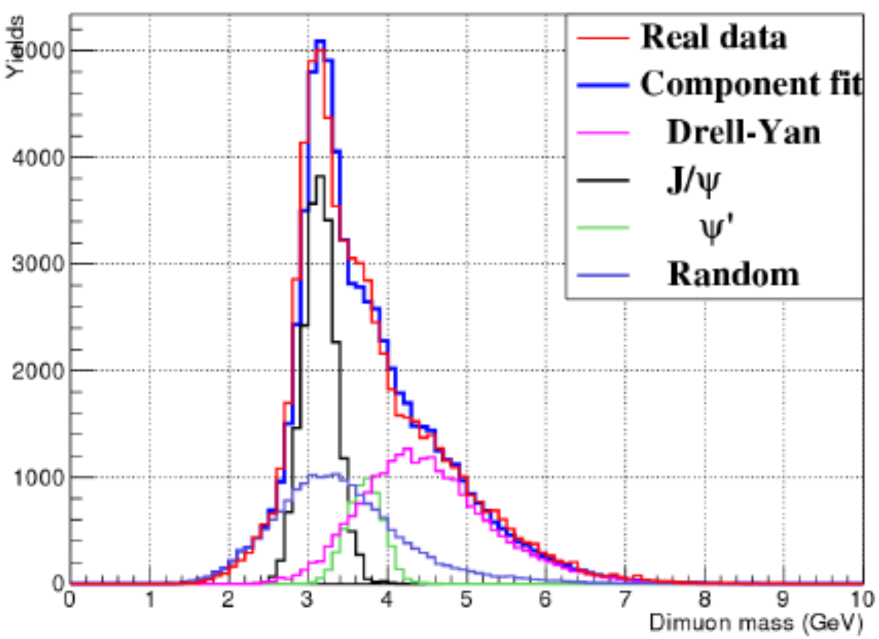


SeaQuest Dimuons:
Improve acceptance for low mass dimuons

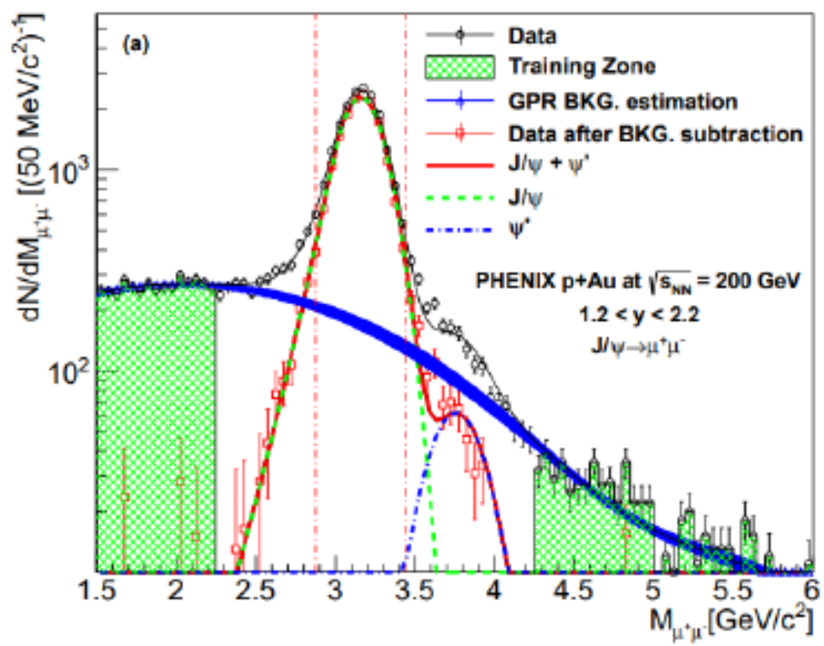
Open up dimuon acceptance at trigger level:

- Possible with the dark photon triggers
- Improved DAQ
- Better background determination

PHENIX dimuons

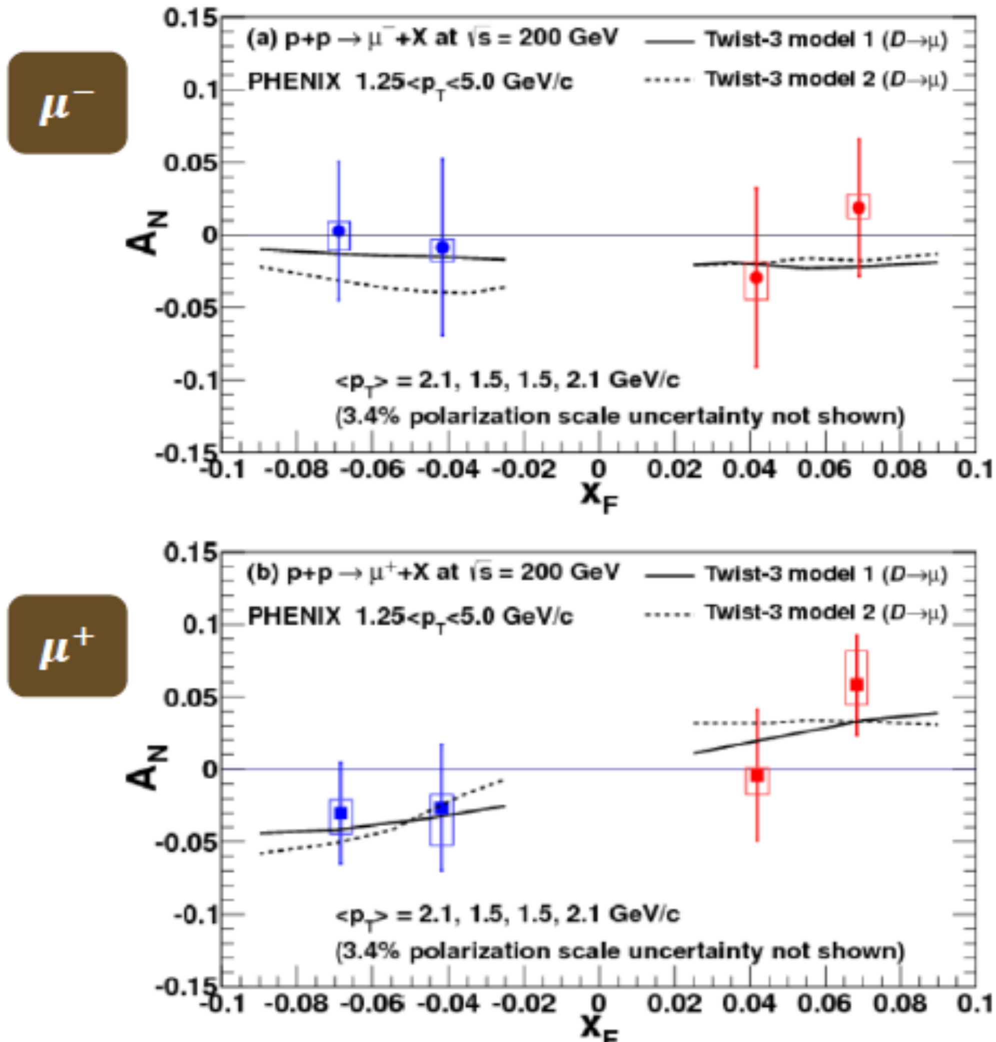


E906 preliminary



First Precision Open HF A_N from PHENIX

Phys.Rev. D95, 112001 (2017)



$$x_F = 2p_L/\sqrt{s}$$