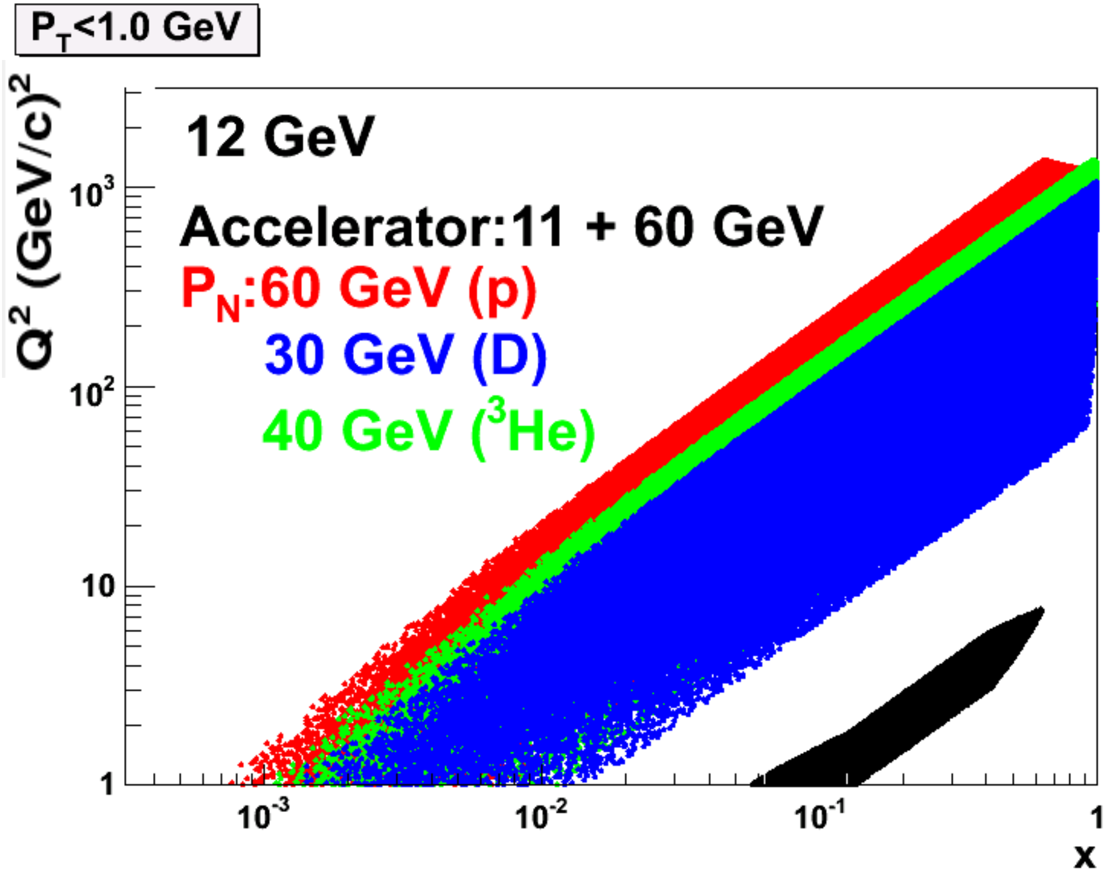
## Duke/JLab Workshop on Partonic Transverse Momentum in Hadrons: Quark Spin-Orbit Correlations and Quark-Gluon Interactions, March 2010


Workshop summary paper:
M. Anselmino *et al*. EPJA 47, 35 (2011)

M. Diehl summary of INT program
M. Anselmino *et al*. INT summary paper

# Study both Proton and Neutron




ion momentum ∝ Z

$P_N \propto$ Z/A

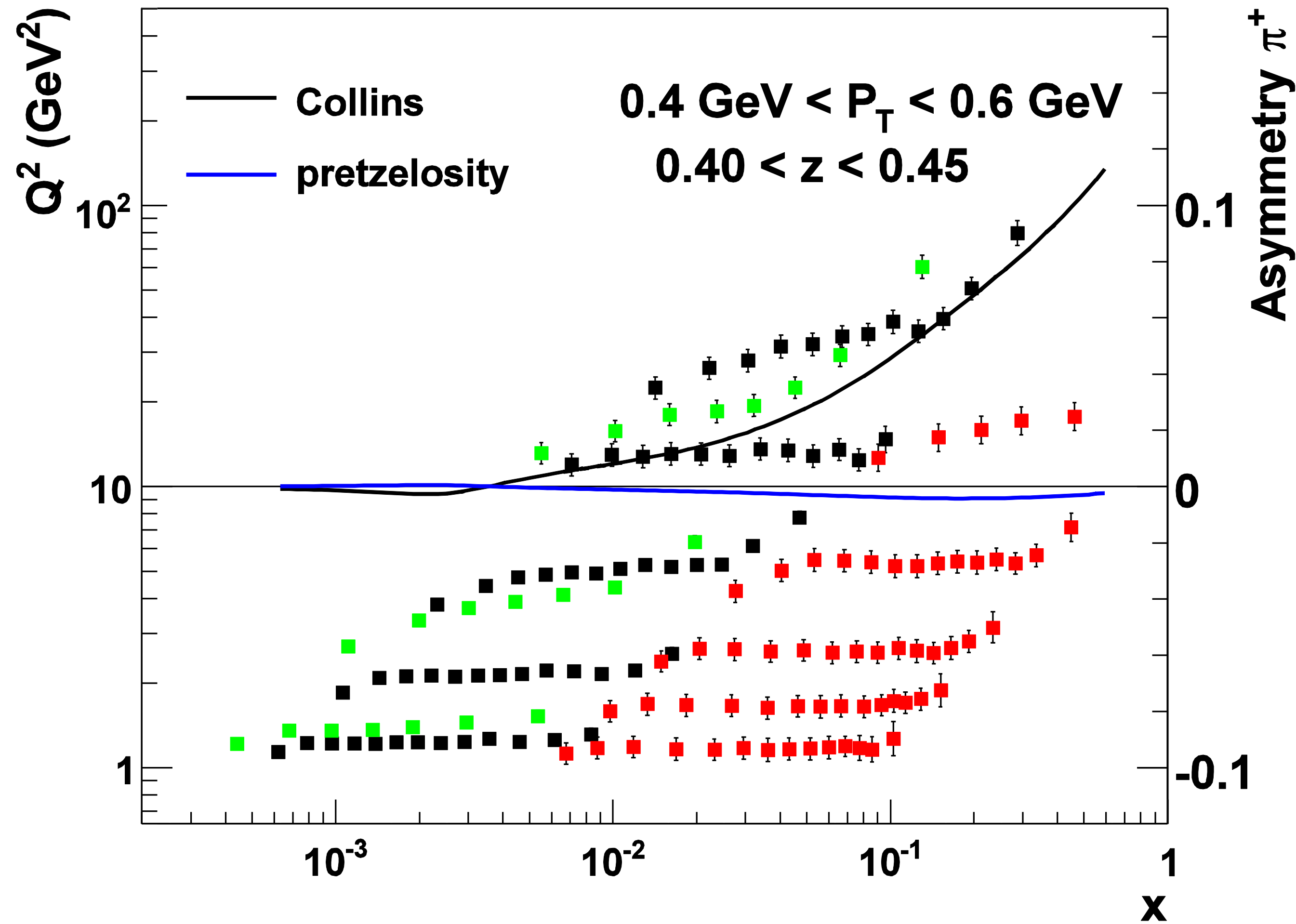
Not weighted by Cross section.

Flavor separation, Combine the data the lowest achievable x limited by the effective neutron beam and the $P_T$ cut

# Projections with Proton (Collins)

- **11 + 60 GeV**
  ***36 days***
  L = 3x10$^{34}$ /cm$^2$/s
- **11 + 100 GeV**
  ***36 days***
  L = 1x10$^{34}$/cm$^2$/s

  2x10$^{-3}$ , $Q^2$<10 GeV$^2$
  4x10$^{-3}$ , $Q^2$>10 GeV$^2$
- **3 + 20 GeV**
  ***36 days***
  L = 1x10$^{34}$/cm$^2$/s
  4x10$^{-3}$ , $Q^2$<10 GeV$^2$
  5x10$^{-3}$ , $Q^2$>10 GeV$^2$

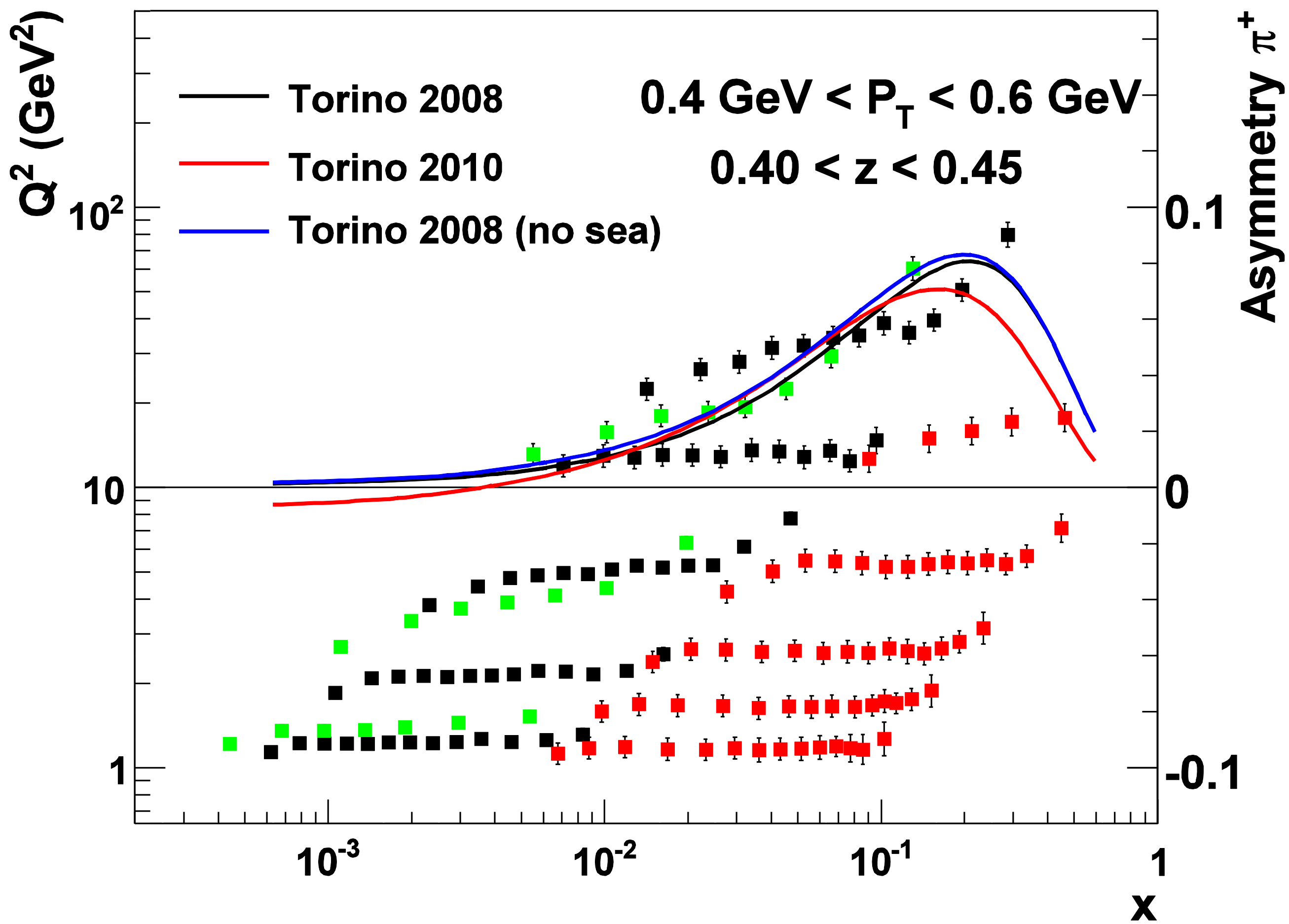



Results on kaons also

# Projections with Proton (Sivers)

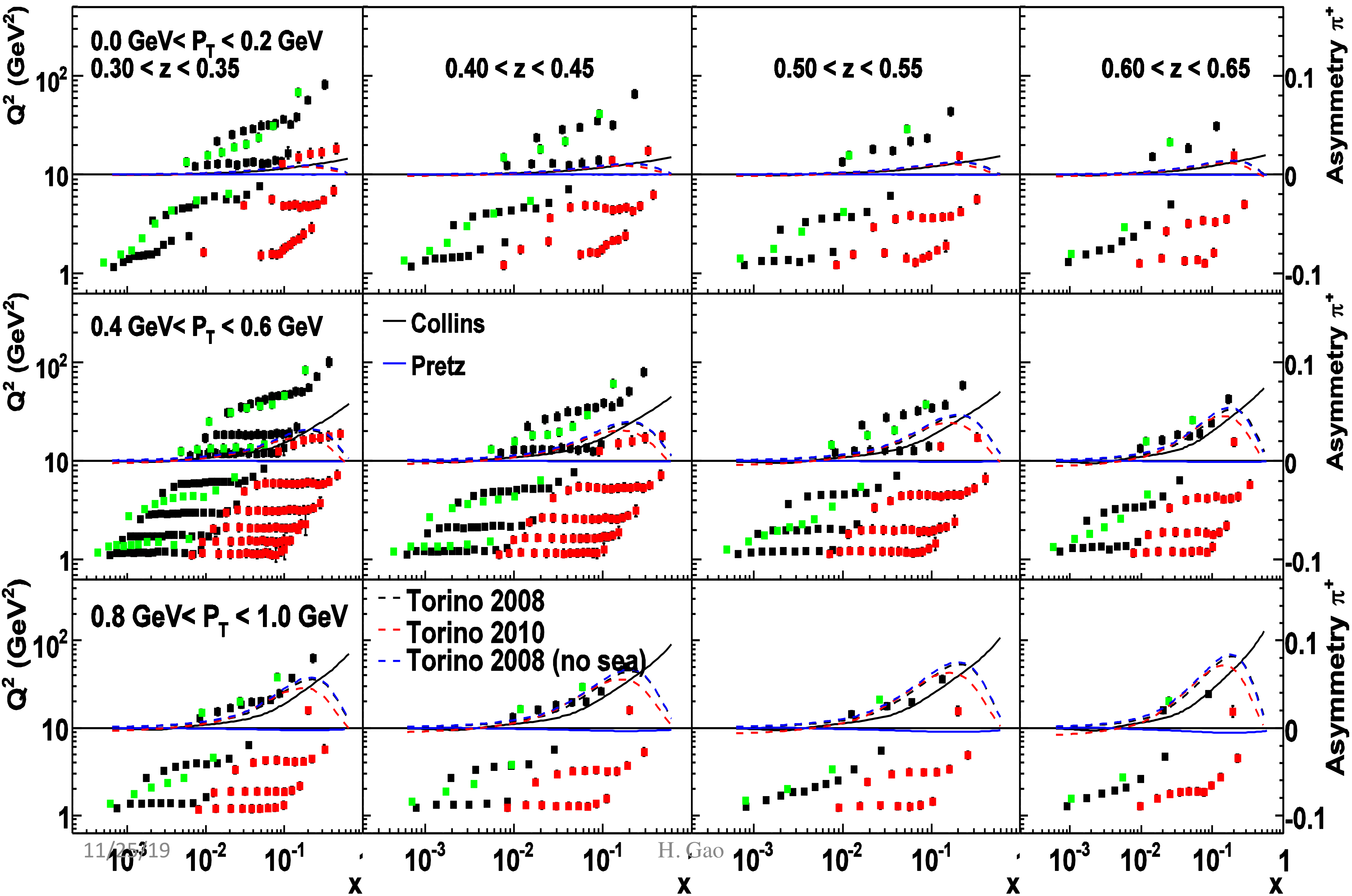
Polarization 70%
Overall efficiency 50%

z: 12 bins 0.2 - 0.8
$P_T$: 5 bins 0-1 GeV
Also $\pi^-$




Results on kaons also

# Proton π+ (z = 0.3-0.7)

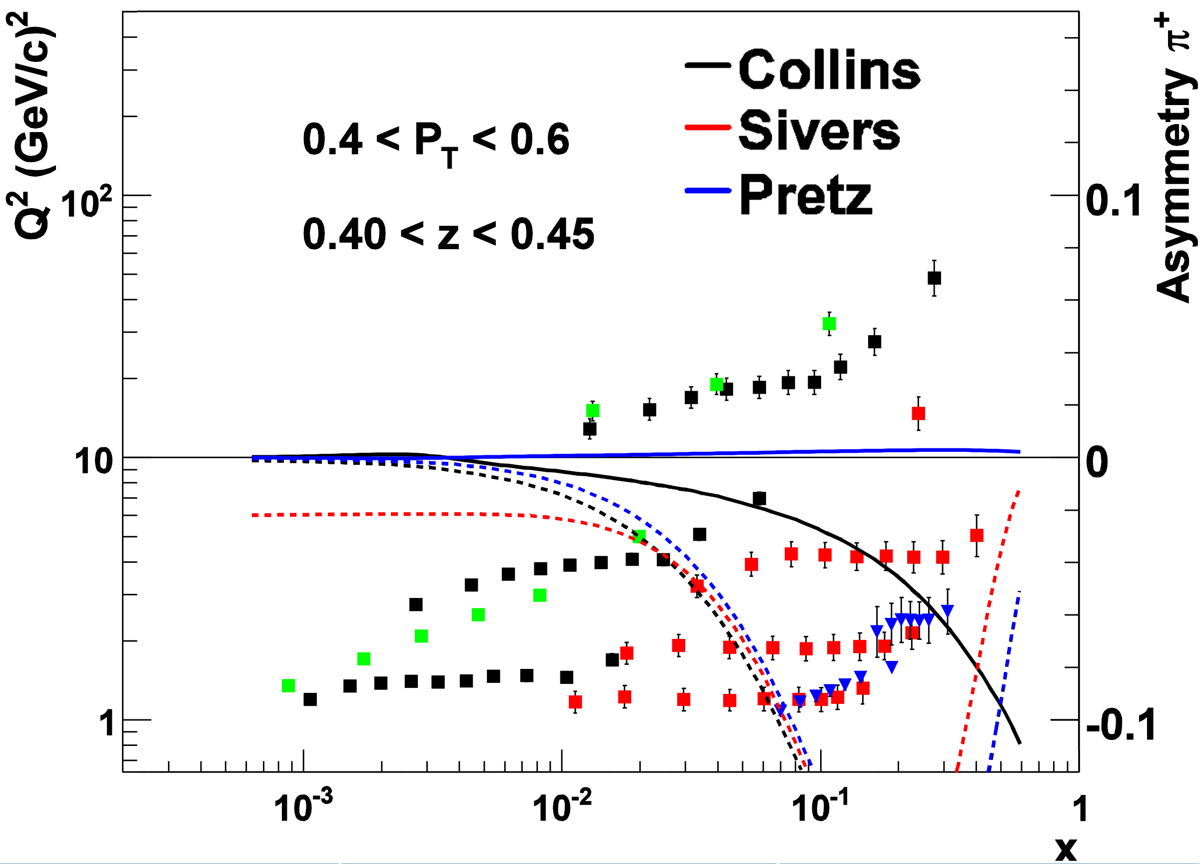


# Projections with $^3$He (neutron)

- 11 + 60 GeV
  72 days
- 11 + 100 GeV
  72 days
- 12 GeV SoLid

$^3$He: 87% effective polarization

Equal stat. for proton and neutron (combine $^3$He and D)



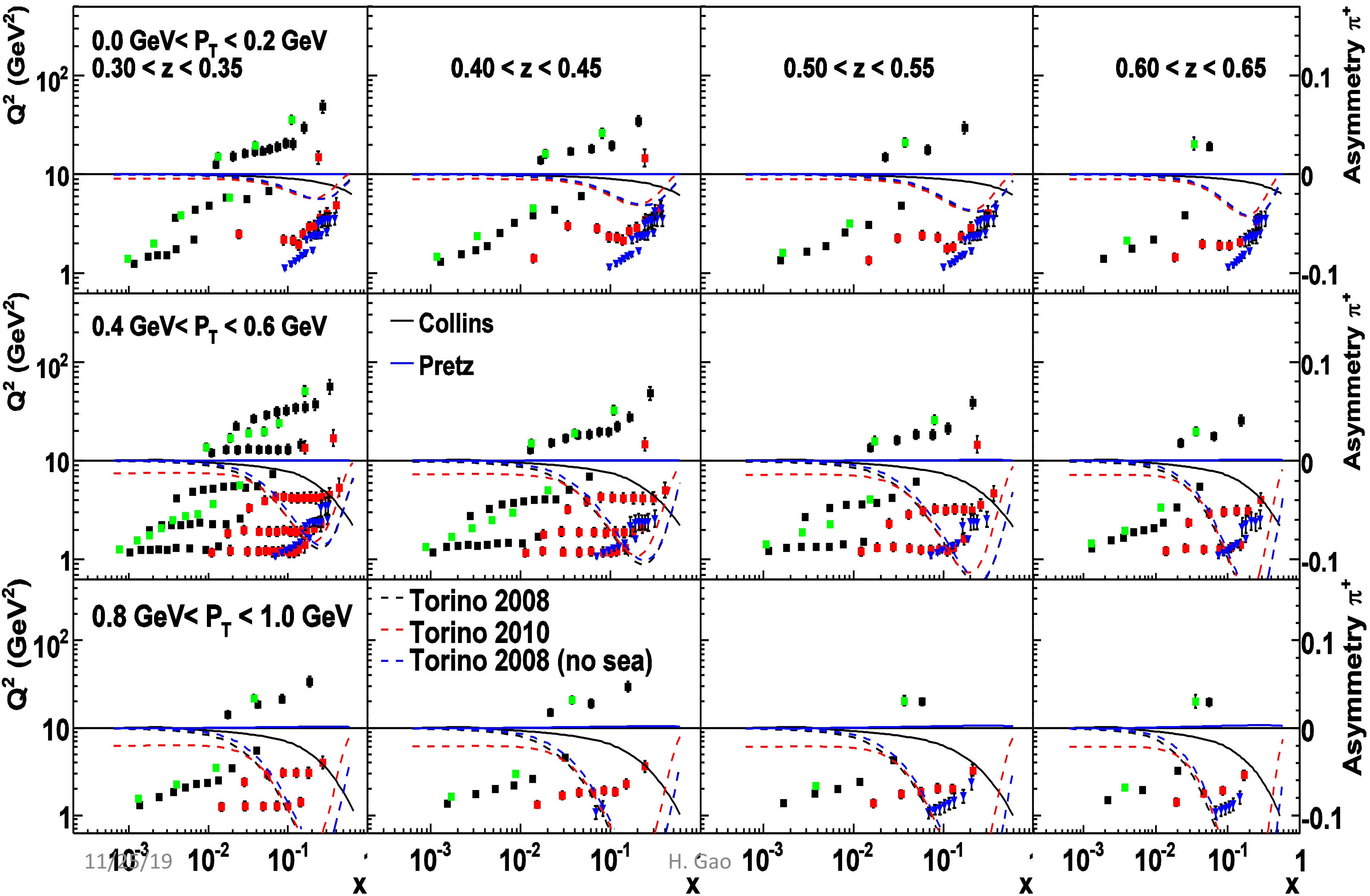

| | 11 + 60 GeV | 11 + 100 GeV | 3+20 GeV |
|---|---|---|---|
| P | 36 d ($3x10^{34}/cm^2/s$) | 36 d ($1x10^{34}/cm^2/s$) | 36 d ($1x10^{34}/cm^2/s$) |
| D | 72 d | 72 d | 72 d |
| $^3$He | 72 d | 72 d | 72 d |

# $^{3}$He $\pi^{+}$ (4-D)

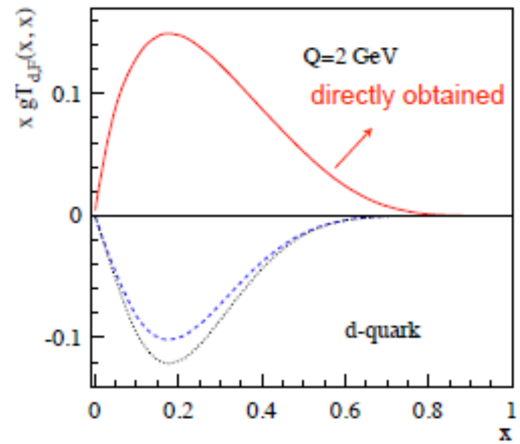
12 GeV Jlab
11x100 GeV

combine $^{3}$He and D 120 fb$^{-1}$

Calculations from A. Prokudin, B. Ma

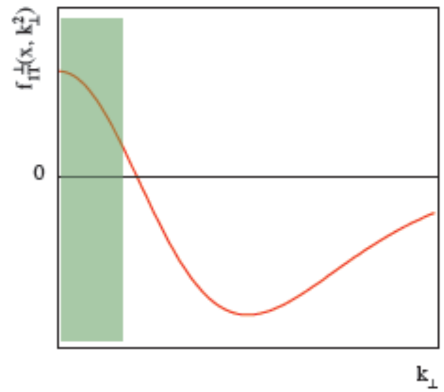


# High $P_T$ Physics




- TMD: $P_T << Q$
- Twist-3 formulism: $\Lambda_{QCD} << P_T$
- Unified picture in $\Lambda_{QCD} << P_T << Q$
  - Ji et al. PRL 97 082002 (2006)

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




- $P_T$ weighted integral Asymmetries

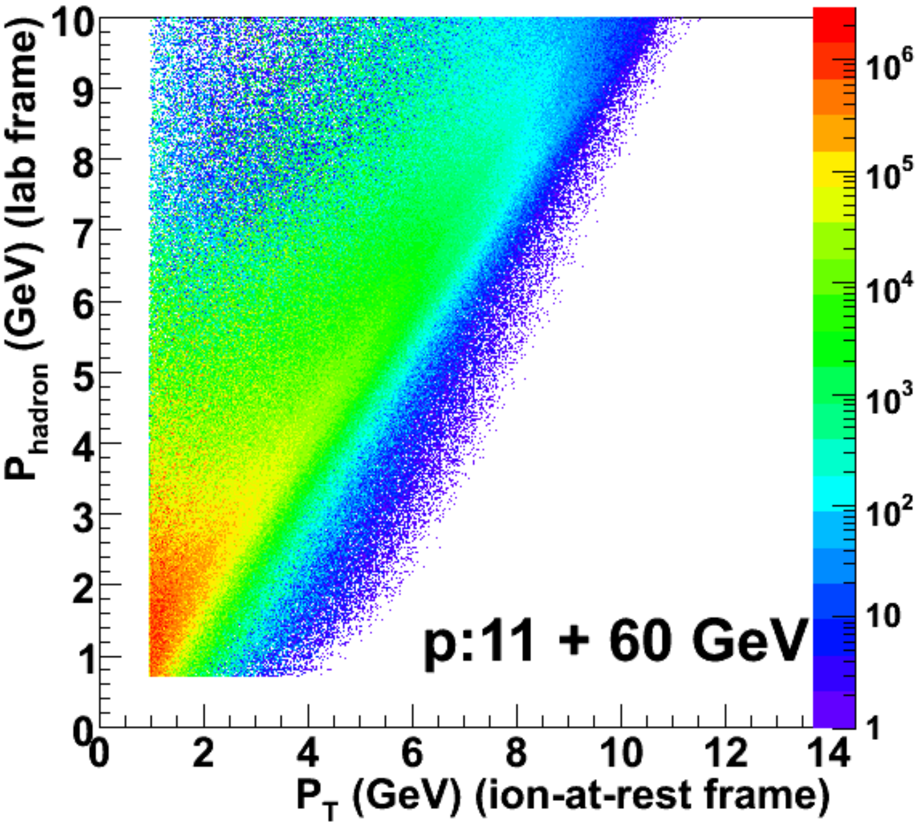
$$A_{UT}^{J\sin(\phi_h-\phi_S)} = \frac{\int dP_T J(P_T) A_{UT}^{\sin(\phi_h-\phi_S)} \cdot \sigma_{UU}}{\int dP_T \sigma_{UU}}$$

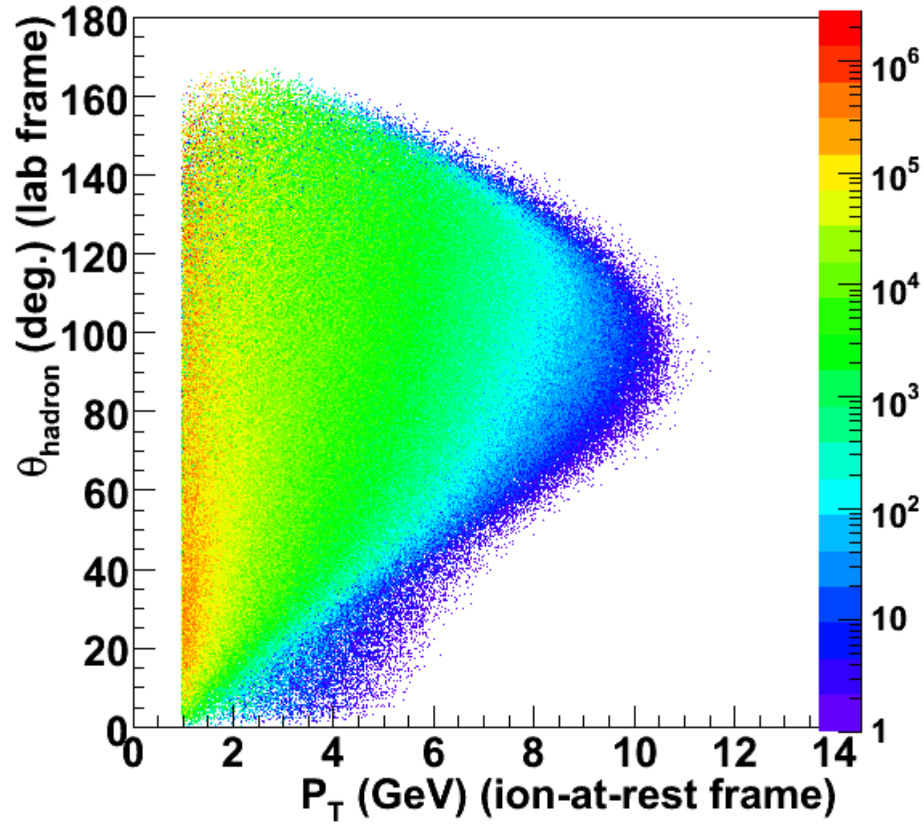
Z. Kang's talk @ Spin Physics , Transverse II

L. Gamberg' talk @ Spin Physics, Transverse II

Kang, Qiu, Vogelsang and Yuan: arxiv: 1103.1591

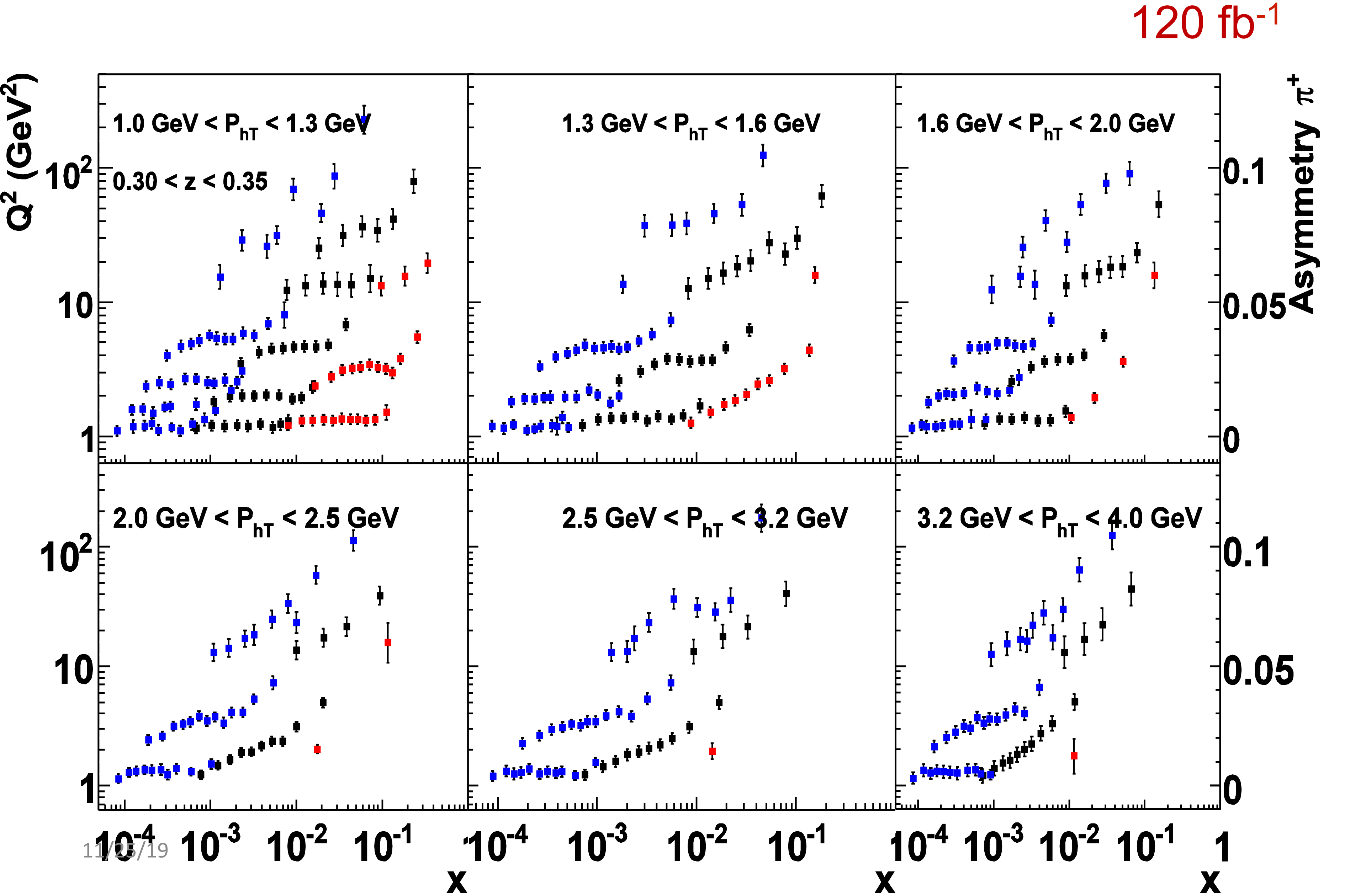
# High $P_T$ kinematics



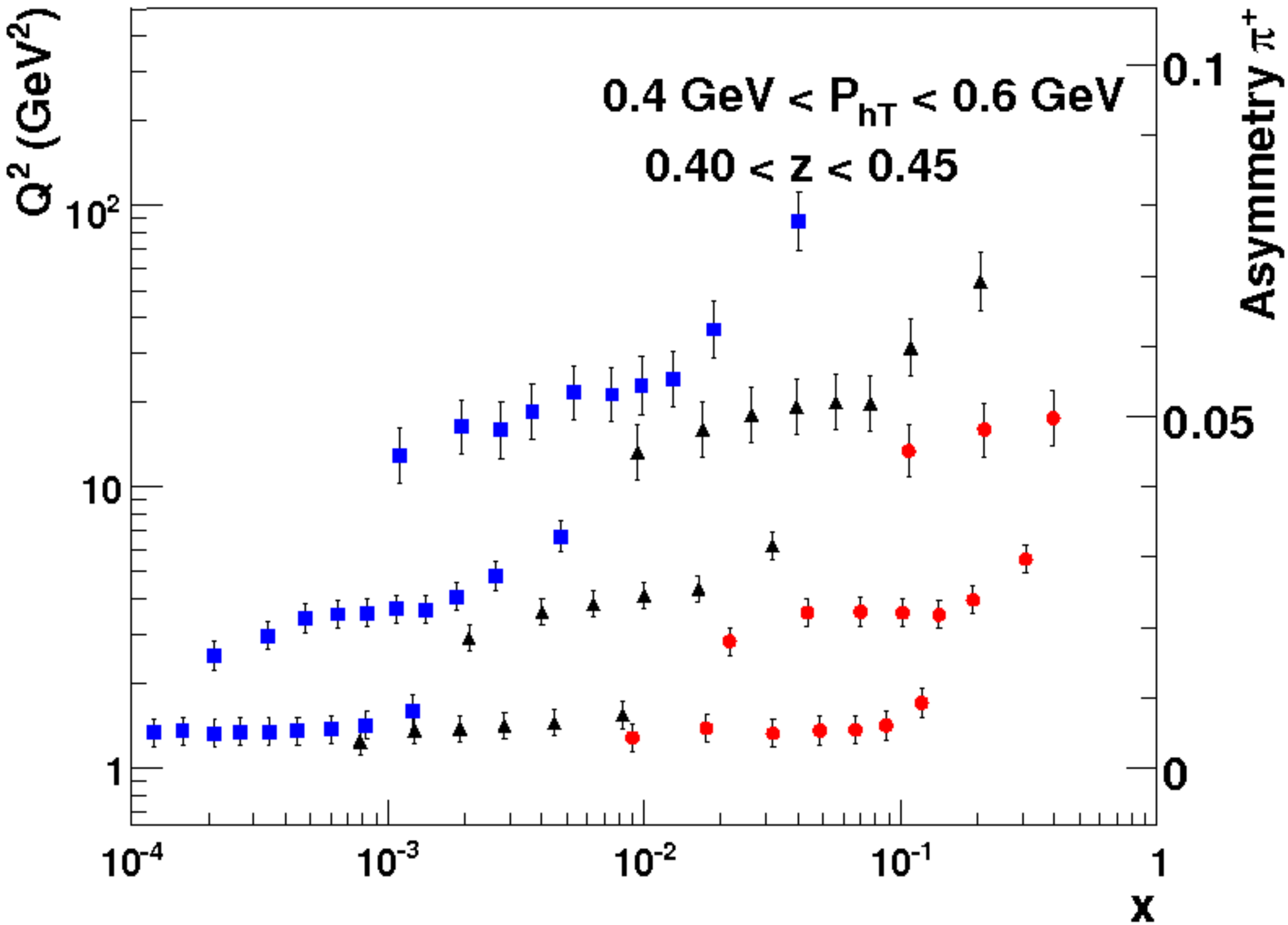




High $P_T$ : hadron momenta dramatically increase
require high momentum PID, large polar angular coverage

# $P_T$ dependence (High $P_T$) on p of $\pi^+$

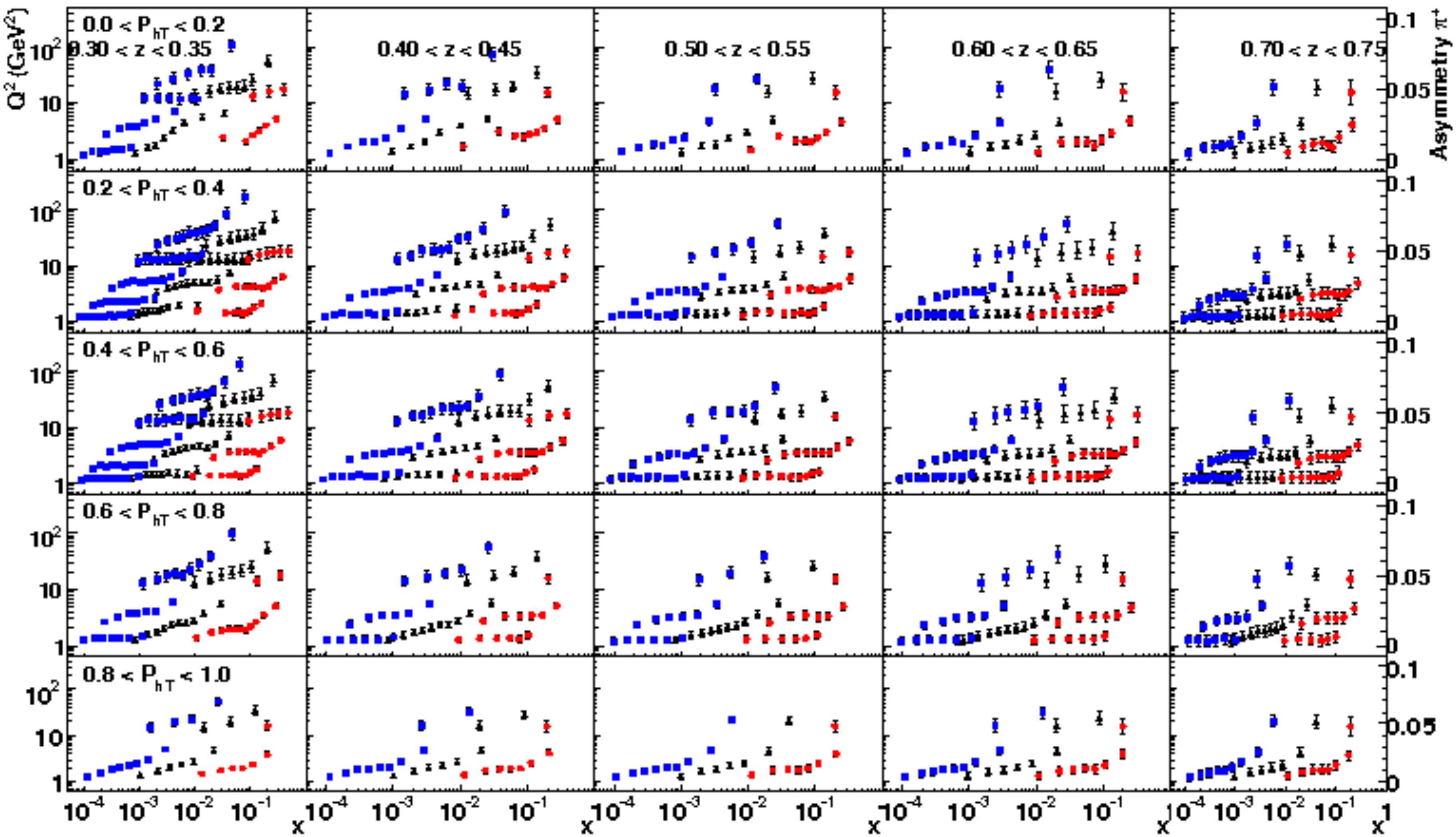


# Higher center-of-mass energies



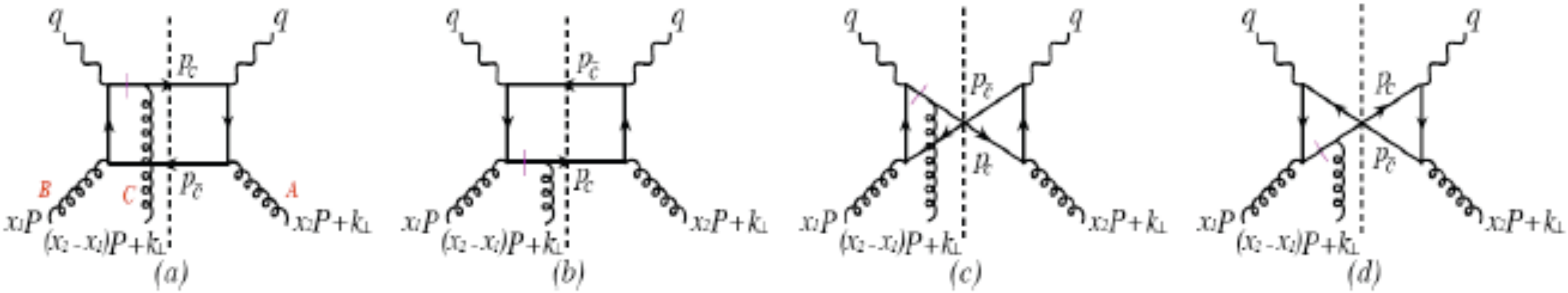

blue: 140 GeV, black 50 GeV, red 15 GeV, integrated lumi: 30 $fb^{-1}$

# Higher center-of-mass energies



# D-meson Production at EIC

- Dominated by tri-gluon subprocesses (Kang Qiu PRD 2008)

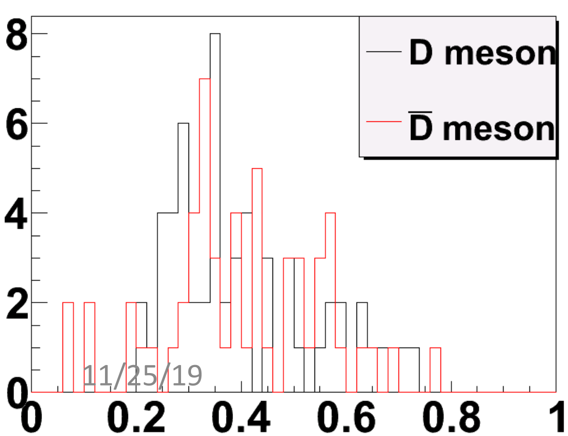


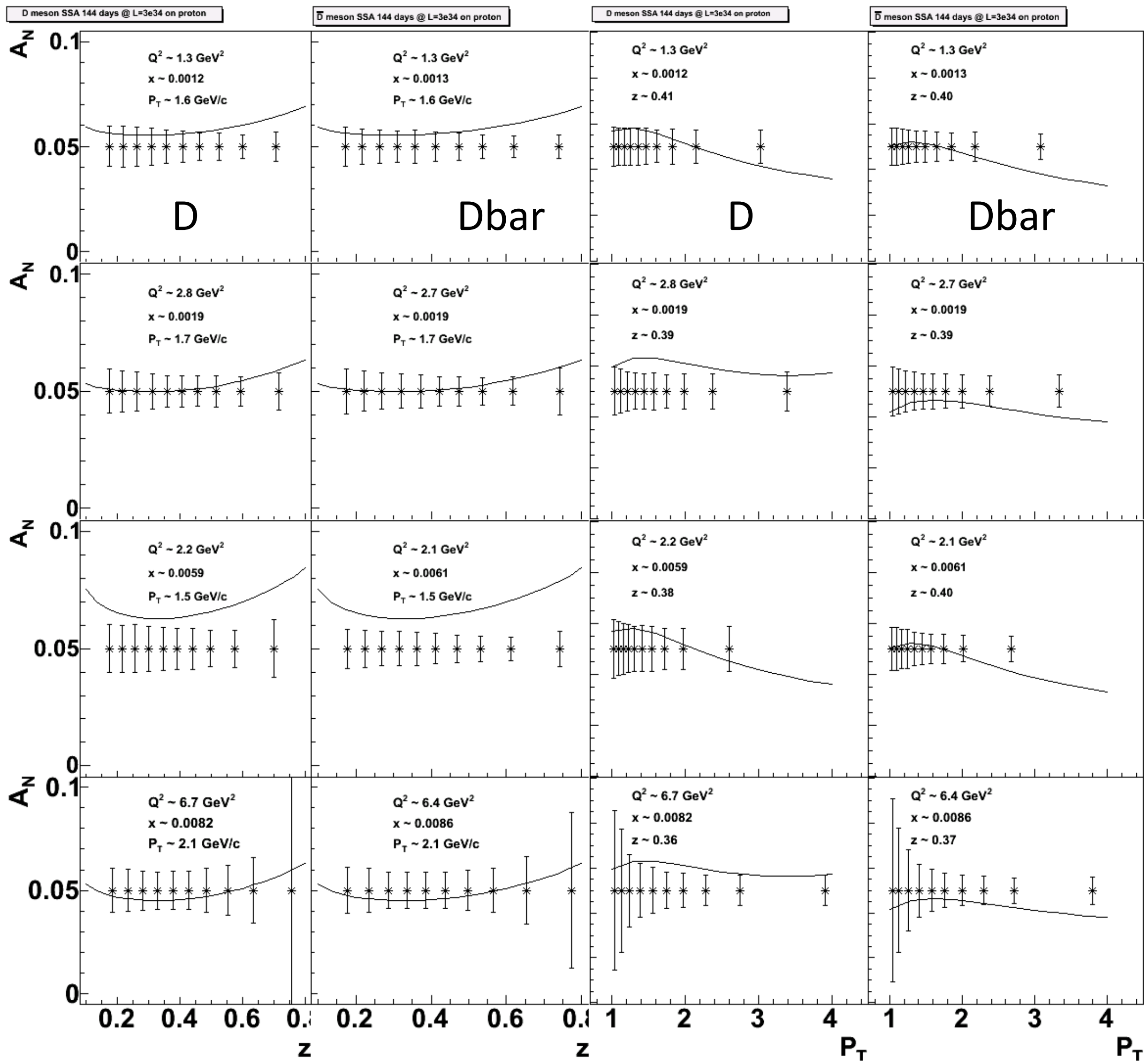

  - Four tri-gluon distributions (Kang, Koike, Tanaka)
  - Closely related to gluon Sivers function
  - Intrinsic charm is not important at large $P_T$
- Single transverse Spin Asymmetries
  - Twist-3 effect, fall off as $1/P_T$
  - Proportional to tri-gluon functions
  - Any small SSA is discovery of tri-gluon distribution functions.
  - Differentiate different tri-gluon functions with D-meson and Dbar-meson


X. Qian

# 144 Days @ L = 3x10$^{34}$ on Proton

10 GeV > Momentum > 0.6 GeV
Polar angle > 10 degree
0.9 > y > 0.05; $Q^2$>1GeV$^2$,
$P_T$ > 1GeV; z > 0.15
Include decay of kaon and pion
Additional 60% efficiency
80% polarization
Sqrt(2) for angular separation.
Dilution factor due to other processes and accidental pion and kaons.
2x2 bins in x and $Q^2$.




Calculations from Z. B. Kang, slide from Xin Qian

# Gluon Sivers Distribution

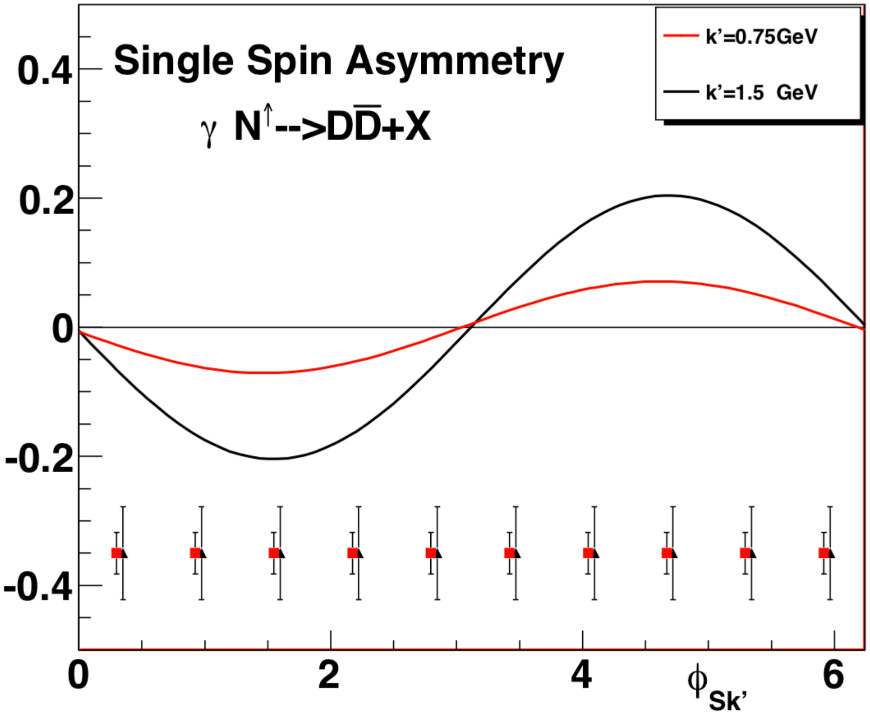
- Focus on charm production  back-to-back D Dbar

$$\gamma^* g \to Q\overline{Q}$$

- Approximate a factor of 50 suppression compare to the single D meson production at 11x60 GeV
  - Higher C.M. energy -> Larger Xs
  - Explore other decay channels

    **-> Larger branching ratio**
  - **Higher luminosity (projection W=60 GeV, 100 fb$^{-1}$)**

$$\gamma^* p \to D^0 \bar{D}^0 + X$$




*Markus Diehl, Bo-Wen Xiao*

# What's next?

- Update previous studies with the latest taking into account both the designs of the accelerator(s) and the associate detectors and to inform the design
- Update studies with the latest from theory/phenomenology/ modeling
- Carry out studies of systematic uncertainties including model dependence and studies  of physics impact, similar to what have been done for the SoLID SIDIS
- Provide requirements on the detector design: kinematic reach, resolutions, PID,
- Other related studies, such as cross section measurements, fragmentation functions, etc.

Most of the studies were done by Dr. Min Huang and Dr. Xin Qian