TSSA Measurements from SIDIS at EIC

M. Anselmino et al.
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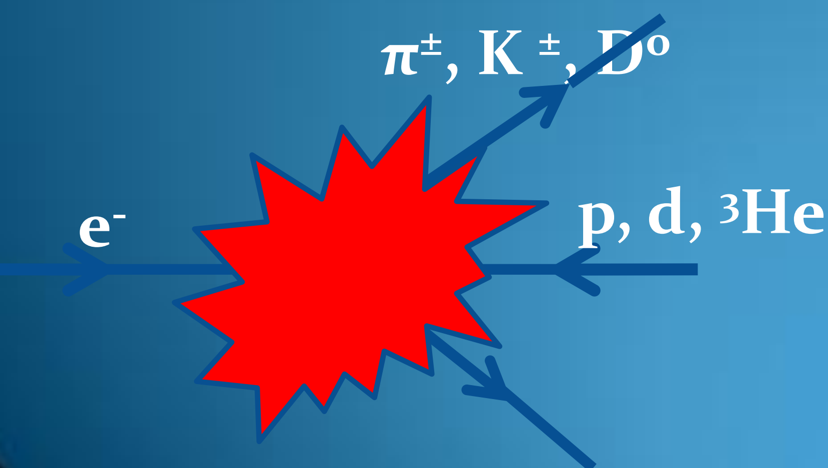
NPN, VA, Apr 14, 2011

Min Huang
Duke University

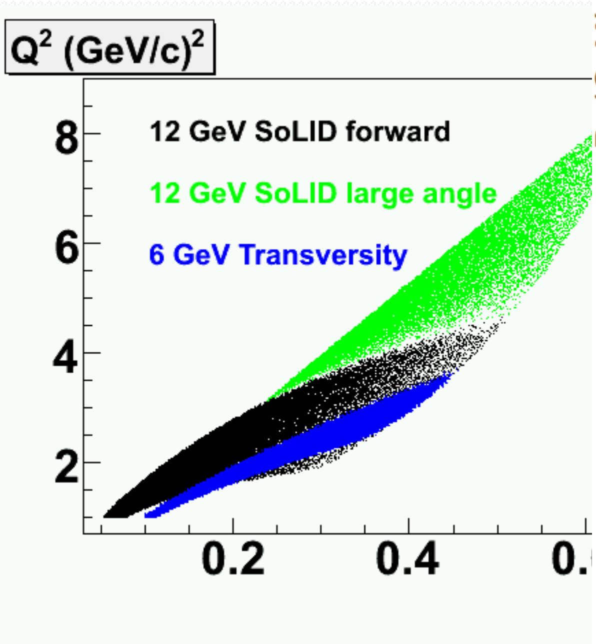


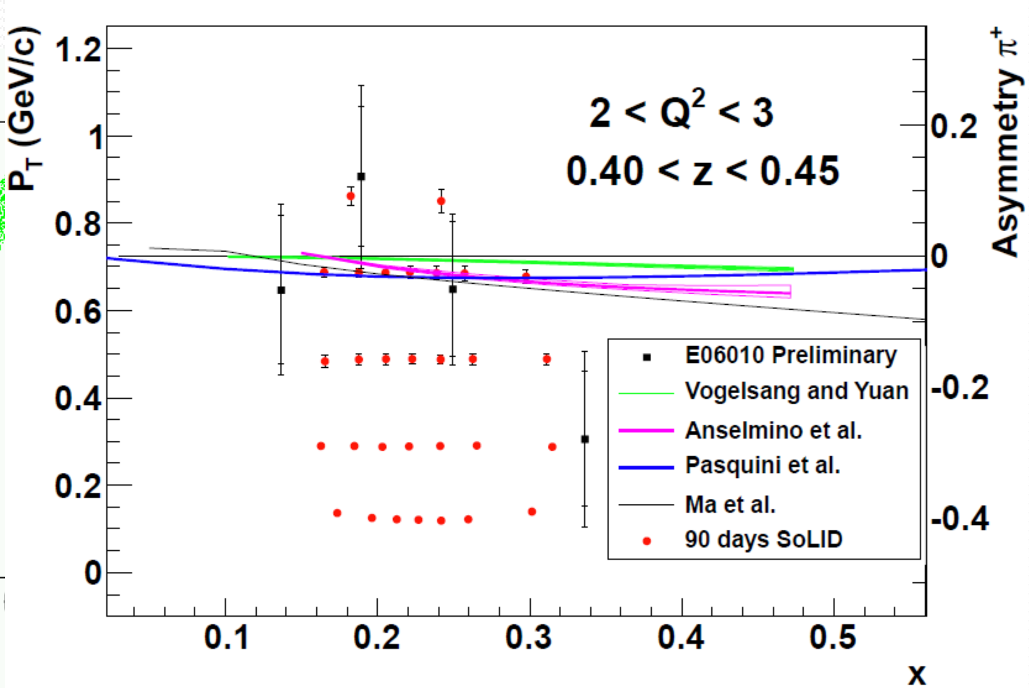
Duke UNIVERSITY

TSSA Measurements

- Pioneer: HERMES (p), COMPASS (p,d), Hall A (n)
- By the time of EIC running, what will we learn in addition?
  - JLab 12 GeV

eg. X. Qian's talk @ Future of DIS, Session 3





TSSA Measurements

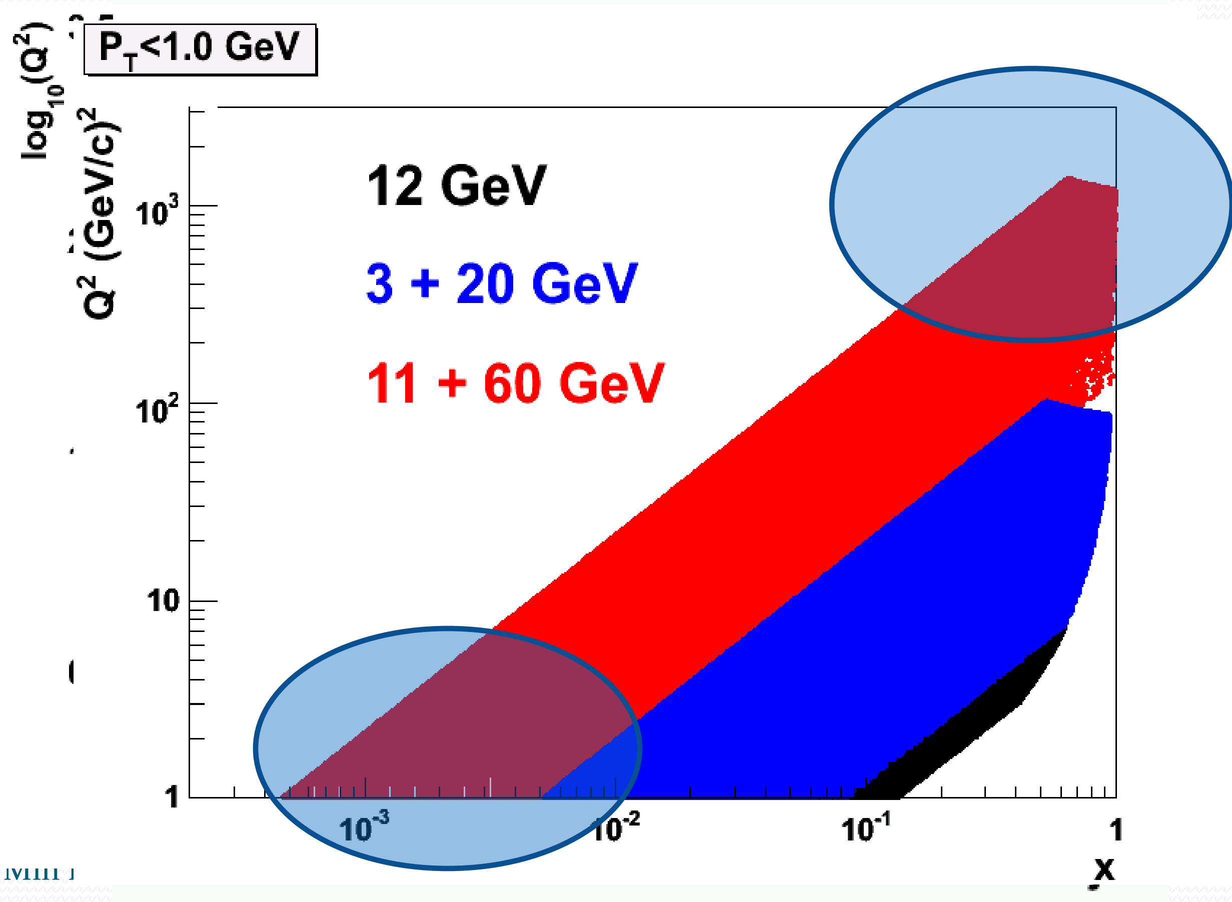
- Pioneer: HERMES (p), COMPASS (p,d), Hall A (n)
- By the time of EIC running, what will we learn in addition?
  - Potential of JLab 12 GeV

eg. X. Qian's talk @ Future of DIS, Session 3)

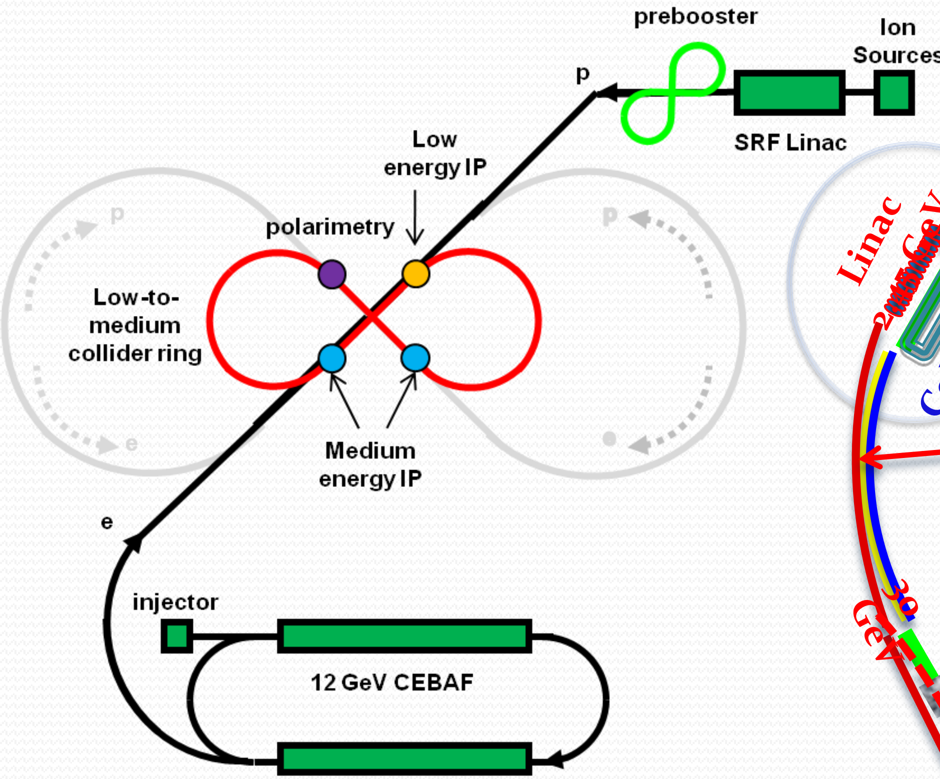
- low x →Study sea & gluon

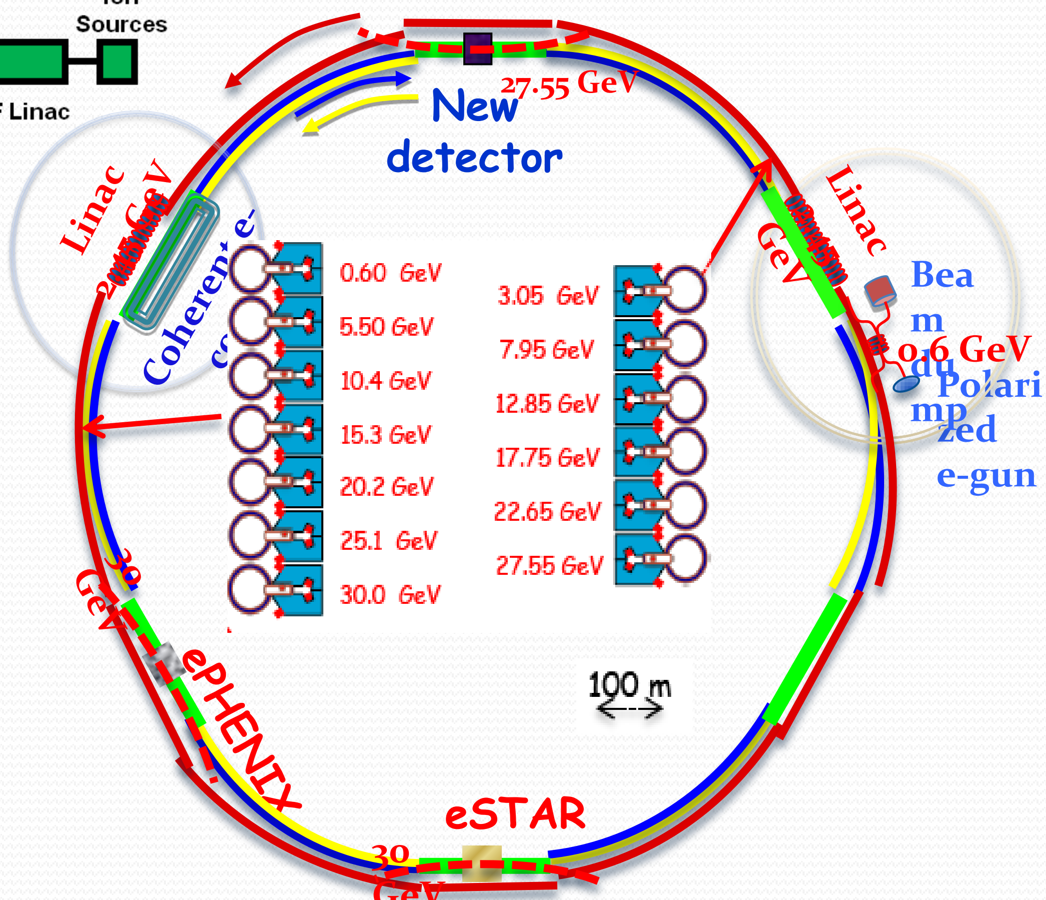
- High Q² + High Luminosity -> Study Evolution

Electron-Ion Collider!



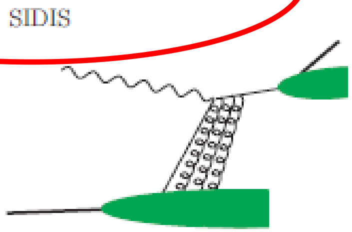
EIC: The Next-Generation QCD Machine

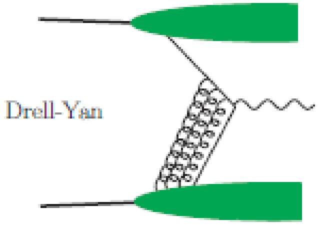




Three-dimensional structure: transverse momentum

- transverse momentum of quarks and gluons:
  - influences momenta in final state → practical relevance
  - fundamental aspect of hadron structure
  - correlations with flavor structure largely unexplored
- correlation of k_T with polarization reveals deep properties of QCD: Sivers effect as a golden measurement





  - partons are not isolated but embedded in environment of gluons
  - Sivers distribution = indicator for this effect
    changes sign between SIDIS and DY (RHIC measurements)
  - Sivers distribution essentially unknown for sea quarks and gluons

SIDIS Events Distributions

-- in Current Fragmentation Region

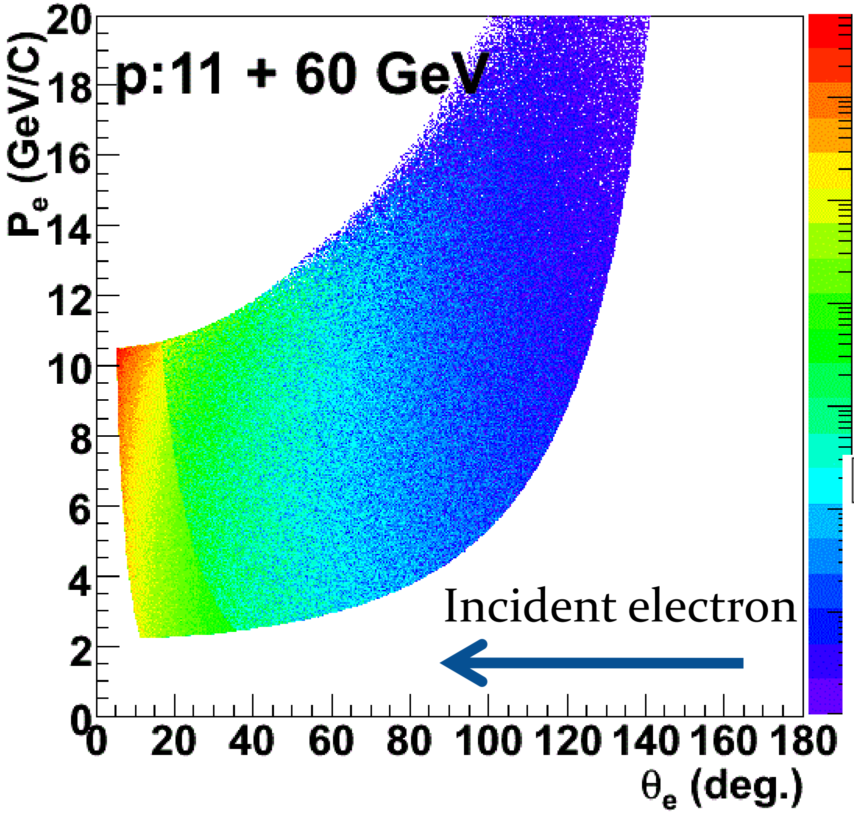
DIS cut: $Q^2 > 1$ GeV^2

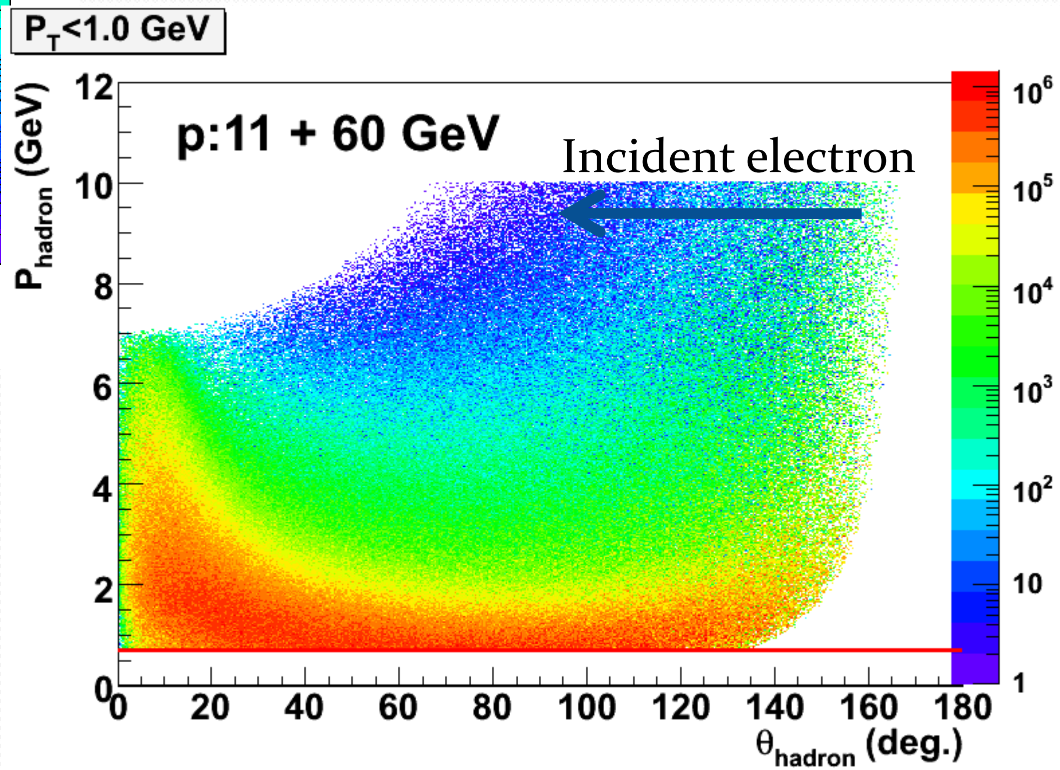
$W > 2.3$ GeV

$0.8 > y > 0.05$

SIDIS cut: $W' > 1.6$ GeV

$0.8 > z > 0.2$





$Q^2 > 1$ GeV^2 ➡ $\theta_e > 5°$

No need to cover extreme forward angle for electron and extreme backward angle for hadrons

Projections with Proton on π^+

$\sqrt{s}$ 140 GeV (20x250)
50 GeV (11x60)
15 GeV (3x20)

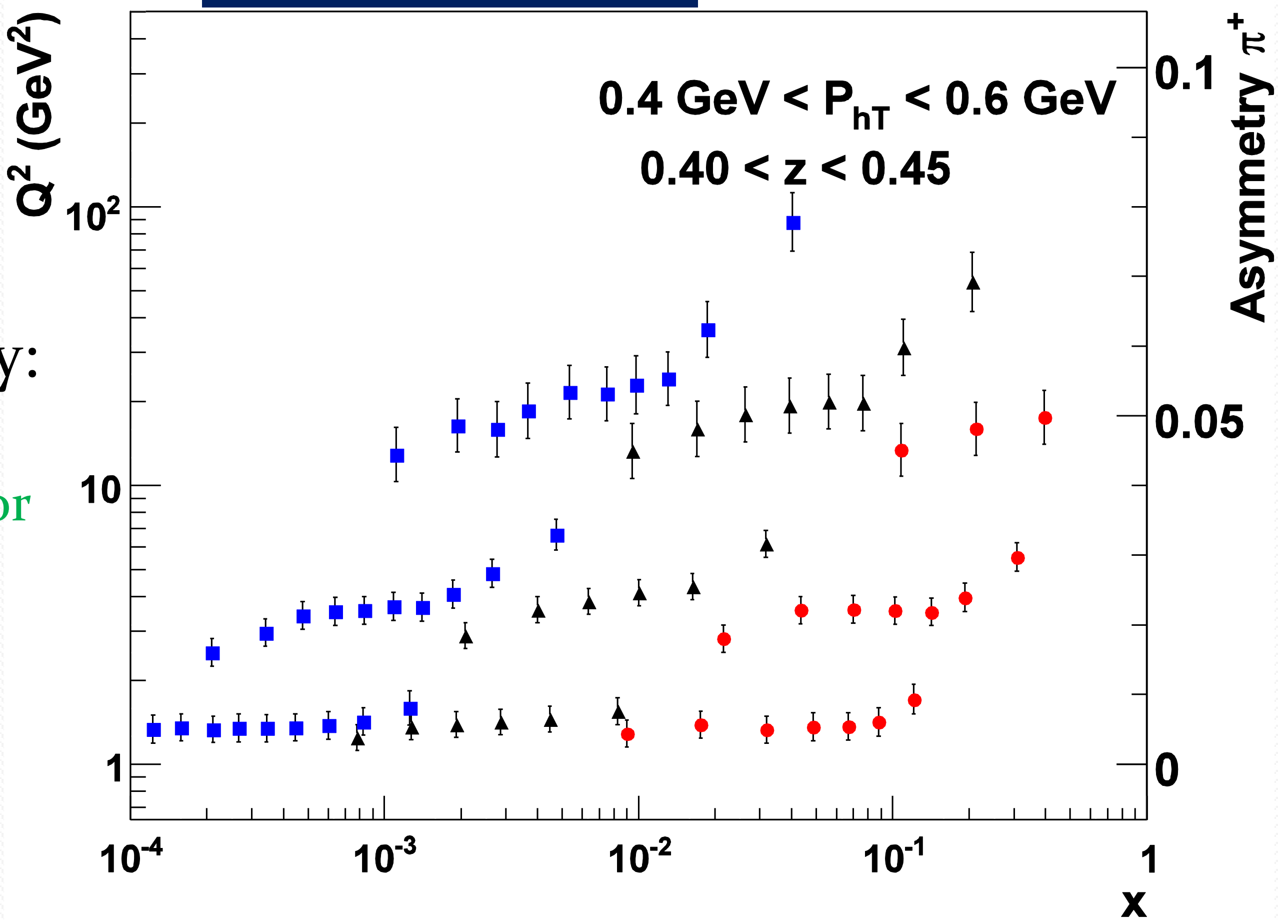
Integrated Luminosity:
30 fb^{-1}
(about 1 month running for 10^{34}/cm^2/s)

0.8>y>0.05

Polarization 70%
Overall efficiency 50%

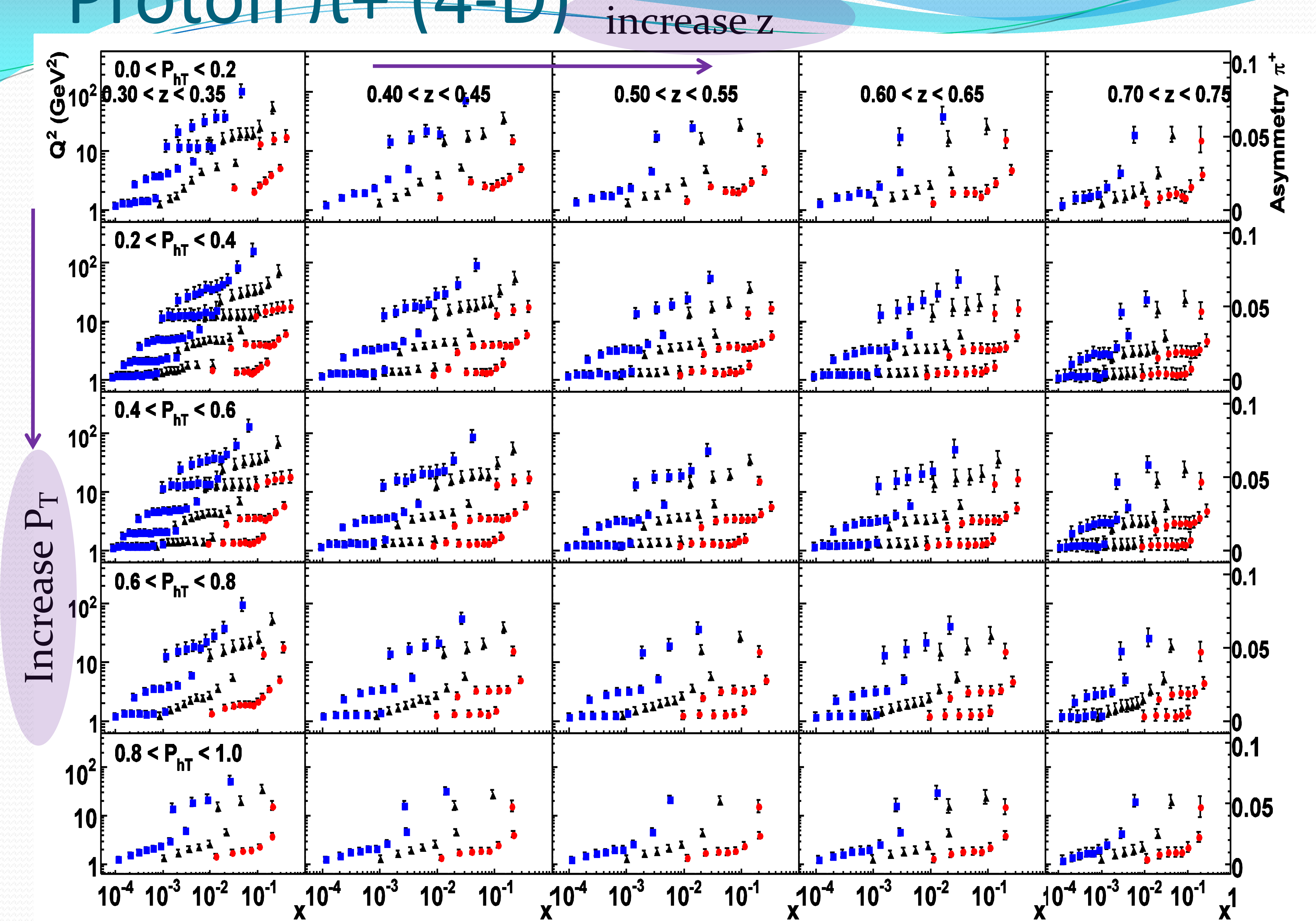
z: 12 bins 0.2 - 0.8
P_T: 5 bins 0-1 GeV

1/60 bins on (P_T, z)



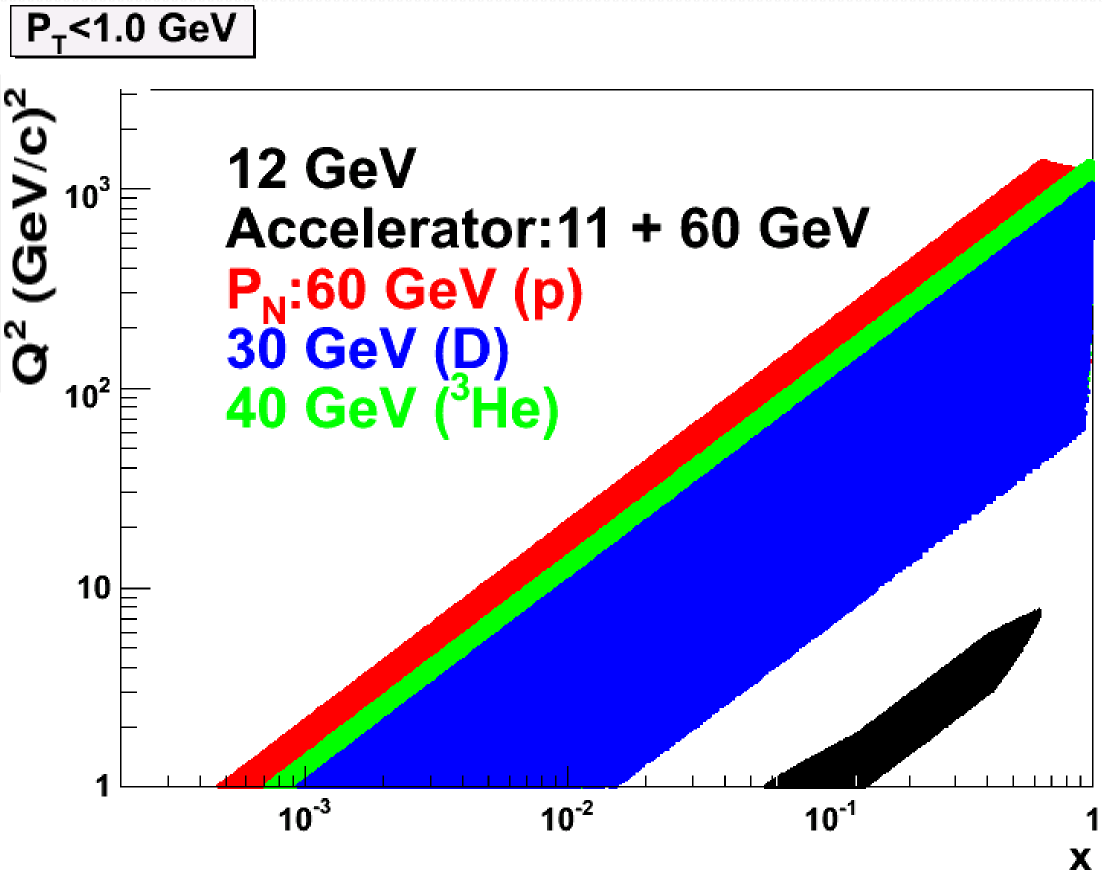
Also π-, K+, K-

Proton π+ (4-D)



increase z
Increase P_T
Q^2 (GeV²)
Asymmetry π^+
0.0 < P_{hT} < 0.2
0.2 < P_{hT} < 0.4
0.4 < P_{hT} < 0.6
0.6 < P_{hT} < 0.8
0.8 < P_{hT} < 1.0
0.30 < z < 0.35
0.40 < z < 0.45
0.50 < z < 0.55
0.60 < z < 0.65
0.70 < z < 0.75
x

Study both Proton and Neutron



Neutron as important as proton in nucleon structure study

Flavor separation

ion momentum ∝ Z

P_N ∝ Z/A

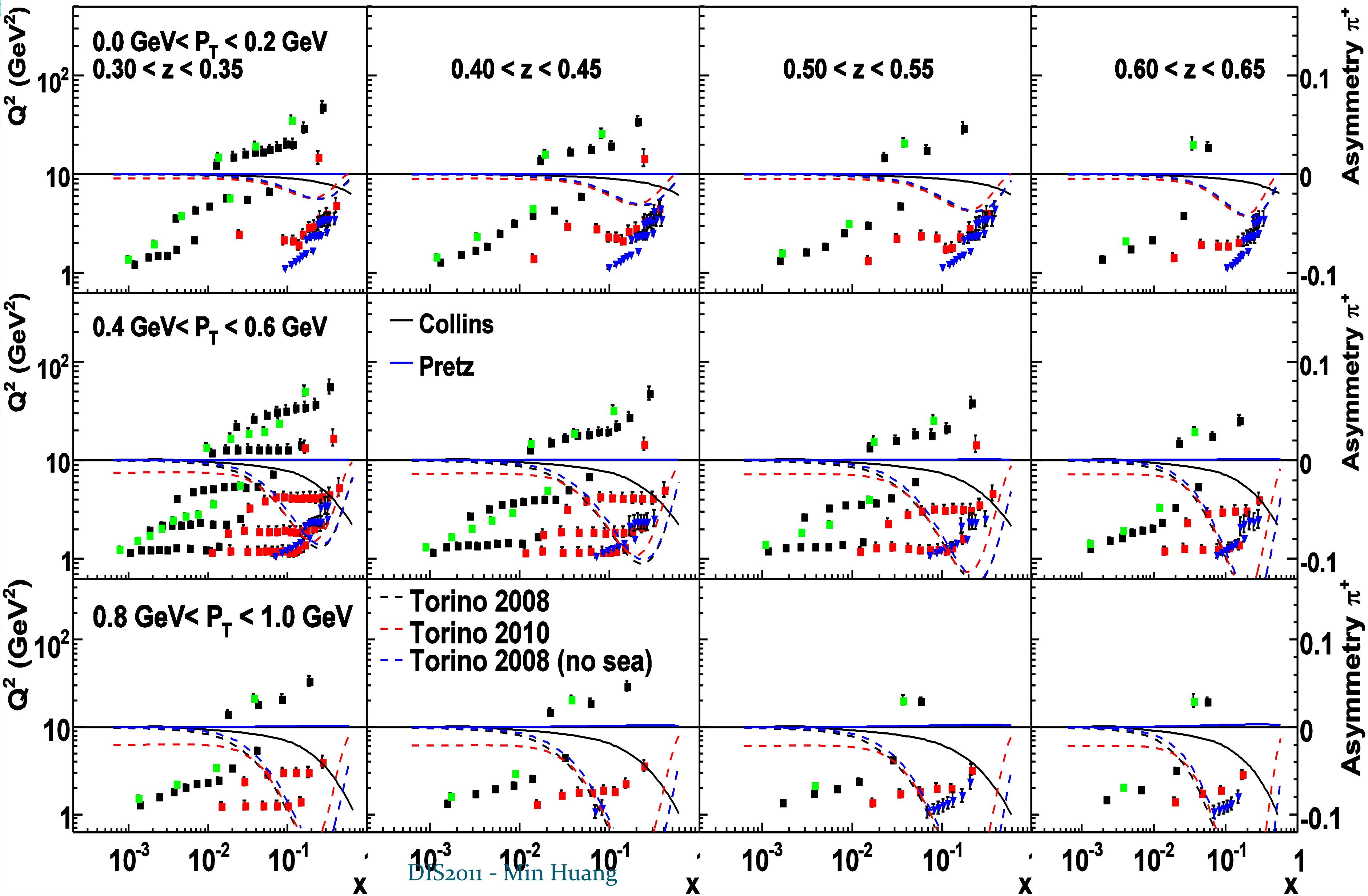
Combine the data, the lowest achievable x limited by the effective neutron beam

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

12 GeV Jlab
11x100 GeV

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

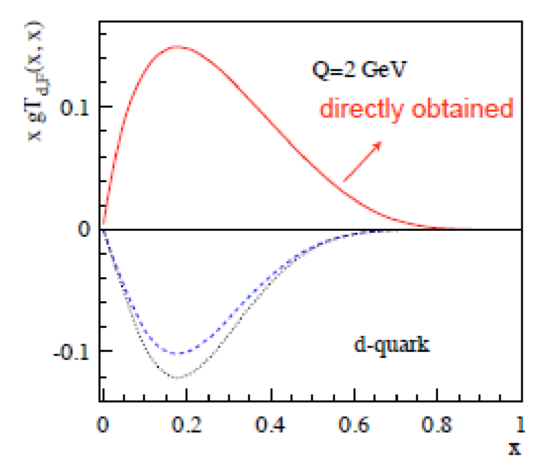
Calculations from A. Prokudin, B. Ma

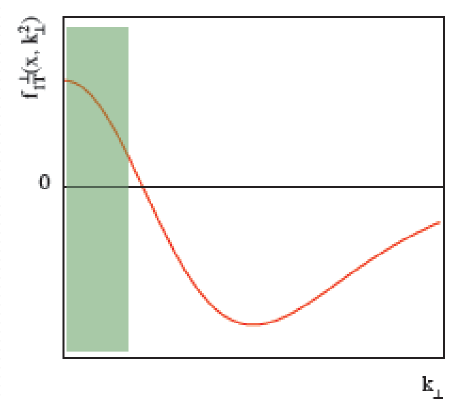


High P_T Physics

- 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

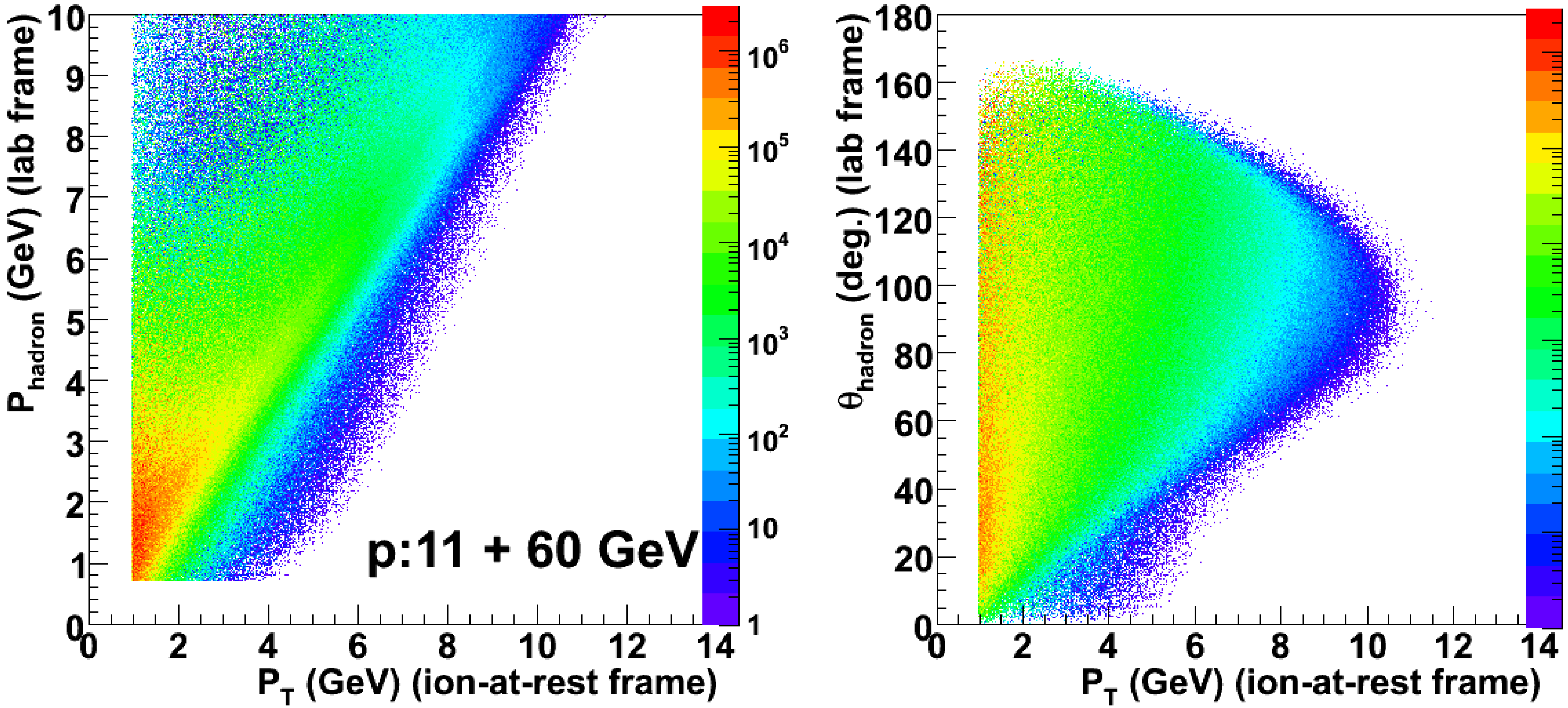
$$A_{UT}^{J\sin(\phi_h-\phi_S)} = \frac{\int dP_T\, J(P_T) A_{UT}^{\sin(\phi_h-\phi_S)} \cdot \sigma_{UU}}{\int dP_T \sigma_{UU}}$$

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

L. Gamberg' talk @ Spin Physics, Transverse II

Kang, Qiu, Vogelsang and Yuan: arxiv: 1103.1591

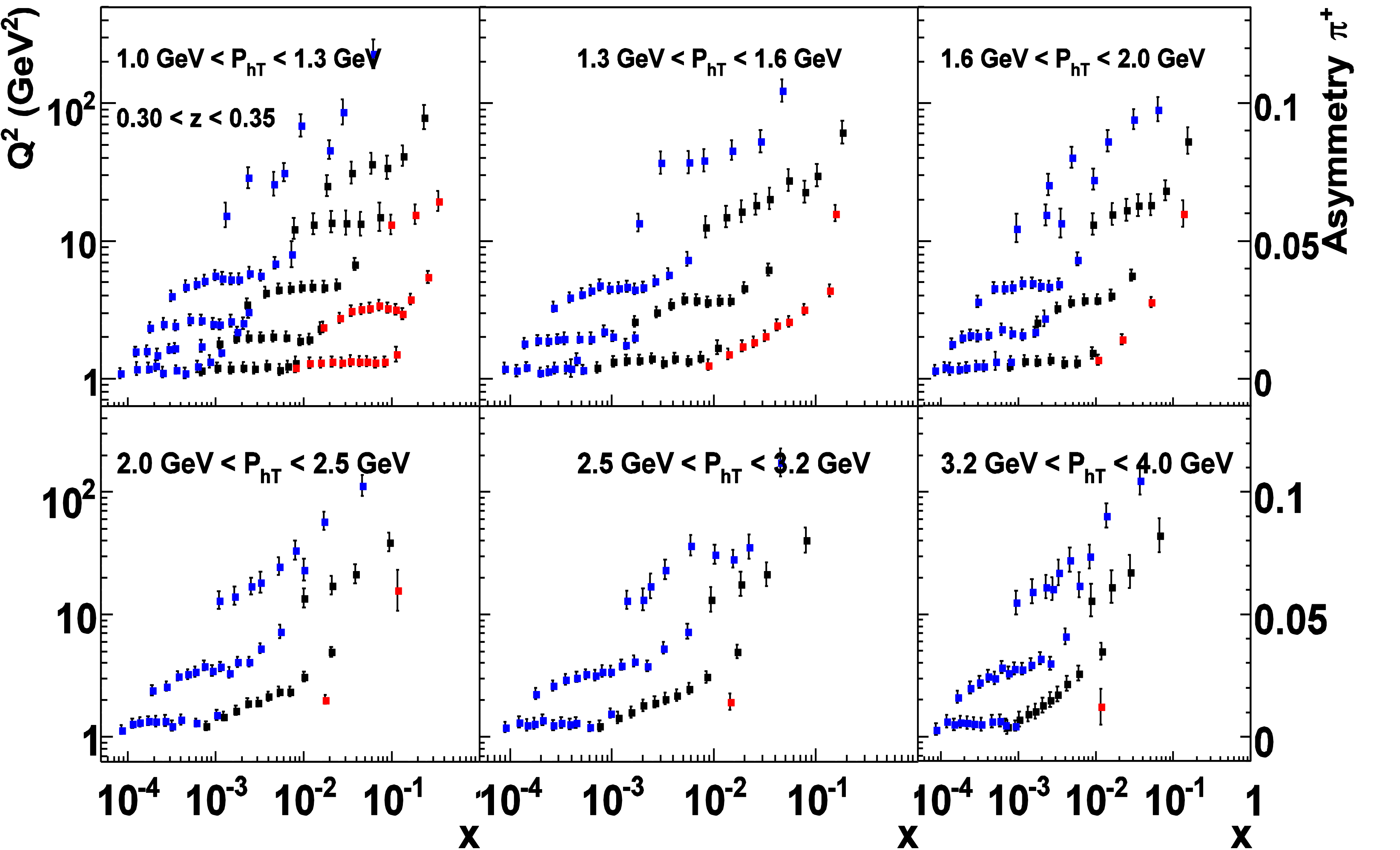
High P_T kinematics



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

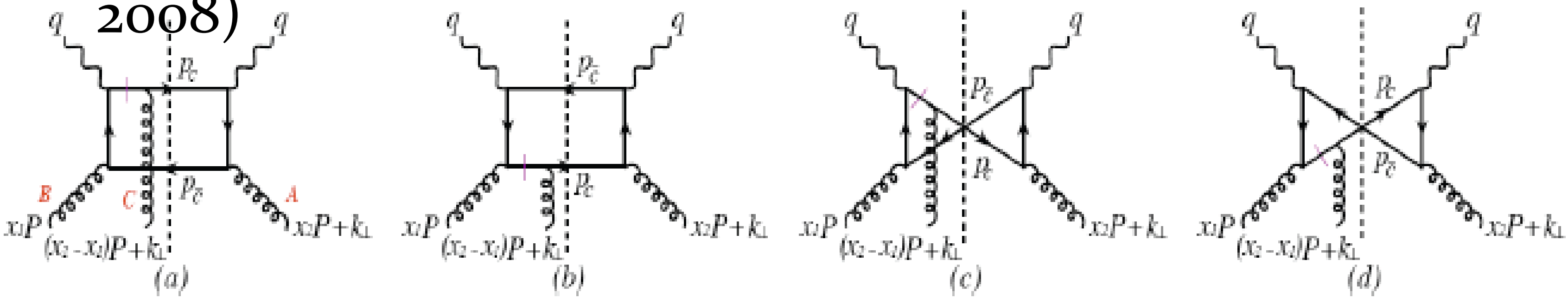
P_T dependence (High P_T) on p of π^+

120 fb^{-1}



D-meson Production

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



  - Four tri-gluon distributions (Kang, Koike, Tanaka)

K. Tanaka's talk @ Spin Physics , Joint Parallel Session: Future of DIS

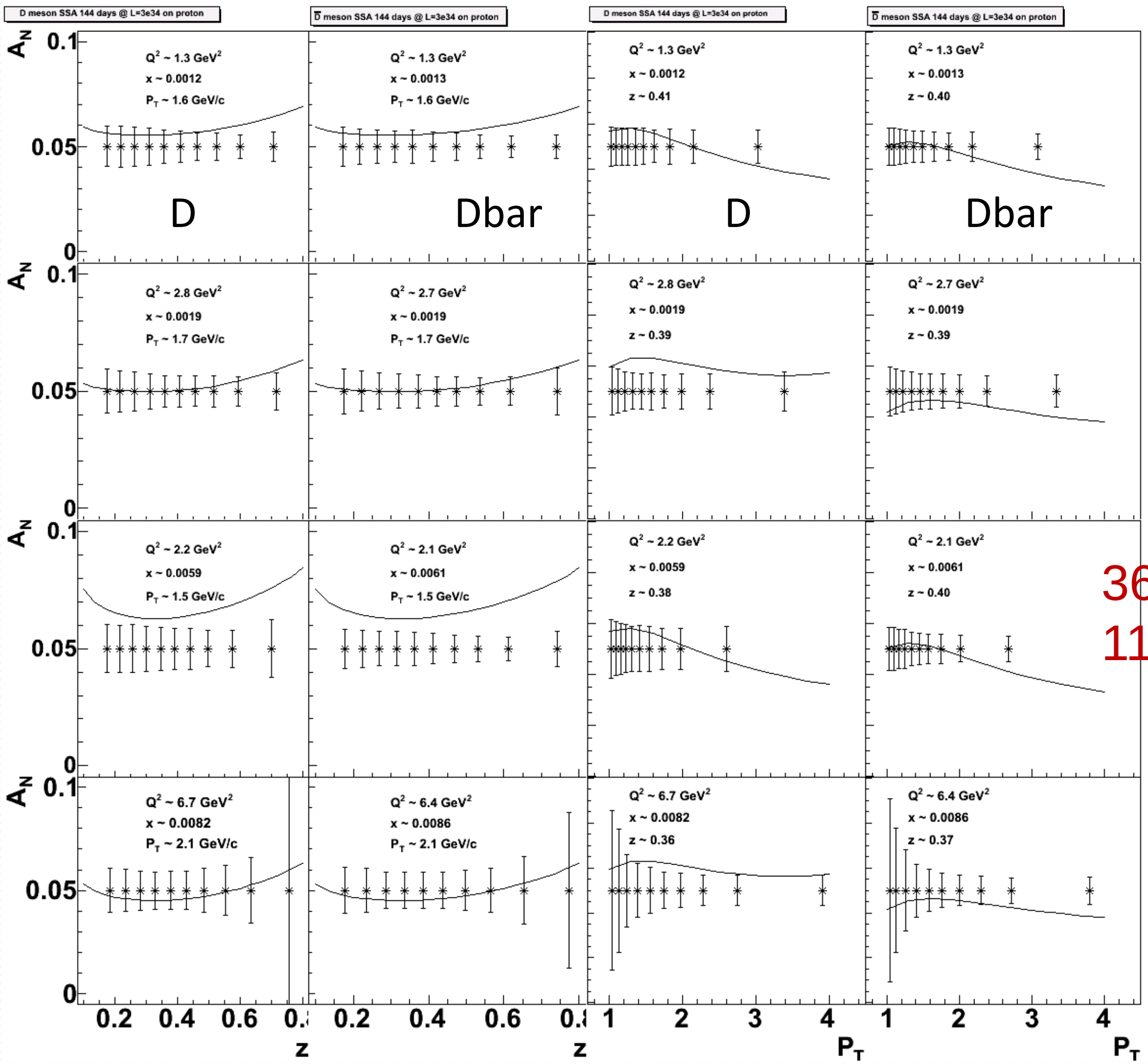
  - Closely related to gluon Sivers function
- Single transverse Spin Asymmetries
  - Proportional to tri-gluon functions

$$D^0(c\bar{u}) \rightarrow \pi^+(u\bar{d})K^-(s\bar{u})$$
$$\overline{D^0}(\bar{c}u) \rightarrow \pi^-(\bar{u}d)K^+(u\bar{s})$$

Branching ratio: 3.8+-0.07%

D-meson Projection

X. Qian



360 fb^{-1} on Proton
11x60 GeV

Calculations from Z. B. Kang

Gluon Sivers Distribution

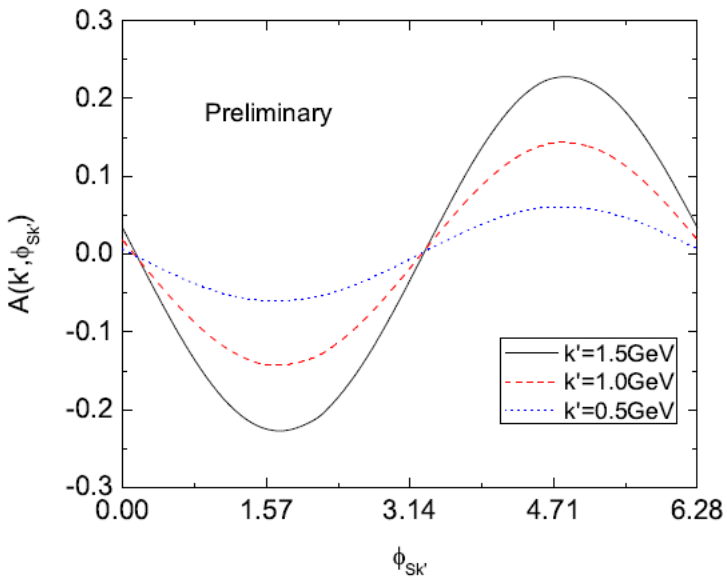
Markus Diehl, Bo-Wen Xiao

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

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

- 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

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



Summary of Luminosity

Typically for 11 + 60 Gev, s = 50 GeV

ion	Detected hadron	P_T region (divide @ 1GeV)	Luminosity (fb^{-1})
p	π	Low	30
n(^3He + D)	π	low	120
p	K	low	>3 x 30 (match with pion)
p	π	high	120
p	D	high	360 (multi-D binning, much fewer bins)
p	$D + \overline{D}$	high	Tens of 360 or high s?

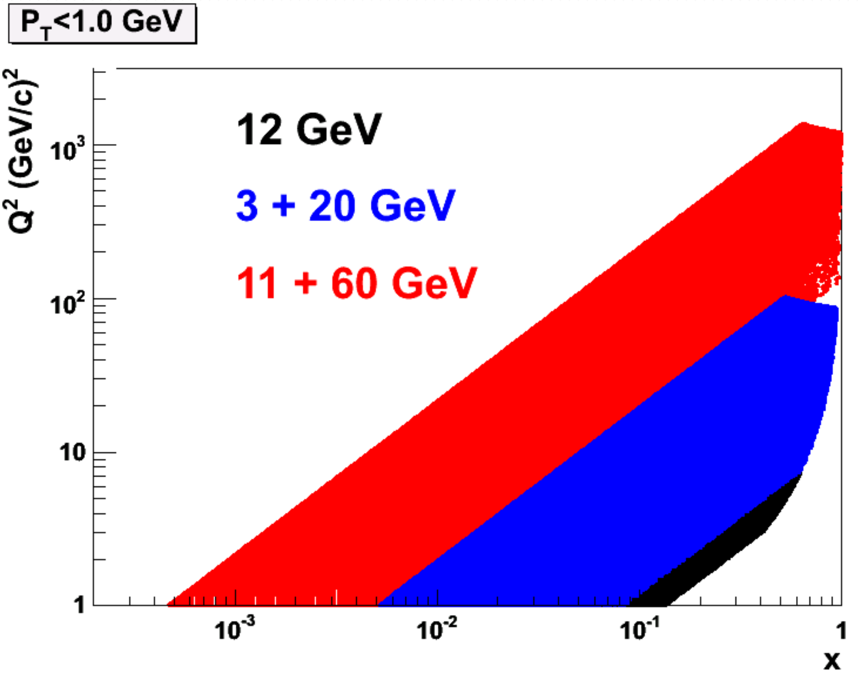
Summary

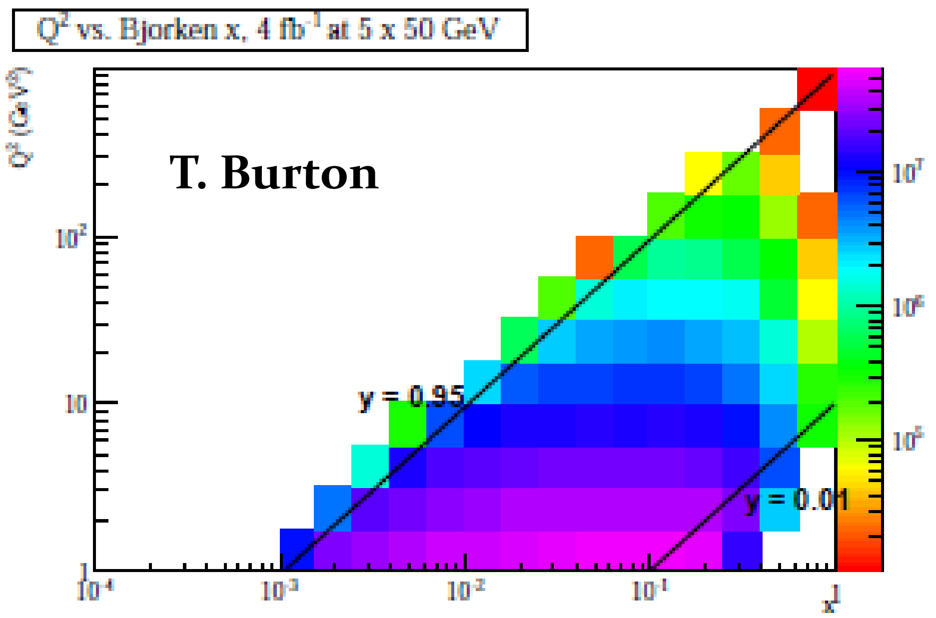
- EIC is an ideal machine to study QCD dynamics for Sea & Gluon
  - One of the golden channels: Sivers Effect
- High luminosity is essential for 4-D mapping of TSSA for π, K, D, back-to-back D meson production, and high P_T physics
  - Sea Quark Sivers, Gluon Sivers, Twist-3 tri-gluon correlation functions, ……
- Detector Requirement (SIDIS)

Supported in part by U.S. Department of Energy under contract number DE-FG02-03ER41231

backup

Different Ways to Obtain large Q^2-x coverage





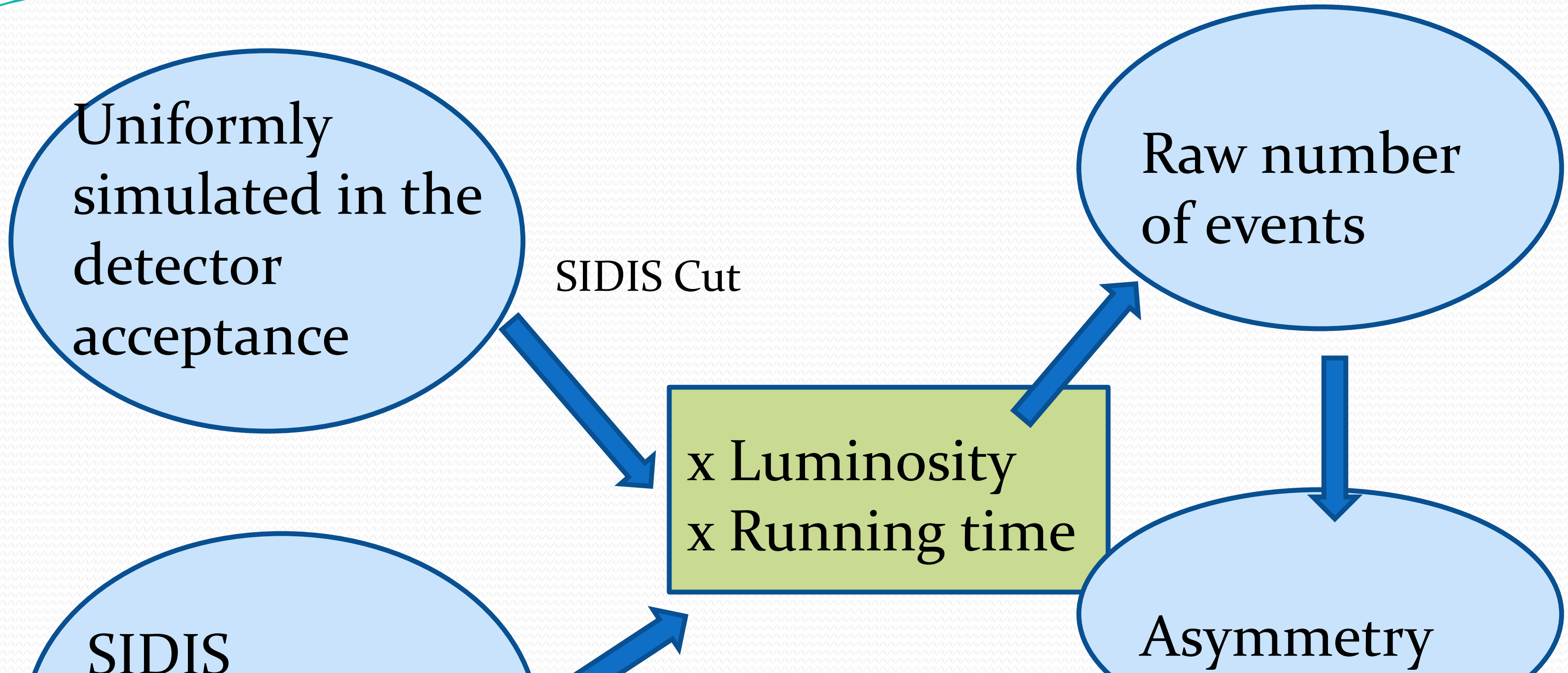
0.05<y<0.8

Lepton reconstruction, unnecessary extreme forward/backward coverage →Higher luminosity → Shorter running time, but more different s configurations

0.01<y<0.95

Hadronic exclusive reconstruction, 4π coverage → Lower luminosity → Longer running time, but one configuration

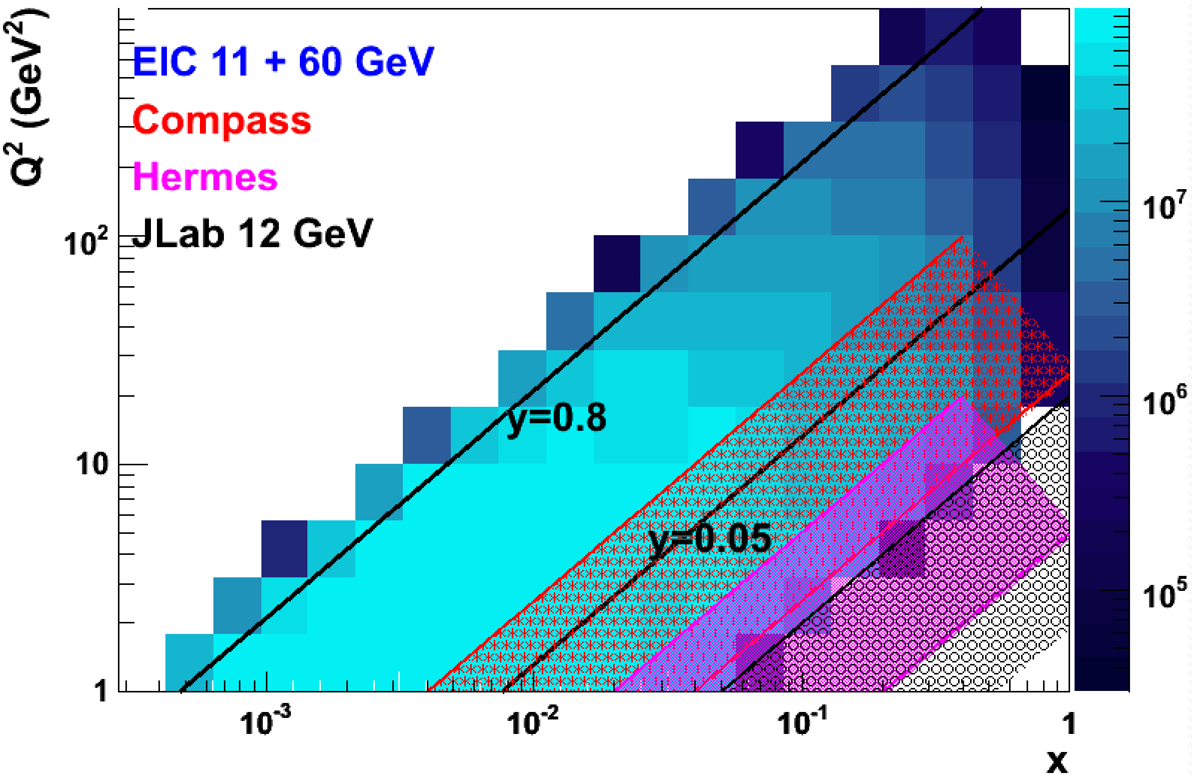
Monte-Carlo Method



$$\delta A = \frac{1}{P} \cdot \frac{1}{\sqrt{N_{raw}}}$$

Additional factors are introduced to mimic the increase of uncertainties due to the azimuthal angular separation of Collins, Sivers, and pretzelosity asymmetries.

Phase Space Coverage



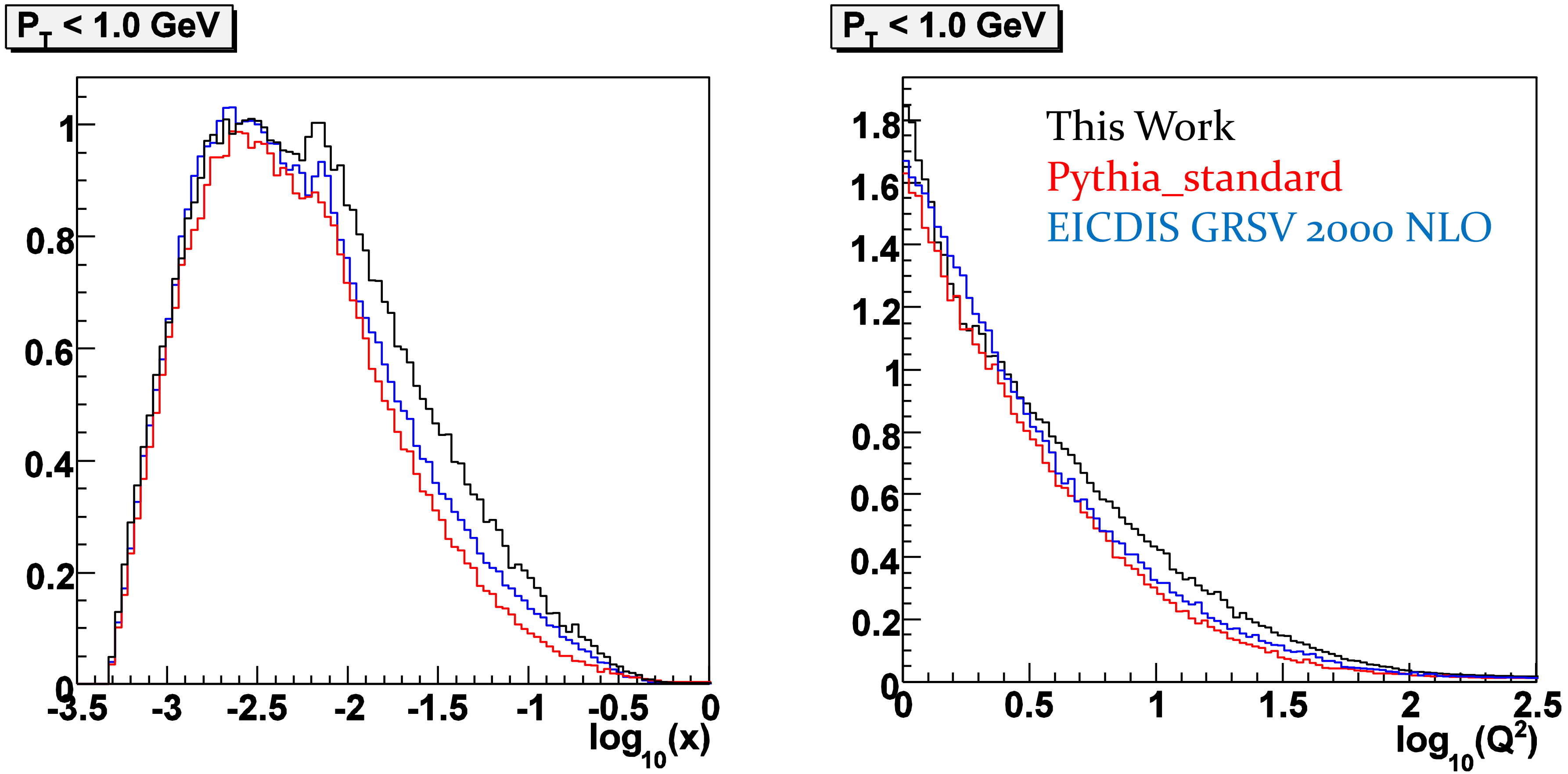
Lower y cut, more overlap with 12 GeV

$0.05 < y < 0.8$

Note that the coverages of Compass Hermes & Jlab 12 may not be able to do 4D mapping

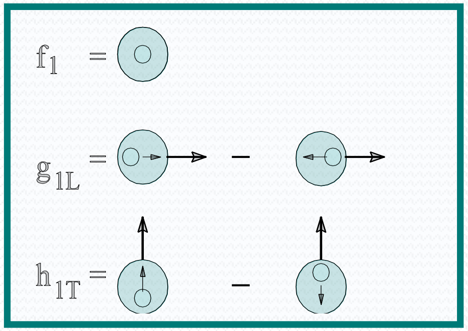
$$\frac{\delta x}{x} \equiv \frac{\delta P_e^f}{P_e^f} \cdot \frac{1}{y} + 2\frac{\delta \theta_e^f}{\tan\frac{\theta_e^f}{2}} \cdot \left(1 + \tan^2\frac{\theta_e^f}{2} \cdot \left(1 - \frac{1}{y}\right)\right)$$

Comparison with Other Event Generator



Pythia & EICDIS has been scaled down a factor of 1.5

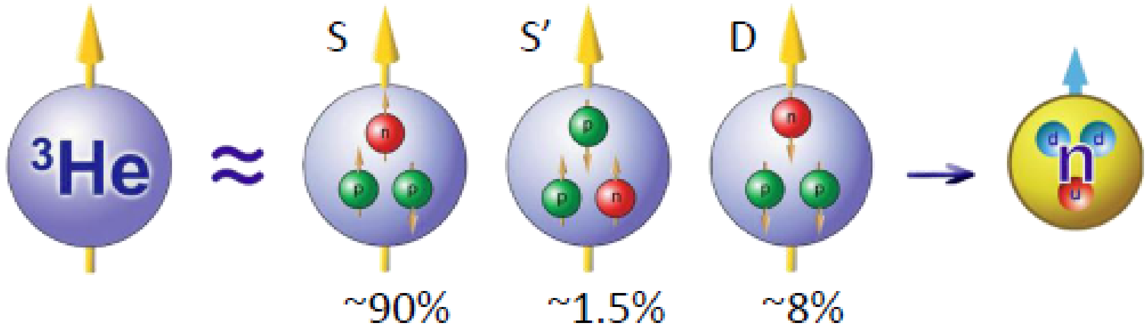
Rich Physics in TMDs (Transversity & Sivers)



- Transversity
  - $h_{1T} = g_{1L}$ for non-relativistic quarks
  - No gluon transversity (valence like)
  - Chiral-odd → difficult to access in inclusive DIS

- Sivers
  - Correlation between nucleon spin with quark angular momentum → a new type of distribution function
    - Parton orbital angular momentum?
  - Naive T-odd, also moments

Why Polarized ^{3}He Target ?

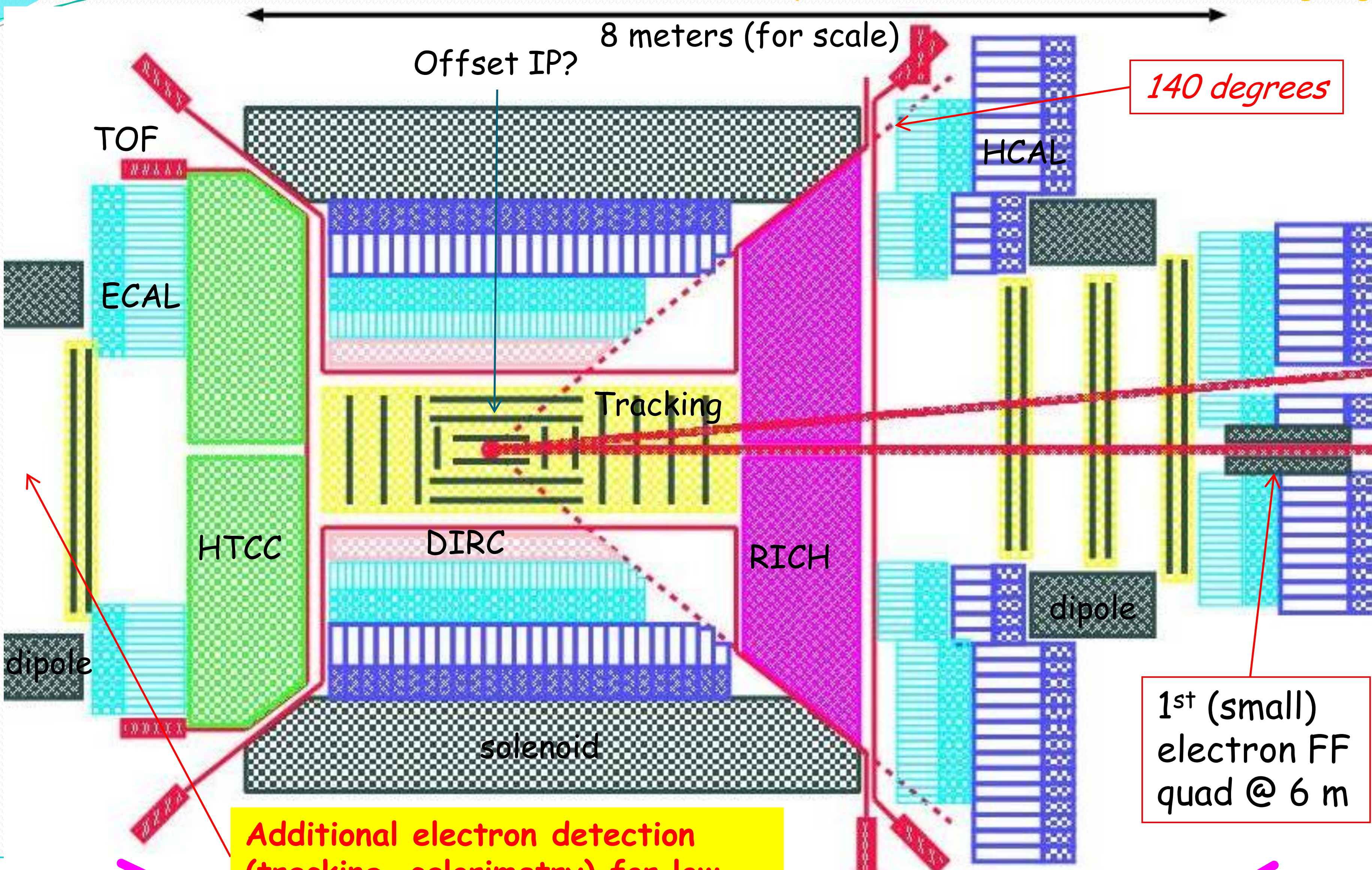


Effective Polarized Neutron Target!

- Greater figure of merit than polarized Deuteron target
  - Nuclear Polarization: 40~60% vs. 30~50%
  - Neutron Polarization: 90% vs. 90%
- Less systematic uncertainty coming from proton asymmetry
- Polarized through spin exchange optical pumping (SEOP)
- Compact size: No cryogenic support needed
- Much higher luminosity

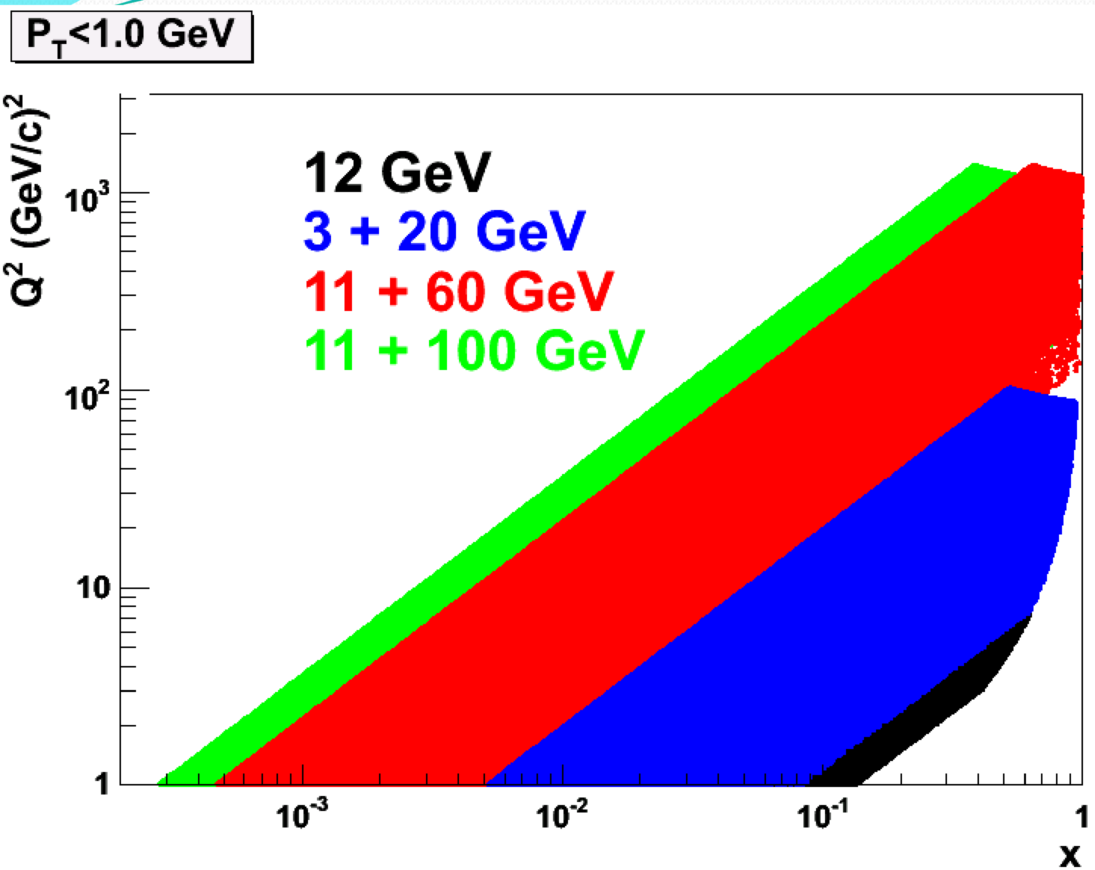
ELIC detector cartoon - Oct. 09

("Old": 1st electron quad now at 3 m, and 100 mr crossing angle)



Additional electron detection (tracking, calorimetry) for low-Q^2 physics not on cartoon

Mapping of TSSA (just phase space)



12 GeV --> approved SIDIS experiment Jlab E-10-006

Lower y cut, more overlap with 12 GeV

$0.05 < y < 0.8$

$$\frac{\delta x}{x} \equiv \frac{\delta P_e^f}{P_e^f} \cdot \frac{1}{y} + 2\frac{\delta \theta_e^f}{\tan\frac{\theta_e^f}{2}} \cdot \left(1 + \tan^2\frac{\theta_e^f}{2} \cdot \left(1 - \frac{1}{y}\right)\right)$$

Projection derivation

- At low x , $\sigma_n = \sigma_p$

  $$A_D \approx 0.5A_p + 0.5A_n$$

  $$A_n = 2A_D - A_p$$

  $$\delta A_n^{\ 2} = 4 \cdot \delta A_D^2 + \delta A_p^2$$

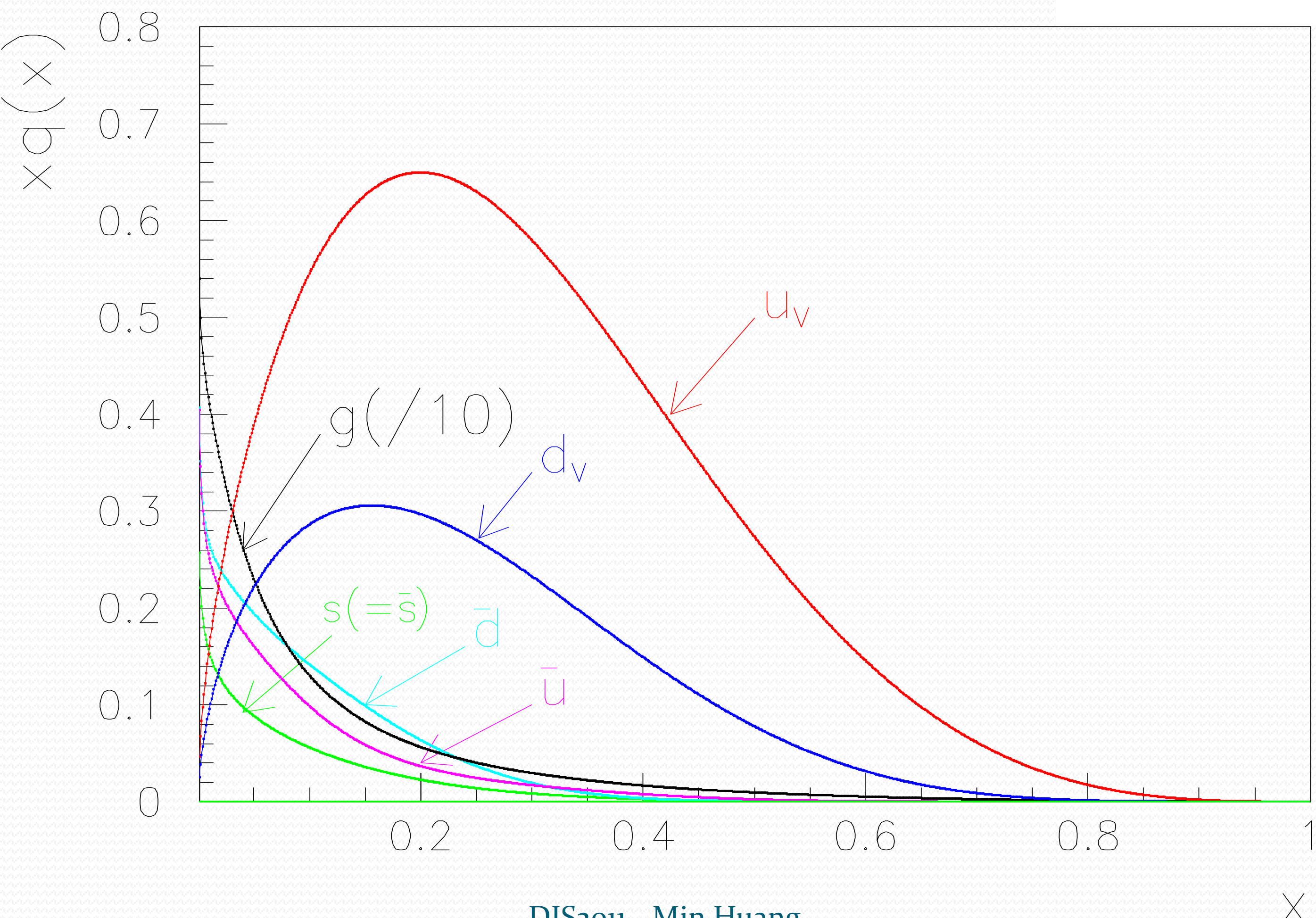
- D running time 2 times of H, thus $\delta A_p^{\ 2} = 4 \cdot \delta A_D^2$

$$\delta A_n^{\ 2} = 4 \cdot \delta A_D^2 + 4 \cdot \delta A_D^2 = 8 \cdot \delta A_D^2$$

$$\delta A_n = \sqrt{8} \cdot \delta A_D$$

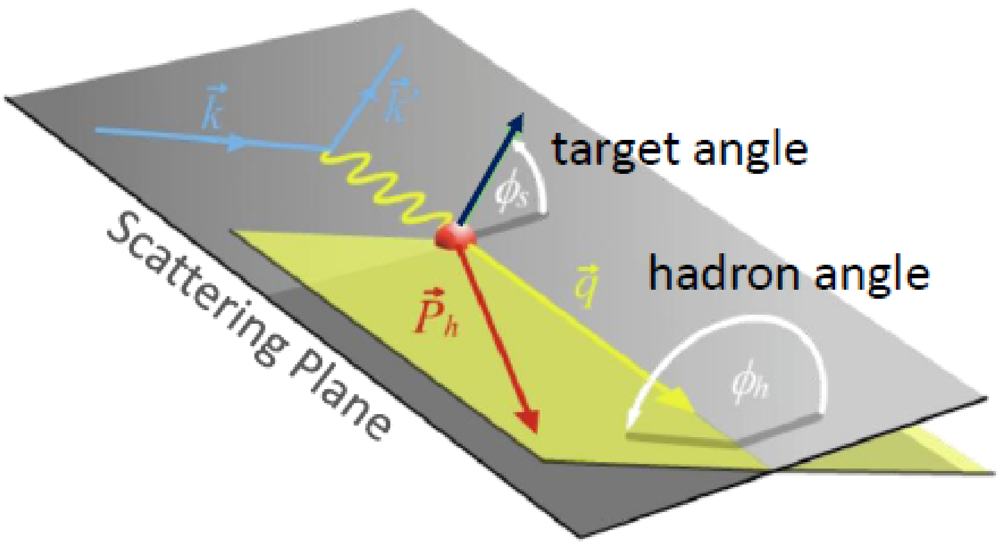
- equal stat for proton and neutron (combine 3He and D)
- If take p for 1
- 3He: 9/0.865/0.865/3/2≈1/2
- D: 8/0.88/0.88/2/2≈1/2.6
- 1/2+1/2.6 ≈ 1

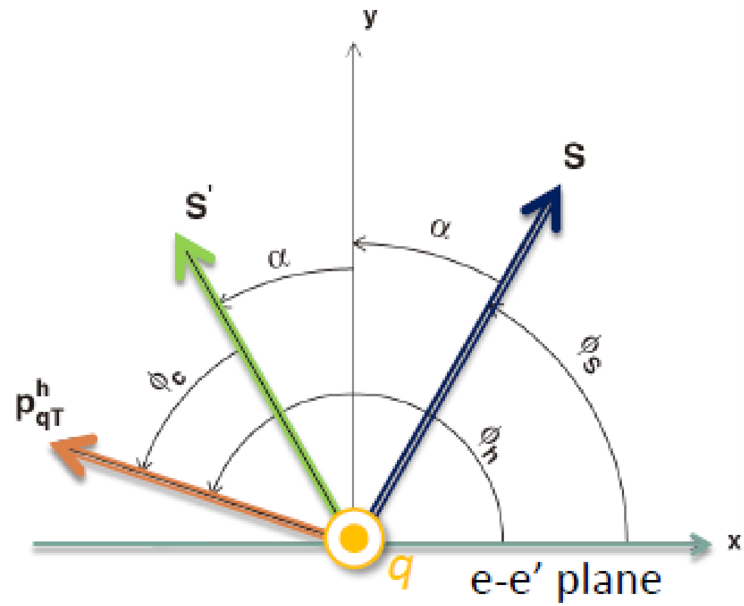
$$L = f_c \frac{N_h N_e}{4\pi\beta^* \varepsilon}$$



SIDIS Electroproduction of Pions

- Separate Sivers and Collins effects





- **Sivers** angle, effect in distribution function:
  - $(\phi_h-\phi_s)$ = angle of hadron relative to ***initial*** quark spin
- **Collins** angle, effect in fragmentation function:
  - $(\phi_h+\phi_s) = \pi+(\phi_h-\phi_{s'})$ = angle of hadron relative to ***final*** quark spin

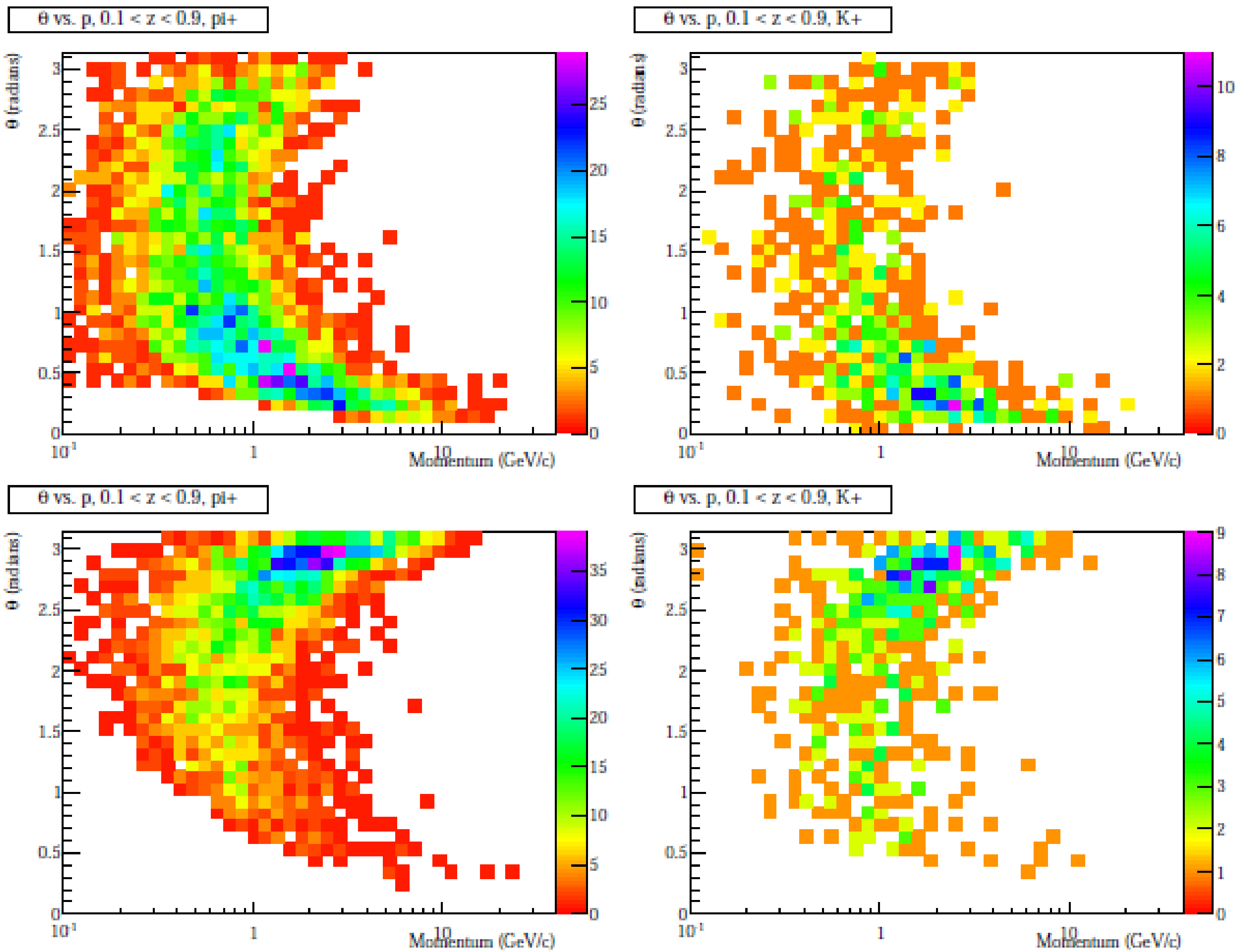
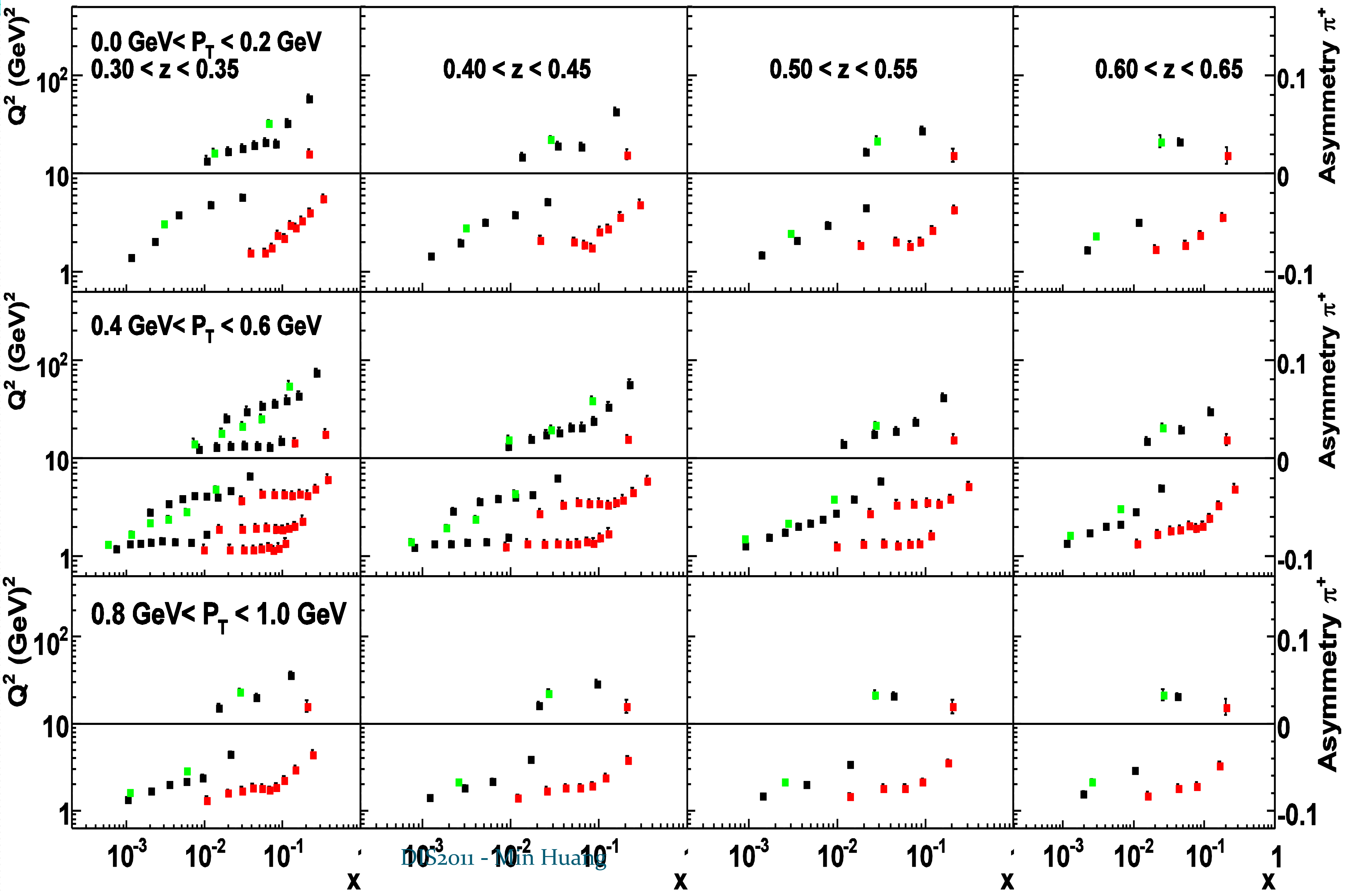


Figure 7: Leading hadrons momenta and polar angles vs. P_h for pions and kaon at EIC EIC 5 x 100 GeV $\sqrt{s} = 44.7$ GeV, EIC 20 x 250 GeV $\sqrt{s} = 141.4$ GeV

Proton K+ (4-D)



0.0 GeV< P_T < 0.2 GeV
0.30 < z < 0.35
0.40 < z < 0.45
0.50 < z < 0.55
0.60 < z < 0.65
0.4 GeV< P_T < 0.6 GeV
0.8 GeV< P_T < 1.0 GeV
Q^2 (GeV)^2
Asymmetry π^+
x

Cross Section in MC

- Low P_T cross section:
  - A. Bacchetta hep-ph/0611265 JHEP 0702:093 (2003)
- High P_T cross section:
  - M. Anselmino *et al*. Eur. Phys. J. A31 (2007) 373

$$\frac{d\sigma}{dx\, dy\, dz\, d\psi\, d\phi_H\, dP_{h\perp}^2} \xrightarrow[\text{calculation}]{\text{6x6 Jacobian}} \frac{d\sigma}{dp_e^f\, d\cos\theta_e^f\, d\phi_e^f\, dp_h\, d\cos\theta_h\, d\phi_h}$$

- PDF: CTEQ6M
- FF: Binnewies *et al.* PRD 52 (1995) 4947
- $\langle p_t^2 \rangle = 0.2\ \mathrm{GeV}^2$ $\langle k_t^2 \rangle = 0.25\ \mathrm{GeV}^2$
- NLO calculation at large PT
  - $\langle p_t^2 \rangle = 0.25\ \mathrm{GeV}^2$
  - $\langle k_t^2 \rangle = 0.28\ \mathrm{GeV}^2$

– A factor K generated to interpolate between high and low P_T

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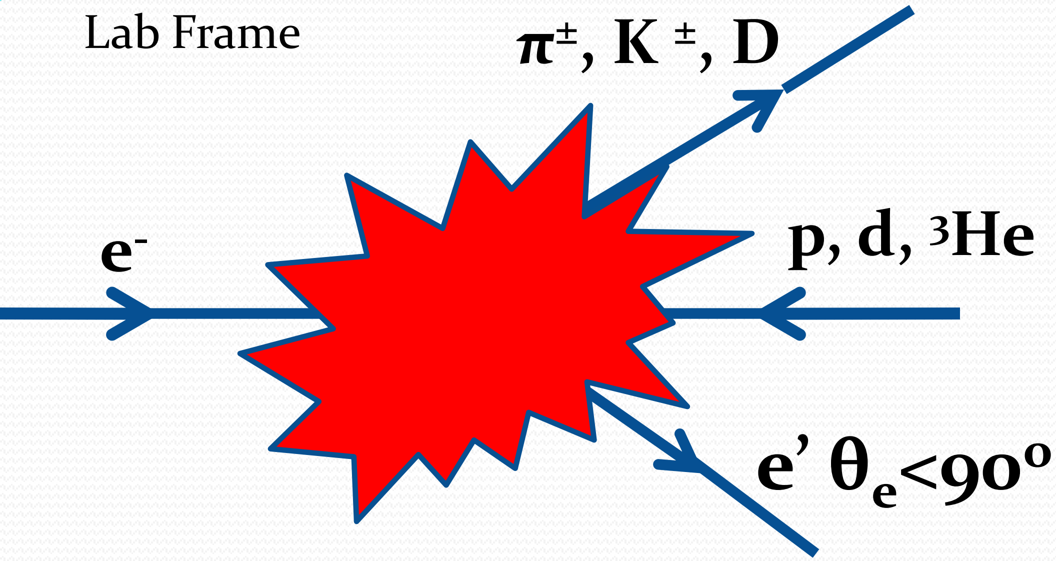
Lab Frame



Ion-at-rest (collinear) frame

$\phi_S \quad \phi_h$

$$P_T = \frac{|\vec{p}_h \times \vec{q}|}{|\vec{q}|}$$

$$x = \frac{Q^2}{2P_p \cdot q}$$

$$y = \frac{P_p \cdot q}{P_p \cdot P_e^i}$$

$$z = \frac{P_p \cdot P_h}{P_p \cdot q}$$

$$\frac{Q^2}{x \cdot y} = 2P_p \cdot P_e^i \approx s$$

$$Q^2 = x \cdot y \cdot s$$