Study of TMDs at EicC

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Tianbo Liu (刘天博)
Thomas Jefferson National Accelerator Facility

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Nucleon Spin Structure

Proton spin puzzle

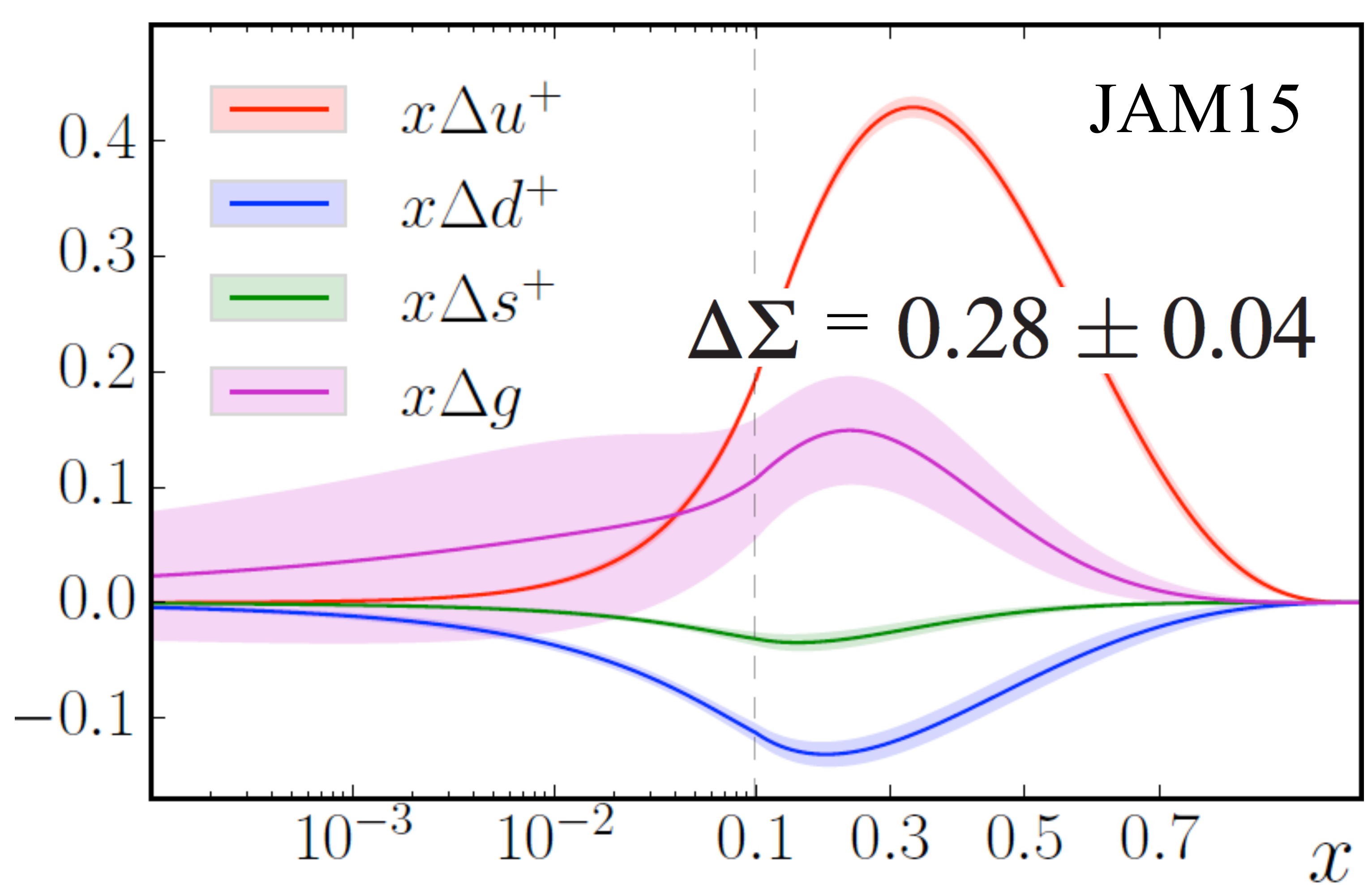
$$\Delta\Sigma = \Delta u + \Delta d + \Delta s \sim 0.3$$

Quark spin only contributes a small fraction to the nucleon spin.

J. Ashman *et al.*, PLB 206, 364 (1988); NP B328, 1 (1989).

Spin decomposition

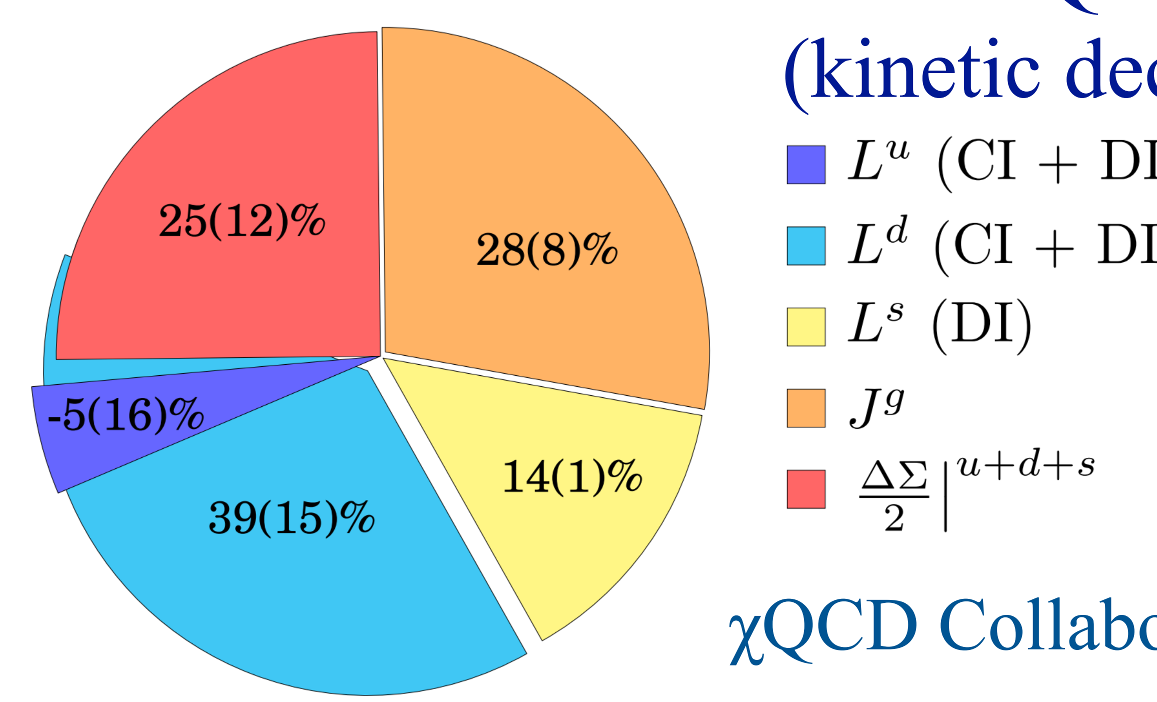
$$J = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$



JAM Collaboration, PR D 93, 074005 (2016).

JAM17: $\Delta\Sigma = 0.36 \pm 0.09$

JAM Collaboration, PRL 119, 132001 (2017).



χQCD Collaboration, PR D 91, 014505 (2015).

Gluon spin from LQCD: $S_g = 0.251(47)(16)$

50% of total proton spin

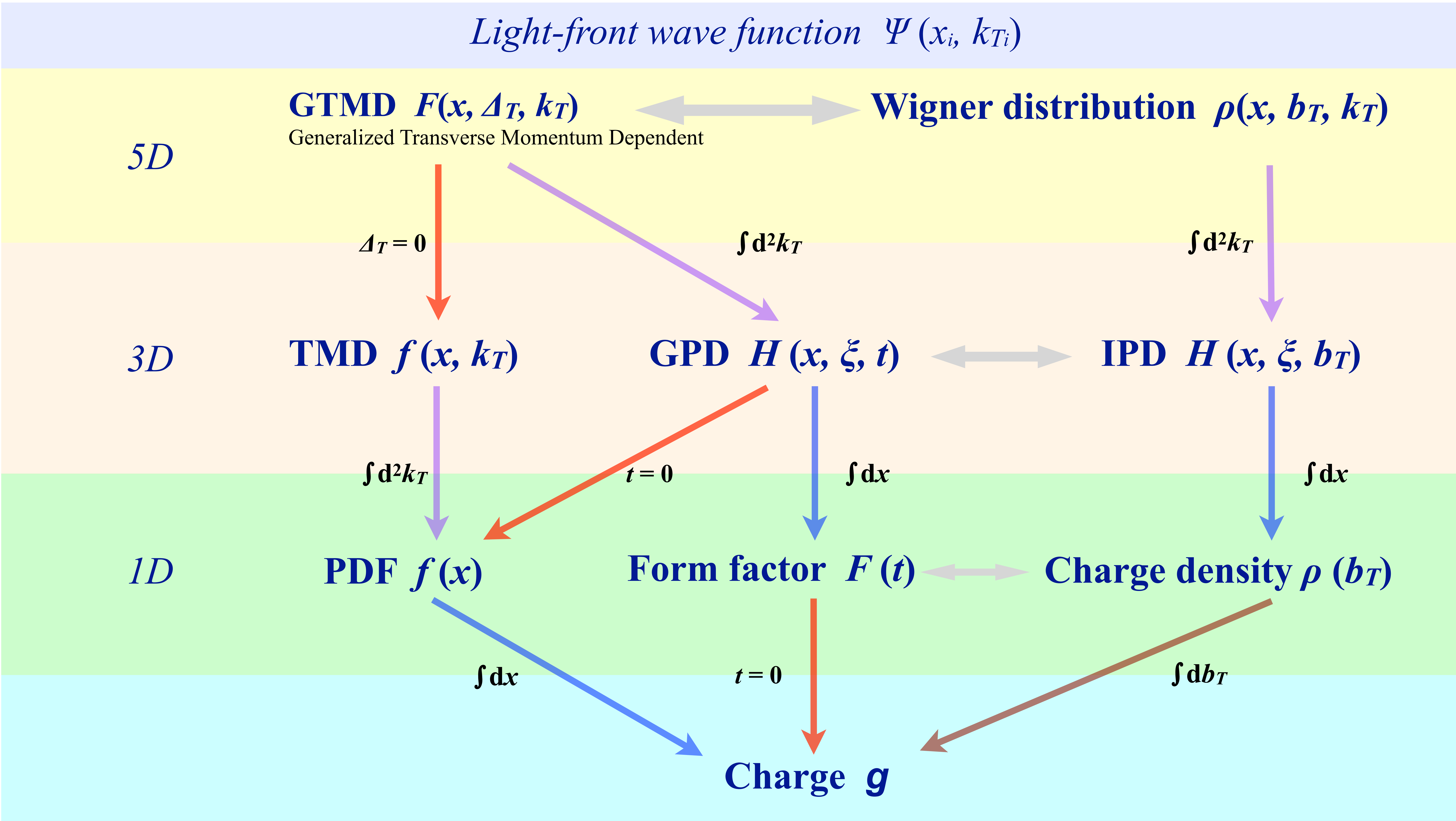
Y.-B. Yang *et al.* (χQCD Collaboration), PRL 118, 102001 (2017).

Access to $L_{q/g}$

It is necessary to have transverse information.

3*D* imaging of the nucleon.

Unified View of Nucleon Structures



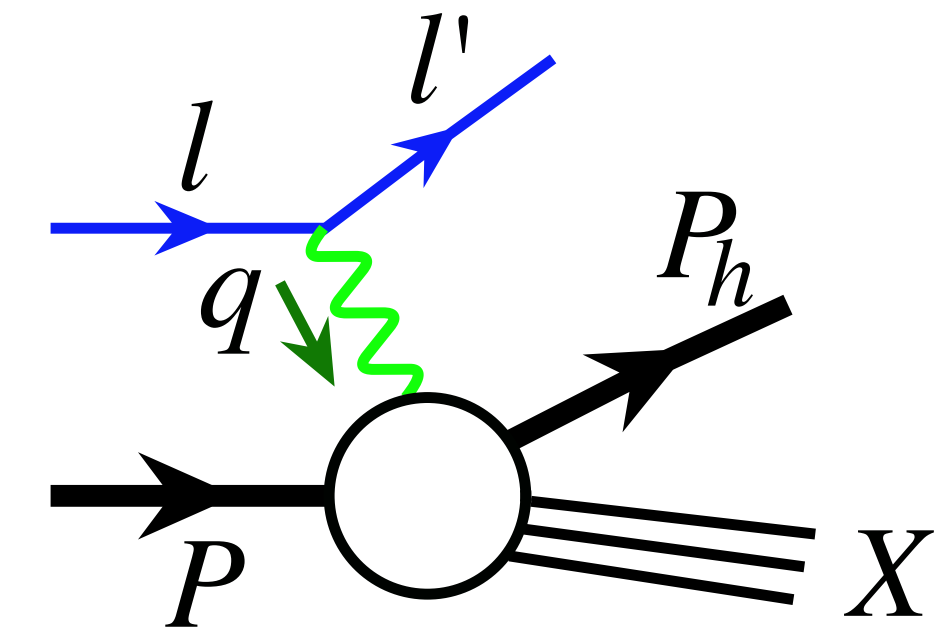
Leading Twist TMDs

Nucleon Polarization	Quark Polarization: U	L	T
U	f_1 **unpolarized**		$h_1^{\perp}$ **Boer-Mulders**
L		g_{1L} **helicity**	$h_{1L}^{\perp}$ **longi-transversity (worm-gear)**
T	$f_{1T}^{\perp}$ **Sivers**	g_{1T} **trans-helicity (worm-gear)**	h_1 **transversity** $h_{1T}^{\perp}$ **pretzelosity**

Nucleon spin   Quark spin

Semi-inclusive Deep Inelastic Scattering

SIDIS process $\quad l + P \rightarrow l' + h + X$

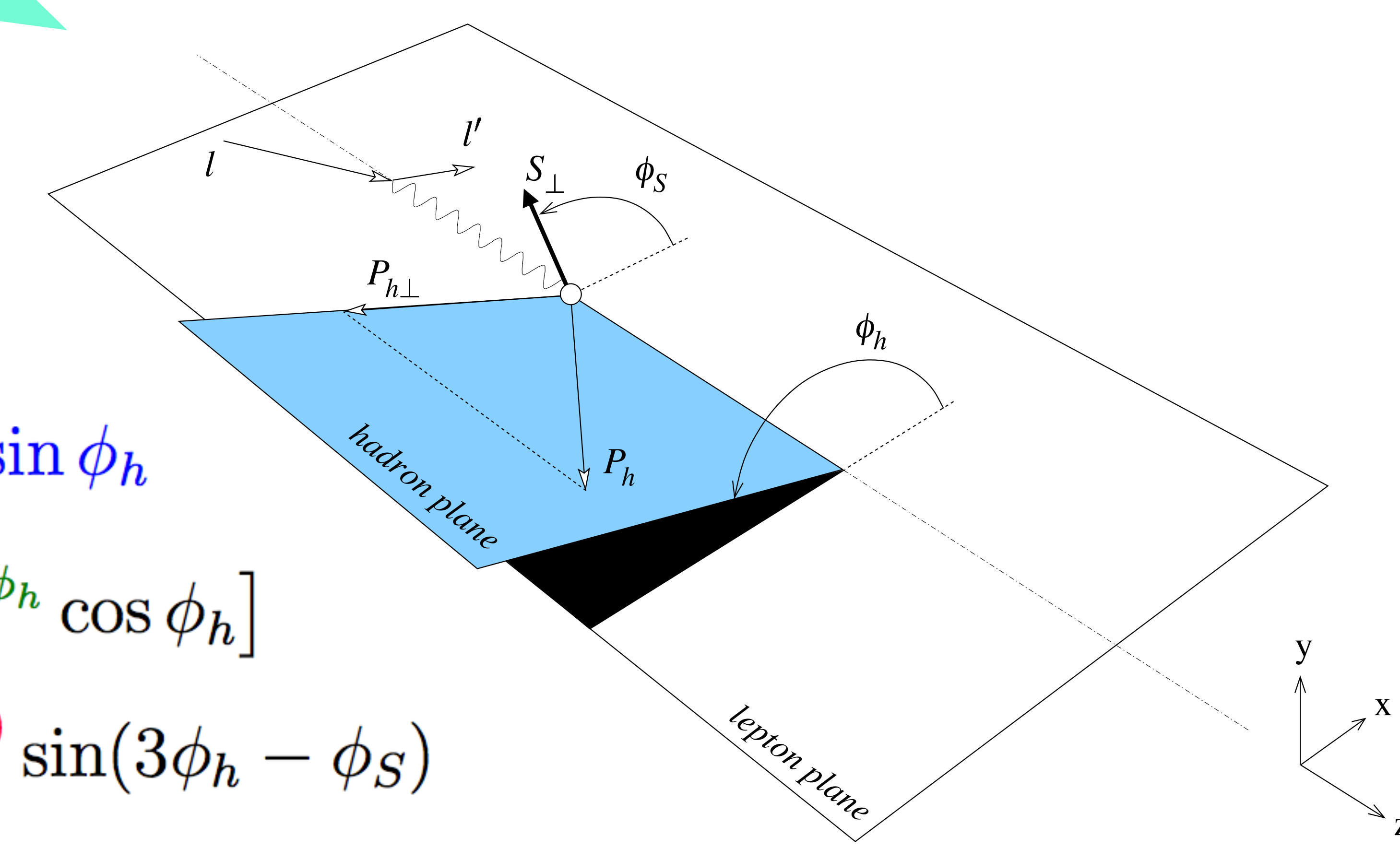


Kinematic variables

$$Q^2 = -q^2 = -(l-l')^2 \qquad x = \frac{Q^2}{2P\cdot q} \qquad y = \frac{P\cdot q}{P\cdot l} \qquad W^2 = (P+q)^2$$

$$z = \frac{P\cdot P_h}{P\cdot q} \qquad W'^2 = (P+q-P_h)^2 \qquad P_{h\perp}, \phi_h, \phi_S$$

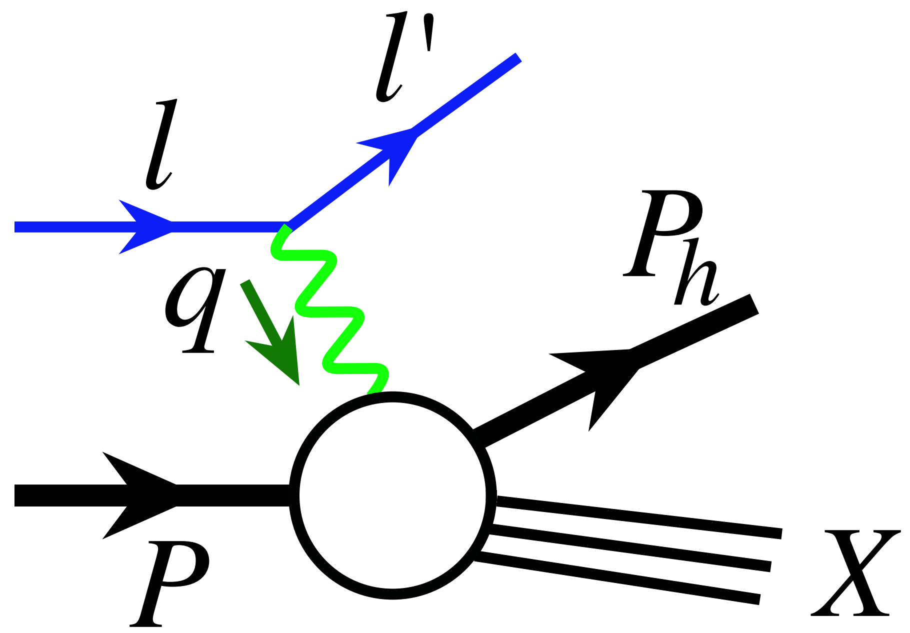
$$\begin{aligned}
&\frac{d\sigma}{dx\,dy\,dz\,dP_T^2\,d\phi_h\,d\psi} \\
&= \frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\epsilon)}\left(1+\frac{\gamma^2}{2x}\right) \\
&\times \Big\{ F_{UU,T} + \epsilon F_{UU,L} + \sqrt{2\epsilon(1+\epsilon)}F_{UU}^{\cos\phi_h}\cos\phi_h + \epsilon F_{UU}^{\cos 2\phi_h}\cos 2\phi_h + \lambda_e\sqrt{2\epsilon(1-\epsilon)}F_{LU}^{\sin\phi_h}\sin\phi_h \\
&+ S_L\Big[\sqrt{2\epsilon(1+\epsilon)}F_{UL}^{\sin\phi_h}\sin\phi_h + \epsilon F_{UL}^{\sin 2\phi_h}\sin 2\phi_h\Big] + \lambda_e S_L\Big[\sqrt{1-\epsilon^2}F_{LL} + \sqrt{2\epsilon(1-\epsilon)}F_{LL}^{\cos\phi_h}\cos\phi_h\Big] \\
&+ S_T\Big[\big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \epsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\big)\sin(\phi_h-\phi_S) + \epsilon F_{UT}^{\sin(\phi_h+\phi_S)}\sin(\phi_h+\phi_S) + \epsilon F_{UT}^{\sin(3\phi_h-\phi_S)}\sin(3\phi_h-\phi_S) \\
&\qquad + \sqrt{2\epsilon(1+\epsilon)}F_{UT}^{\sin\phi_S}\sin\phi_S + \sqrt{2\epsilon(1+\epsilon)}F_{UT}^{\sin(2\phi_h-\phi_S)}\sin(2\phi_h-\phi_S)\Big] \\
&+ \lambda_e S_T\Big[\sqrt{1-\epsilon^2}F_{LT}^{\cos(\phi_h-\phi_S)}\cos(\phi_h-\phi_S) \\
&\qquad + \sqrt{2\epsilon(1-\epsilon)}F_{LT}^{\cos\phi_S}\cos\phi_S + \sqrt{2\epsilon(1-\epsilon)}F_{LT}^{\cos(2\phi_h-\phi_S)}\cos(2\phi_h-\phi_S)\Big]\Big\}
\end{aligned}$$

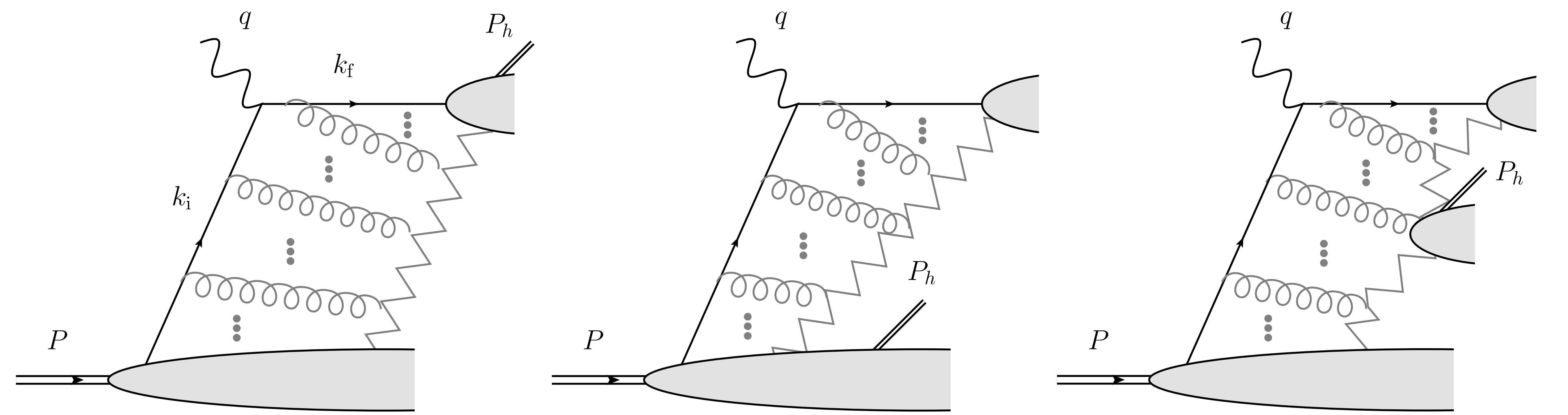


[Trento convention 2004]

SIDIS Kinematic Regions

M. Boglione *et al.*, Phys. Lett. B 766, 245 (2017).





(a) (b) (c)

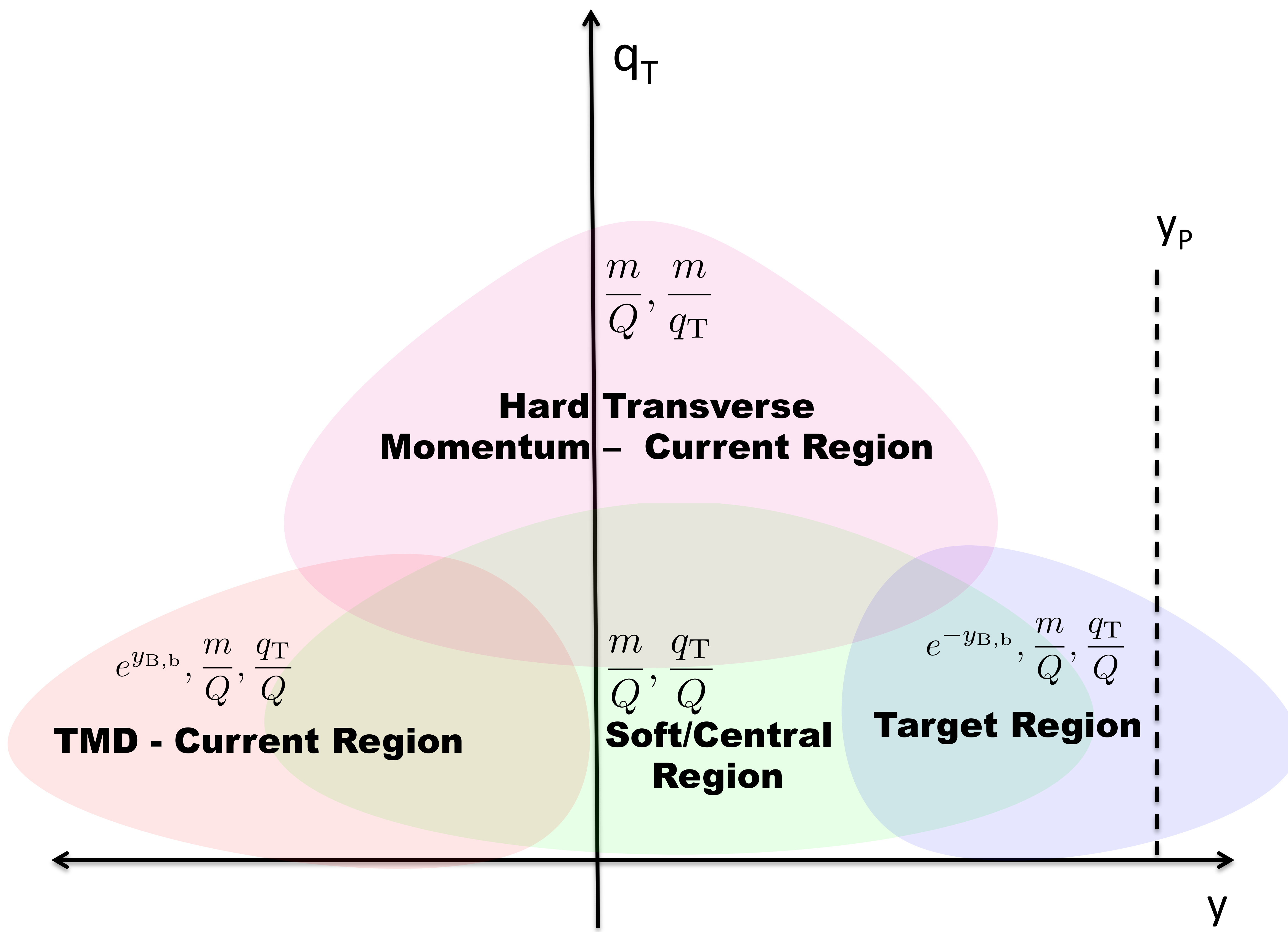
(a) Current fragmentation region; (b) Target fragmentation region; (c) Central fragmentation region

Regions overlap with each other. Classification boundaries are not sharp.

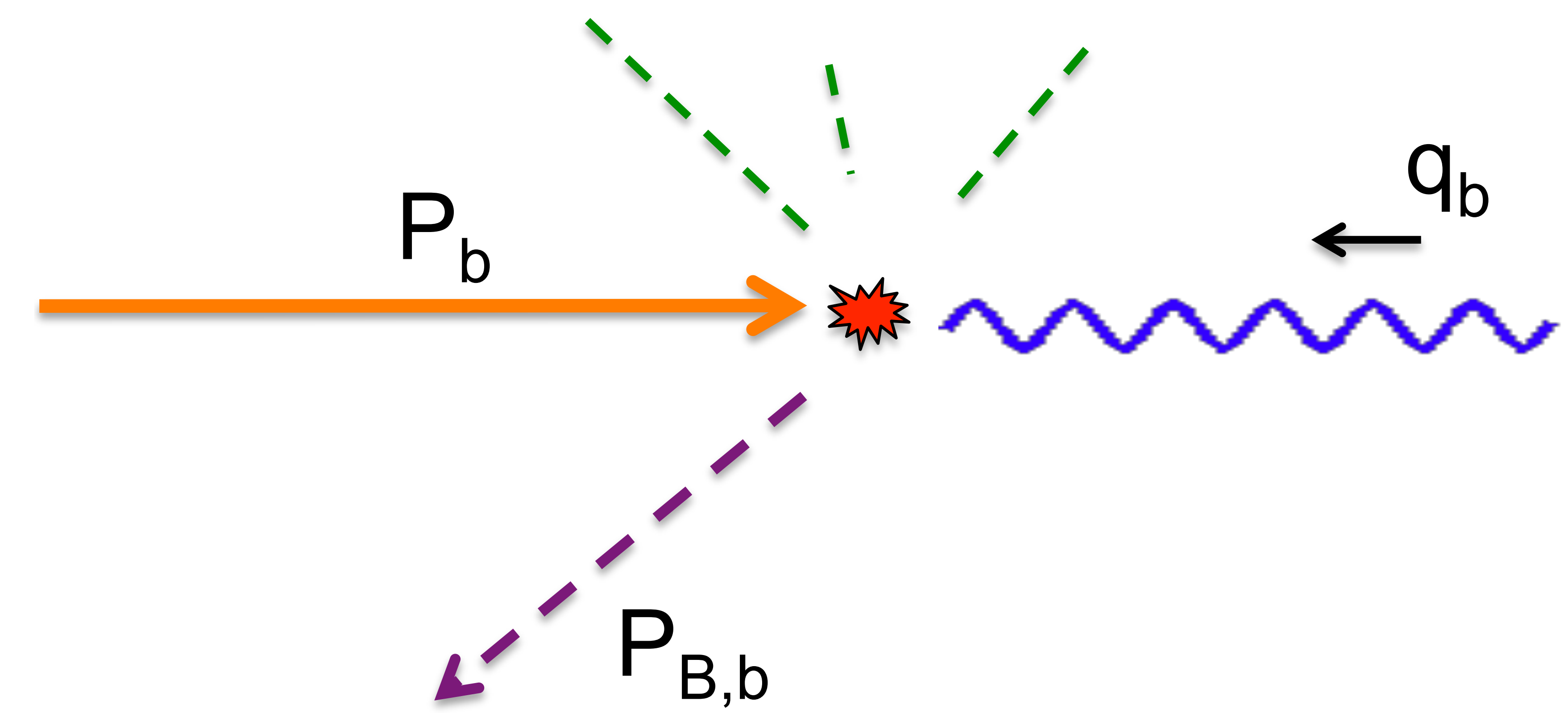
Some criteria may help to select events in the kinematic region dominated by current/target fragmentation.

SIDIS Kinematic Regions

Sketch of kinematic regions of the produced hadron



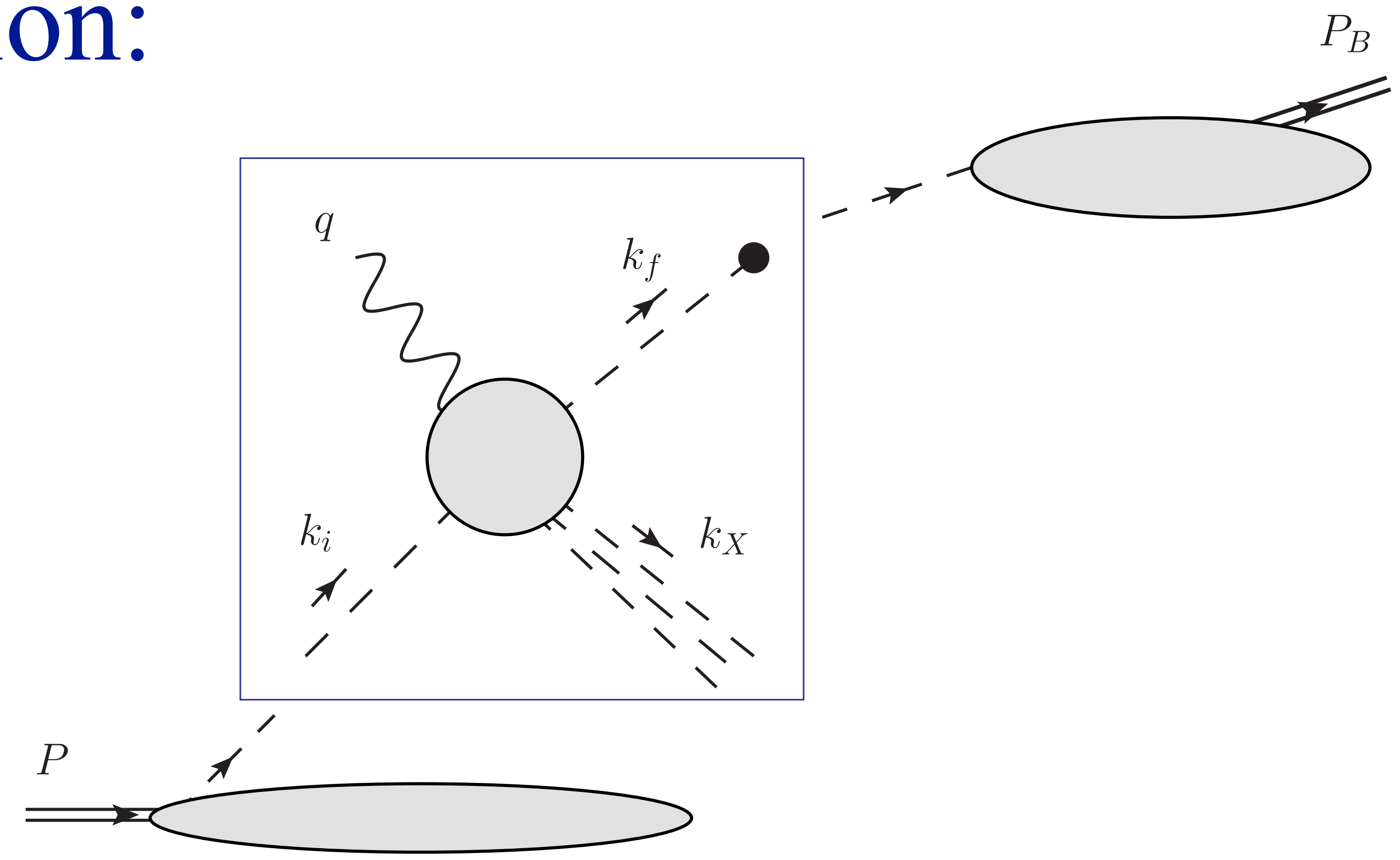
[Figure from arXiv:1904.12882]

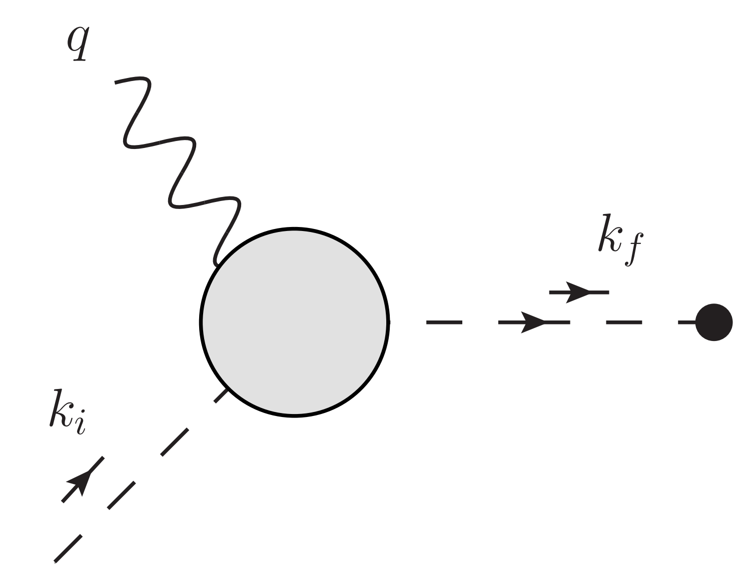


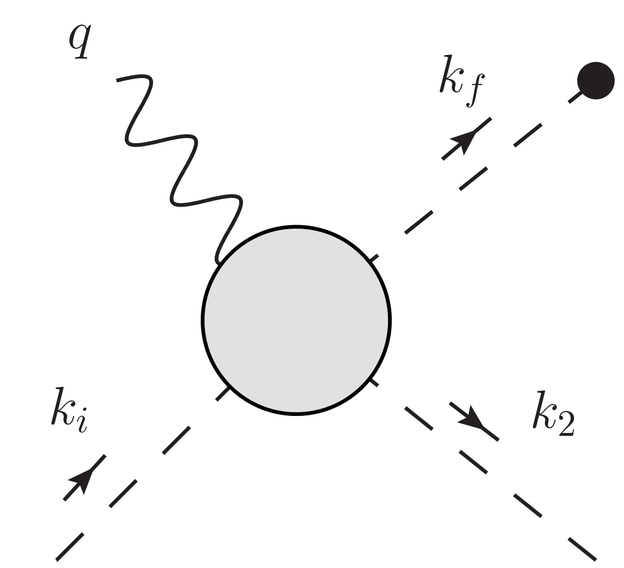
Nucleon-photon frame / Breit frame:
y: rapidity
$q_T = P_{hT} / z$: transverse momentum

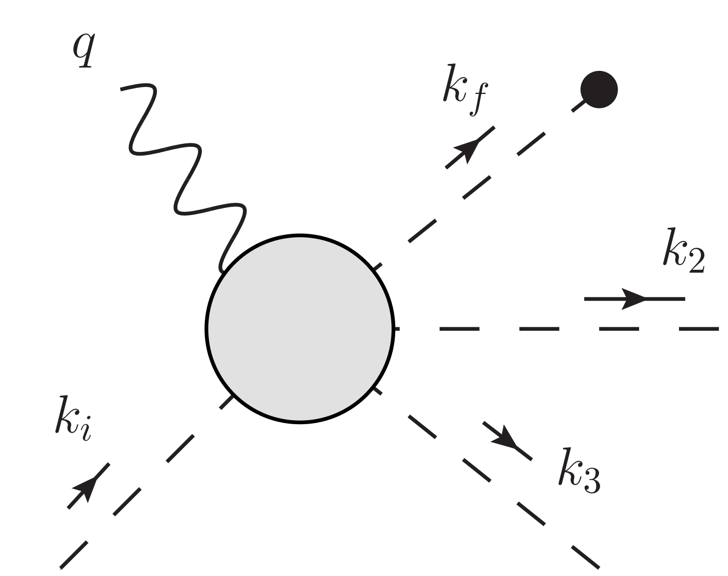
SIDIS Kinematic Regions

Current region:









General hardness ratio: $$R_0 \equiv \max\left(\left|\frac{k_i^2}{Q^2}\right|, \left|\frac{k_f^2}{Q^2}\right|, \left|\frac{\delta k_T^2}{Q^2}\right|\right)$$

Collinearity ratio: $$R_1 \equiv \left|\frac{P_h \cdot k_f}{P_h \cdot k_i}\right|$$ *small for current region*

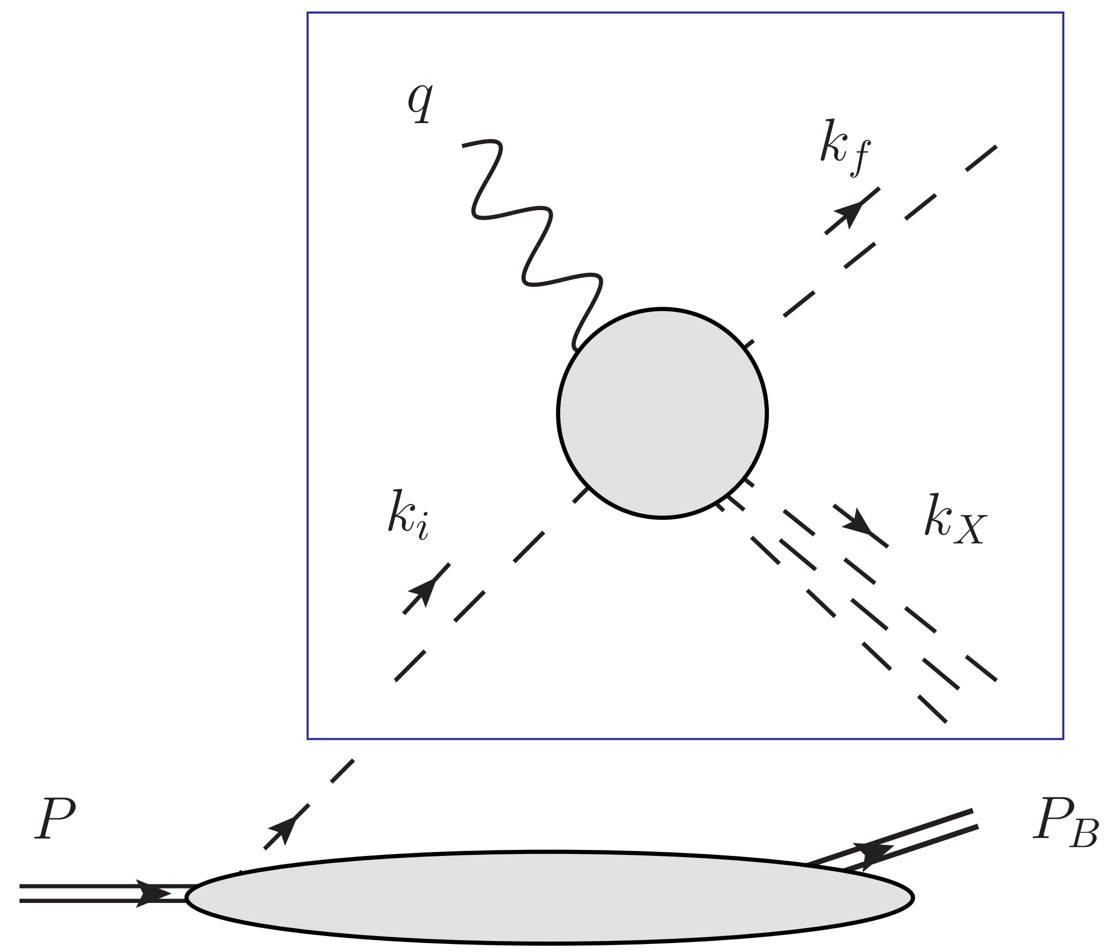
Transverse hardness ratio: $$R_2 \equiv \left|\frac{(k_f - q)^2}{Q^2}\right|$$ *small for TMD factorization*

Spectator virtuality ratio: $$R_3 \equiv \left|\frac{k_X^2}{Q^2}\right|$$

M. Boglione *et al.*, arXiv:1904.12882.

SIDIS Kinematic Regions

Target region:



$$R_1' \equiv \frac{P_h \cdot P}{Q^2}$$ *small for target region*

An alternative criteria: R_1^{-1} is small

Central (soft) region:

Neither R_1 nor R_1' is small.

One does not have any obvious way to associate the produced hadron with a quark or target direction.

M. Boglione *et al.*, arXiv:1904.12882.

SIDIS @ EicC

Electron beam: 3.5 GeV,   polarization ~80%

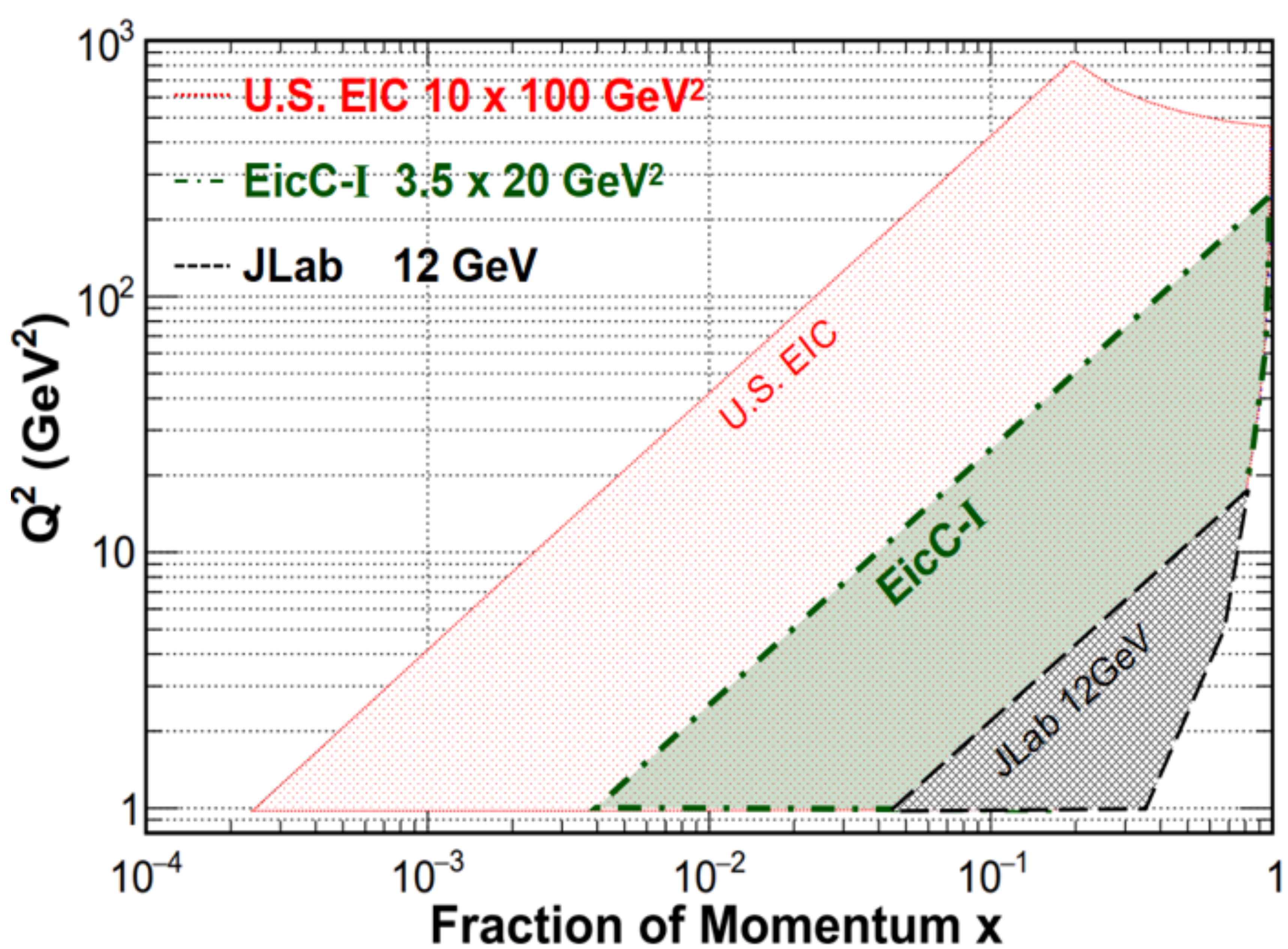
Proton beam: 20 GeV, polarization ~70%

Helium-3 beam: 40 GeV (40/3 GeV per nucleon),
polarization ~70%

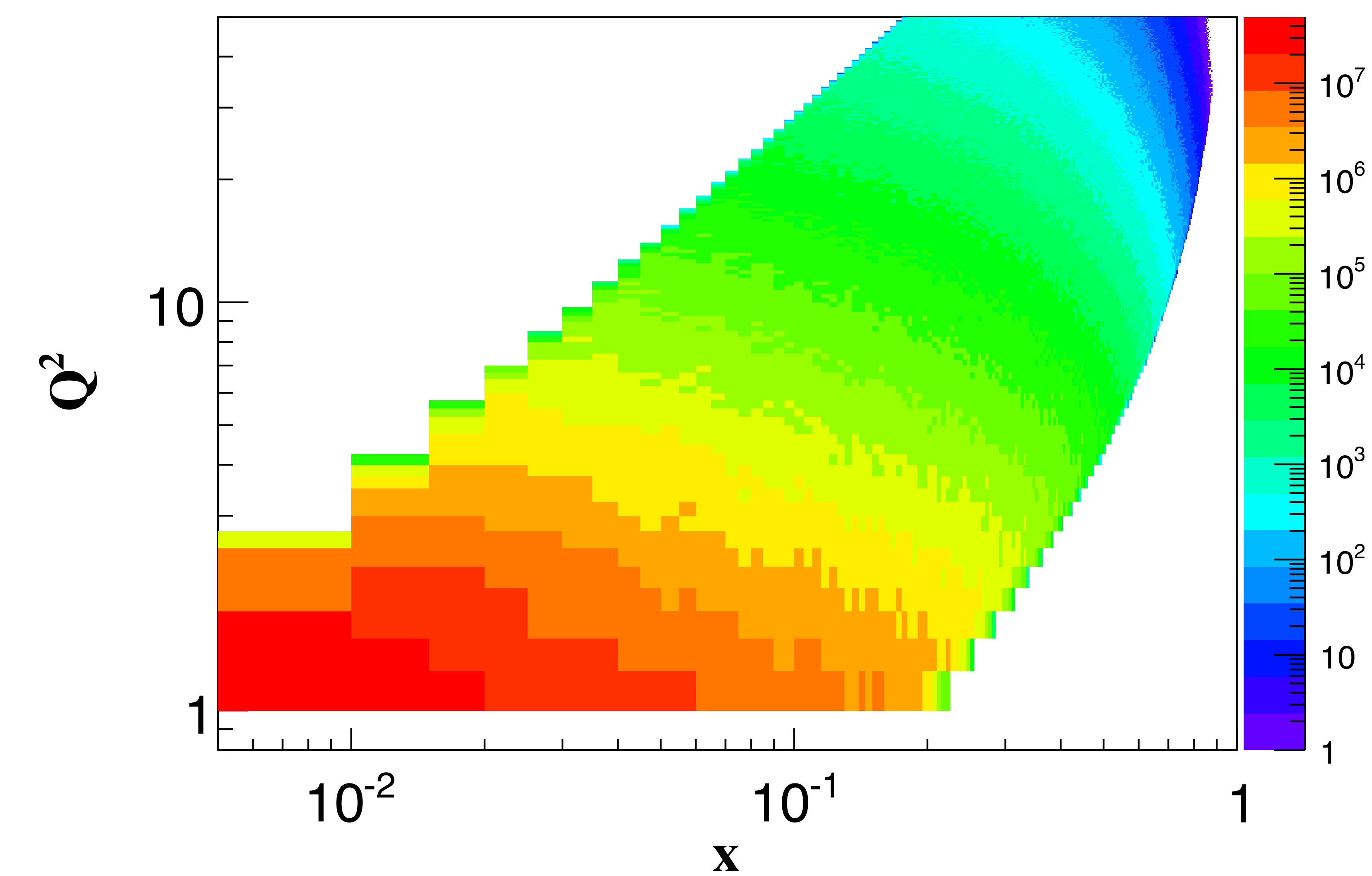
Center of mass energy: 15 ~ 20 GeV

Luminosity: 2 ~ 4 × 10^{33} cm^{-2} s^{-1}

Kinematics coverage:



EicC-SIDIS kinematics (example):
e-p (3.5 GeV×20 GeV), π^-



cuts:

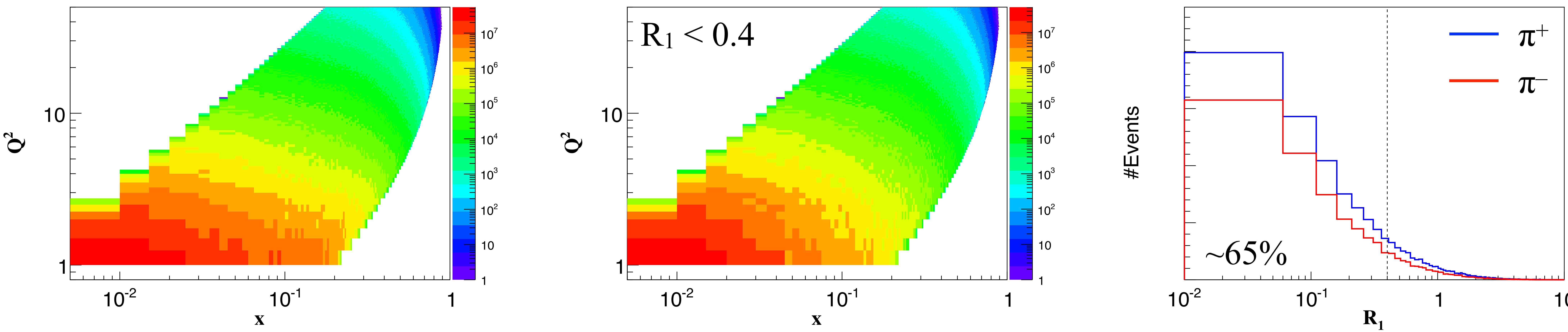
$$Q^2 > 1\,\mathrm{GeV}^2, \quad W > 2.3\,\mathrm{GeV}, \quad W' > 1.6\,\mathrm{GeV}$$

$$0.3 < z < 0.7$$

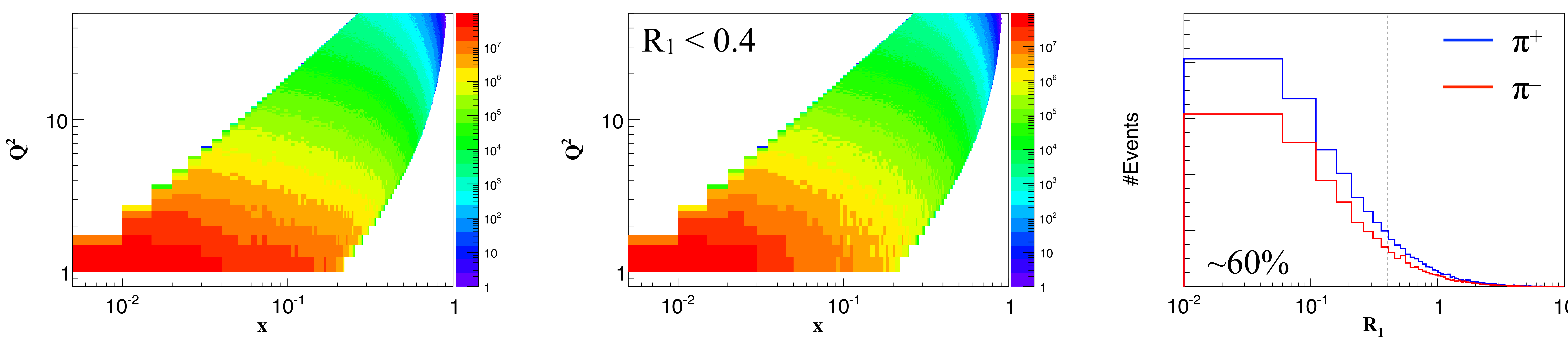
$$l' > 0.35\,\mathrm{GeV}, \quad P_h > 0.3\,\mathrm{GeV}$$

EicC-SIDIS Kinematic Regions

Proton beam (20 GeV):

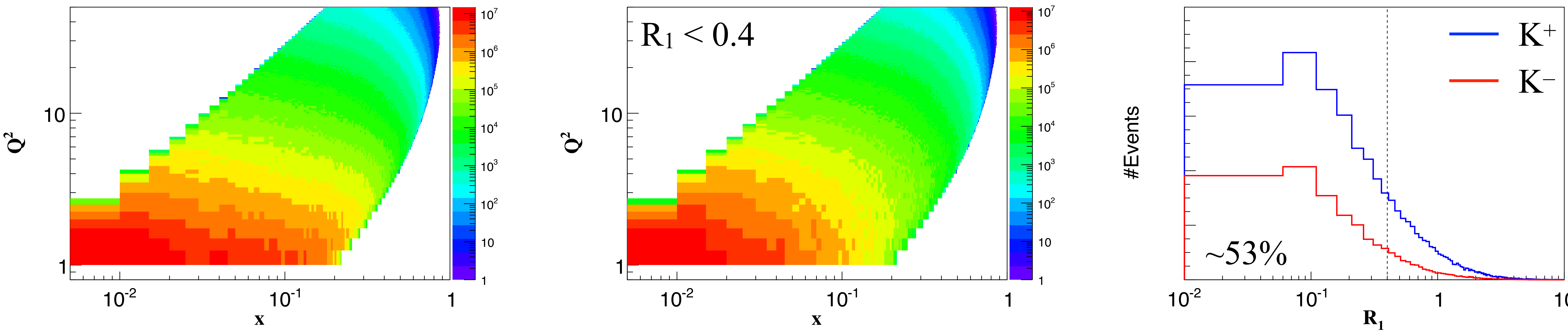


Helium-3 beam (40/3 GeV per nucleon):

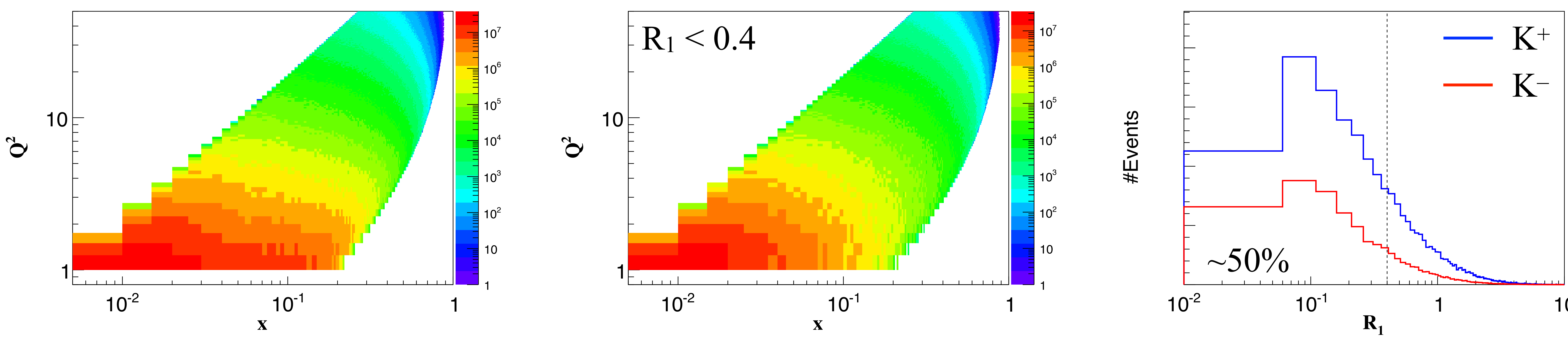


EicC-SIDIS Kinematic Regions

Proton beam (20 GeV):

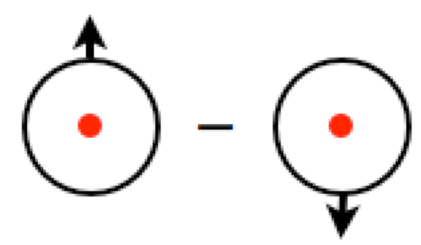


Helium-3 beam (40/3 GeV per nucleon):



Sivers Asymmetry

Sivers distribution

$f_{1T}^{\perp}$ 

naively time-reversal odd.

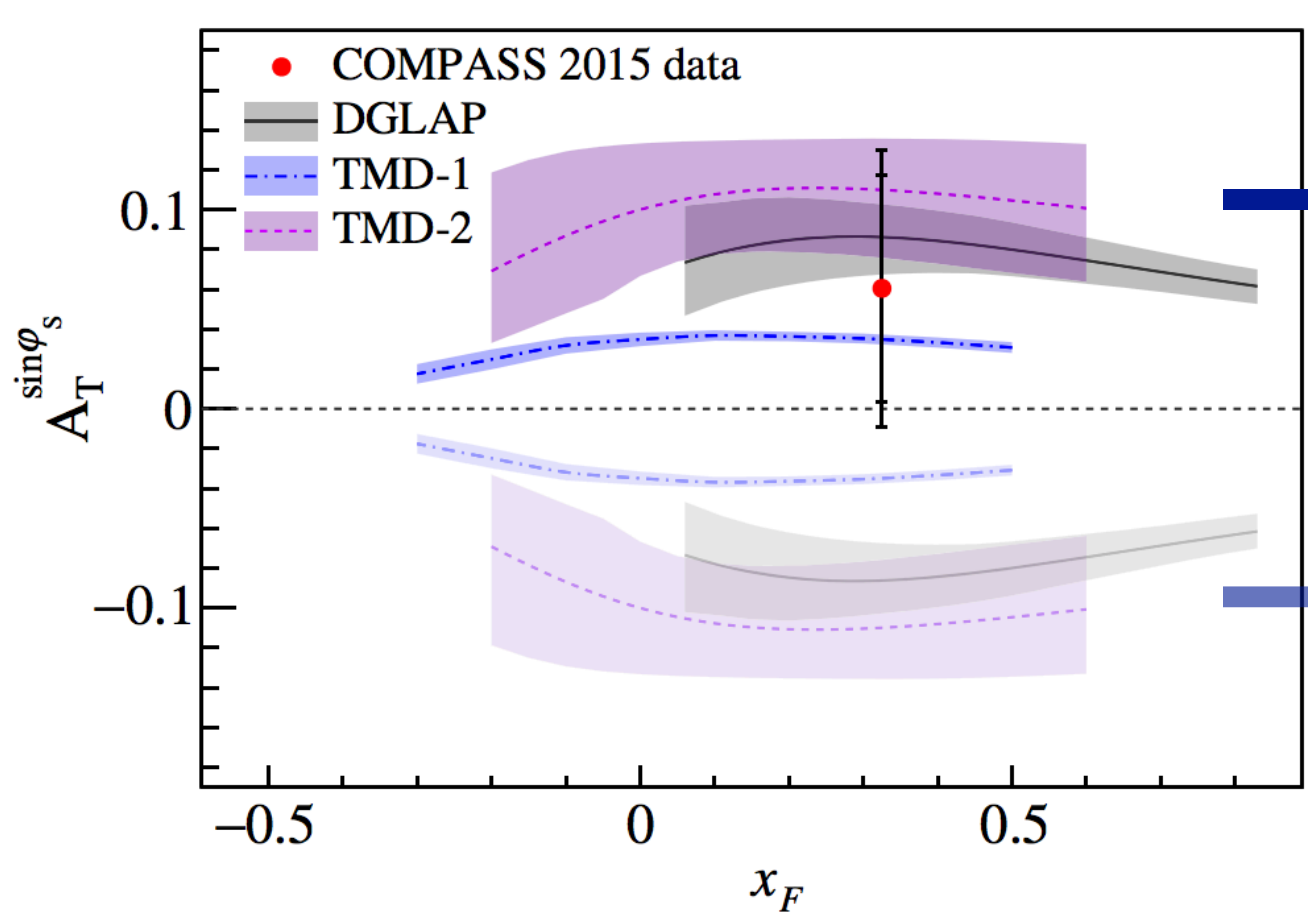
$$f_{1T}^{\perp q}(x, k_\perp)\Big|_{\text{SIDIS}} = -f_{1T}^{\perp q}(x, k_\perp)\Big|_{\text{DY}}$$

Measurement in SIDIS

Single spin asymmetry: Sivers asymmetry

$$A_{UT}^{\sin(\phi_h - \phi_S)} \sim f_{1T}^{\perp}(x, k_\perp) \bigotimes D_1(z, p_\perp)$$

Test of the sign change



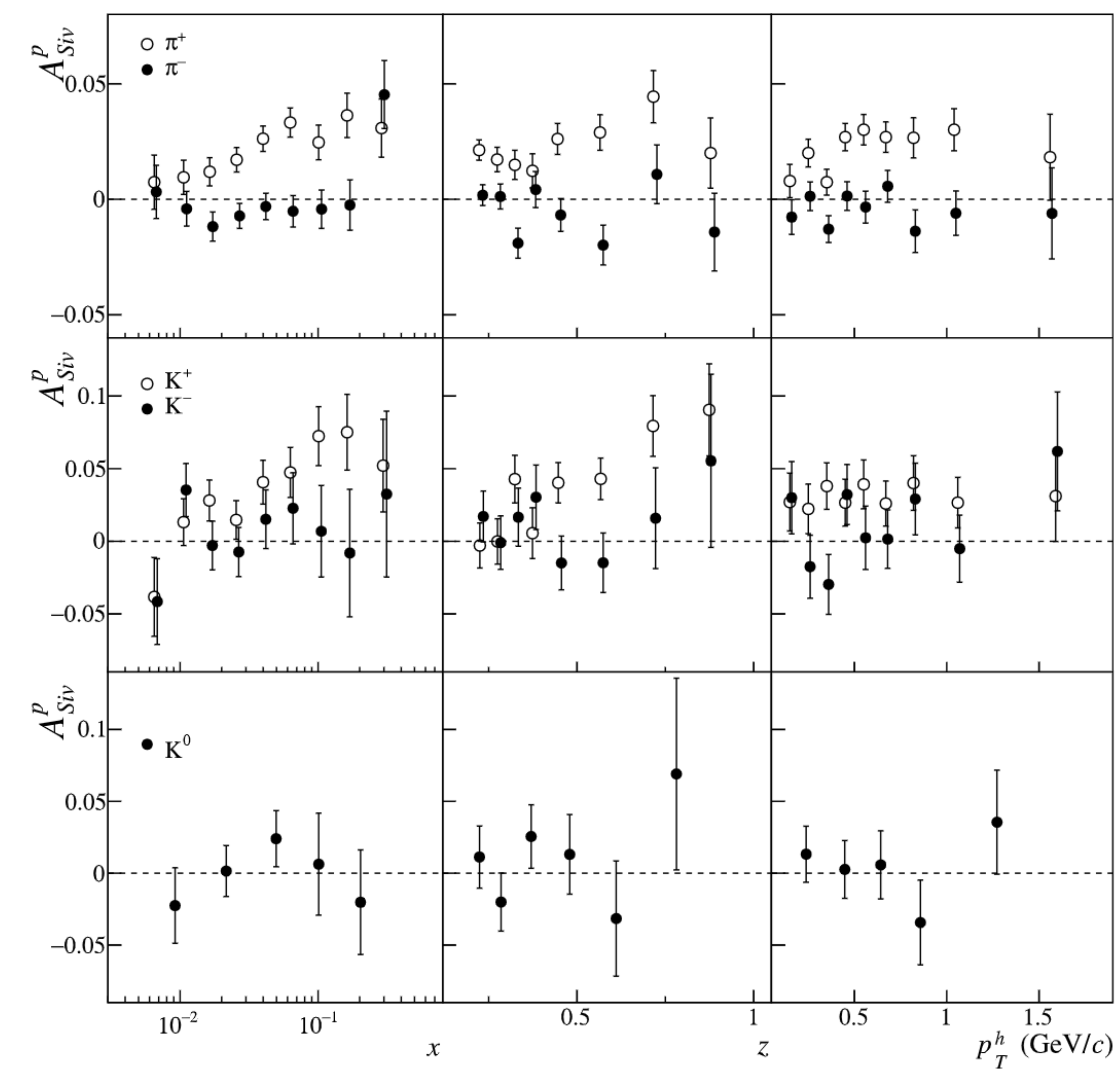
with sign change

without sign change

M. Aghashyan *et al.* (COMPASS Collaboration), PRL 119, 112002 (2017).

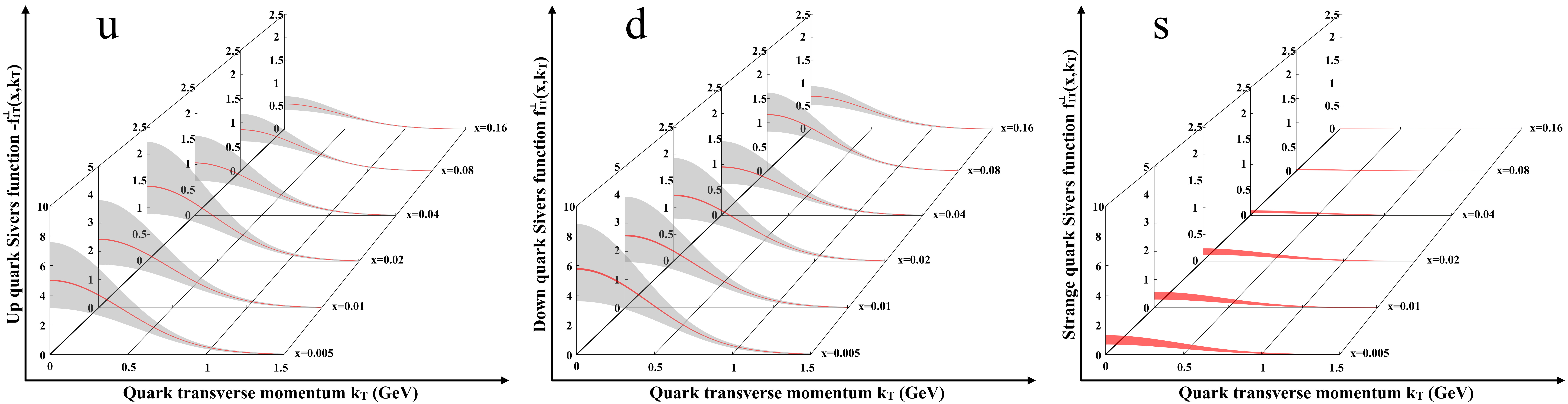
Example of world data

COMPASS muonproduction of pions and kaons off transversely polarized proton target:



Sivers asymmetry in SIDIS has been measured by HERMES, COMPASS, and JLab

Impact of EicC-SIDIS



Parametrization: M. Anselmino *et al.,* J. High Energy Phys. 04 (2017) 046.

World data: HERMES, COMPASS, JLab Hall A, pion and kaon SIDIS data

EicC "data": 50 fb^{-1} e-p and 50 fb^{-1} e-^{3}He, pion and kaon SIDIS data

Summary

- EicC provides a unique opportunity for the study of TMDs via the SIDIS process in a wide kinematic range, particularly in the “sea-quark region”.
- A combination of pion and kaon events from e-p and e-^{3}He allows the flavor separation for all light quarks.
- EicC-SIDIS kinematics fill the gap between JLab and US-EIC coverages, and will in together provide a more complete kinematic coverage for TMD studies.

Thank you!