Prospects for the extraction of the Gluon Sivers Function at the EIC

Javier Jiménez-López, Physics and Mathematics Department, University of Alcalá
Supervisor: Charlotte Van Hulse

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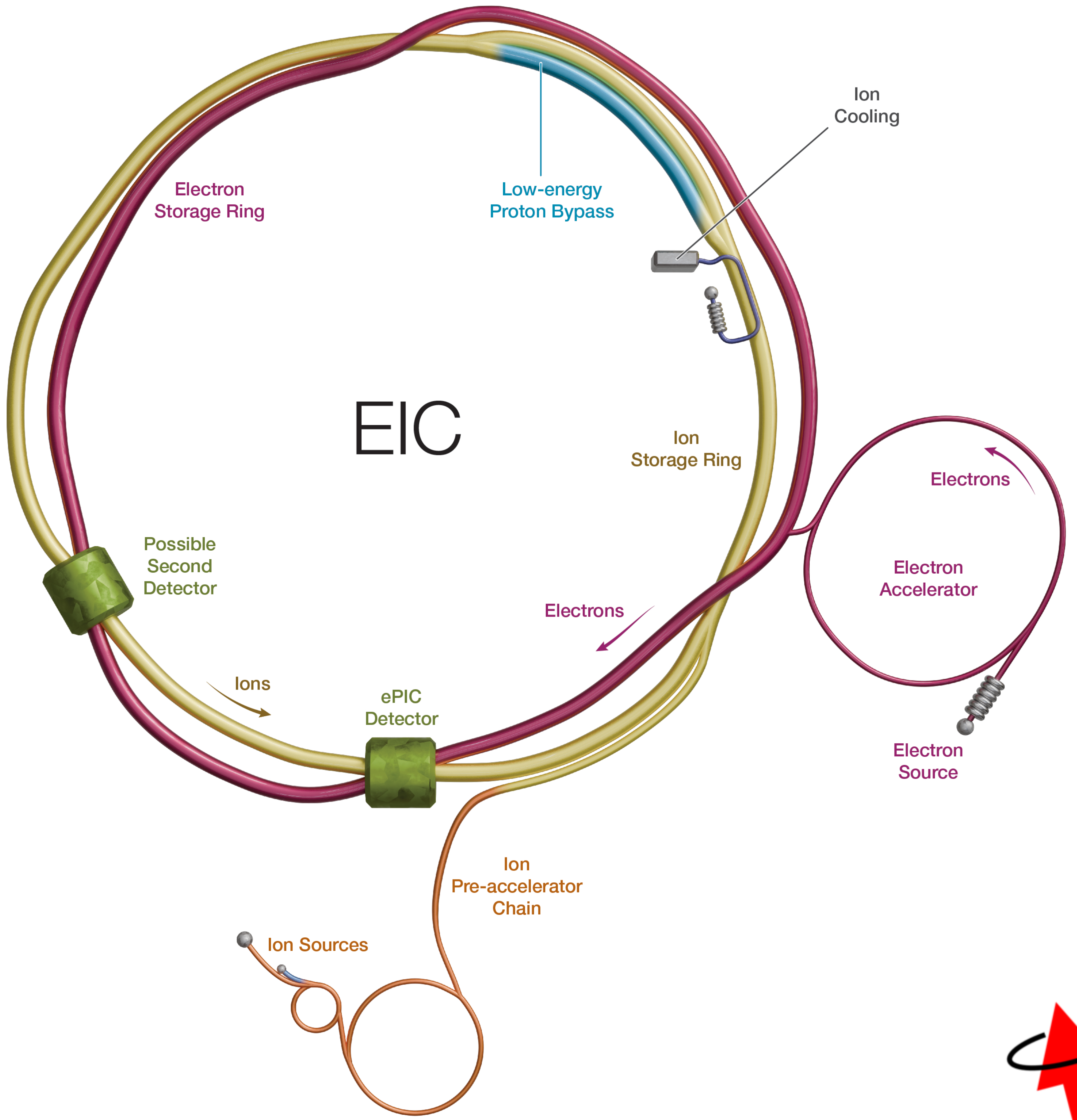
Outline of the talk

- Semi-Inclusive Deep Inelastic Scattering.
- The Sivers function.
- How to actually obtain the Sivers function.
- Results and conclusions.

The Electron Ion Collider



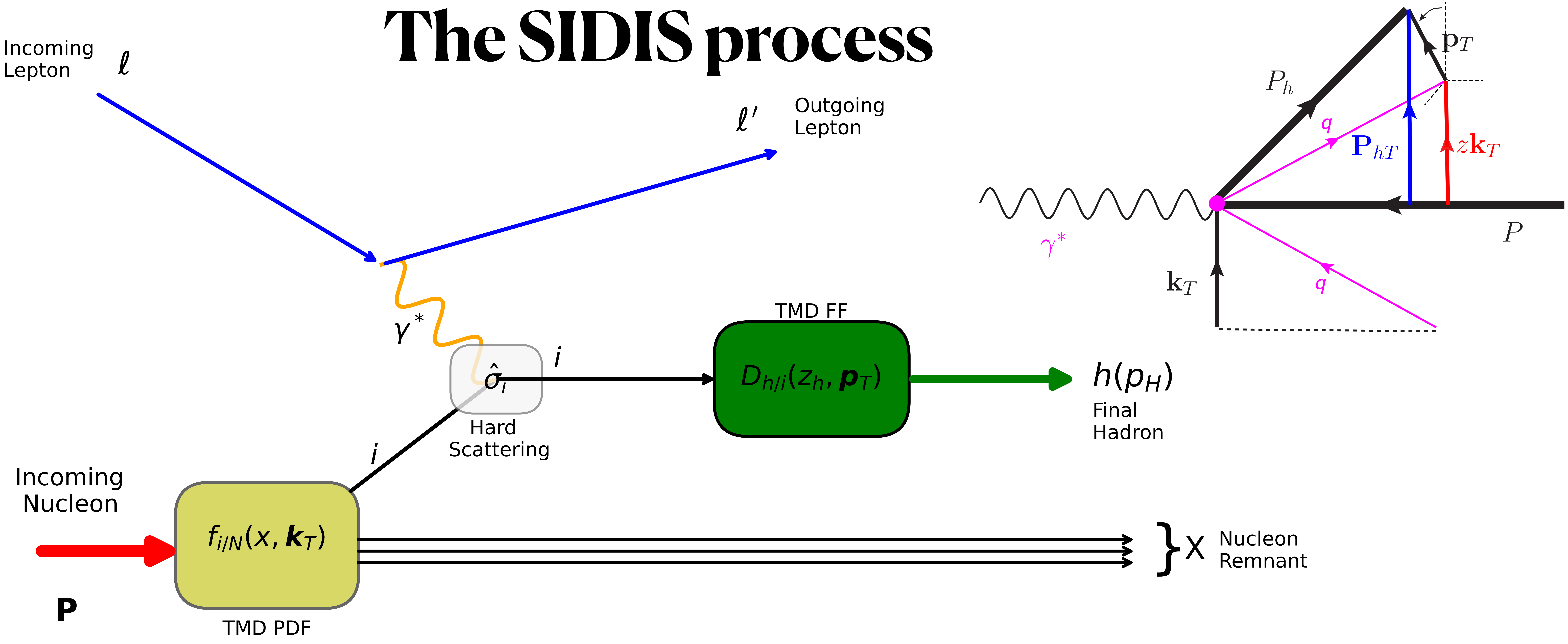
EIC characteristics:

- C.o.m energy range between 28 and 141 GeV.
- High luminosity (10^{33} to 10^{34} $cm^{-2}\,s^{-1}$).
- $e^{-}p$ and $e^{-}A$ collider (from H to U).
- Polarised beams.

ePIC

First $e^{-}p$ collider since HERA

The SIDIS process



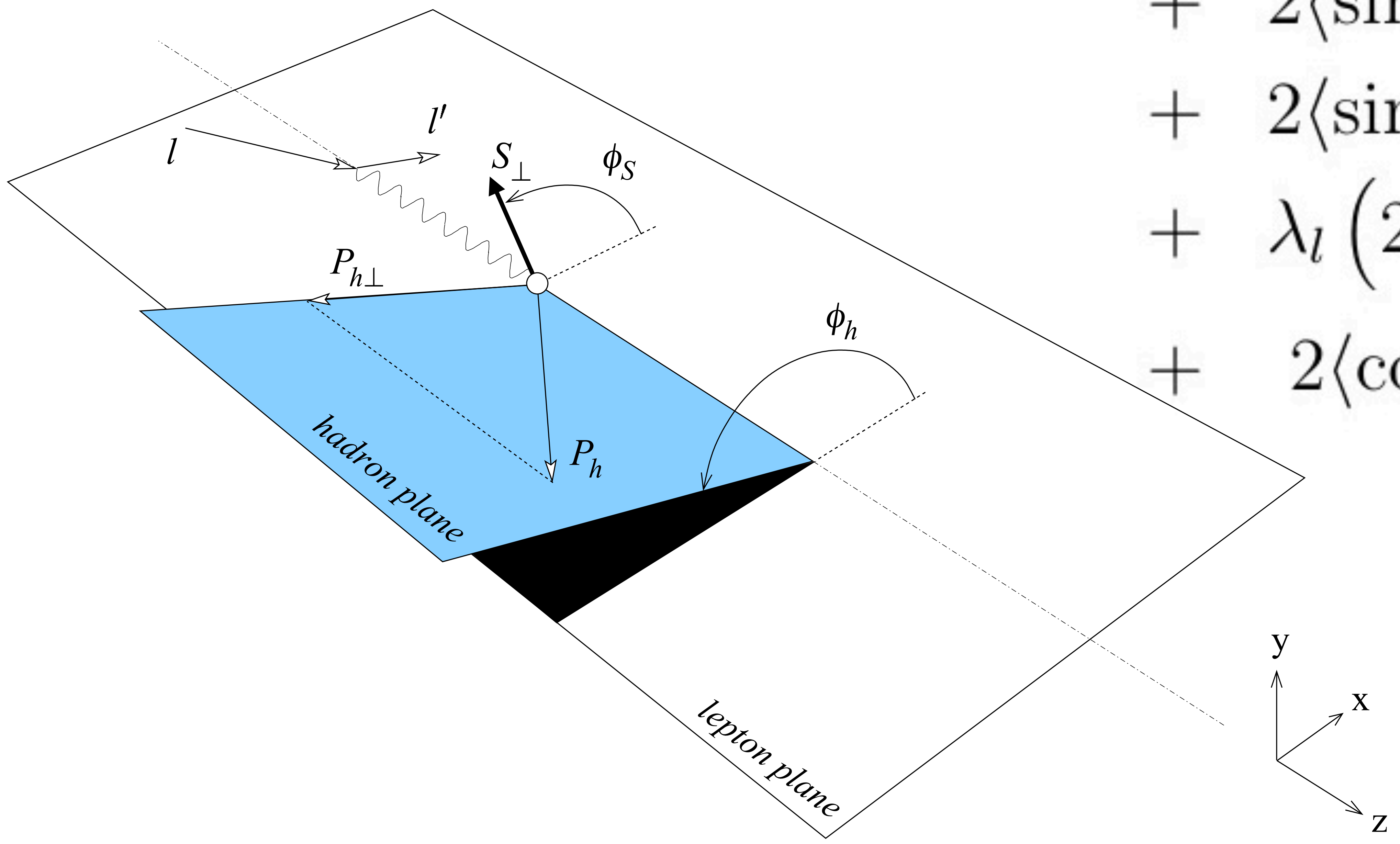
$$\sigma_{\text{SIDIS}} \propto \sum_i \underbrace{f_{i/N}(x, \boldsymbol{k}_\perp, Q^2)}_{\text{TMD PDF}} \otimes \underbrace{\hat{\sigma}_i(x, Q^2)}_{\text{Hard scale}} \otimes \underbrace{D_{h/i}(z_h, \boldsymbol{p}_T)}_{\text{TMD FF}}$$

$$z_h = \frac{P_h \cdot p}{q \cdot p}$$

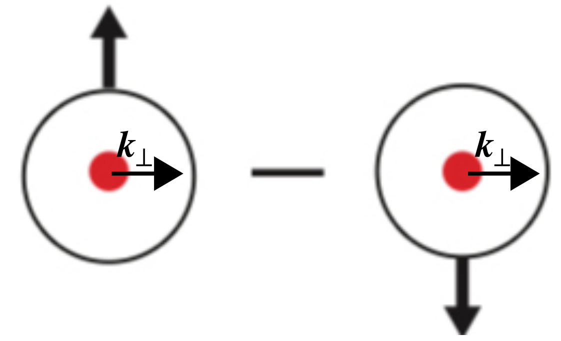
Cross section with spin-dependent effects

$$\begin{aligned}
\sigma^h(\phi,\phi_S) &= \sigma^h_{UU}\Big\{1+2\langle\cos(\phi)\rangle^h_{UU}\ \cos(\phi)+2\langle\cos(2\phi)\rangle^h_{UU}\ \cos(2\phi)\\
&+ \lambda_l\, 2\langle\sin(\phi)\rangle^h_{LU}\ \sin(\phi)\\
&+ S_L\Big[2\langle\sin(\phi)\rangle^h_{UL}\ \sin(\phi)+2\langle\sin(2\phi)\rangle^h_{UL}\ \sin(2\phi)\\
&+ \lambda_l\Big(2\langle\cos(0\phi)\rangle^h_{LL}\ \cos(0\phi)+2\langle\cos(\phi)\rangle^h_{LL}\ \cos(\phi)\Big)\Big]\\
&+ S_T\Big[2\langle\sin(\phi-\phi_S)\rangle^h_{UT}\ \sin(\phi-\phi_S)+2\langle\sin(\phi+\phi_S)\rangle^h_{UT}\ \sin(\phi+\phi_S)\\
&+ 2\langle\sin(3\phi-\phi_S)\rangle^h_{UT}\ \sin(3\phi-\phi_S)+2\langle\sin(\phi_S)\rangle^h_{UT}\ \sin(\phi_S)\\
&+ 2\langle\sin(2\phi-\phi_S)\rangle^h_{UT}\ \sin(2\phi-\phi_S)\\
&+ \lambda_l\Big(2\langle\cos(\phi-\phi_S)\rangle^h_{LT}\ \cos(\phi-\phi_S)\\
&+ 2\langle\cos(\phi_S)\rangle^h_{LT}\ \cos(\phi_S)+2\langle\cos(2\phi-\phi_S)\rangle^h_{LT}\ \cos(2\phi-\phi_S)\Big)\Big]\Big\}
\end{aligned}$$

Sivers function

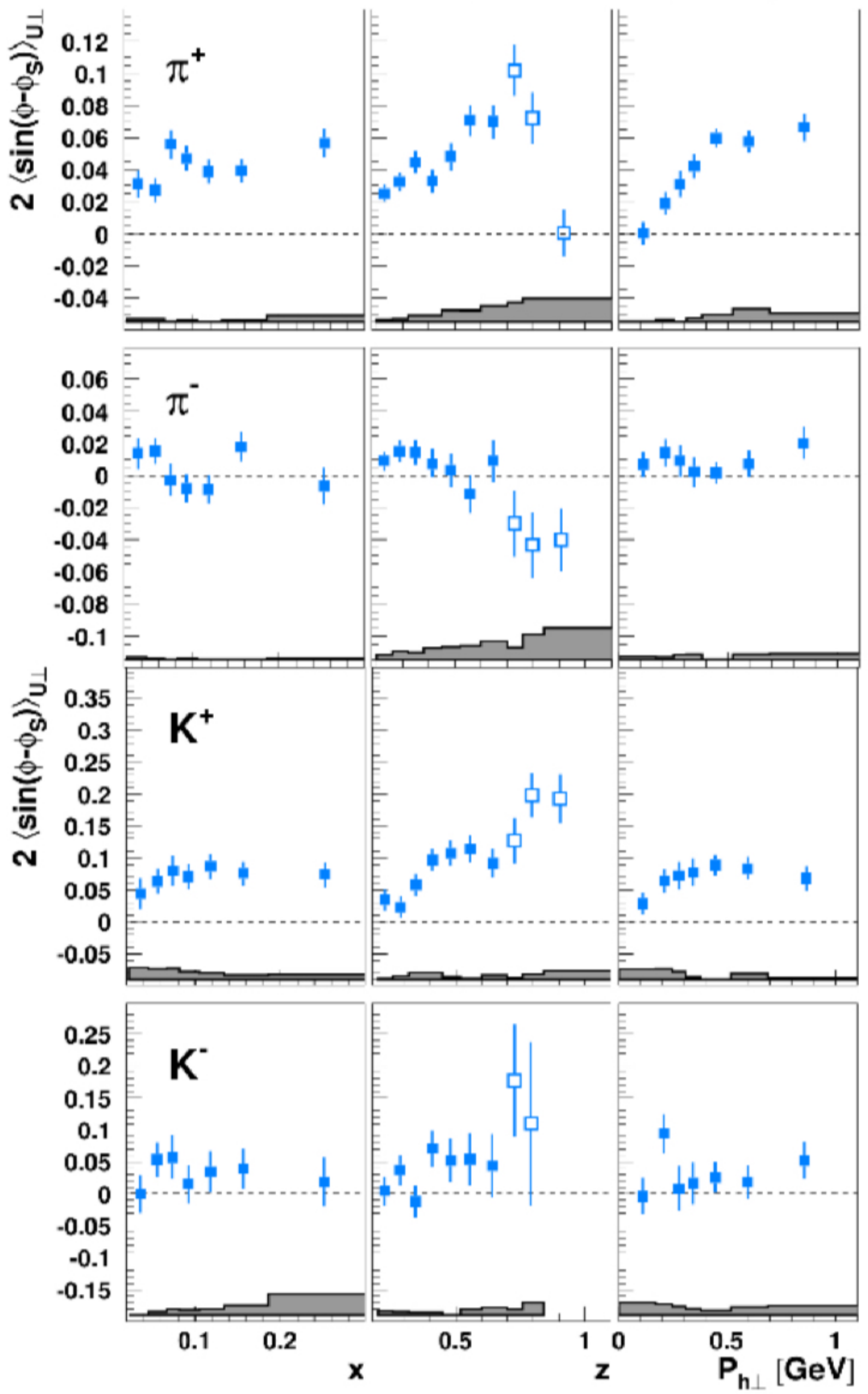


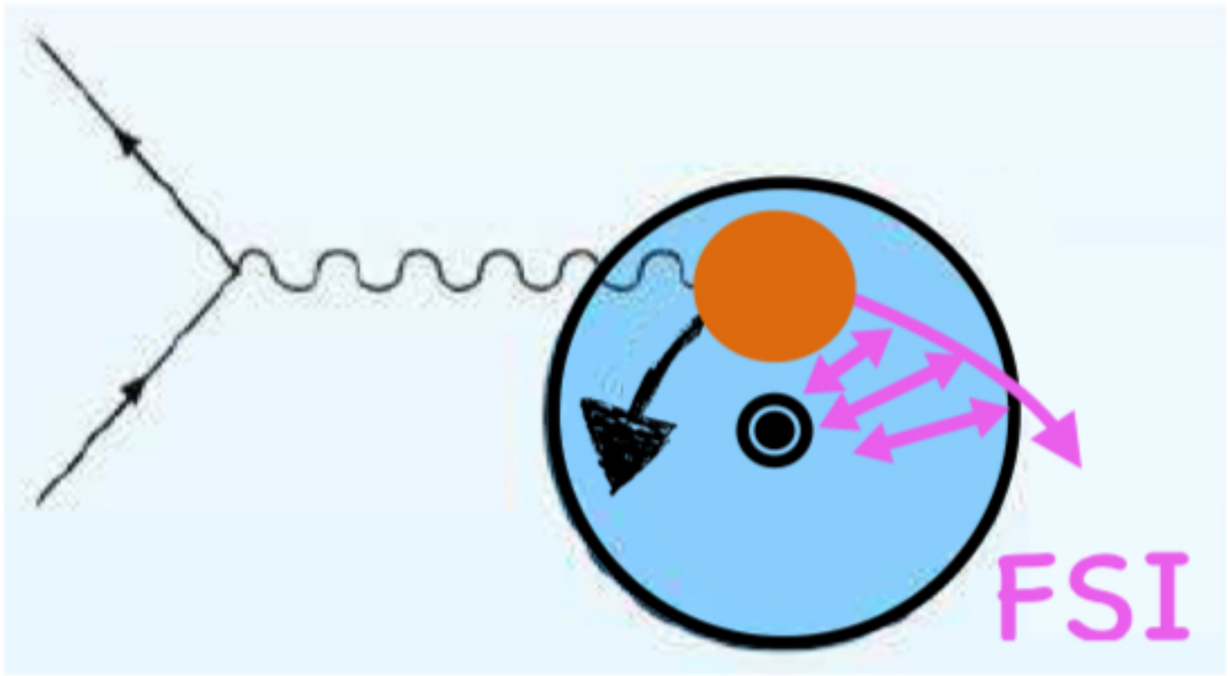
The Sivers function

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

Measures the correlation between the parton's transverse momentum and a transversely polarised proton's spin.

HERMES, JHEP **12**(2020)010



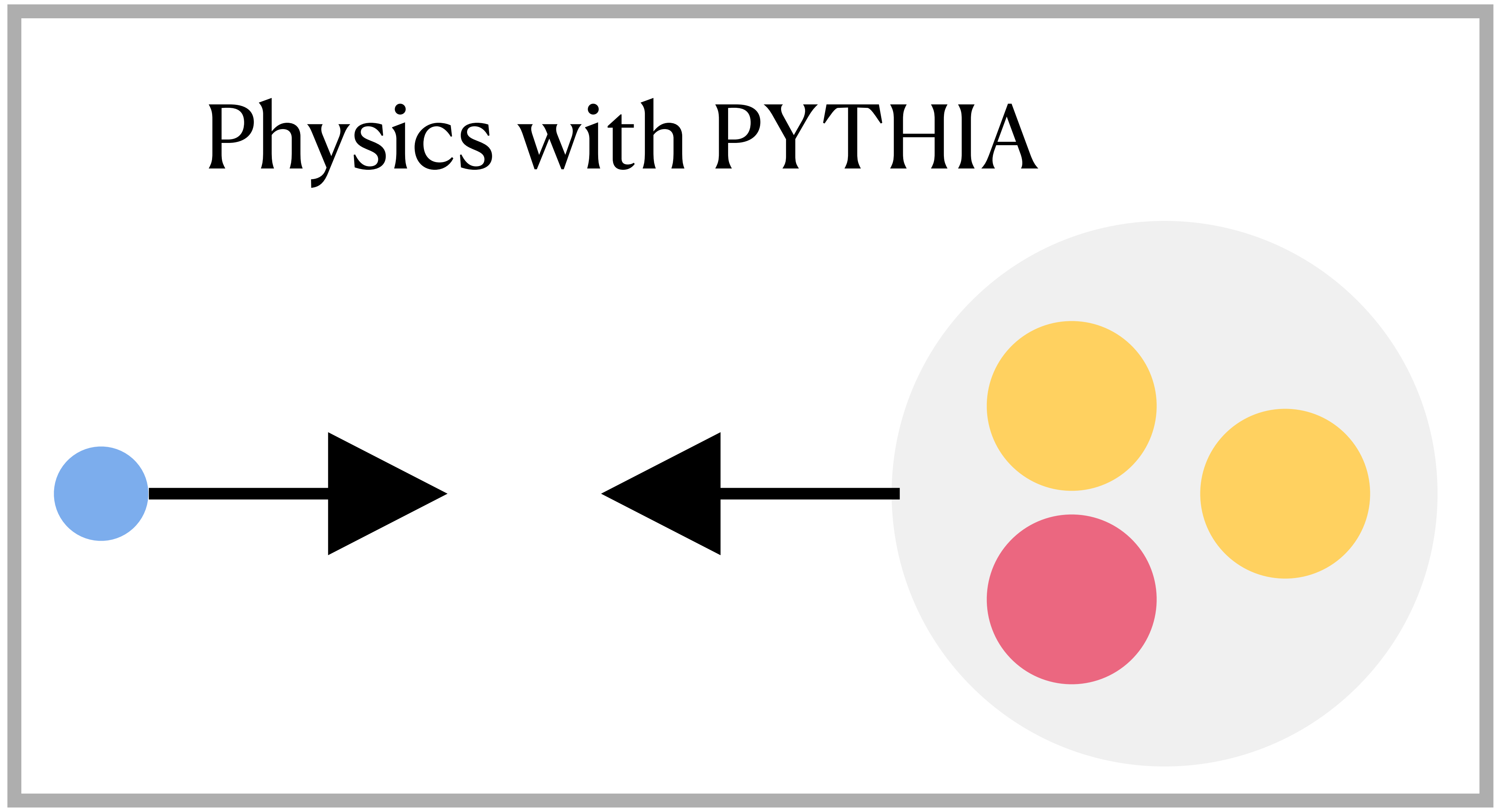


- Positively charged hadrons: non-zero orbital momentum → positive value.
- Negatively charged hadron: u and d contributions cancel → value consistent with zero.

Little is known about it for quarks but almost nothing for gluons.

Software

Particle-Detector interaction with GEANT



- GEANT is very robust and provides accurate detector simulation.
- PYTHIA does not include spin effects or TMD physics → We have to implement them by our own.
- ROOT is a classic in particle physics and is used for data analysis.

Spin: sample an uniform distribution to assign the spin to each proton.

TMDs: for each event, calculate a weight that model the effect of transverse momentum.

Models for the Sivers Function

As a first estimate, it is common to use factorised Gaussian parametrizations

SIDIS1

$$\Delta f_{g/p^\uparrow}(x, k_\perp) = 2\mathcal{N}_g(x) f_{g/p}(x, Q^2) h(k_\perp) \frac{\exp(-k_\perp^2/\langle k_\perp^2\rangle)}{\pi\langle k_\perp^2\rangle}$$

D'Alesio et al. JHEP 09, 119

Positivity bound assumption

$$f_{1T}^{\perp g}(x, k_\perp) = -\frac{2\sigma m_p}{k_\perp^2 + \sigma^2} f_g(x, k_\perp)$$

Anselmino et al. Phys. Rev. D 70, 074025

For the quark Sivers function: *Anselmino et al. JHEP* 04, 046

Gluon Sivers Function and Single Spin Asymmetries

$$\hat{f}_{g/p^\uparrow}(x, k_\perp) = f_{g/p}(x, k_\perp) + \frac{1}{2}\Delta f_{g/p^\uparrow}(x, k_\perp)\, \boldsymbol{S} \cdot \left(\hat{\boldsymbol{P}} \times \hat{\boldsymbol{k}}_\perp\right)$$

Bacchetta et al. Phys. Rev. D 70, 117504

$$\Delta f_{g/p^\uparrow}(x, k_\perp) = -\frac{2k_\perp}{m_p} f_{1T}^{\perp g}(x, k_\perp)$$

$$\sin(\phi_h - \phi_S)$$

$$A_{UT}(\phi_{hS} = \phi_h - \phi_S, k_T) = \frac{d\sigma^\uparrow(\phi_{hS}, k_T) - d\sigma^\downarrow(\phi_{hS}, k_T)}{d\sigma^\uparrow(\phi_{hS}, k_T) + d\sigma^\downarrow(\phi_{hS}, k_T)} \propto \frac{\Delta f_{a/p^\uparrow}(x, k_\perp, Q^2)}{2f_{a/p}(x, k_\perp, Q^2)}$$

Extraction of A_{UT} from simulated events

$$A_{UT} = \frac{1}{P}\frac{N^{\uparrow}/\mathscr{L}^{\uparrow} - N^{\downarrow}/\mathscr{L}^{\downarrow}}{N^{\uparrow}/\mathscr{L}^{\uparrow} + N^{\downarrow}/\mathscr{L}^{\downarrow}} \longrightarrow A_{UT} = \frac{1}{NP}\sum_{i=1}^{N} w_i$$

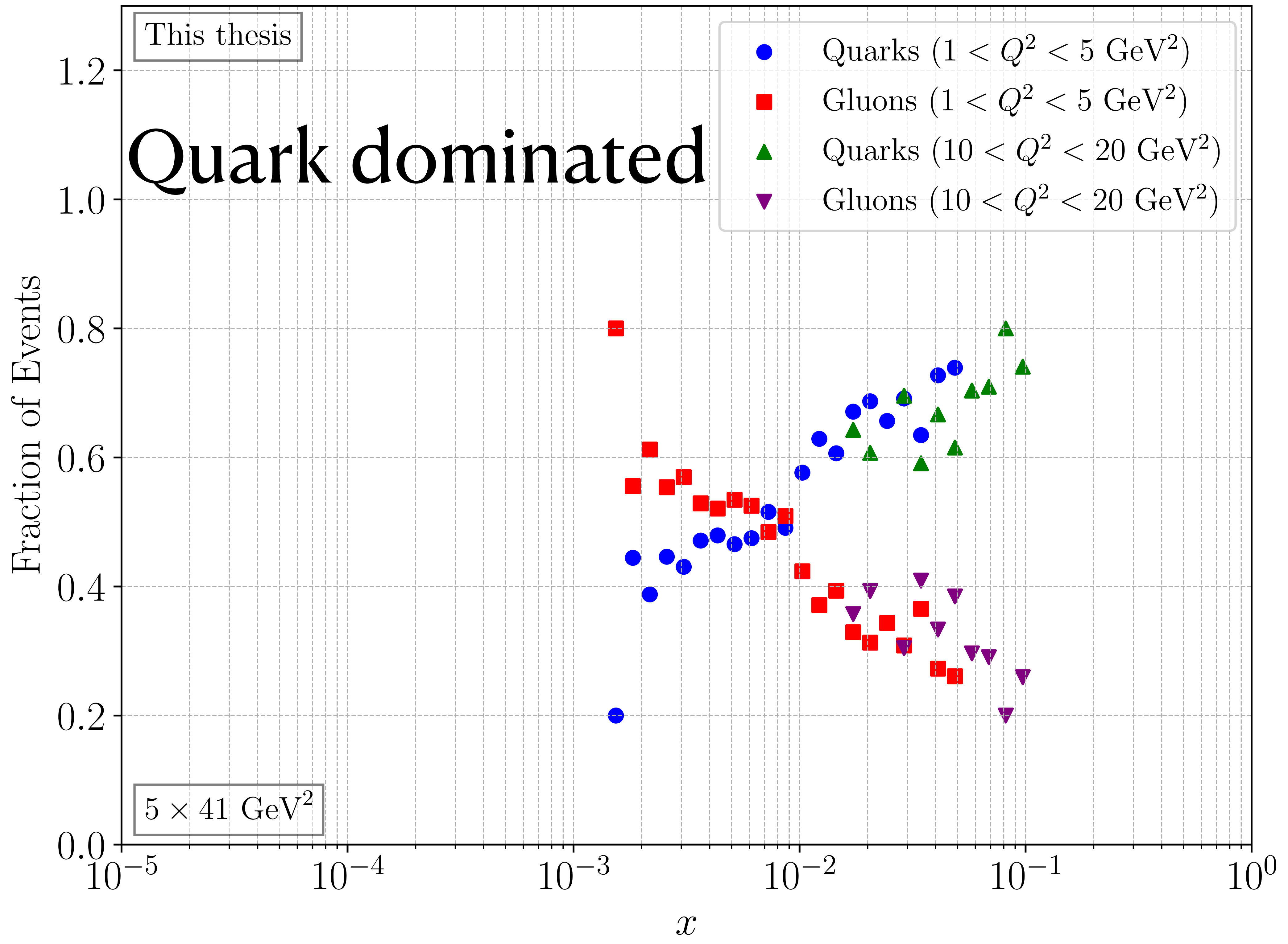
Experimental formula

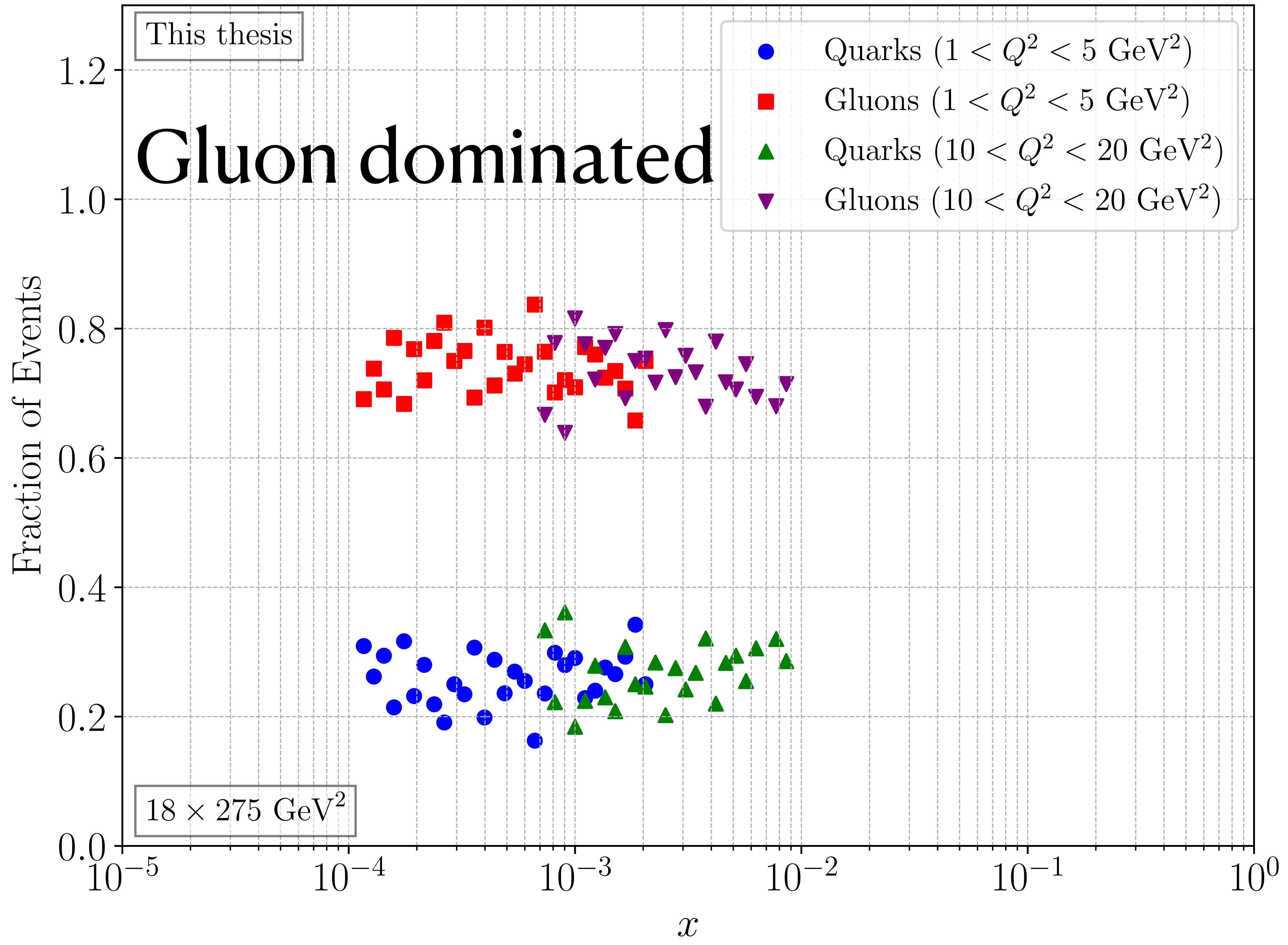
$$w_i = \frac{\Delta f_{a/p^{\uparrow}}(x, k_{\perp}, Q^2)}{2f_{a/p}(x, k_{\perp}, Q^2)}$$

Airapetian et al. JHEP 08, 130
Zheng et al. Phys. Rev. D 98, 034011

For the EIC, P is expected to be around 70 % .

Which beam configuration shall we use?





In order to access the kinematic region dominated by gluons,
it is crucial to use the highest center of mass energy available

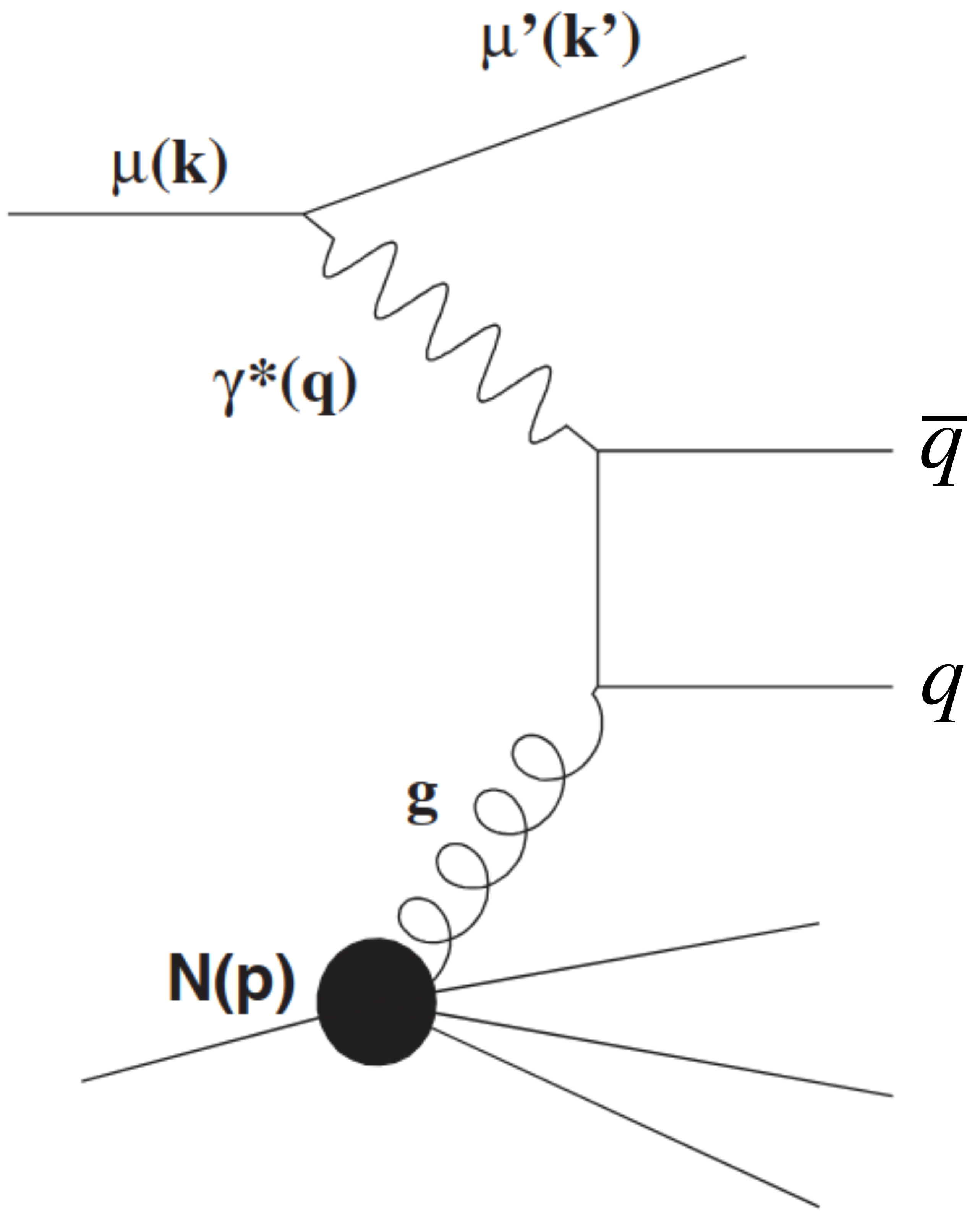
Kinematic cuts and estimators

$$Q^2 > 1 \ \left[\mathrm{GeV}^2\right]$$

$$0.1 < y < 0.9$$

$$W^2 > 10 \ \left[\mathrm{GeV}^2\right]$$

$$z_h > 0.1$$



Photon-Gluon Fusion

It is not possible to access the parton's transverse momentum

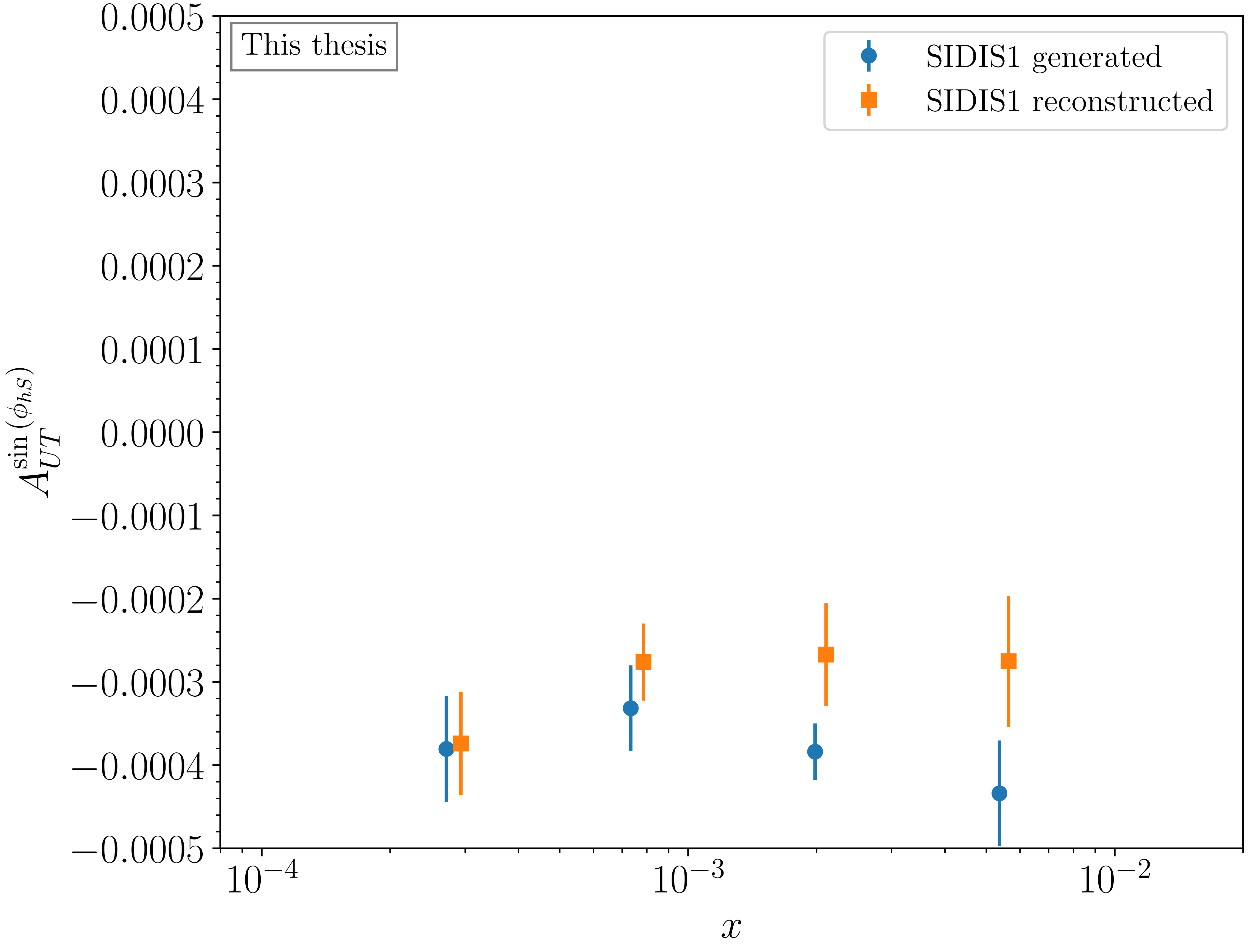
$$P_T = \frac{\left|\boldsymbol{p}_{h_1 T} - \boldsymbol{p}_{h_2 T}\right|}{2}$$

$$k_T = \left|\boldsymbol{p}_{h_1 \perp} + \boldsymbol{p}_{h_2 \perp}\right|$$

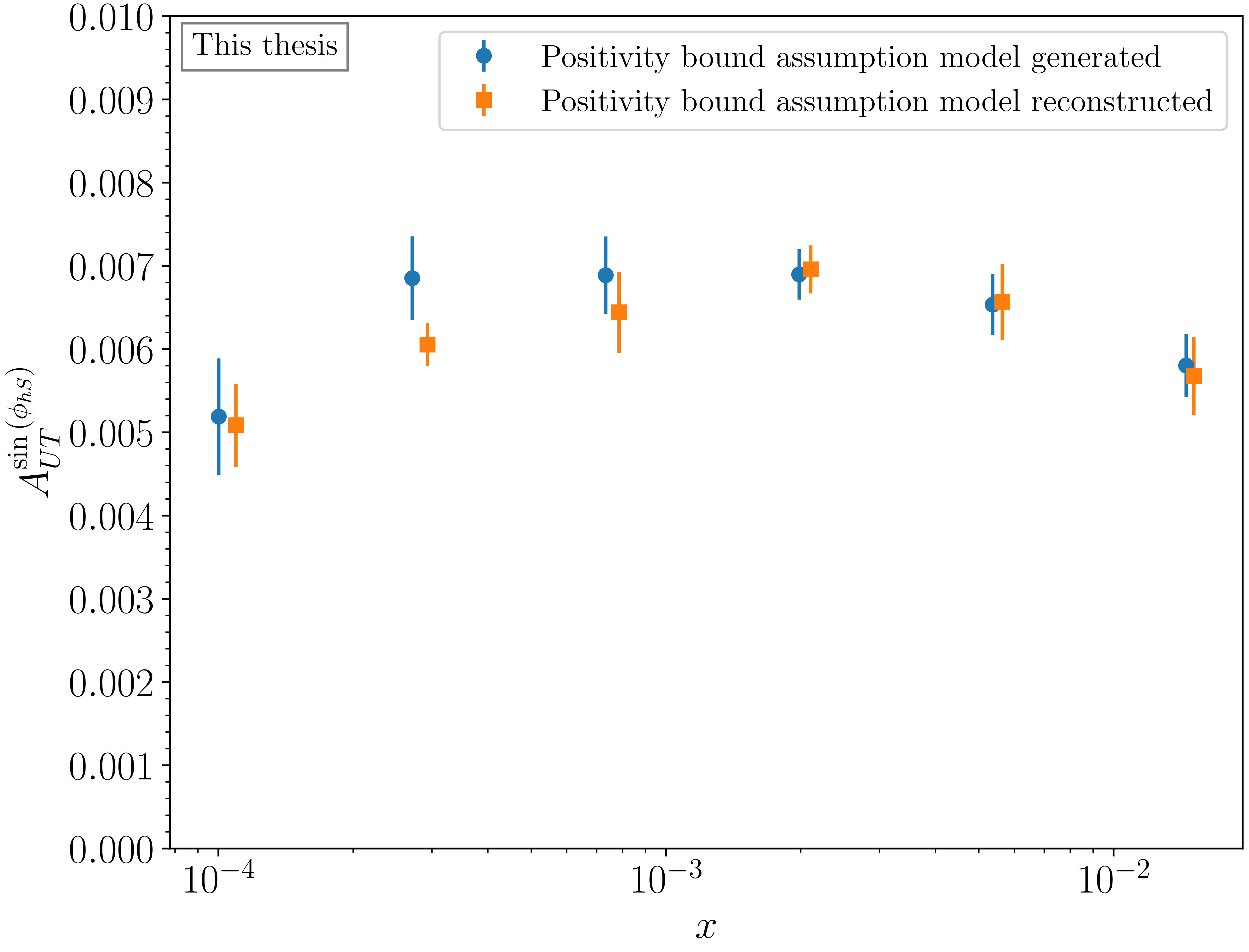
$$p_{h_i T} \geq 1.4 \ [\mathrm{GeV}]$$

$$k_T \leq 0.7 P_T$$

Results



This thesis
SIDIS1 generated
SIDIS1 reconstructed
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
−0.0001
−0.0002
−0.0003
−0.0004
−0.0005
$A_{UT}^{\sin(\phi_h S)}$
10^{-4}
10^{-3}
10^{-2}
x



This thesis
Positivity bound assumption model generated
Positivity bound assumption model reconstructed
0.010
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0.000
$A_{UT}^{\sin(\phi_h S)}$
10^{-4}
10^{-3}
10^{-2}
x

Final remarks and conclusions

- The Sivers function is still highly unknown for quarks but specially for gluons.
- With the capabilities of EIC (high luminosity) it will be possible to study the Gluon Sivers Function for the first time.
- Not much difference has been observed between generated and reconstructed results. Once the detector is fully understood, corrections will be added to the experimental measurements.
- $A_{UT} \neq 0$ but it is close to it $\rightarrow$ precision is key to extract meaningful measurements.

Thank you for your time!

Email: javier.jimenezl@edu.uah.es