SIDIS topics at the EIC

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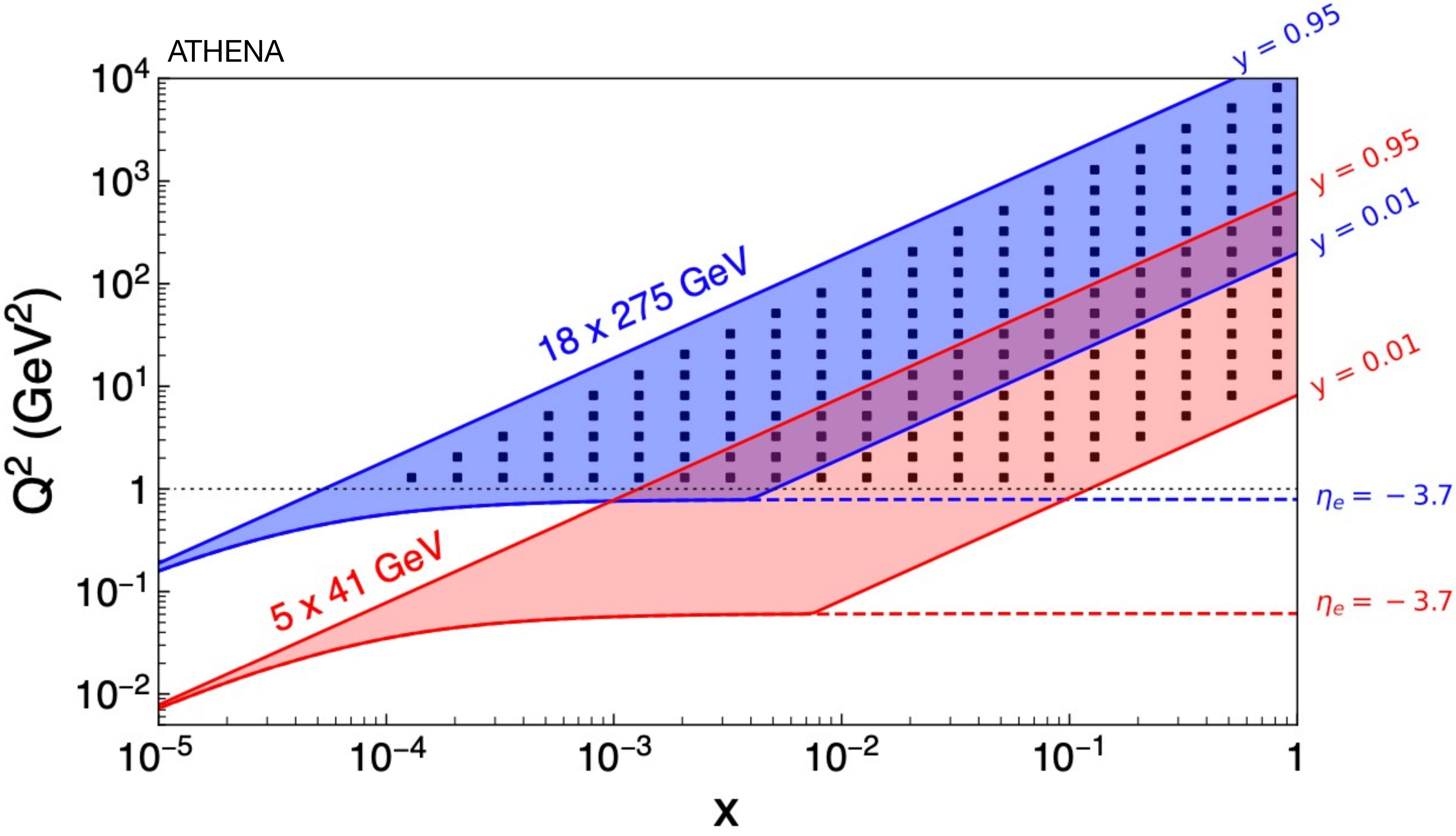
UAH

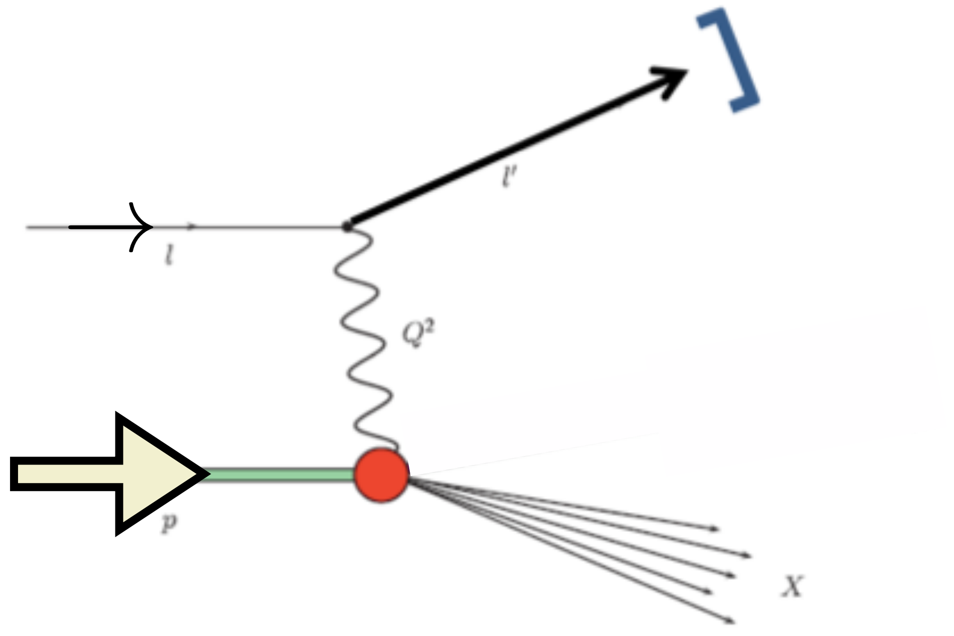
Programa de atracción de talento
Comunidad de Madrid

2022 RHIC/AGS Annual Users' Meeting
7 – 10 June 2022

Kinematic coverage for DIS

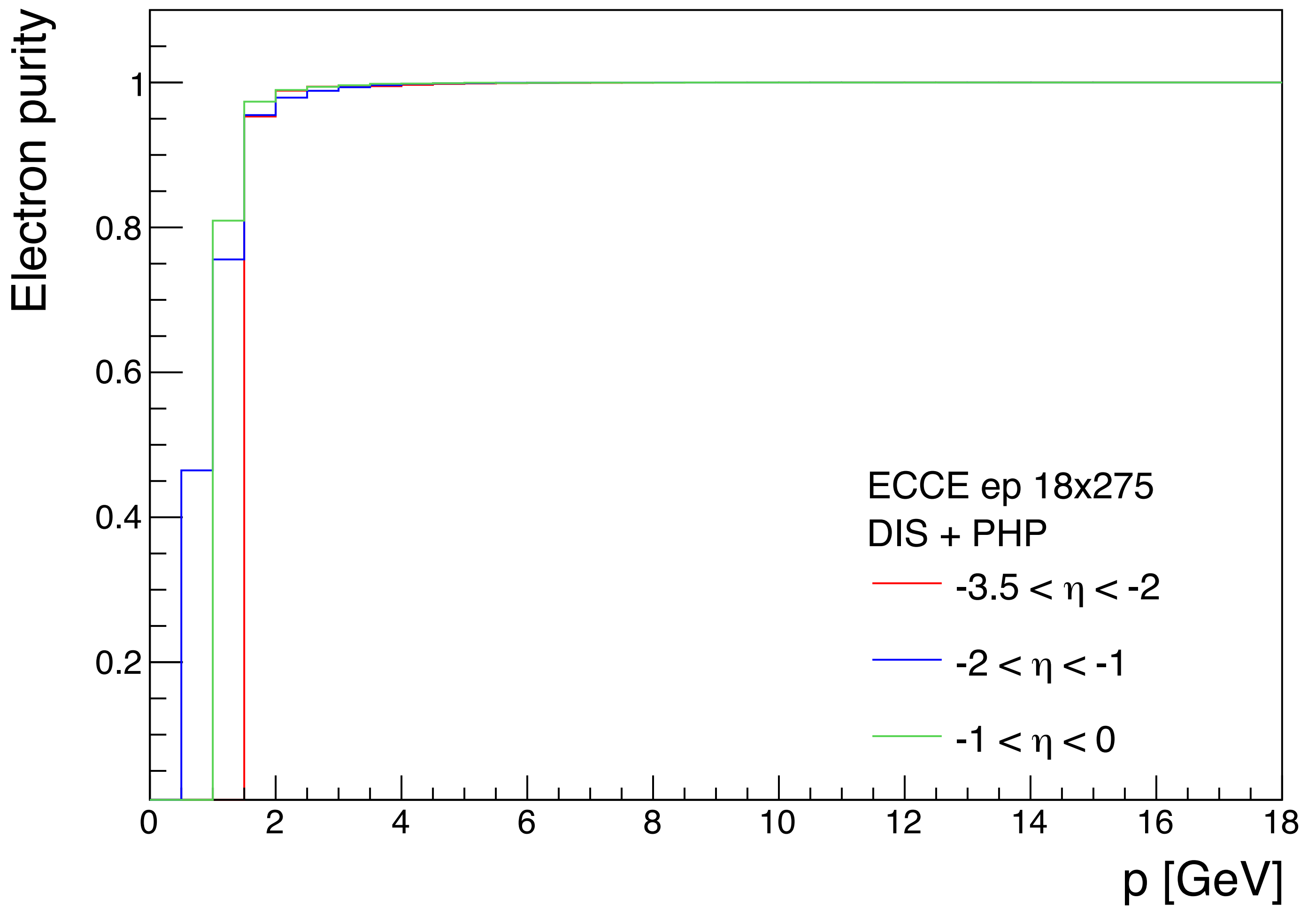


Helicity structure of the nucleon: gluons



Inclusive measurements
→ access to gluon spin

High e^- purity needed, e.g. ECCE via EMCAL:
<2% π contamination for p>2 GeV



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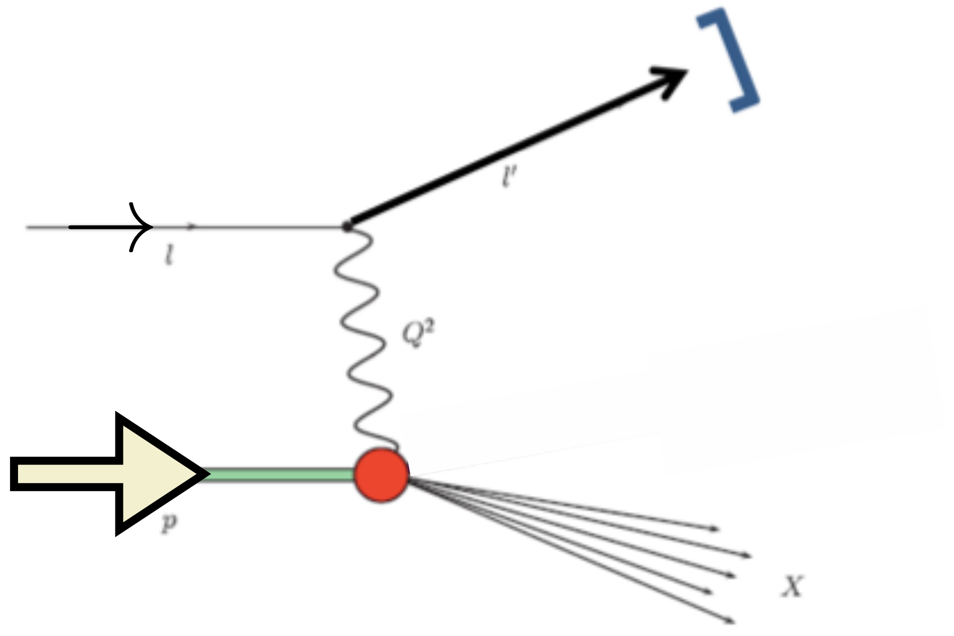

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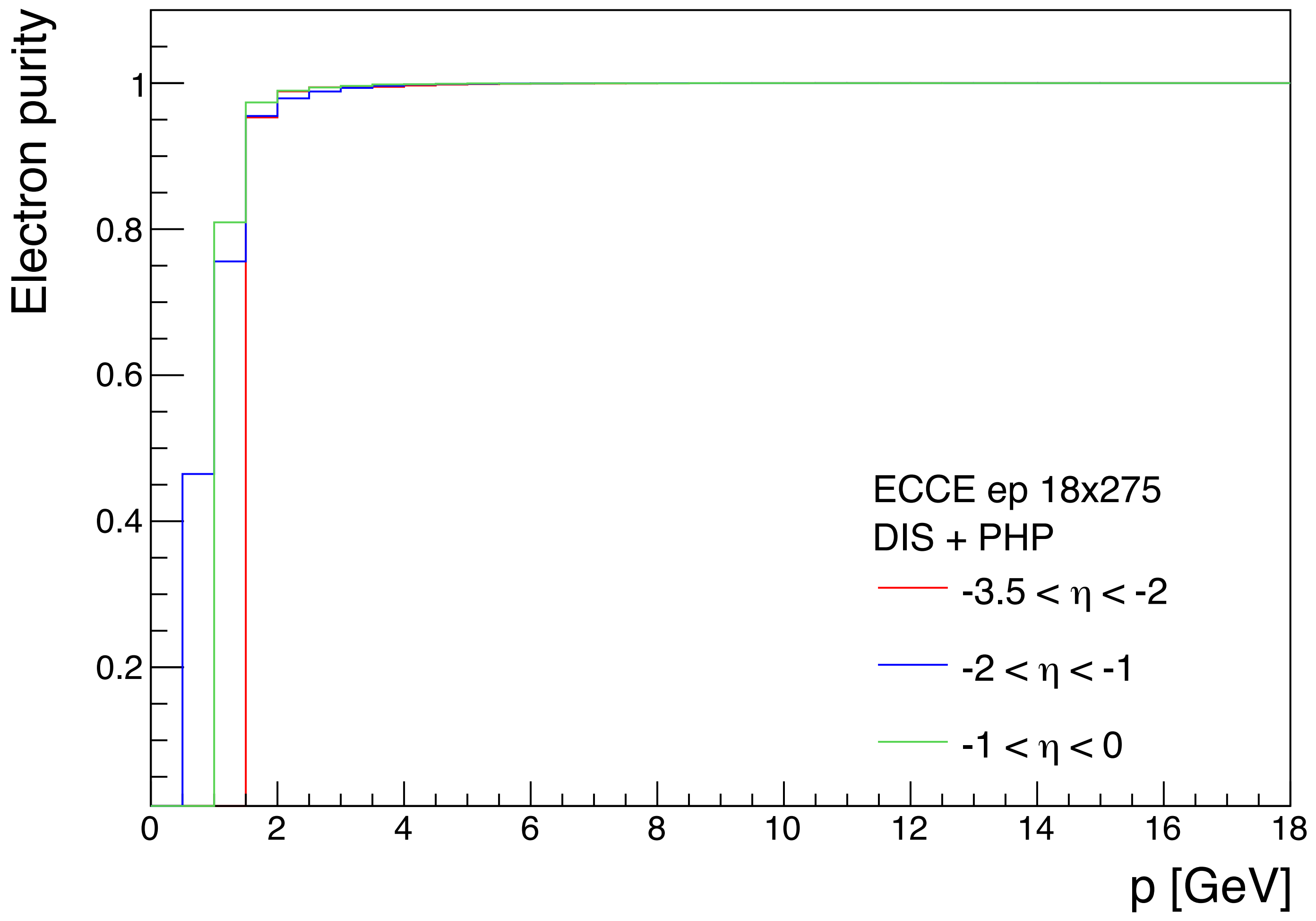
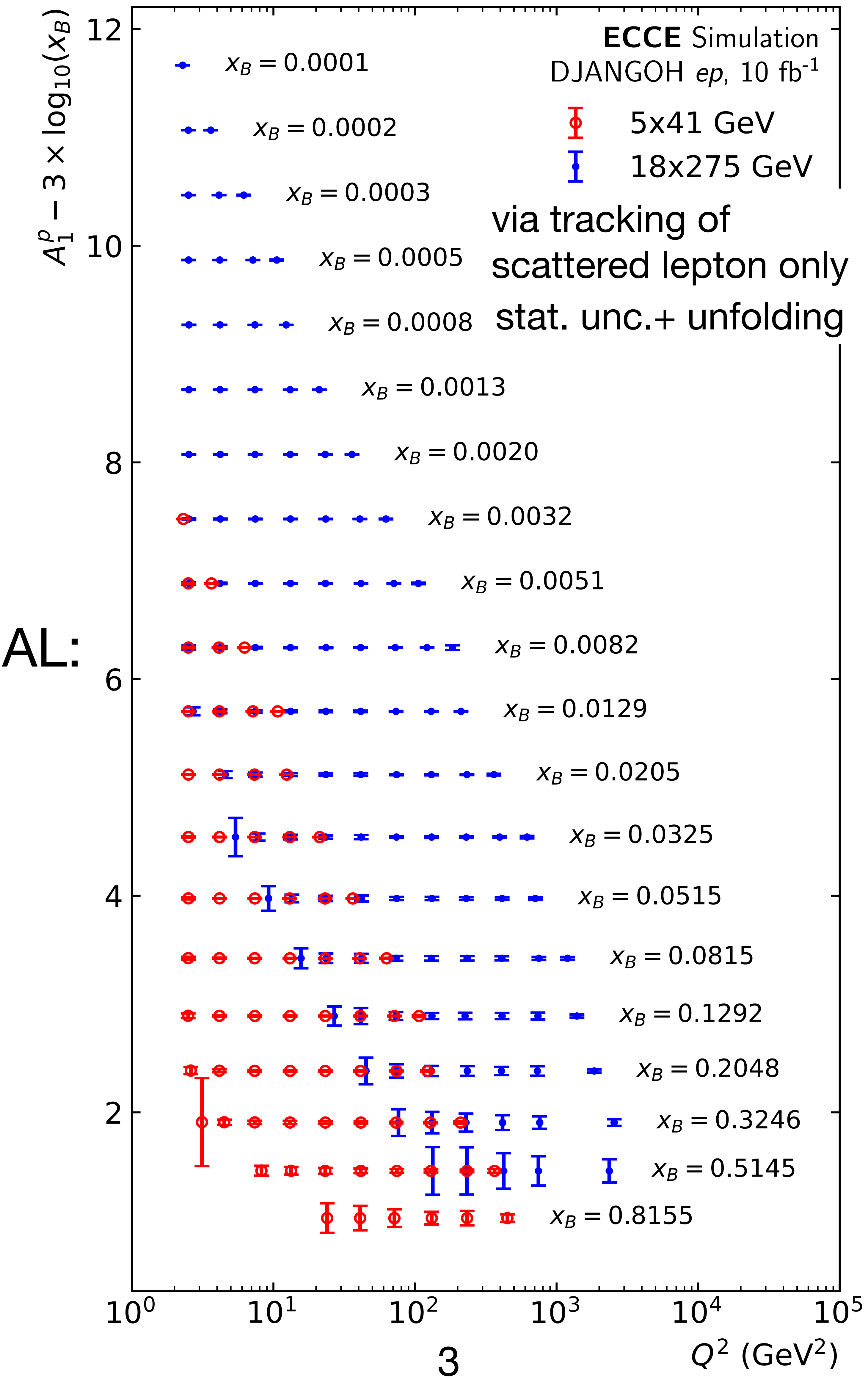
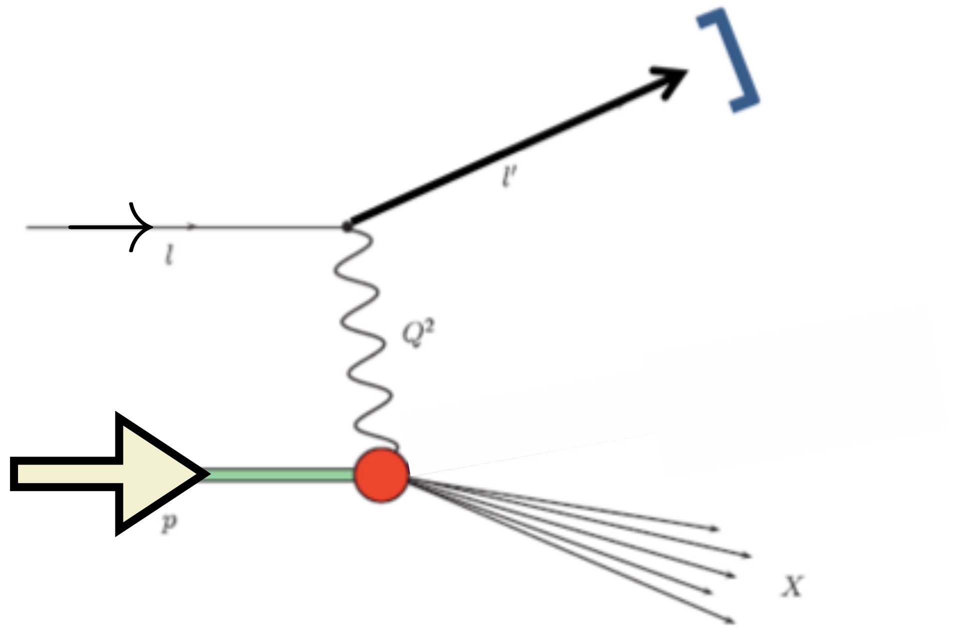




via tracking of
scattered lepton only
stat. unc.+ unfolding

Helicity structure of the nucleon: gluons



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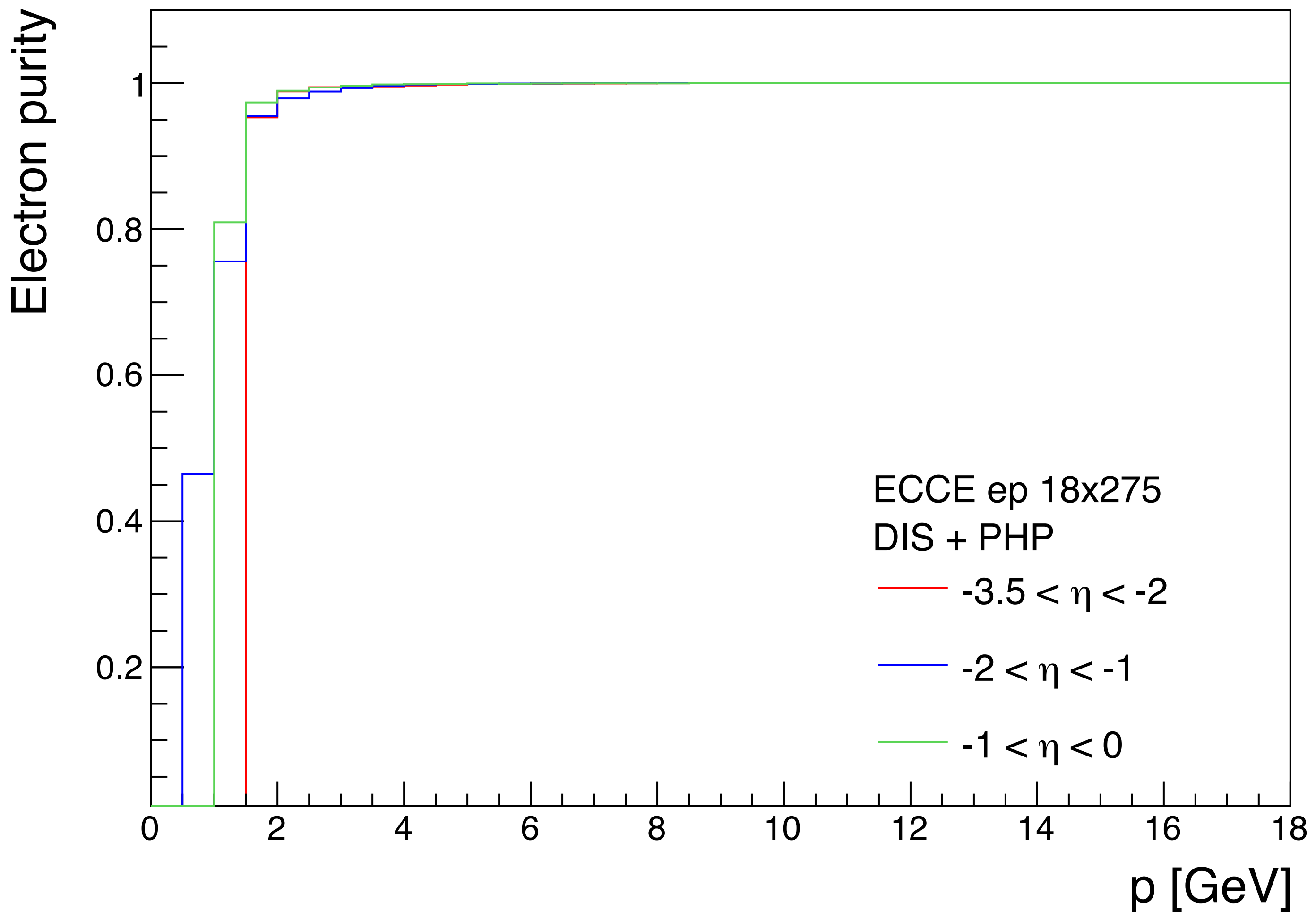

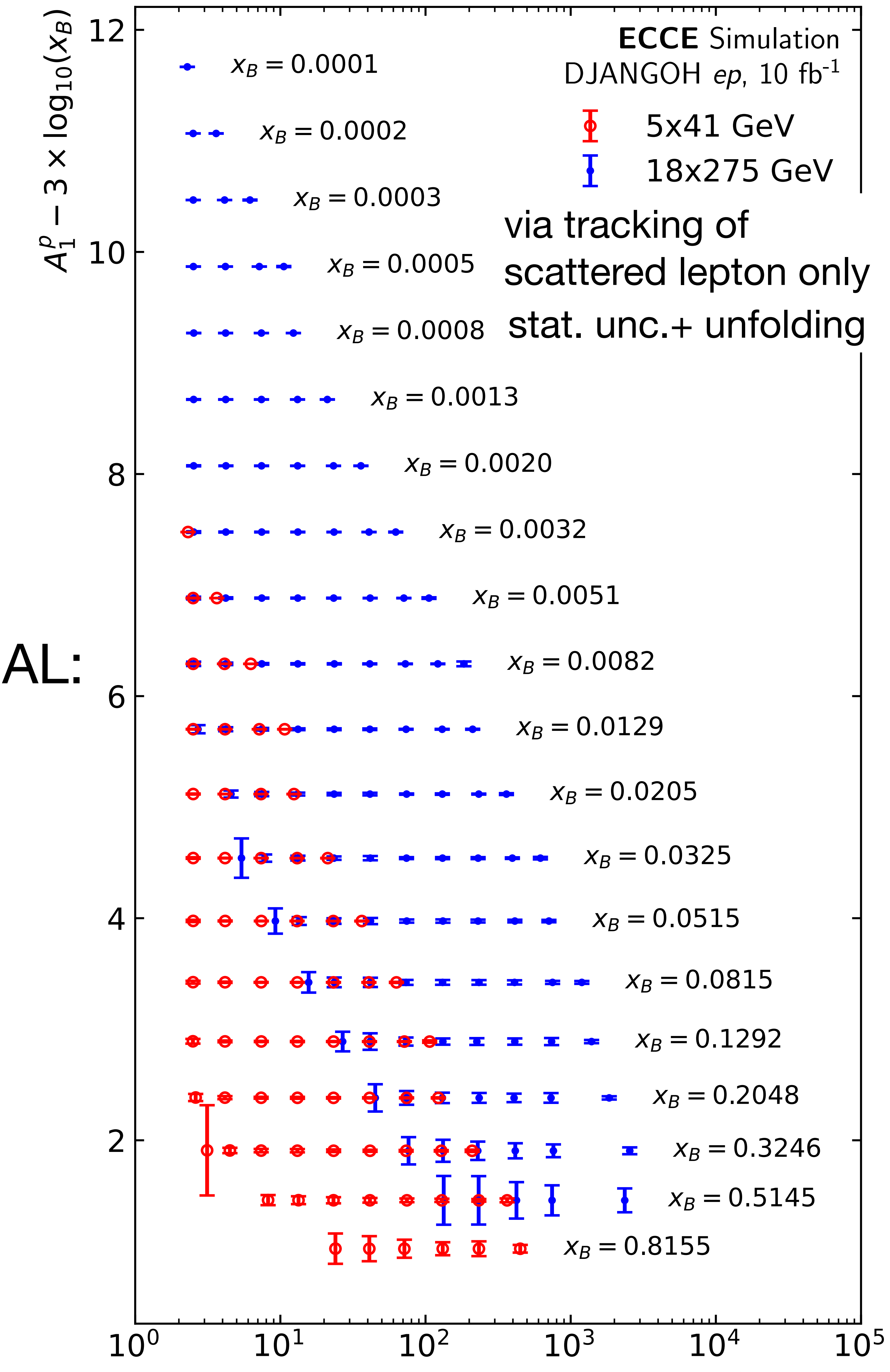

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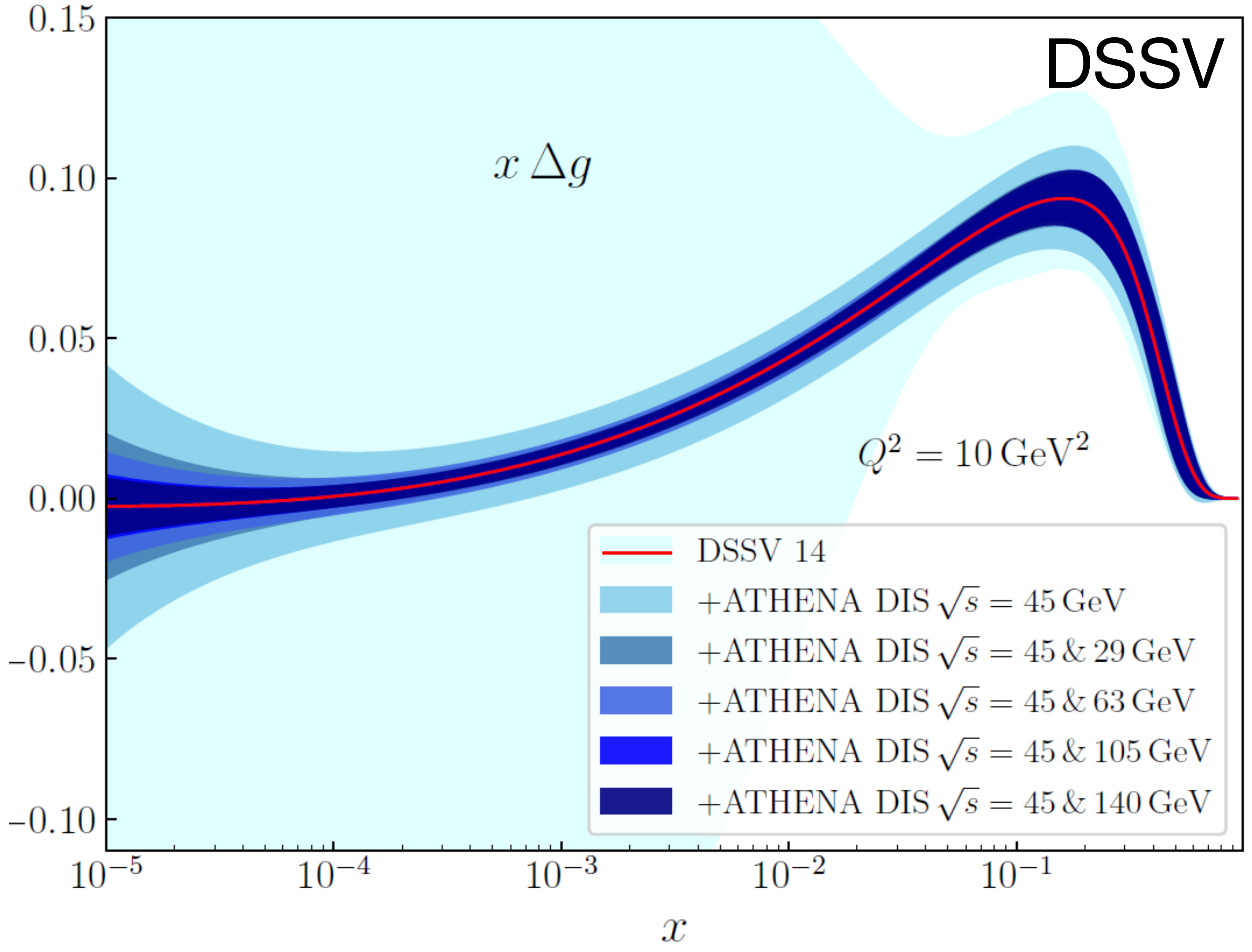
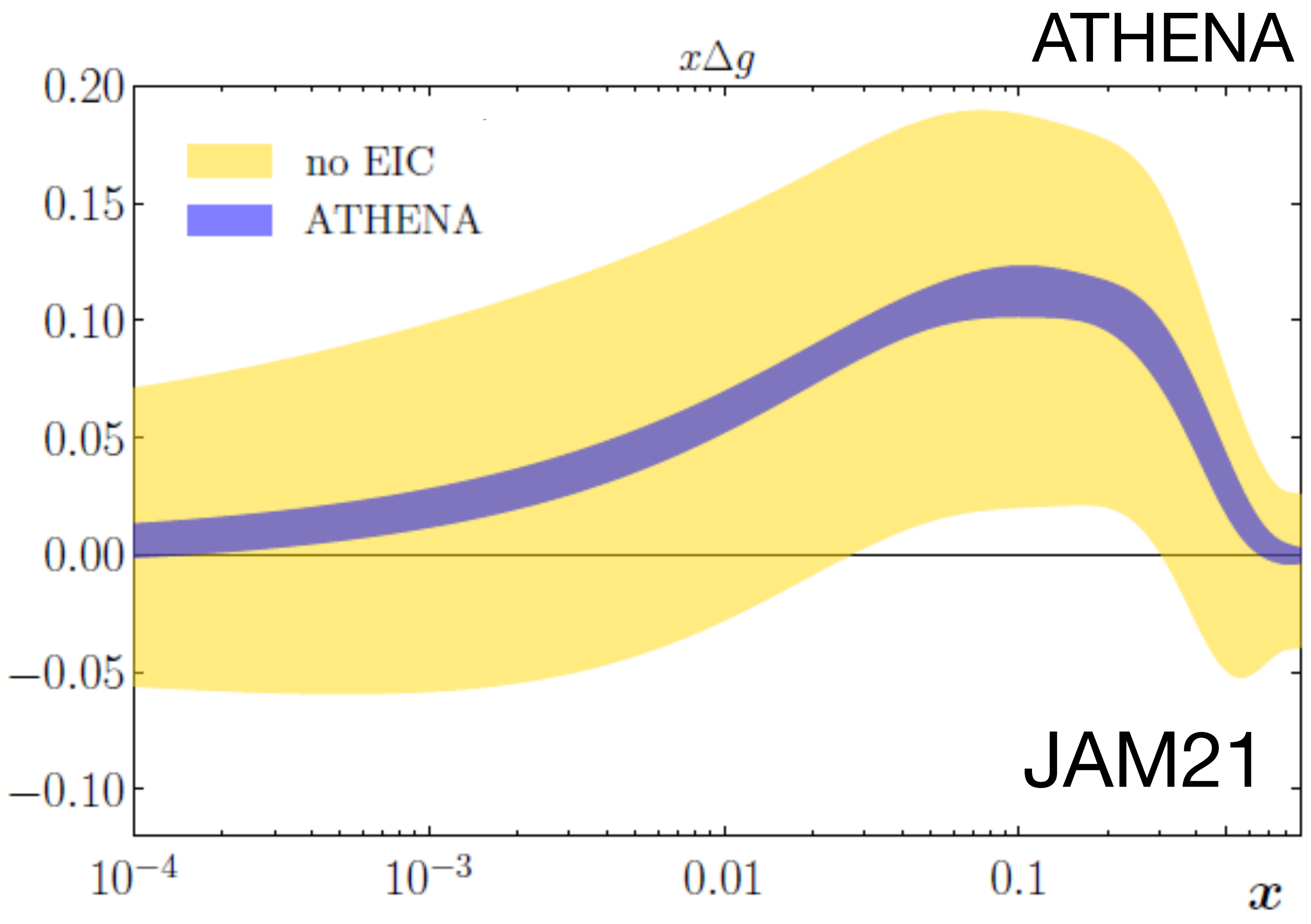
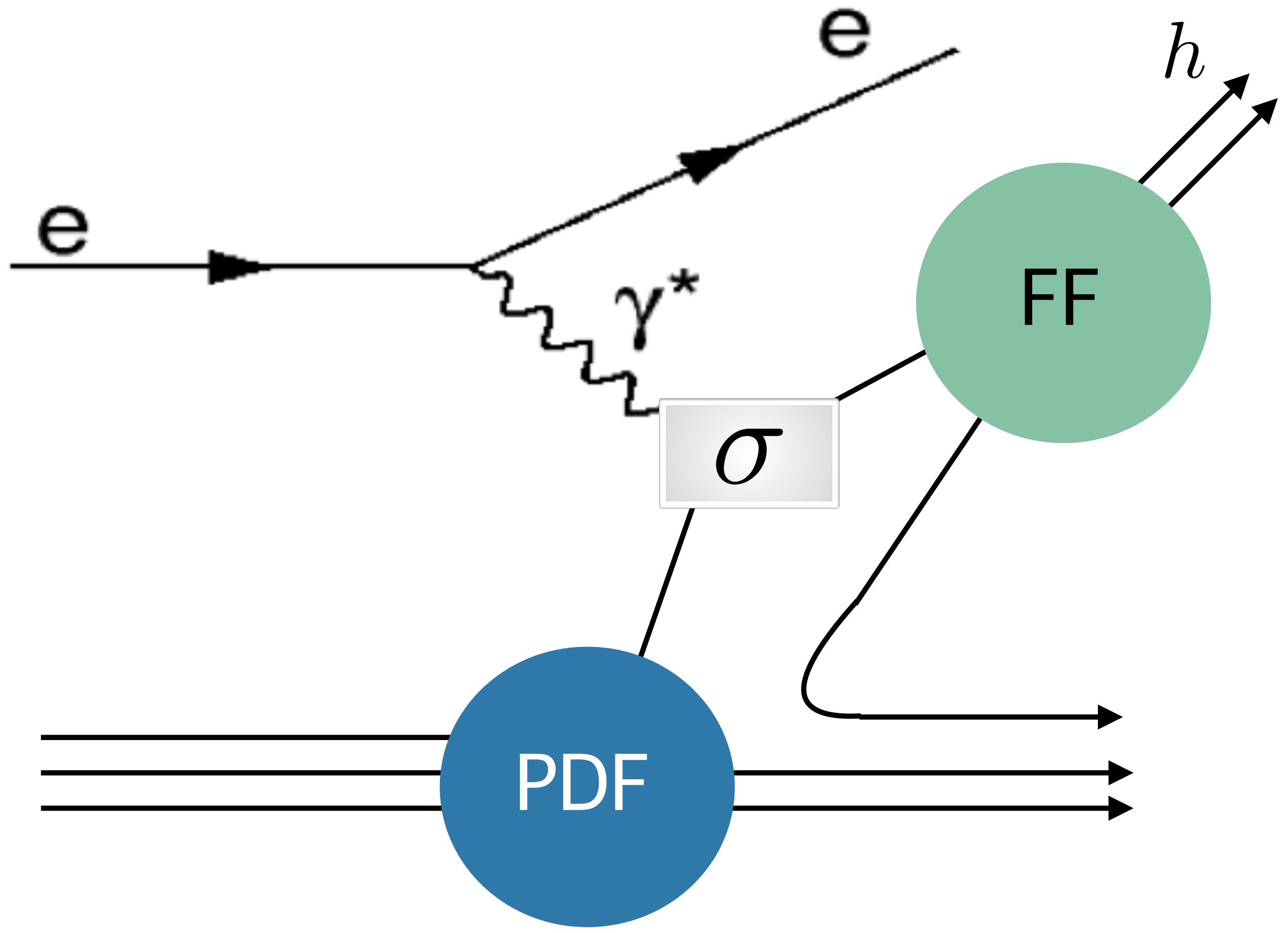
ATHENA I. Borsa





Helicity structure of the nucleon via collinear SIDIS



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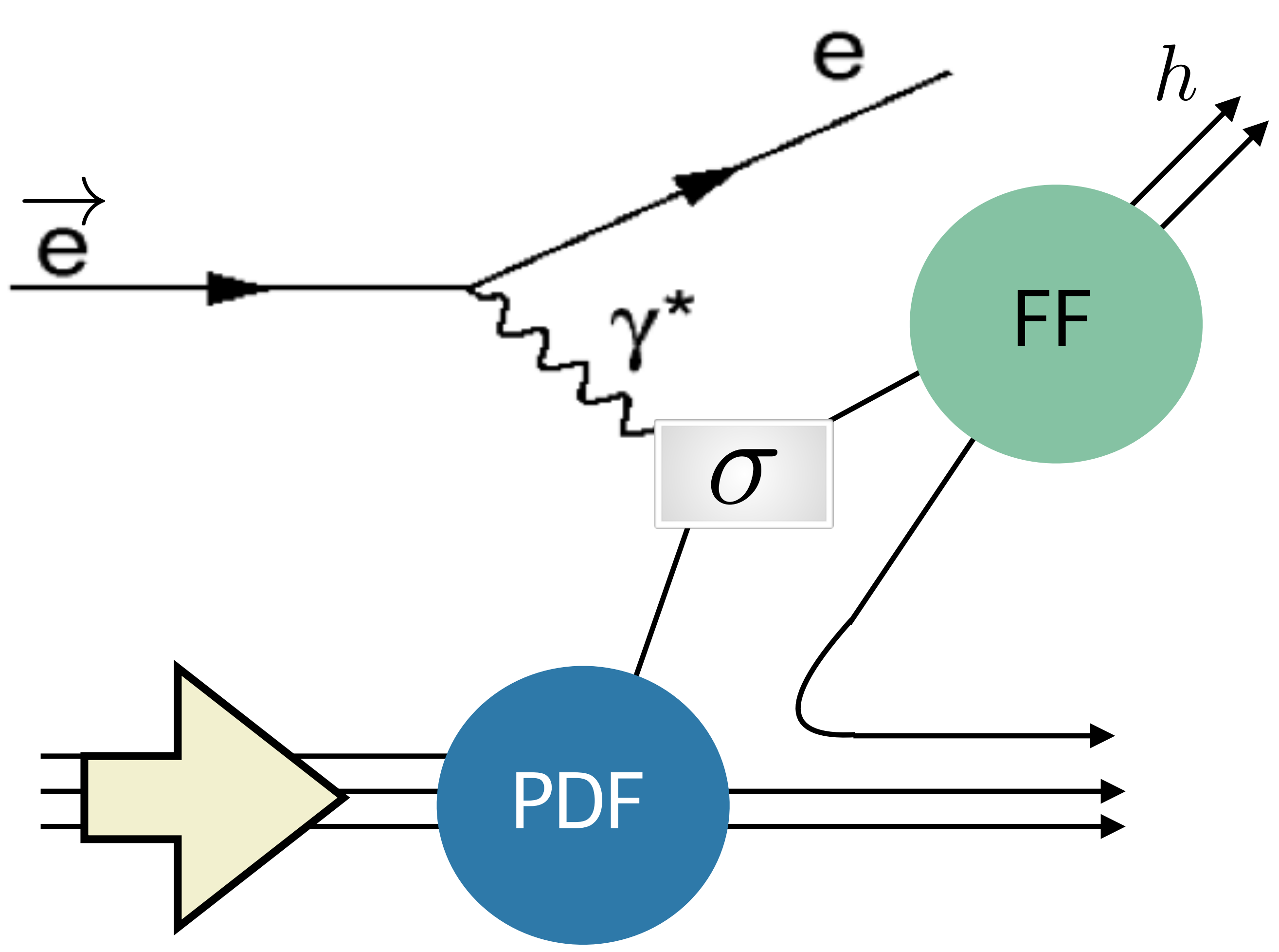
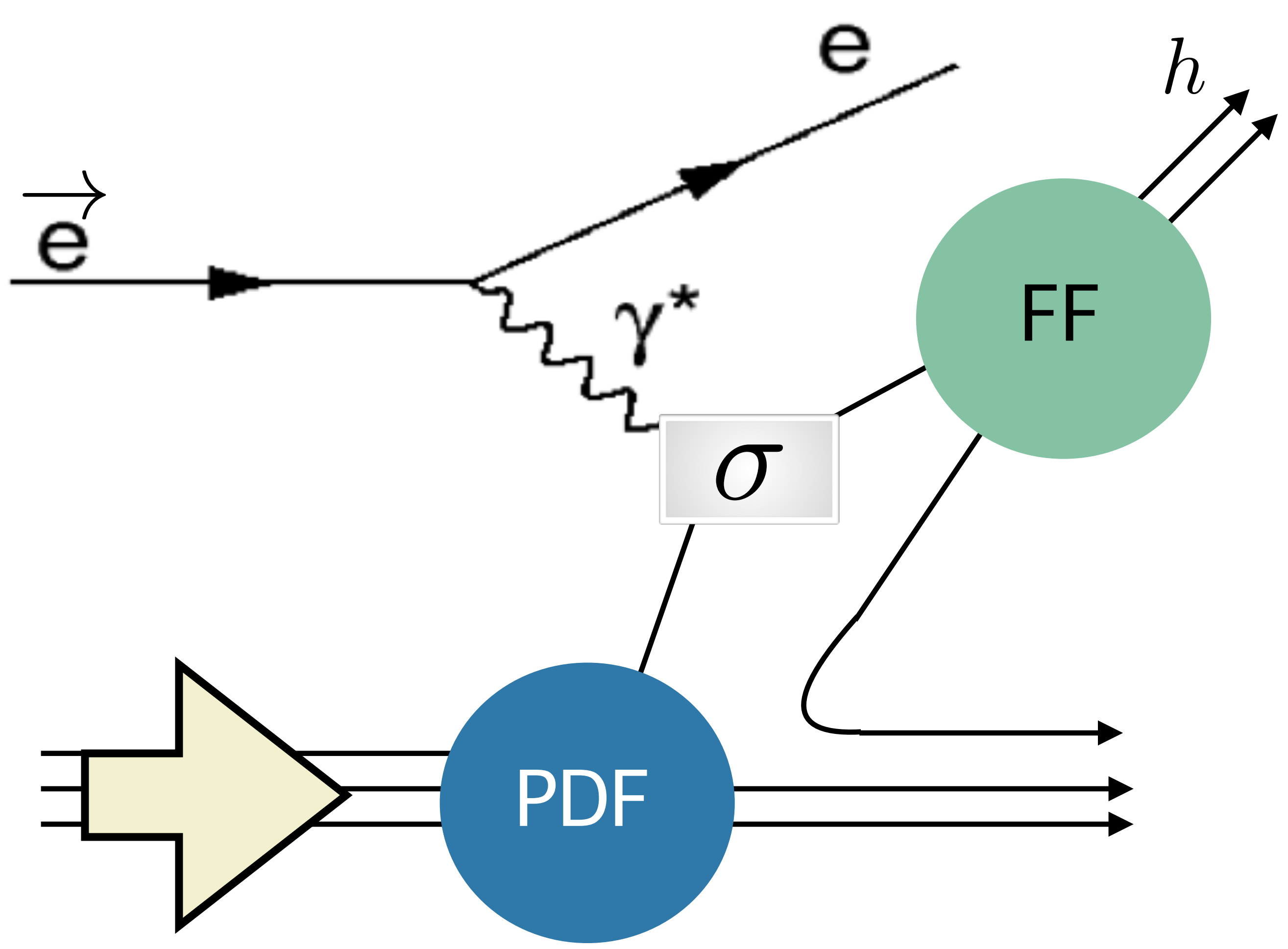


$$A_{\parallel}^{h}(x_B, Q^2, z) = \frac{1}{P_e\, P_p} \frac{\frac{\overset{\rightrightarrows}{N}^h}{\overset{\rightrightarrows}{L}} - \frac{\overset{\leftrightarrows}{N}^h}{\overset{\leftrightarrows}{L}}}{\frac{\overset{\rightrightarrows}{N}^h}{\overset{\rightrightarrows}{L}} + \frac{\overset{\leftrightarrows}{N}^h}{\overset{\leftrightarrows}{L}}}(x_B, Q^2, z)$$

$$= D(y) A_1^h(x_B, Q^2, z)$$

$$\left(z \overset{\text{lab}}{=} \frac{E_h}{E_{\gamma*}}\right)$$

Helicity structure of the nucleon via collinear SIDIS



$$A_{\parallel}^{h}(x_B,Q^2,z) = \frac{1}{P_e\,P_p}\,\frac{\frac{\overset{\rightrightarrows}{N}^h}{\overset{\rightrightarrows}{L}} - \frac{\overset{\leftleftarrows}{N}^h}{\overset{\leftleftarrows}{L}}}{\frac{\overset{\rightrightarrows}{N}^h}{\overset{\rightrightarrows}{L}} + \frac{\overset{\leftleftarrows}{N}^h}{\overset{\leftleftarrows}{L}}}(x_B,Q^2,z)$$

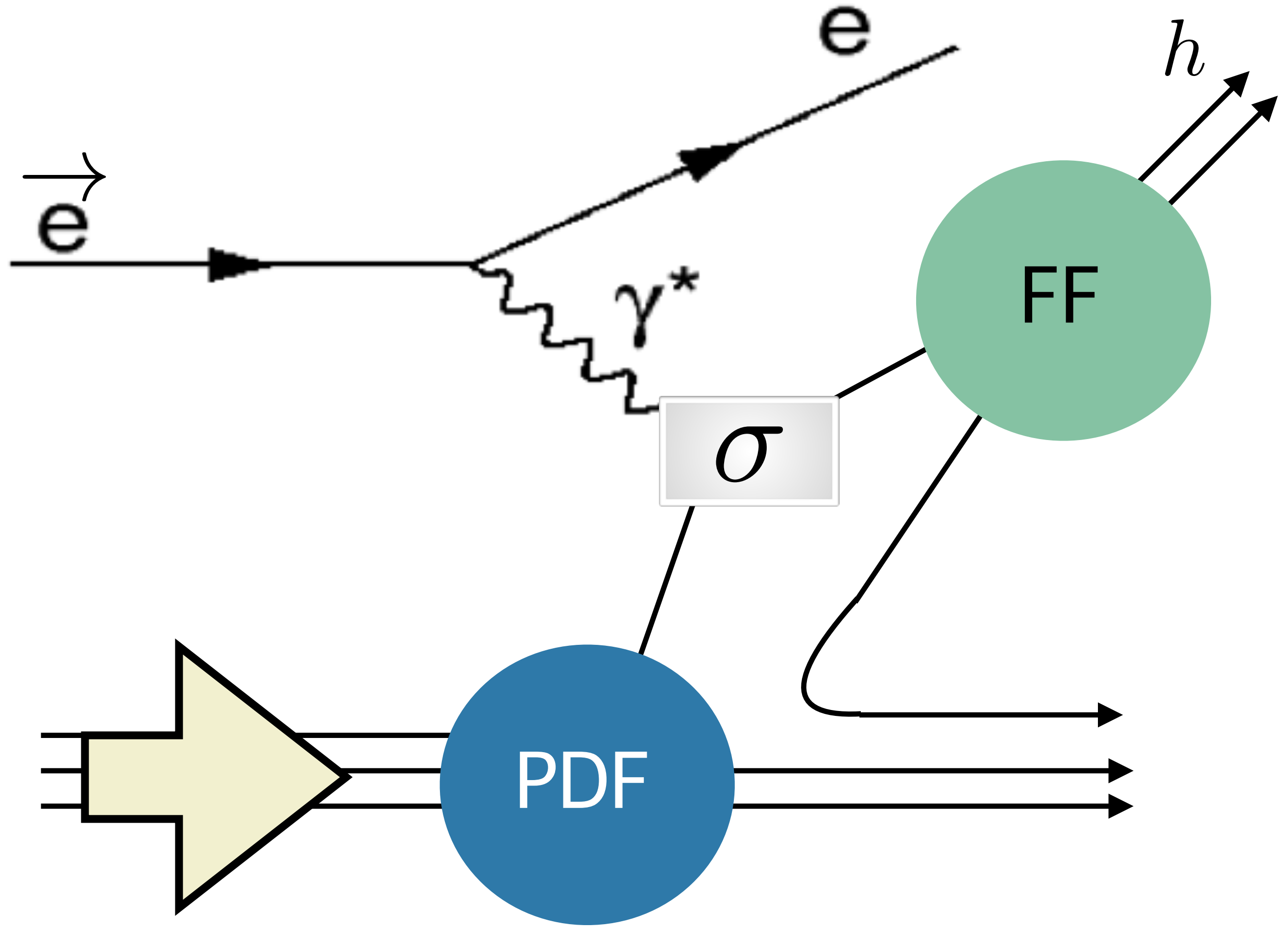
$$= D(y)\,A_1^h(x_B,Q^2,z)$$

$$\left(z \overset{\text{lab}}{=} \frac{E_h}{E_{\gamma*}}\right)$$

$$\propto \sum_q e_q^2 \left[\Delta q \otimes w_1\, D_1^{q\to h}\right]$$

Semi-inclusive measurements, via good hadron PID
→ access to sea-quark spin

Helicity structure of the nucleon via collinear SIDIS



$$A_{\parallel}^{h}(x_B, Q^2, z) = \frac{1}{P_e\, P_p} \frac{\frac{\overset{\rightrightarrows}{N^h}}{\overset{\rightrightarrows}{L}} - \frac{\overset{\leftrightarrows}{N^h}}{\overset{\leftrightarrows}{L}}}{\frac{\overset{\rightrightarrows}{N^h}}{\overset{\rightrightarrows}{L}} + \frac{\overset{\leftrightarrows}{N^h}}{\overset{\leftrightarrows}{L}}}(x_B, Q^2, z)$$

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Semi-inclusive measurements, via good hadron PID
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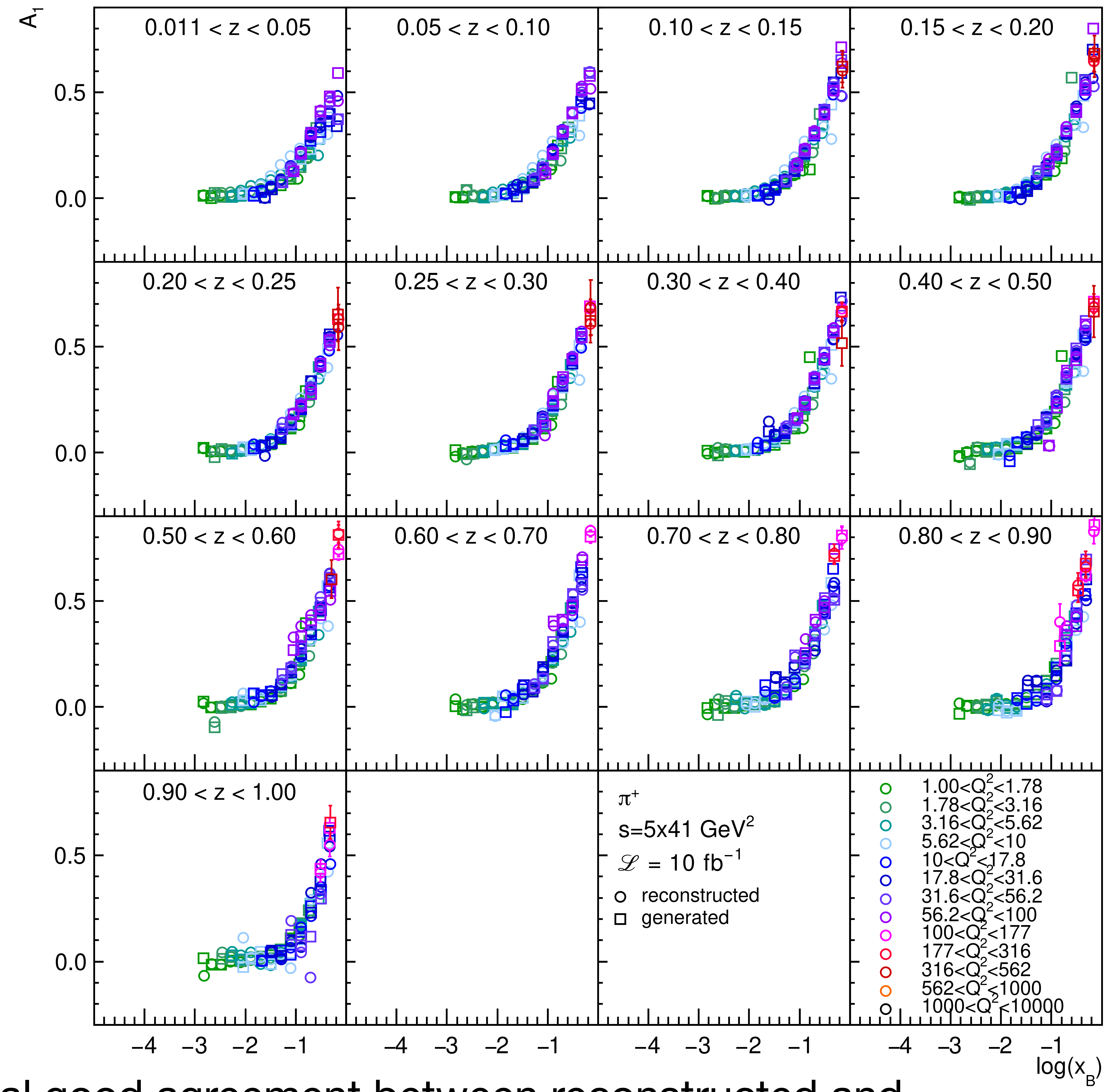
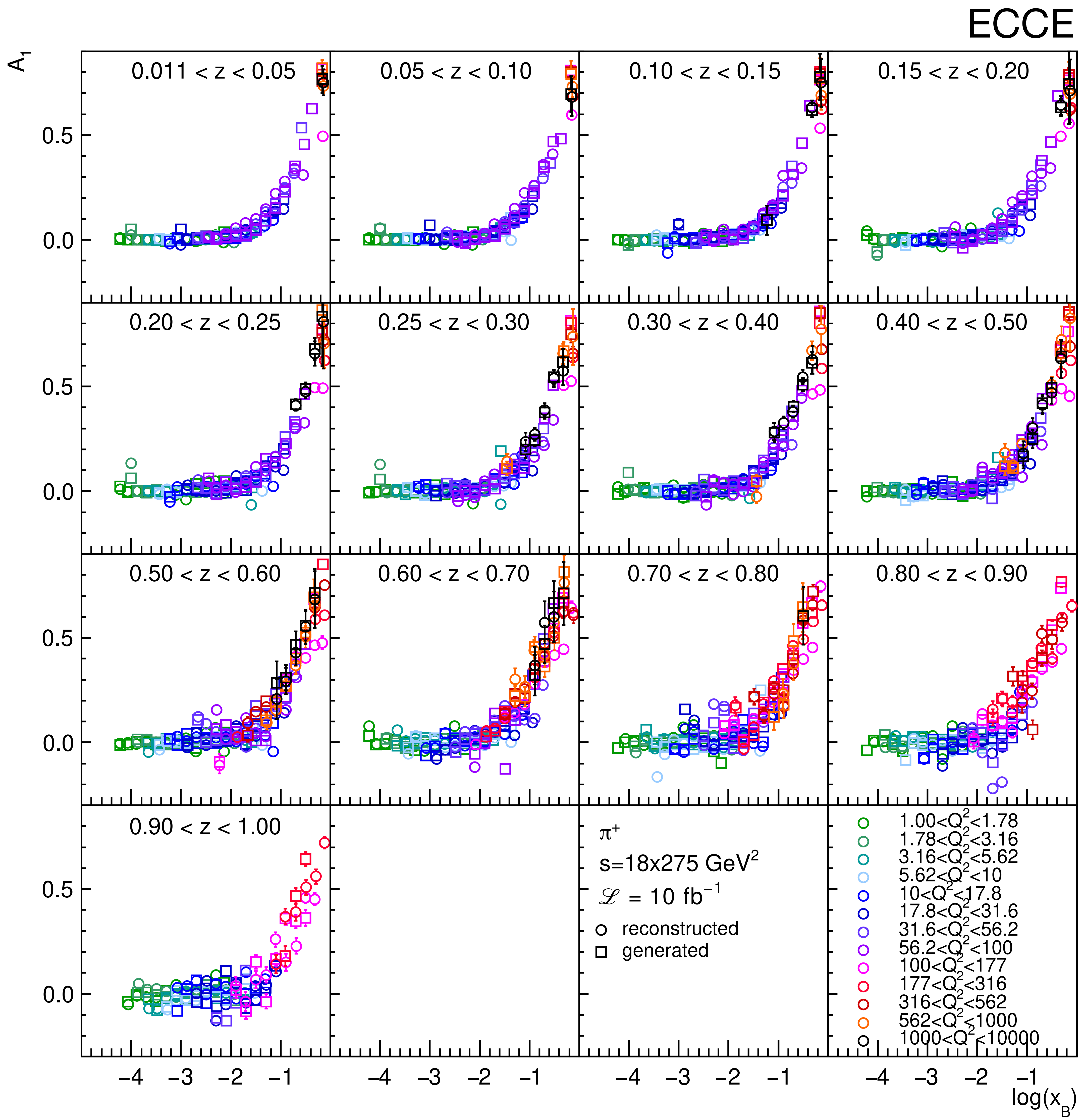
Beam polarisations assumed to be 70%.

Generated and reconstructed A_1

$D(y) = 1$



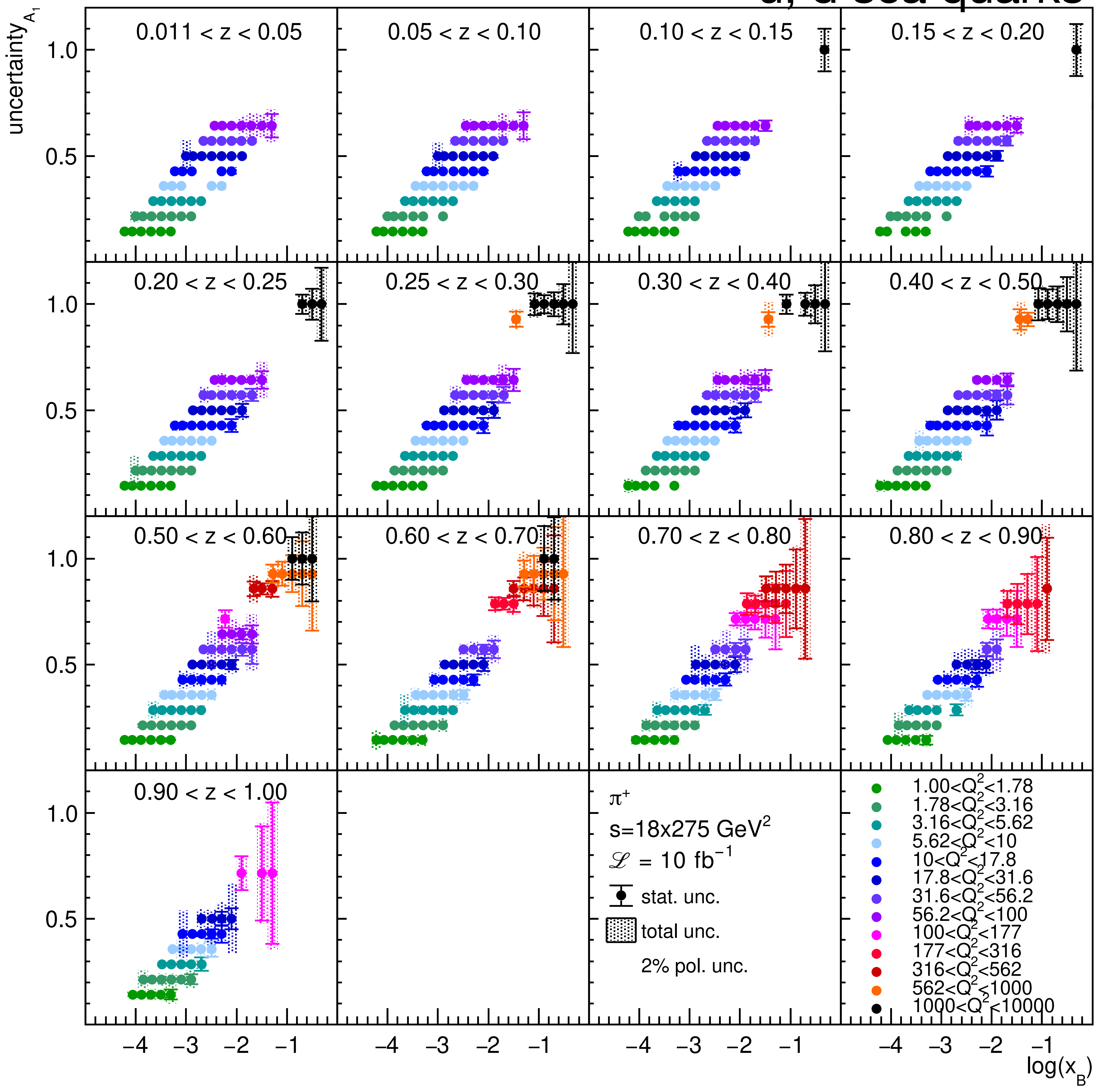


General good agreement between reconstructed and generated asymmetry: moderate smearing.

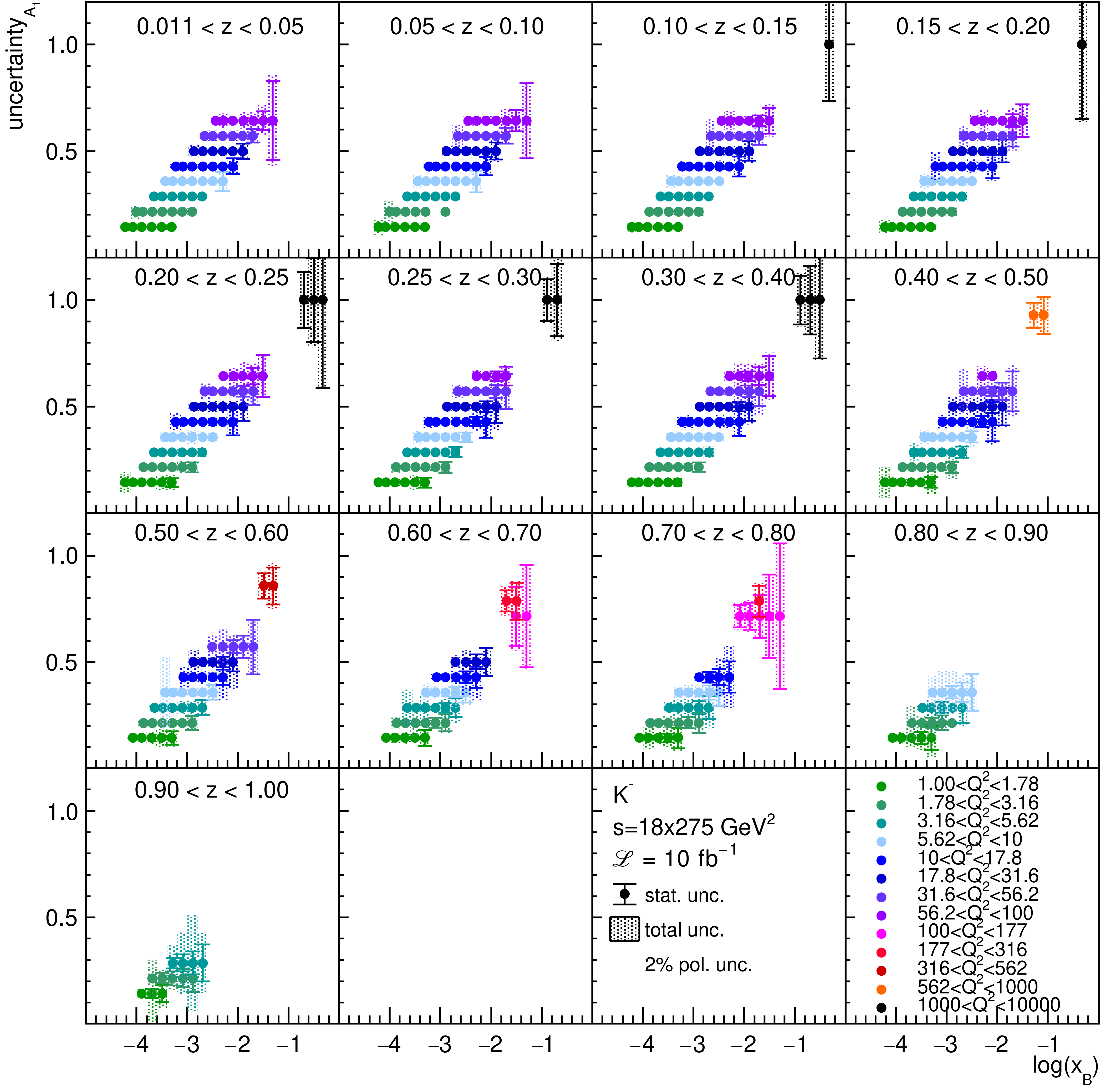
Kinematic coverage and uncertainties

ECCE

u, d sea quarks



strange quarks



via tracking of scattered lepton only

systematic uncertainty= |generated - reconstructed|

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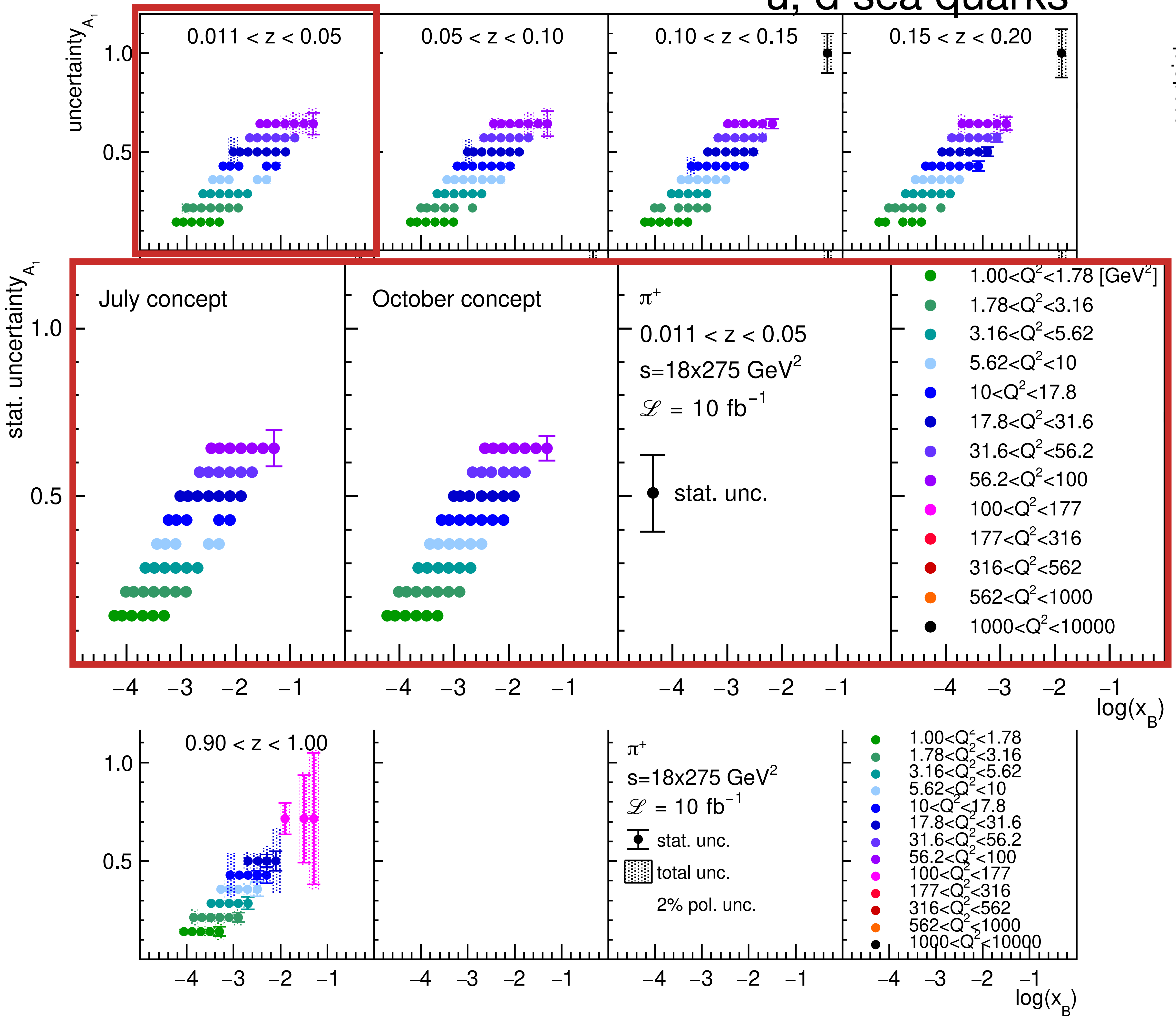

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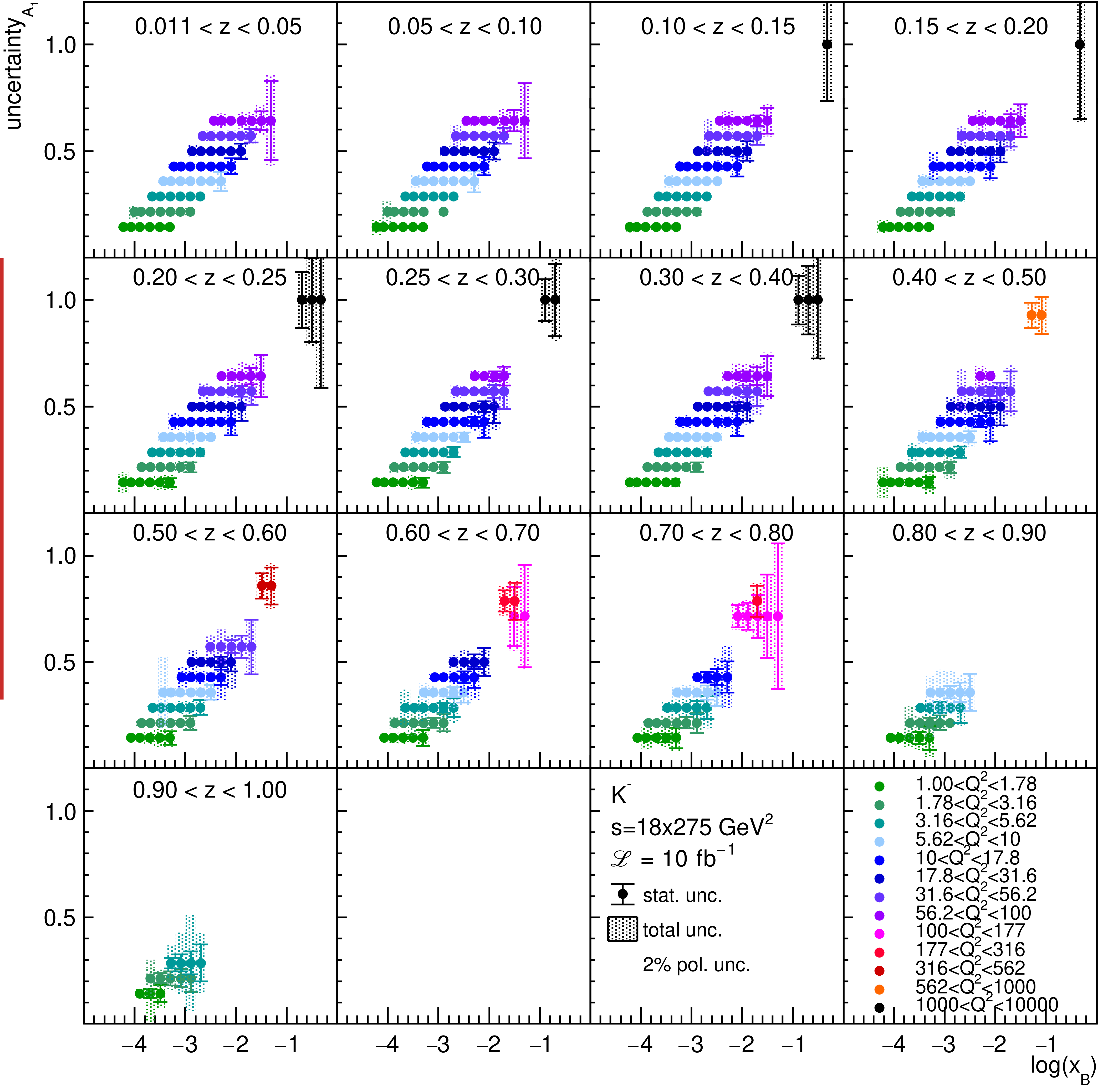

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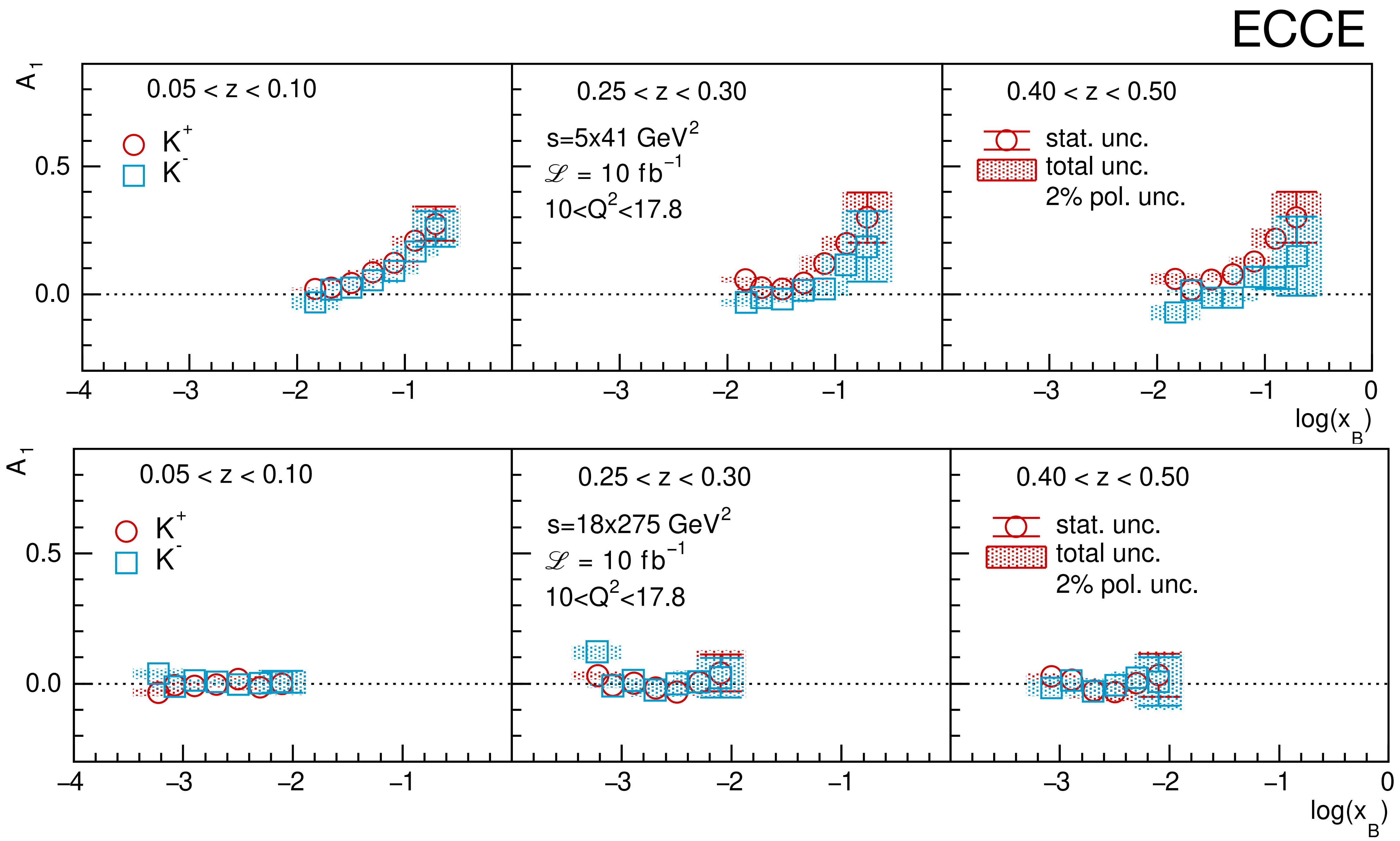
Helicity structure of the nucleon via SIDIS



Reweighting of Pythia MC at NLO,
using DSSV14 helicity distributions
and DSS14 pion and kaon FFs

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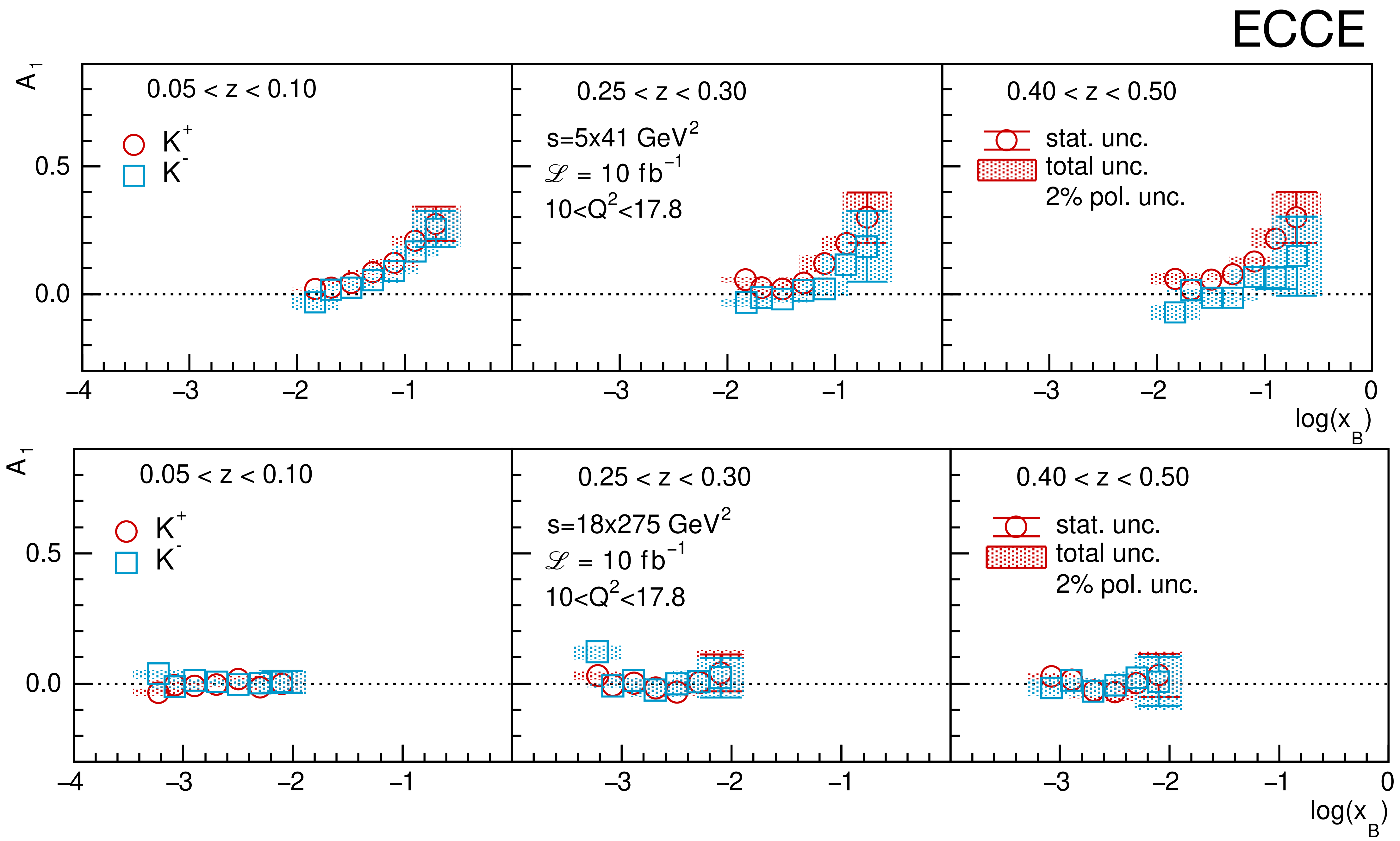
Helicity structure of the nucleon via SIDIS



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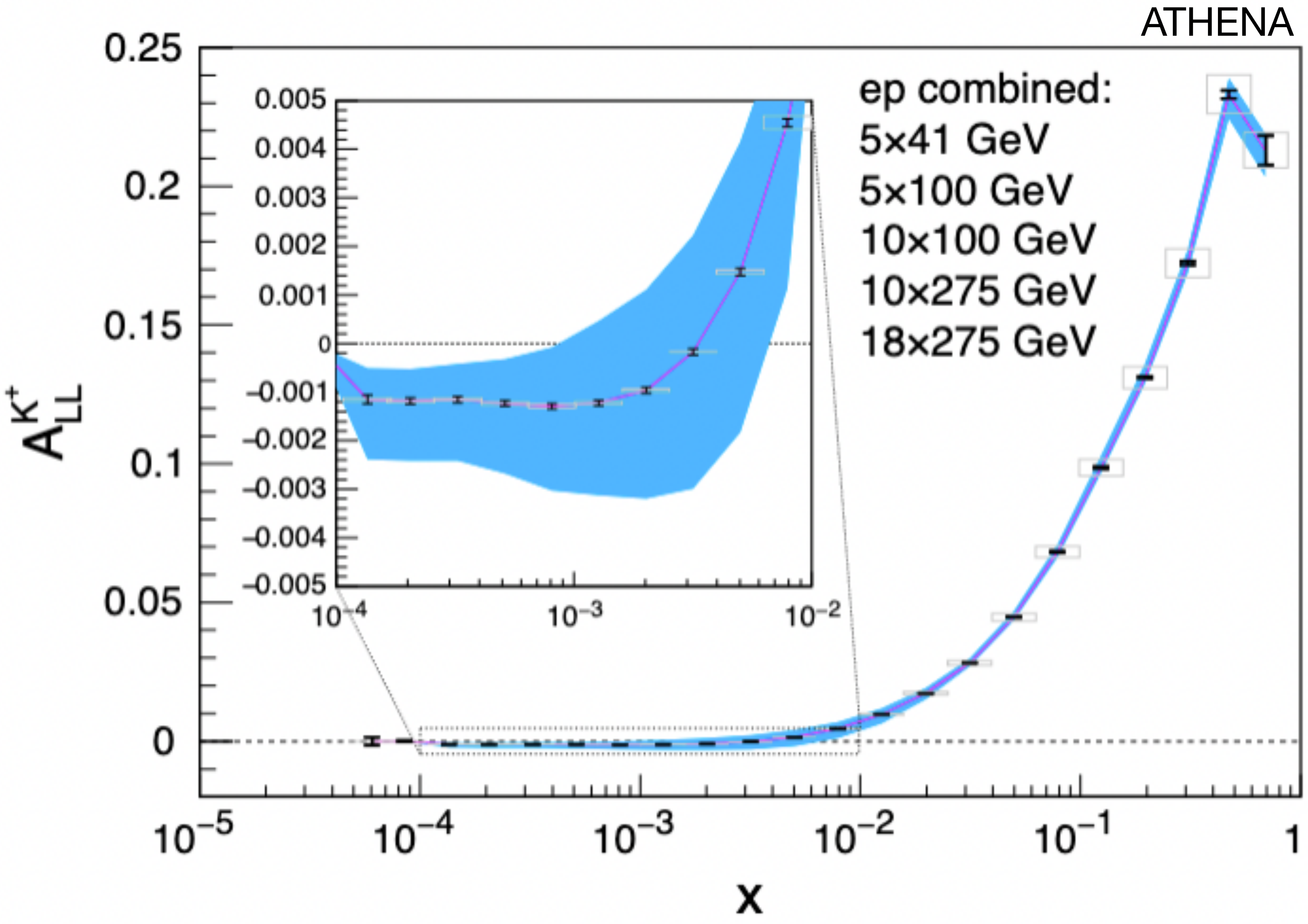

Transverse-momentum dependent SIDIS cross section for single-hadron production

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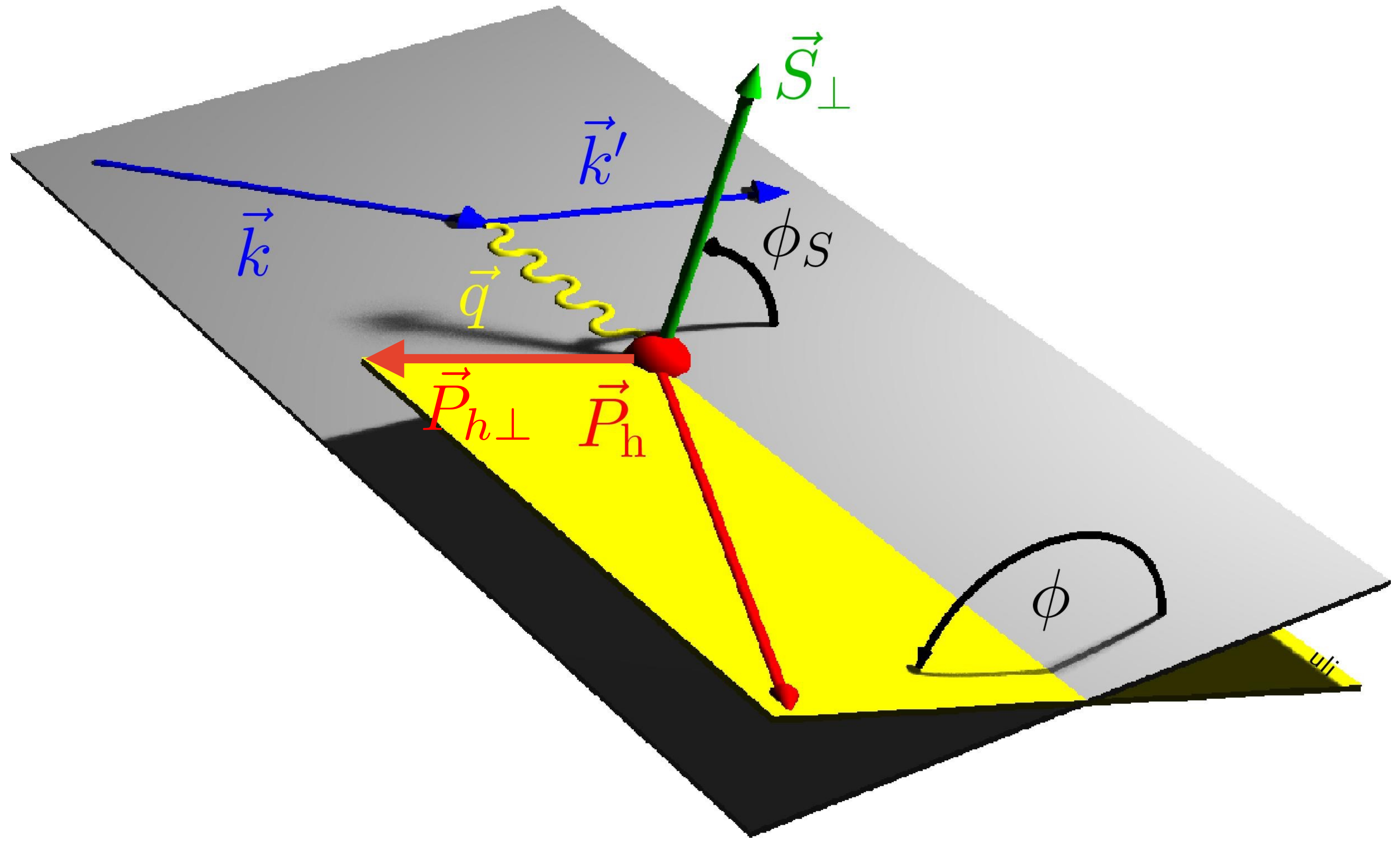
&+\ \ 2\langle\cos(\phi_S)\rangle^h_{LT}\,\cos(\phi_S)+2\langle\cos(2\phi-\phi_S)\rangle^h_{LT}\,\cos(2\phi-\phi_S)\Big)\Big]\Big\}
\end{aligned}$$



Transverse-momentum dependent SIDIS cross section for single-hadron production

longitudinal target polarization

transverse target polarization

beam polarization

$$\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)\\
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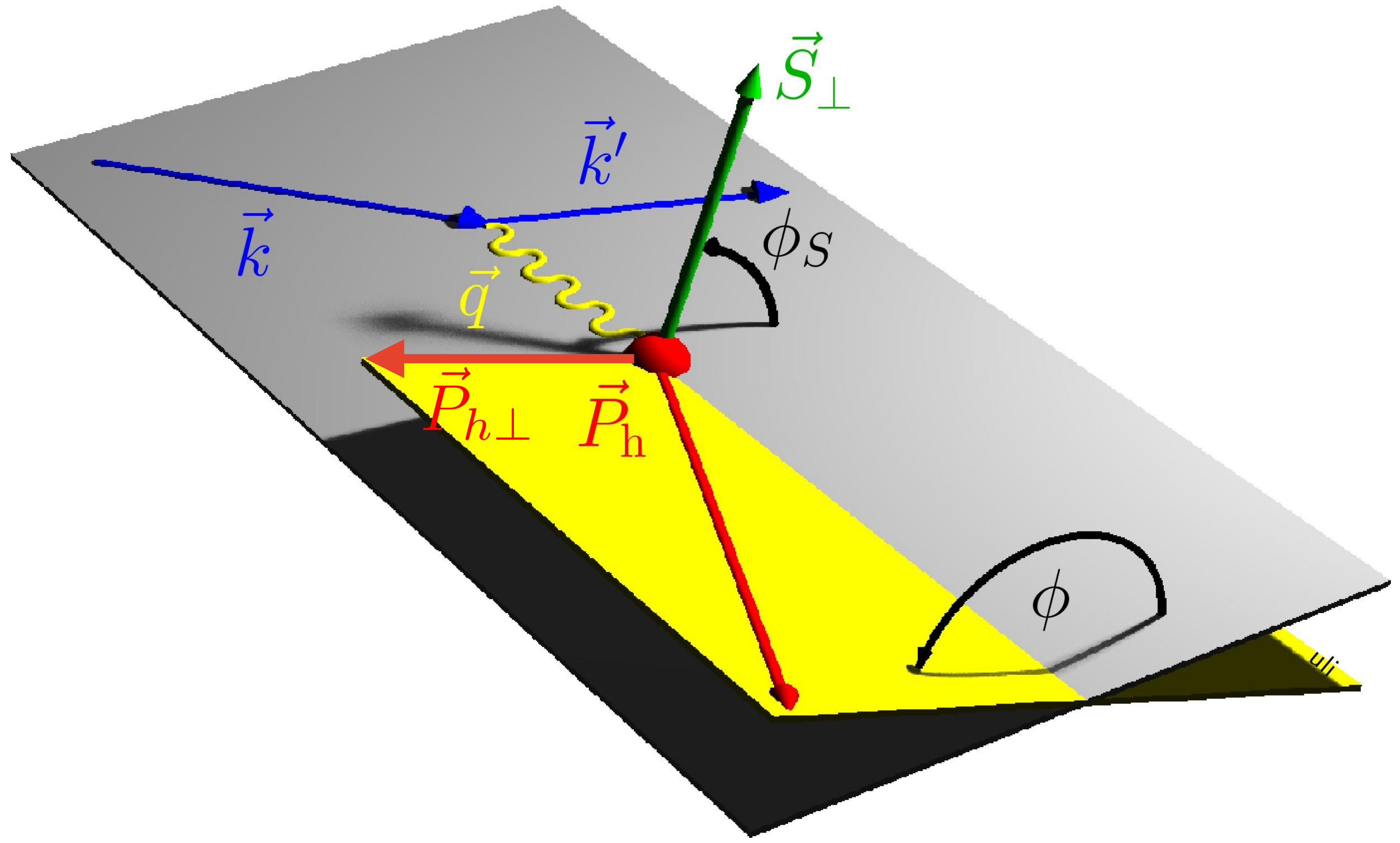

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\end{aligned}
$$

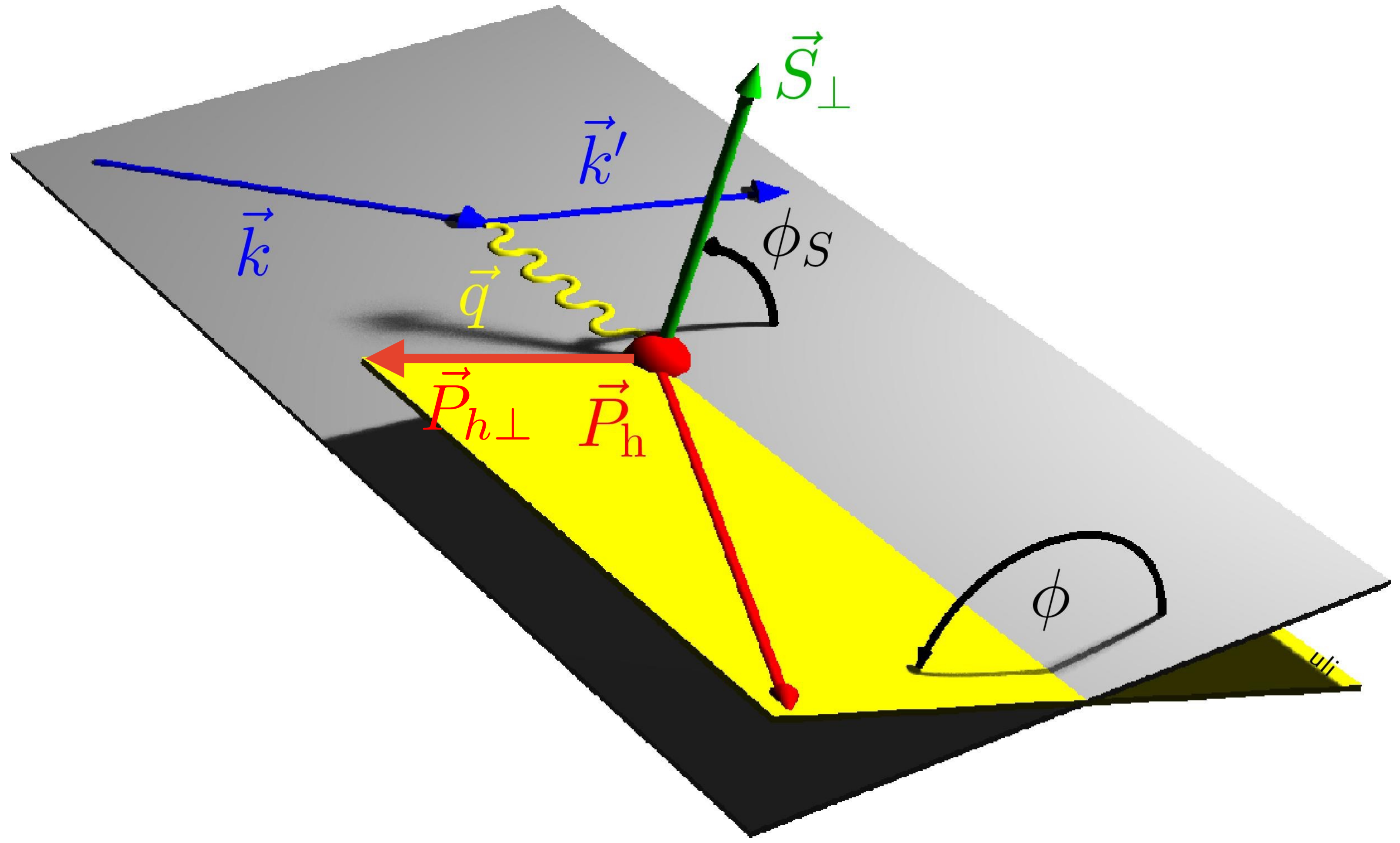
longitudinal target polarization

transverse target polarization

beam polarization

beam polarization

target polarization



Transverse-momentum dependent SIDIS cross section for single-hadron production

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longitudinal target polarization

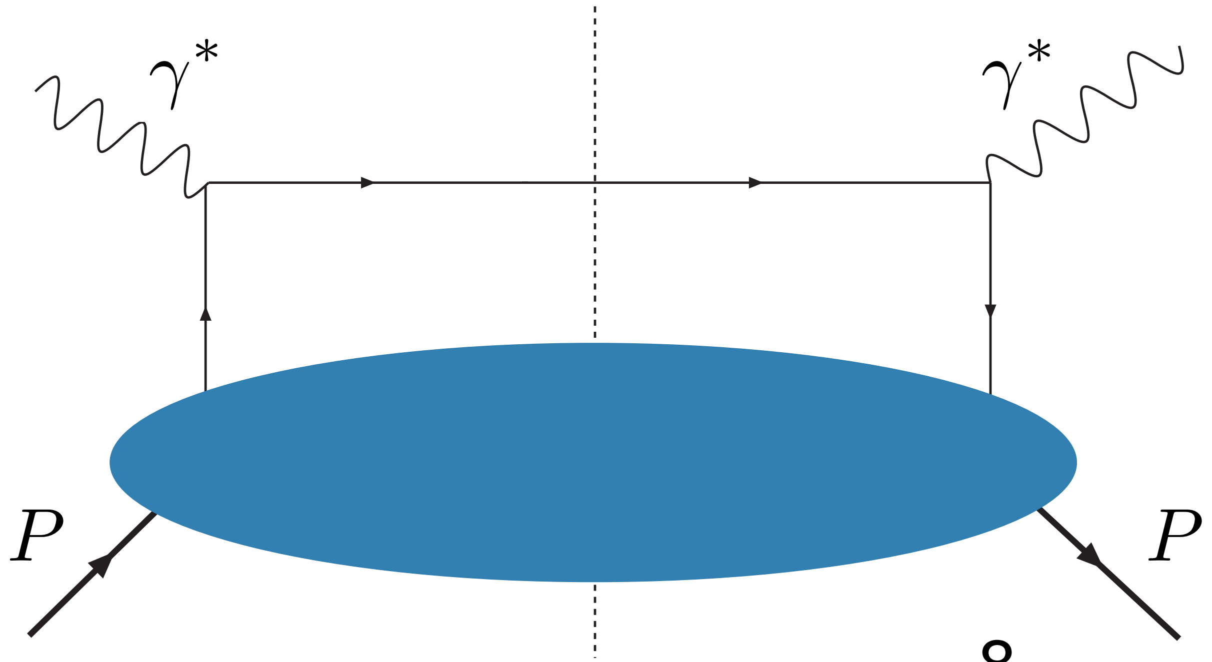
transverse target polarization

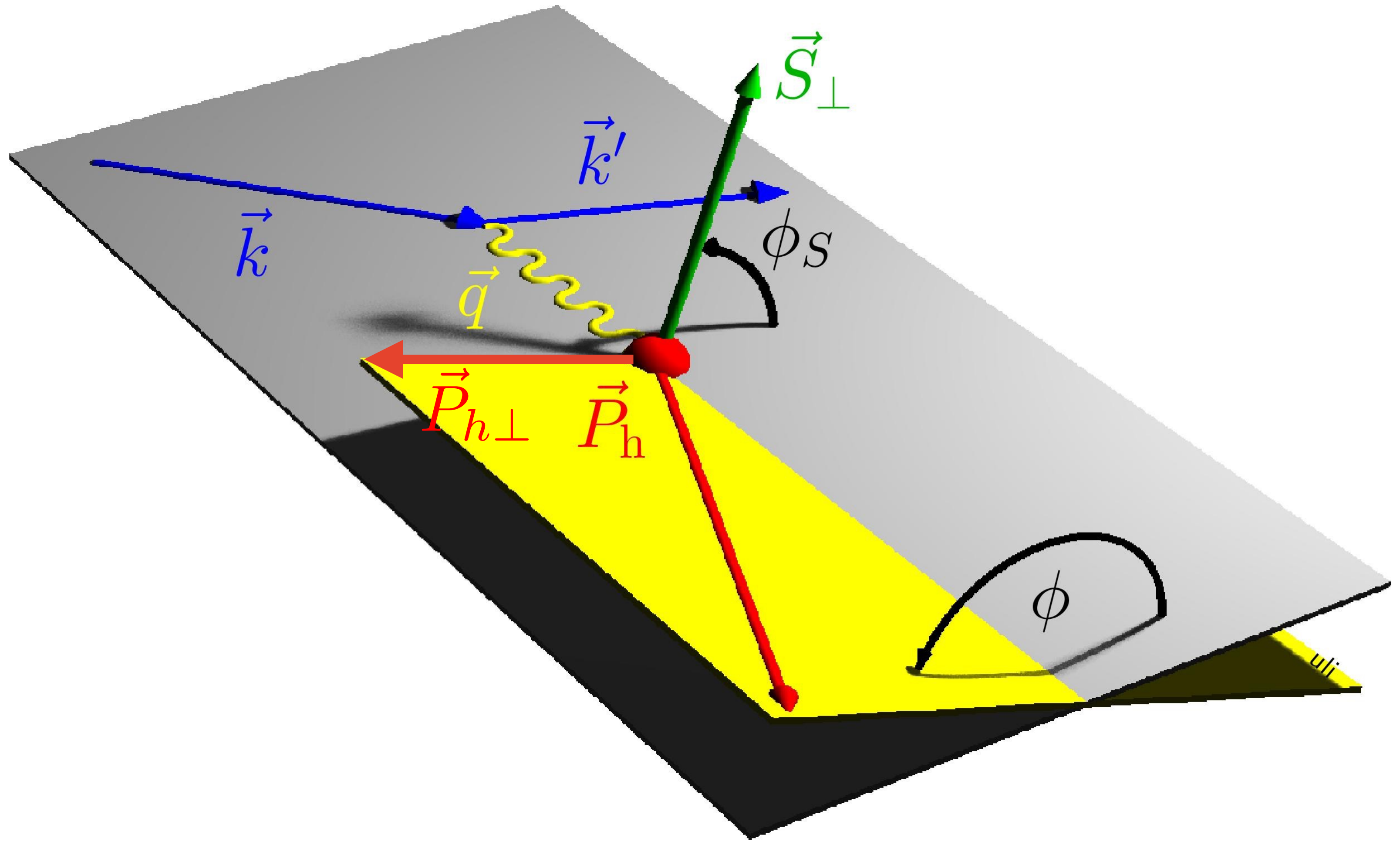
beam polarization

beam polarization

target polarization

leading twist





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longitudinal target polarization

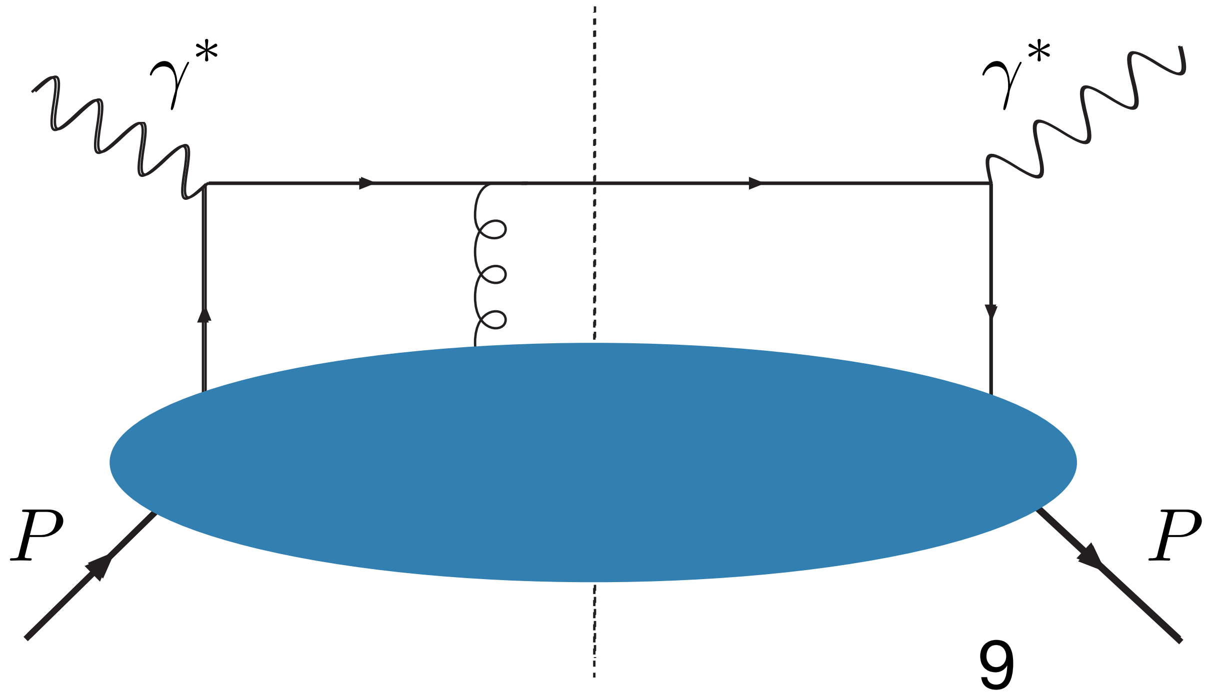
transverse target polarization

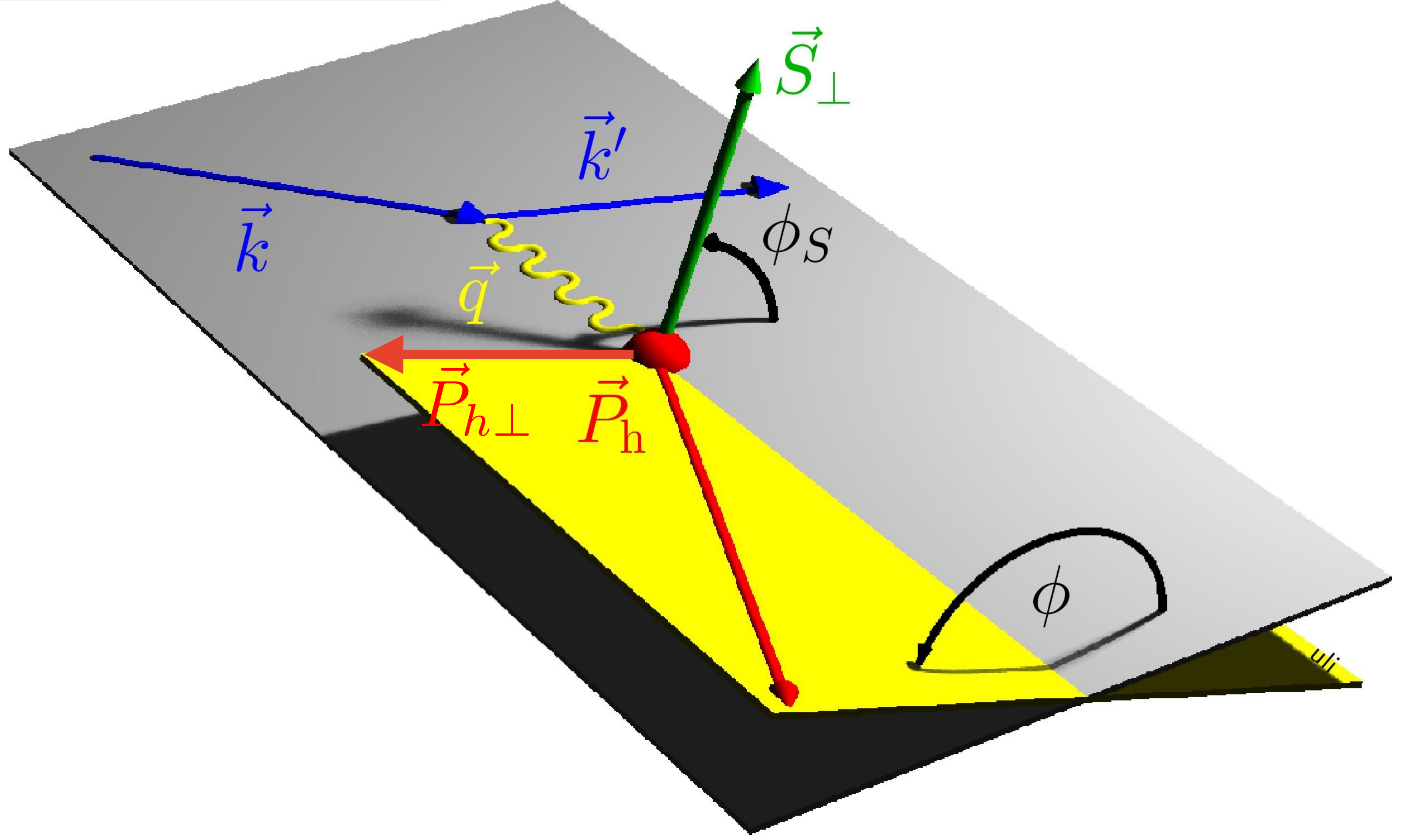
beam polarization

beam polarization

target polarization

sub-leading twist





Transverse-momentum dependent SIDIS cross section for single-hadron production

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\end{aligned}
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longitudinal target polarization

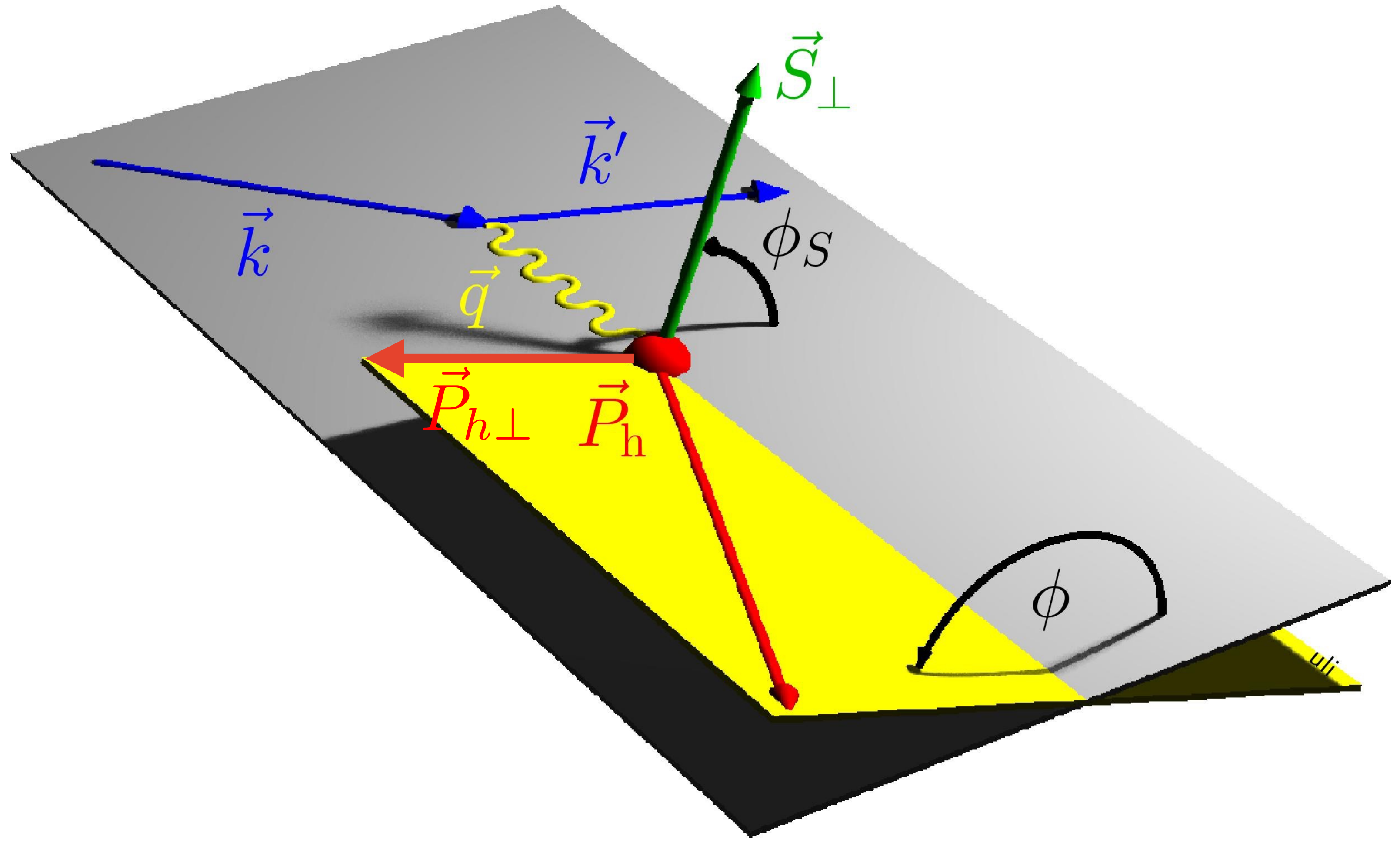
transverse target polarization

beam polarization

beam polarization

target polarization

presented here



TMD PDFs and fragmentation functions (FFs)

Azimuthal amplitudes related to structure functions F_{XY}:

$$2\langle \sin(\phi + \phi_S)\rangle_{UT}^{h} = \epsilon\, F_{UT}^{\sin(\phi+\phi_S)}$$

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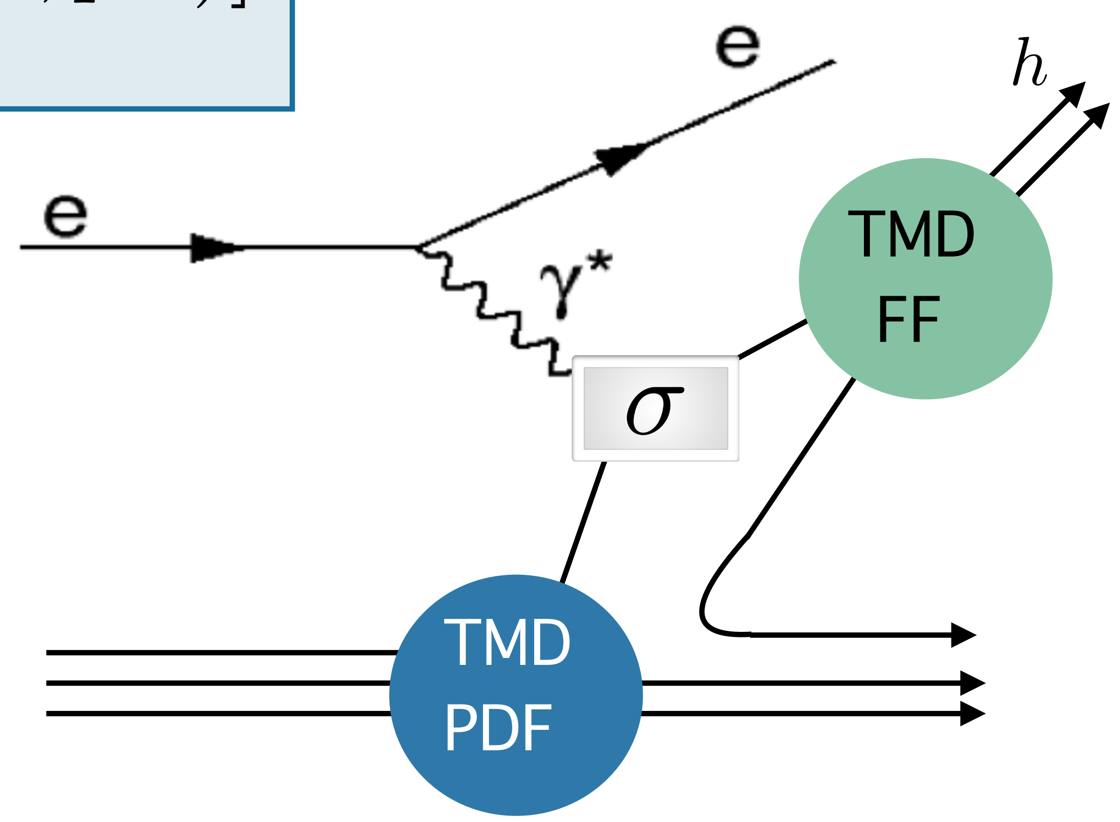

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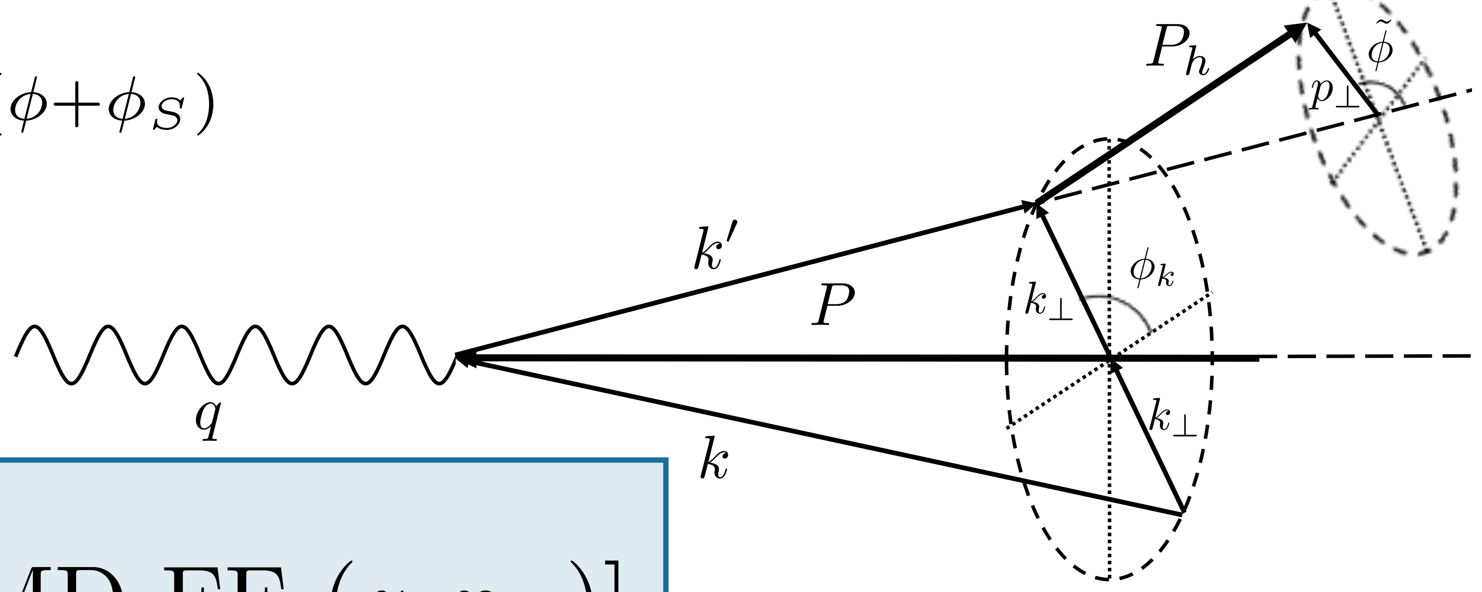
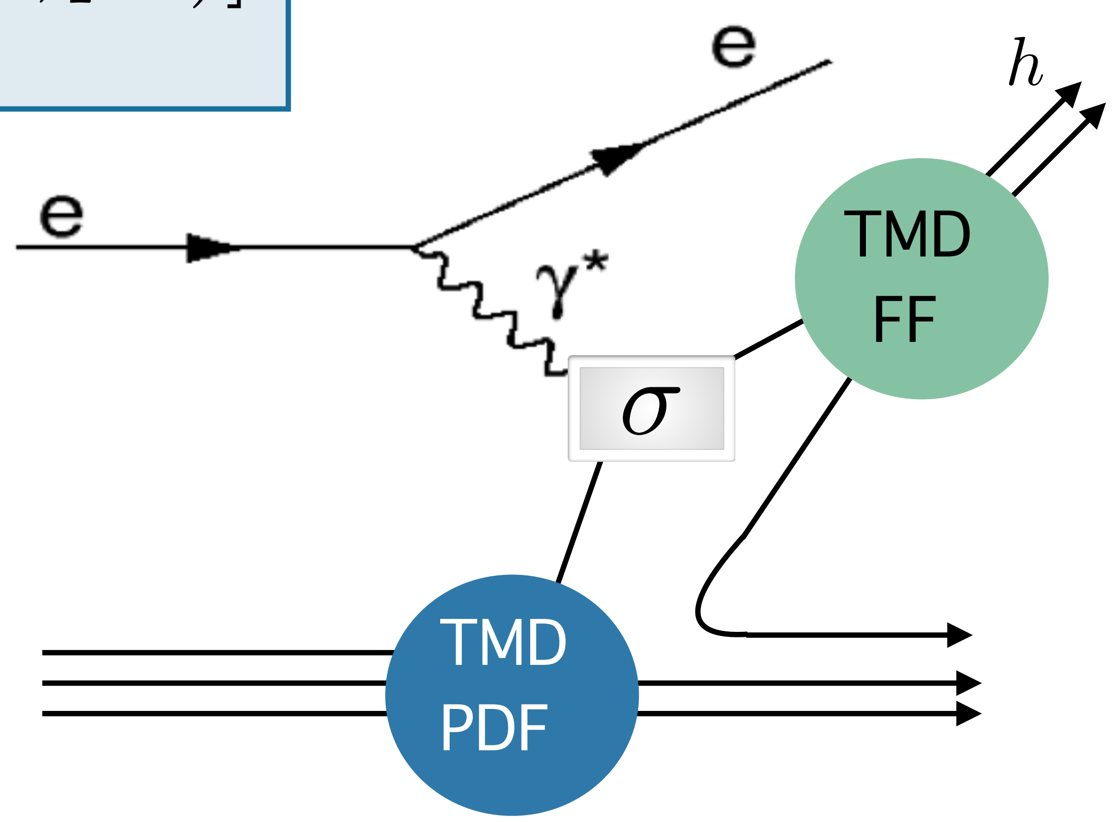


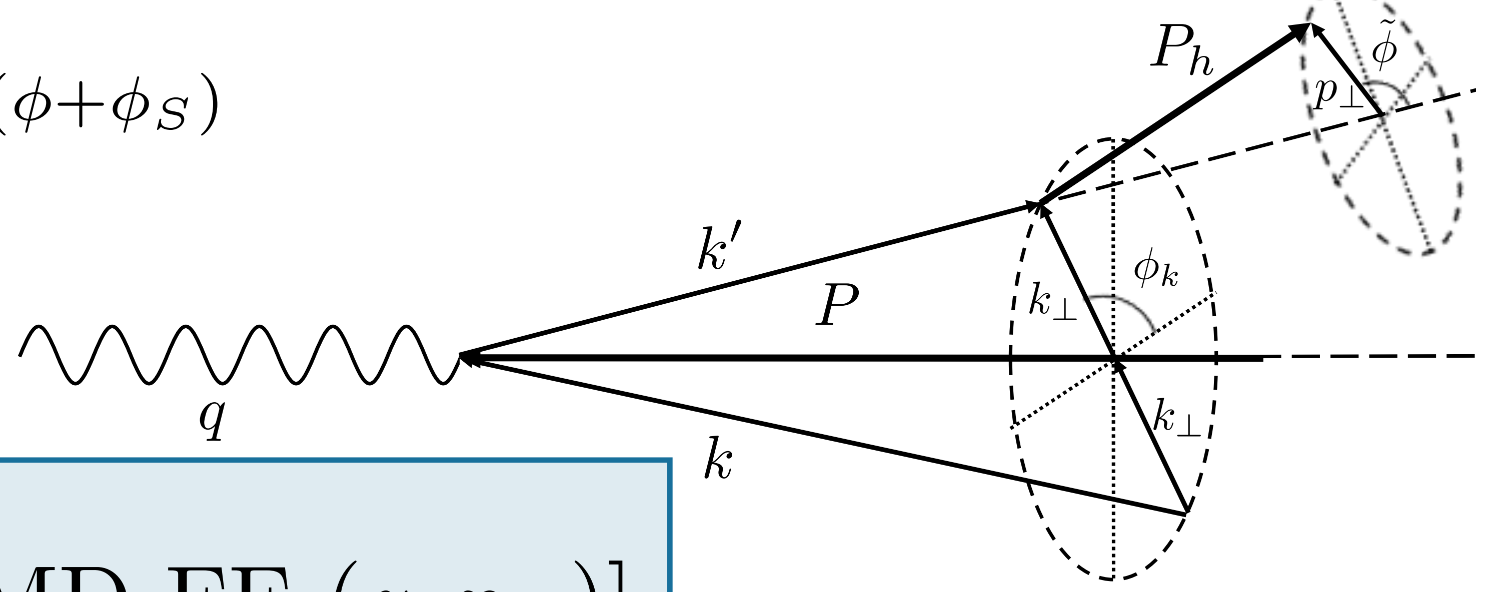
$$F_{XY} \propto \mathcal{C}\,[\text{TMD PDF}(x,k_\perp) \times \text{ TMD FF }(z,p_\perp)]$$



TMD PDFs and fragmentation functions (FFs)

Azimuthal amplitudes related to structure functions F_{XY}:

$$2\langle \sin(\phi+\phi_S)\rangle^h_{UT} = \epsilon\, F^{\sin(\phi+\phi_S)}_{UT}$$



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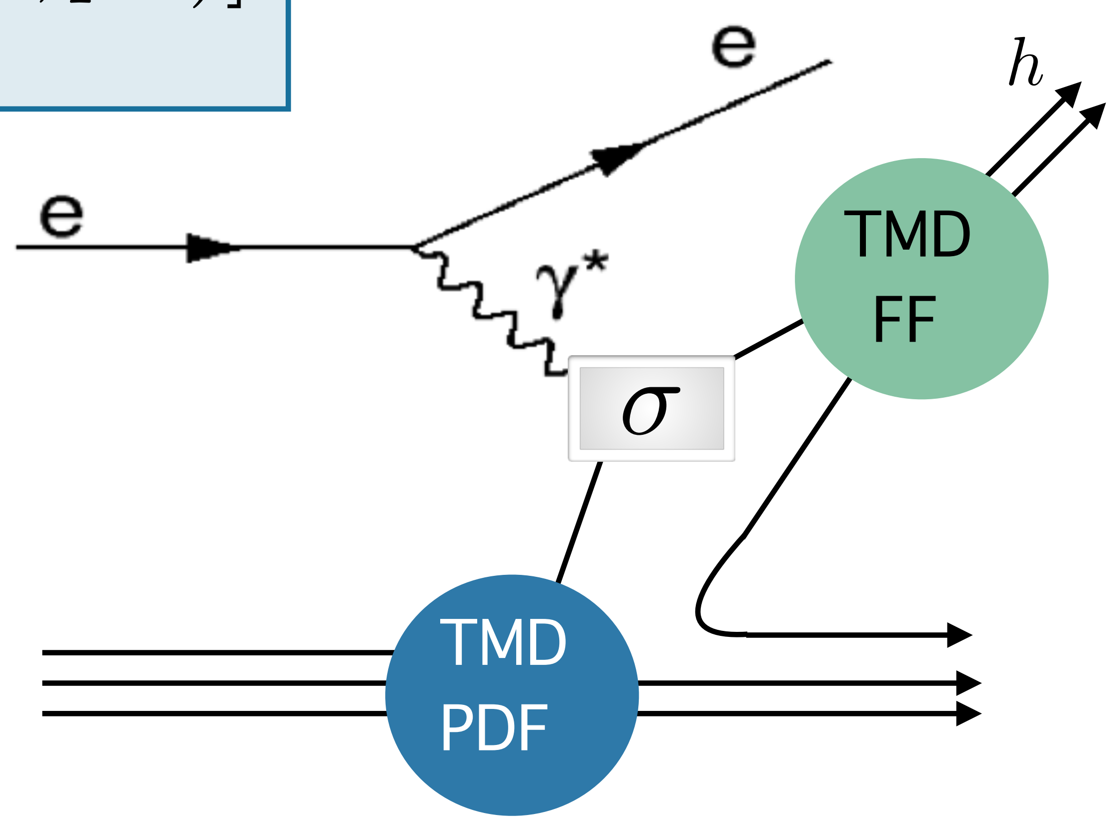

quark polarization

nucleon polarization

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	$g_{1T}^\perp$	$h_{1T}\, h_{1T}^\perp$

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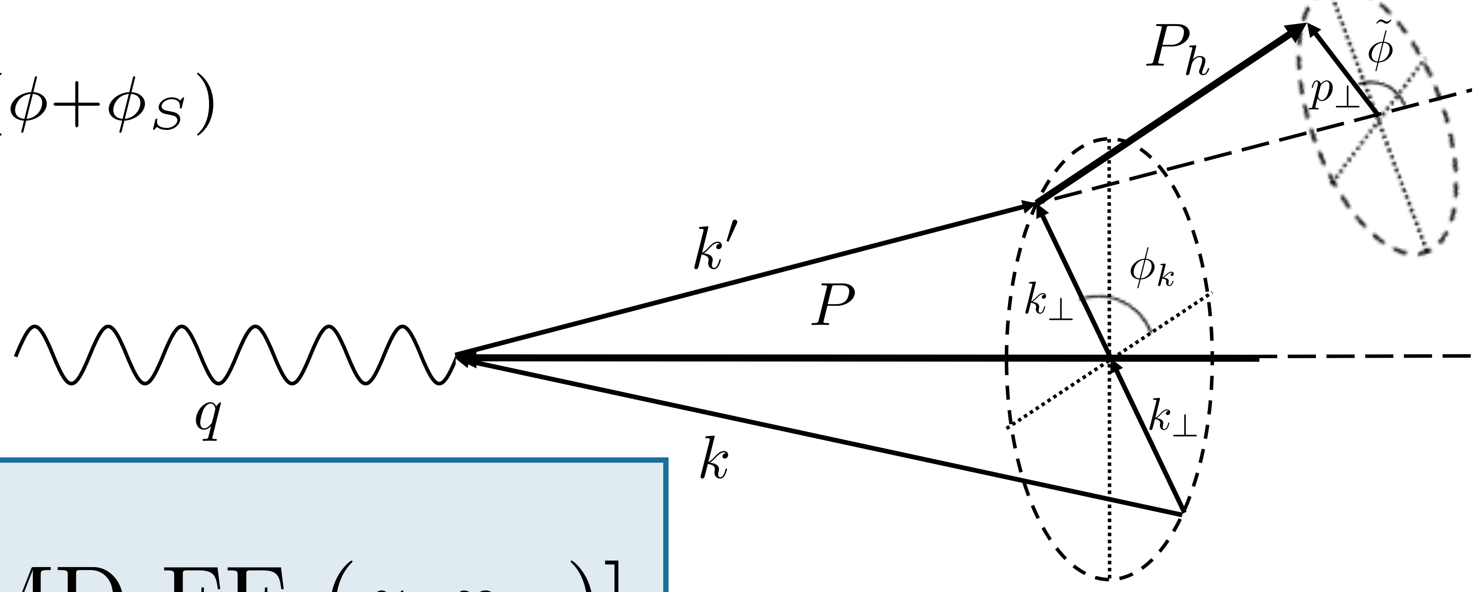

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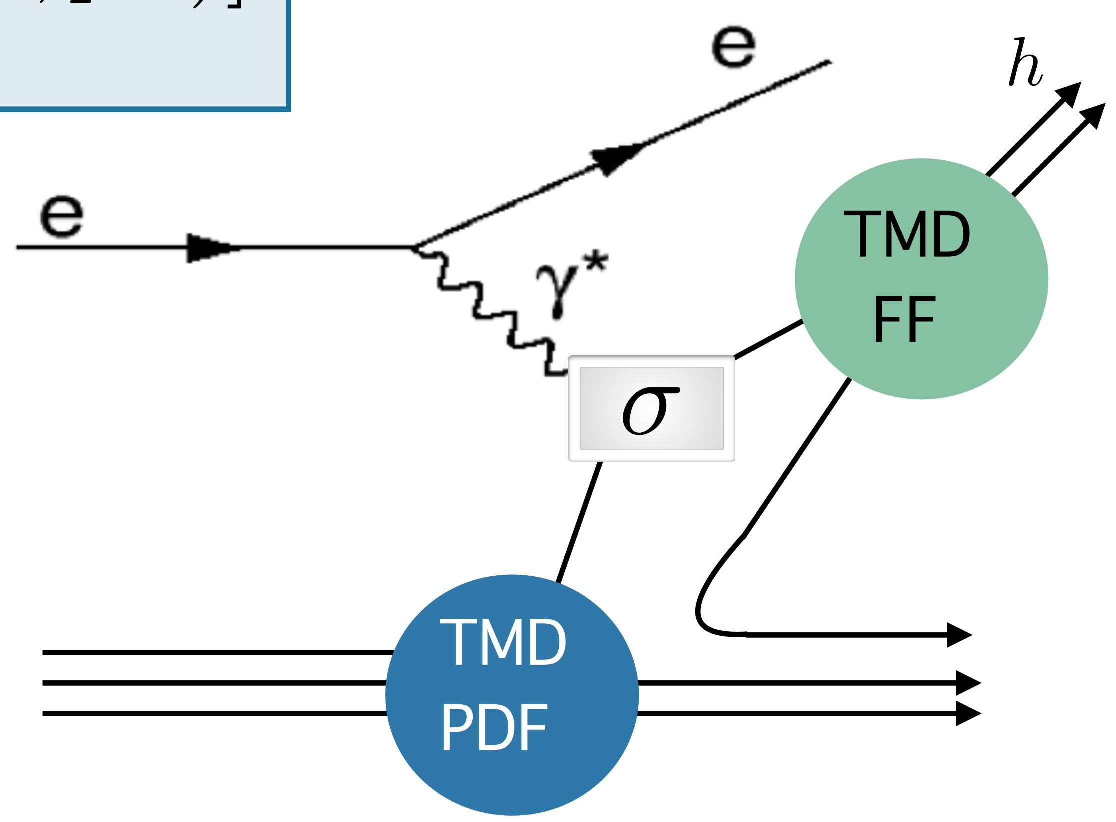

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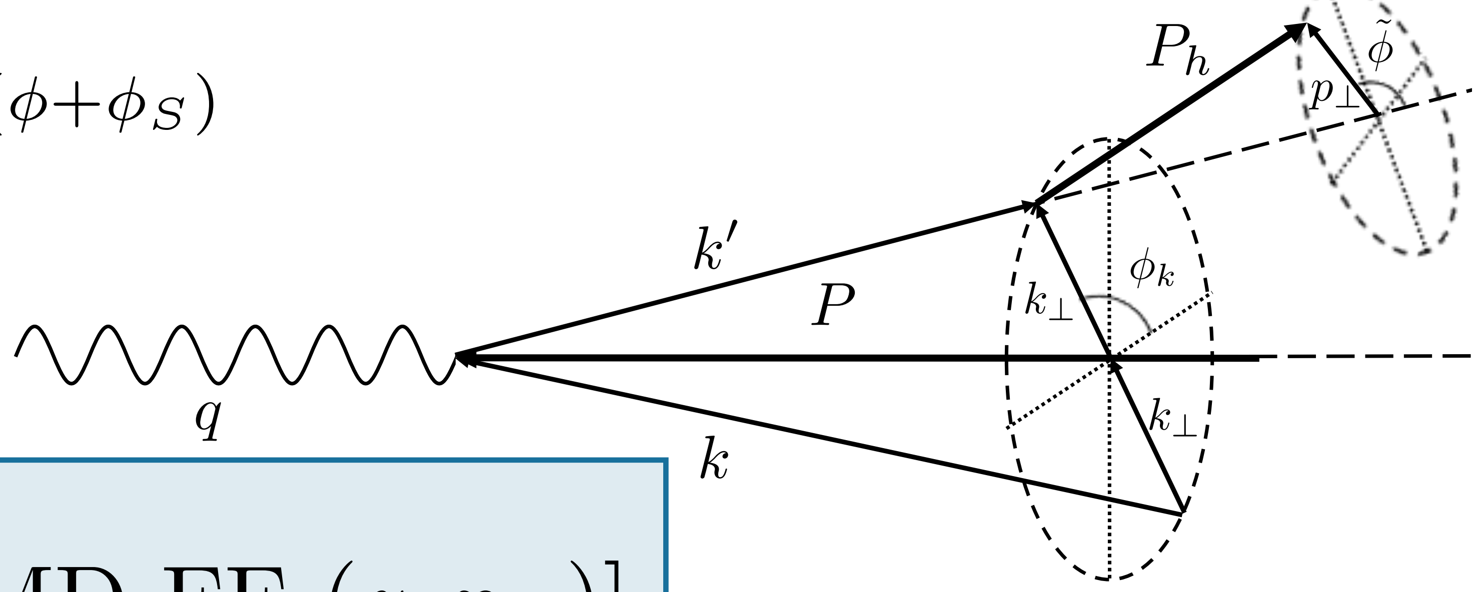

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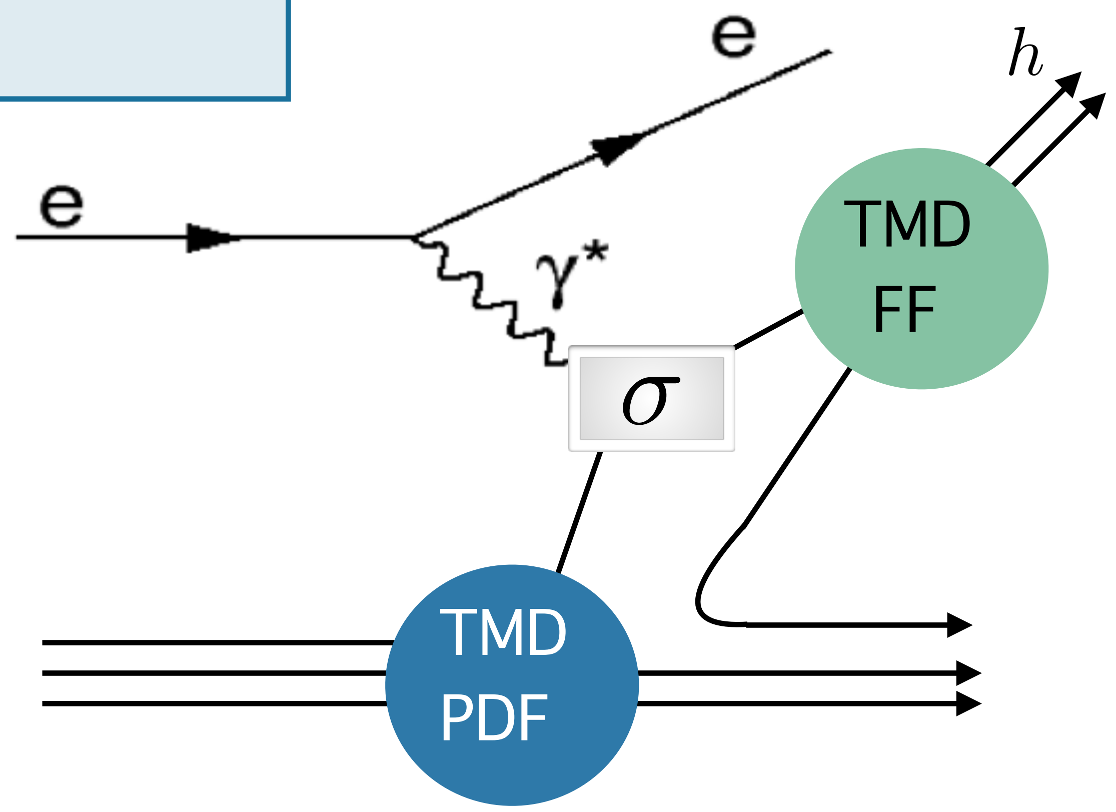

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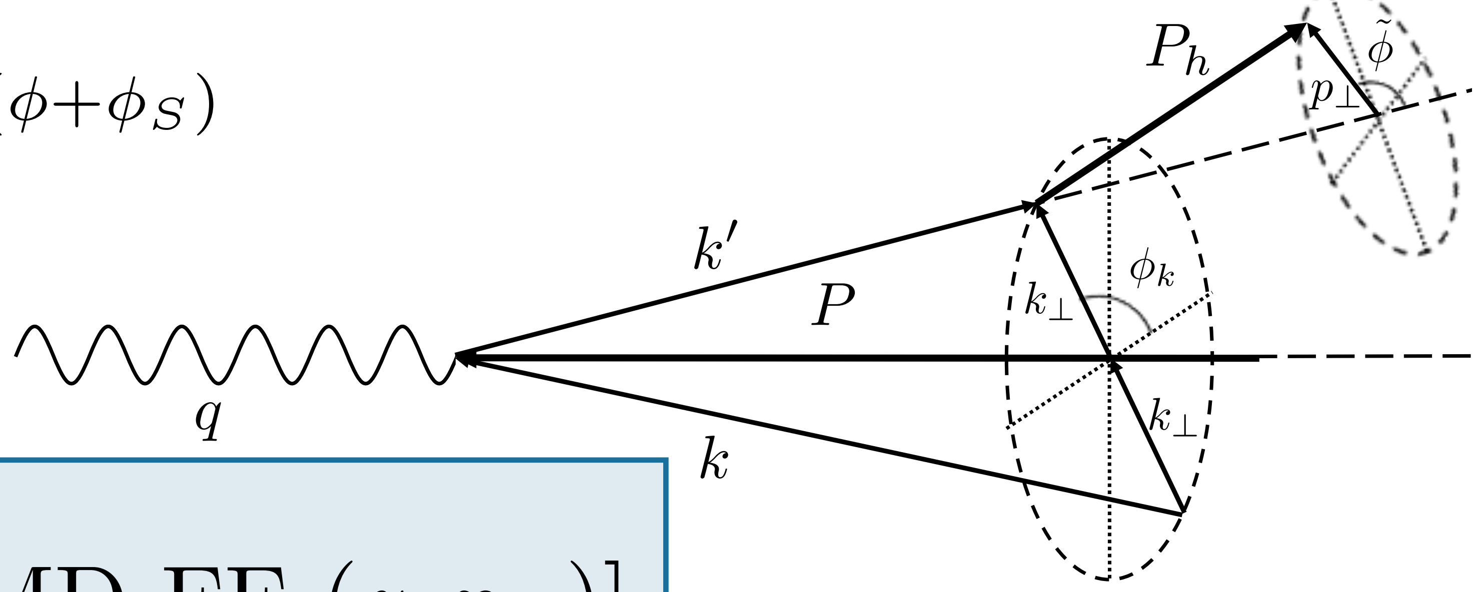

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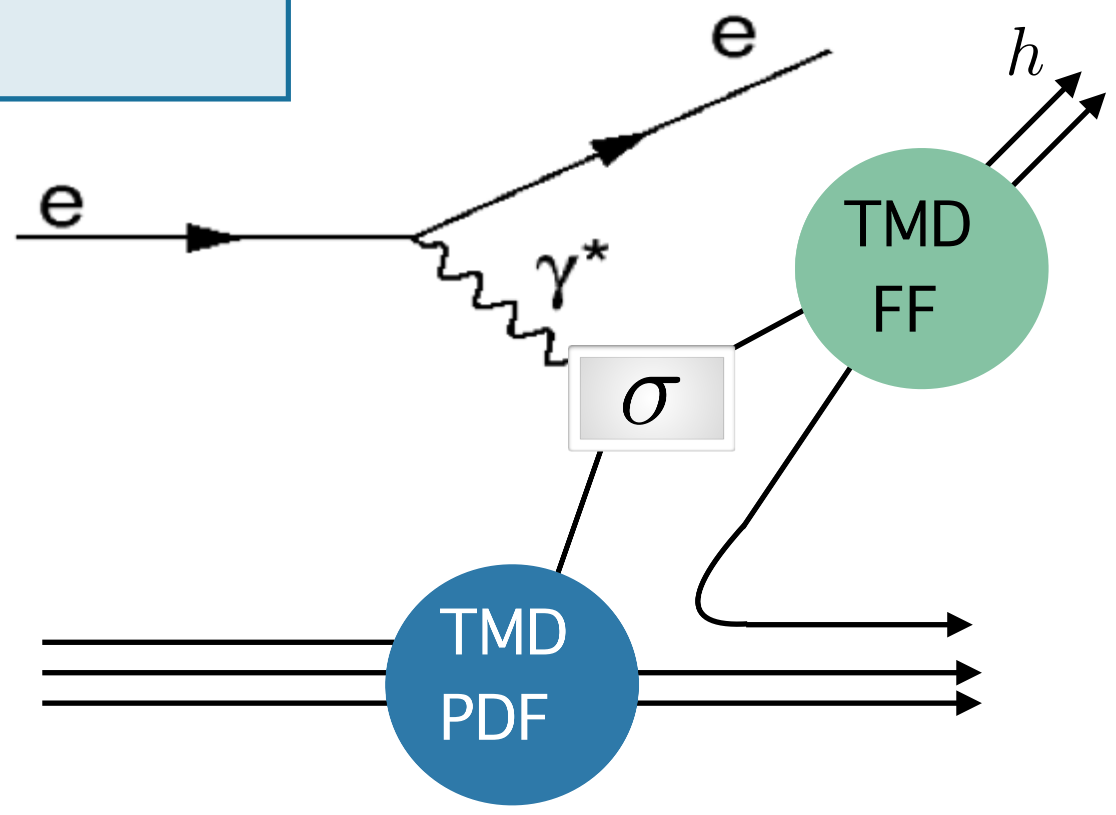

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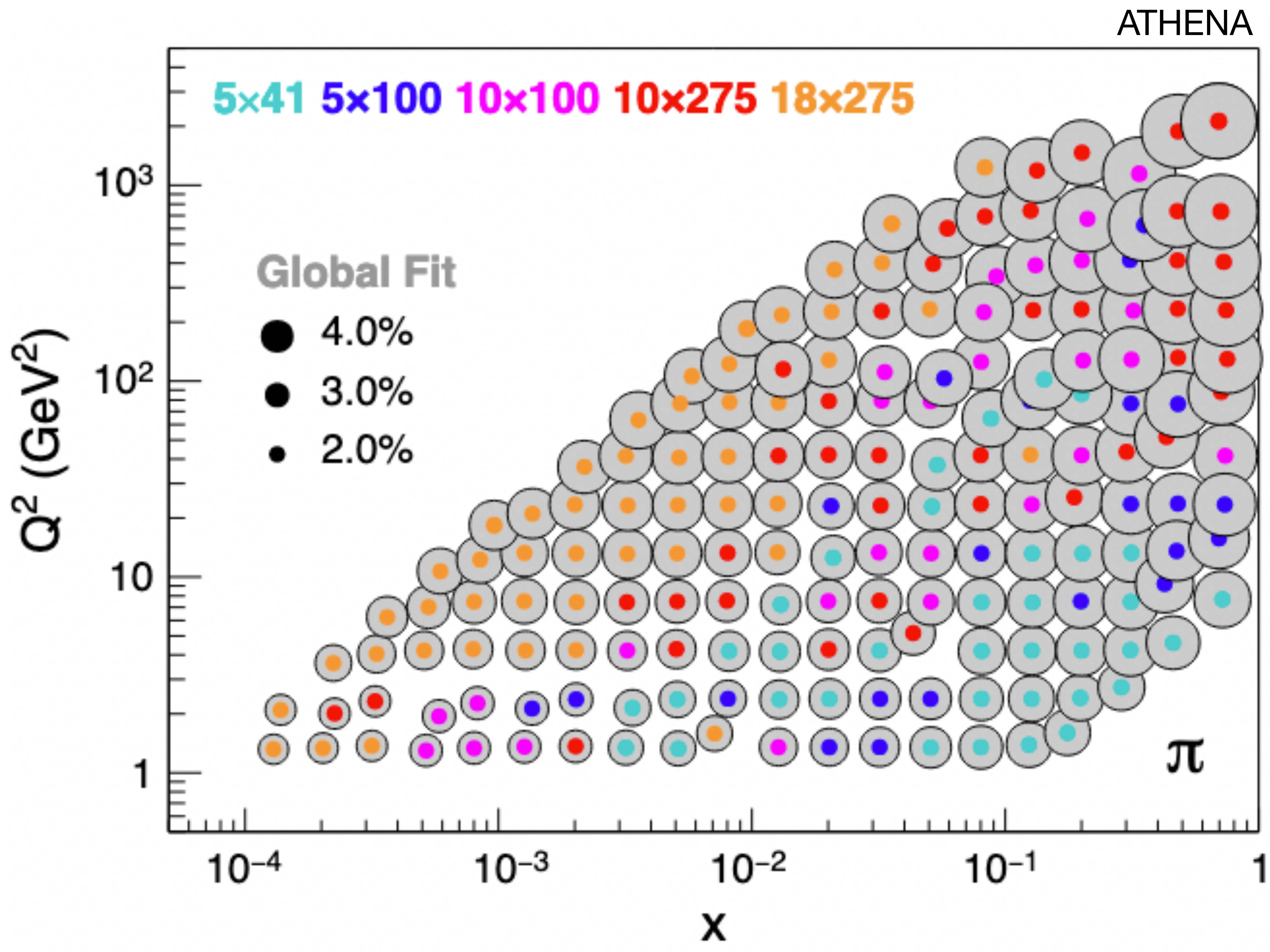
Spin-independent TMD PDF



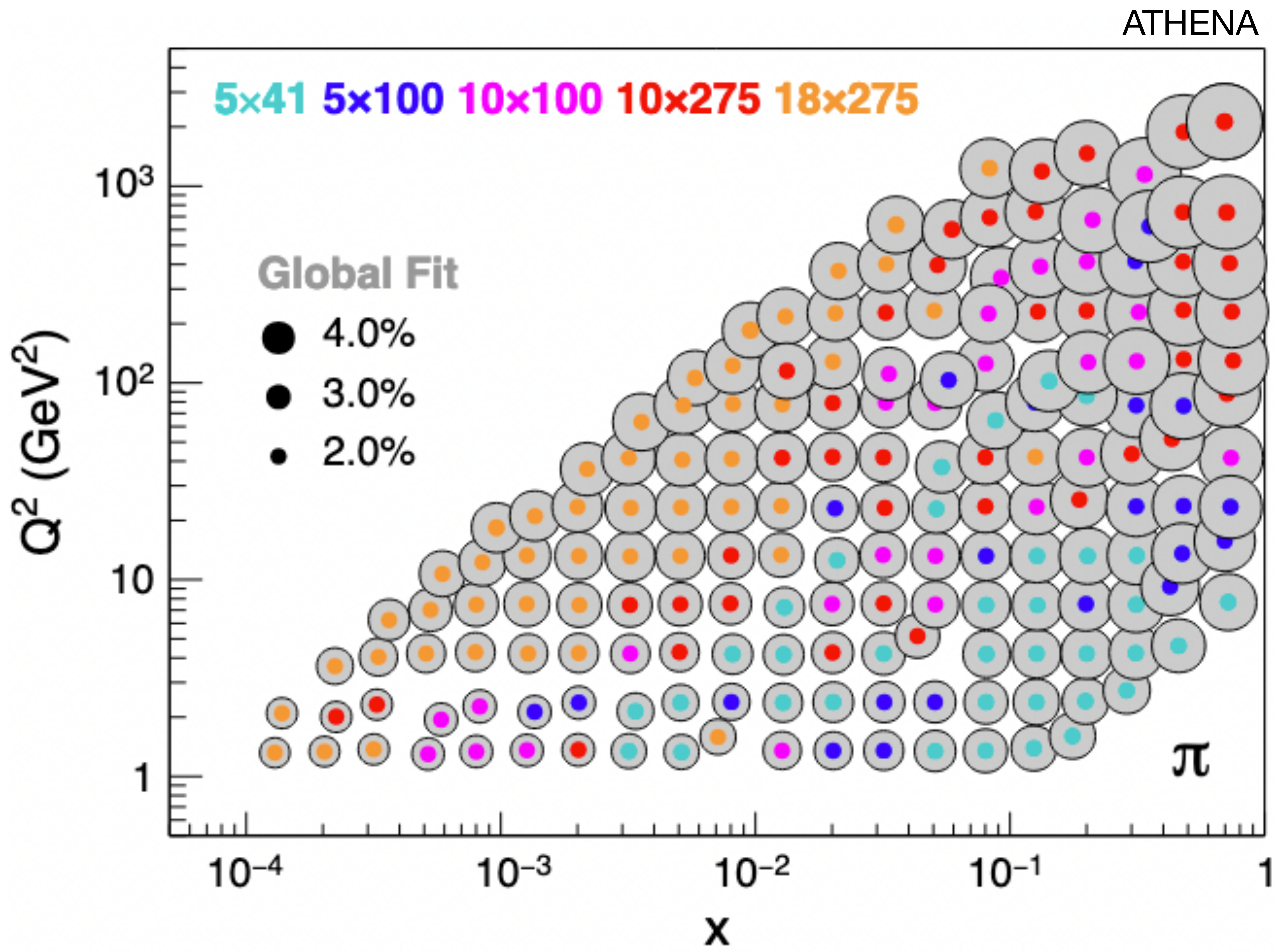
Fit:
A. Bacchetta et al.,
JHEP 06 (2017) 081,
JHEP 06 (2019) 051 (erratum)

EIC uncertainties dominated by assumed
3% point-to-point uncorrelated uncertainty
3% scale uncertainty

Theory uncertainties dominated by TMD evolution.

Spin-independent TMD PDF

Large lever-arm in Q^2 over large x range
→ Q^2 evolution of TMD PDF



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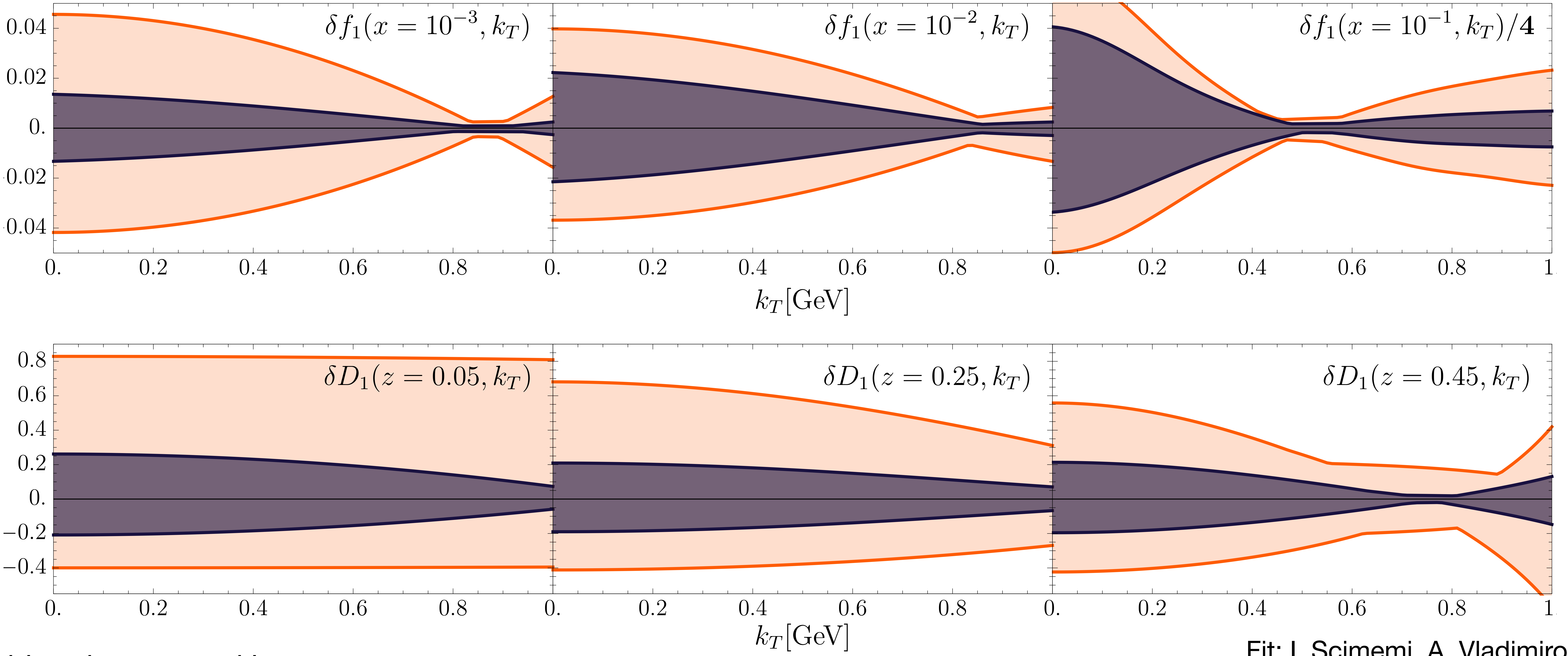
Spin-independent TMD PDF: impact of EIC

ECCE



Fit: I. Scimemi, A. Vladimirov
JHEP, 06:137, 2020

systematic uncertainty= |generated - reconstructed|

DIS variables via scattered lepton

$Q^2 > 1\ \mathrm{GeV}^2$

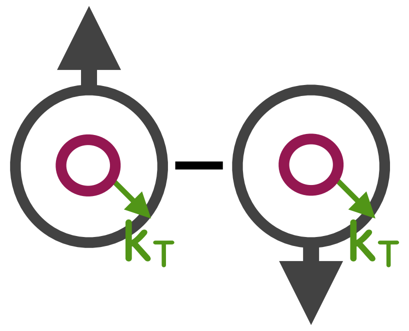
$0.01 < y < 0.95$

$W^2 > 10\ \mathrm{GeV}^2$

$5 \times 41\ \mathrm{GeV}^2$
$10 \times 100\ \mathrm{GeV}^2$
$18 \times 100\ \mathrm{GeV}^2$
$18 \times 275\ \mathrm{GeV}^2$

$\mathcal{L} = 10\ \mathrm{fb}^{-1}$ for each collision energy

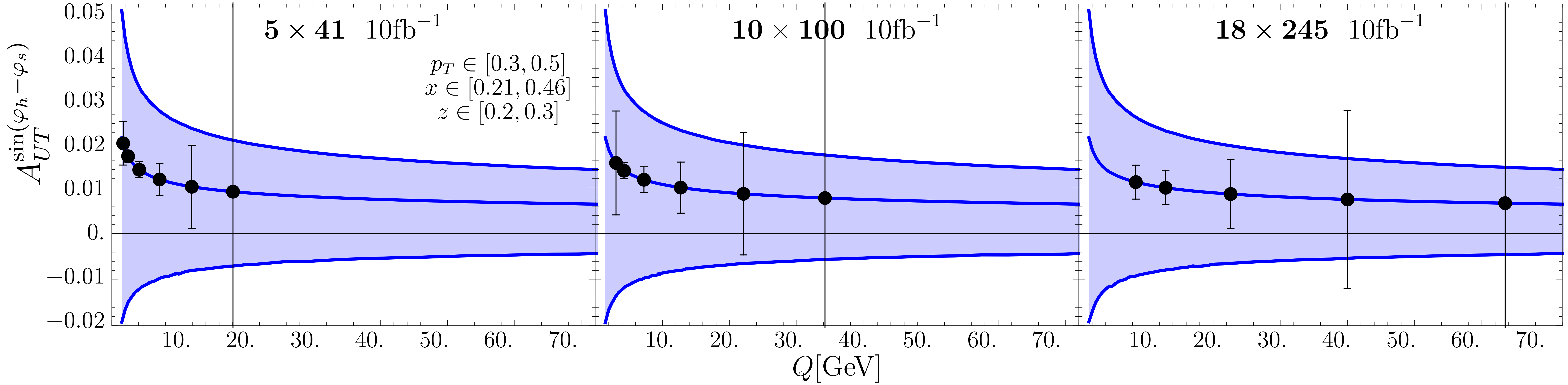
TMD evolution of the Sivers TMD PDF



Sivers asymmetry

$\mathcal{C}[f_{1T}^{\perp} \times D_1^{q\to h}]$

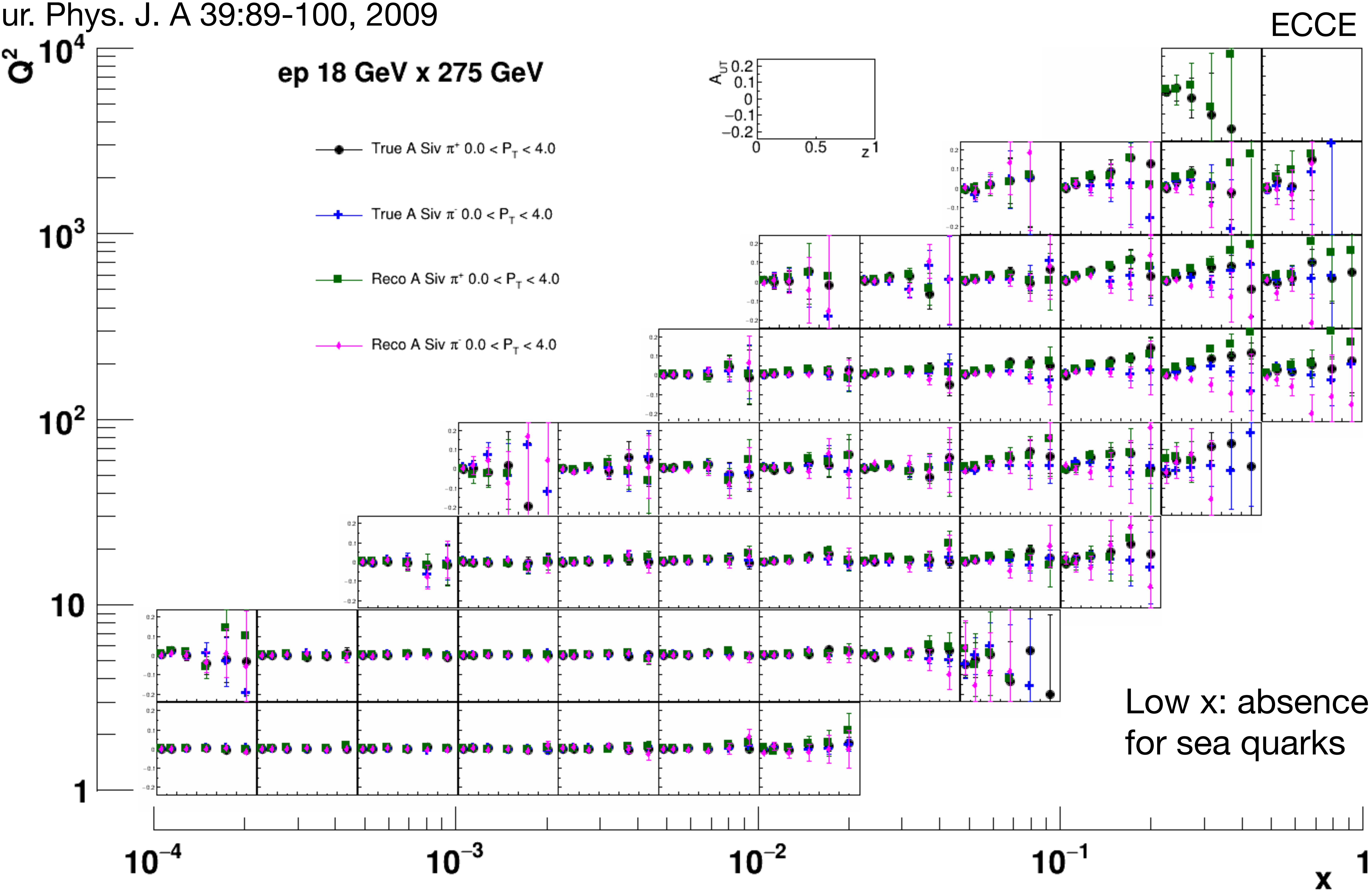
M. Bury et al., JHEP, 05:151, 2021.



Decrease of asymmetry with increasing Q^2 → need high precision (<1%) to measure asymmetry at high Q^2

Generated and reconstructed Sivers asymmetry

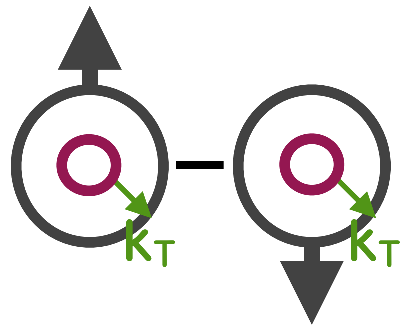
Reweighting of Pythia at LO using Sivers extraction from existing SIDIS and e^+e^- data
M. Anselmino et al., Eur. Phys. J. A 39:89-100, 2009



Low x: absence of parametrisitation for sea quarks

General good agreement between reconstructed and generated asymmetry: moderate smearing.

Uncertainties Sivers asymmetry



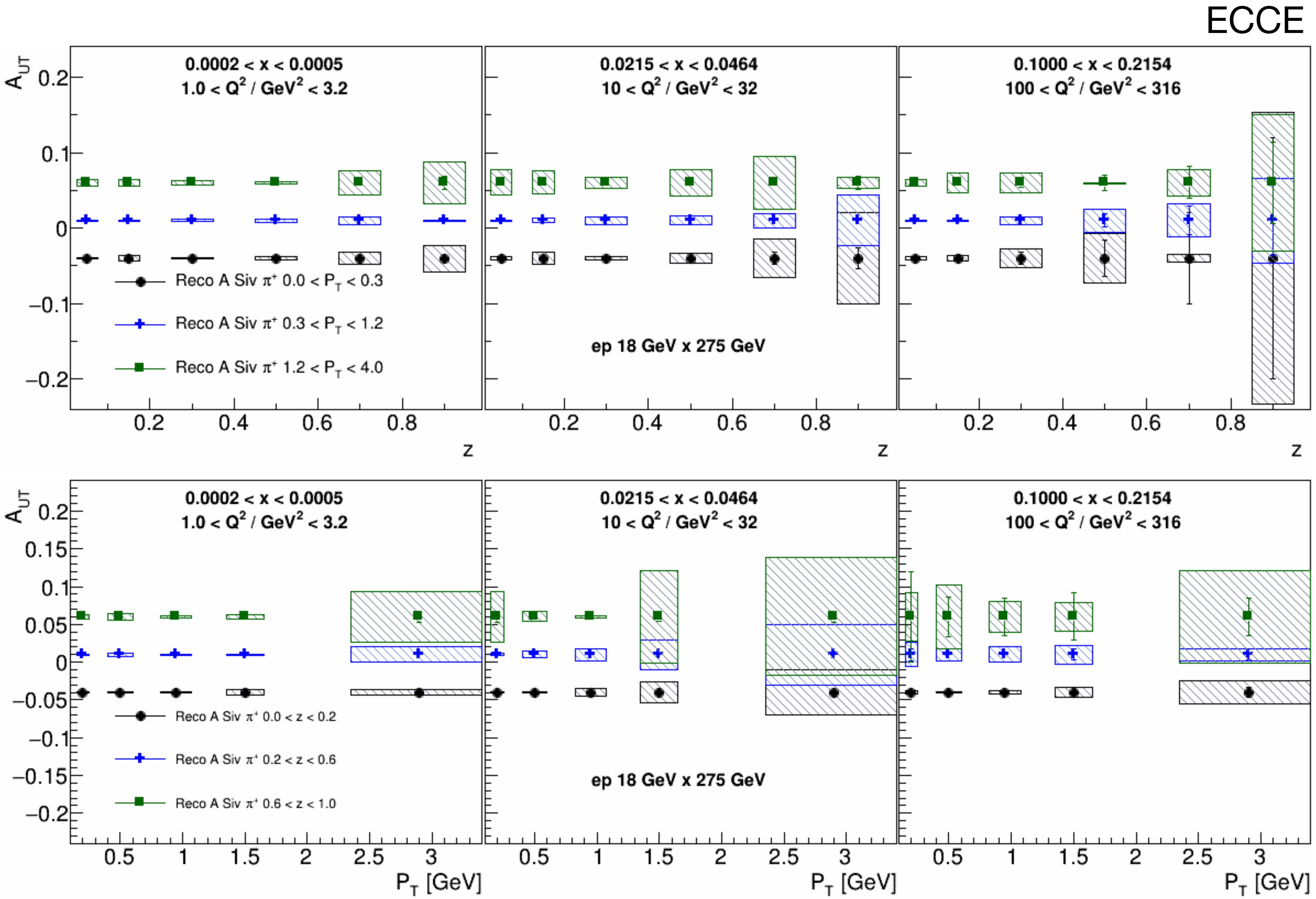
Sivers asymmetry

$$\mathcal{C}[f_{1T}^{\perp} \times D_1^{q \to h}]$$

Beam polarisations assumed to be 70%.

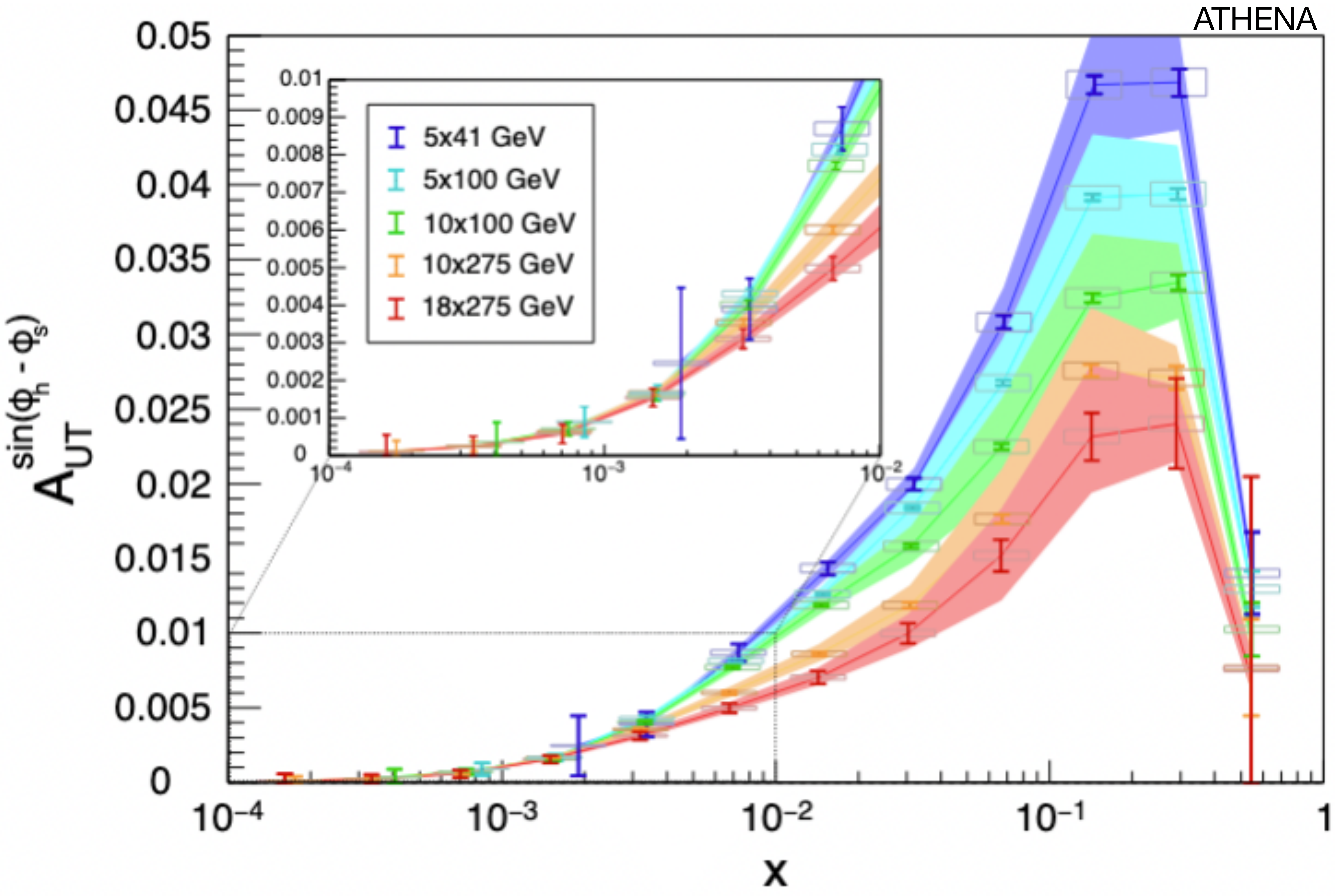
systematic uncertainty= |generated - reconstructed|

Additionally: 3% scale uncertainty



- Low x and Q^2: small statistical uncertainty. High precision is needed since asymmetry at low x and Q^2 well below 1%.
- For not too large z and P_T, statistical uncertainty well below 1%.
- Systematic uncertainties increase with z and P_T: likely because of higher smearing effects.

Uncertainties Sivers asymmetry

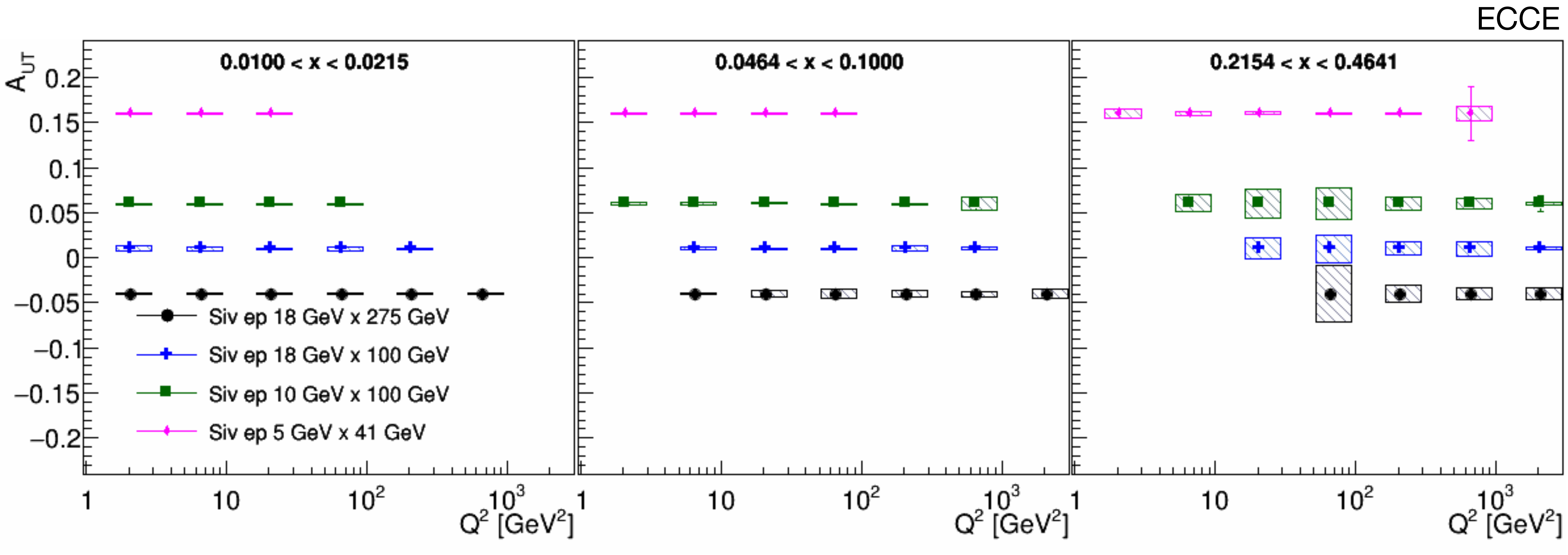


Fit:
A. Bacchetta et al.,
JHEP 06 (2017) 081,
JHEP 06 (2019) 051 (erratum)

Increase of uncertainties with COM E

2% point-to-point uncorrelated uncertainty
1.5% scale uncertainty

Q^2 dependence of the Sivers asymmetry



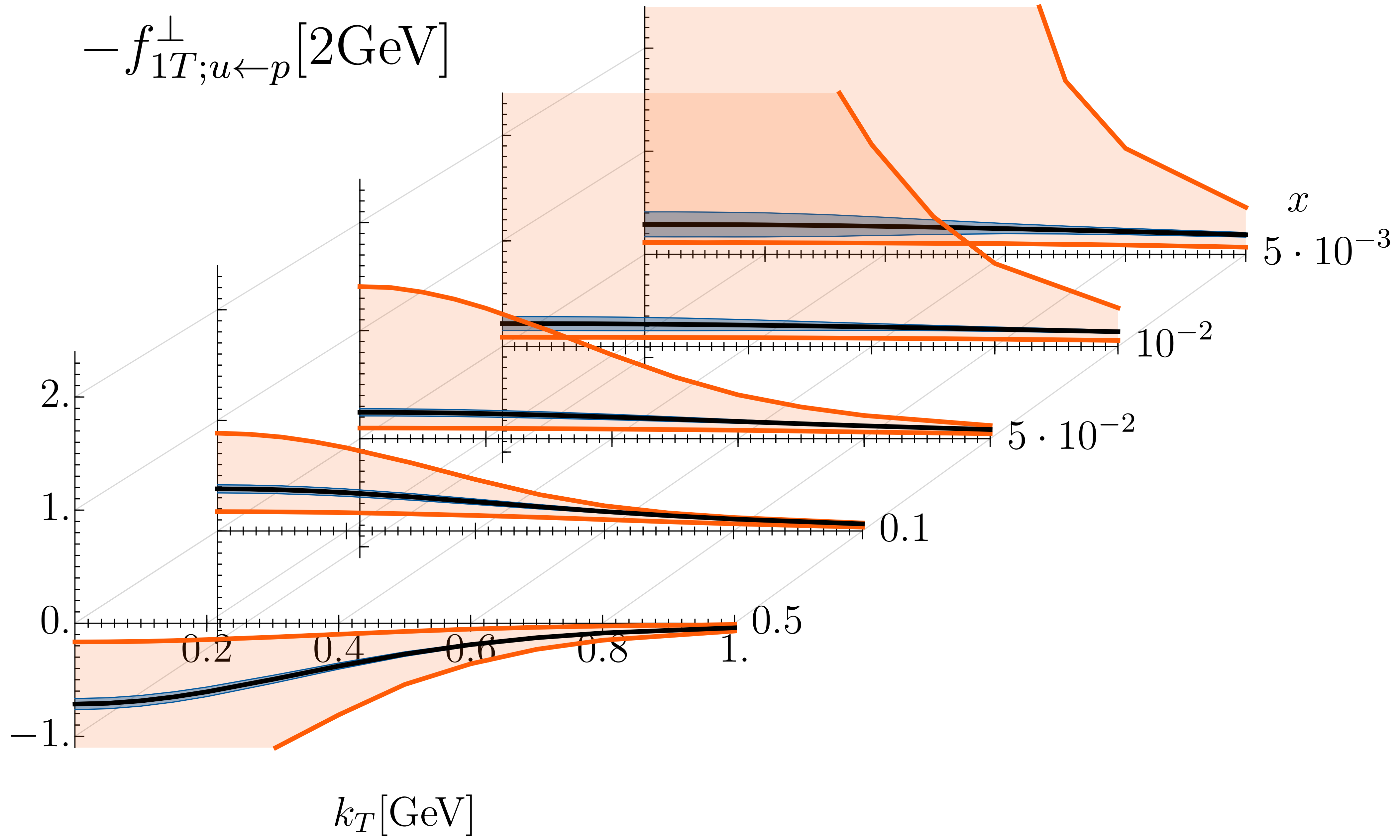
Intermediate and high x: good coverage in Q^2,
with complementarity in coverage at different COM energies.

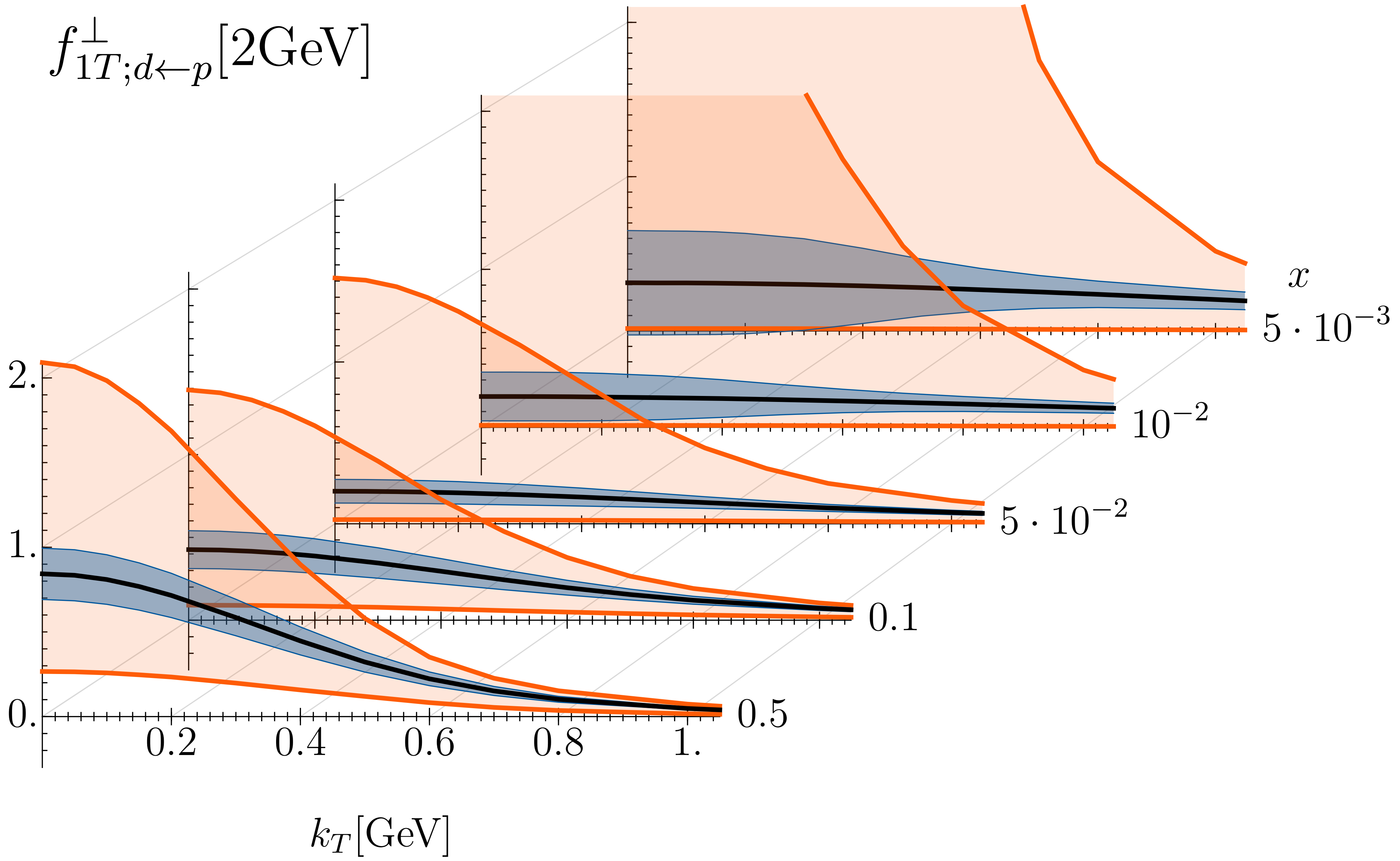
Sivers TMD PDF: impact of EIC

Parametrisation from
M. Bury et al., JHEP, 05:151, 2021

Q=2 GeV

ECCE





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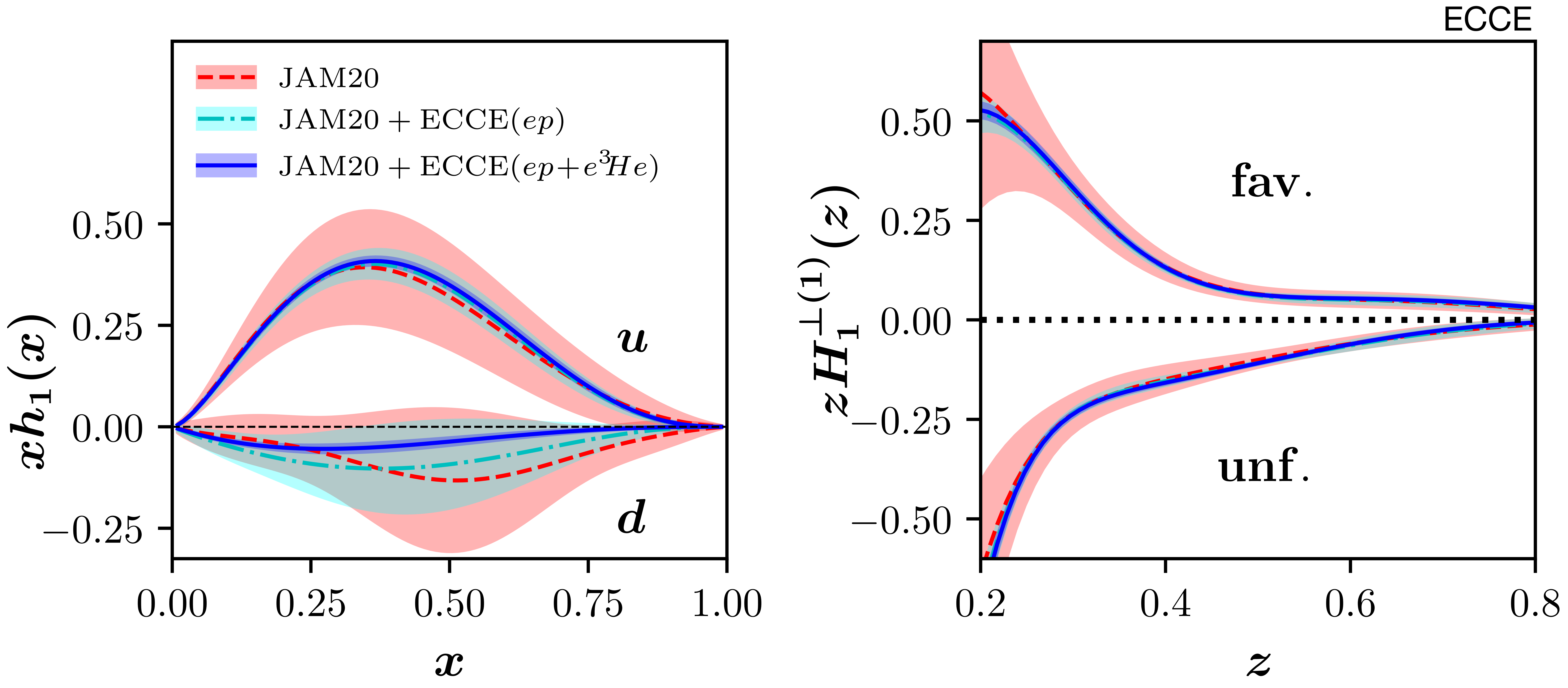
Transversity: impact of EIC

Parametrisation from J. Cammarota, Phys. Rev. D 102(5):054002, 2020.



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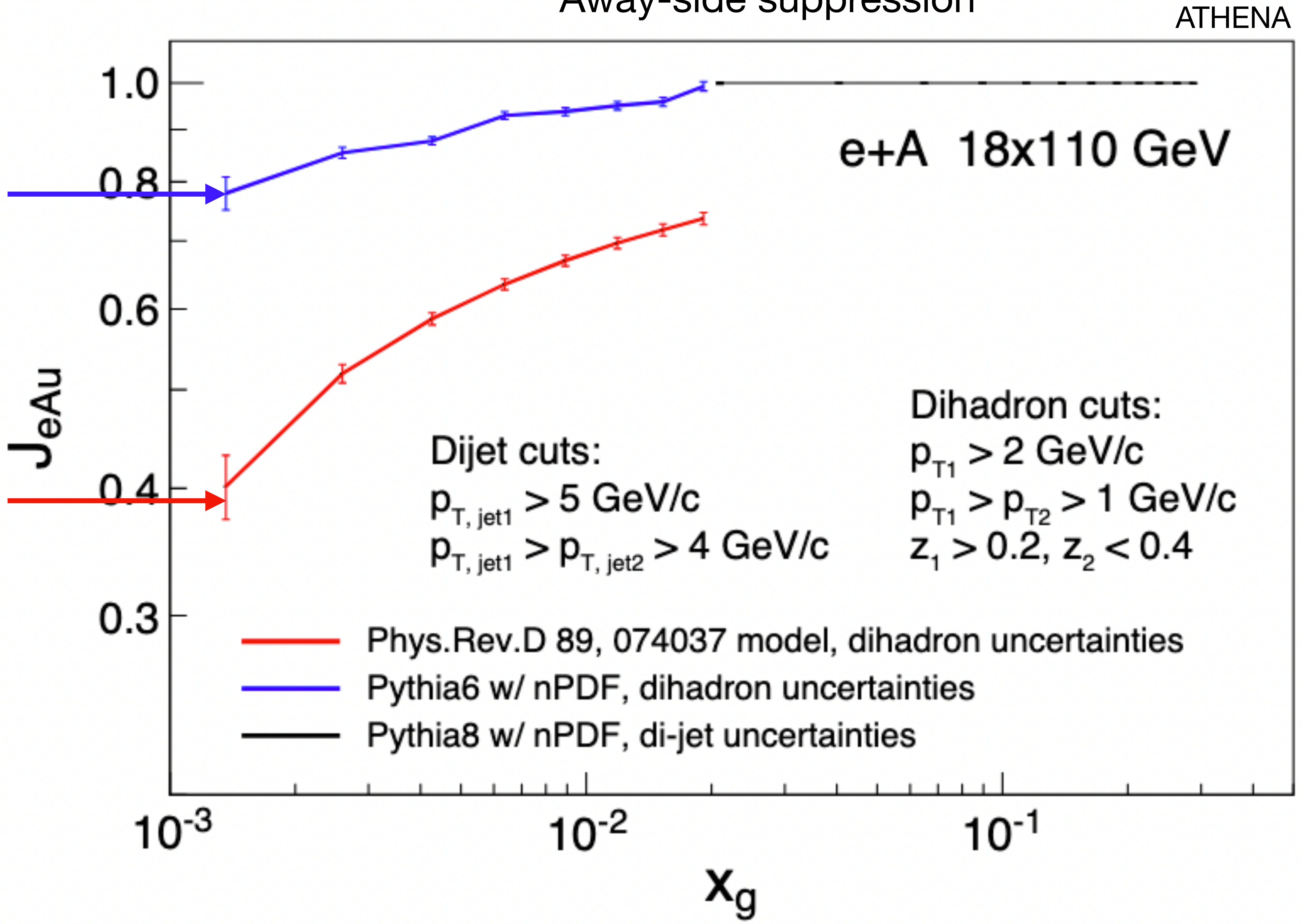
Back-to-back dihadron production in eA

- Access to the Weizsäcker-Williams gluon distribution
- Sensitive to saturation effects
- Complementarity region covered by dihadron and jet production

Away-side suppression



No saturation

Saturation

Summary and outlook

Semi-inclusive measurements at EIC provide access to a range of information:

- Helicity distributions of sea and valence quarks
- 3D (spin-dependent) momentum structure of the nucleon, and study of TMD evolution
- Probe gluon saturation

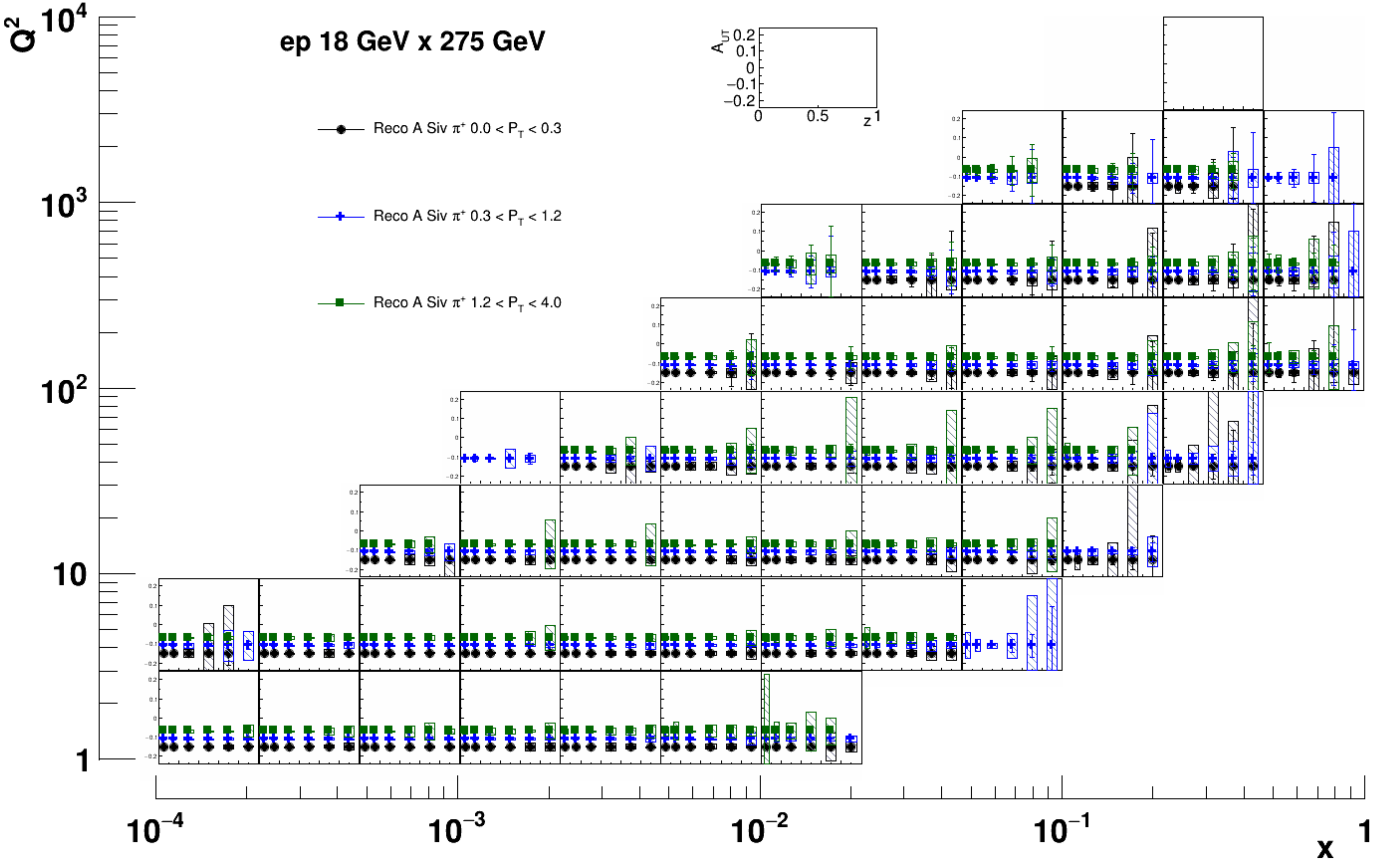
Full GEANT simulations have been performed by ATHENA and ECCE, which demonstrate the EIC capabilities to perform measurements with a large kinematic coverage and with high precision.
This is needed in order to allow for a precise determination of the various distributions.

Next steps:

- reference design optimisation and consolidation phase, with joints efforts from ATHENA and ECCE.
- towards the formation of a new detector 1 collaboration.

Back up

Sivers: statistical and systematic uncertainties



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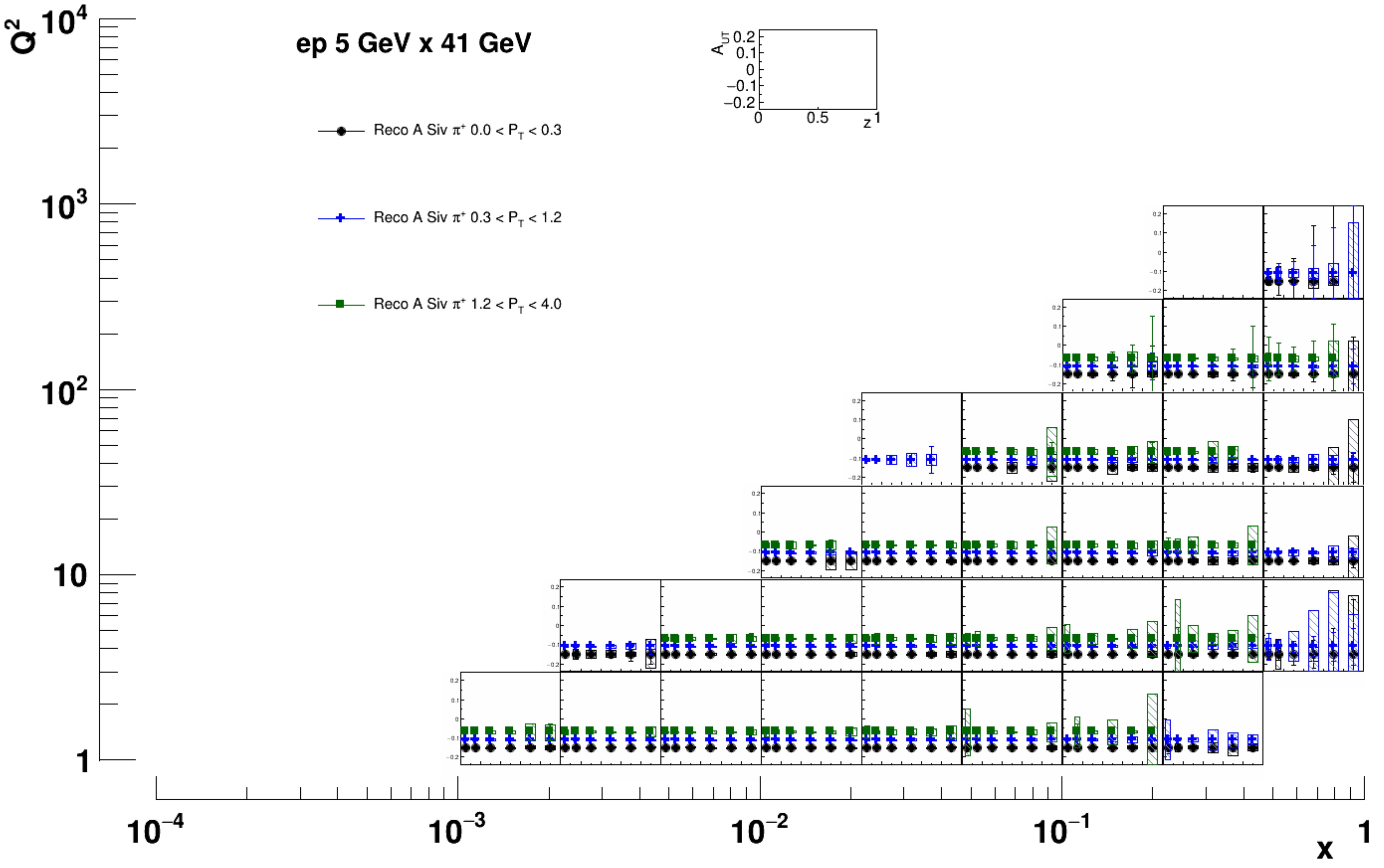

Sivers: Q^2 coverage