A_N in $l\,p \to h\,X$
TMD approach and quasireal photon contribution

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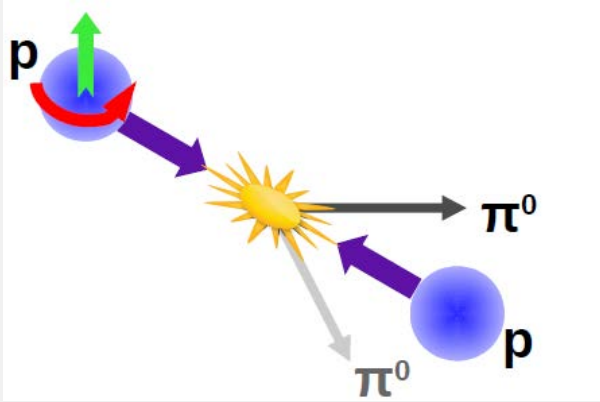
UD, C. Flore and F. Murgia PRD95 (2017)

- TMD approach and SSAs in inclusive processes: lp vs. pp
- Quasireal photon contribution
- Comparison with data on SSAs
- Predictions at (and role of) EIC
- Conclusions

❑ Transverse SSAs in inclusive processes:

large amount of data in pp collisions: sizeable from low to high energies (RHIC)

❑ Single scale processes, sub-leading SSAs



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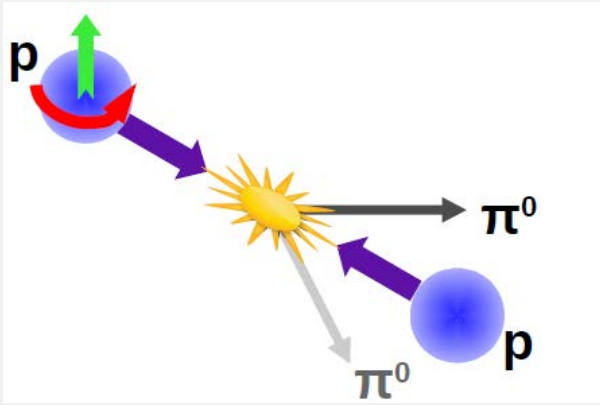

❑ Approaches:
Twist-three formalism (collinear factorization proven)
TMD scheme (phenomenological approach)

❑ In both cases phenomenology quite involved: many channels, many effects

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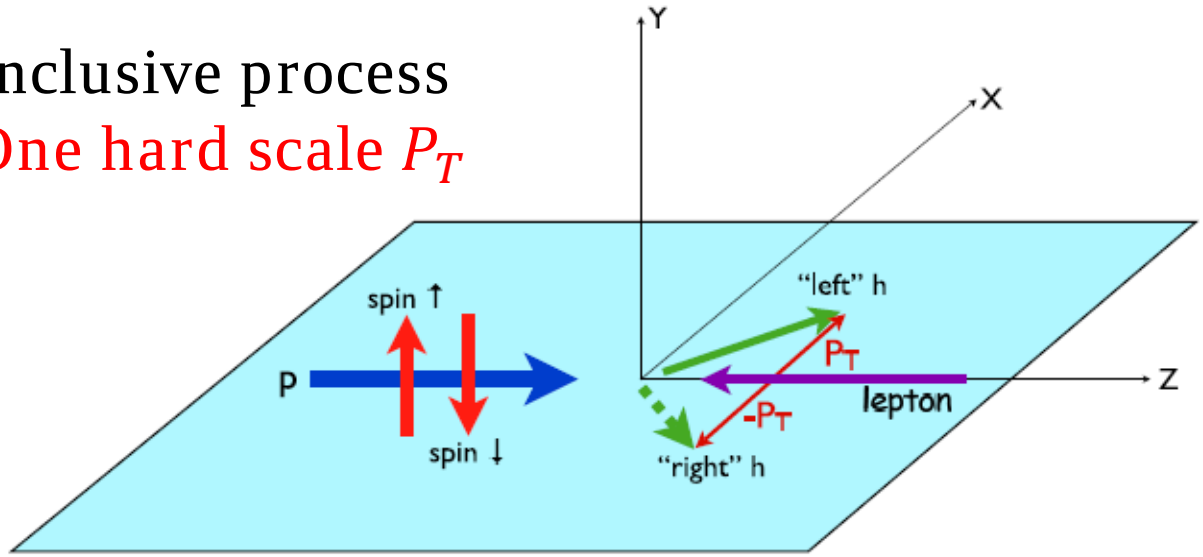
❑ SSAs in inclusive particle production in lepton-proton collisions
Simpler (theor.): less channels, less color structure
- Close to SIDIS…a sort of bridge to pp collisions
A testing ground for
- approaches (twist-3 vs. TMD)
- a TMD unified picture (use of same TMDs as extracted from SIDIS)

A_N in $l\,p \to h\,X$

Inclusive process

One hard scale P_T



$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}}$$

$$A(\phi_S, S_T) = \boldsymbol{S}_T \cdot (\hat{\boldsymbol{p}} \times \hat{\boldsymbol{P}}_T) = S_T \sin\phi_S \, A_N$$

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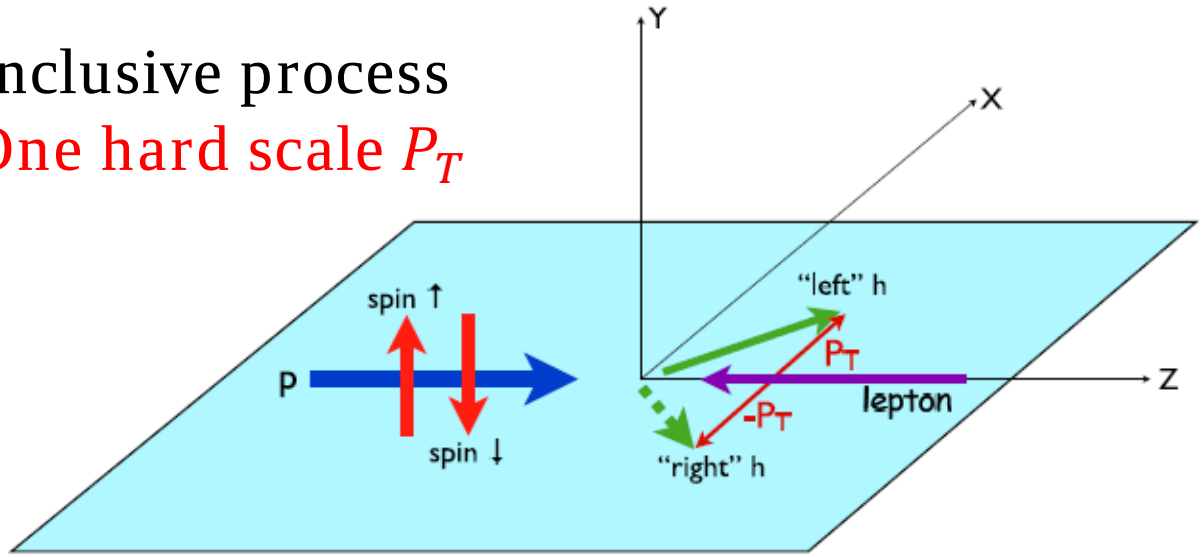

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Anselmino, Boglione, UD, Melis, Murgia, Prokudin
(2010: first study; 2014: comparison with data)

Fairly good description of HERMES data but

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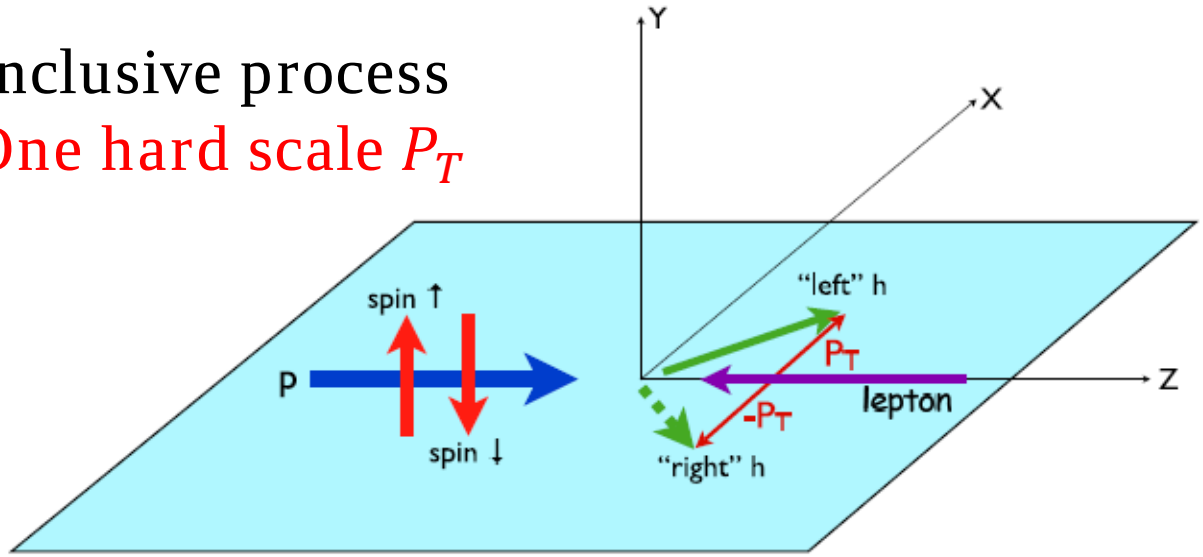

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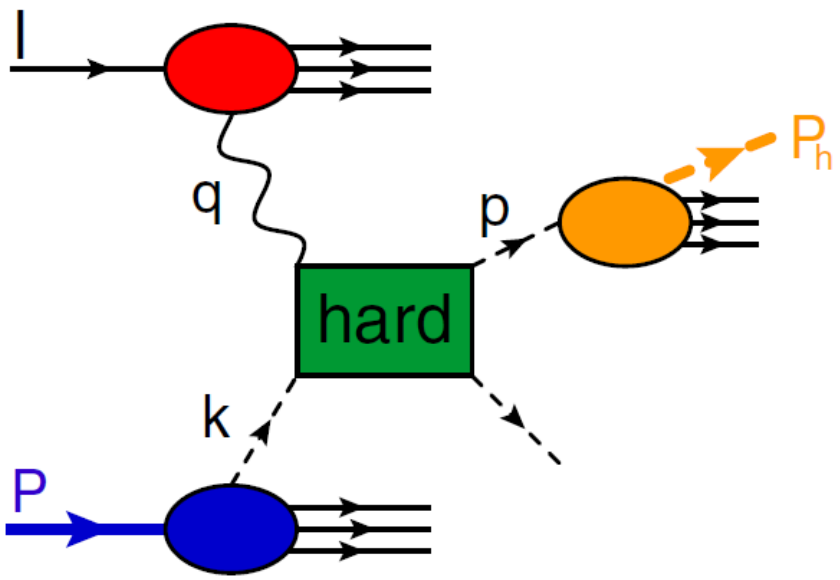
Inclusive events: final lepton scattered almost collinear $Q^2 \approx 0$

Quasireal photon exchange



- Lepton as a source of quasi-real γ

  $l \to l' \gamma$: final lepton almost collinear

$$\sigma^{\mathrm{WW}}(\ell p \to hX) = \int dy f_{\gamma/\ell}(y)\, \sigma(\gamma p \to hX)$$

$$f_{\gamma/\ell}(y) = \frac{\alpha}{2\pi} \frac{1+(1-y)^2}{y} \left[\ln\left(\frac{\mu^2}{y^2 m_\ell^2} \right) - 1 \right]$$

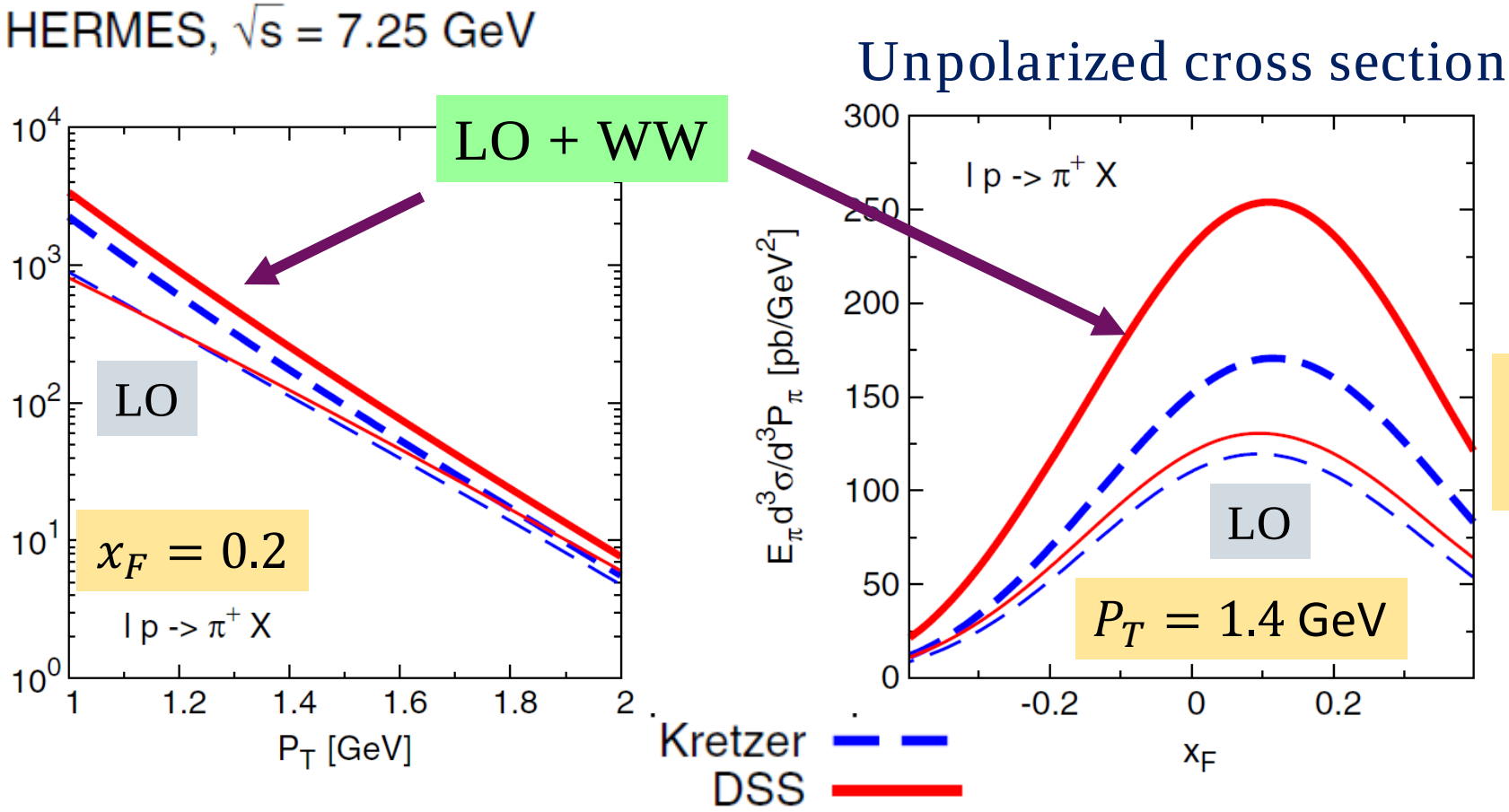
unpol xsecs. at NLO and WW in a collinear framework Hinderer, Schlegel, Vogelsang (2015)

Weizsäcker-Williams approximation

Reanalysis of SSAs (and unpol. xsecs): UD, Flore, Murgia 2017

TMD scheme + Weizsäcker-Williams approx.

two fragmentation function sets (Kretzer, DSS)



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WW $\gamma q \to gq$ $\gamma g \to q\bar{q}$

NOTICE $x_F > 0$
backward proton hemisph.

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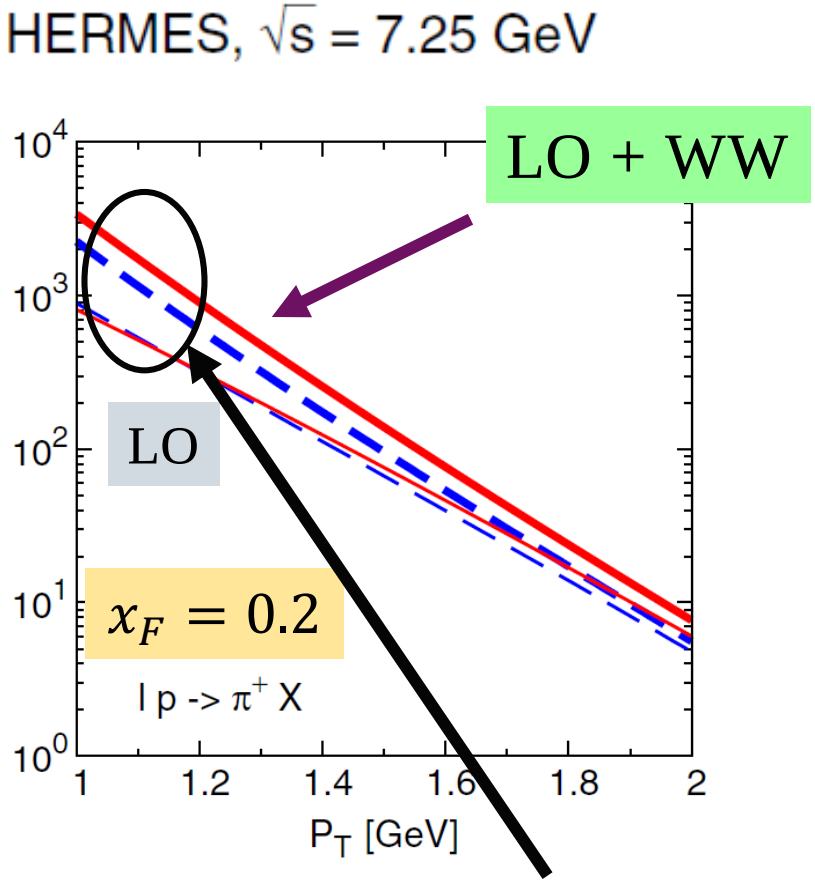
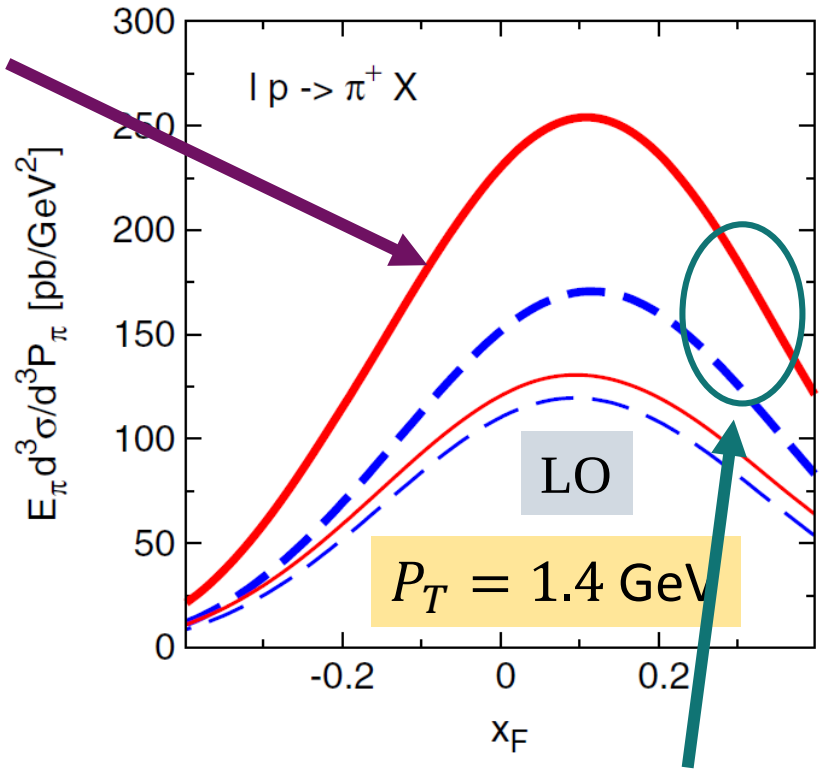


Unpolarized cross sections



LO $lq \to lq$

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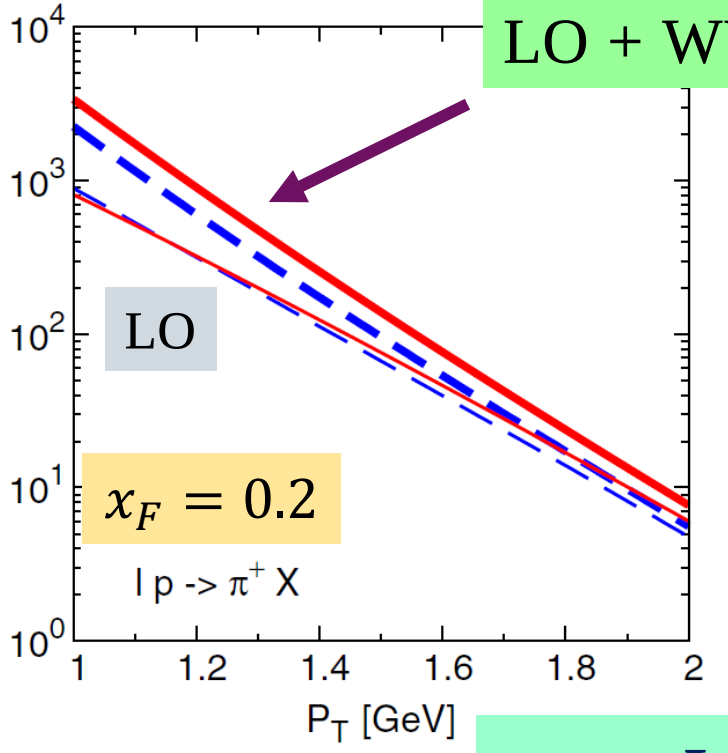
DSS: larger gluon FF

WW dominates at **smaller P_T** (smaller y) and in the **backward** region ($x_F > 0$):
Naively $Q \sim 0$ (real photon) expected for forward scattering but
LO only $1/t^2 \equiv 1/Q^2$ while WW also $1/su$, with $|u| \ll |t|$ in the backward region

TMD scheme + Weizsäcker-Williams approx.

two fragmentation function sets (Kretzer, DSS)

HERMES, $\sqrt{s}$ = 7.25 GeV



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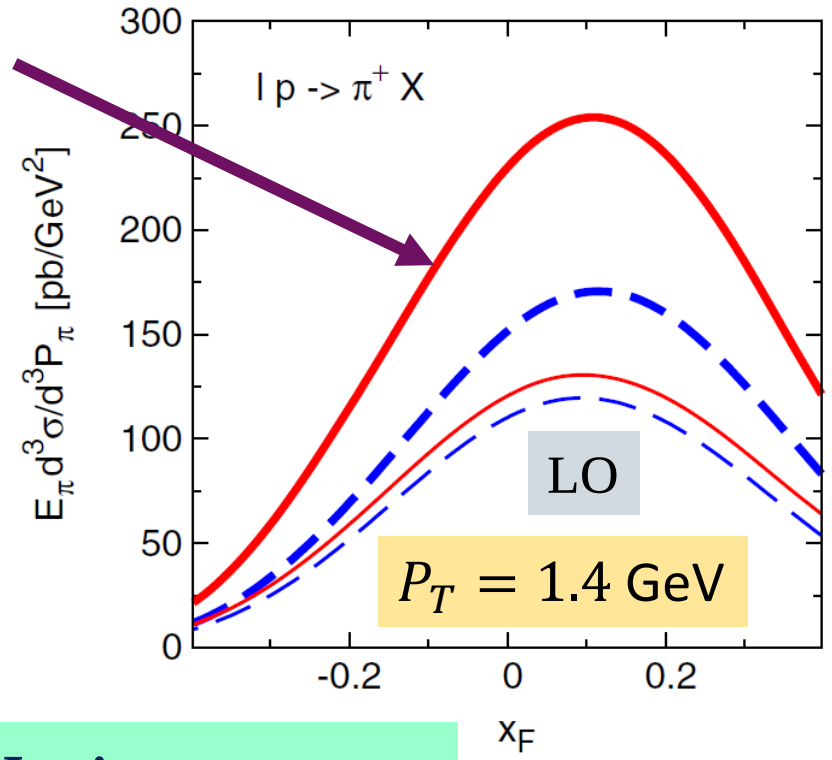

LO $lq \to lq$

WW $\gamma q \to gq$ $\gamma g \to q\bar{q}$

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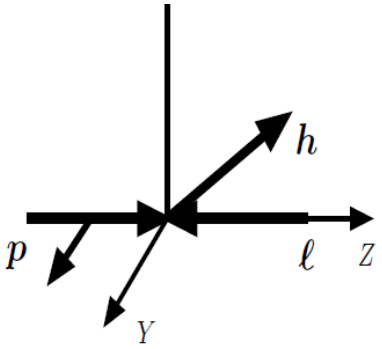
backward proton hemisph.

WW piece:
up to 70% of the total

SSAs in a TMD approach

$$A_N = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{d\sigma^{\uparrow} + d\sigma^{\downarrow}} = \frac{d\sigma^{\uparrow} - d\sigma^{\downarrow}}{2d\sigma^{\mathrm{unp}}}$$



LO

$ql \to ql$

$$\Delta^N f_{q/p^{\uparrow}} \cos\phi_q \otimes d\hat{\sigma} \otimes D_{h/q}$$

Sivers quark

$$h_1^{q/p} \otimes d\Delta\hat{\sigma} \otimes \Delta^N D_{h/q^{\uparrow}} \cos\phi_C$$

Collins

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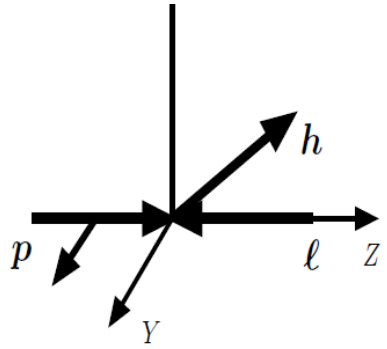

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Collins

NOT separable

WW

$$\Delta^N f_{q/p^\uparrow} \cos\phi_q \otimes [d\hat{\sigma}^{q\gamma\to q} \otimes D_{h/q} + d\hat{\sigma}^{q\gamma\to g} \otimes D_{h/g}]$$

$$\Delta^N f_{g/p^\uparrow} \cos\phi_g \otimes [d\hat{\sigma}^{g\gamma\to q} \otimes D_{h/q} + d\hat{\sigma}^{g\gamma\to \bar{q}} \otimes D_{h/\bar{q}}]$$

$$h_1^{q/p} \otimes d\Delta\hat{\sigma}^{q\gamma\to q} \otimes \Delta^N D_{h/q^\uparrow} \cos\phi_C$$

Sivers quark

Sivers gluon

Collins

$$A_N = \frac{d\Delta\sigma^{\mathrm{LO}} + d\Delta\sigma^{\mathrm{WW}}}{2[d\sigma^{\mathrm{LO}} + d\sigma^{\mathrm{WW}}]},$$

- HERMES SSA data (backward region)
  - higher statistics at $P_T \ll 1$ GeV: out of pQCD regime
  - anti-tagged events, $P_T \geq 1$ GeV: mixture of low and large Q^2 components
  - tagged events: $Q^2 > 1$ GeV^2

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First study: LO (Anselmino, Boglione, UD, Melis, Murgia, Prokudin 2014):

❑ inclusive and tagged event categories (large Q^2 component)

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This study (UD, Flore, Murgia 2017):

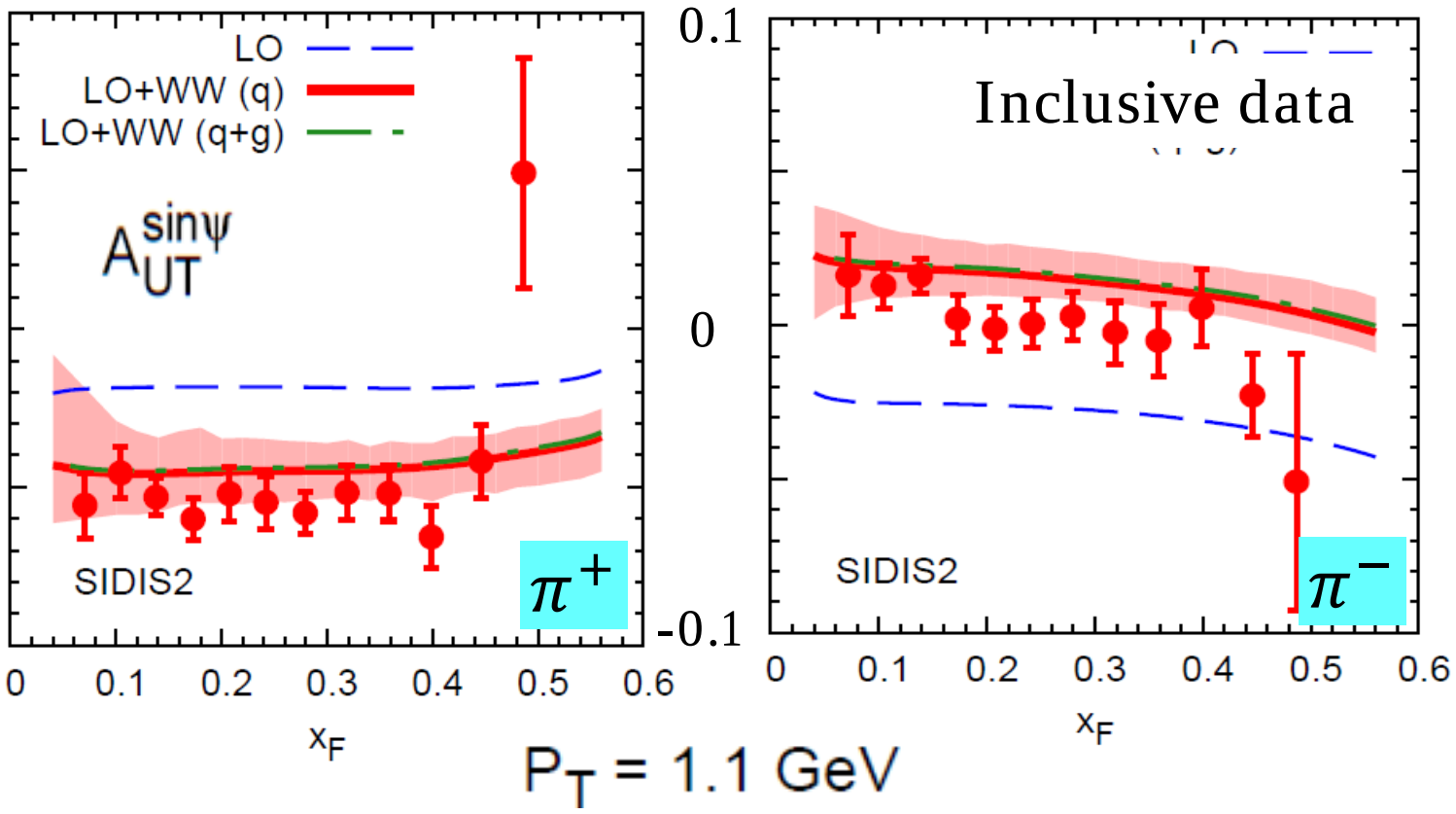
❑ improvement in description of inclusive events (low Q^2component)

❑ anti-tagged events (new)

Only quark Sivers and (marginally) Collins effects sizeable

Predictions from SIDIS extractions

HERMES data (2014), $P_T > 1$ GeV



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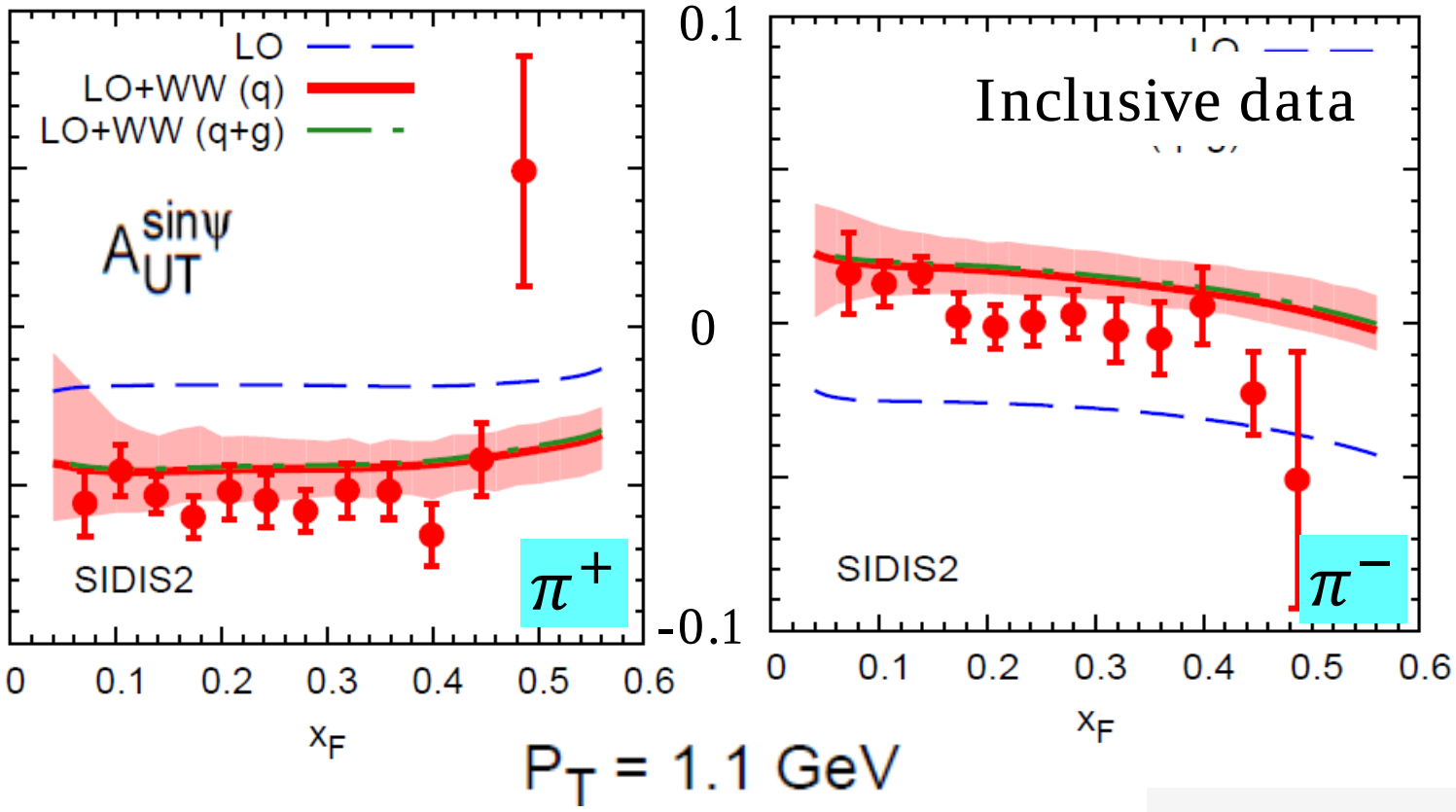

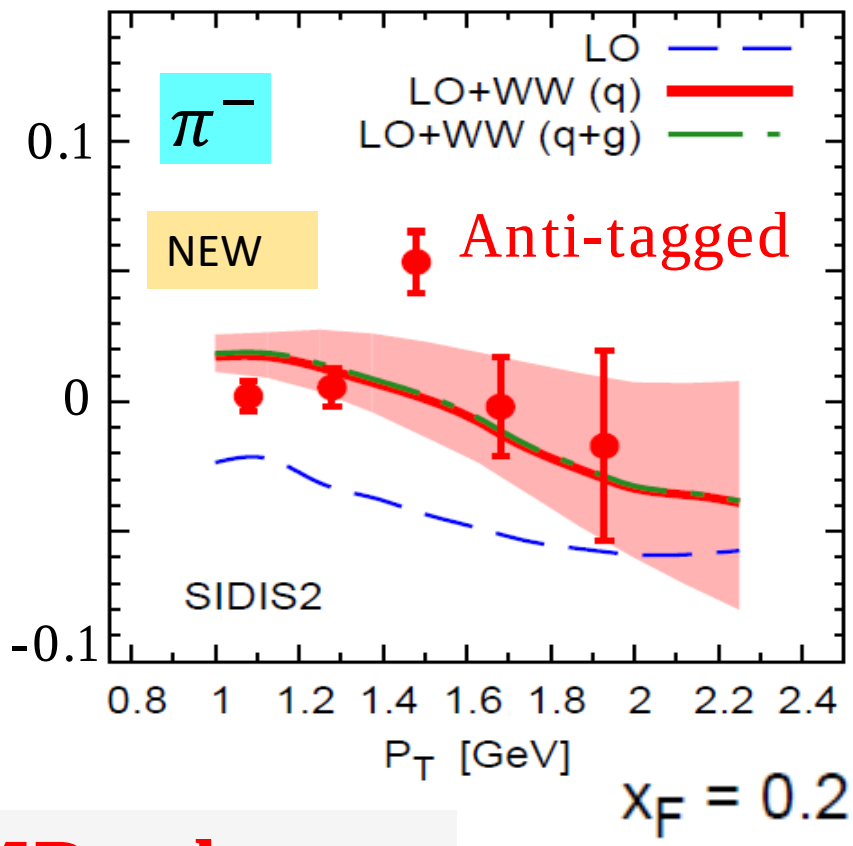

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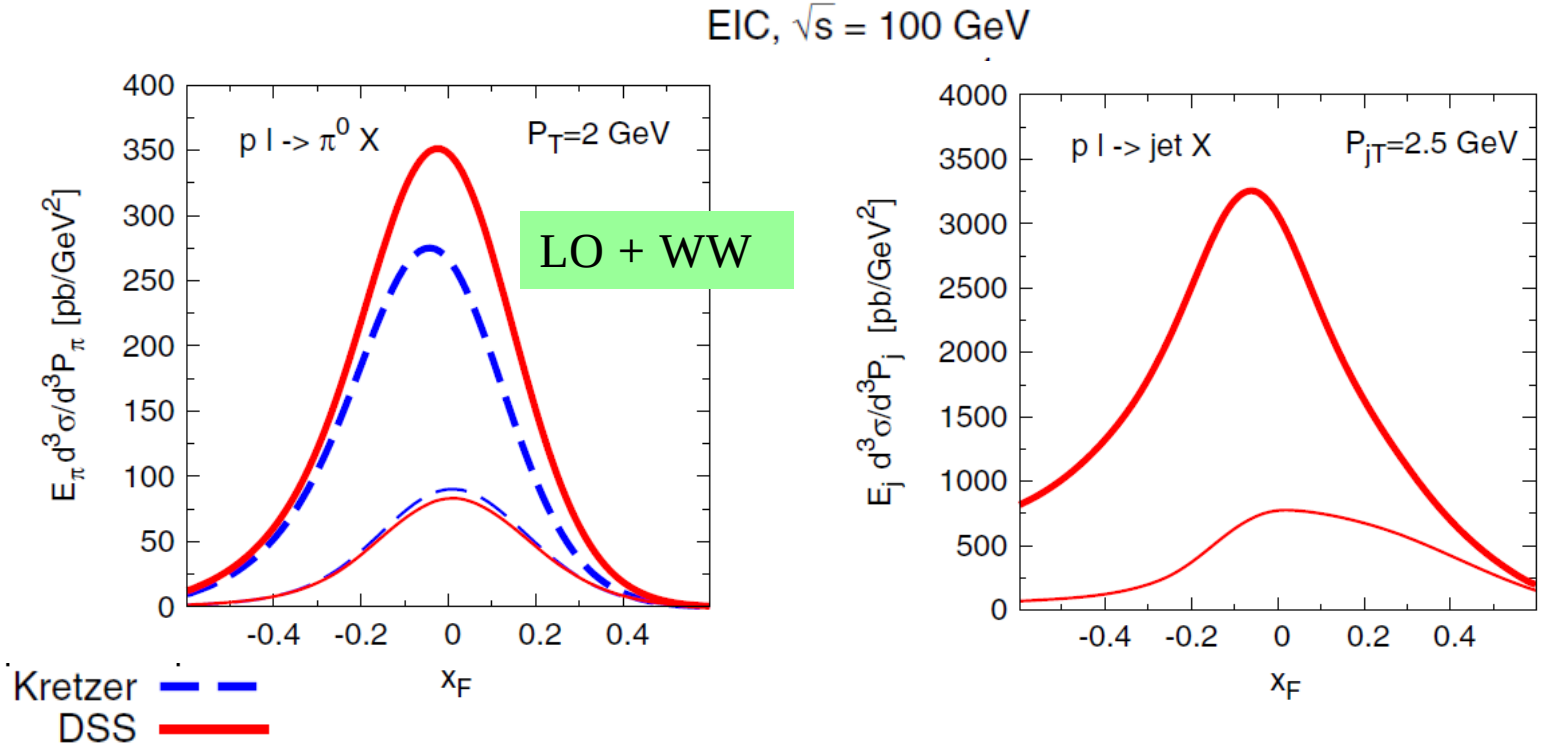
Unified TMD scheme

EIC studies: inclusive hadron or jet production

Unpolarized cross sections



Here $x_F > 0$:
forward proton hemisphere
(like pp collisions)

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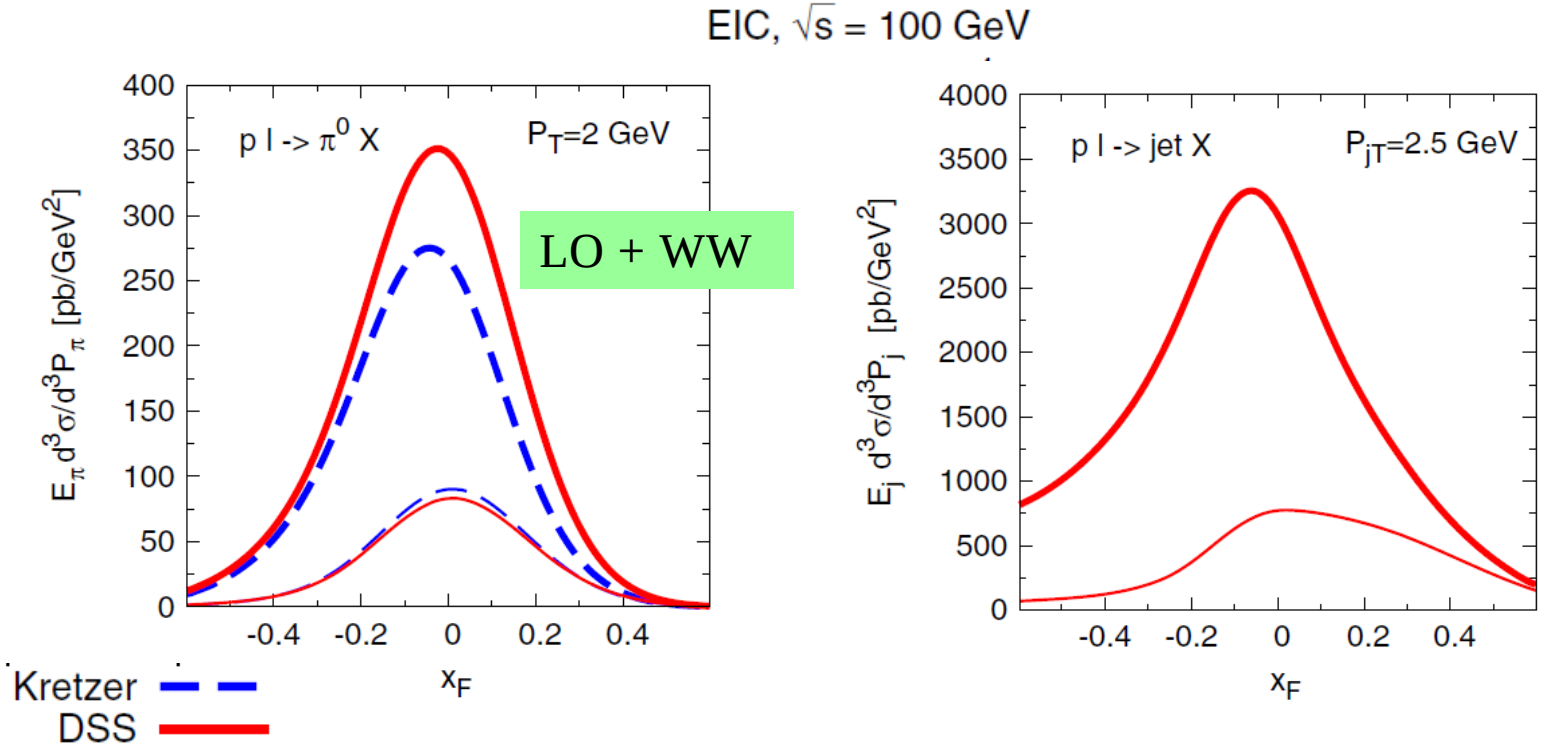

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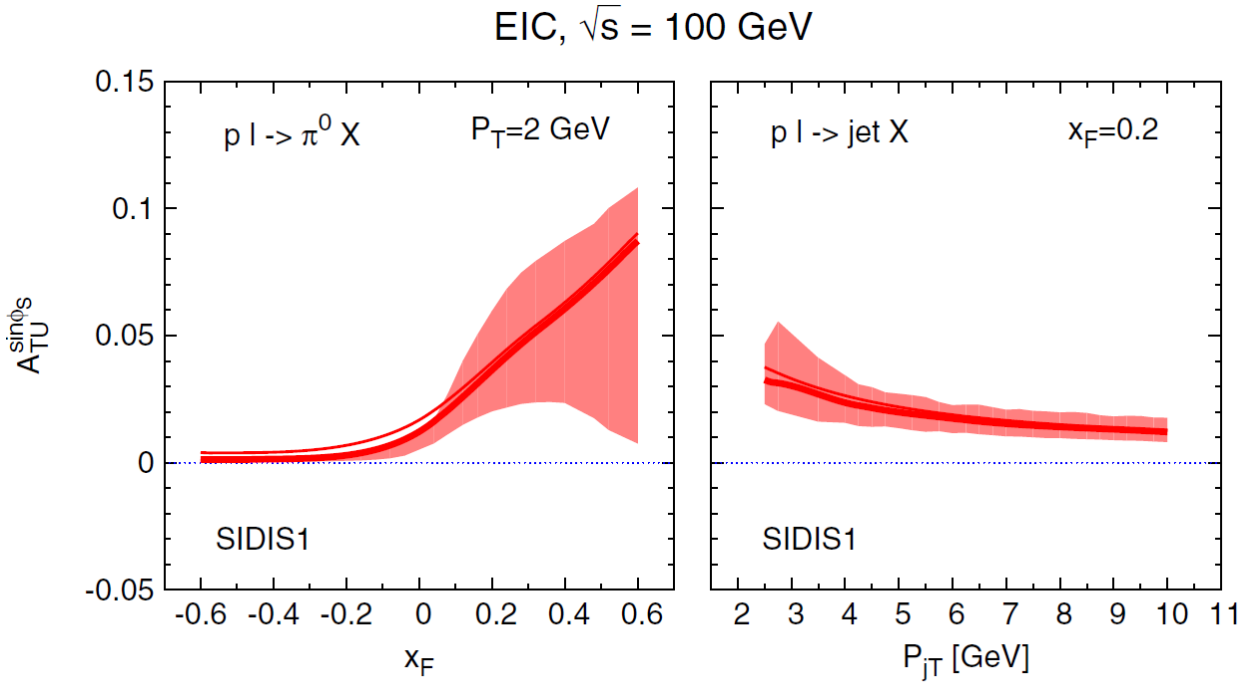
- WW here much bigger (4-5 times) than LO:
- $x_F > 0$ very small y at such P_T and large energies;
- $x_F < 0$ $|u| \ll |t|$

EIC studies: inclusive hadron or jet production

Transverse single spin asymmetries



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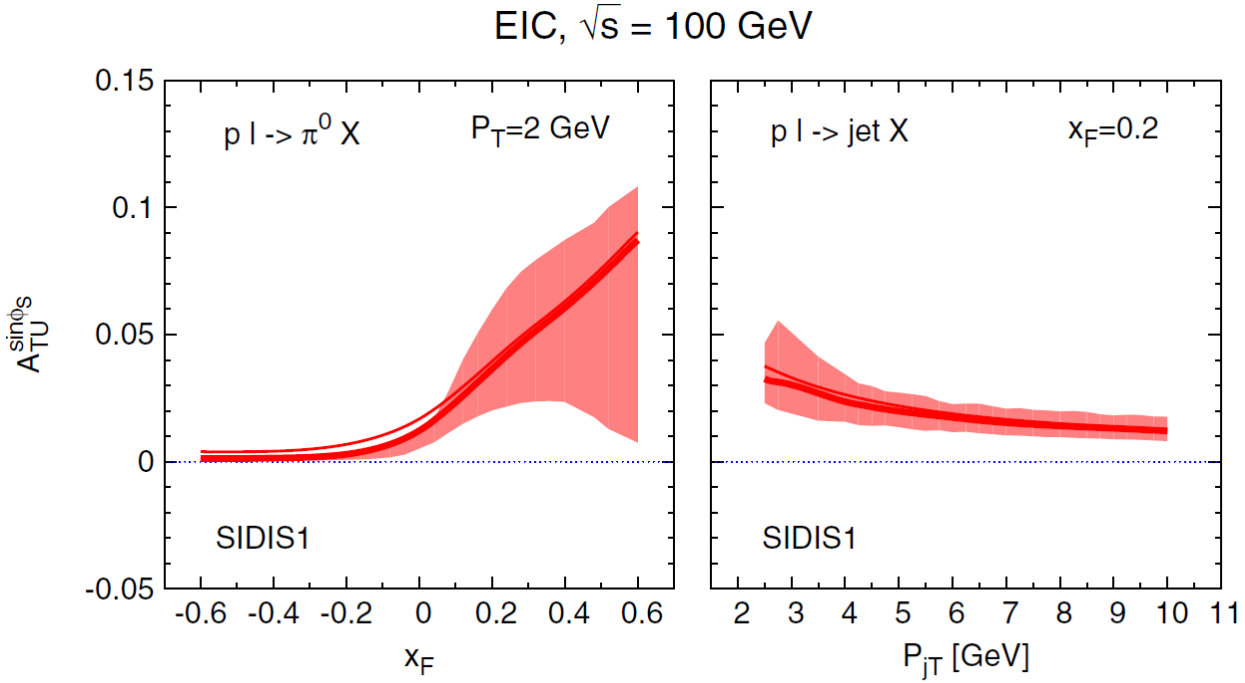

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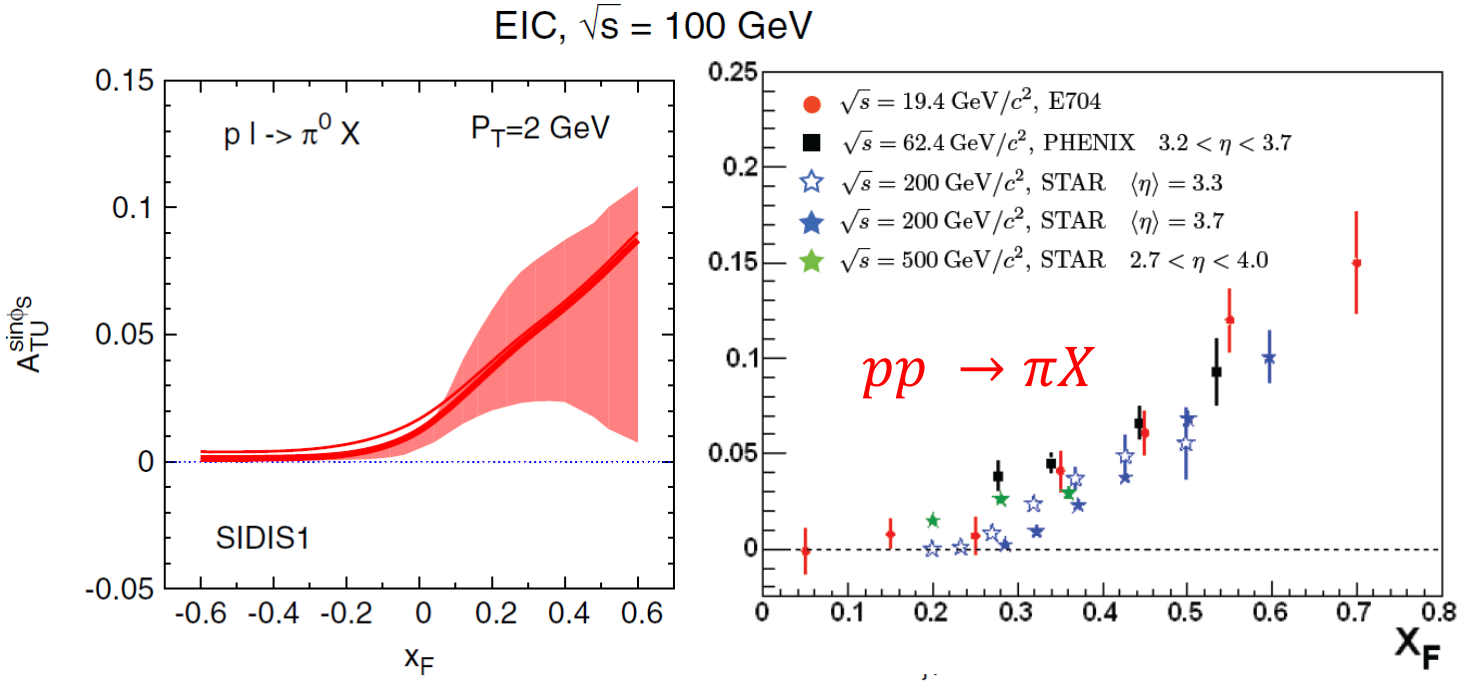

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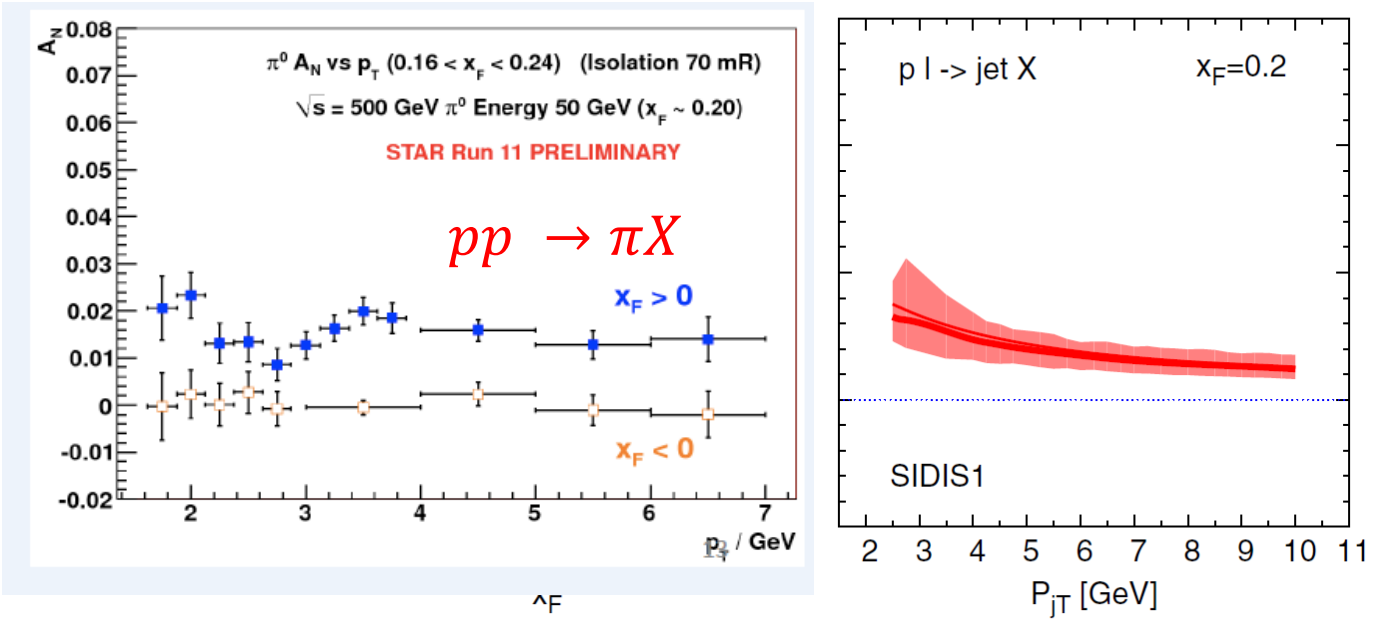
EIC studies: inclusive hadron or jet production

Transverse single spin asymmetries

EIC, $\sqrt{s}$ = 100 GeV



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EIC studies: inclusive hadron or jet production

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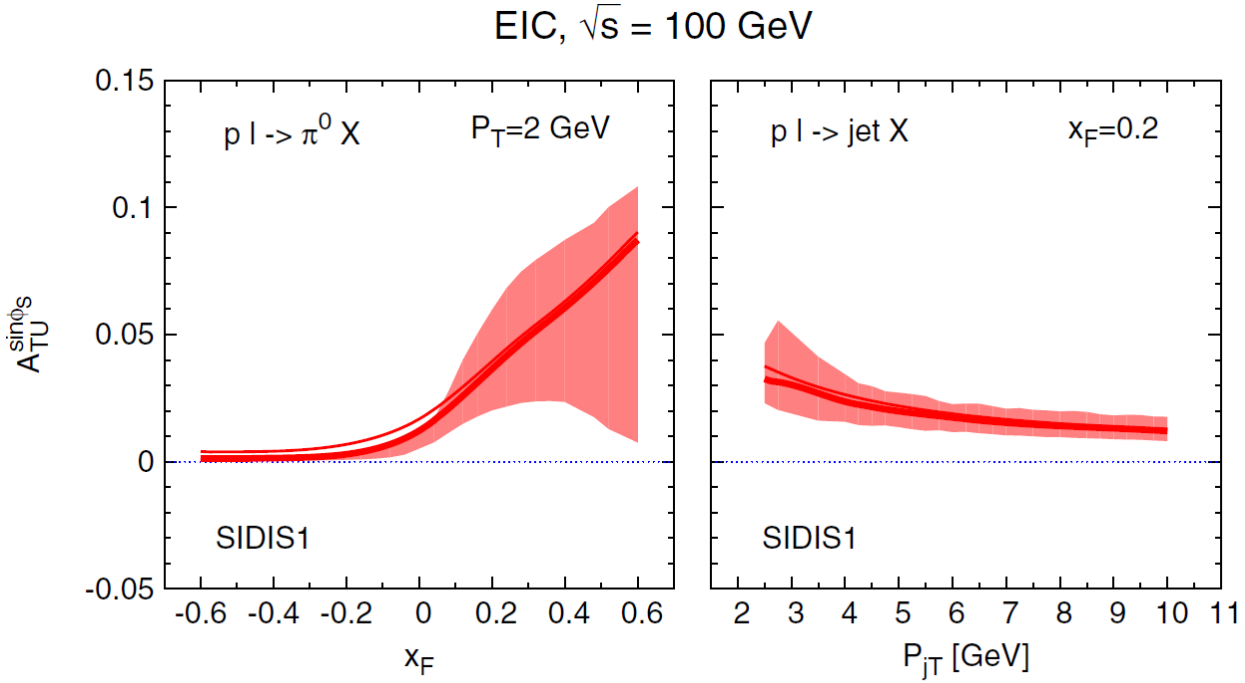

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CHECK OF A
UNIFIED PICTURE

Conclusions

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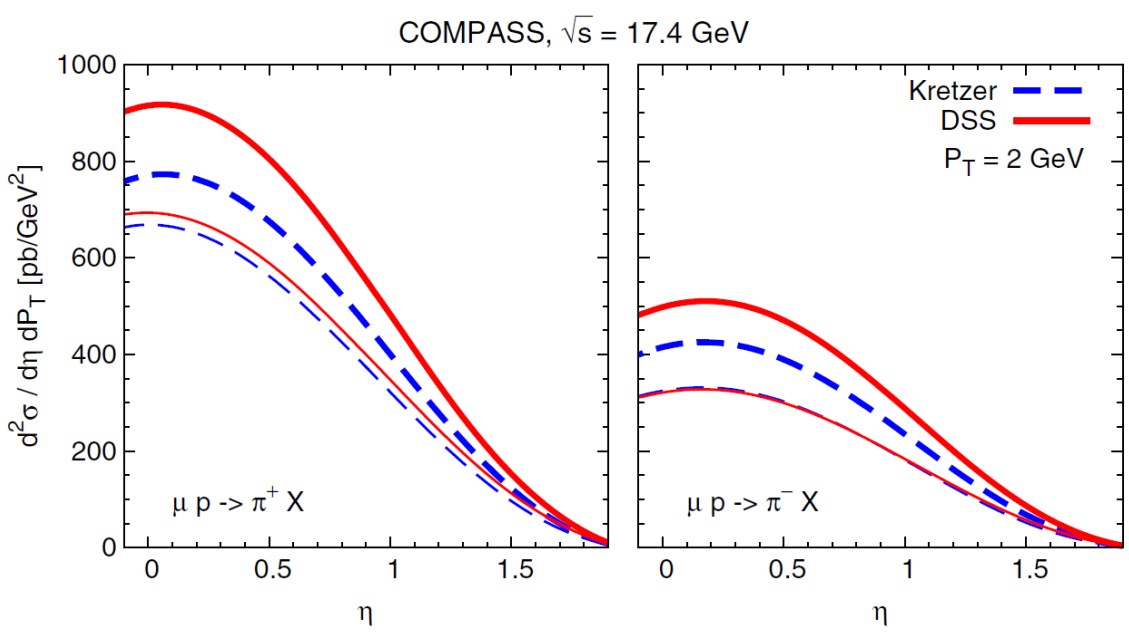
  - improvement in description of available SSA data
- Studies of SSAs at EIC: expected similar behaviour in x_F and P_T as in $pp \to hX$

towards a unified TMD picture of SSAs

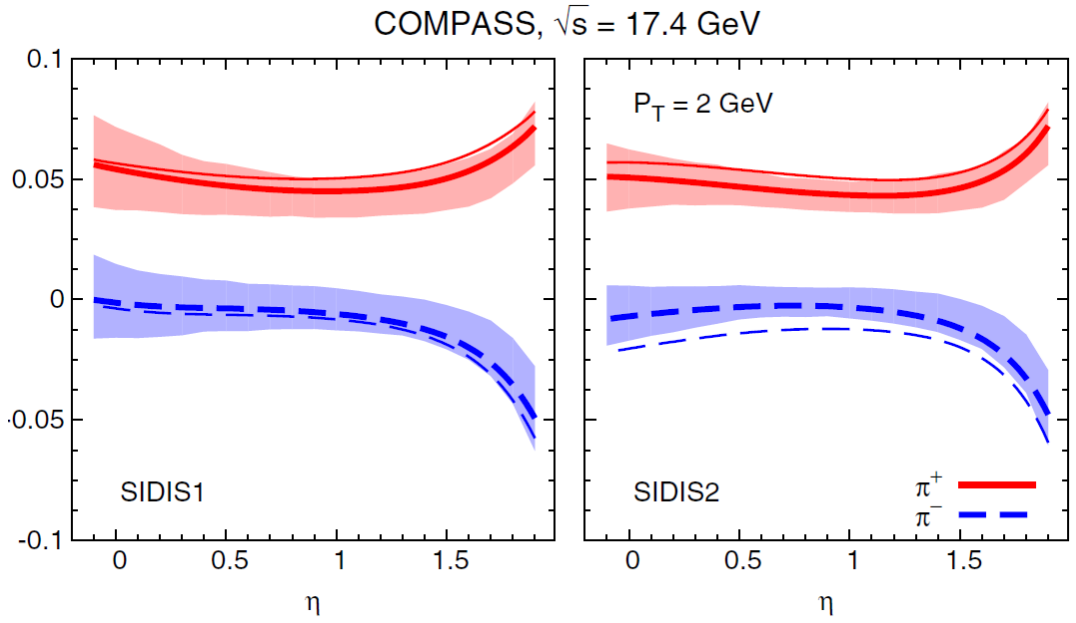
BACK-UP SLIDES

COMPASS

Unpolarized xsecs.



Transverse SSAs

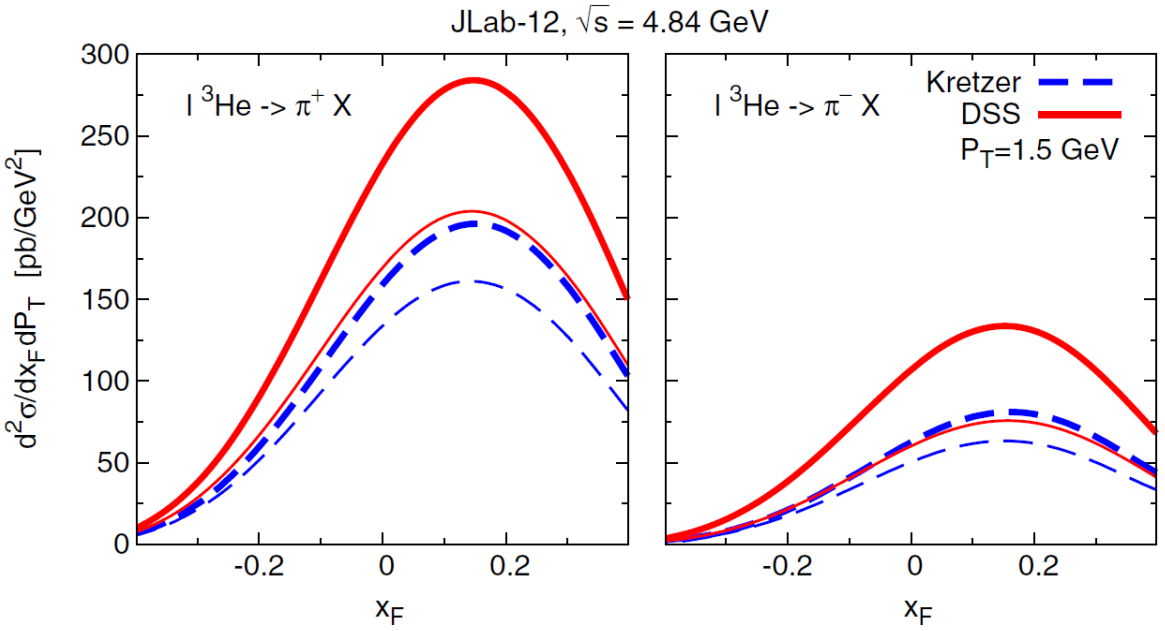


μ 200 times heavier than e:
less role of WW

NOTICE $x_F > 0$
backward proton hemisph.

JLAB 12 GeV

Unpolarized xsecs.



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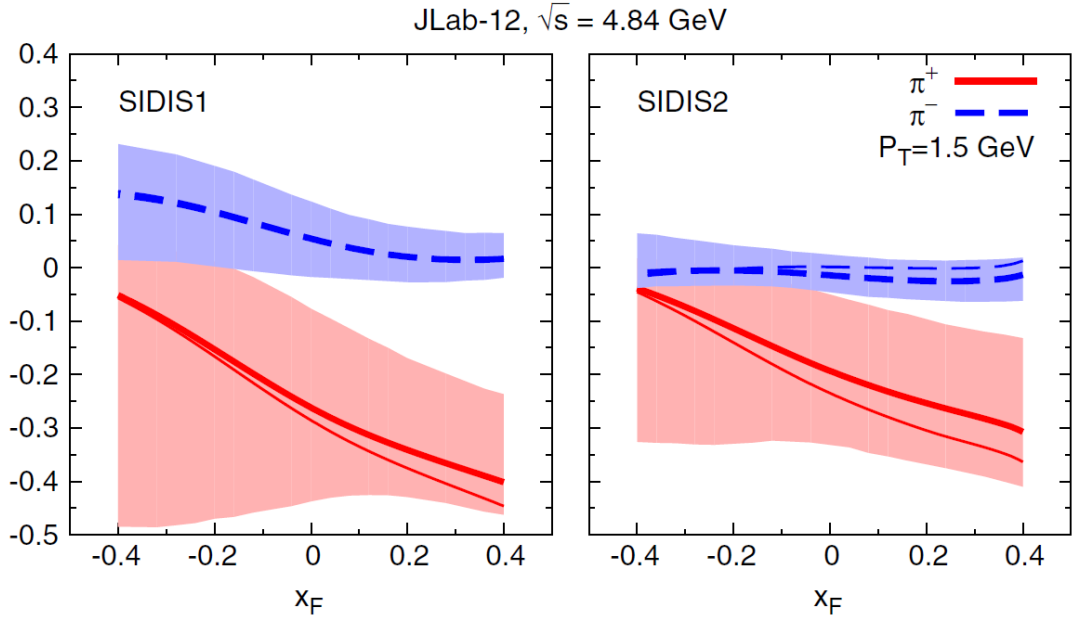

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