QCD Evolution 2017, JLab, May 22 - 26, 2017

Double-Longitudinal Spin Asymmetry in Single-Inclusive Lepton Scattering

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Institute for Theoretical Physics
University of Tübingen

in collaboration with W. Vogelsang and P. Hinderer
based on

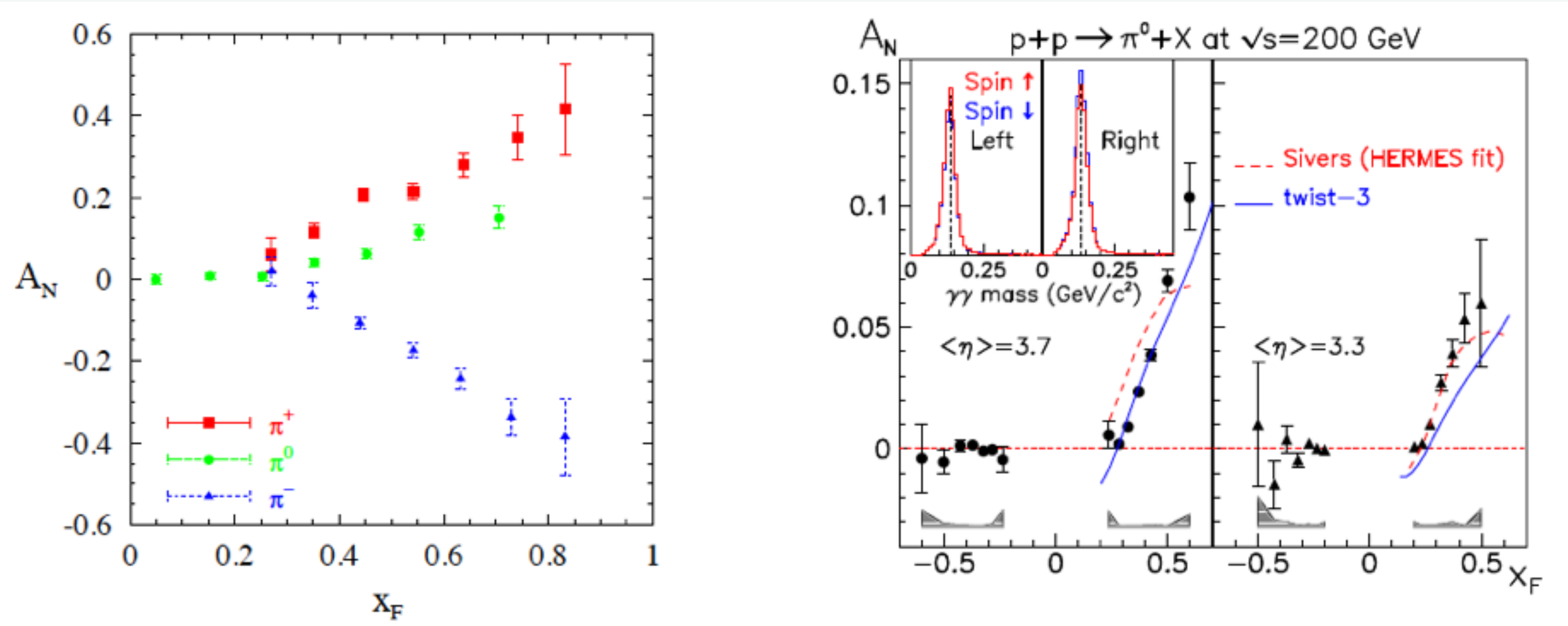
- *PRD92,014001 (2015), Erratum: PRD93,119903 (2016), arXiv:1505.06415*
- *arXiv:1703.10872*

Transverse Spin Effects in single-inclusive processes

Transverse SSA

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

$$p + p^\uparrow \to \pi + X$$



$\sqrt{s} = 20$ GeV [*E704 coll. (1991)*]

$\sqrt{s} = 200$ GeV [*STAR coll. (2008)*]

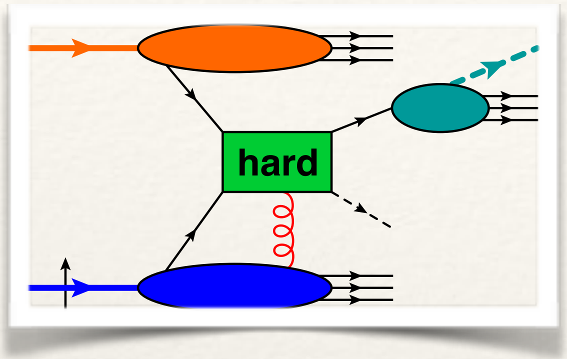
large effects

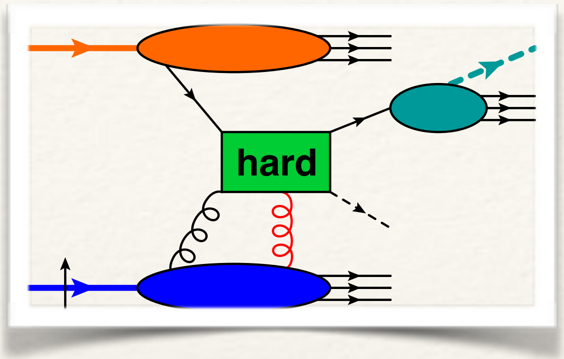
cannot be explained in the standard parton model

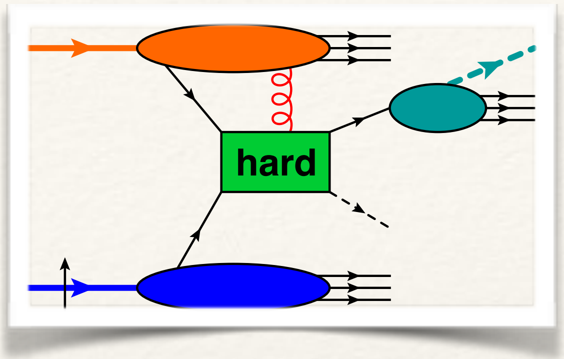
→ collinear Twist-3 Formalism

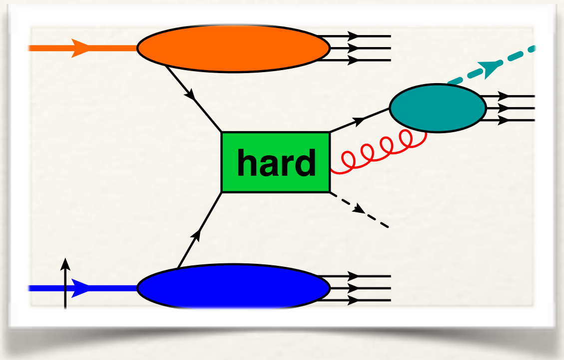
Collinear Twist-3: Many competing contributions in pp (even at LO):

[Qiu, Sterman, Kouvaris, Yuan, Koike, Yuan, Metz, Pitonyak,….]









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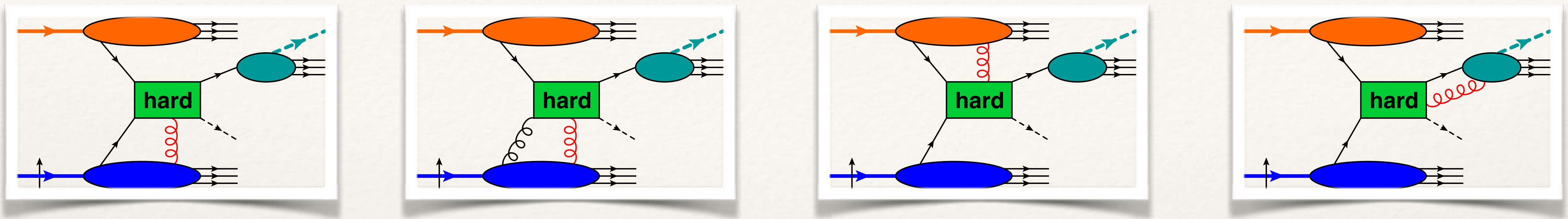

Many (unknown) three-parton correlation functions

$$F(x, x') = \int \frac{d\lambda}{2\pi} \int \frac{d\mu}{2\pi} \, \mathrm{e}^{i\lambda x'} \, \mathrm{e}^{i\mu(x-x')} \, \langle P, S_T | \, \mathcal{O}_1(0) \, \mathcal{O}_2(\mu n) \, \mathcal{O}_3(\lambda n) \, | P, S_T \rangle$$

(chiral-even/odd) QGQ - correlation ~ Sivers function (SGP)

GGG - correlations (transverse spin only)

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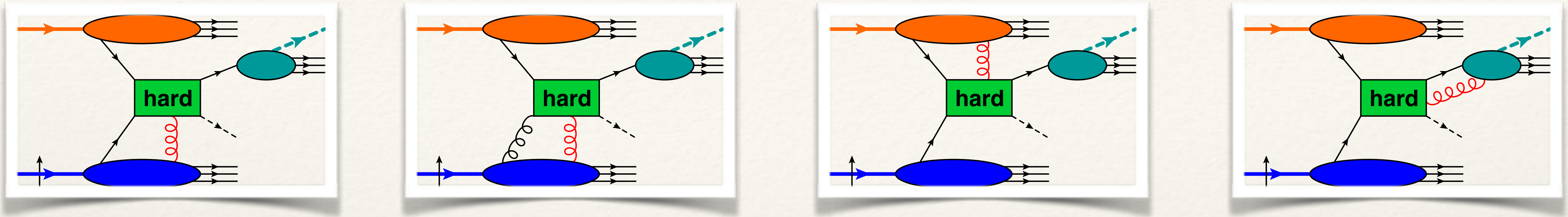

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Three-parton fragmentation functions

$$D(z, z') = \sum_X \int \frac{d\lambda}{2\pi} \int \frac{d\mu}{2\pi} \, e^{i\lambda \frac{1}{z'}} \, e^{i\mu(\frac{1}{z} - \frac{1}{z'})} \, \langle 0 | \, \mathcal{O}_1(0) \, | P_h; X \rangle \, \langle P_h; X | \, \mathcal{O}_2(\mu n) \, \mathcal{O}_3(\lambda n) \, | 0 \rangle$$

dominating effect (?)

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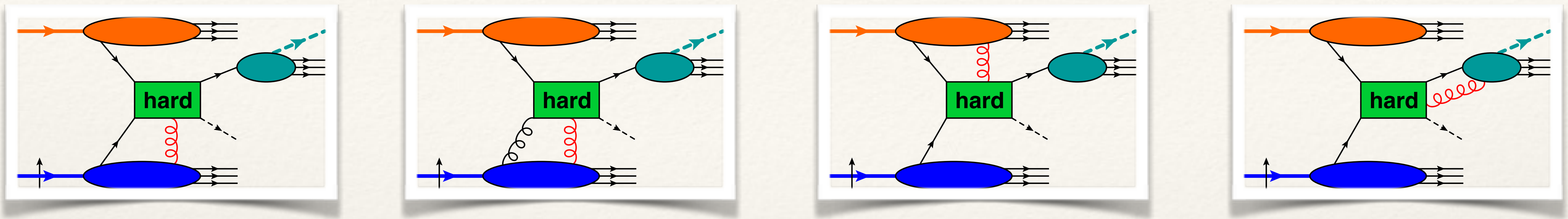

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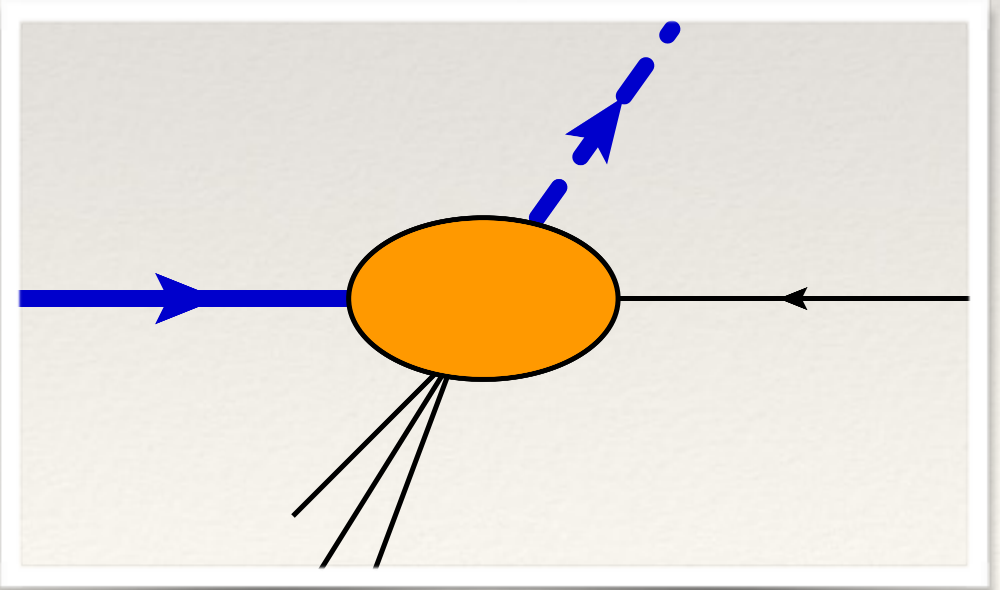
pure QCD-induced process: many hard diagrams

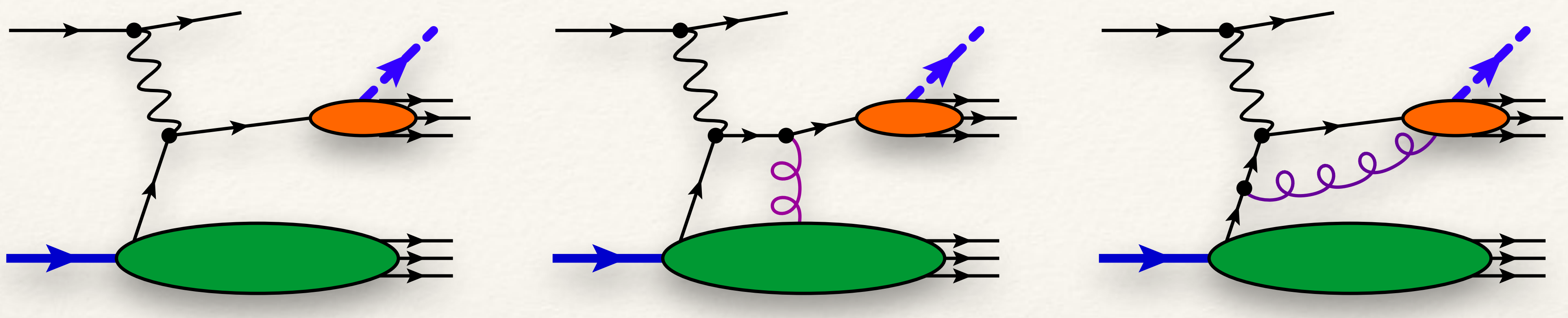
Single-hadron production in lepton - nucleon collisions

$(e + p^{\uparrow} \longrightarrow h + X)$

$P_T \gg \Lambda_{QCD}$



LO calculation of transverse spin observables:



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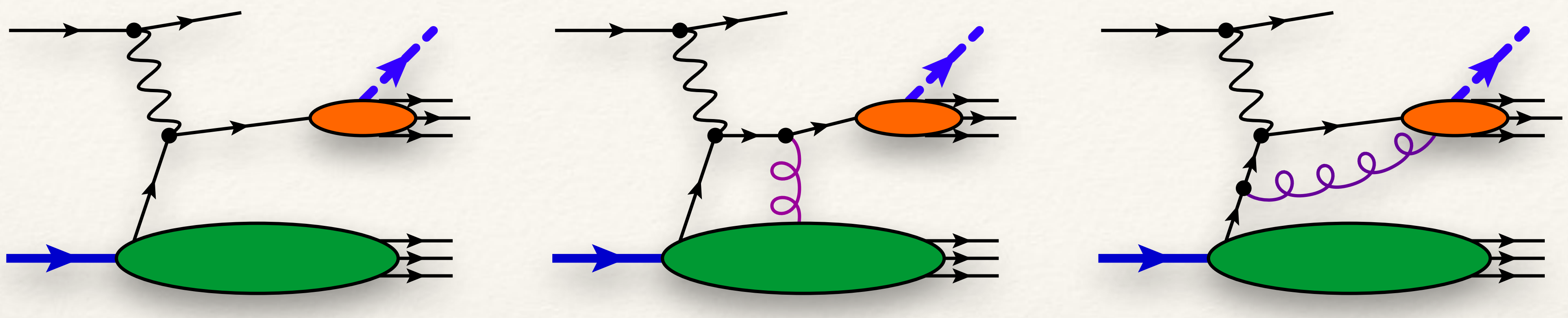

Single Spin Asymmetry: $e + N^{\uparrow} \longrightarrow h + X$

[Gamberg, Kang, Metz, Pitonyak, Prokudin; PRD90, 074012 (2014)]

Double Spin Asymmetry: $e^{\rightarrow} + N^{\uparrow} \longrightarrow h + X$

[Kanazawa, Metz, Pitonyak, MS; PLB742, 340 (2015)]

Transverse Λ Spin Asymmetry: $e + N \longrightarrow \Lambda^{\uparrow} + X$

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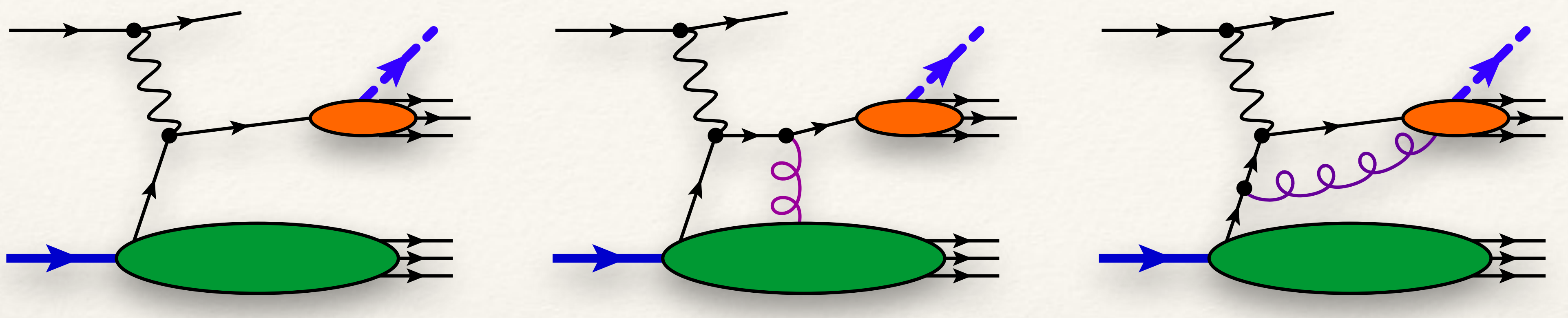

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Measurements of SSA at HERMES, JLab6 $\Longrightarrow$ Opportunity at EIC (Jets)!

LO analysis of HERMES data [Gamberg et al] $\Longrightarrow$ Factor $\times 2$ discrepancy

How well do we understand this process?

Unpolarized Cross Section at NLO

[Hinderer, M.S., Vogelsang, PRD 92, 014001 (2015), arXiv:1505.06415]

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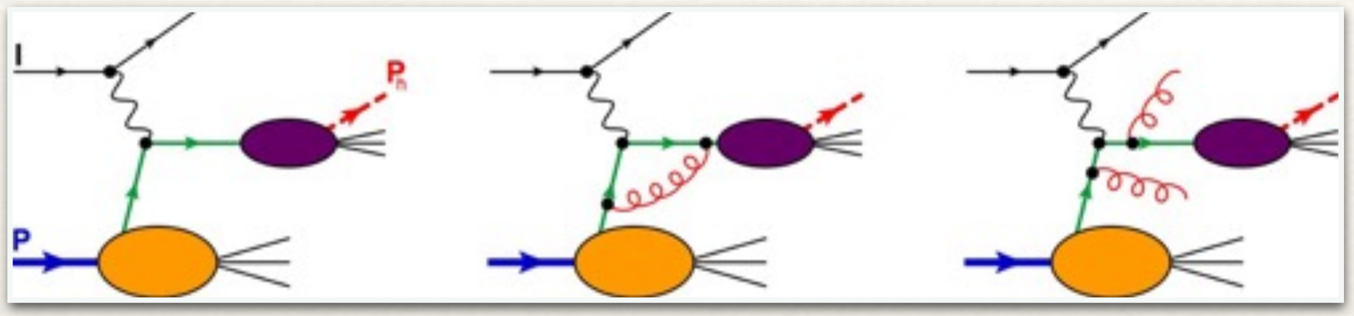

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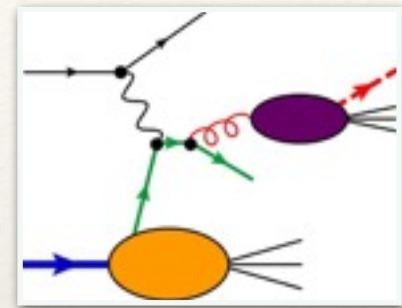

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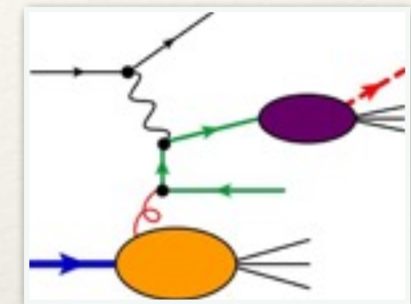

- As usual: Infrared ‘safe’ observable
- Initial / Final State collinear singularities cancel after MSbar - renormalization of PDFs and FFs!

Peculiarity: collinear singularity of final state lepton remains

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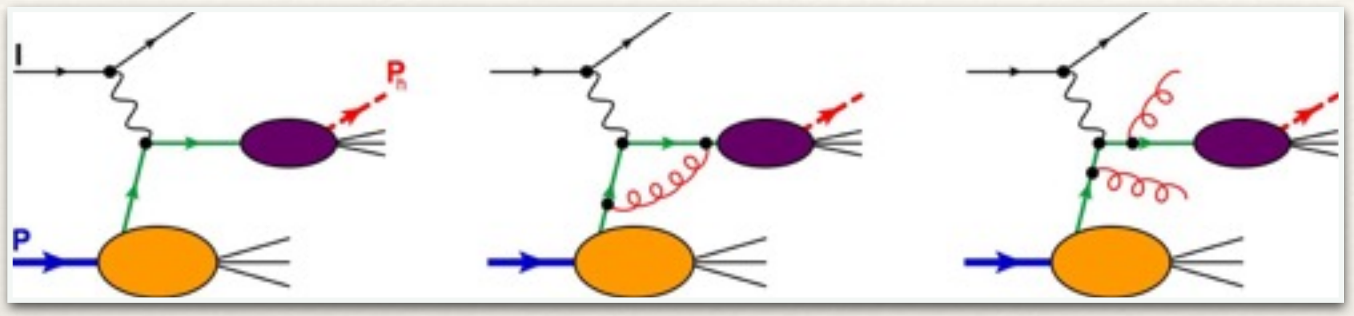

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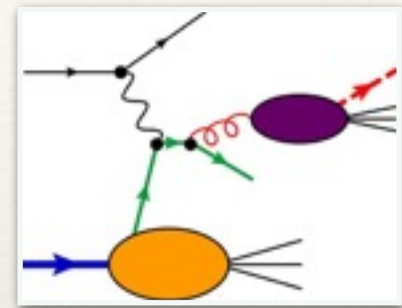

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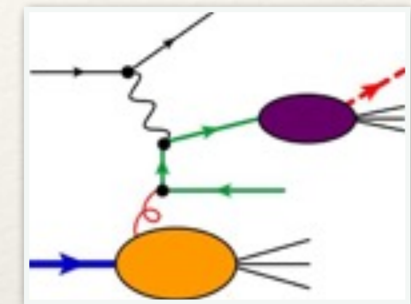

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Peculiarity: collinear singularity of final state lepton remains

1) work with non-zero lepton mass $m_l \neq 0$

$$\hat{\sigma}_{\rm NLO}(s,t,u,m_l^2) = \ln\left(\frac{m_l^2}{\Lambda^2}\right)\hat{\sigma}_1(s,t,u) + \hat{\sigma}_2(s,t,u,\Lambda^2) + \mathcal{O}(m_l^2/\Lambda^2)$$

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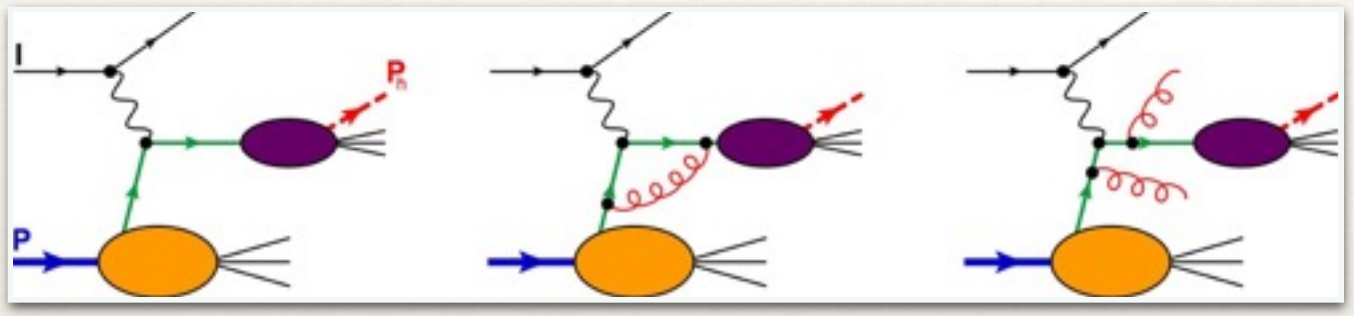

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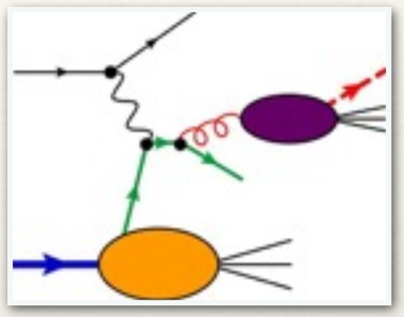

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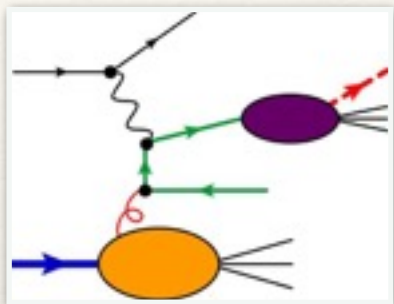

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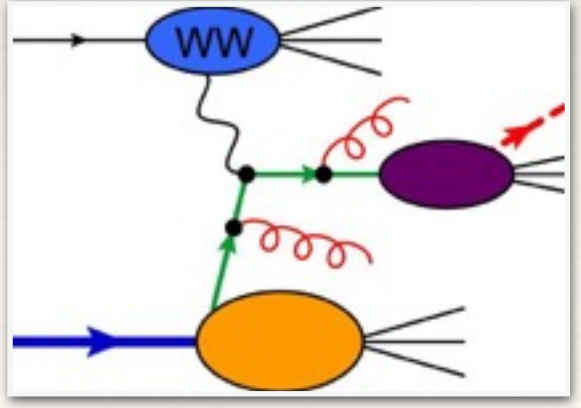
2) add Weizsäcker - Williams (WW) contribution with $m_l = 0$



$$d\sigma_{WW} \sim f_1^{WW}(y) \otimes f_1(x) \otimes D_1(z) \otimes \hat{\sigma}^{\gamma i \to f x}$$

both approaches are equivalent!

WW - contribution sometimes (but not always!) dominant

NLO - predictions for unpolarized π - production

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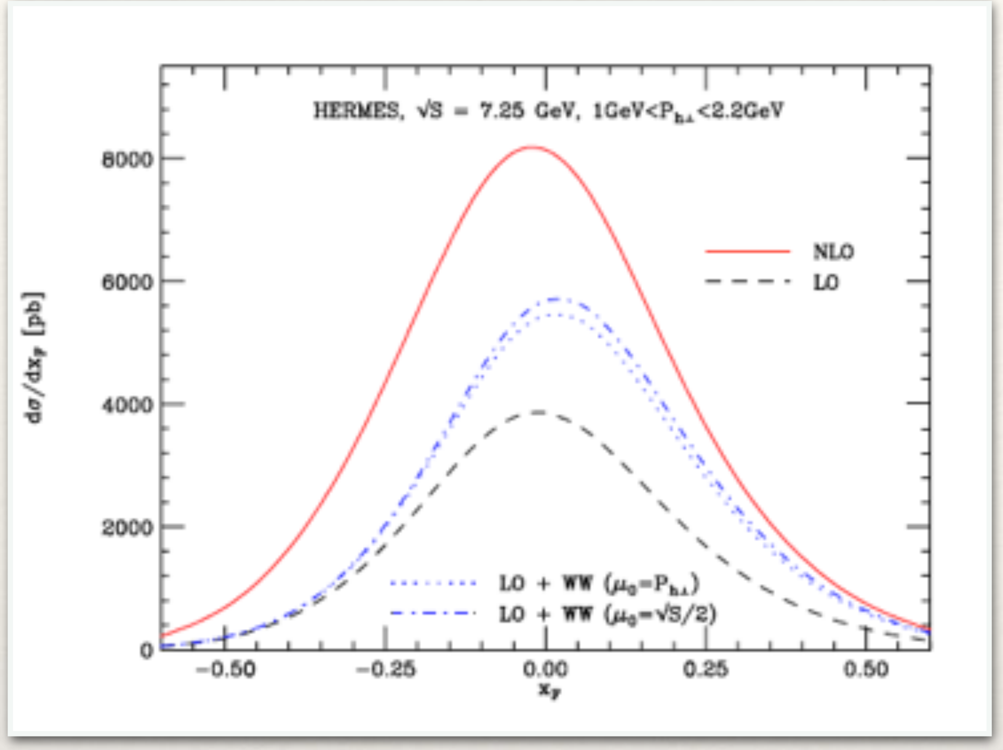

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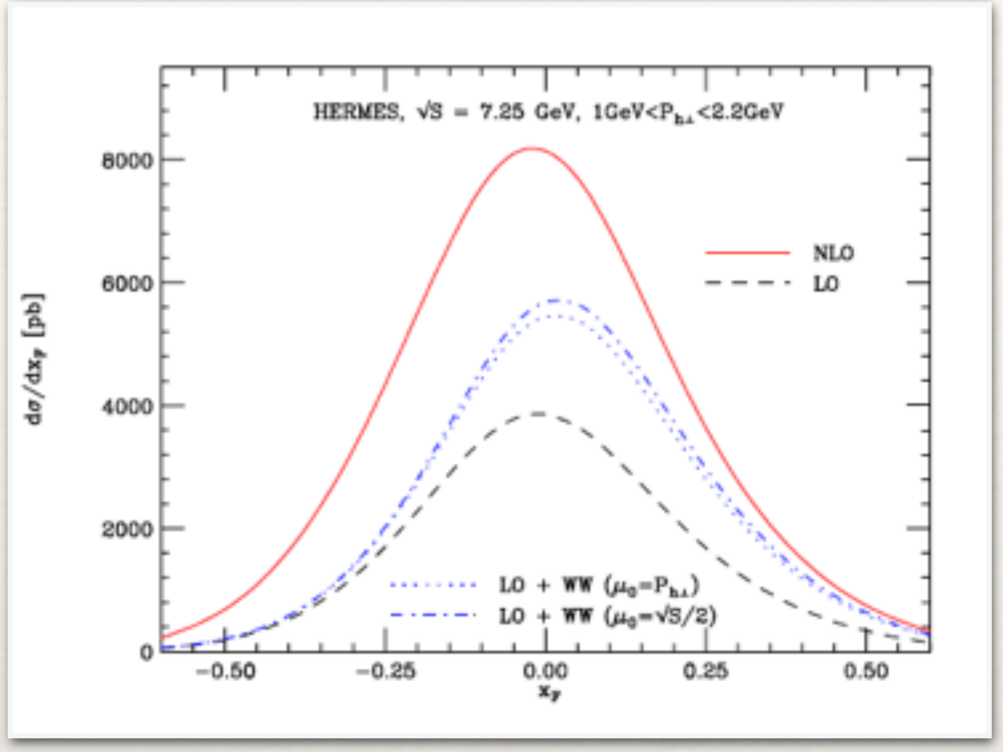
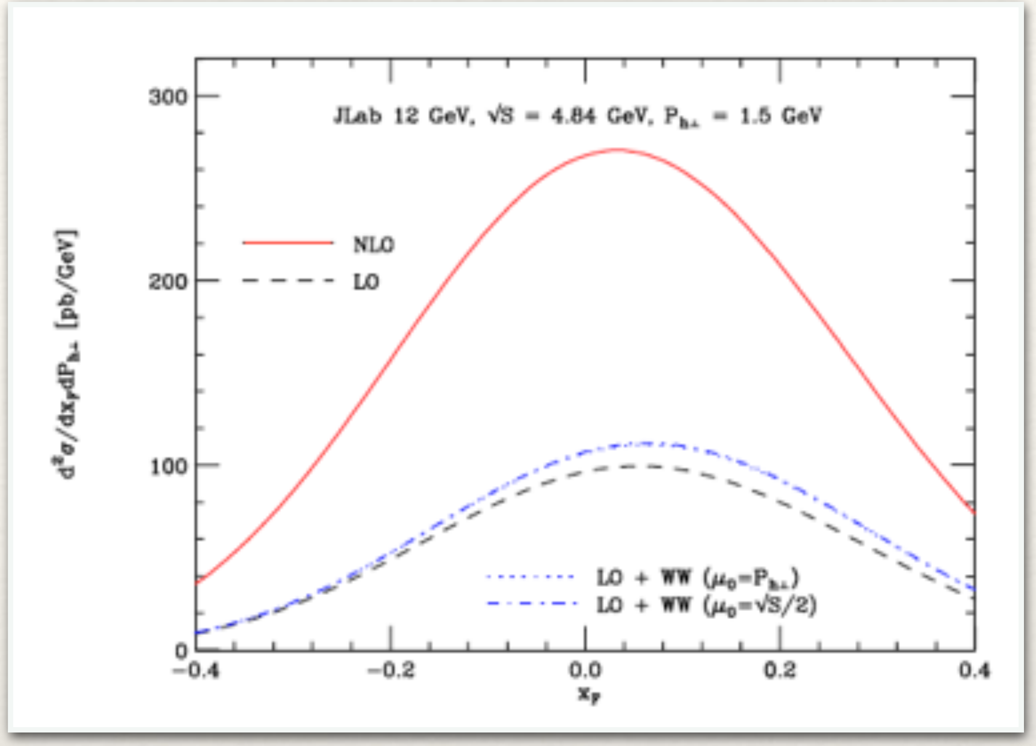


<u>JLab12</u>: $K = \sigma_{NLO}/\sigma_{LO} \sim 2.5 - 3.5$



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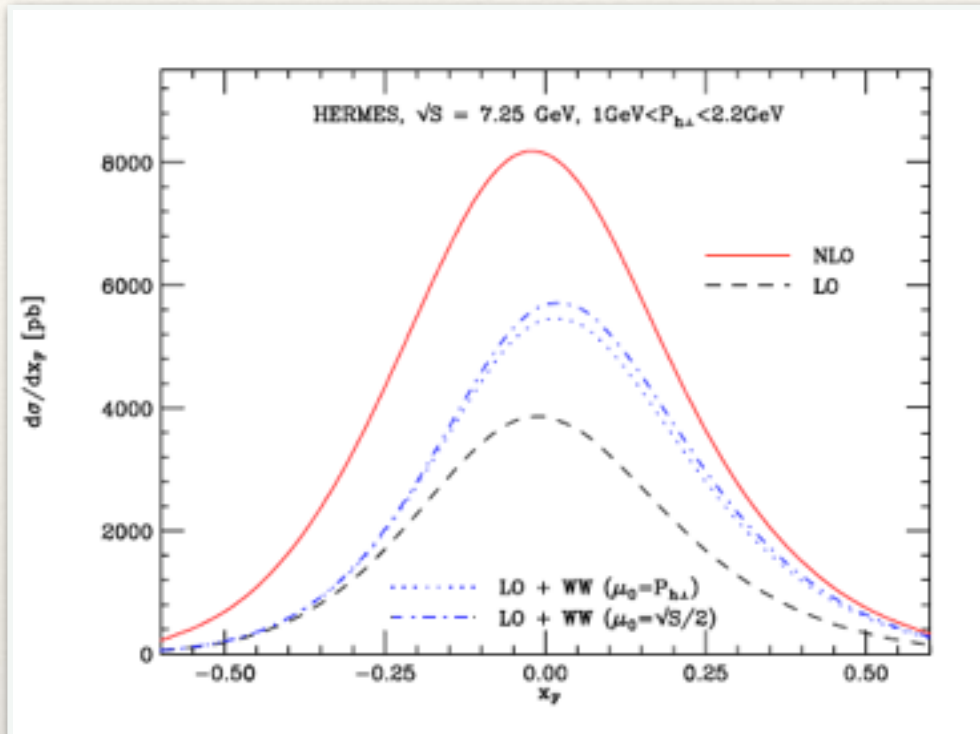

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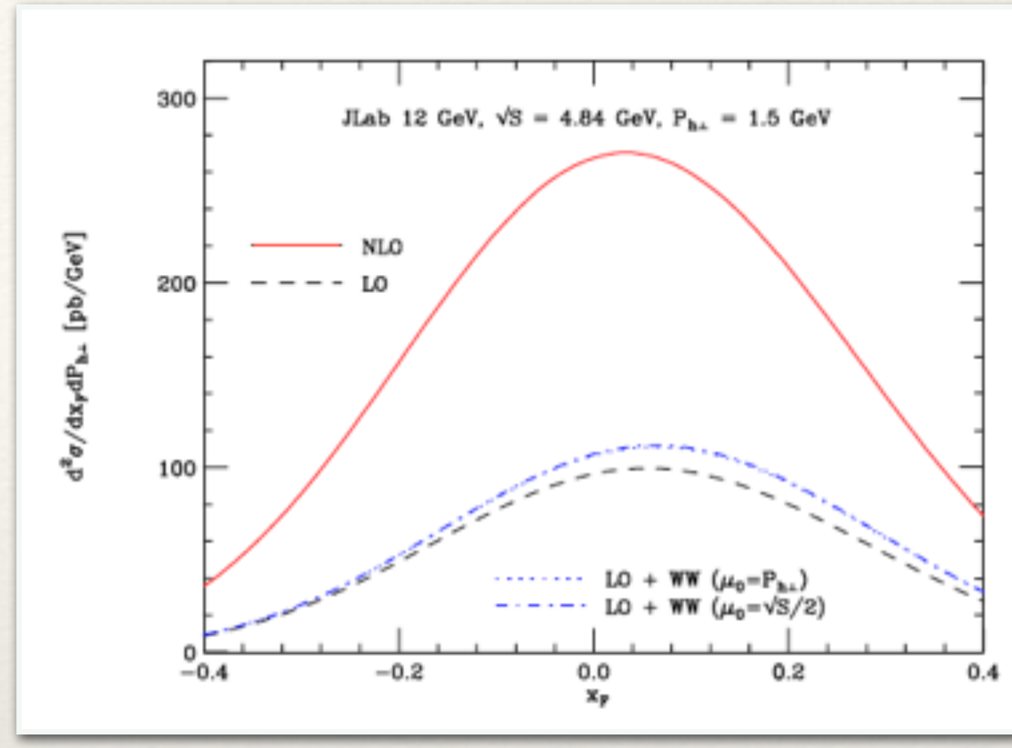
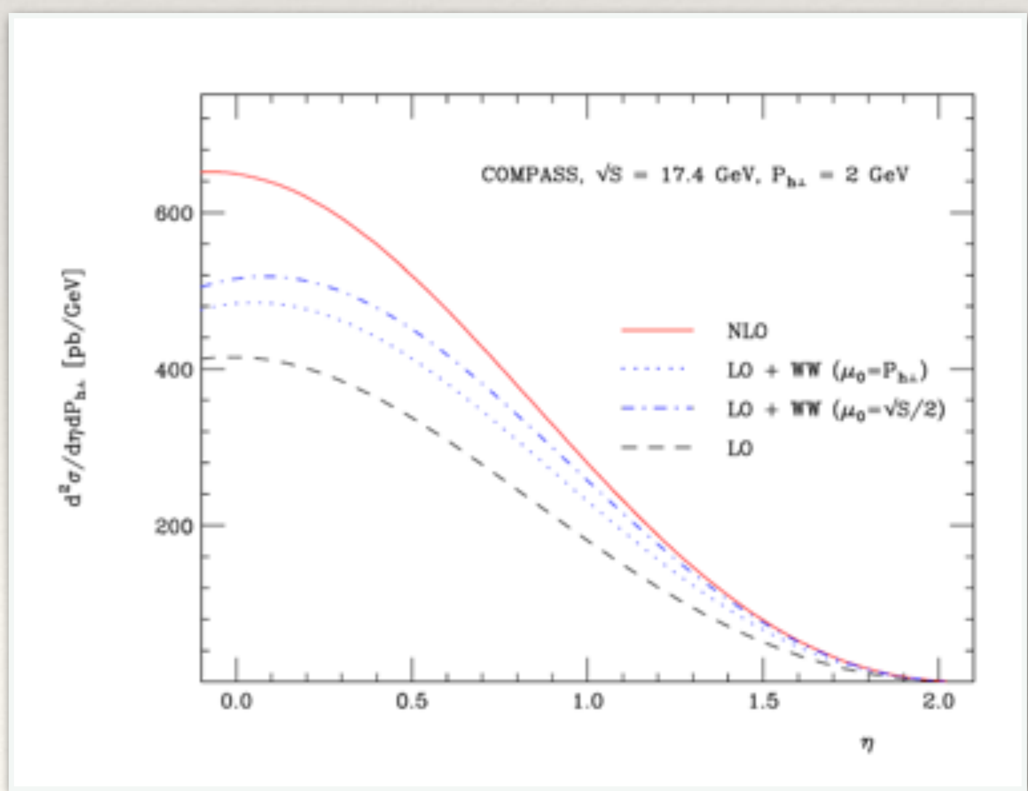


<u>COMPASS</u>: $K = \sigma_{NLO}/\sigma_{LO} \sim 1.6$



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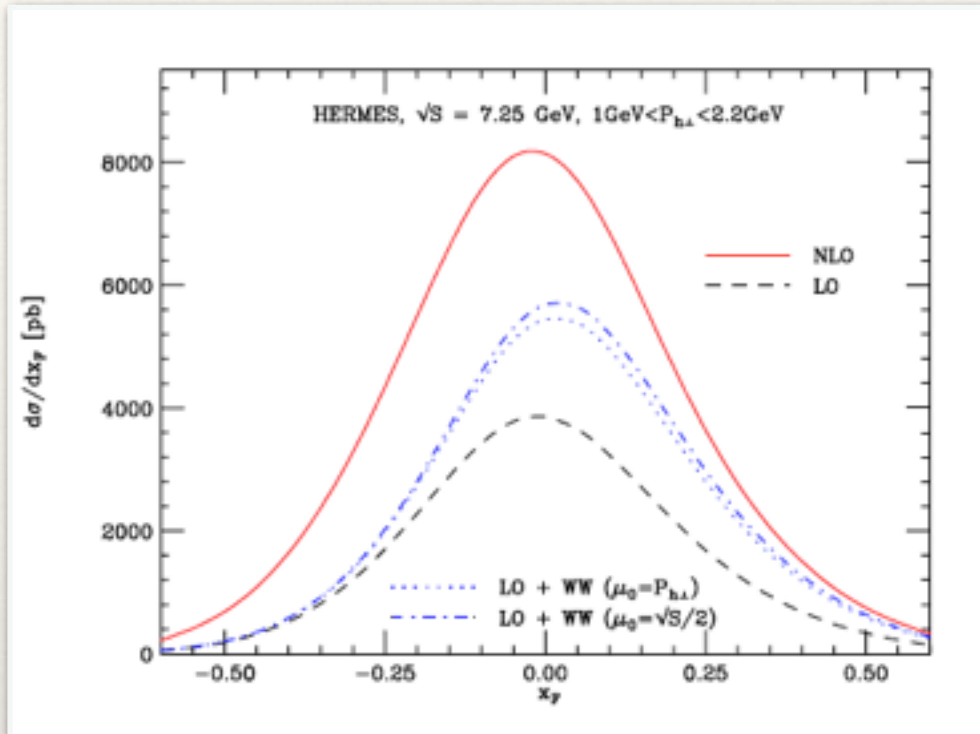

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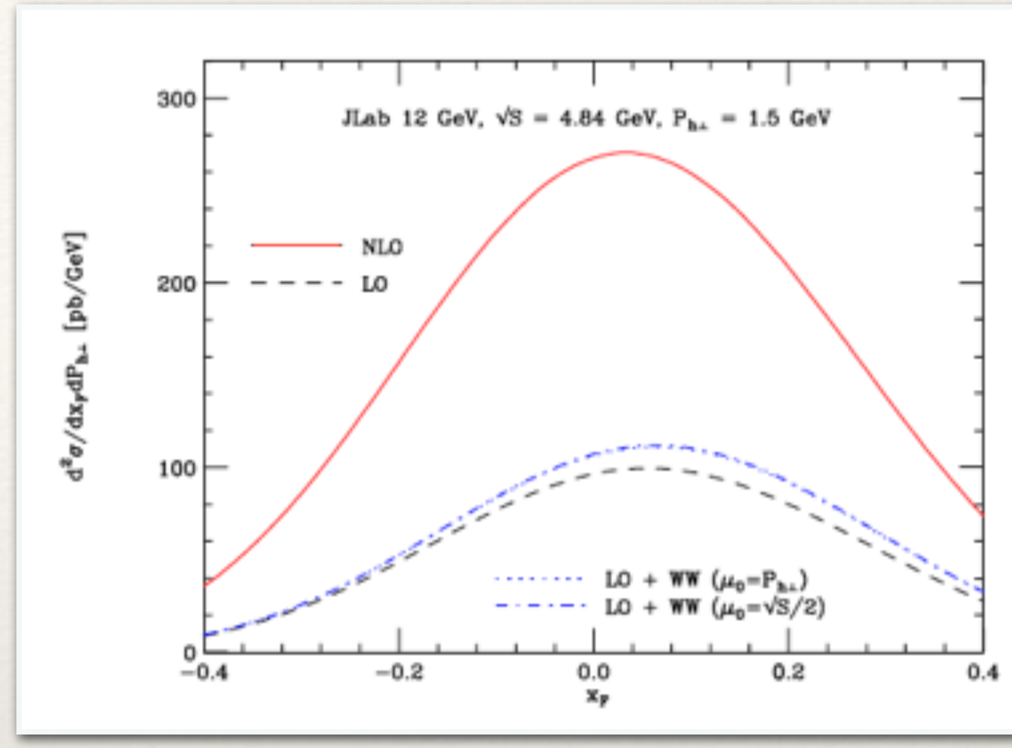

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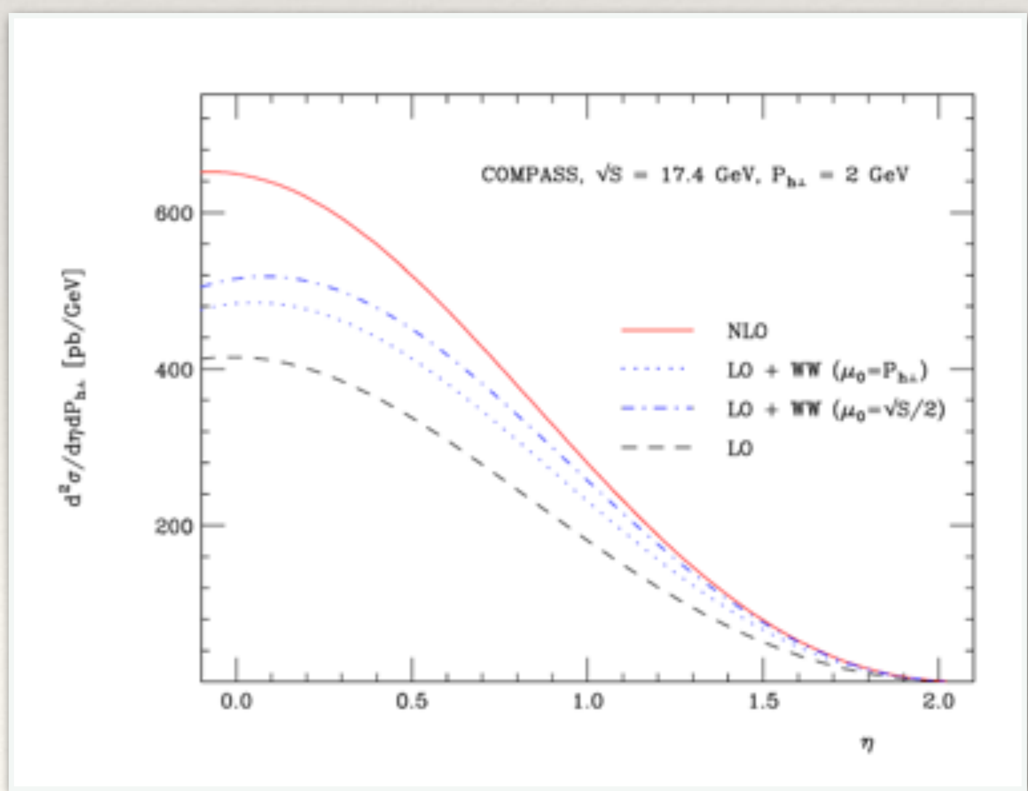

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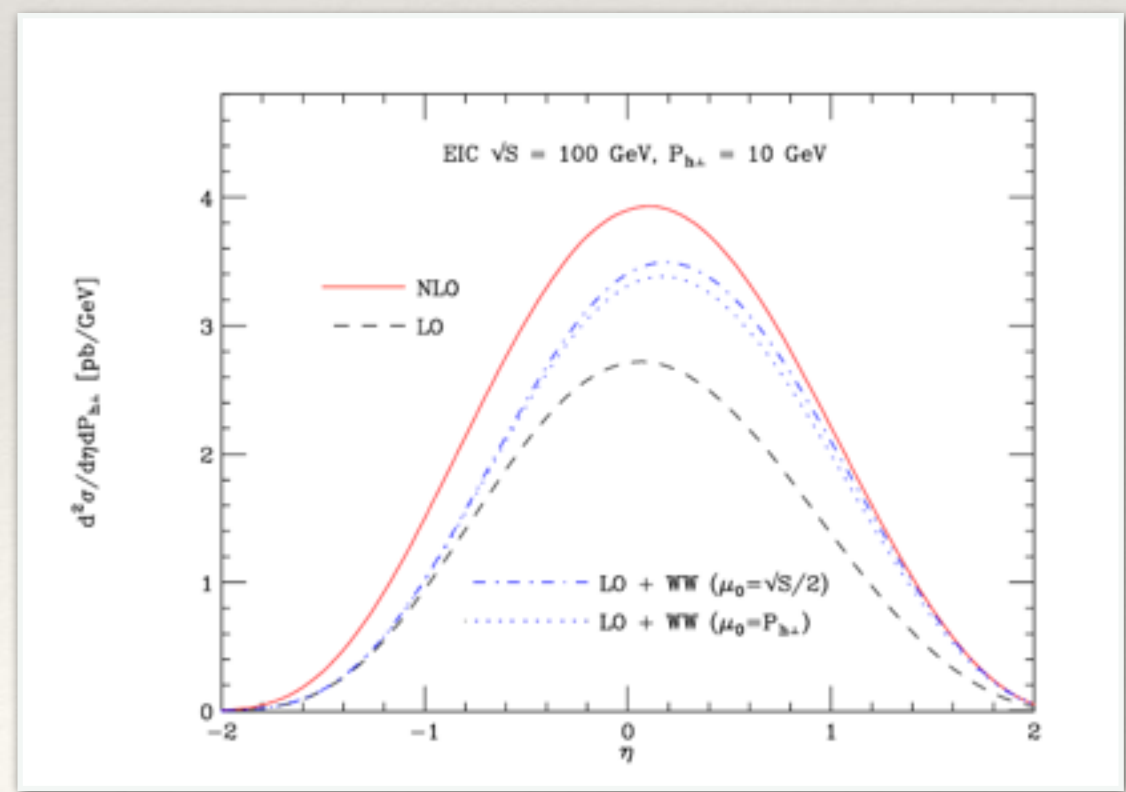

Jet Production at EIC

<u>'Narrow Jet Approximation':</u> analytic treatment for cone size ~ R < 0.7

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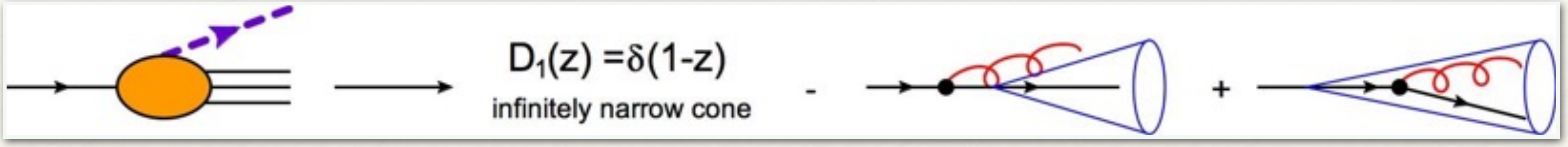
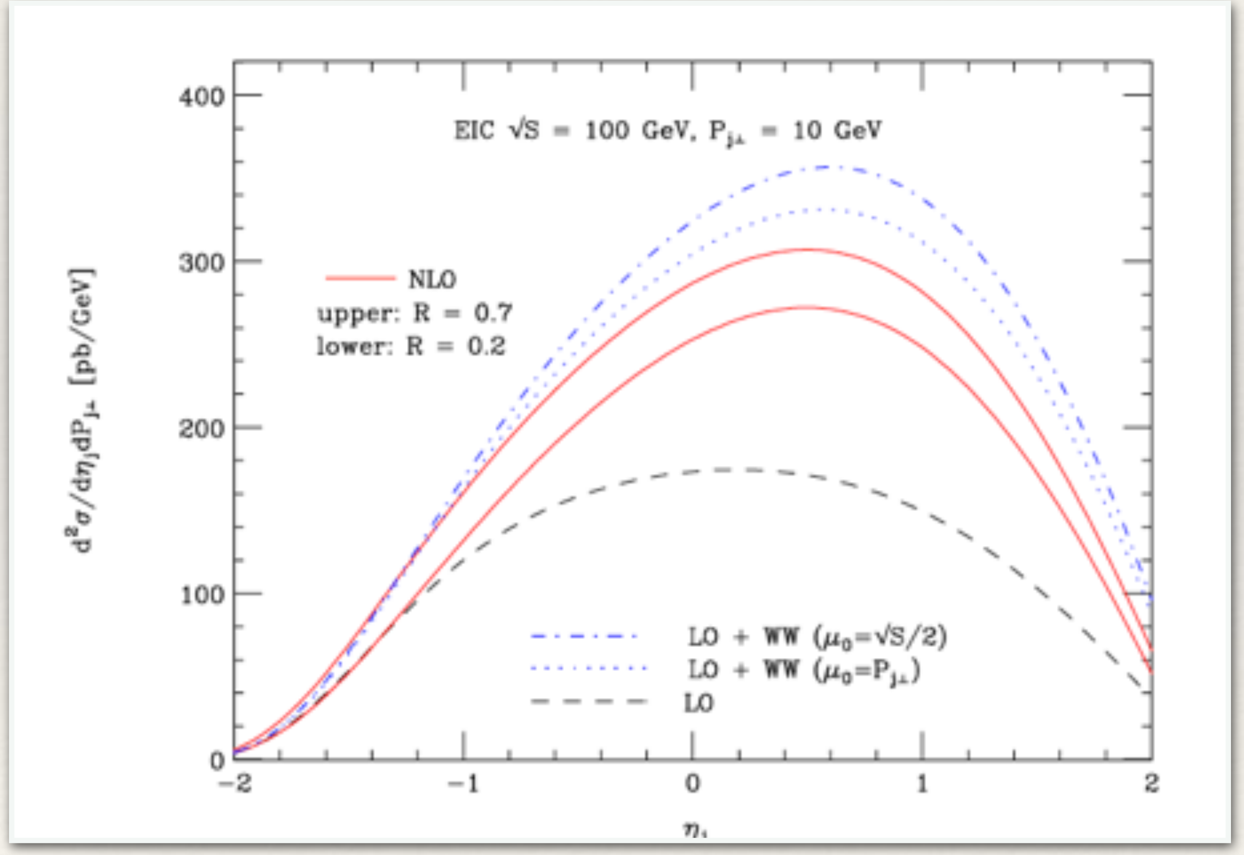


NLO: K ~ 1 - 2



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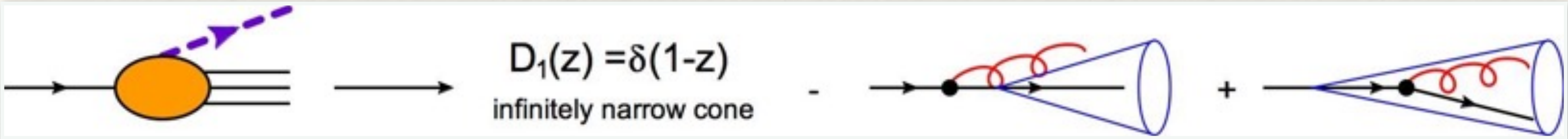

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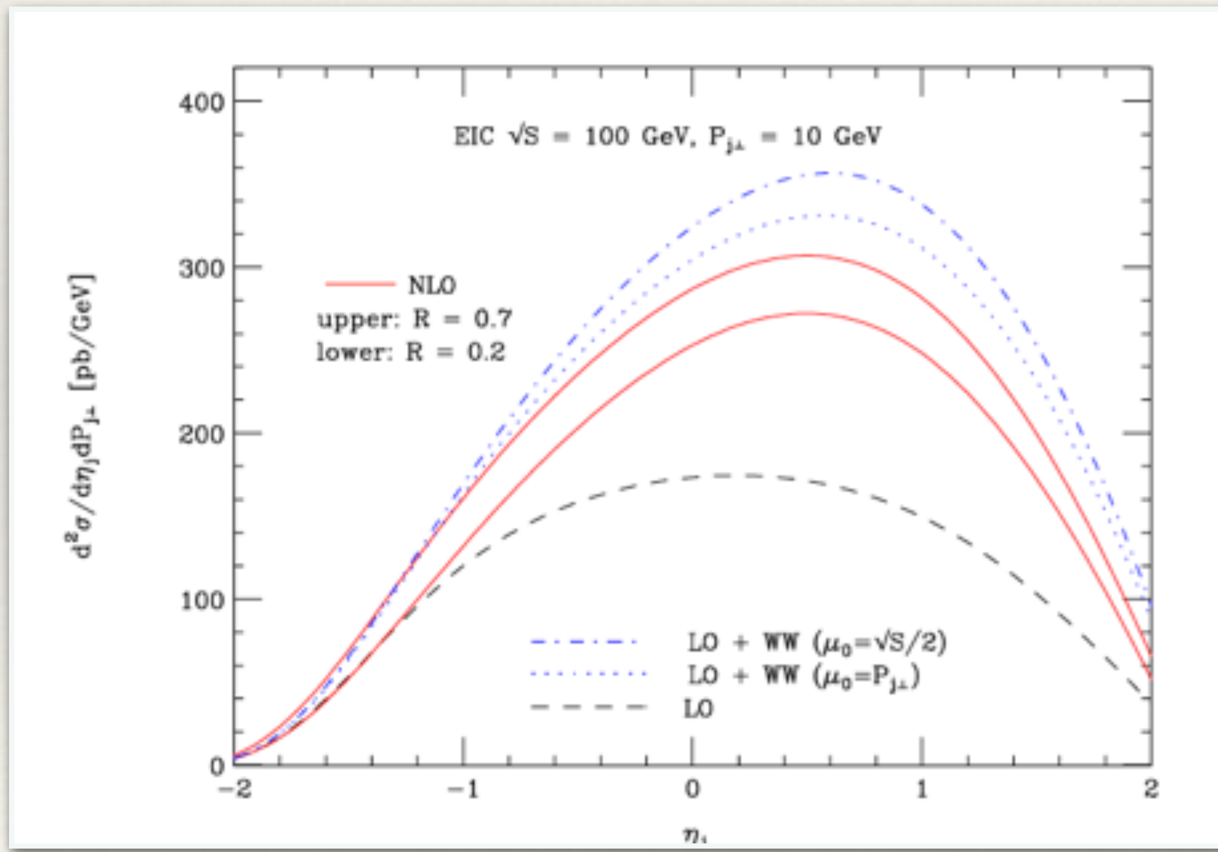
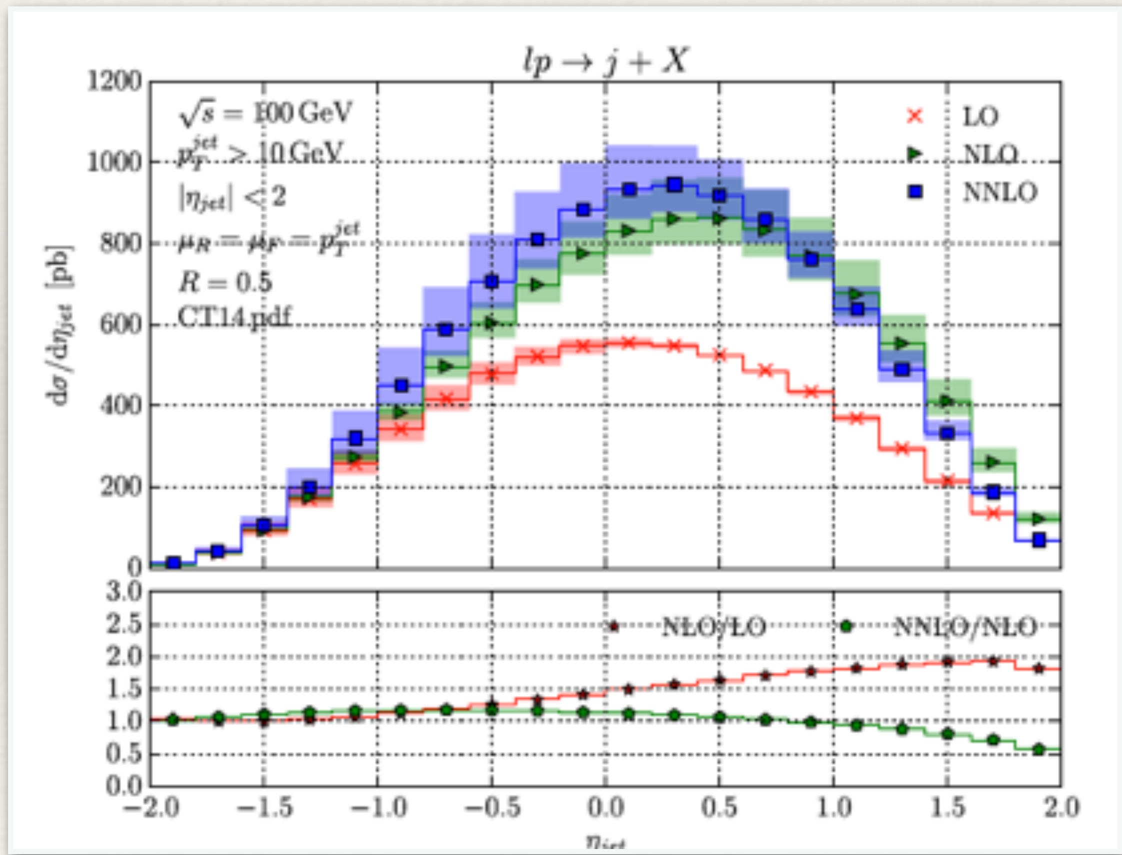


NNLO

[Abelof et al., PLB 763, 52 (2016)]



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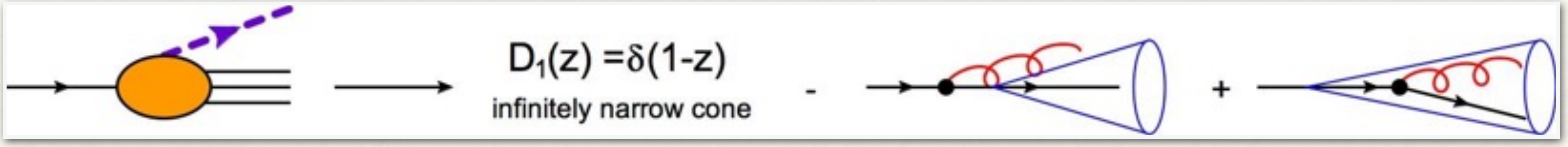

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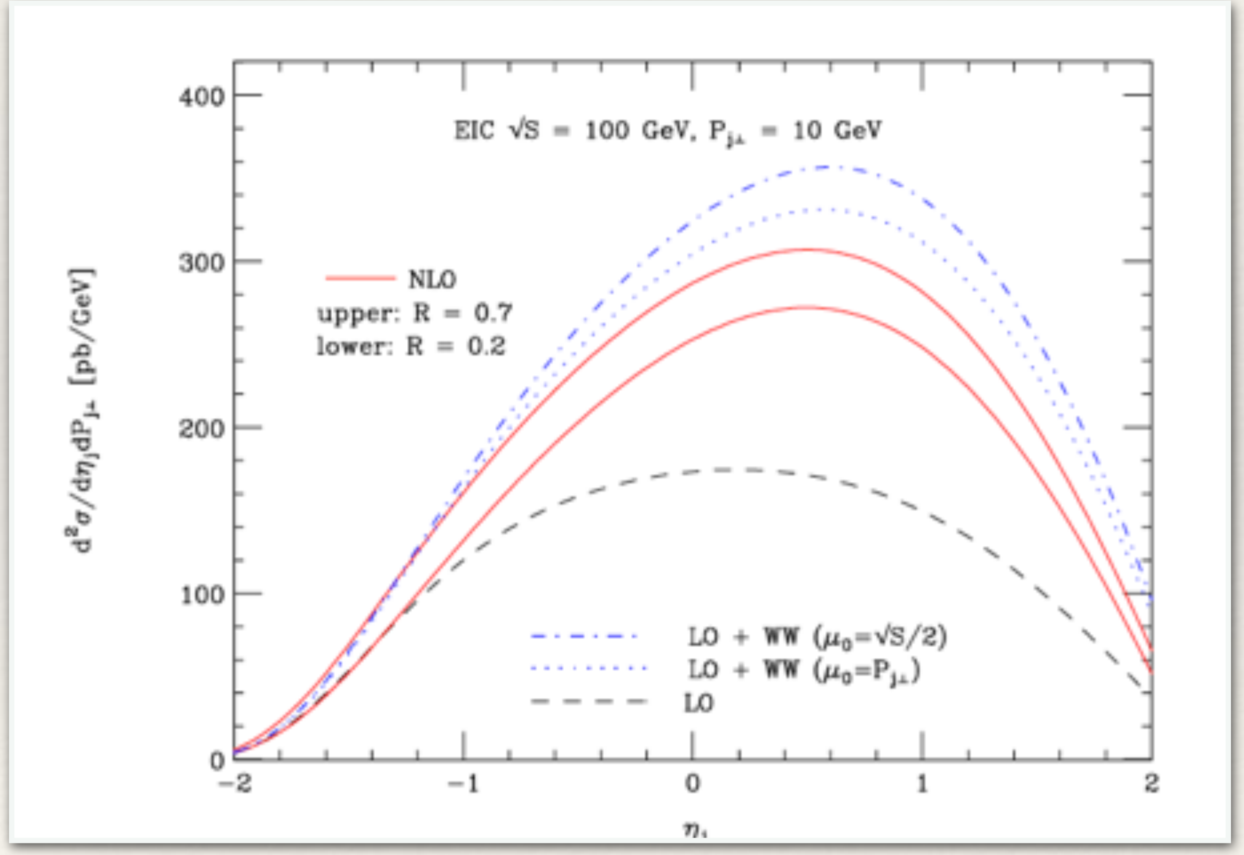

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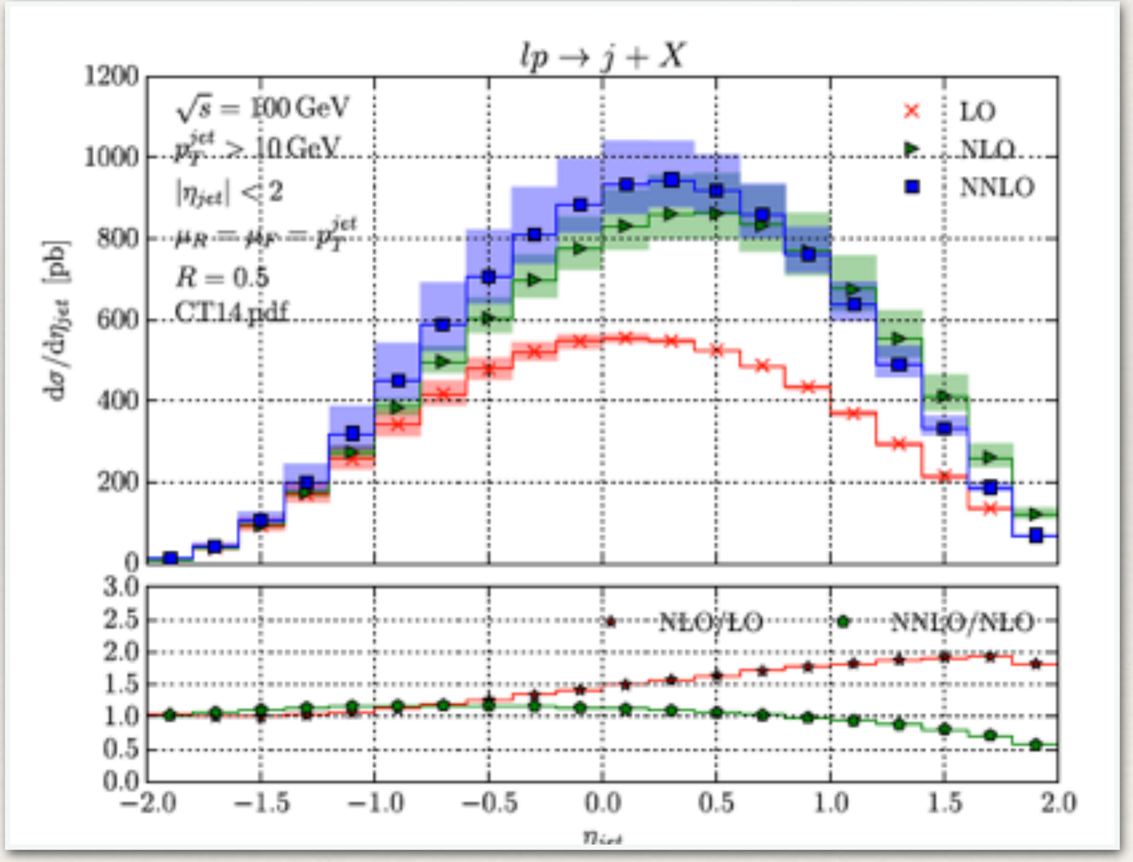

→ perturbative series converges at NNLO

Unfortunately, no data on unpolarized cross section… but

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Longitudinal Double Spin Asymmetry at NLO

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Twist-2 observable: similar to unpolarized cross section

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SLAC E155 (1999):

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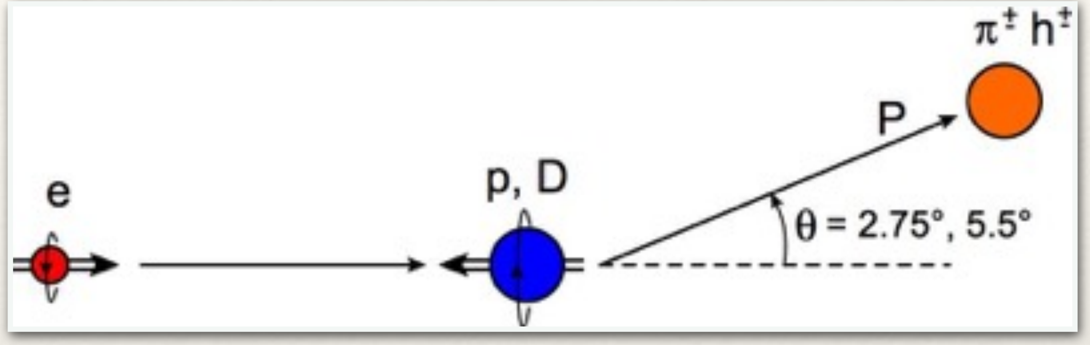
16 different data sets



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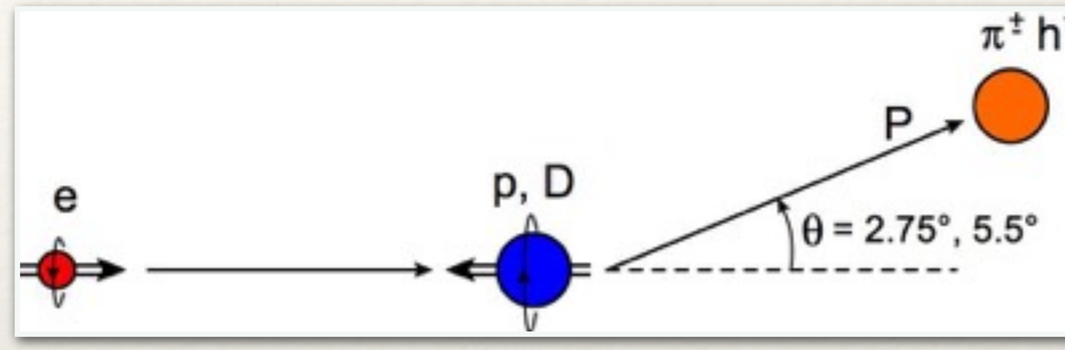
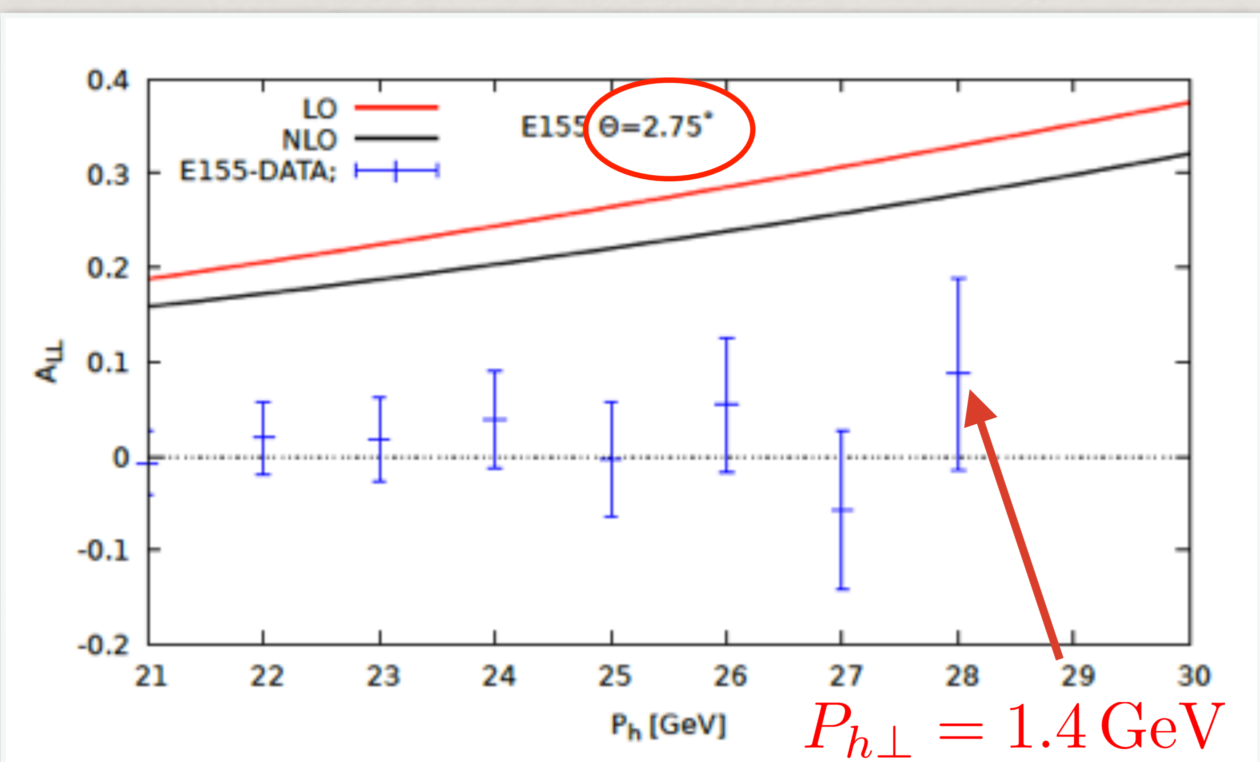
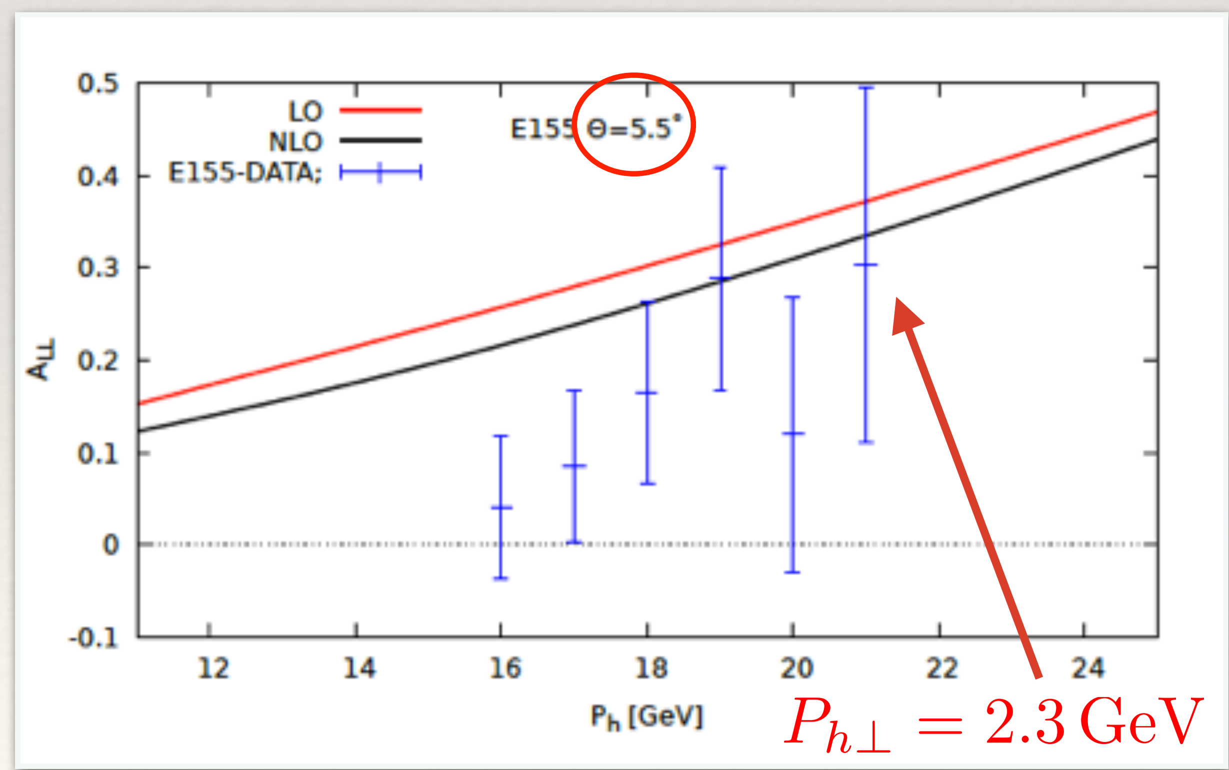


$e^{\rightarrow} + p^{\rightarrow} \longrightarrow \pi^{+} + X$



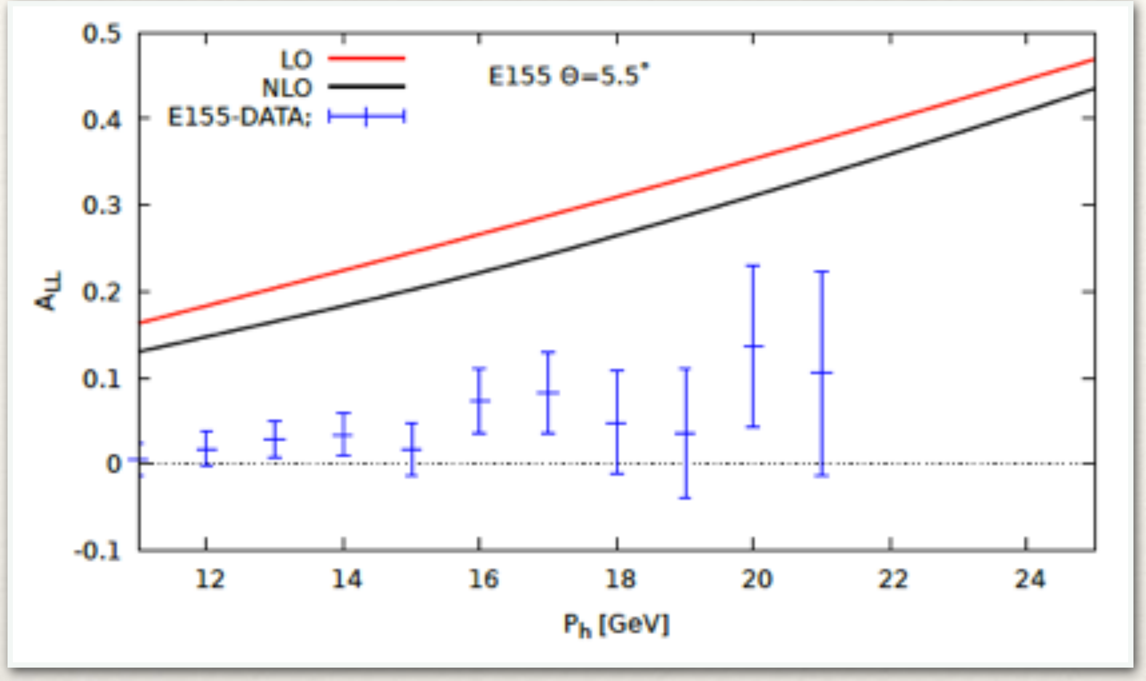
[2x too large]



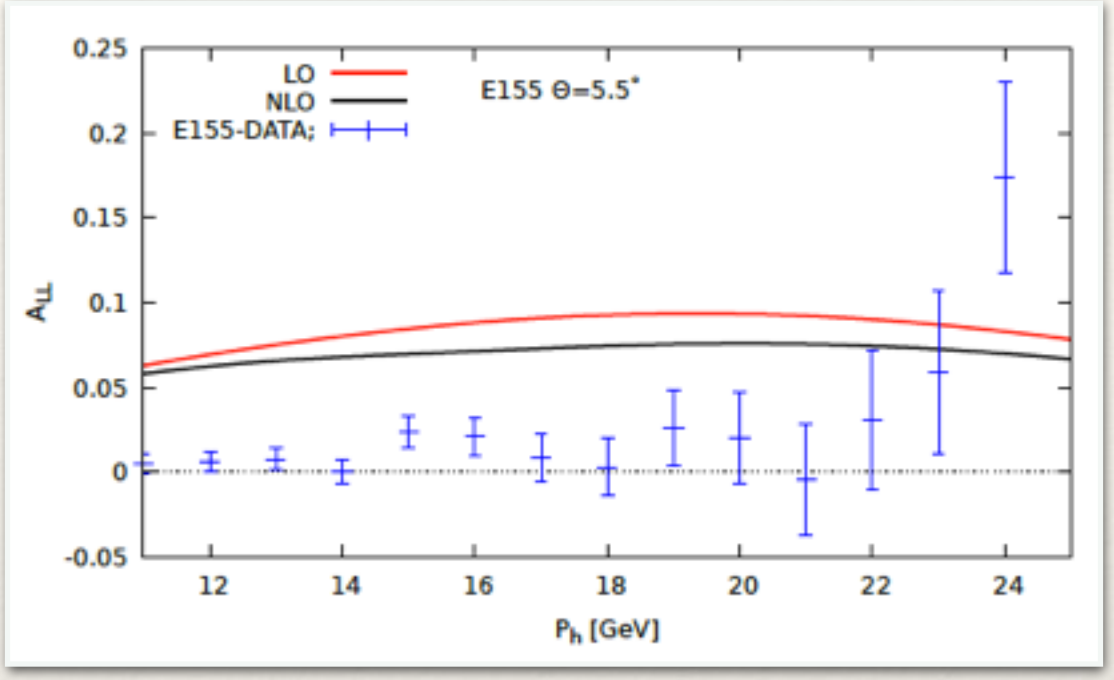
[ok agreement]

Bad agreement: more examples

$e^{\rightarrow} + p^{\rightarrow} \longrightarrow h^{+} + X$



$e^{\rightarrow} + p^{\rightarrow} \longrightarrow h^{-} + X$



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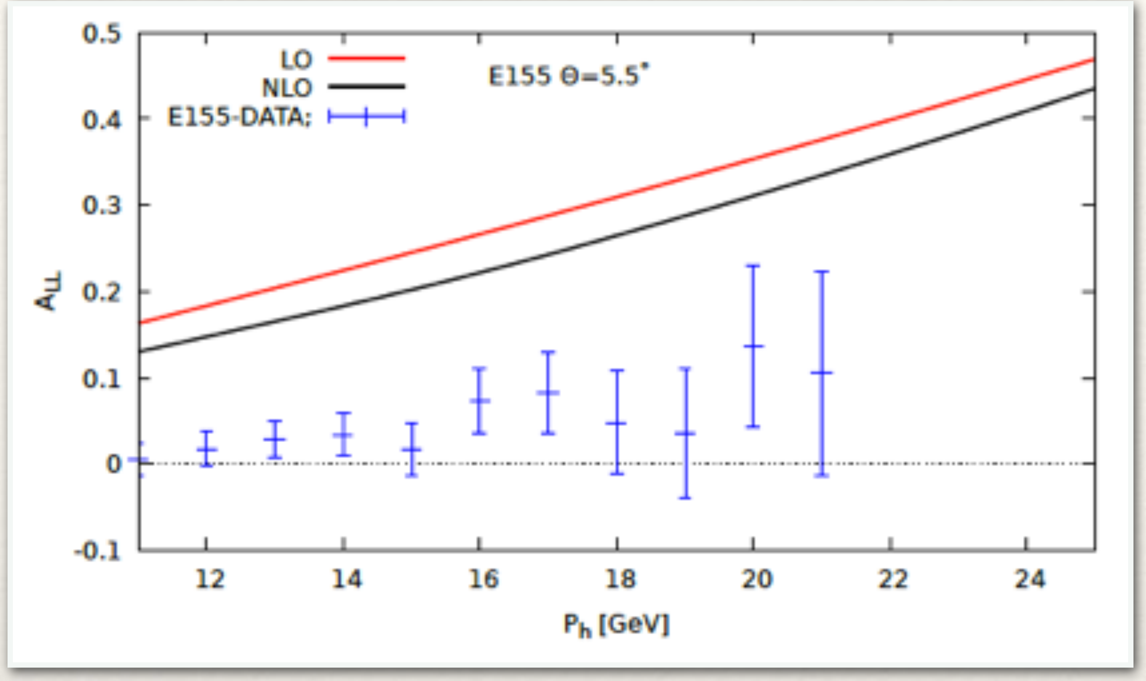

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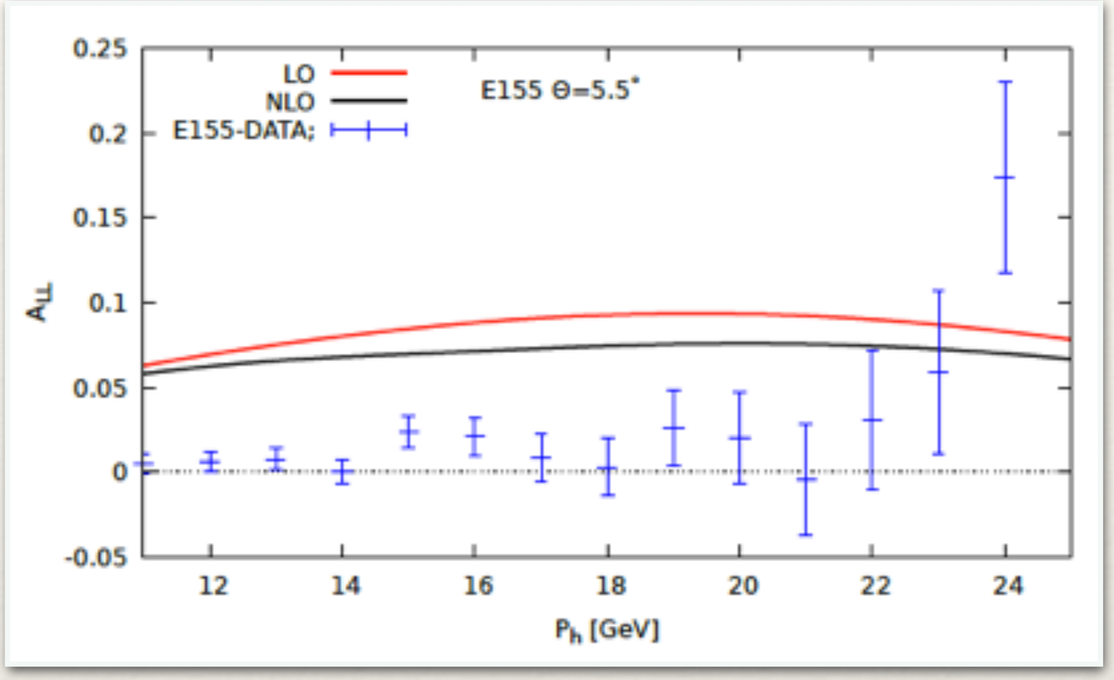
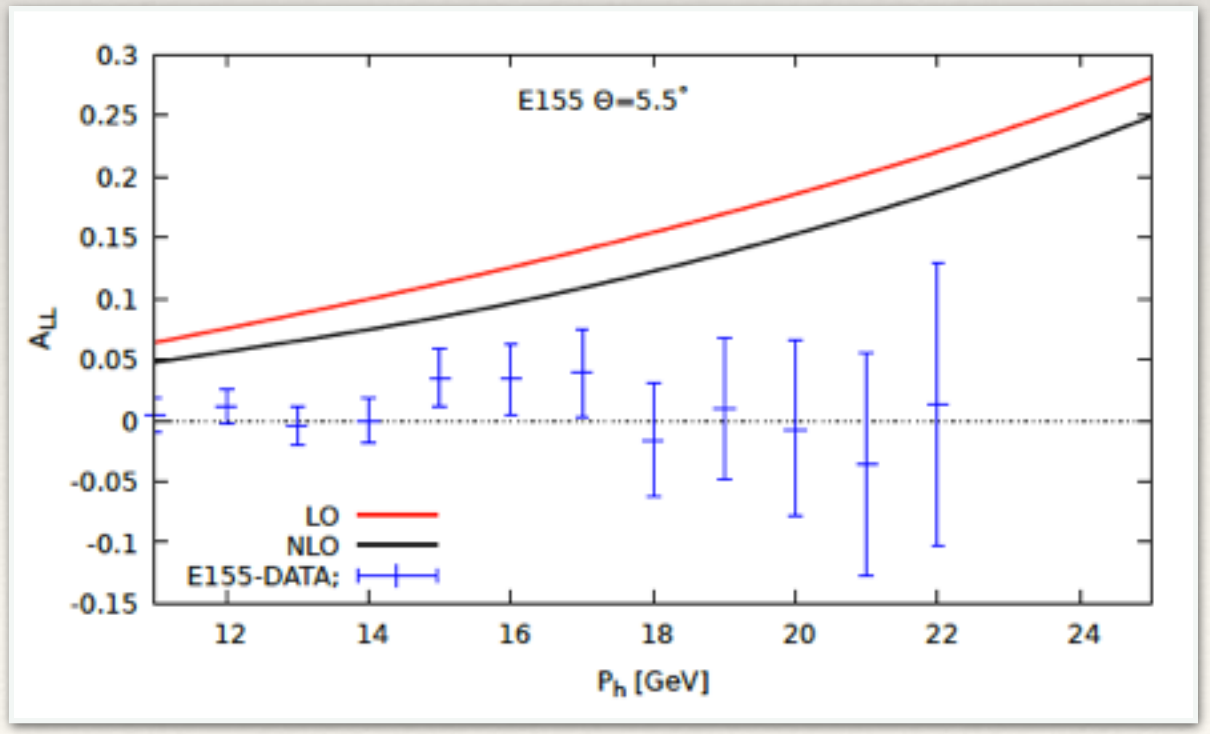


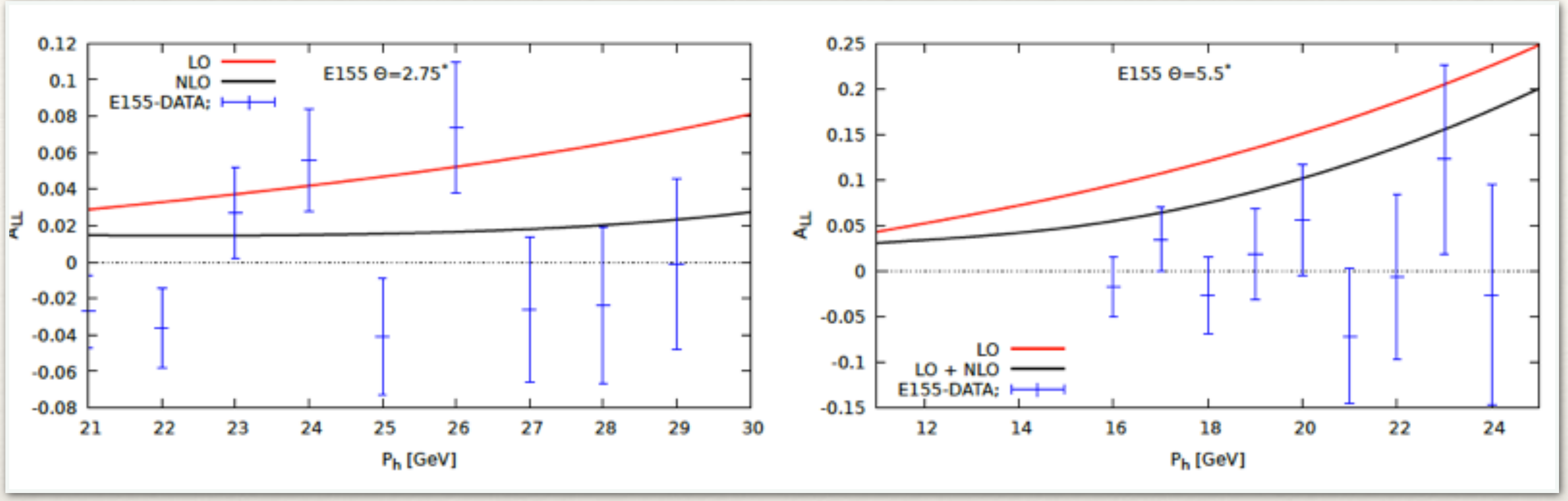
generally works (a bit) better for deuterium

$e^{\rightarrow} + D^{\rightarrow} \longrightarrow h^{+} + X$



ok agreement: more examples

$\vec{e} + \vec{D} \longrightarrow \pi^- + X$



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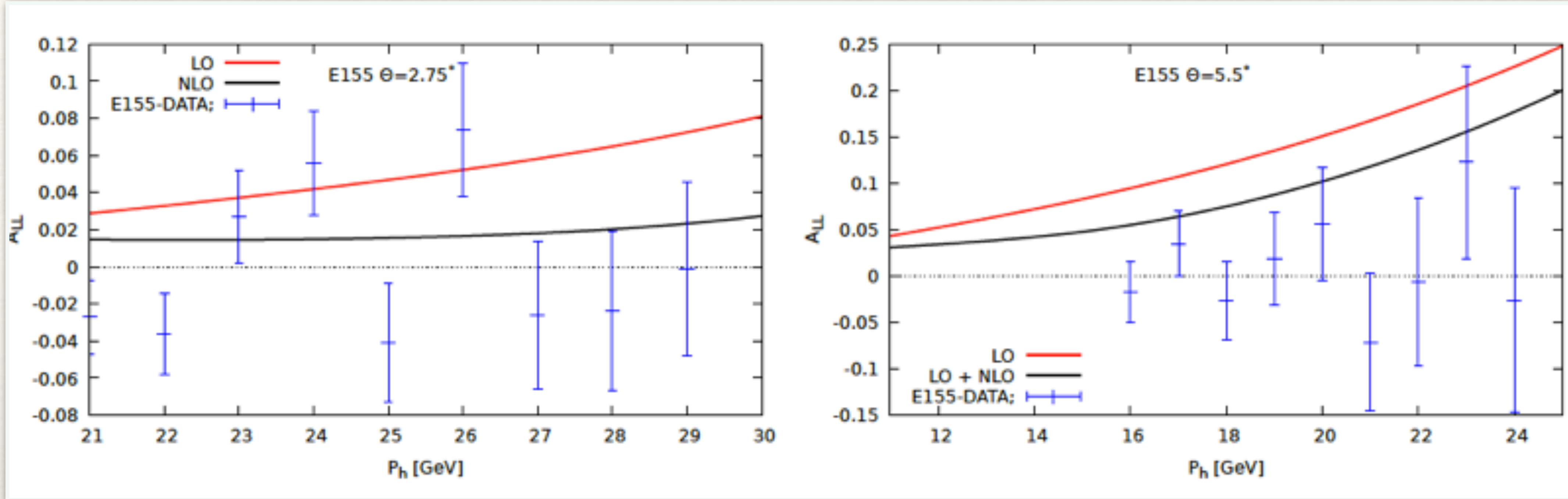

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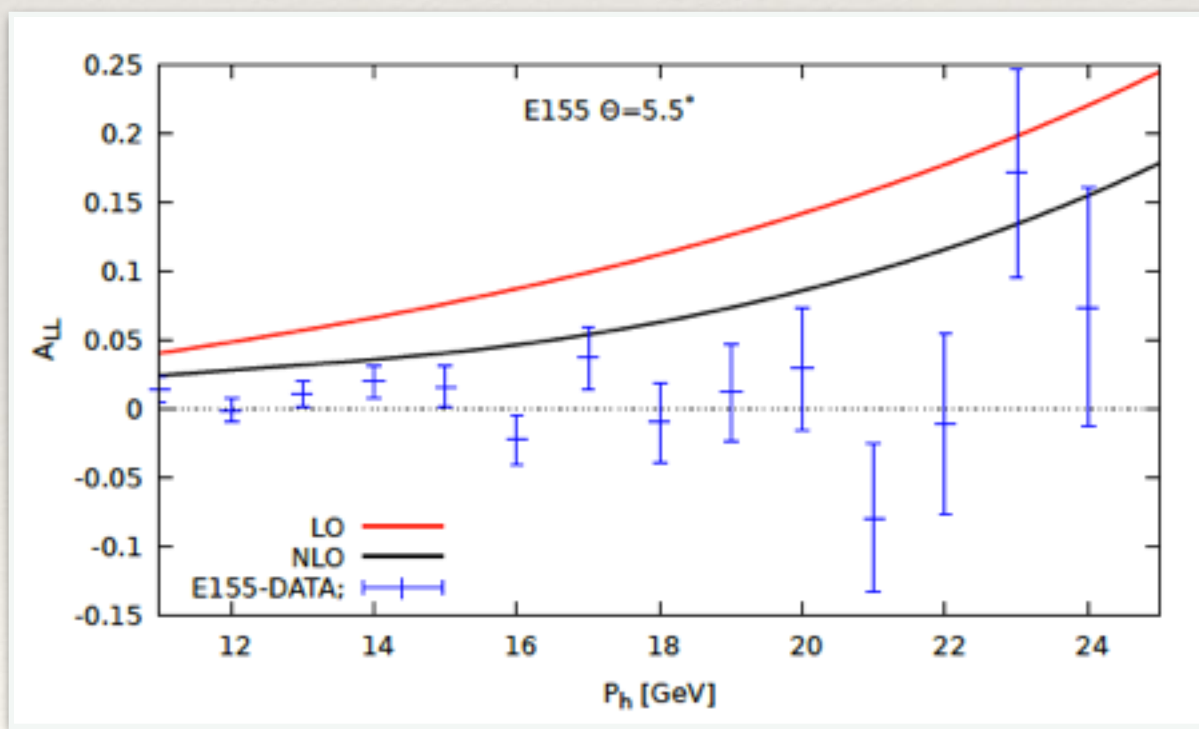

Agreement with data not satisfactory, no systematics: What's going on?

- Theory: NNLO? Higher twists ($P_T \sim$ 1-2 GeV)? Refit of helicity distributions/FFs?
- Experiment: Errors underestimated?

Situation unclear

$\Longrightarrow$ Measurements (unpol. and pol.) should be repeated at COMPASS, JLab, EIC(!)

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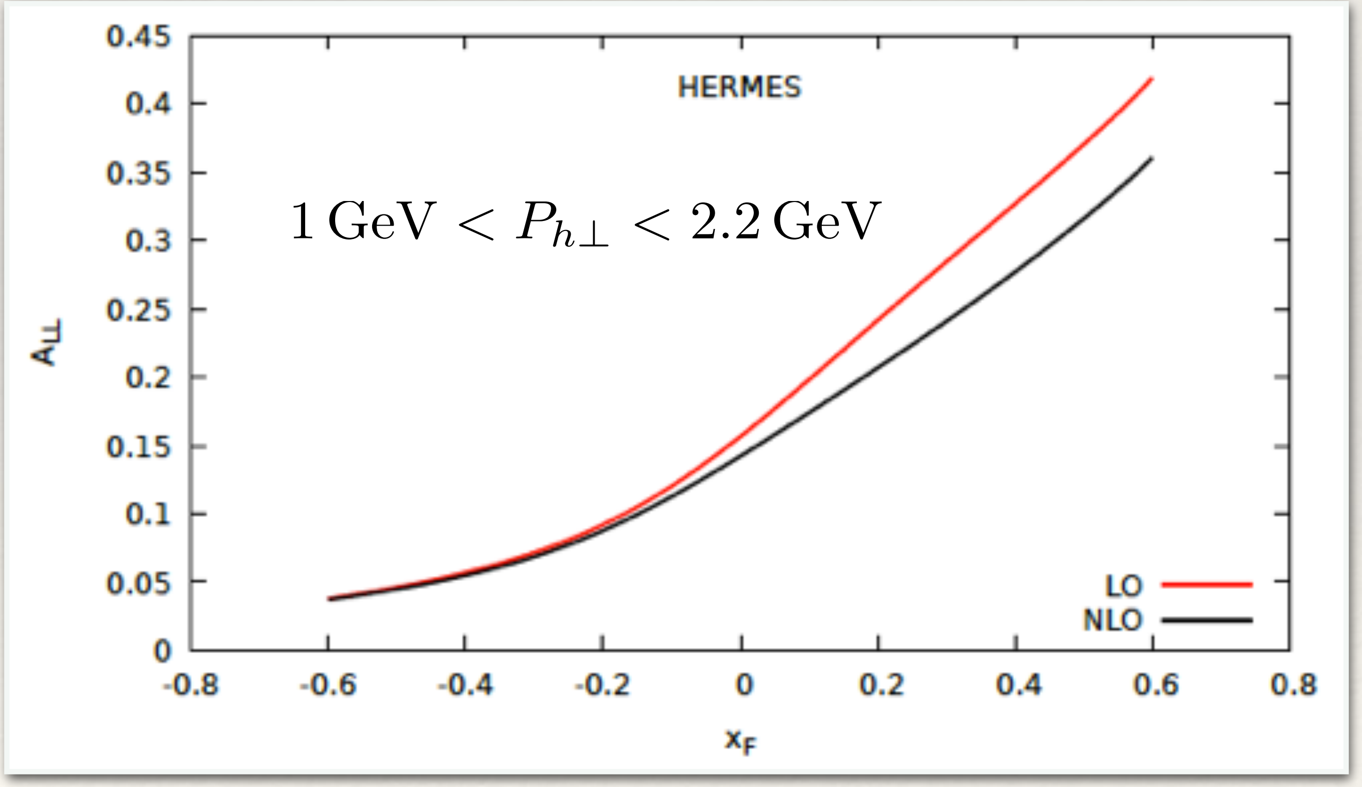
Predictions

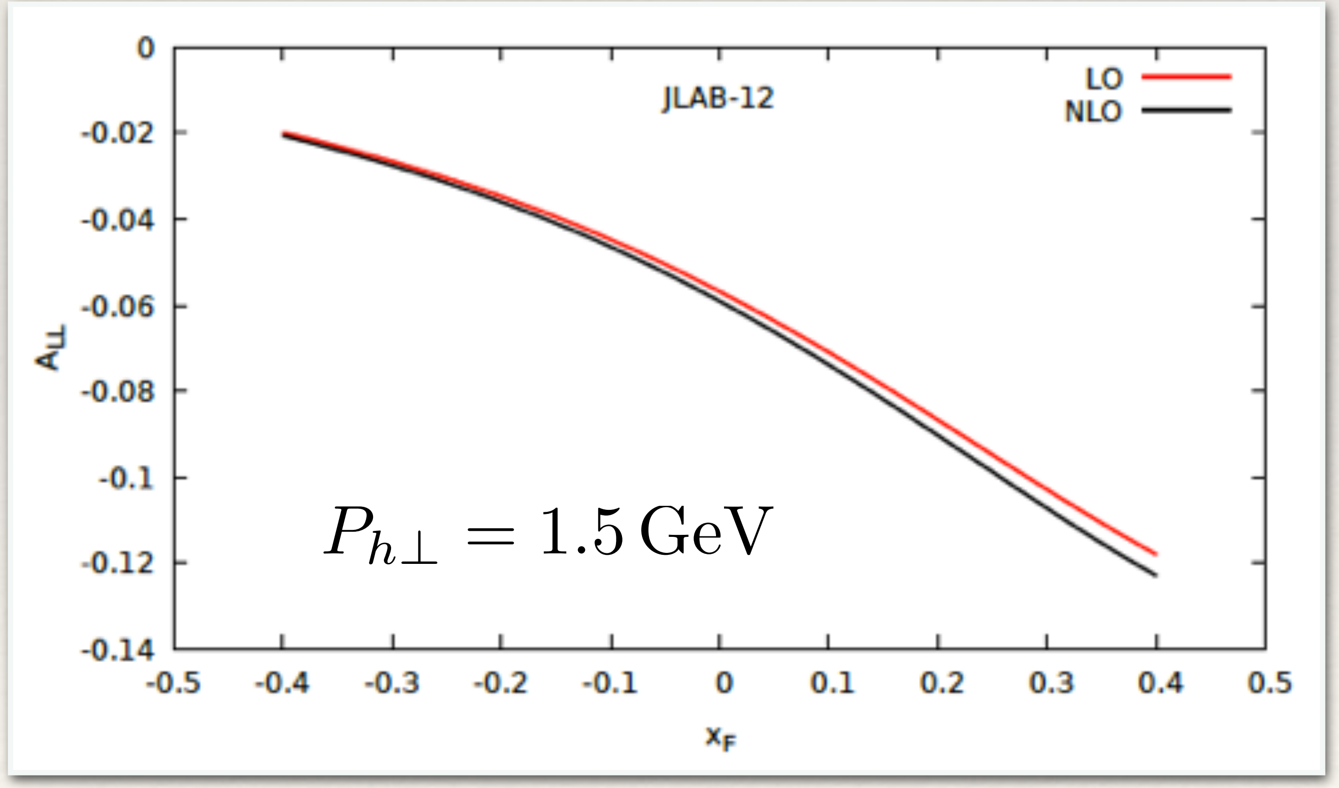
HERMES: $A_{LL} \sim$ 15%

$\vec{e} + \vec{p} \longrightarrow \pi^+ + X$

JLab12: $A_{LL} \sim$ -5%

$\vec{e} + {}^3\vec{He} \longrightarrow \pi^+ + X$

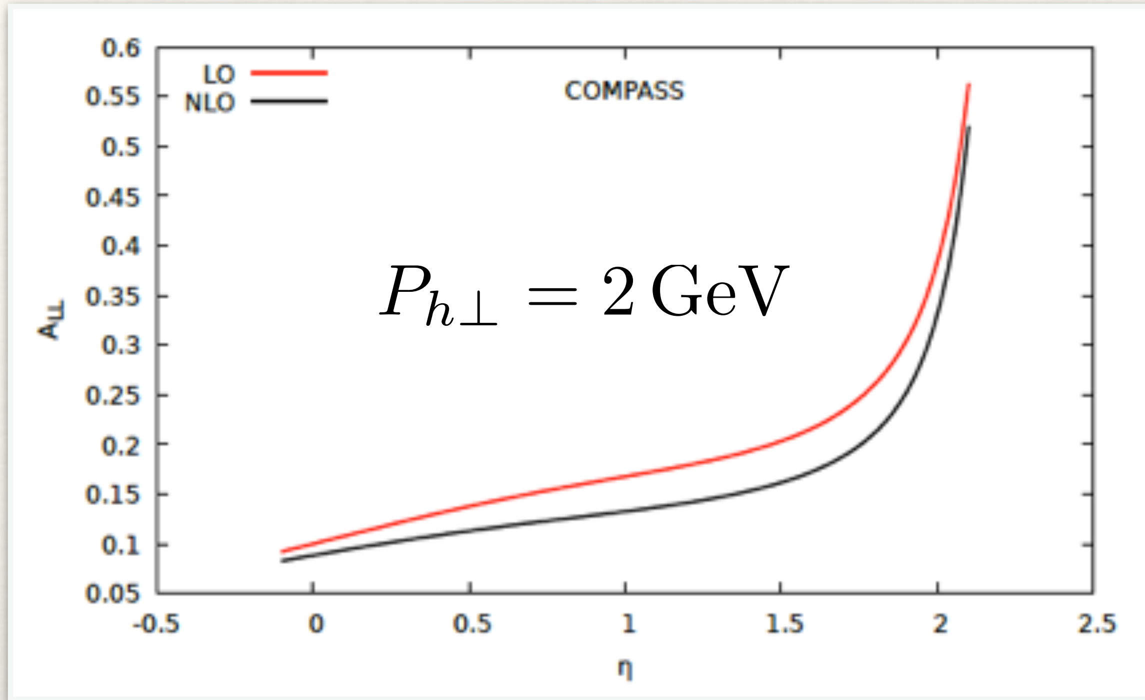




A_{LL} not very sensitive to NLO corrections

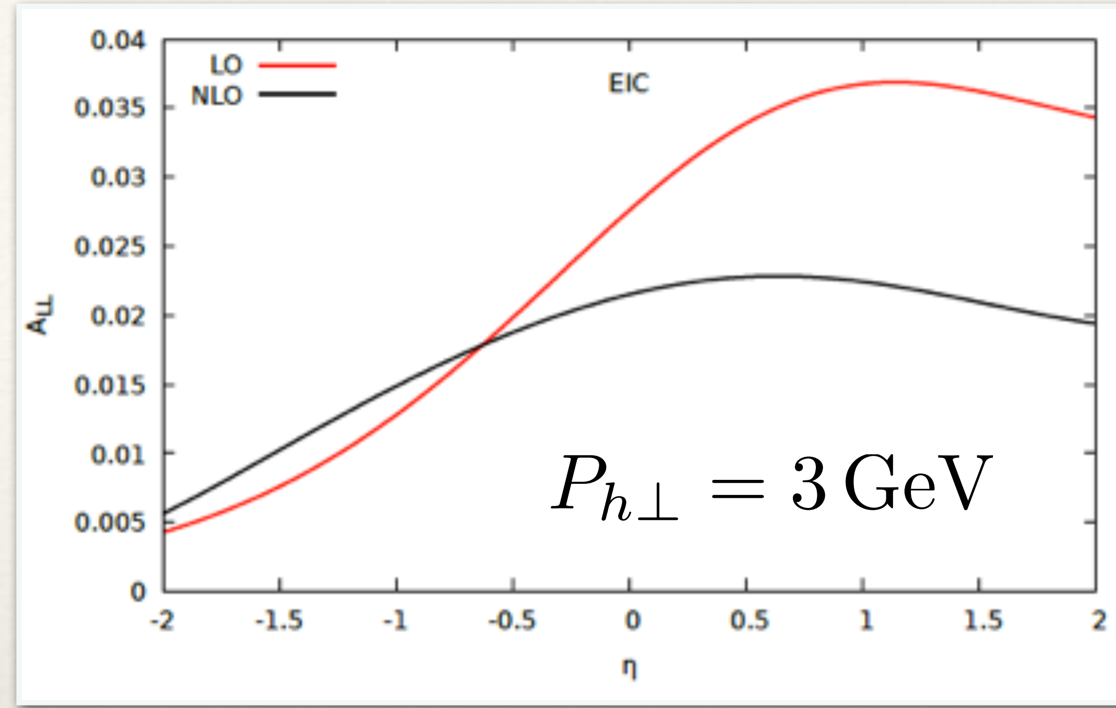
COMPASS: A_{LL} ~ 10%

$\vec{\mu} + \vec{p} \longrightarrow \pi^0 + X$



EIC: A_{LL} ~ 2.5%

$\vec{e} + \vec{p} \longrightarrow \pi^+ + X$



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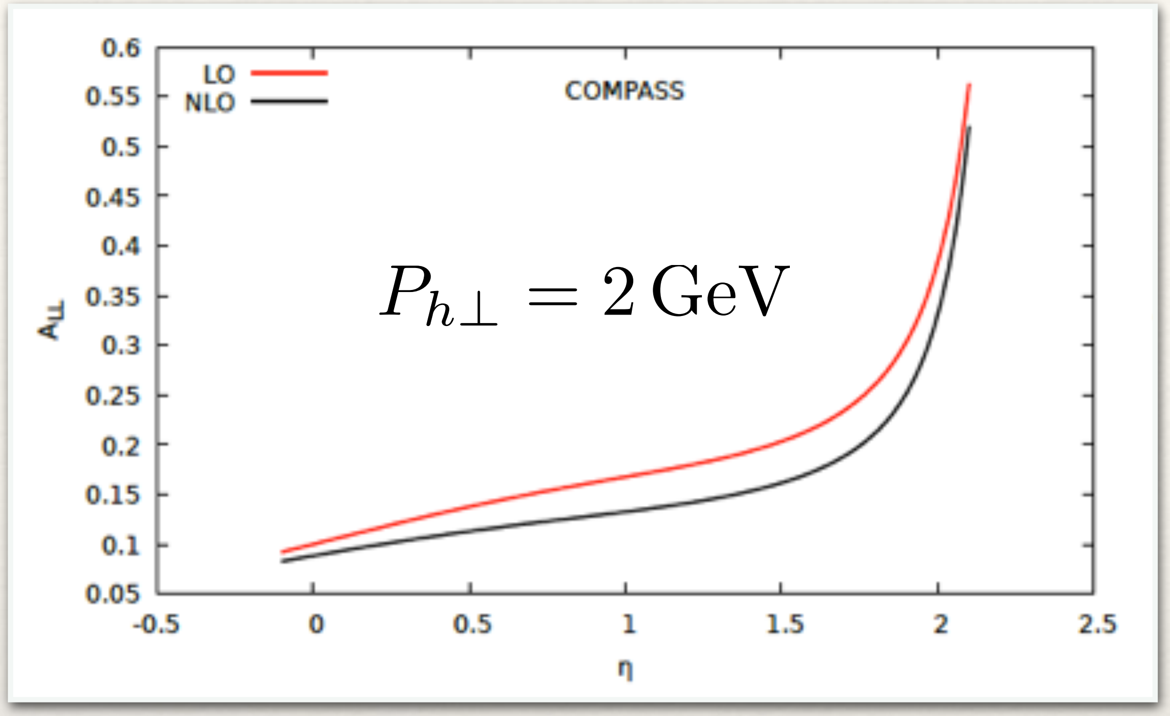

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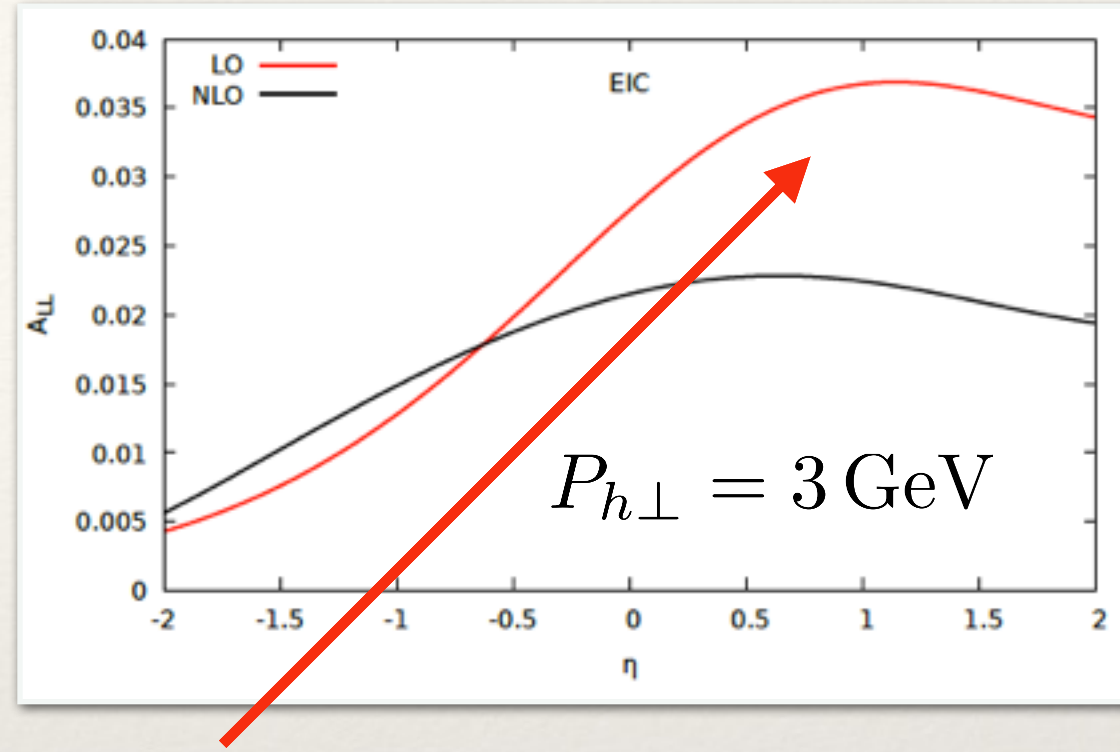

EIC: WW-contribution dominant, sensitive to $\Delta g(x)$ at NLO

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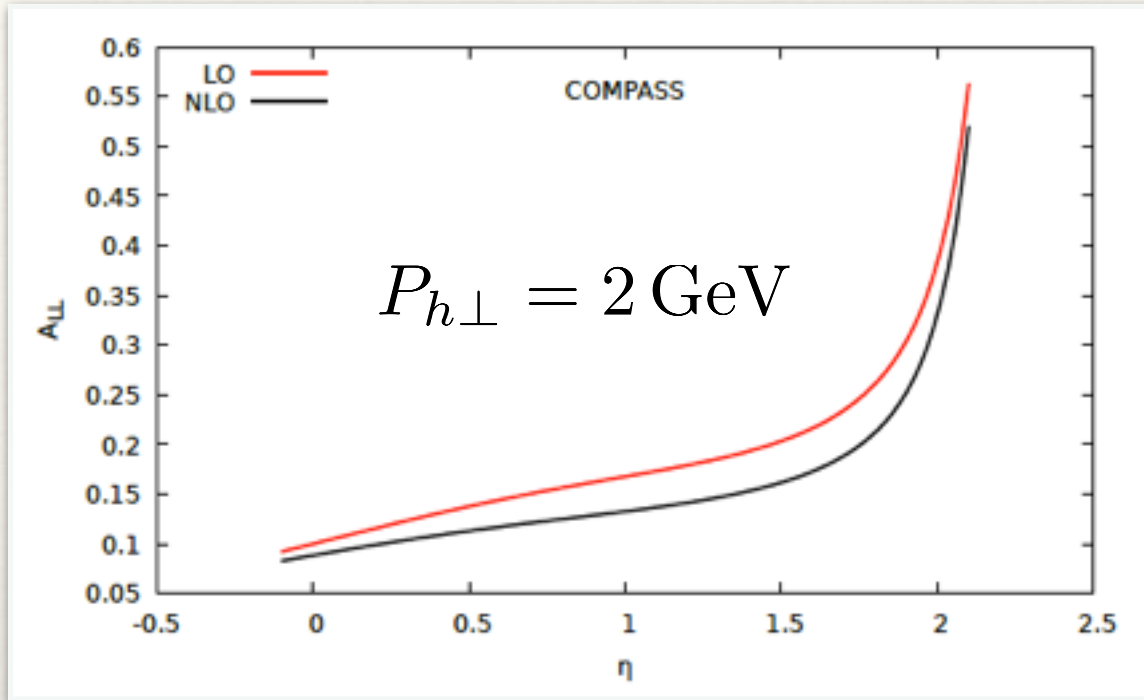

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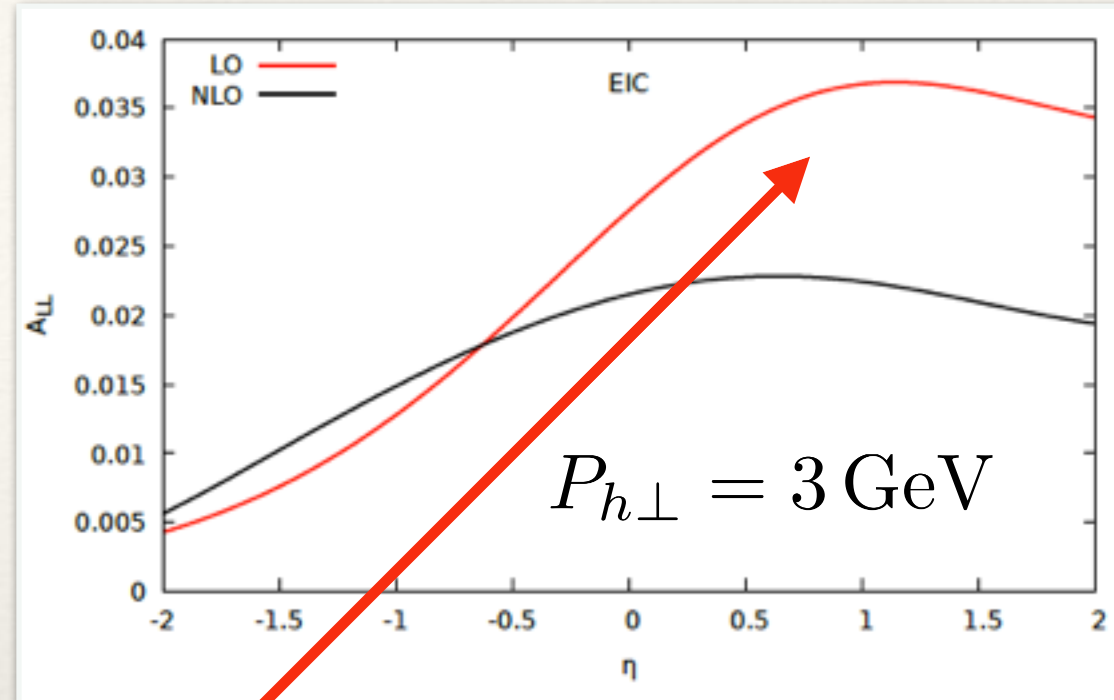
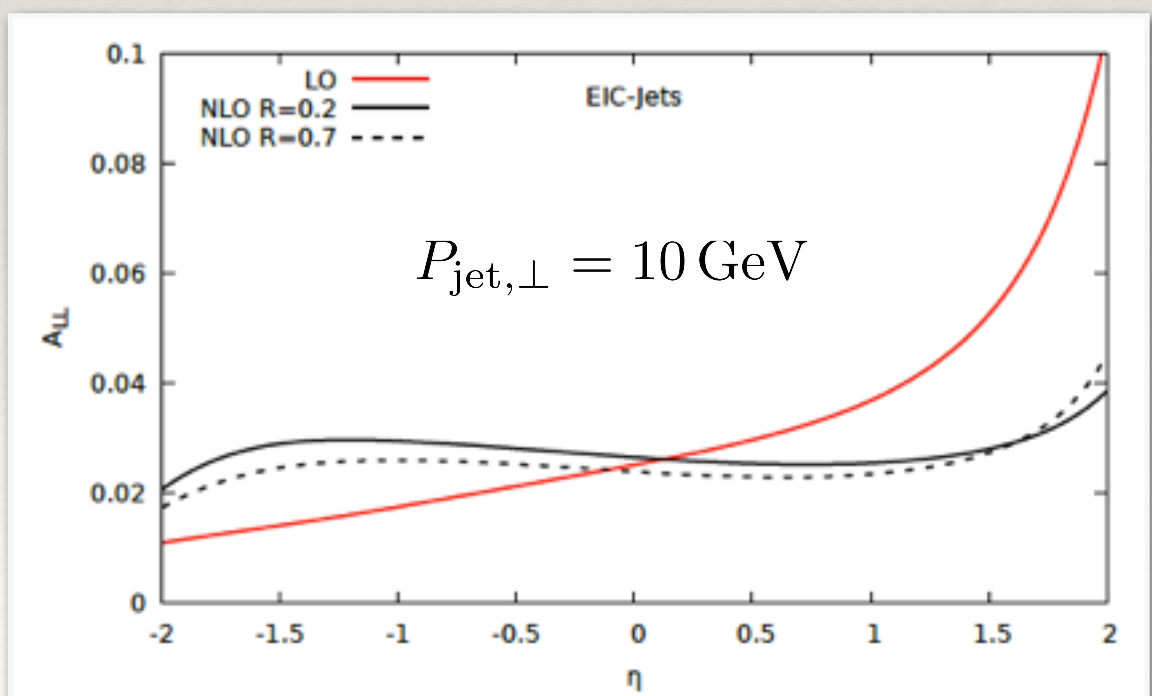


EIC: WW-contribution dominant, sensitive to $\Delta g(x)$ at NLO

Jets at EIC: A_{LL} ~ 2-3%



Summary & Outlook

- Leptoproduction of hadrons and jets nice ‘playground’ to study transverse spin effects.
- Potentially measurable at various experiments (JLab12, COMPASS, EIC).
- Unpolarized Cross Section:
  NLO corrections important, Weizsäcker-Williams (quasi-real photons) contributions typically not dominant.
- Testing the leptoprction process:
  Double-Longitudinal Spin Asymmetry at NLO
  Comparison to E155 data:
  Agreement with data only partially satisfying: Why?
  $\Longrightarrow$ Need more data
- Work in progress: Determine the effect of ‘resolved photon’ contributions