Nuclear parton density functions from jet production at an EIC

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Work done in collaboration with K. Kovarik and J. Potthoff

DFG

Graduiertenkolleg 2149
Research Training Group

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

References

Two recent publications:

- MK, K. Kovarik, J. Potthoff
  Nuclear PDFs from jet production in DIS at an EIC
  Phys. Rev. D 95 (2017) 094013 [arXiv:1703.02864]
- MK, K. Kovarik
  Nuclear PDFs from dijet photoproduction at an EIC
  Submitted to Phys. Rev. D [arXiv:1803.nnnnn]

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- MK, K. Kovarik
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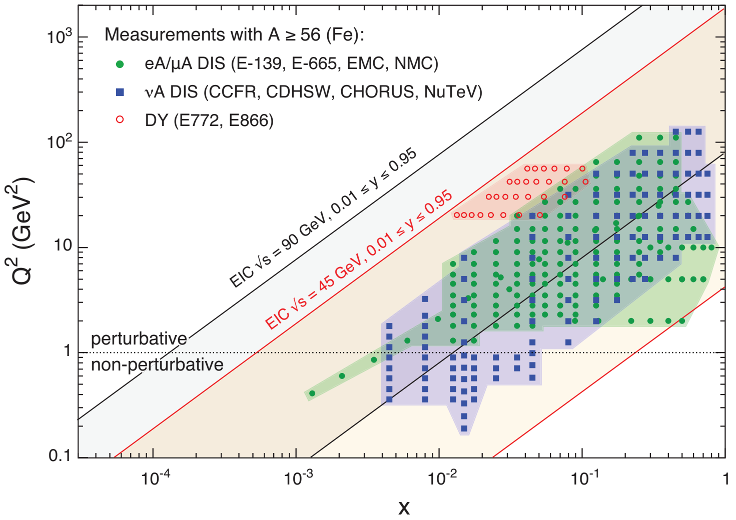
  Submitted to Phys. Rev. D [arXiv:1803.nnnnn]

Related work:

- E. Aschenauer *et al.*
  Nuclear structure functions at a future EIC
  Phys. Rev. D 96 (2017) 114005
- X. Chu *et al.*
  Photon structure studied at an EIC
  Phys. Rev. D 96 (2017) 074035

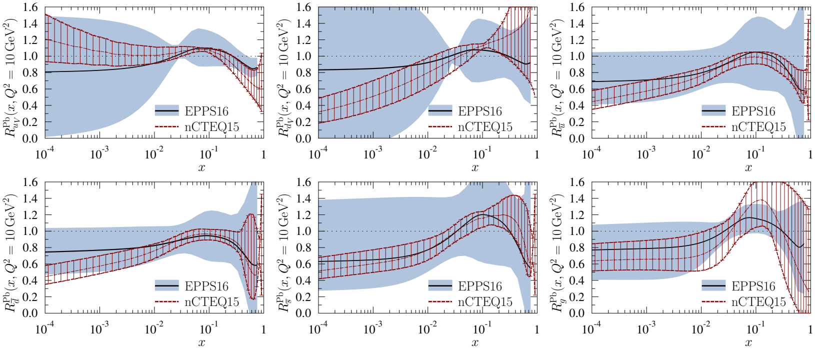
Kinematic acceptance in DIS, DY and at two EICs

EIC White Paper, 1212.1701 [nucl-ex]



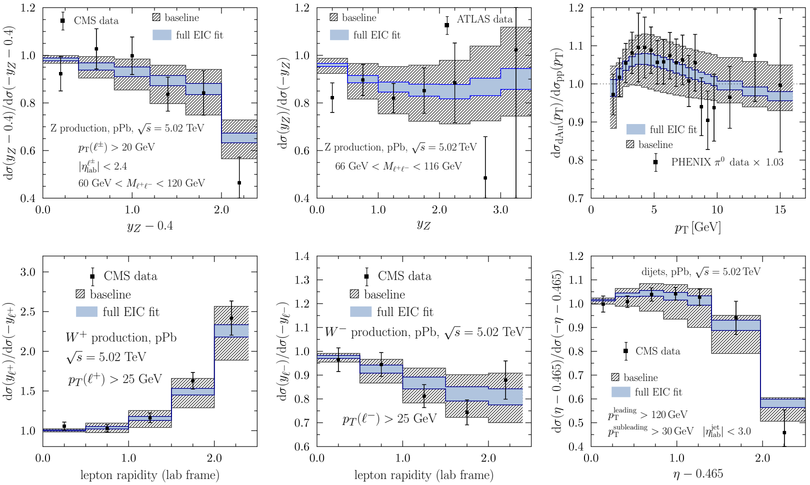
Status of nuclear PDFs (12/2016)

K. Eskola et al., Eur. Phys. J. C 77 (2017) 163



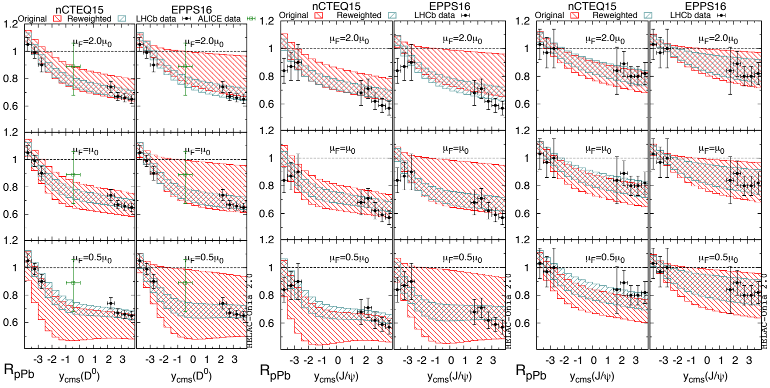
Impact of RHIC π^0 and LHC $W^\pm/Z^0$/dijet data

E. Aschenauer et al., Phys. Rev. D 96 (2017) 114005



Impact of LHC heavy quark data (1)

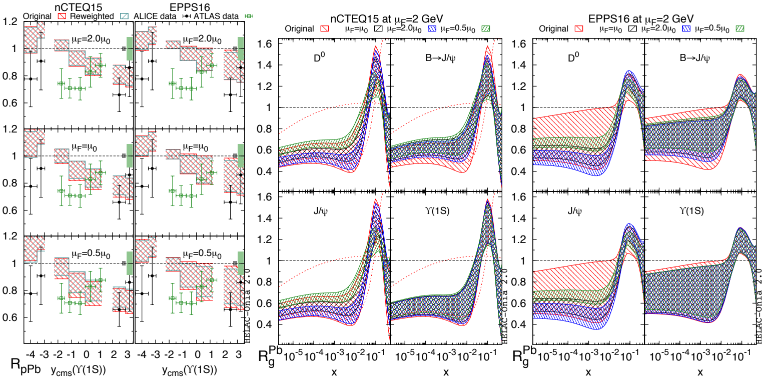
A. Kusina et al., 1712.07024



(a) Prompt D^0 (b) Prompt J/ψ (c) $B \to J/\psi$

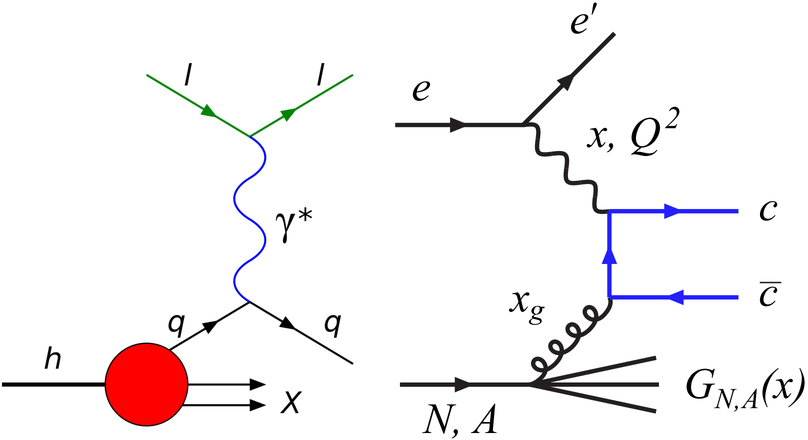
Impact of LHC heavy quark data (2)

A. Kusina et al., 1712.07024



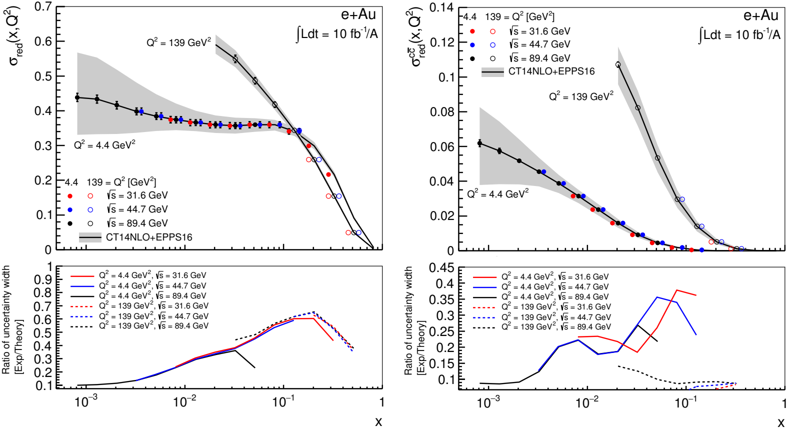
(d) $\Upsilon(1S)$ (e) nCTEQ15 nPDF (f) EPPS16 nPDF

DIS (inclusive and heavy quarks)

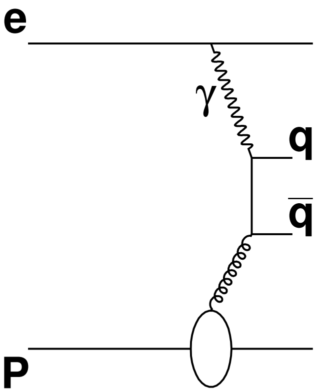


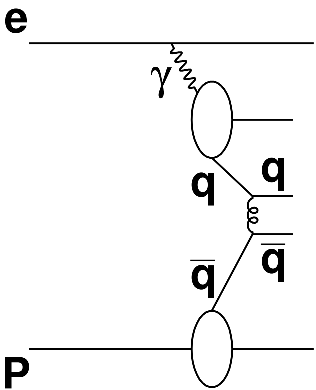
Impact of F_2 and F_2^c on nuclear PDFs

E. Aschenauer et al., Phys. Rev. D 96 (2017) 114005



Photoproduction of dijets





Current experimental and theoretical status

EIC White Paper, 1212.1701 [nucl-ex]

eRHIC conditions:

- $E_e = 16 \ldots 21$ GeV and $E_A = 100$ GeV $\rightarrow \sqrt{s} = 80 \ldots 90$ GeV
- Integrated luminosity: $\mathcal{L} = 10 \ldots 3\ \text{fb}^{-1}$

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MEIC conditions:

- $E_e = 12$ GeV and $E_A = 40$ GeV $\rightarrow \sqrt{s} = 45$ GeV
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Detector specifications:

- Electron or JB method: $Q^2 < 0.1$ $[> 1]$ GeV^2 and $0.01 \leq y \leq 0.95$
- Electromagn. (hadr.) calorimeter: $-4\,(-1) < \eta^{\rm jet} < 4$
- Jets: Anti-k_T algorithm with $R = 1$ and $p_T^{\rm jet} > 5/4.5$ [4] GeV

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Theoretical input:

- Ren./fact. scales: $\mu^2_{R/F} = \bar{p}_T^2$ [$\mu^2 = (Q^2 + p_T^2)/2$, $\mu_p^2 = Q^2$]
- Nuclear PDFs: nCTEQ15(-np) with 32 error PDFs

Unified approach to NNLO soft and virtual corrections

N. Kidonakis, Int. J. Mod. Phys. A 19 (2004) 1793

- Full NNLO calculations challenging, slowly making progress
- Soft/virtual corrections often dominant, e.g. close to threshold

$$z \equiv \frac{(p_1 + p_2)^2}{(p_a + p_b)^2} \to 1$$

- Resummation of these corrections possible to all orders
- Reexpansion gives approximate NNLO (aNNLO) results
- Results depend on 1PI or PIM kinematics, $\overline{\mathrm{MS}}$ or DIS scheme

NLO master formula

$$
\begin{aligned}
\mathrm{d}\sigma_{ab} &= \mathrm{d}\sigma_{ab}^{B}\frac{\alpha_s(\mu)}{\pi}\left[c_3 D_1(z) + c_2 D_0(z) + c_1\delta(1-z)\right] \\
&+ \frac{\alpha_s^{d_{\alpha_s}+1}(\mu)}{\pi}\left[A^c D_0(z) + T_1^c\delta(1-z)\right] \\
D_l(z) &= \left[\frac{\ln^l(1-z)}{1-z}\right]_+ \\
d_{\alpha_s} &= 0, 1, 2, ..., \text{ if Born is of } \mathcal{O}(\alpha_s^{0,1,2,\cdots})
\end{aligned}
$$

Leading coefficients (simple color flow)

QCD Compton process: $\gamma q \to qg$

$$
\begin{aligned}
c_3 &= C_F - N_C, \\
c_2 &= C_F \left[-\ln\left(\frac{\mu_p^2}{s}\right) - \frac{3}{4} + 2\ln\left(\frac{-u}{s}\right) \right] + N_C \ln\left(\frac{t}{u}\right) - \frac{\beta_0}{4}, \\
c_1^\mu &= -\frac{3C_F}{4} \ln\left(\frac{\mu_p^2}{s}\right) + \frac{\beta_0}{4} \ln\left(\frac{\mu^2}{s}\right)
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\end{aligned}
$$

Photon gluon fusion: $\gamma g \to q\bar{q}$

$$
\begin{aligned}
c_3 &= 2(N_C - C_F), \\
c_2 &= -\frac{3C_F}{2} + N_C \left[-\ln\left(\frac{\mu_p^2}{s}\right) + \ln\left(\frac{tu}{s^2}\right) \right], \\
c_1^\mu &= -\frac{\beta_0}{4} \ln\left(\frac{\mu_p^2}{s}\right) + \frac{\beta_0}{4} \ln\left(\frac{\mu^2}{s}\right).
\end{aligned}
$$

Leading coefficients (complex color flow)

Quark-(anti-)quark scattering: $qq \to qq$ and $q\bar{q} \to q\bar{q}$

$$
\begin{aligned}
c_3 &= 2C_F, \\
c_2 &= -C_F \ln\left(\frac{\mu_\gamma^2}{s}\right) - C_F \ln\left(\frac{\mu_p^2}{s}\right) - \frac{11}{2} C_F \\
c_1^\mu &= -C_F \left[\ln\left(\frac{p_T^2}{s}\right) + \frac{3}{2}\right] \ln\left(\frac{\mu_p^2}{s}\right) + \frac{\beta_0}{2} \ln\left(\frac{\mu^2}{s}\right)
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$$

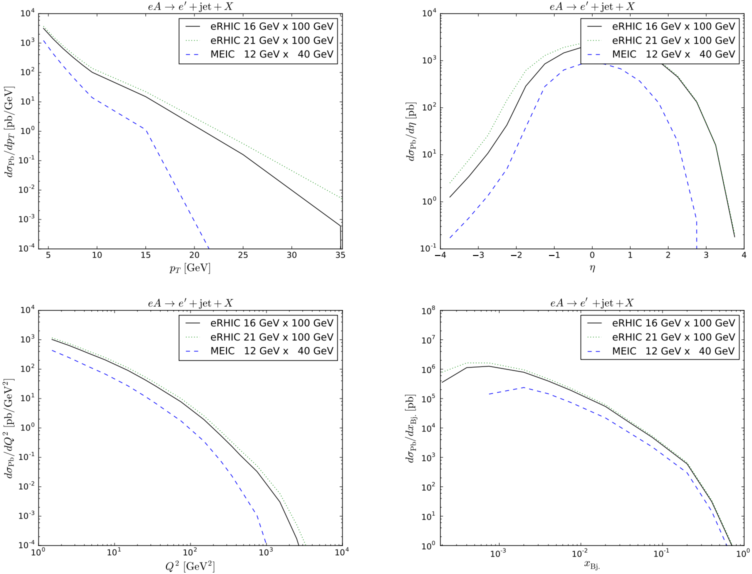
Similarly for $q\bar{q} \leftrightarrow gg$, $qg \to qg$, and $gg \to gg$.

NNLO master formula (simple color flow)

$$
\begin{aligned}
\mathrm{d}\sigma_{ab} = \; & \mathrm{d}\sigma^{B}_{ab}\frac{\alpha_s^2(\mu)}{\pi^2}\left\{\frac{1}{2}c_3^2 D_3(z) + \left[\frac{3}{2}c_3c_2 - \frac{\beta_0}{4}c_3 + \sum_j C_{f_j}\frac{\beta_0}{8}\right]D_2(z)\right. \\
& + \left[c_3c_1 + c_2^2 - \zeta_2 c_3^2 \frac{\beta_0}{2}T_2 + \frac{\beta_0}{4}c_3 \ln\left(\frac{\mu^2}{s}\right) + \ldots\right]D_1(z) \\
& + \left[c_2c_1 - \zeta_2 c_2 c_3 + \zeta_3 c_3^2 - \frac{\beta_0}{2}T_1 + \frac{\beta_0}{4}c_2 \ln\left(\frac{\mu^2}{s}\right) + \ldots\right]D_0(z) \\
& + \left.\left[\frac{1}{2}c_1^2 - \frac{\zeta_2}{2}c_2^2 + \frac{1}{4}\zeta_2^2 c_3^2 + \zeta_3 c_3 c_2 + \ldots + R\right]\delta(1-z)\right\}
\end{aligned}
$$

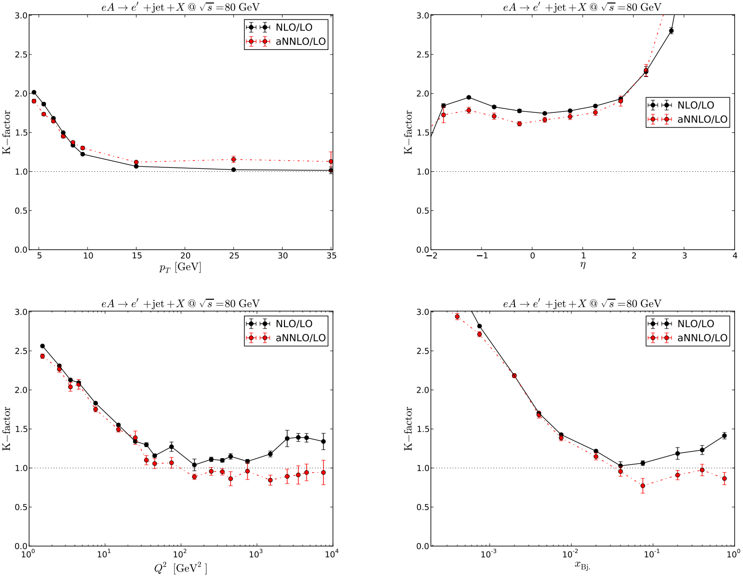
Inclusive jet production in DIS at different EICs

MK, K. Kovarik, J. Potthoff, Phys. Rev. D 95 (2017) 094013



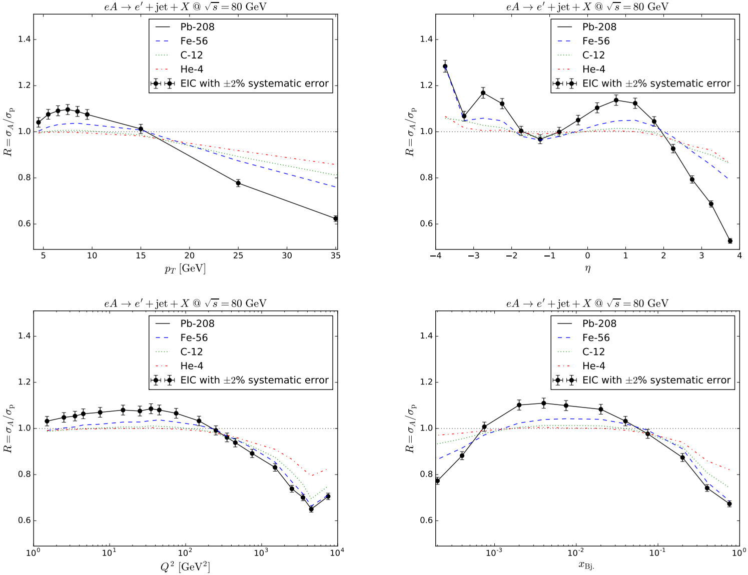
NLO and aNNLO K-factors

MK, K. Kovarik, J. Potthoff, Phys. Rev. D 95 (2017) 094013



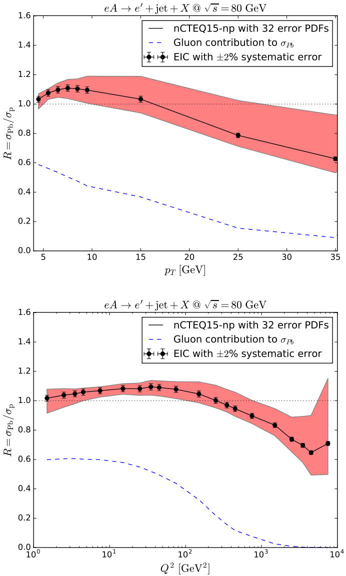
Inclusive jet production in DIS on different nuclei

MK, K. Kovarik, J. Potthoff, Phys. Rev. D 95 (2017) 094013



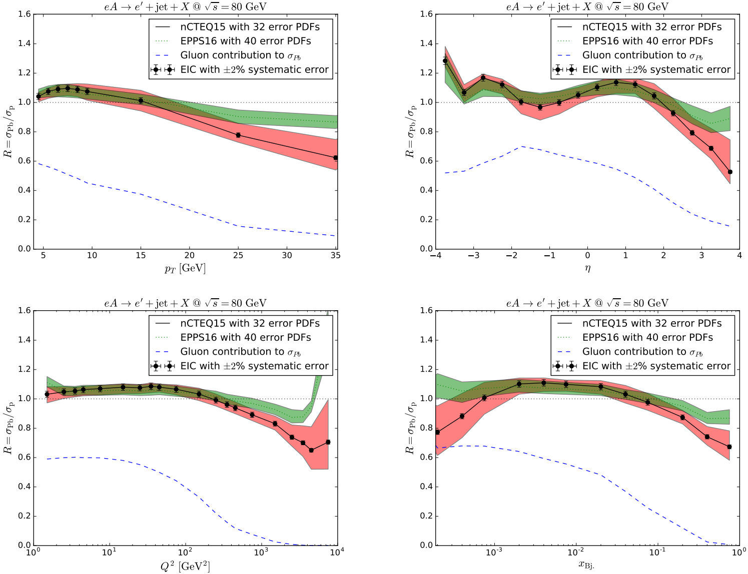
Sensitivity to nPDFs estimated with nCTEQ15-np

MK, K. Kovarik, J. Potthoff, Phys. Rev. D 95 (2017) 094013



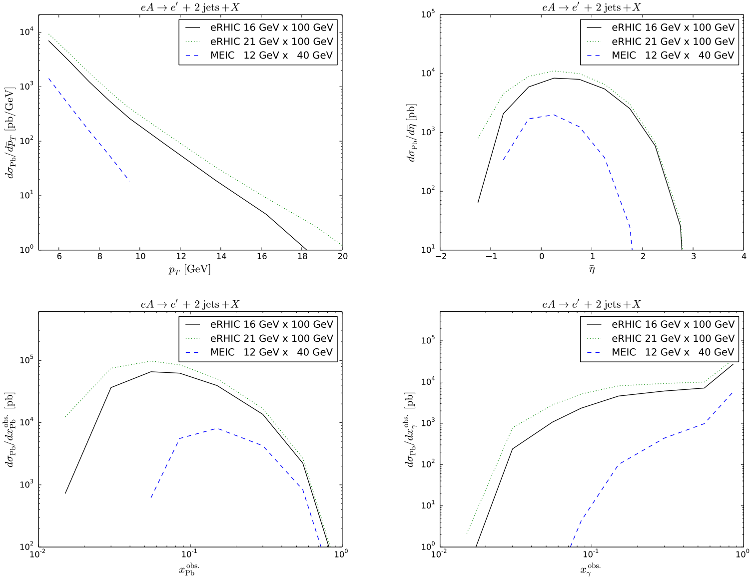
Sensitivity to nPDFs estimated with nCTEQ15/EPPS16

MK, K. Kovarik, J. Potthoff, Phys. Rev. D 95 (2017) 094013



Dijet photoproduction at different EICs

MK, K. Kovarik, in preparation



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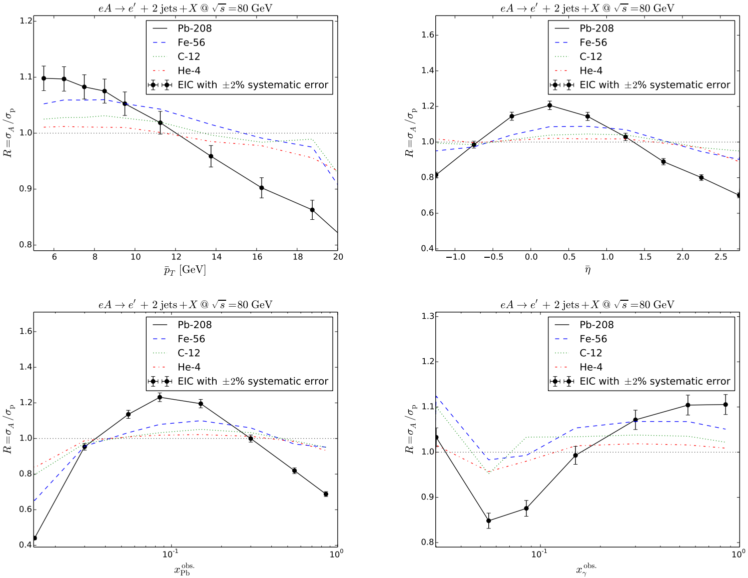

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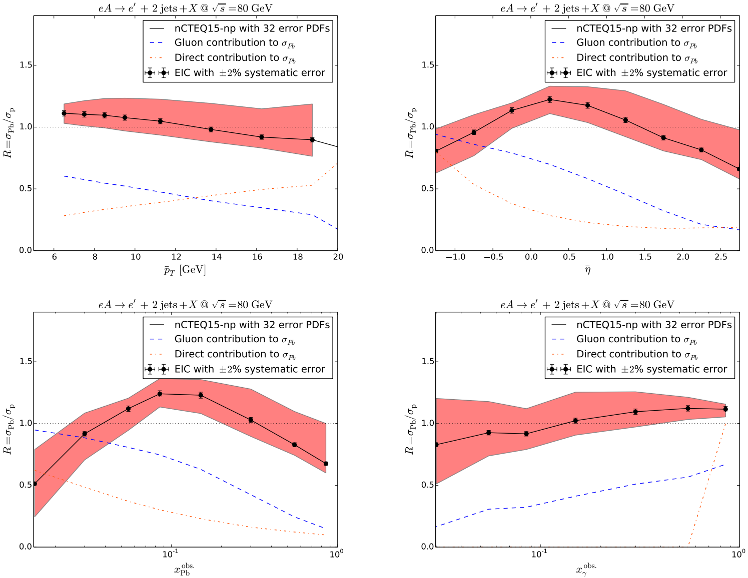

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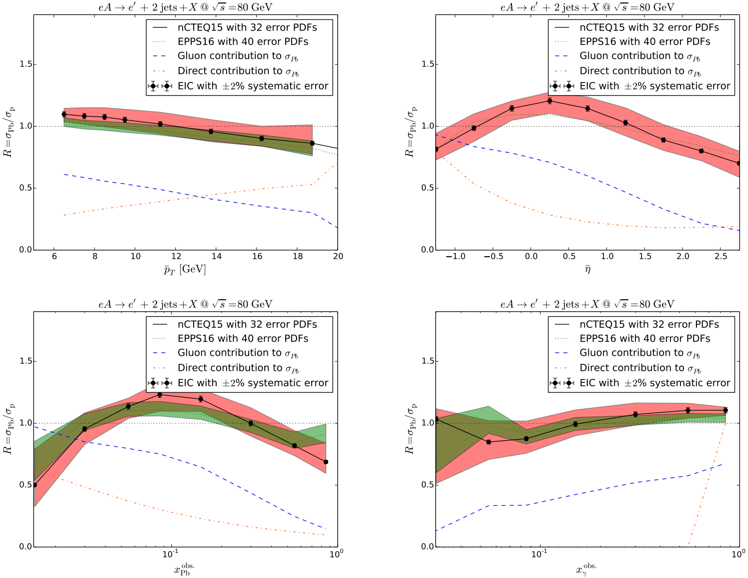

Conclusion

Theoretical approach:

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Nuclear PDFs from jets at the EIC:

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Outlook:

- Improve Kidonakis formalism to account for finite jet mass
  D. de Florian, P. Hinderer, A. Mukherjee, F. Ringer, W. Vogelsang, Phys. Rev. Lett. 112 (2014) 082001
- Full NNLO calculations, e.g. $gg \to gg$
  J. Currie, A. Gehrmann, N. Glover, J. Pires, JHEP 1401 (2014) 110