Dijets in p+Pb collisions and their quantitative constraints for nuclear PDFs

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Based mainly on

Eskola, Paukkunen, Salgado: JHEP 1310 (2013) 213
The nuclear gluon quest

- High-pT jets in p+Pb at the LHC: possible resolution to the nuclear-gluon controversy?

- EPS09 and nCTEQ: RHIC pion data suggests gluon antishadowing and EMC effect

\[ E \frac{d^3\sigma^H}{dp^3} = \sum_{a,b,c} f_a(x_a, \mu_f) \otimes f_b(x_b, \mu_f) \otimes D^H_c(z_c, \mu_f') \otimes d\sigma_{ab->cX} \]

- DSSZ: Nuclear modifications in fragmentation functions - no effects in gluons PDFs.

- HKN07: No pion data at all - almost no gluon constraints
Kinematics of the CMS dijet measurement

- Dijets binned in dijet “pseudorapidity” ...

\[ \eta_{\text{dijet}} \equiv (\eta_1 + \eta_2)/2. \]

... and normalized to the total yield

- Advantage of large pT:
  
  non-perturbative corrections less important

Proton beam with \( E_p = 4 \text{ TeV} \)

Lead beam with \( E_{\text{Pb}} = (82/208) \times 4 \text{ TeV} = 1.58 \text{ TeV} \)

\[ \begin{array}{c}
\text{Pb} \\
\text{p} \\
\end{array} \]

The midrapidity shifts by

\[ \eta_{\text{shift}} \equiv 0.5 \log \left( \frac{E_{\text{Pb}}}{E_p} \right) \approx -0.465 \]

Some extra “tweaking” needed to include such shifts to NLO Monte-Carlos
Large NLO correction and scale uncertainty for the absolute spectrum (no cut on dijet mass)

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Normalize by the total cross section

Normalized distribution (in the central region) stable against QCD corrections

Reduction of the baseline errors

Expect also the non-perturbative corrections (underlying event, hadronization) to partly cancel
Comparison to the preliminary data

\[ \sqrt{s} = 5.02 \text{TeV} \]

Data points from arXiv:1401.4433 "by eye"
CT10 alone is close but not quite...
Comparison to the preliminary data

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- CT10+DSSZ: almost no effects
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CT10+DSSZ: almost no effects...
CT10+HKN07: wrong corrections...

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The data support gluon antishadowing + EMC effect

Predicted in EPS09 by low-pT RHIC pion data

Valence quarks become important here – constraints for the up vs. down flavor separation?
The Hessian reweighting

- **Standard Hessian method to quantify PDF errors**

\[
\chi^2\{a\} = \sum_k \left[ \frac{X^\text{theory}_k[f] - X^\text{data}_k}{\delta^\text{data}_k} \right]^2 \approx \chi^2_0 + \sum_{ij} \delta a_i H_{ij} \delta a_j \approx \chi^2_0 + \sum_i z_i^2
\]

- **In the case of a global tolerance, the error sets are defined in the \( z \) space**

\[
z(S_0) = (0, 0, \ldots, 0), \quad z(S_1^+) = \pm \sqrt{\Delta \chi^2} (1, 0, \ldots, 0) \\
z(S_2^+) = \pm \sqrt{\Delta \chi^2} (0, 1, \ldots, 0) \\
\vdots \\
z(S_{N_{\text{eig}}}^+) = \pm \sqrt{\Delta \chi^2} (0, 0, \ldots, 1)
\]

- **Add the contribution of new data \( \{y\} \) (with covariance matrix \( C \)) to the expression above**

\[
\chi^2_{\text{new}} \equiv \chi^2_0 + \sum_k z_k^2 + \sum_{i,j=1}^{N_{\text{data}}} (y_i[f] - y_i) C_{ij}^{-1} (y_j[f] - y_j)
\]

and estimate the theory values \( y_i[f] \) by

\[
y_i[f] \approx y_i[S_0] + \left. \sum_{k=1}^{N_{\text{eig}}} \frac{\partial y_i[S]}{\partial z_k} \right|_{S=S_0} z_k \approx y_i[S_0] + \sum_{k=1}^{N_{\text{eig}}} D_{ik} w_k
\]

\[
D_{ik} \equiv \frac{y_i\left[S_k^+\right] - y_i\left[S_k^-\right]}{2}
\]

\[
w_k \equiv \frac{z_k}{\sqrt{\Delta \chi^2}}
\]
The Hessian reweighting

The new global minimum is obtained by the matrix equation

\[ B_{kn} = \sum_{i,j} D_{ik} C_{ij}^{-1} D_{jn} + \Delta \chi^2 \delta_{kn} \]

\[ \tilde{w}_{\min} = -B^{-1} \tilde{a} \]

The corresponding set of PDF is given by

\[ a_k = \sum_{i,j} D_{ik} C_{ij}^{-1} (y_j [S_0] - y_j) \]

The new \( \chi^2 \) can be written as

\[ \chi^2_{\text{new}} = \chi^2_{\text{new}} \bigg|_{\tilde{w} = \tilde{w}_{\min}} + \sum_{ij} \delta w_i B_{ij} \delta w_j \]

...and the new PDF error sets defined by diagonalizing the new “Hessian matrix” B

Estimates the effect of new data in a global PDF fit
Effect on EPS09?

- All uncertainties taken as uncorrelated and lifted from arXiv:1401.4433
- The baseline (CT10NLO) errors accounted for as correlated systematic errors

Relatively small effects – only a moderate variation in $\chi^2$ for different PDF eigenvectors
Effect on EPS09?

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- Give these data more weight to better see the tendency

- The data appear completely consistent with EPS09 – would improve the large-x gluons

Could substitute the RHIC pion data
Forward-to-backward asymmetry extracts the nuclear modification explicitly

Even more robust against NNLO corrections!
Baseline > 1 for asymmetric cuts in the c.m. frame

Need the correlated data systematics to fully use the forward-to-backward ratios
Summary

- The data from LHC p+Pb run expected to probe various aspects of nPDFs

  Are they really universal?

- Already the very first CMS dijet data appears to distinguish between available parametrizations

  Suggests antishadowing and EMC effect for gluons

- The effect of CMS dijet data for EPS09 estimated by PDF reweighting technique

  Consistent with EPS09

  Would provide constraints for large-x gluons

- To get most out of the p+Pb jet data need the systematic data correlations

  In the same way as in p+p