Impact of CMS 5.02 TeV dijet measurements on gluon PDFs

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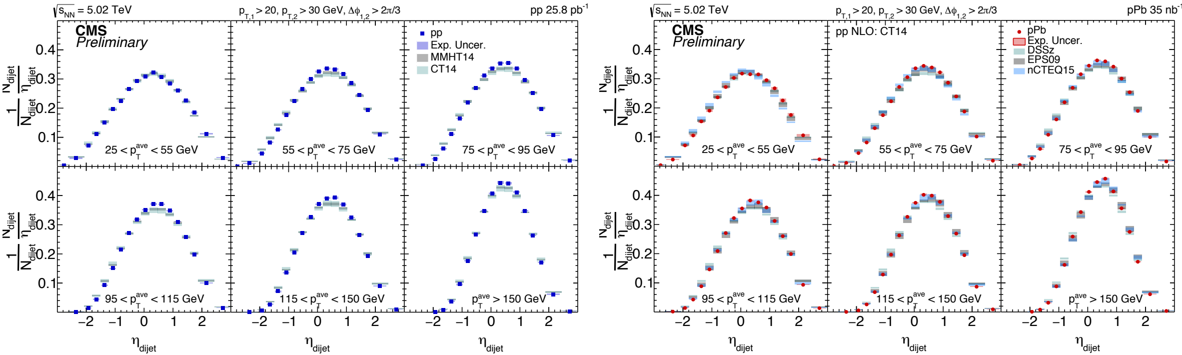
CMS 5.02 TeV pp and pPb dijets (*Preliminary data*)

- Data given as $\eta_{\rm dijet} = \frac{\eta^{\rm leading}+\eta^{\rm subleading}}{2}$ distributions in bins of $p_{\rm T}^{\rm ave} = \frac{p_{\rm T}^{\rm leading}+p_{\rm T}^{\rm subleading}}{2}$
  (pp data shifted to pPb nucleon–nucleon center-of-mass frame)



- [CMS PAS HIN-16-003]: predicted distributions from NLO calculations with different PDFs significantly wider than the data
- **This talk**: study the impact of these data first on CT14 and then on EPPS16 PDFs using Hessian reweighting (aka profiling) with NLO calculations

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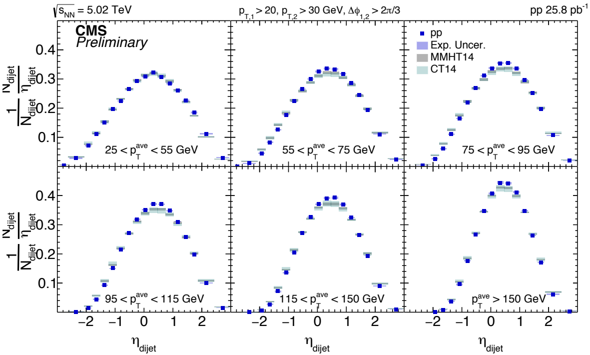
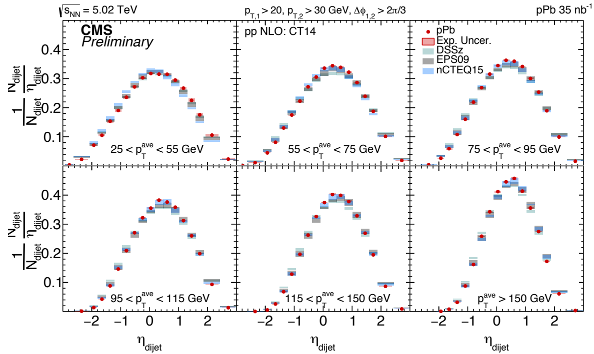
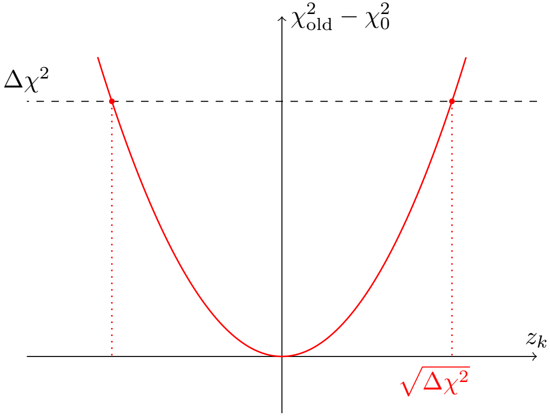


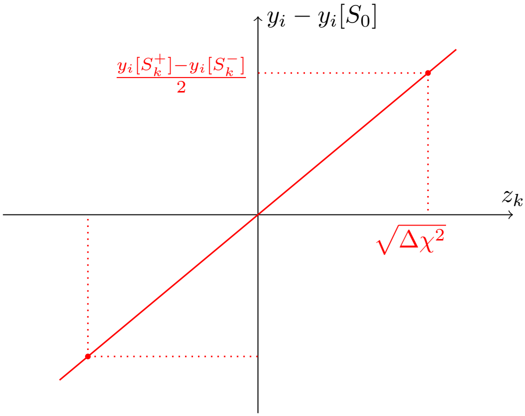


- [CMS PAS HIN-16-003]: predicted distributions from NLO calculations with different PDFs significantly wider than the data
- **This talk**: study the impact of these data first on CT14 and then on EPPS16 PDFs using Hessian reweighting (aka profiling) with NLO calculations
- Disclaimer: preliminary data read from plot — uncertainties might not be extracted reliably

PDF reweighting: different approximations

$$\chi^2_{\mathsf{new}}(\mathbf{z}) = \chi^2_{\mathsf{old}}(\mathbf{z}) + \sum_{ij} \left(y_i(\mathbf{z}) - y_i^{\mathsf{data}}\right) C_{ij}^{-1} \left(y_j(\mathbf{z}) - y_j^{\mathsf{data}}\right)$$





quadratic–linear: $\chi^2_{\mathsf{old}} \approx \chi^2_0 + \sum_k z_k^2,$

$y_i \approx y_i[S_0] + \sum_k d_{ik} z_k$

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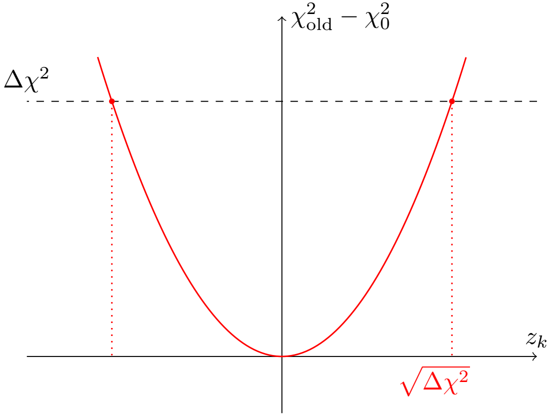

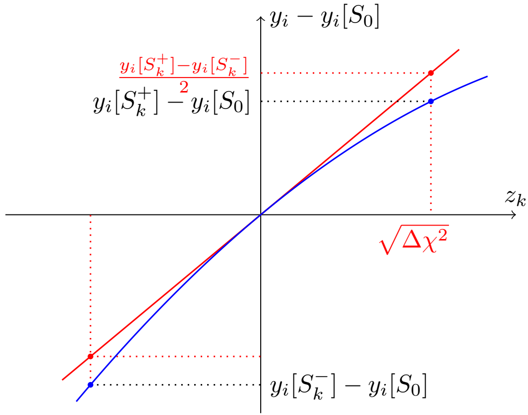

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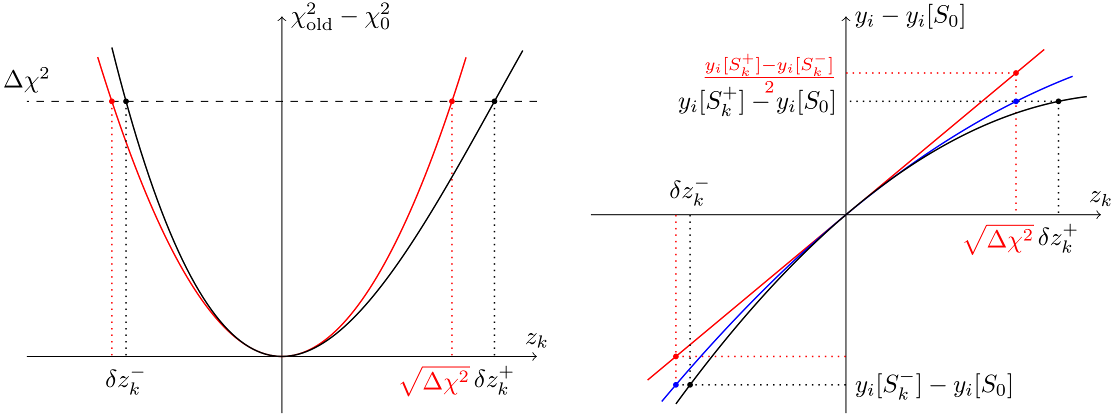

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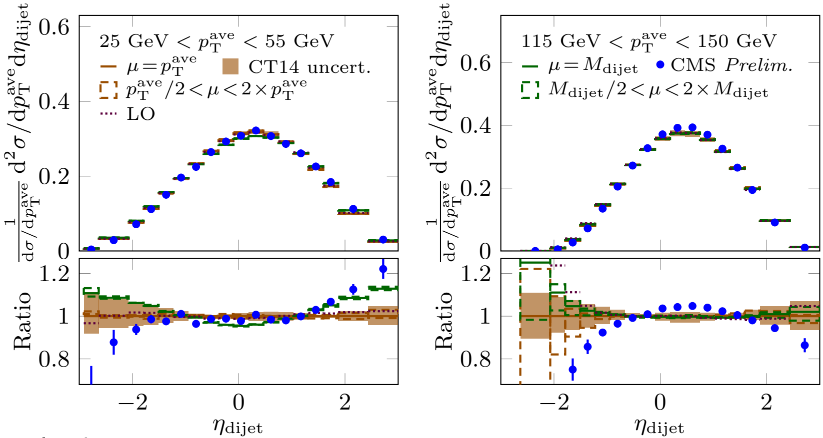
cubic–quadratic: $\chi^2_{\text{old}} \approx \chi^2_0 + \sum_k (a_k z_k^2 + b_k z_k^3)$, $\quad y_i \approx y_i[S_0] + \sum_k (d_{ik} z_k + e_{ik} z_k^2)$



Showing two scale choices:

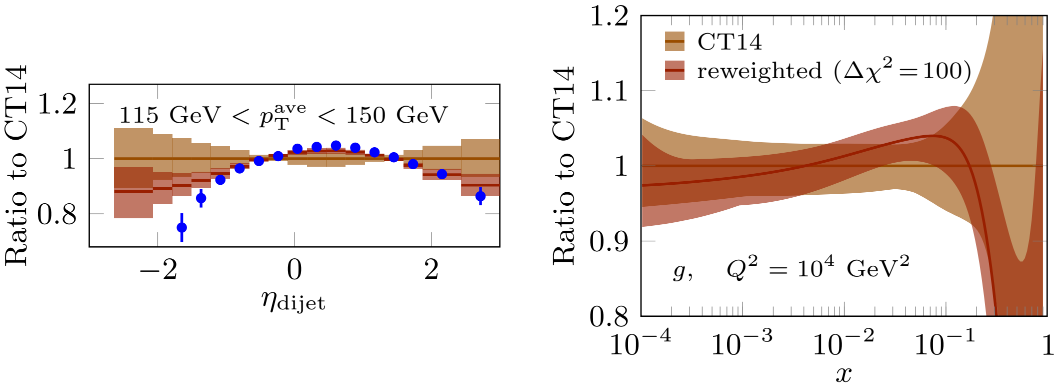
- $\mu = p_T^{ave}$ commonly used for dijets
- $\mu = M_{dijet}$ argued to have better perturbative convergence [Currie *et al.* PRL 119, 152001 (2017)]

Neither reproduces the data in all kinematic regions!

- High-p_T^{ave} midrapidity robust against scale variations and LO-to-NLO effects
  - → Hard to accommodate discrepancy with NNLO corrections

pp: CT14 reweighted (with **quadratic–quadratic** approximation)

using CT14nlo proton PDFs



Reweighting (using $\mu = p_T^{ave}$ and excluding the lowest-p_T^{ave} bin with large scale uncertainty):

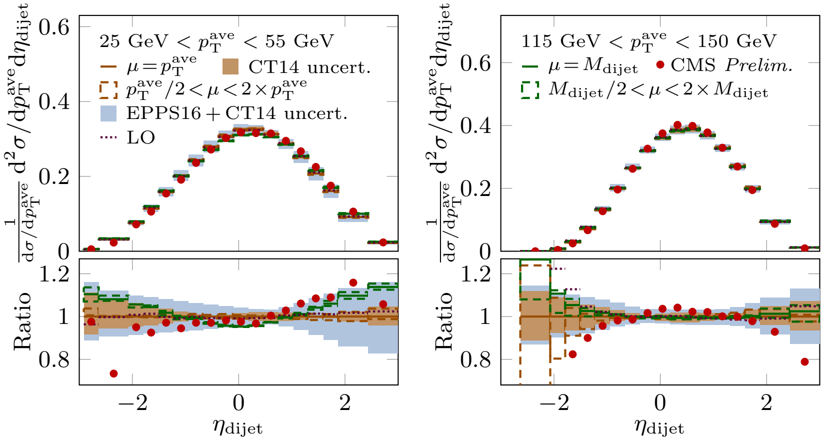
- cures the midrapidity discrepancy
- is not able to reproduce data at large rapidities

high-x parametrization issue? NNLO? threshold resummation?

Significant gluon modifications needed especially at large x

- Similar effects seen when including high luminosity 7 TeV jet data in MMHT PDFs
  [Harland-Lang *et al.* Eur.Phys.J. C78 (2018) no.3, 248]
- Reminder: data uncertainties possibly underestimated here!

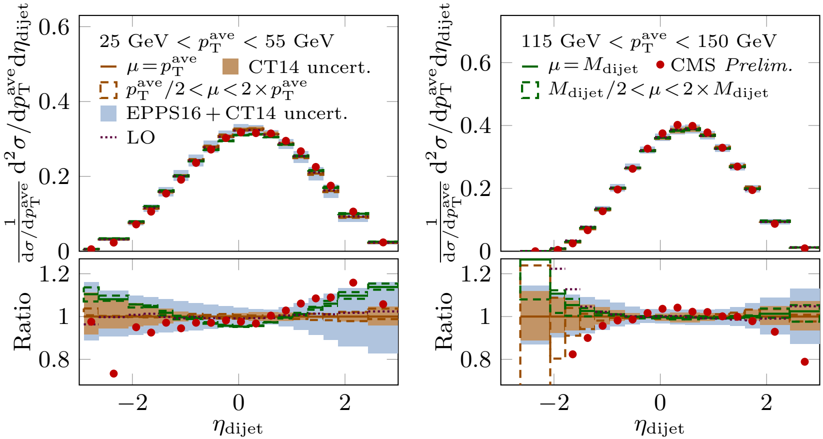
pPb: low vs. high p_T^{ave}



- pPb data deviates from NLO calculations *the same way* as the pp data
- Data mostly within the combined EPPS16+CT14 uncertainty, *but*. . .
- Using these data directly in nuclear PDF analysis with CT14 proton PDFs would lead to
  - overestimating nuclear effects
  - large scale-choice bias

pPb: low vs. high p_T^{ave}

using CT14nlo proton PDFs
and EPPS16 nuclear modifications



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➔ Need a way to mitigate these

pPb: two ways to reduce uncertainties

- Forward-to-backward ratio

$$R_{\mathrm{FB}} = \frac{\frac{1}{\mathrm{d}\sigma^{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}}\,\mathrm{d}^2\sigma^{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}\mathrm{d}\eta_{\mathrm{dijet}}(\eta_{\mathrm{dijet}} - \eta_{\mathrm{shift}})}{\frac{1}{\mathrm{d}\sigma^{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}}\,\mathrm{d}^2\sigma^{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}\mathrm{d}\eta_{\mathrm{dijet}}(\eta_{\mathrm{shift}} - \eta_{\mathrm{dijet}})}$$

  - $\eta_{\mathrm{shift}} \neq 0$ to account for $\mathrm{CMS}_{\text{nucleon–nucleon}} \neq \mathrm{LAB}$ in pPb
    - ➔ maximally cancel proton-PDF uncertainties
  - Lose some information — only sensitive to low-to-high-x correlation of nuclear PDFs
  - Best option (used in EPPS16) when no pp baseline measurement available

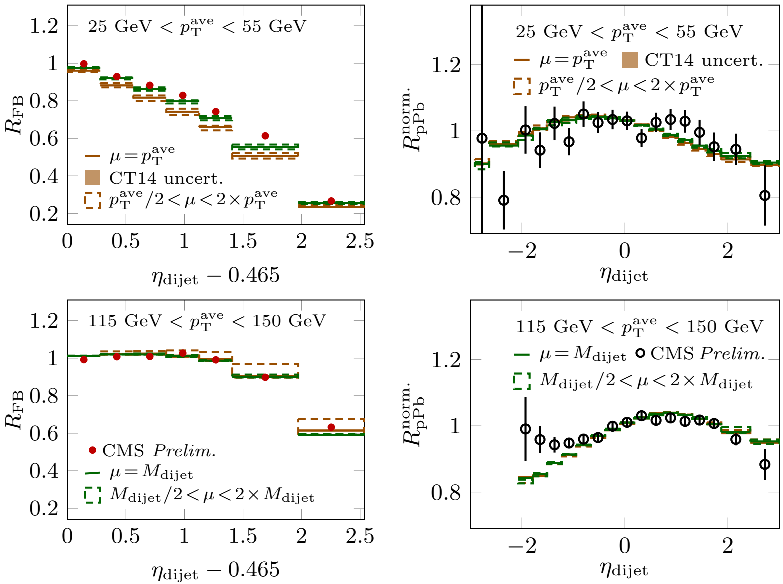
- Nuclear modification factor

$$R_{\mathrm{pPb}}^{\mathrm{norm.}} = \frac{\frac{1}{\mathrm{d}\sigma^{\mathbf{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}}\,\mathrm{d}^2\sigma^{\mathbf{pPb}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}\mathrm{d}\eta_{\mathrm{dijet}}}{\frac{1}{\mathrm{d}\sigma^{\mathbf{pp}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}}\,\mathrm{d}^2\sigma^{\mathbf{pp}}/\mathrm{d}p_{\mathrm{T}}^{\mathrm{ave}}\mathrm{d}\eta_{\mathrm{dijet}}}$$

  - Need a pp baseline measurement (and preferably systematic experimental correlations between pp and pPb)

R_{FB} vs. $R^{\mathrm{norm.}}_{\mathrm{pPb}}$

using CT14nlo proton PDFs
and EPPS16 nuclear modifications



- Proton-PDF uncertainties cancel in both observables
- R_{FB} retains a scale dependence (at low $p_{\mathrm{T}}^{\mathrm{ave}}$) while $R^{\mathrm{norm.}}_{\mathrm{pPb}}$ shows scale independence

$R_{\text{pPb}}^{\text{norm.}}$: EPPS16 uncertainties

using CT14nlo proton PDFs
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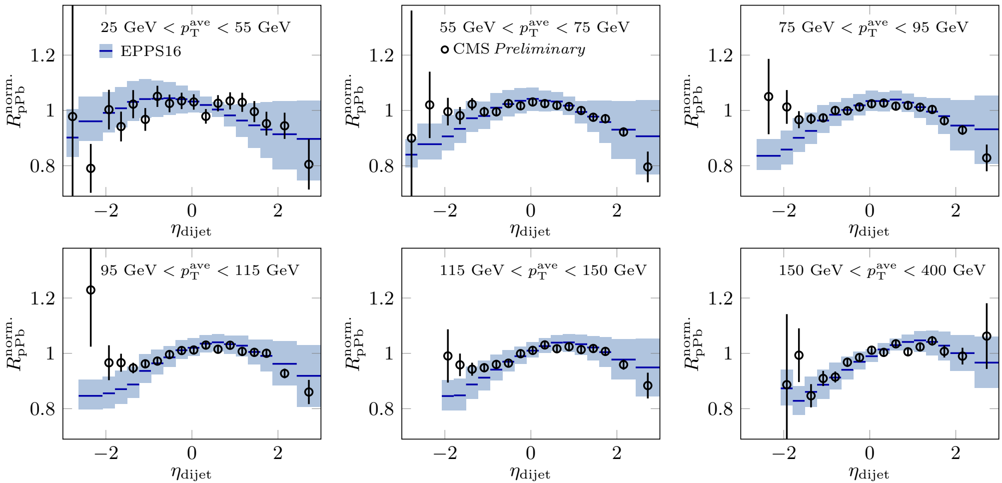

- Data well in line with EPPS16 predictions

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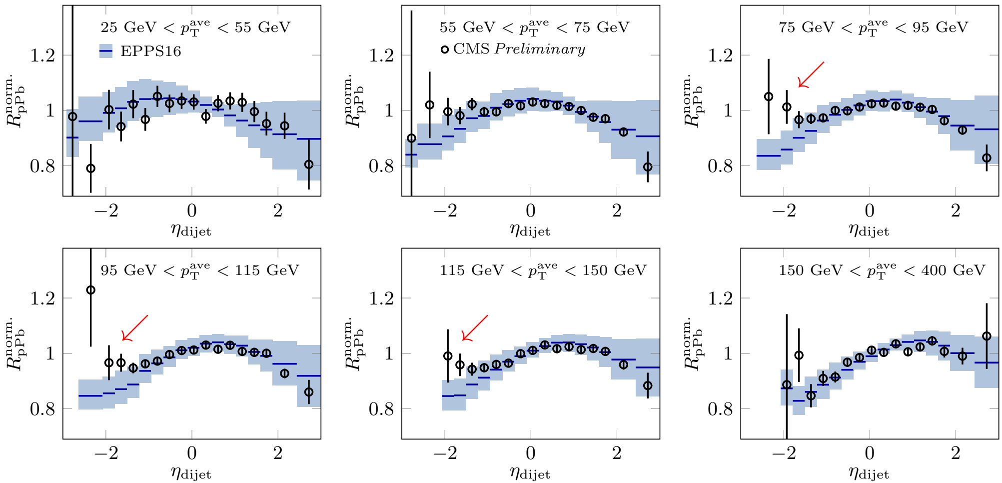

- Data well in line with EPPS16 predictions except at backward rapidities (high-x_{Pb})
  - Since other uncertainties cancel, this is likely a nuclear PDF issue
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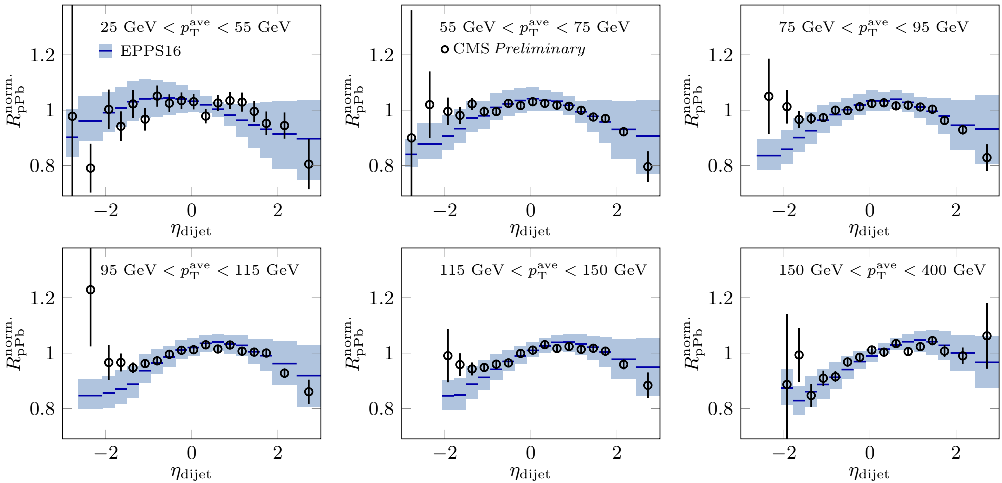

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$R^{\text{norm.}}_{\text{pPb}}$: EPPS16 reweighted (with **cubic–quadratic** approx.)

using CT14nlo proton PDFs
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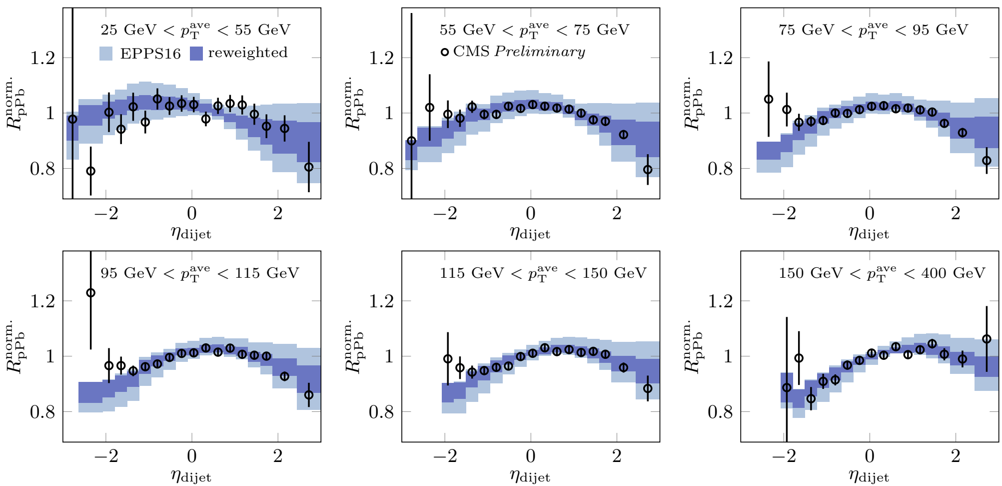

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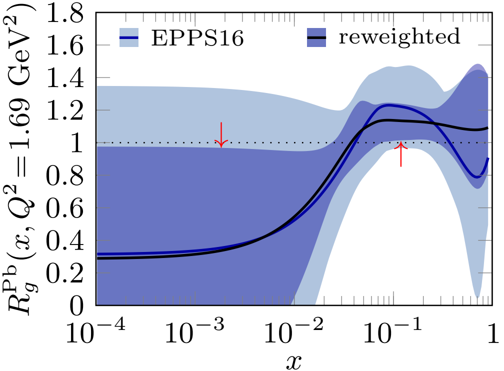
  - → Drastic reduction of EPPS16 uncertainties in reweighting



- Support for small-x gluon shadowing and mid-x antishadowing
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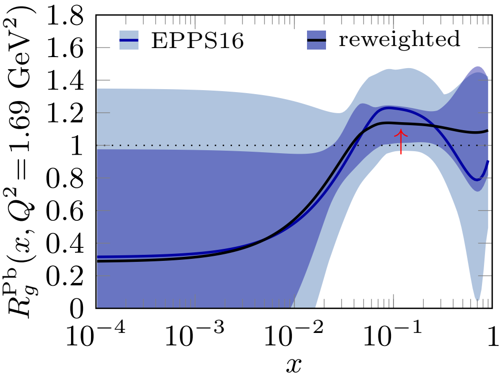

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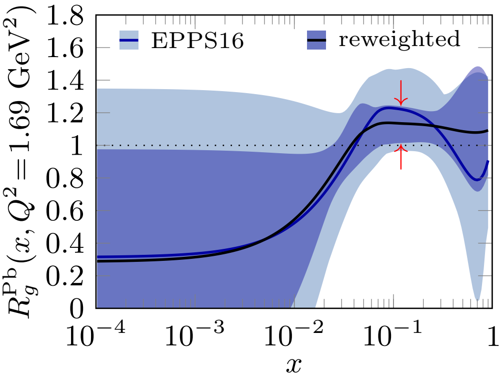

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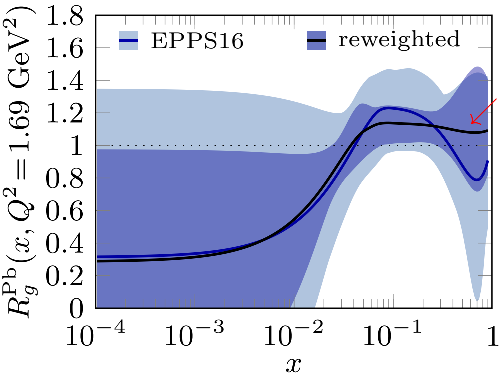

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- Large x problematic: data seem to prefer EMC pit at smaller x than allowed in EPPS16
  - ➔ Flatness perhaps due to too restrictive parametrization

Summary

Implications for proton PDFs:

- Discrepancy between preliminary 5.02 TeV dijet data and NLO predictions
  - Difference cannot be accommodated with the associated scale uncertainties
  - ➔ Possibly large gluon modifications needed

Implications for nuclear PDFs:

- pPb η_{dijet} spectra sensitive to proton-PDFs and scale uncertainties
  - ➔ Use nuclear modification factors instead
- Reweighting with preliminary data yields a large reduction of EPPS16 gluon uncertainty
- Data and EPPS16 deviate at backward rapidities
  - ➔ Need to understand the cause before including data to nuclear PDF fit
  - ➔ Should allow more freedom in the parametrization at large x

Finalized data expected (hopefully) soon

➔ Include correlated uncertainties