Status of EPPS nPDF global analysis and connection with the LHC HI data combination work

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Short intro to EPPS16

[Eur.Phys.J. C77 (2017) 163]

- Define nPDFs in terms of

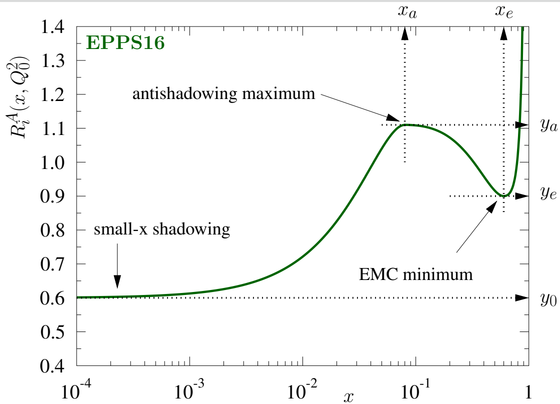
$$\underbrace{f_i^{p/A}(x,Q^2)}_{\text{bound-proton PDF}} = \overbrace{R_i^A(x,Q^2)}^{\text{nuclear modification}} \underbrace{f_i^p(x,Q^2)}_{\text{free-proton PDF}}$$

- Parametrize the x and A dependence of $R_i^A(x,Q_0^2)$ at $Q_0^2 = m_{\rm charm}^2$

- PDFs of the full nucleus are then constructed with

$$f_i^A(x,Q^2) = Z f_i^{p/A}(x,Q^2) + N f_i^{n/A}(x,Q^2),$$

  where the neutron content is obtained via isospin symmetry



- Allow full flavour separation and include heavy-quark mass effects with a general-mass variable flavour number scheme (GM-VFNS)

- Most extensive data set to date, with νA DIS, πA DY, LHC pPb dijets and EW bosons

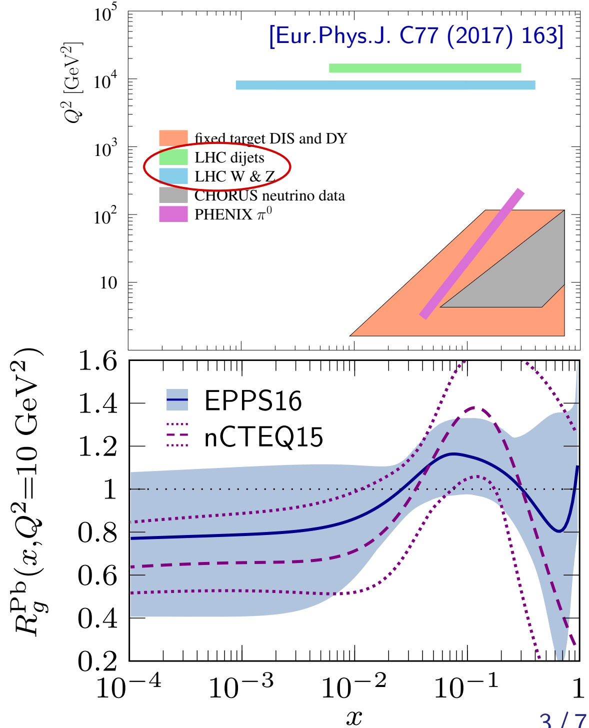
LHC constraints in EPPS16

- No 5.02 TeV pp baseline was available at this time, used forward-to-backward ratios

$$R_{\mathrm{FB}} = \frac{\mathrm{d}\sigma(\eta > 0)}{\mathrm{d}\sigma(\eta < 0)}$$

  Cancel part of the free-proton uncertainty, but lose also some information

- Main LHC constraints come from the CMS dijet R_{FB} data
  - Better control over the gluon antishadowing & EMC effect
- Too low statistics for W & Z R_{FB} to make strong impact

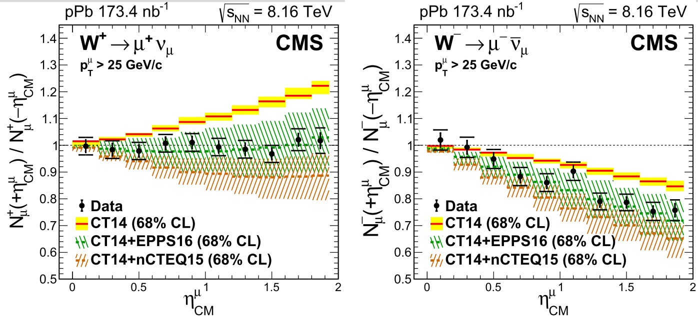


$$R_i^A(x, Q^2) = f_i^{p/A}(x, Q^2) \,/\, f_i^p(x, Q^2)$$

nuclear modification bound-proton PDF free-proton PDF

Since then...

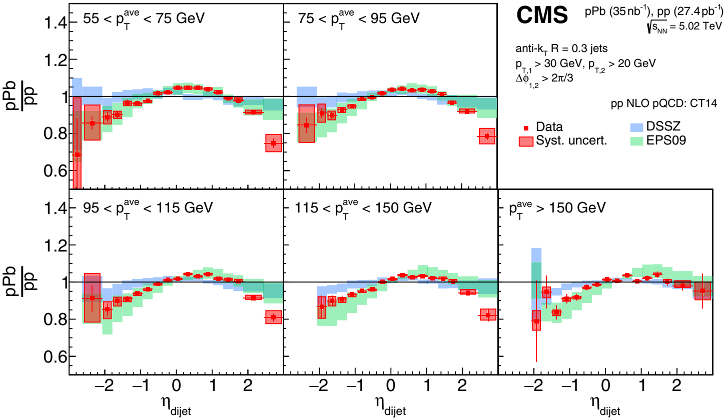
[Phys.Lett.B 800 (2020) 135048]



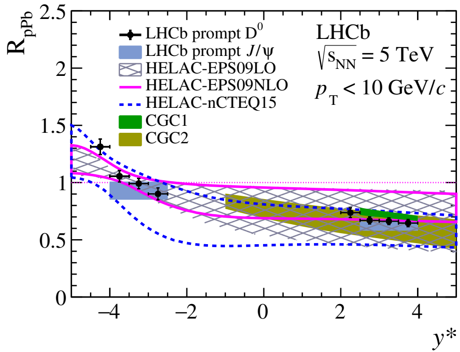
Plentiful of new measurements

- 5.02 TeV R_{pA}s
  - More direct probes of the R_i^A than R_{FB}
- 8.16 TeV R_{FB}s

[Phys.Rev.Lett. 121 (2018) 062002]



[JHEP 1710 (2017) 090]



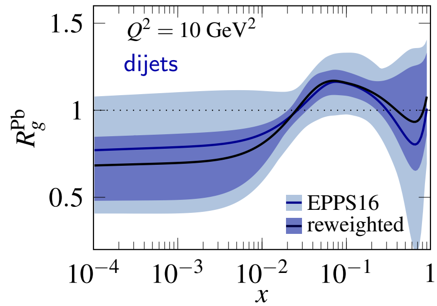
We have performed Hessian PDF reweighting studies to see the impact of dijets and D^0s

- Large reduction of EPPS16 gluon uncertainties
- Support for mid-x antishadowing and rather deep small-x gluon shadowing
- D-meson R_{pPb} sensitive to nPDFs down to $x \sim 10^{-5}$
- Constraints from dijet and D-meson data mutually consistent!

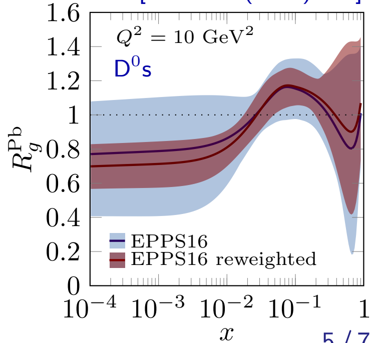
Work in progress: Include these and the 8.16 TeV CMS W bosons into a global analysis

- Studies in more relaxed parametrization ongoing
- "Final call" for new observables

[Eur.Phys.J. C79 (2019) 511]



[JHEP 05 (2020) 037]



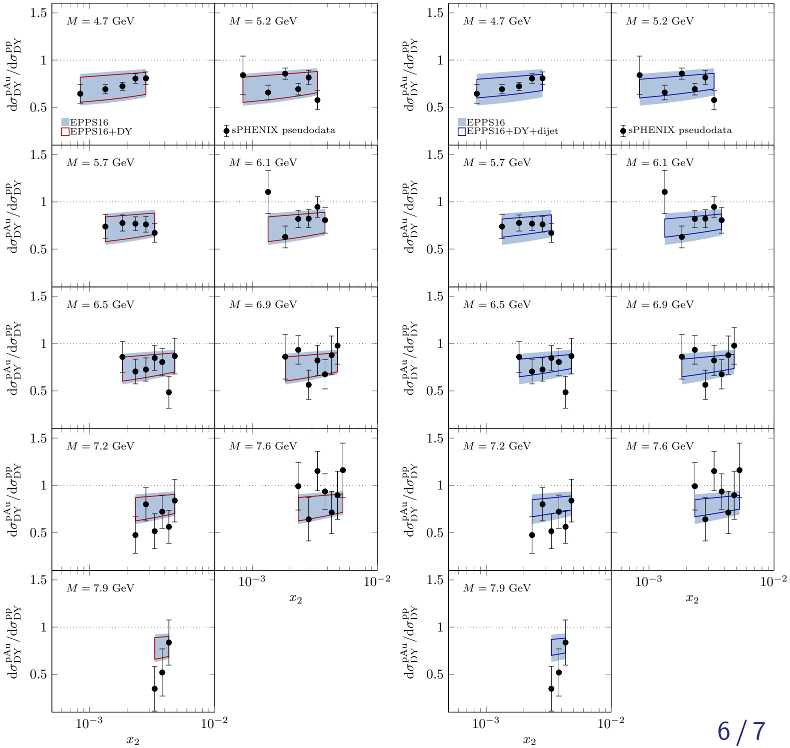
Correlations are important!

[Phys.Rev.D 100 (2019) 014004]

We have studied the prospects of using future sPHENIX Drell–Yan data for nPDF constraints

- If we include the Drell–Yan data alone, a large luminosity uncertainty prevents getting any meaningful constraints

- Since this uncertainty is correlated across observables, we can use dijet measurement to fix this problem, but we need to know the correlations to do so!



Global analysis and data combination

- For $k \in \{1, \dots, N\}$ separate data sets, we define the global χ^2 figure of merit as

$$\chi^2_{\text{global}} = \sum_k \chi^2_k$$

please publish your correlations!

where (simplifying)

$$\chi^2_k = [D_k - T_k]^T C_k^{-1} [D_k - T_k]$$

- Now, **if** a combined data set $(D_{\text{comb}}, C_{\text{comb}})$ contains the same information as separate data sets (D_1, C_1) and (D_2, C_2), i.e.

$$\chi^2_{\text{comb}} = \chi^2_1 + \chi^2_2$$

then it does not matter if we include the separate or combined data in our analysis

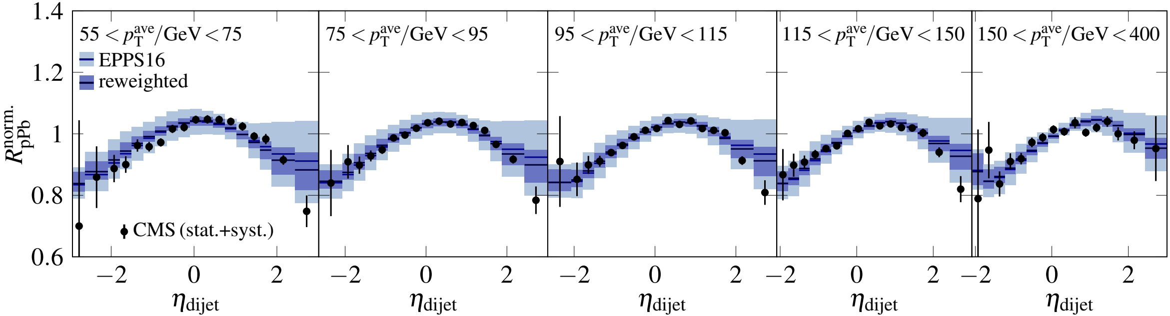
- For a data combination to be useful to us, some uncertainty reduction **beyond** a simple quadratic sum would be needed (requires understanding the inter-detector correlations)
  - At HERA, they were able to "cross calibrate" the detectors [JHEP 01 (2010) 109]

  Whether this can be done at the LHC is an experimental problem (**I am all ears!**)

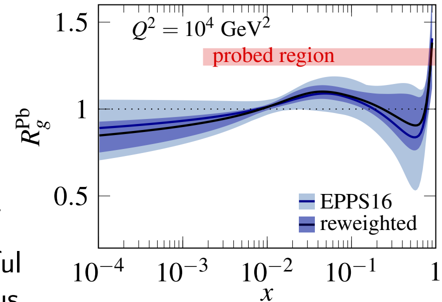
Backup

CMS dijet $R_{\mathrm{pPb}}^{\mathrm{norm.}}$ – EPPS16 reweighted

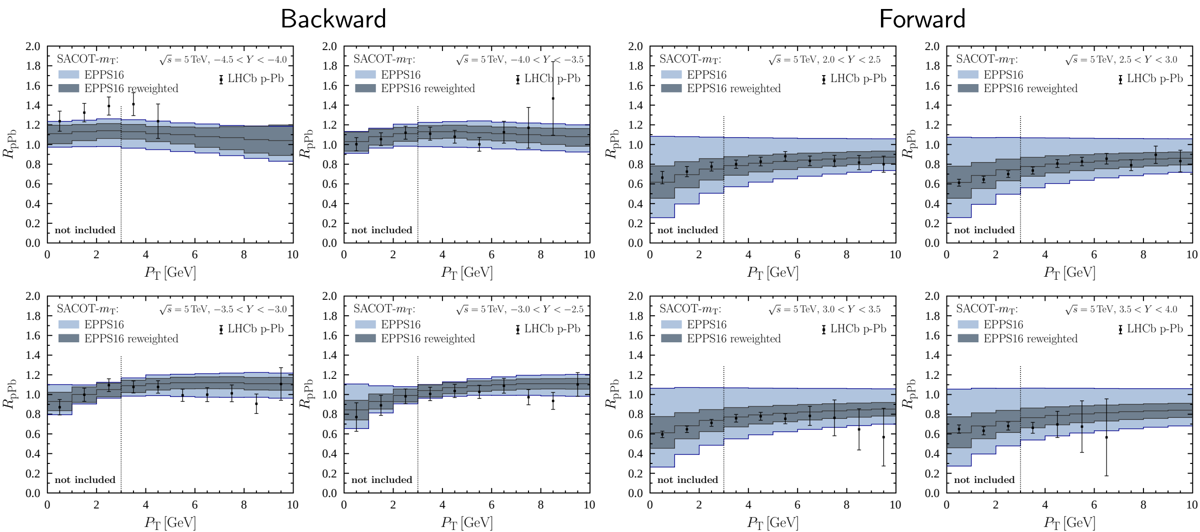
[Eur.Phys.J. C79 (2019) 511]



- Drastic reduction in EPPS16 uncertainties!
- Downward pull in the forward region
- The most forward data points lie systematically below the reweighted uncertainty band – could be due to
  - inflexibility in EPPS16 parametrization at small x
  - systematics of the measurement – would be helpful to have correlations of uncertainties available to us



EPPS16 reweighted with LHCb D-meson R_{pPb} at 5.02 TeV [JHEP 05 (2020) 037]



- Data well reproduced with the reweighted results
- Significant reduction in EPPS16 uncertainties especially in forward bins
- Good agreement with data below cut – no physics beyond collinear factorization needed

Heavy-flavour production mass schemes

FFNS

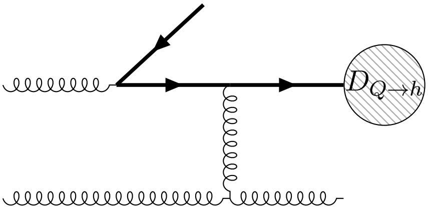
In *fixed flavour number scheme*, valid at small p_{T}, heavy quarks are produced only at the matrix element level

Contains $\log(p_{\mathrm{T}}/m)$ and m/p_{T} terms

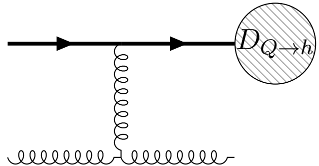
ZM-VFNS

In *zero-mass variable flavour number scheme*, valid at large p_{T}, heavy quarks are treated as massless particles produced also in ISR/FSR

Resums $\log(p_{\mathrm{T}}/m)$ but ignores m/p_{T} terms



$-$ subtraction term $+$



GM-VFNS

A *general-mass variable flavour number scheme* combines the two by supplementing subtraction terms to prevent double counting of the resummed splittings, valid at all p_{T}

Resums $\log(p_{\mathrm{T}}/m)$ and includes m/p_{T} terms in the FFNS matrix elements

Important: includes also gluon-to-HF fragmentation – large contribution to the cross section!

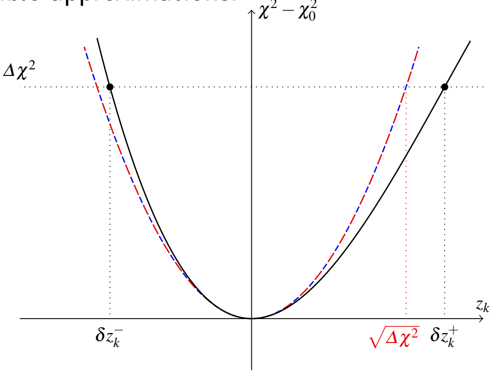
PDF reweighting: different approximations

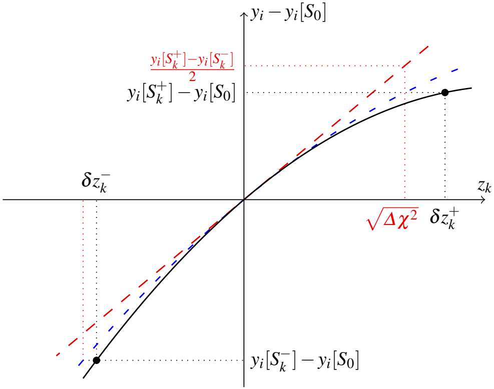
[Eur.Phys.J. C79 (2019) 511]

The Hessian reweighting is a method to study the impact of a new set of data on the PDFs without performing a full global fit

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

Possible approximations:





quadratic–linear: $\chi^2_{\text{old}} \approx \chi^2_0 + \sum_k z_k^2,$ $\quad y_i \approx y_i[S_0] + \sum_k d_{ik} z_k$

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

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