Pion–nucleus Drell–Yan data as a novel constraint for nuclear PDFs

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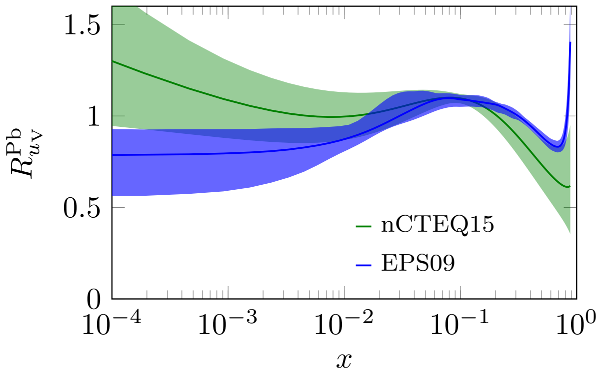
Motivation: Status of nPDFs in the beginning of 2016

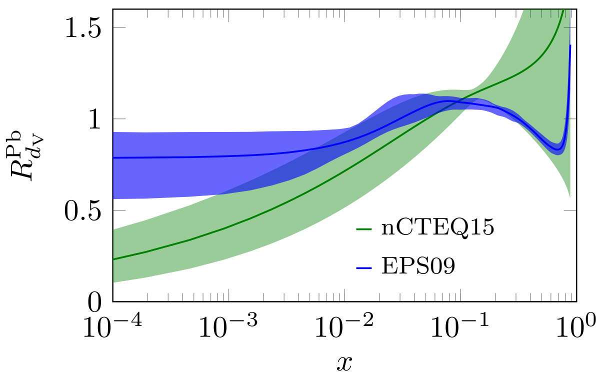
- Many global analyses (EPS09, DSSZ, nCTEQ15. . .) available.
- Limited amount of data (mostly DIS and DY, but also inclusive pion production) with restricted kinematical reach.
  - ➔ Many assumptions needed in the parametrization.
- One of the poorly constrained features is the possible asymmetry in nuclear modifications of valence u and d quarks.
- In EPS09 analysis these are fixed to be the same at $Q = 1.3$ GeV, while nCTEQ15 fit allows them to vary independently.
  - ➔ Significantly different results.

? How could we better constrain this?

  - ➔ Dutta *et al.* [PRC 83 (2011) 042201] suggested that pion–nucleus Drell–Yan dilepton data could be used.

Valence quark modifications at $Q = 1.3$ GeV:





Cancellation of pion PDFs in nuclear ratios

- Consider following ratios:

$$R_A^{+/-}(x_2) \equiv \frac{\mathrm{d}\sigma_{\text{DY}}^{\pi^+ + A}/\mathrm{d}x_2}{\mathrm{d}\sigma_{\text{DY}}^{\pi^- + A}/\mathrm{d}x_2}$$

$$R_{A_1/A_2}^{-}(x_2) \equiv \frac{\frac{1}{A_1}\mathrm{d}\sigma_{\text{DY}}^{\pi^- + A_1}/\mathrm{d}x_2}{\frac{1}{A_2}\mathrm{d}\sigma_{\text{DY}}^{\pi^- + A_2}/\mathrm{d}x_2}$$

- Assuming isospin (IS) and charge conjugation (CC) symmetry

$$u_{\pi^+} \overset{\text{IS}}{=} d_{\pi^-} \overset{\text{CC}}{=} \bar{d}_{\pi^+} \overset{\text{IS}}{=} \bar{u}_{\pi^-}$$

$$d_{\pi^+} \overset{\text{IS}}{=} u_{\pi^-} \overset{\text{CC}}{=} \bar{u}_{\pi^+} \overset{\text{IS}}{=} \bar{d}_{\pi^-}$$

when pion sea quarks can be neglected, the LO approximation for a narrow enough invariant mass bin gives

$$R_A^{+/-}(x_2) \approx \frac{4\bar{u}_A(x_2) + d_A(x_2)}{4u_A(x_2) + \bar{d}_A(x_2)}$$

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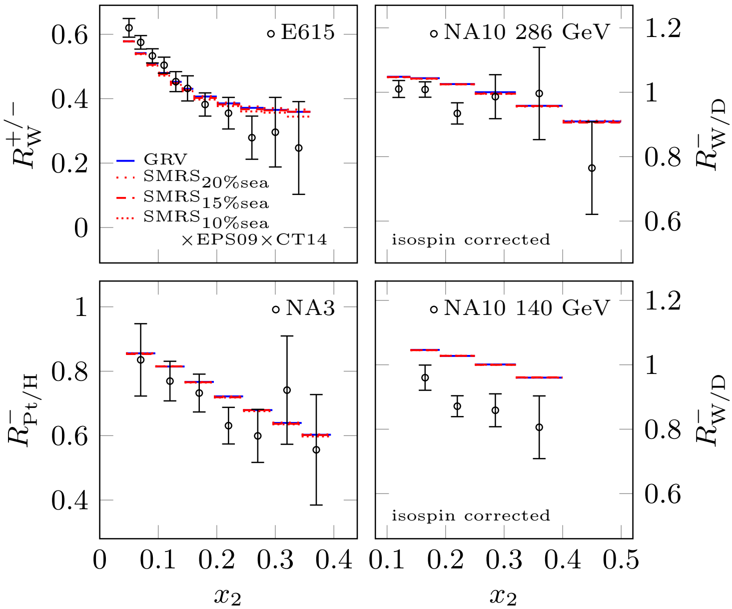
→ The dependence on pion PDFs essentially cancels. . . *also in NLO* [PLB 768 (2017) 7-11]:



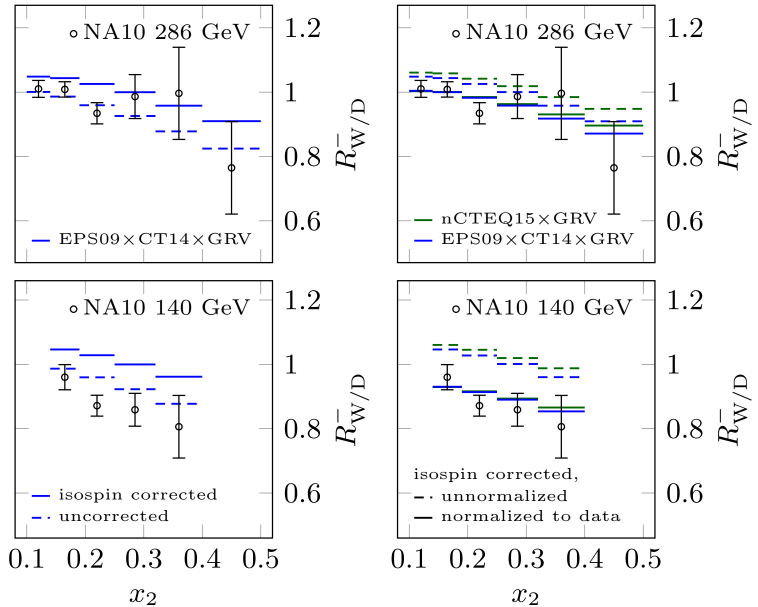
- The NA10 collaboration has corrected their data for isospin effects: D is perfectly isoscalar ($Z = A/2$), but W is not ($A = 184$ and $Z = 74$).

  We correct our results similarly with

  $$(R^{-}_{\mathrm{W/D}})^{\text{NLO}}_{\text{isospin corrected}} = (R^{-}_{\text{isocalar-W/W}})^{\text{LO}}_{\text{no nPDFs}} \times (R^{-}_{\mathrm{W/D}})^{\text{NLO}}$$

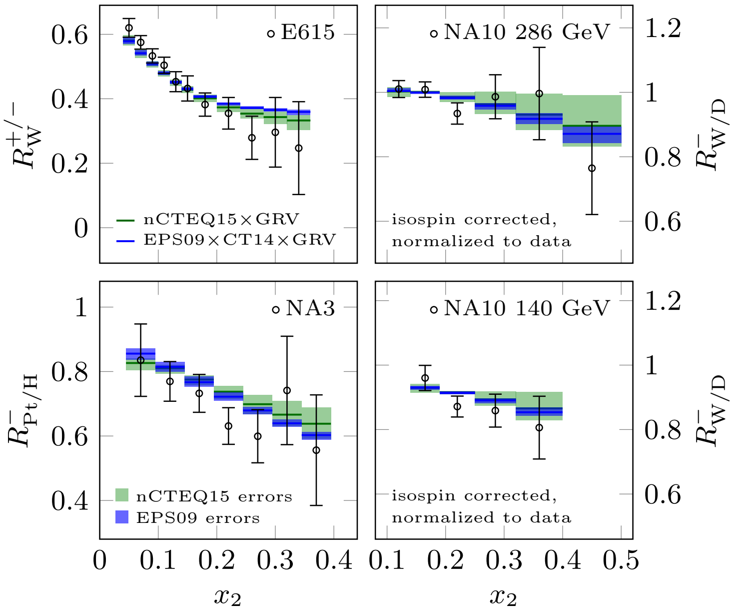
- We also need to account for the 6% systematic overall normalization uncertainty in the NA10 data.

  We find the higher beam energy predictions to be within the given uncertainty interval, but for the lower energy we need $\sim 12\%$ correction.



Comparison of nPDF results

- Both the EPS09 [JHEP 0904 (2009) 065] and nCTEQ15 [PRD 93 (2016) no.8, 085037] are in a good agreement with the data.
  - ! Large differences in the uncertainty estimates.



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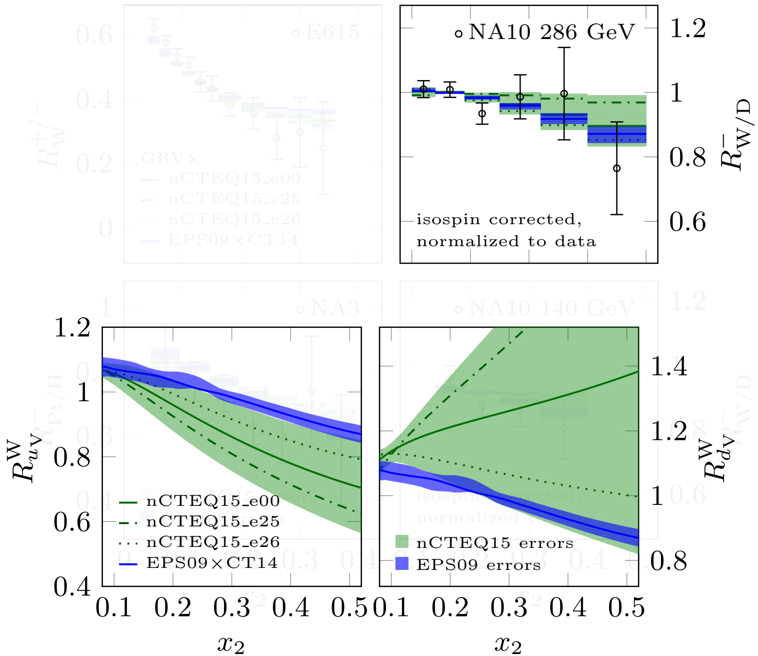
- Study the $R^{-}_{\mathrm{W/D}}$ ratio measured by NA10 at large x_2, where only the valence quarks in nuclei contribute.
- A clear mutual separation in the predictions with nCTEQ error sets 25 $(R^A_{u_\mathrm{V}} \ll R^A_{d_\mathrm{V}})$ and 26 $(R^A_{u_\mathrm{V}} \sim R^A_{d_\mathrm{V}})$.
  - ➔ The studied observables are thus sensitive to mutual differences in valence quark nuclear modifications.



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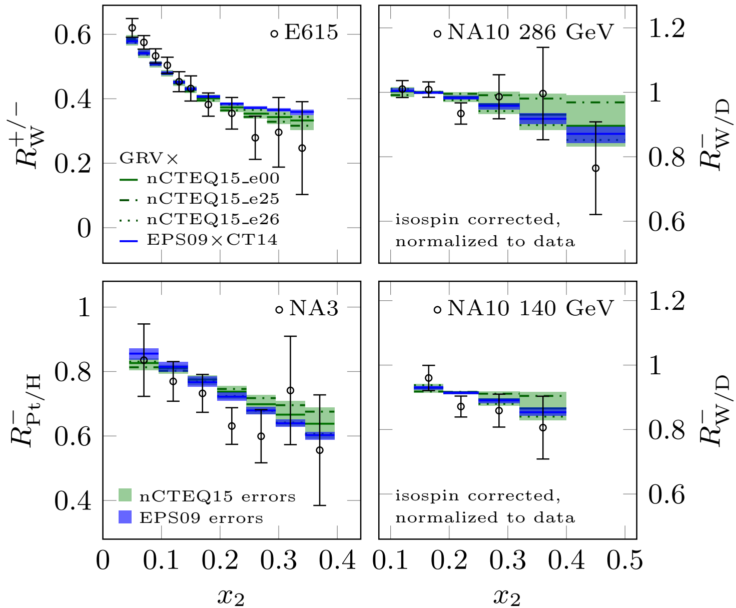
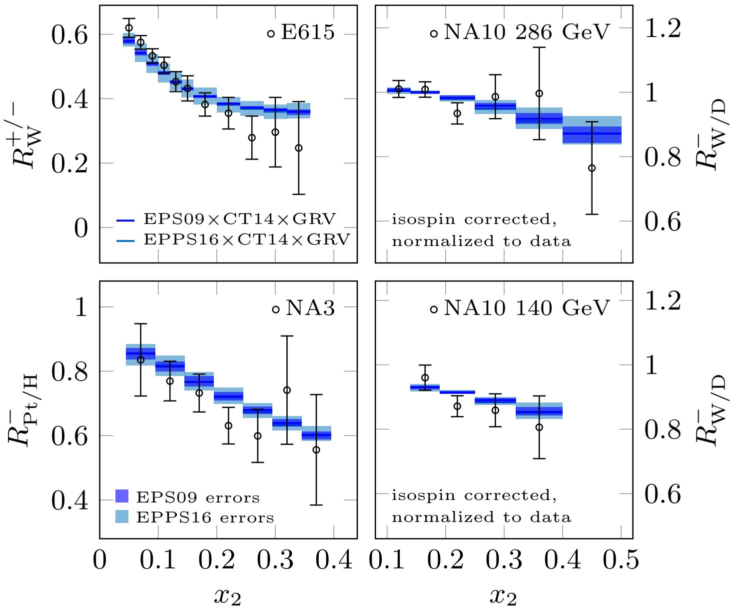
  - ➔ The studied observables are thus sensitive to mutual differences in valence quark nuclear modifications.
- The nCTEQ15 error bands are large since the flavor dependence was allowed, but not well constrained.
- The EPS09 error sets underestimate the true uncertainty because flavor dependence of valence quark nuclear modifications was not allowed.



Results with EPPS16

- Motivated by the above results, these data were used in the new EPPS16 [EPJC 77 (2017) no.3, 163] analysis.
  - ➔ See the following talk by H. Paukkunen.
- Similar results as with EPS09, but with larger errors (as expected).



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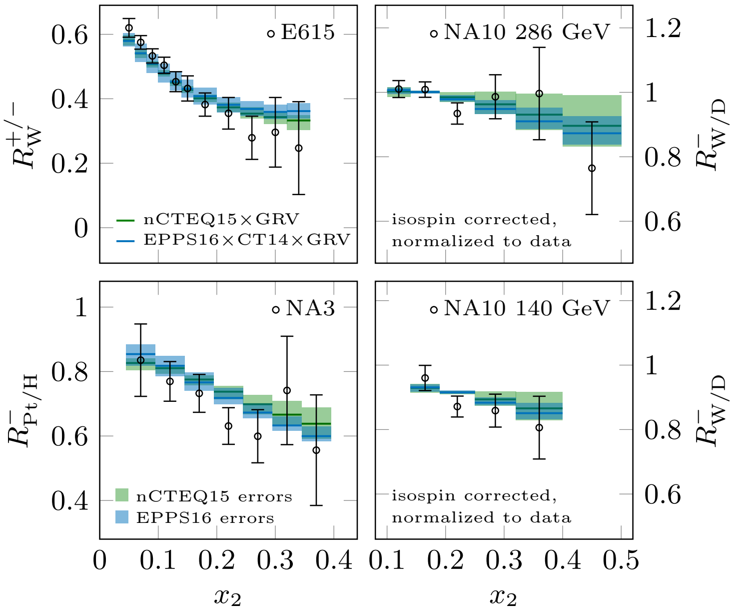
  - ➔ See the following talk by H. Paukkunen.
- Similar results as with EPS09, but with larger errors (as expected).
- Compared to nCTEQ15 there is a reduction in error estimates.
  - ! Not due to these data: At the moment more stringent constraints come from neutrino DIS.
  - ➔ These observables could in principle constrain the valence asymmetry, but the available data is not precise enough.



- Dependence on sea quarks can be reduced by studying ratio of the *difference* of the negative and positive charged pion cross-sections

$$R^{\text{diff.}}_{A_1/A_2}(x_2) \equiv \frac{\frac{1}{A_1}(\mathrm{d}\sigma_{\text{DY}}^{\pi^-+A_1}/\mathrm{d}x_2 - \mathrm{d}\sigma_{\text{DY}}^{\pi^++A_1}/\mathrm{d}x_2)}{\frac{1}{A_2}(\mathrm{d}\sigma_{\text{DY}}^{\pi^-+A_2}/\mathrm{d}x_2 - \mathrm{d}\sigma_{\text{DY}}^{\pi^++A_2}/\mathrm{d}x_2)}$$

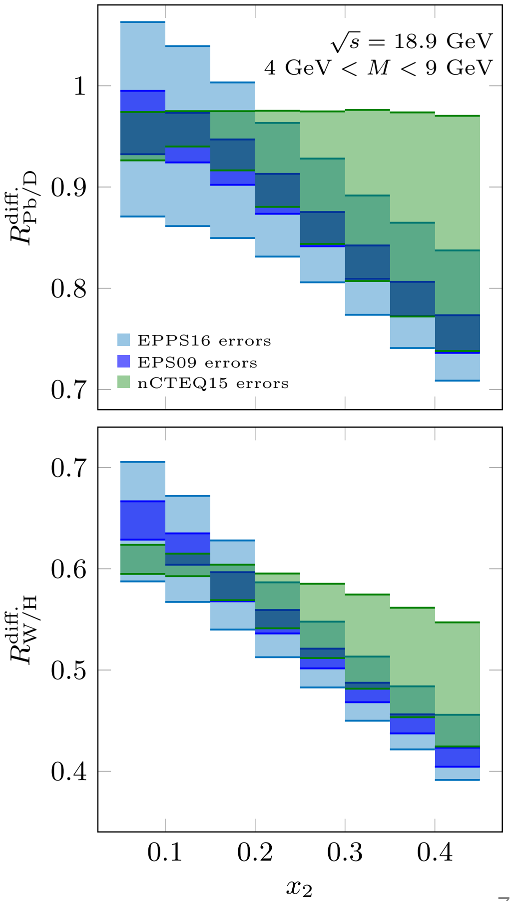
- In LO this ratio depends only on nuclear valence distributions

$$R^{\text{diff.}}_{A_1/A_2}(x_2) \approx \frac{4u^{\mathrm{V}}_{A_1}(x_2) - d^{\mathrm{V}}_{A_1}(x_2)}{4u^{\mathrm{V}}_{A_2}(x_2) - d^{\mathrm{V}}_{A_2}(x_2)}$$

- Good sensitivity to the u/d-asymmetry

$$R^{\text{diff.}}_{A/\text{D}} \approx \frac{u^{\mathrm{V}}_{p/A} + d^{\mathrm{V}}_{p/A}}{u^{\mathrm{V}}_{p} + d^{\mathrm{V}}_{p}} - \frac{5}{3}\left(1 - \frac{2Z}{A}\right)\frac{u^{\mathrm{V}}_{p/A} - d^{\mathrm{V}}_{p/A}}{u^{\mathrm{V}}_{p} + d^{\mathrm{V}}_{p}}$$

- Predictions of $R^{\text{diff.}}_{A_1/A_2}$ with beam energy and acceptance available at the COMPASS experiment are shown.



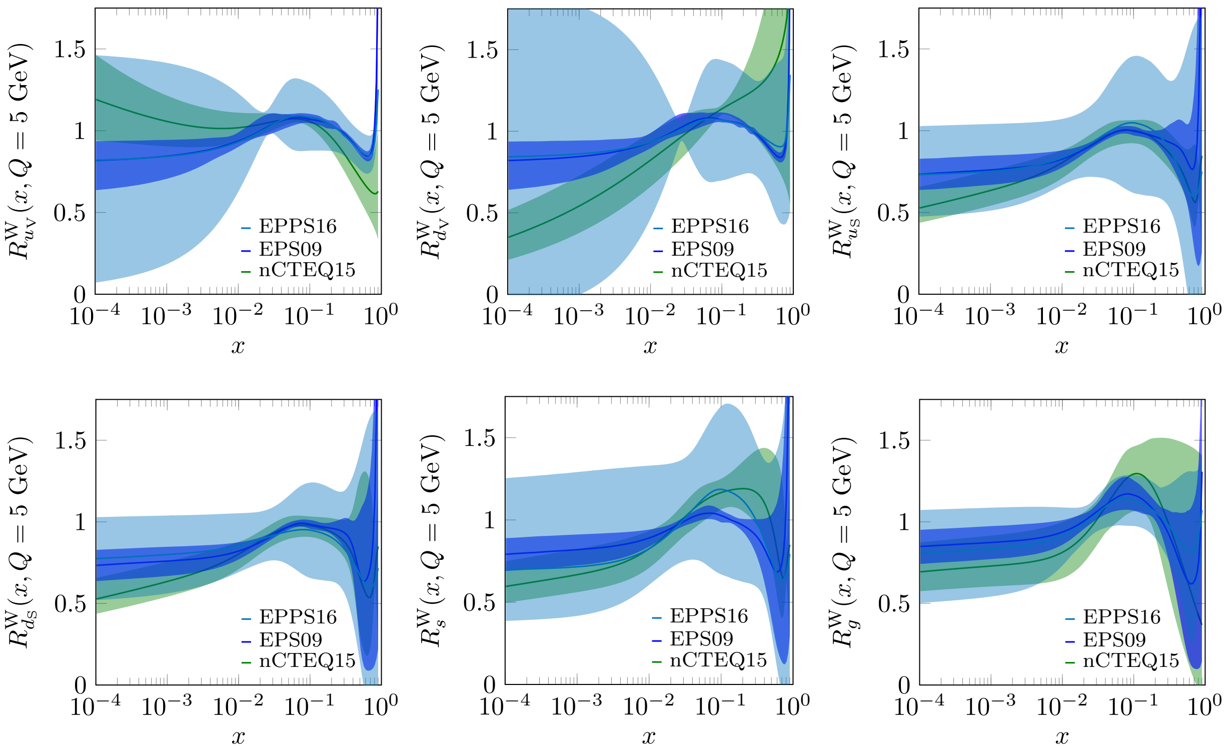
Conclusions

- The considered $\pi + A$ DY data are compatible with modern nPDFs.
  - → Can be used in a global analysis without causing significant tension (as seen in EPPS16).

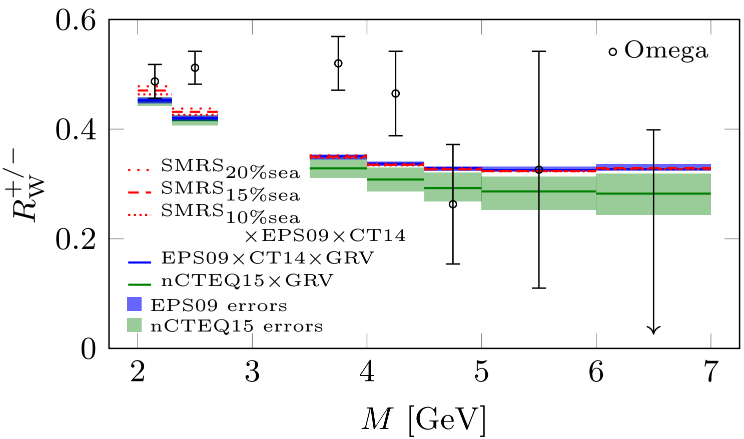
- The cross-section ratios are largely independent of pion PDFs.
  - → The inclusion of these data in global fits of nuclear PDFs does not impose significant new theoretical uncertainties.

- The considered observables are sensitive to the possible u/d-asymmetry of nuclear modification factors.
  - The data are not precise enough to pin this down completely.
  - We find a good agreement between the data and u/d-symmetric (EPS09) nuclear modifications.
  - Our analysis suggests that the most extreme differences in u and d quark nuclear modifications as given by particular nCTEQ15 error sets are disfavored by the NA3 and NA10 datasets.
  - → We propose a new observable which has a good sensitivity to the valence modification asymmetry.

Backup: nPDFs



Backup: Omega data



- Data not precise and disagrees with predictions.
- Choise of pion PDFs become significant at low masses.

→ Not reasonable to include into a global analysis.