PDF studies with aMC@NLO

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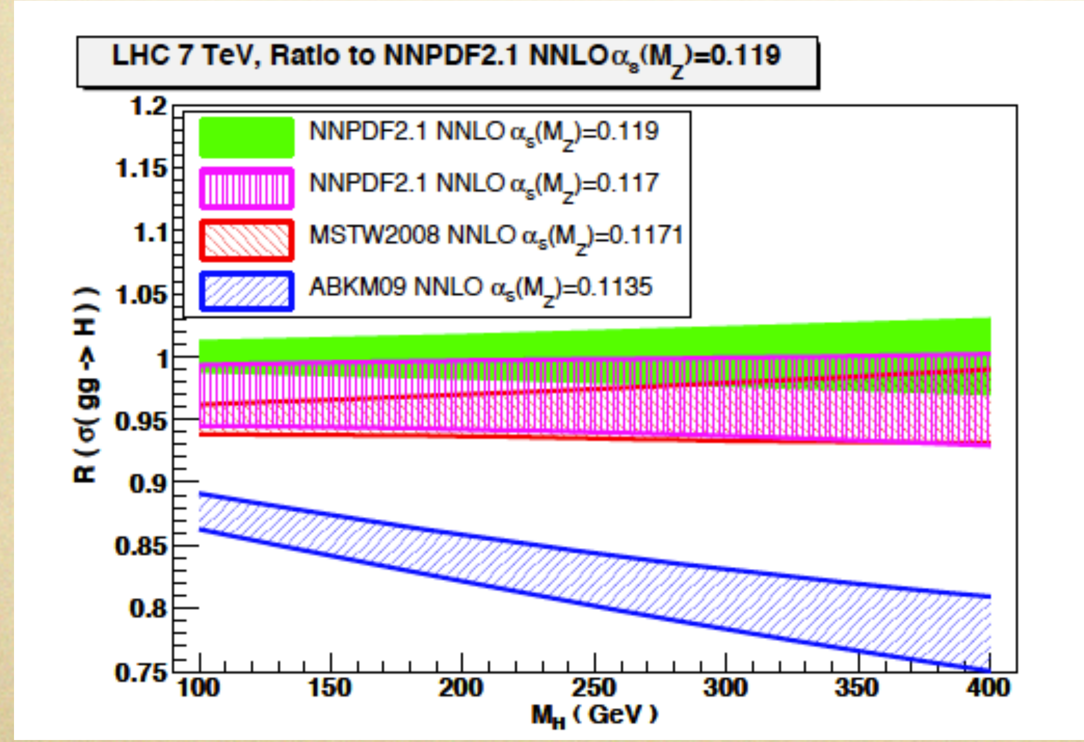
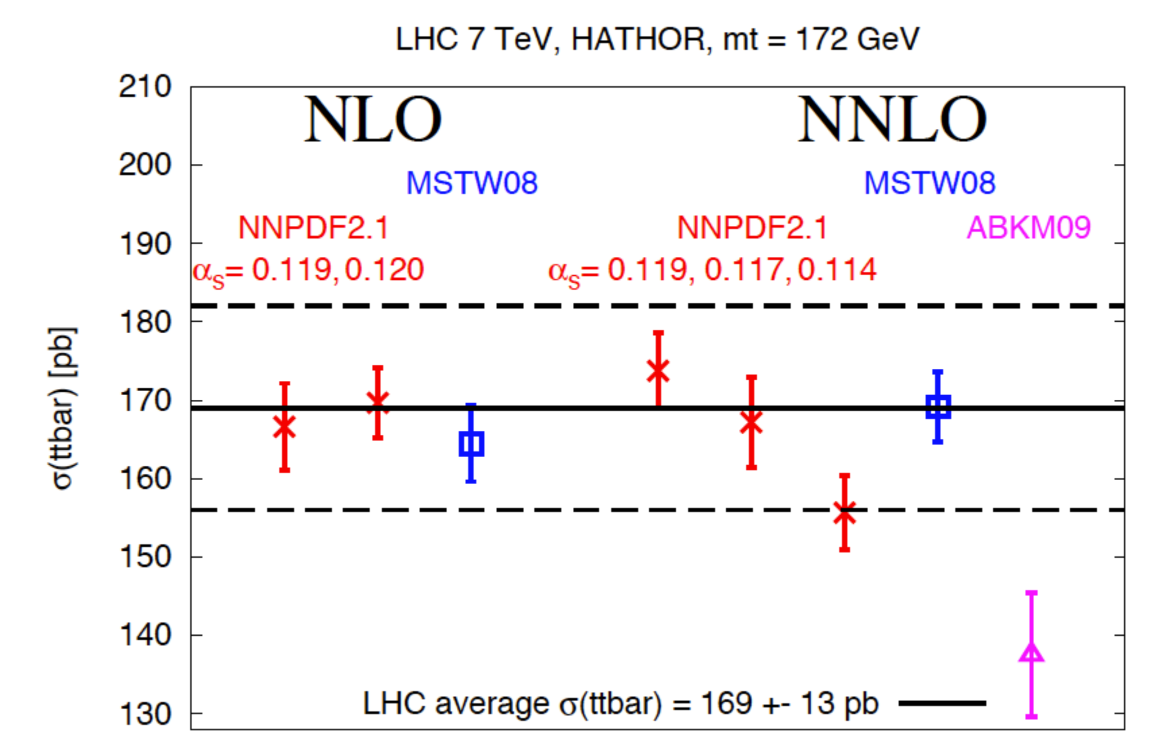
Parton Distributions in the LHC era

- **PDFs** important ingredient of precision physics at the LHC. The **NNPDF approach** aims to achieve a similar level to robustness as in **hard matrix element calculations**
  - Use the **most precise data** from HERA, LHC,
  - **Most updated theoretical information**: exact NLO/NNLO, GM-VFN for heavy quarks, resummations, ...
  - **Advanced statistical methodology**: unbiased neural networks, machine learning techniques, stochastic minimization, ...

Reliable PDFs paramount to LHC program: **precision cross section predictions** (Higgs, top, W/Z), determination of SM parameters (MW, lepton mixing angle, EWK couplings), optimization of new physics searches ....





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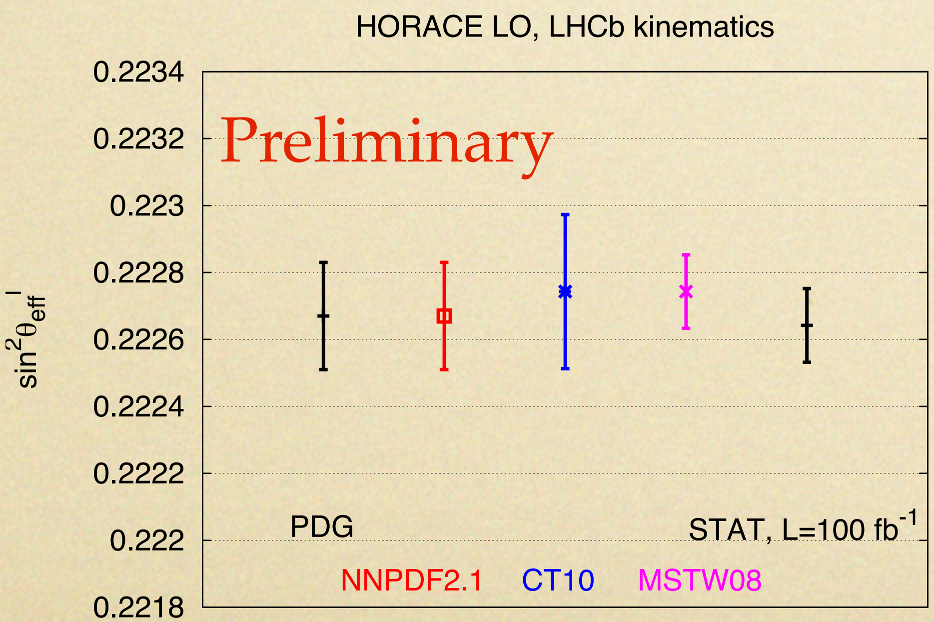
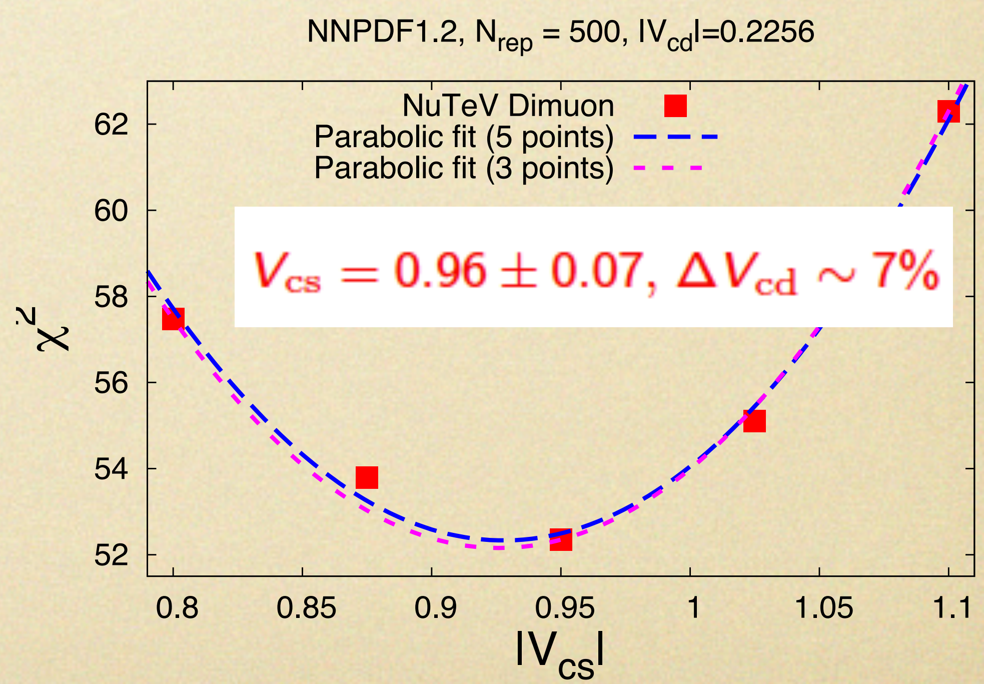


Effective weak mixing angle could be measured with LEP-like precision at LHCb

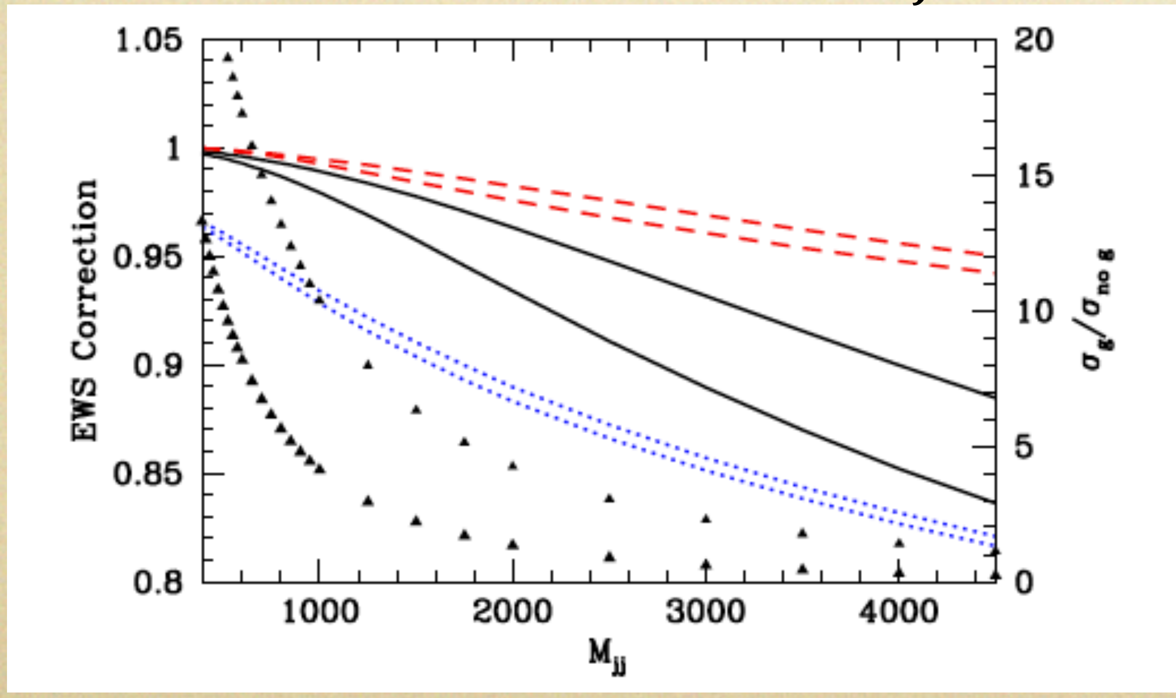


Precision determination of **Vcs from DIS neutrino data**
Contributes to **PDG 2012 average**

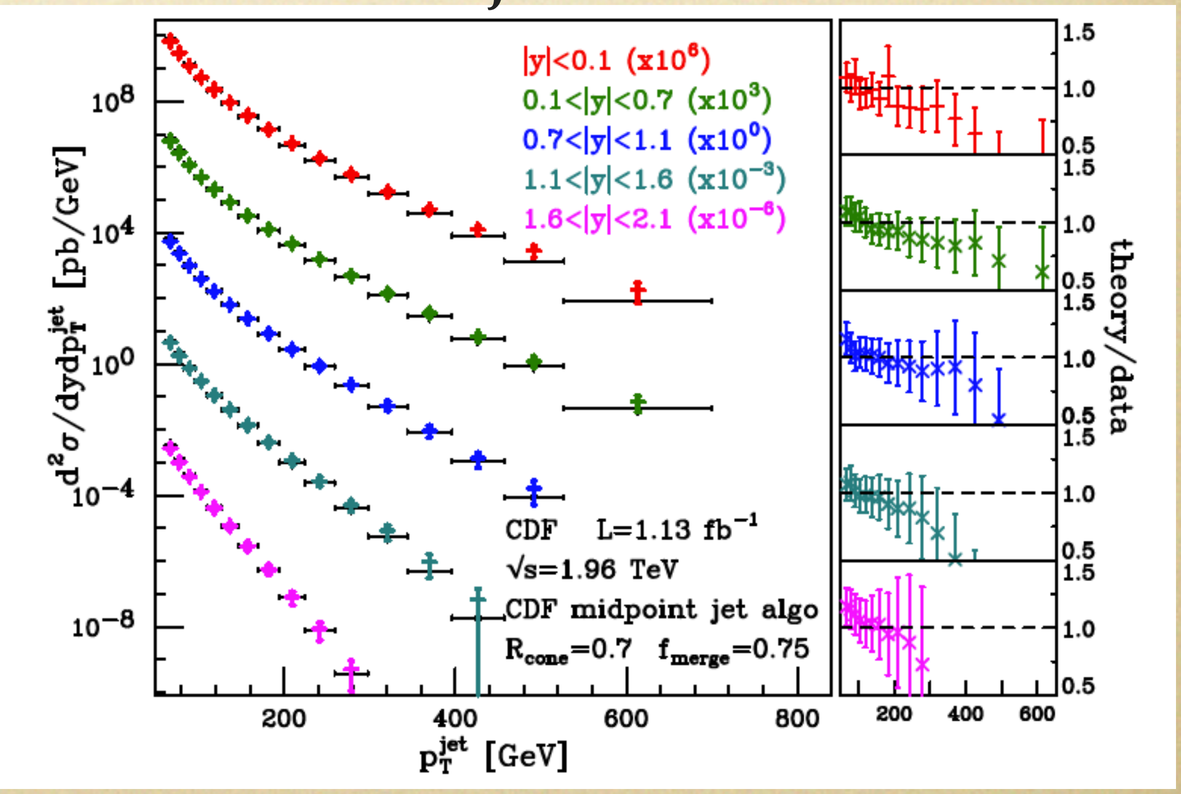
Current limitations in PDF analyses

- Fast NLO QCD interfaces available for a **very restricted subset** of processes
- Many interesting LHC processes never considered for PDF input because **too differential / difficult to evaluate reliably**
- **No NNLO fast interface available**
- **Shower effects** neglected when comparing to experimental data, or corrected by experimental analysis
- **QED and Electroweak** corrections not included: potentially relevant for the analysis of high-ET LHC data

EW corrections to LHC dijets



POWHEG jet cross sections



PDF aMC@NLO wishlist

- **Automated Fast NLO QCD calculations** with **parton showers**: as much close as possible to **experimentally measurable quantities**
- Combined implementation of **QCD and EWK** corrections
- Automated NNLO QCD calculations for LHC processes
- Automated SUSY/BSM predictions with NLO corrections for LHC processes
- **Phenomenology studies**: use aMC@NLO to obtain "**best theory predictions**" for PDF sensitive processes and parameter determination

Automation of fast NLO calculations

- To include hadron collider data exactly at NLO/NNLO in global PDF analysis a fast interface is required. In 2010, NNPDF2.0 was the **first (and only) NLO global PDF analysis** (other sets based on the K-factor approximation)
- Several tools available: APPLgrid, FastNLO, FastKernel, but restricted number of available process, only NLO QCD, no parton shower
- Constructing a fast interface to aMC@NLO would **automatically translated all aMC@NLO developements** (new processes, EWK, updated showers, NNLO, BSM, ...) to the **global PDF analysis framework**
- **Fast interface to NLO+PS processes** much more efficient that to NLO processes thanks to the PS subtraction that allows to **construct unweighted samples**

Automation of fast NLO calculations

- For aMC@NLO cross sections, the dependence on PDFs and scales can be factorized wrt (time-consuming) matrix element computation

$$d\sigma_H = \sum_\alpha f_1(x_1^{(\alpha)}, \mu_F^{(\alpha)}) f_2(x_2^{(\alpha)}, \mu_F^{(\alpha)}) W^{(\alpha)} d\mu_{Bj} d\mu_{n+1} \, ,$$

- **Fast-aMC@NLO** interface: expand PDFs into an interpolation basis

$$f_r(x,\mu) \equiv \sum_{j=1}^{m} f_{r,j} l_{r,j}(x) \, , \quad f_{r,j} = f_r(x = x_j) \, ,$$

- Recompute the aMC@NLO event weights for the basis PDF, so now any observable for a general PDF can be very efficiently evaluated

$$\mathcal{O}(k, k_{\rm min}, k_{\rm max}) \equiv \sum_{i=1}^{N_{\rm ev}} \omega_i^{(0)} \theta(k_{\rm max} - k) \theta(k - k_{\rm min}) \, , \quad \longrightarrow \quad \mathcal{O}(k, k_{\rm min}, k_{\rm max}) = \sum_{j,j'=1}^{m} f_j^{(k)} g_{j'}^{(k)} P_{jj'}^{fg}$$

LO $\longrightarrow$

$$P_{jj'}^{fg} \equiv \sum_{i=1}^{N_{\rm ev}} \omega_i^{(0)} \frac{l_j(x_{1i}) l_{j'}(x_{1i})}{f^{(0)}(x_{1i}) g^{(0)}(x_{2i})} \theta(k_{\rm max} - k) \theta(k - k_{\rm min})$$

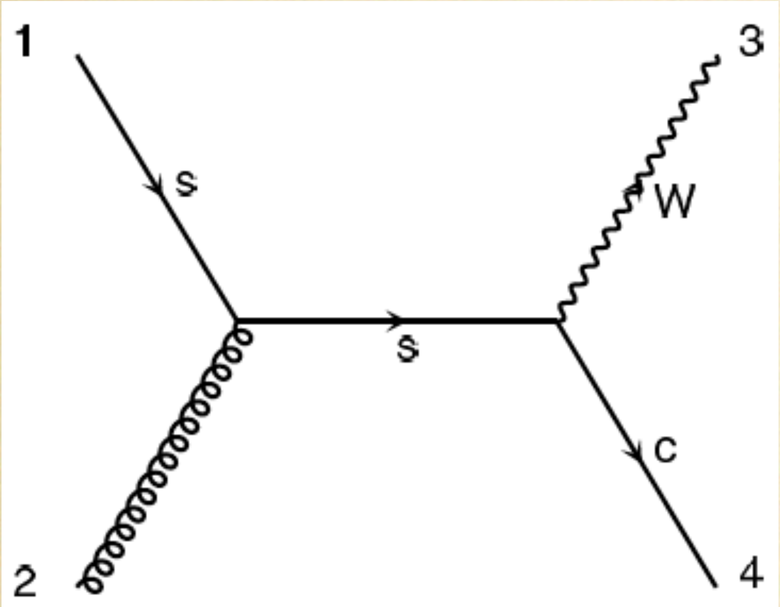
work in progress ....

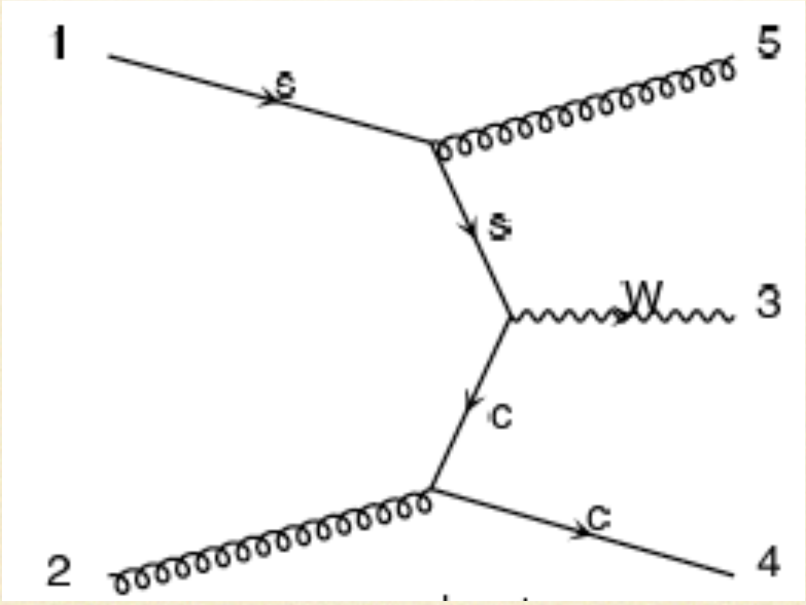
PDF studies with aMC@NLO

Application example:

Constrain strangeness from W+c production

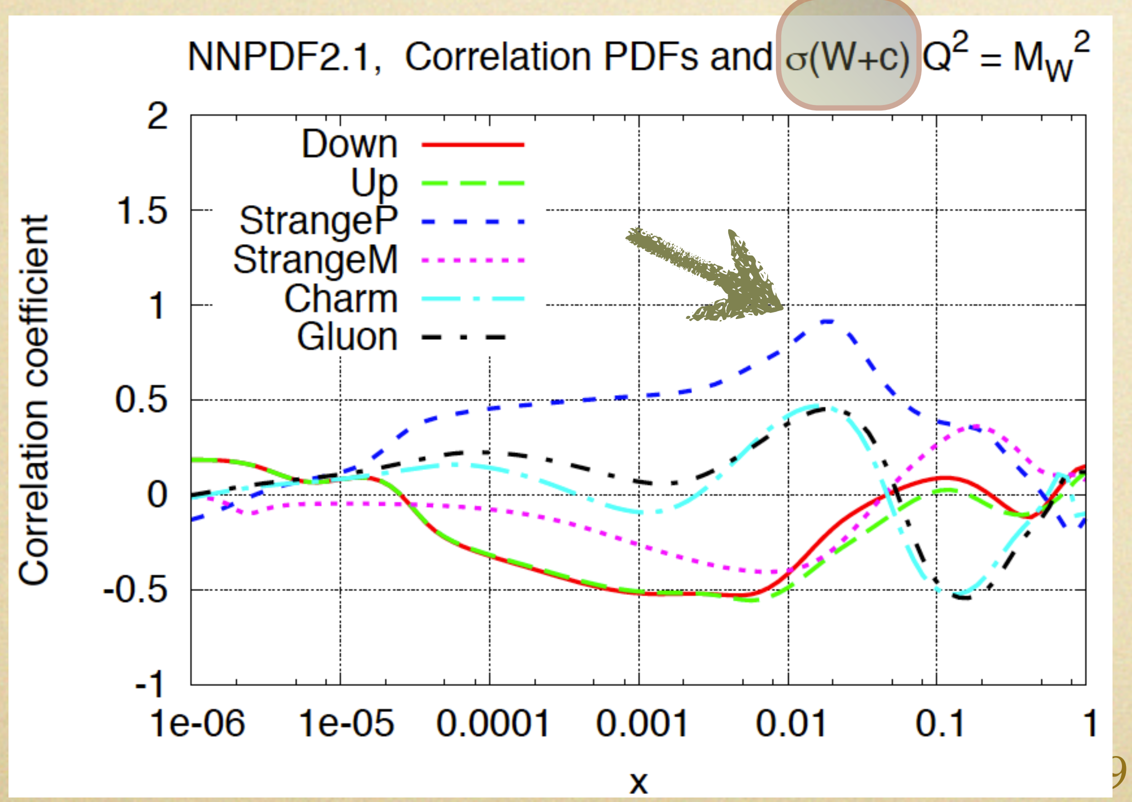
W+charm at hadron colliders

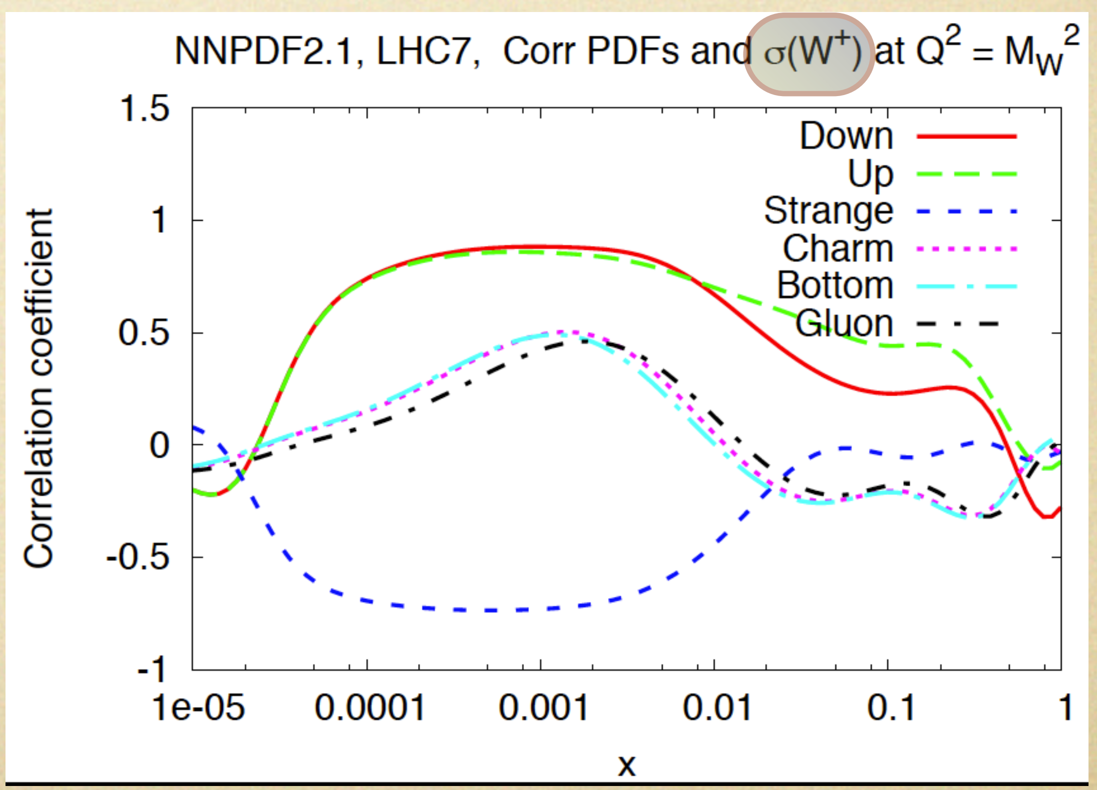




- Strangeness is the **worse known** light quark PDF
- W+c direct probe of the strange PDF
- s valence can be disentangled tagging W^+ and W^- events
- Unique constraints in wide kinematical region

- Maximum correlation in W+c for s(x) at **x~0.02**
- Large sensitivity to s(x) for **0.0001 ≤ x ≤ 0.1**





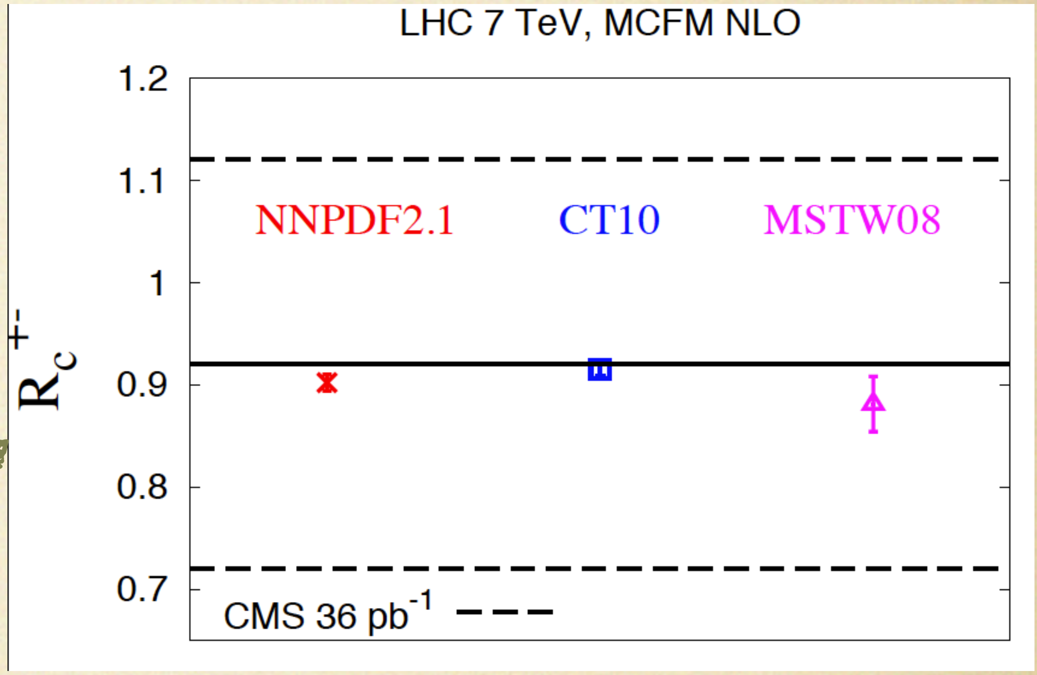
A closer look to the CMS results

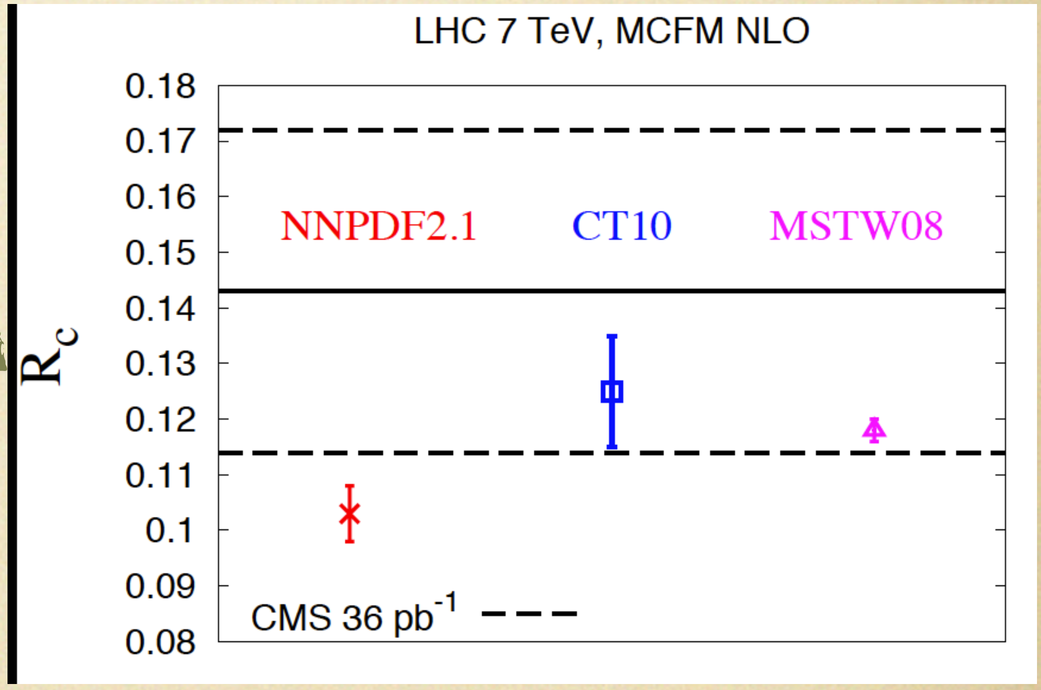
- CMS W+c production (CMS-PAS-EWK-11-013)

$R_c^\pm = \sigma(W^+\bar{c})/\sigma(W^-c)$ $R_c = \sigma(W+c)/\sigma(W+jets)$

CMS measurement

$$R_c^\pm = 0.92 \pm 0.19\,(stat.) \pm 0.04\,(syst.)$$
$$R_c = 0.143 \pm 0.015\,(stat.) \pm 0.024\,(syst.)$$





- Still large experimental uncertainties, but clearly towards **discrimination between PDF sets**
- **Strangeness** is where larger differences between sets are found
- Experimental uncertainties to be reduced with the 2011 dataset

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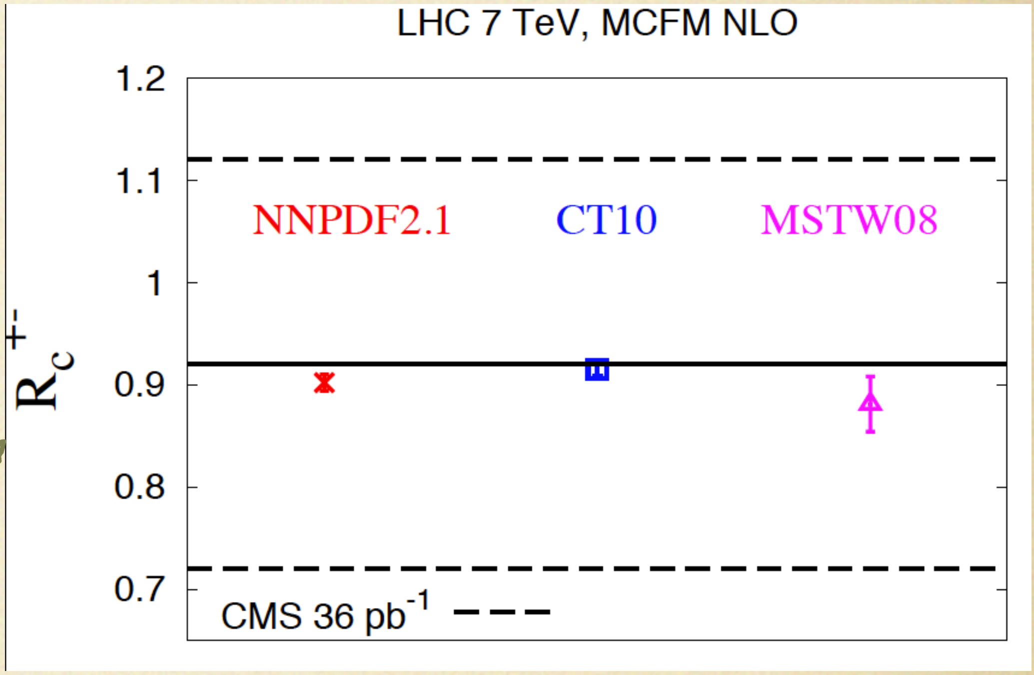
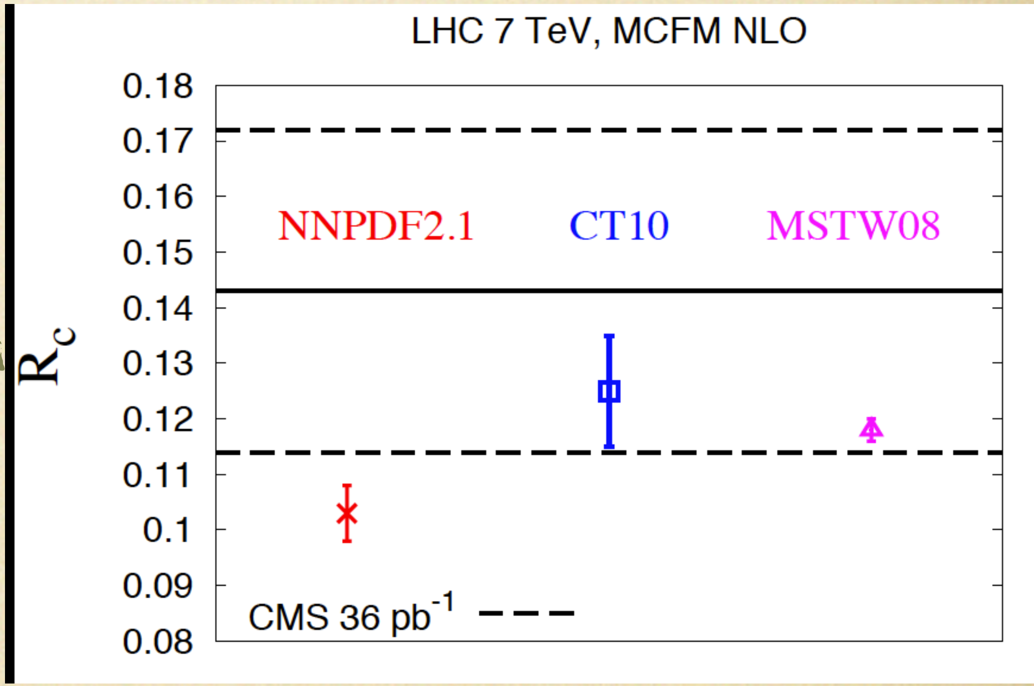
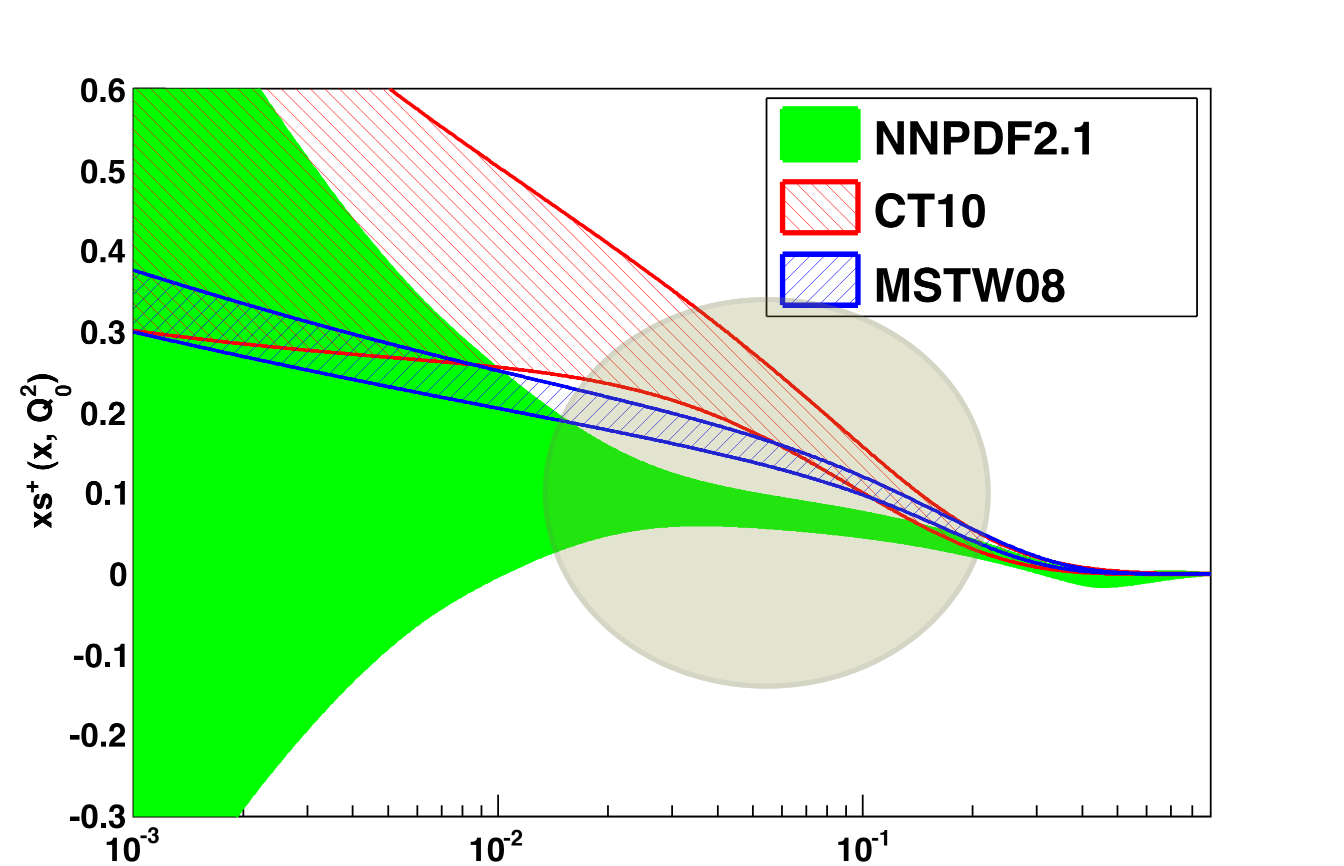


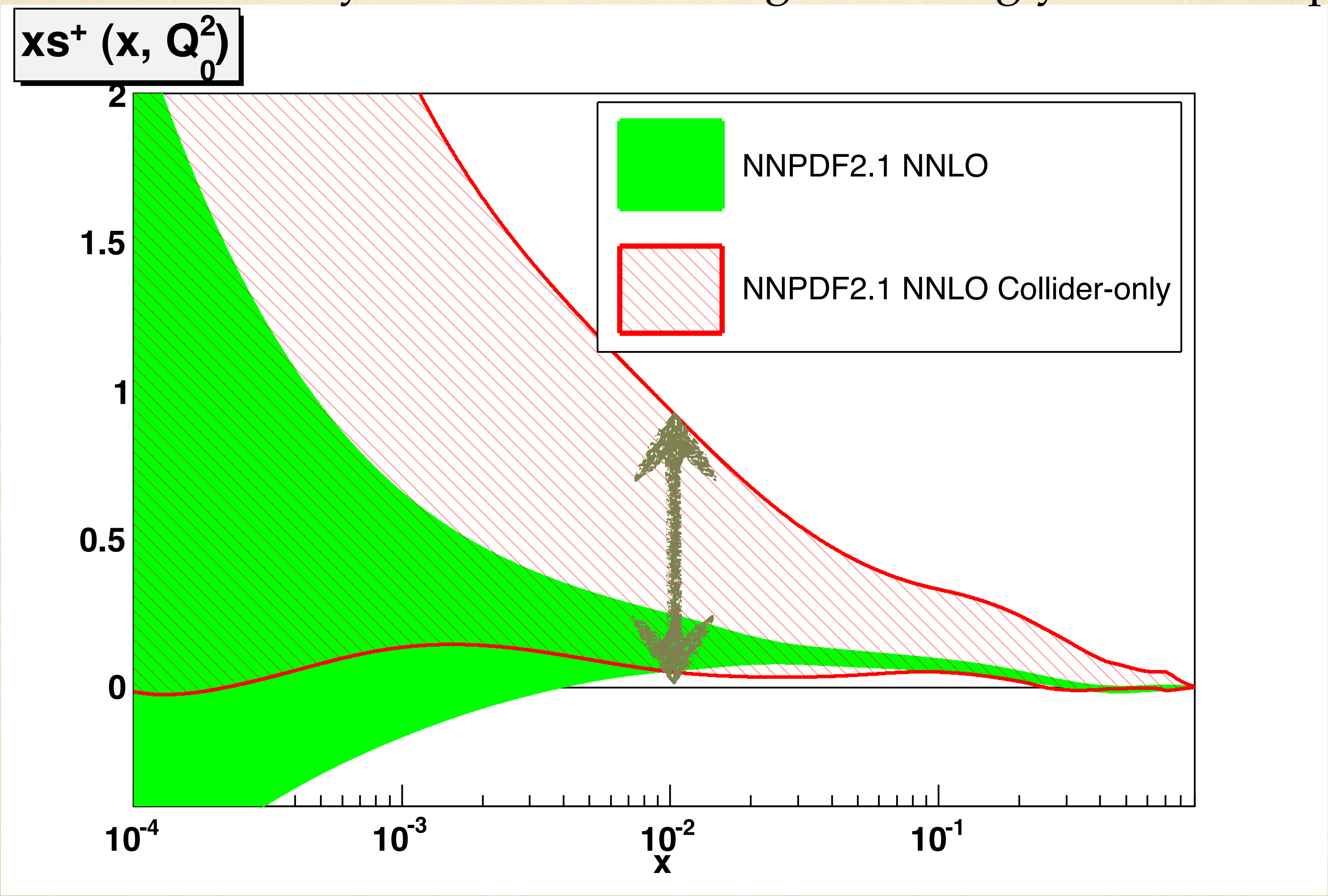




- Origin of differences not well understood: issues with **DIS neutrino data**? PDF **parametrizations**? **Heavy quark** treatment?

NNPDF2.1 Collider-only PDFs

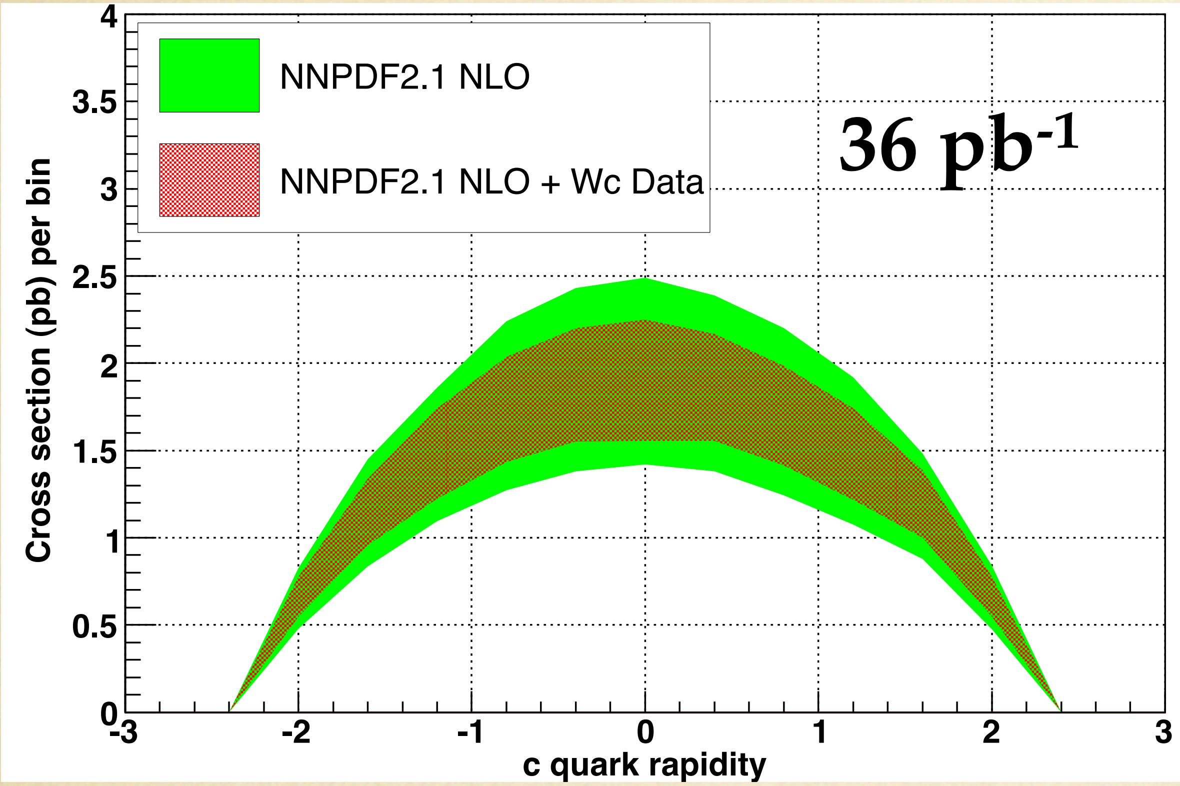
- NNPDF2.1 NLO and NNLO sets based on **reduced datasets** available in LHAPDF
- With pre-LHC collider-only data:
  - ☑ Small and large-x gluon, small-x singlet, ...
  - ☒ Flavor decomposition, d/u ratio, **strangeness, ...**
- With **LHC data** collider-only PDFs are becoming increasingly a reliable option

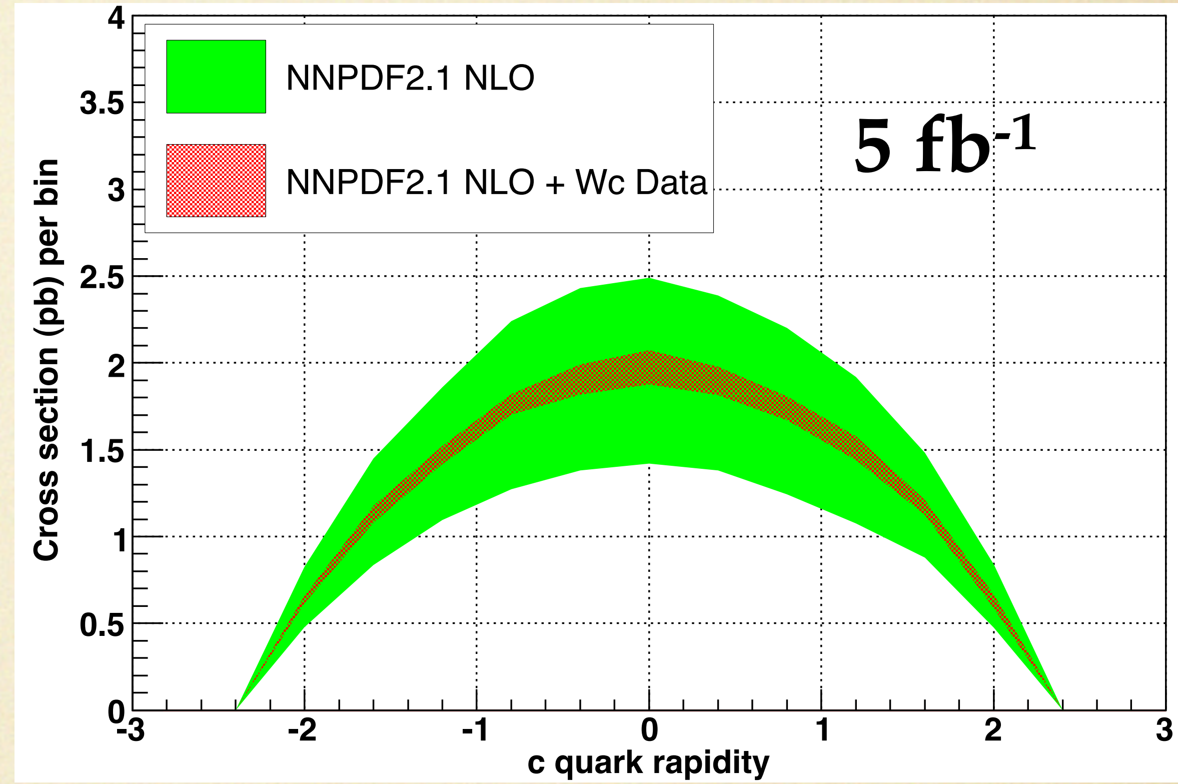


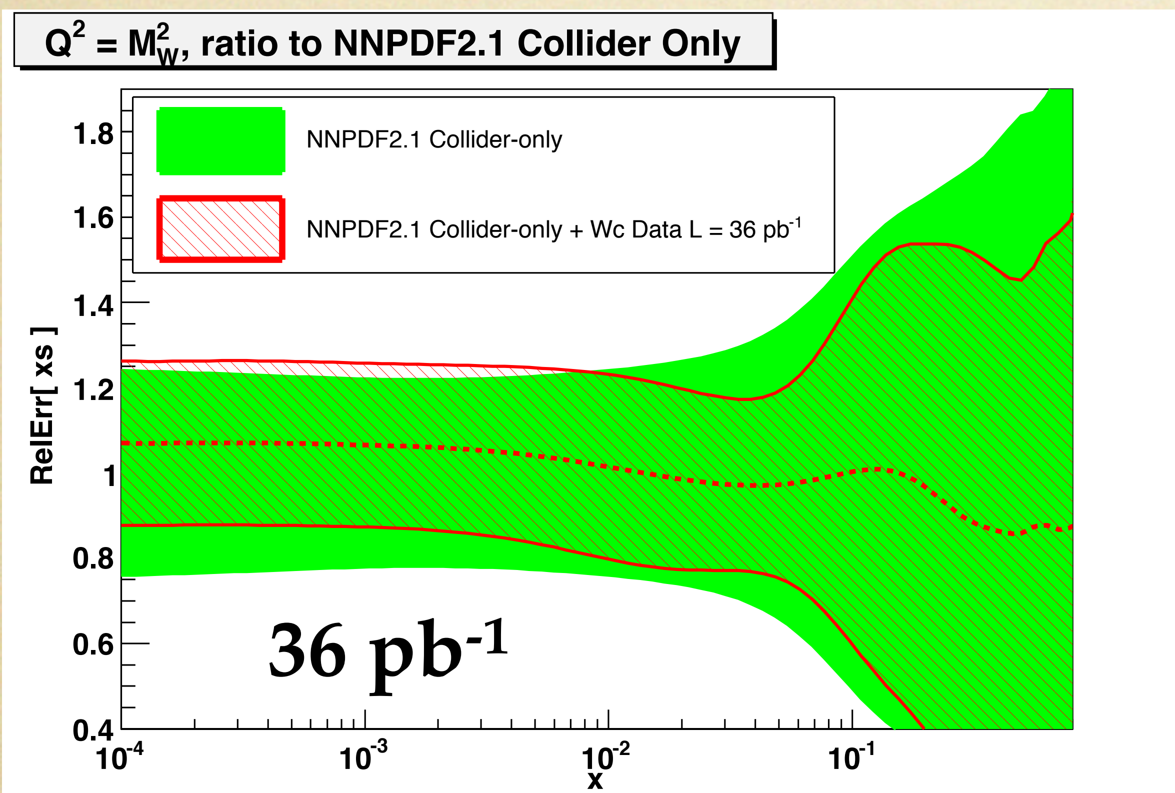
aMCatNLO analysis Setup

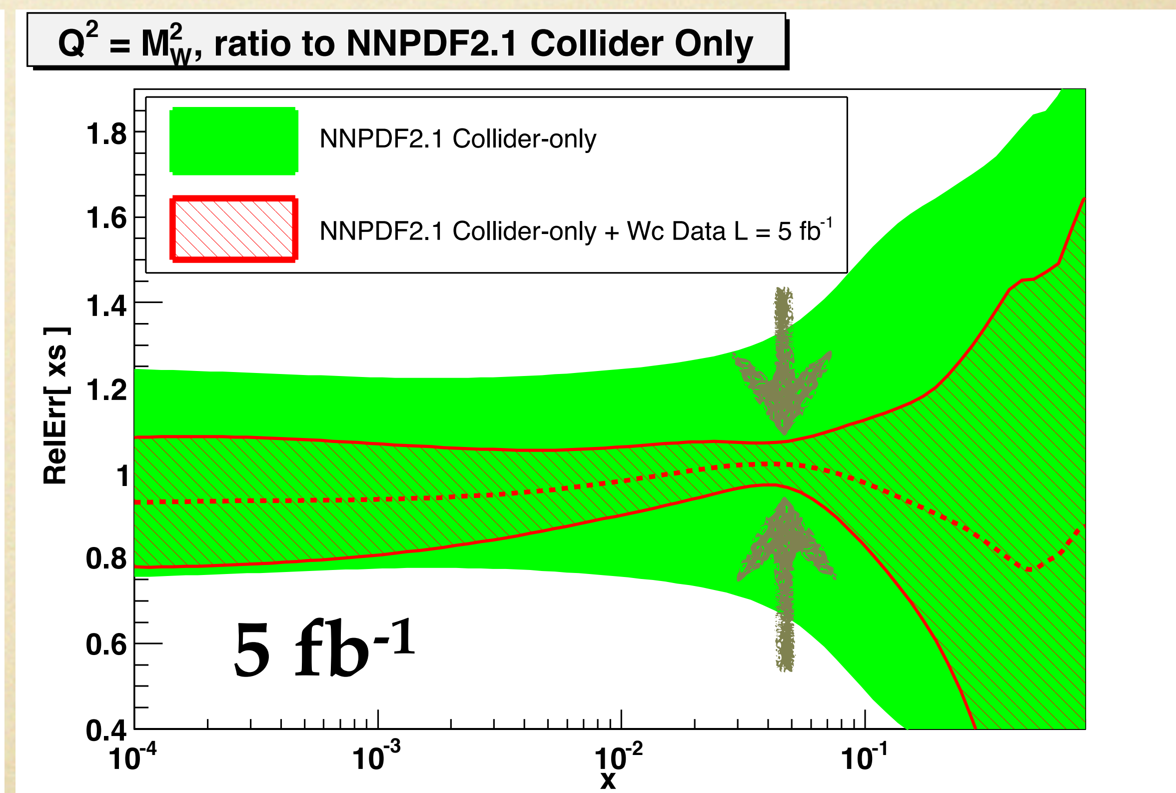
- Generate Wc samples with **aMC@NLO** with **HERWIG** for the parton shower
- Charm quark mass effects taken into account in the matrix element
- CMS kinematical cuts: **$p_T^{jet} > 20$ GeV, $p_T^{\mu} > 25$ GeV, $|\eta^{\mu}|, |\eta^{jet}| < 2.1$**
- A ~15% factor simulate the **c tagging efficiency** in the CMS analysis
- With 36 pb^{-1} one gets **O(500)** Wc events, consistent with the **CMS-PAS-EWK-11-013** results
- Generate **pseudo-data** from NNPDF2.1, statistical uncertainties from **expected number of events** per bin, luminosity uncertainty ~**4**%.
- Different scenarios for the integrated luminosity: **36 pb^{-1}, 5 fb^{-1}, 100 fb^{-1}**
- Impact of Wc pseudo-data on PDFs with the **NNPDF Bayesian reweighting method** (arxiv:1012.0836,1108.1758 + PDF4LHC yesterday's talk)
- In this talk we consider as an example the impact of the measurement of the **charm jet rapidity distribution**, but other distributions also studied (charm p_T, lepton rapidity, ...)
- We consider the impact both on the NNPDF2.1 **global** and **collider-only** PDFs: the latter case really gauges the **impact of the Wc measurement**

Impact on Strangeness



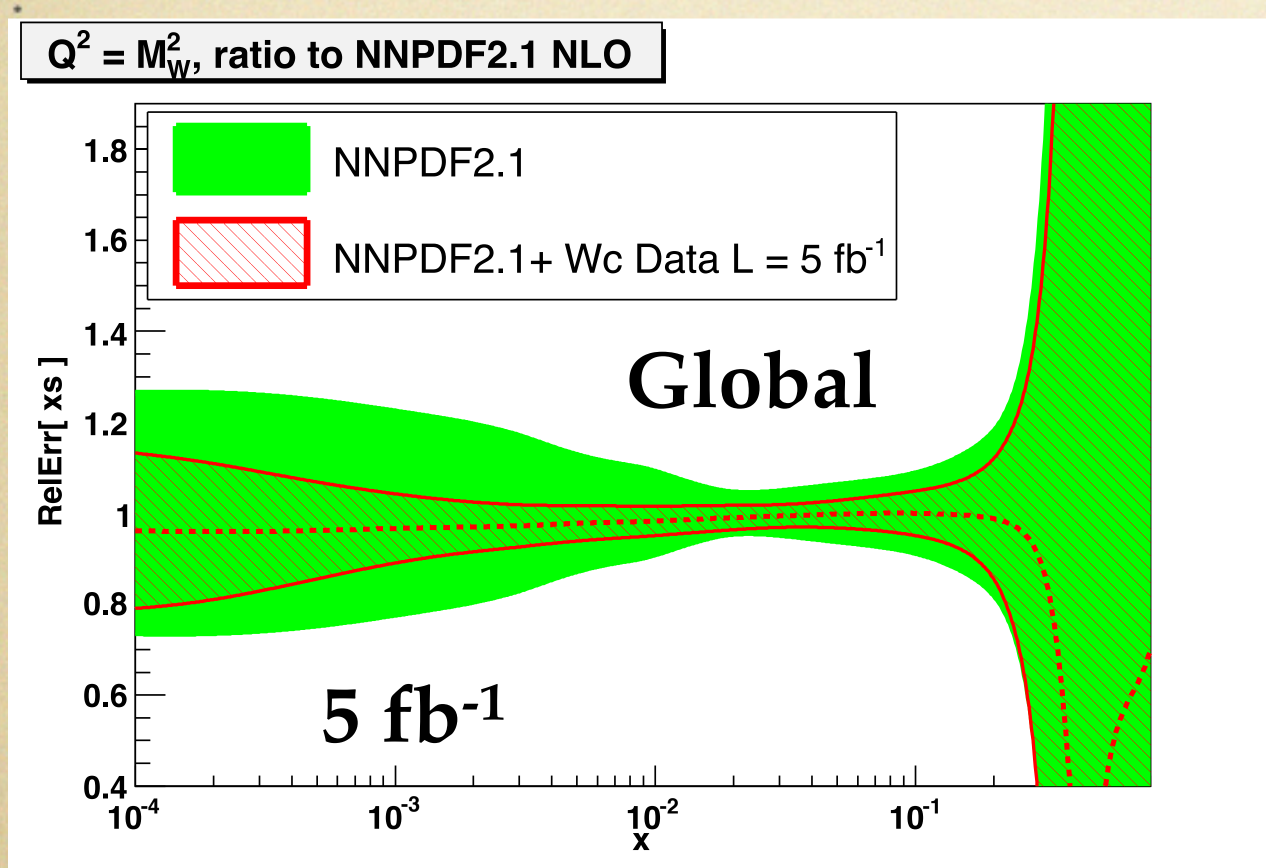


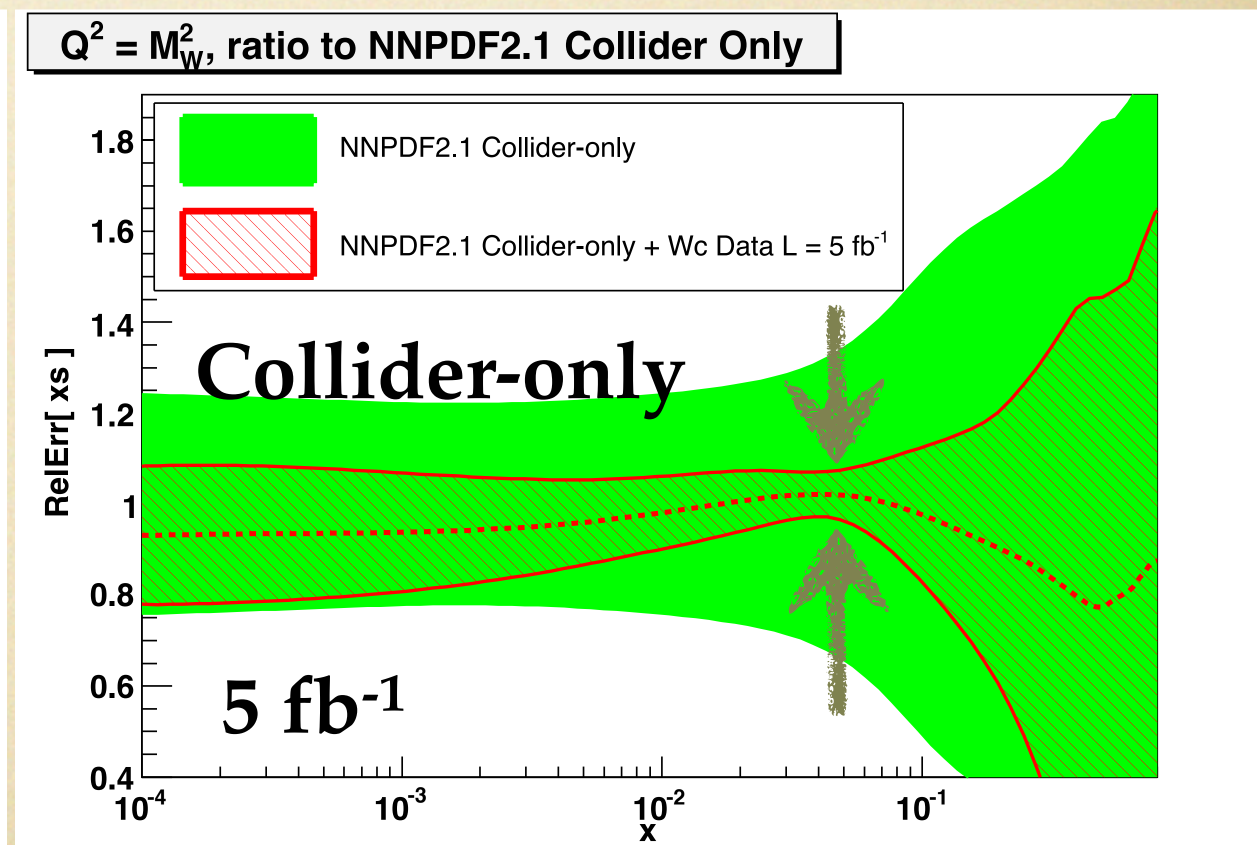




Impact on Strangeness

- With **5 fb^{-1}** of LHC data it becomes possible to determine strangeness with the **comparable accuracy** as in a global PDF fit but **without** low energy neutrino data
- With more statistics results do not improve due to luminosity uncertainties: normalize to the W+jet cross section (in progress)





Summary and outlook

- Reliable PDFs are a crucial ingredient of the LHC physics program

- aMC@NLO offers the potential to improve substantially global PDF analysis: use **new and more differential observables**, account for **shower effects**, more **accurate NLO/NNLO QCD/QED/EW corrections** ...

- Such next generation PDF would allow to **fully exploit the LHC potential** for Higgs and BSM discovery and characterization

- Lots of work to be done !!