NNPDF and The LHC:
the way towards a reliable collider-only PDF fit

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On behalf of

The NNPDF Collaboration
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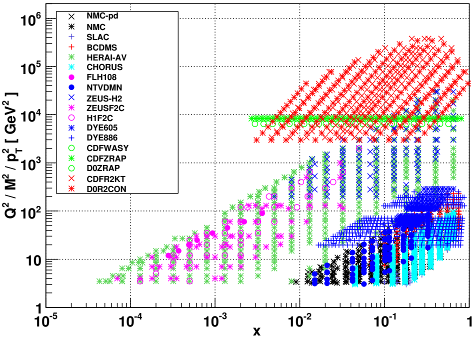
NNPDF2.1

A family of global fits ...

NNPDF2.1 dataset



3415 data points (NLO fit)
(3408 - LO and 3473 - NNLO)

[R. D. Ball et. al, arXiv:1101.1300] - **NLO**
[R. D. Ball et. al, arXiv:1107.2652] - **LO/NNLO**

OBS	*Data set*
Deep Inelastic Scattering	
F_2^d/F_2^p	NMC-pd
F_2^p	NMC, SLAC, BCDMS
F_2^d	SLAC, BCDMS
$\sigma_{NC}^{\pm}$	HERA-I, ZEUS (HERA-II)
$\sigma_{CC}^{\pm}$	HERA-I, ZEUS (HERA-II)
F_L	H1
$\sigma_\nu, \sigma_{\bar\nu}$	CHORUS
dimuon prod.	NuTeV
F_2^c	ZEUS, H1

Drell-Yan & Vector Boson prod.	
$d\sigma^{\rm DY}/dM^2dy$	E605
$d\sigma^{\rm DY}/dM^2dx_F$	E866
W asymm.	CDF
Z rap. distr.	D0/CDF
Inclusive jet prod.	
Incl. $\sigma^{\rm (jet)}$	CDF (k_T) - Run II
Incl. $\sigma^{\rm (jet)}$	D0 (cone) - Run II

NNPDF2.1

... based on the NNPDF Methodology

- **Monte Carlo** determination of errors
  - No need to rely on linear propagation of errors
  - Possibility to test for the impact of non gaussianly distributed errors
  - Possibility to test for non-gaussian behaviour in fitted PDFs ($1-\sigma$ vs. 68% CL)
- **Neural Networks**
  - Provide an **unbiased** parametrization
- **Stopping based on Cross-Validation**
  - Ensures proper fitting avoiding overlearning

NNPDF2.1

... including Heavy Flavour contributions (FONLL)

- We adopt the **FONLL** General Mass-Variable Flavour Number Scheme

  [M. Cacciari, M. Greco and P. Nason, (1998)]

  [S. Forte, P. Nason E. Laenen and J. Rojo, (2010)]

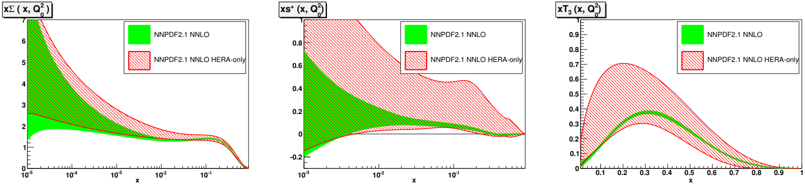
- FONLL gives a prescription to **combine FFN** (Massive) and **ZM-VFN** (Massless) computations, at any given order, **avoiding double counting**.

- With available computations three implementations of FONLL are possibile:
  - **FONLL-A**: $\mathcal{O}(\alpha_s)$ Massless + $\mathcal{O}(\alpha_s)$ Massive - (NLO fit)
  - **FONLL-B**: $\mathcal{O}(\alpha_s)$ Massless + $\mathcal{O}(\alpha_s^2)$ Massive
  - **FONLL-C**: $\mathcal{O}(\alpha_s^2)$ Massless + $\mathcal{O}(\alpha_s^2)$ Massive - (NNLO fit)

- **Fixed Flavour Number Scheme** (3-, 4-, 5-) fits **available**.

NNPDF fits to reduced datasets

- HERAPDF is not the only fit based on **HERA data only**
- HERA-only fit uses the **SAME settings** of global fit
  - No restrictions on **flavour separation**
  - No assumptions on **strangeness** being proportional to non-strange sea
  - Same unbiased **parametrization** (259 parameters)



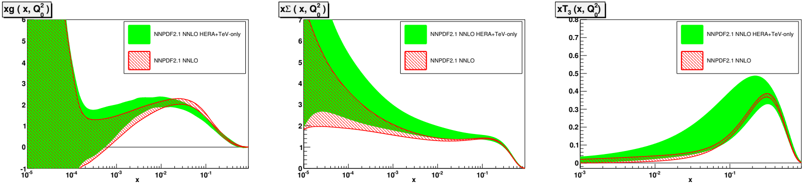
- Large uncertainties due to lack of experimental constraints and no ad-hoc parametrization choices

NNPDF fits to reduced datasets

Collider-only fit

- The fit we would love to have ...
  - Only **high energy data**: minimize effects of higher-twist contribiutions
  - Only **proton data**: no assumptions based on nuclear corrections models

- Based on **HERA and Tevatron** (inclusive jets and W/Z prduction) data



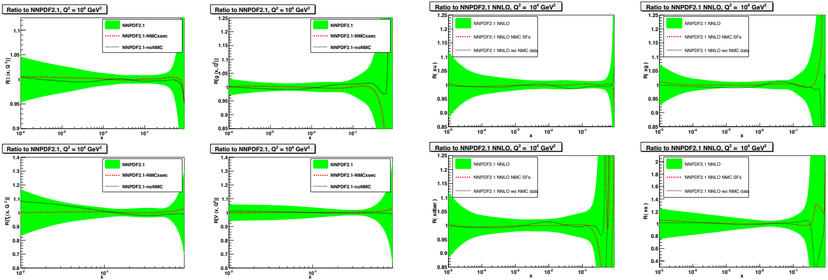
- **LHC** (and HERA-II combined) **data are crucial** in order to improve collider-only fit

Impact of NMC data on PDF determinations

... if you needed one more reason to love a collider-only fit

[R. D. Ball et al, arXiv:1102.3182v2]

- In arXiv:1101.5261, ABM suggested that the **detailed treatment of NMC data** has a **sizable impact on PDF** determinations and the **Higgs cross-section** at the Tevatron and the LHC.
- We addressed the question in the context of the **NNPDF2.1 NLO and NNLO** fits



Impact of NMC data on PDF determinations

... if you needed one more reason to love a collider-only fit

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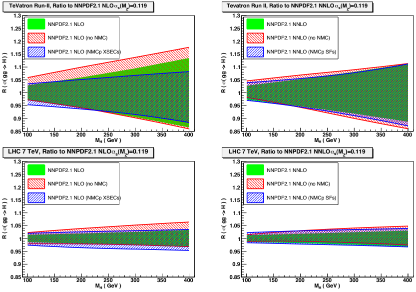
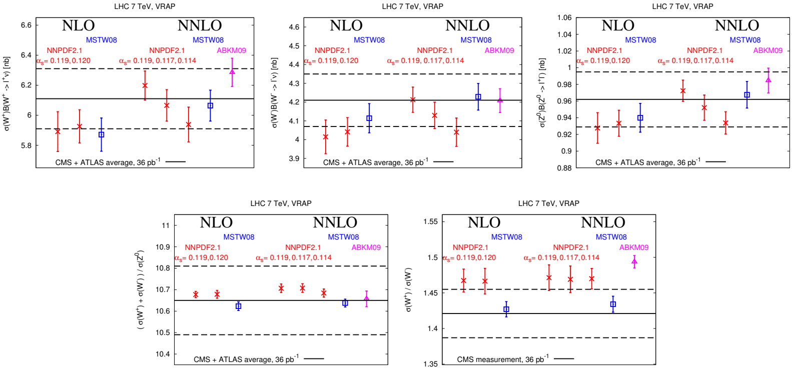


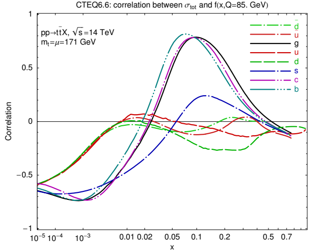
- **Standard Candles** measurements might soon have the ability to **discriminate** among **theory predictions**



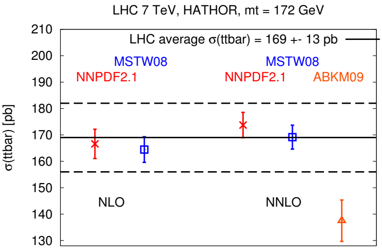
PDF4LHC

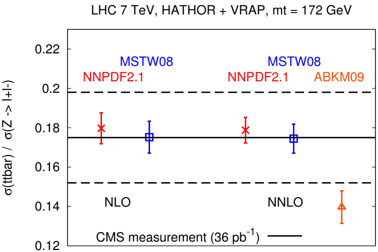
$t\bar{t}$ production

[Nadolsky et al, ArXiv:0802.0007]



- $\sigma_{t\bar{t}}$ correlated to all PDFs
- $\sigma_{t\bar{t}}$ sensitive probe of gluon
- Gluon strongly correlated to α_S





Reweighting NNPDFs

Assessing the impact of new data on PDF fits

[R. D. Ball et al., arXiv:1012.0836]

- The N_{rep} **replicas** of a NNPDF fit give the **probability density** in the space of PDFs

- **Expectation values** for observables computed as

$$\langle \mathcal{F}[f_i(x, Q^2)] \rangle = \frac{1}{N_{rep}} \sum_{k=1}^{N_{rep}} \mathcal{F}\left(f_i^{(net)(k)}(x, Q^2) \right)$$

(... the same is true for errors, correlations, etc.)

- We can **assess the impact** of including **new data** in the fit updating the probability density distribution without refitting.

Reweighting NNPDFs

Assessing the impact of new data on PDF fits

- According to **Bayes Theorem** we have

$$\mathcal{P}_{\rm new}(\{f\}) = \mathcal{N}_\chi \mathcal{P}(\chi^2|\{f\})\mathcal{P}_{\rm init}(\{f\})\,, \quad \mathcal{P}(\chi^2|\{f\}) = [\chi^2(y,\{f\})]^{\frac{n_{dat}-1}{2}} e^{-\frac{\chi^2(y,\{f\})}{2}}$$

- **Averages over the sample** are now **weighted sums**

$$\langle \mathcal{F}[f_i(x,Q^2)]\rangle = \sum_{k=1}^{N_{rep}} w_k \mathcal{F}\left(f_i^{(net)(k)}(x,Q^2)\right)$$

where the **weights** are

$$w_k = \frac{[\chi^2(y,f_k)]^{\frac{n_{dat}-1}{2}} e^{-\frac{\chi^2(y,f_k)}{2}}}{\sum_{i=1}^{N_{\rm rep}}[\chi^2(y,f_i)]^{\frac{n_{dat}-1}{2}} e^{-\frac{\chi^2(y,f_i)}{2}}}$$

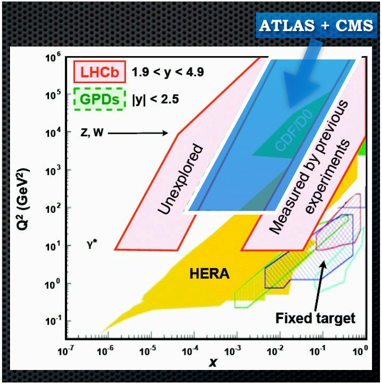
Towards a reliable collider-only fit

W lepton asymmetry data at the LHC

$$A^l_W = \frac{\sigma(pp \to W^+ \to l^+\nu_l) - \sigma(pp \to W^- \to l^-\bar{\nu}_l)}{\sigma(pp \to W^+ \to l^+\nu_l) + \sigma(pp \to W^+ \to l^-\bar{\nu}_l)}$$

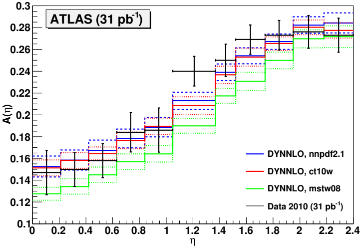
- ATLAS: muon charge asymmetry ($31\mathrm{pb}^{-1}$) [ArXiv:1103:2929]
- CMS: muon charge asymmetry ($36\mathrm{pb}^{-1}$) [ArXiv:1103:3470]
- LHCb: preliminary forward W muon charge asymmetry ($16.5\mathrm{pb}^{-1}$), not corrected for FSR

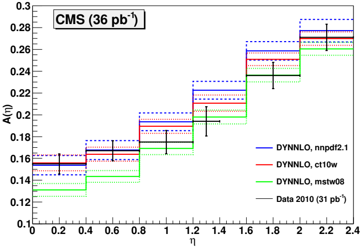
$$A^l_W \sim \frac{u(x_1, M_W^2)\bar{d}(x_2, M_W^2) - d(x_1, M_W^2)\bar{u}(x_2, M_W^2)}{u(x_1, M_W^2)\bar{d}(x_2, M_W^2) + d(x_1, M_W^2)\bar{u}(x_2, M_W^2)}$$



Towards a reliable collider-only fit

The W lepton asymmetry data at LHC





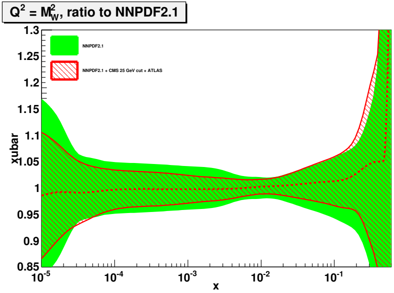
χ^2/d.o.f.	**NNPDF2.1**	**CT10w**	**MSTW08**
ATLAS	0.7	0.8	3.2
CMS e^- $p_T > 25$ GeV	1.9	0.8	2.4
CMS e^- $p_T > 30$ GeV	1.7	1.2	2.5
CMS μ $p_T > 25$ GeV	1.3	0.5	1.1
CMS μ $p_T > 30$ GeV	0.8	0.6	1.3

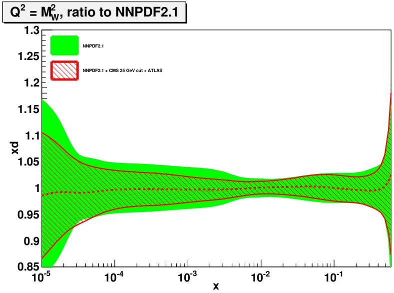
Theory predictions computed using DYNNLO at NLO

[ArXiv:0903.2120]

Towards a reliable collider-only fit

Inclusion of the LHC W lepton asymmetry data (PRELIMINARY)





- ATLAS and CMS data compatible with data included in global analysis
- The provide important constraint to PDFs in the small medium-x region
- Significant uncertainty reduction

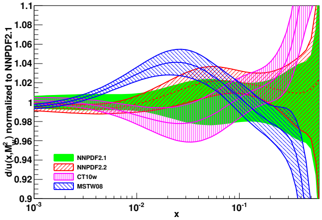
ATLAS
$N_{\mathrm{eff}} = 928$, $\chi^2_{\mathrm{d.o.f.}}$: $0.69 \rightarrow 0.65$
CMS ($p_T^l > 25$GeV)
$N_{\mathrm{eff}} = 554$, $\chi^2_{\mathrm{d.o.f.}}$: $1.41 \rightarrow 0.74$
CMS ($p_T^l > 30$GeV)
$N_{\mathrm{eff}} = 717$, $\chi^2_{\mathrm{d.o.f.}}$: $0.98 \rightarrow 0.72$

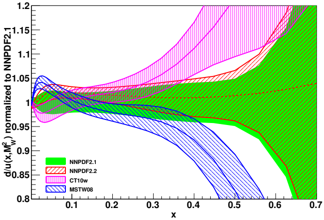
Towards a reliable collider-only fit

Combining Tevatron and LHC data (PRELIMINARY)

LOG scale

LIN scale

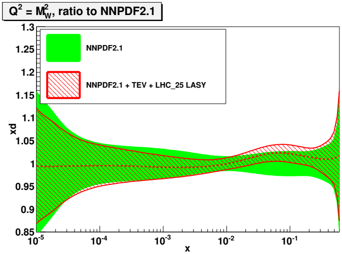




ATLAS+CMS(25)+D0$_\mu$+D0$_e$(20)

$N_{\rm eff}$ = 196, $\chi^2_{\rm d.o.f.}$: 2.18 $\rightarrow$ 0.86

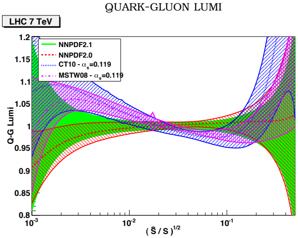
- Uncertainty reduction medium-small x and shift in central value driven by the LHC data
- Uncertainty reduction at medium-large x driven by Tevatron data



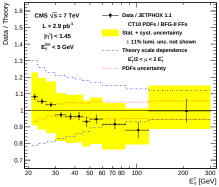
LHC4PDFs

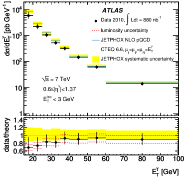
Prompt photons at the LHC

- Direct probe of *qg* luminosity
- Constraint on medium-*x* gluon ... **complementary to inclusive jets**
- Possible “problems” ... but concentrated in the **small-$p_\perp$ region**



- Measurements by ATLAS and CMS should be soon finalized





Theoretical setup: JETPHOX NLO + NNPDF2.1

- JETPHOX 1.3.0 NLO pQCD code [Guillet-Arleo]
- NNPDF2.1 (100 replicas) interfaced via LHAPDF5.8.5
- BFG-II parton-to-photon FFs (but suppressed by isolation cuts).
- All scales set to default: $\mu_R = \mu_F = \mu_{FF} = E_T^\gamma$
- Exp. kinematics+isolation cuts & p_T binnings for 30 systems:

100 replicas direct-γ NLO: ~ 7h CPU / 1M evts (~5 days for 20 Mevts !)
100 replicas frag-γ NLO: ~10h CPU / 1M evts (~1 week for 20 Mevts !)

$\times$**30 !**

- NNPDF2.1 "reweighting technique":

(1) $d\sigma_{NLO}/dp_T$ for 100 (or 1000) replicas: NNPDF21_100.LHgrid

(2) χ^2 analysis $d\sigma_{EXP}/dp_T$ - $d\sigma_{NLO}/dp_T$ for each replica.

(3) Obtain associated "weight" for each replica:

$$w_k = \frac{(\chi_k^2)^{n/2-1} e^{-\frac{1}{2}\chi_k^2}}{\frac{1}{N}\sum_{k=1}^{N} (\chi_k^2)^{n/2-1} e^{-\frac{1}{2}\chi_k^2}}.$$

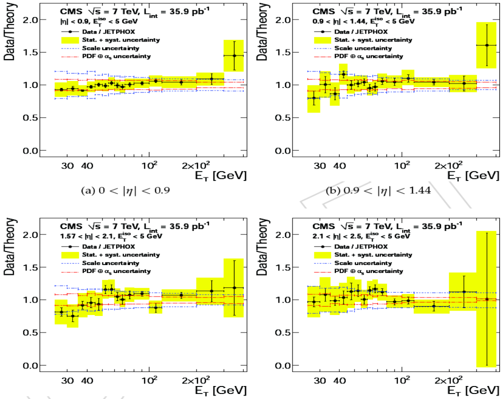
(4) Obtain reweighted PDF replicas:

$$\langle \mathcal{O} \rangle_{\rm new} = \frac{1}{N} \sum_{k=1}^{N} w_k \mathcal{O}[f_k]$$

[R.D.Ball et al. NPB 849 (2011) 112]

LHC isolated-γ vs JETPHOX (example)

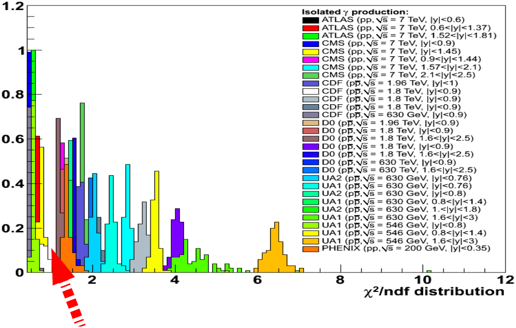
[See talk by Nicholas Chanon (CMS)]



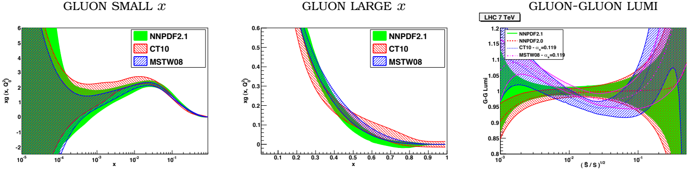
- **Excellent agreement** data-NLO for pp → γ_{isol}+X at 7 TeV

χ^2 world γ-data vs NNPDF replicas

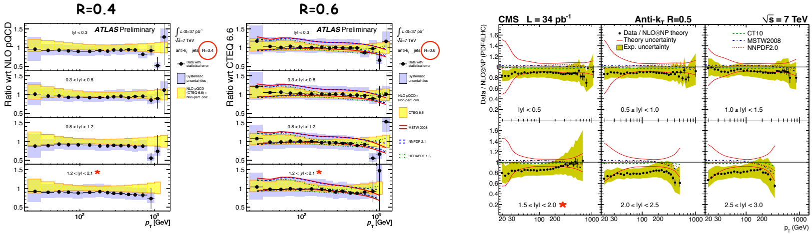
- χ^2/ndf distribution of 100 replicas for each one of 30 systems:
  (syst.+stat. uncertainties in quadrature. Lumi not considered)



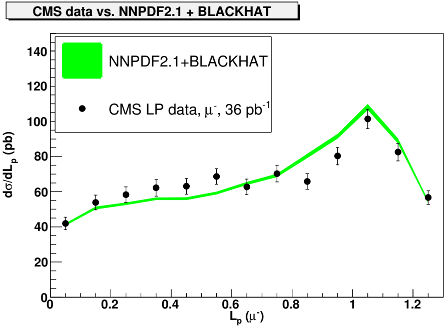
- Larger impact expected on **gluon in medium-x region** $(0.05 \leq x \leq 0.2)$



- Inconsistencies among PDF fits in this region might be resolved by precise data ... uncertainties dominated by systematics



- Can we learn something more looking at *W* **polarization**?
- **CMS measurement** available but still **uncorrected** for: background subtraction, efficiency, resolution.
- NLO calculation implemented in **BLACKHAT** (thanks to Daniel for running the code for us)



LHC4PDFs

... the data we would love to have

- Medium- and large-x **gluon**
  - Prompt photons
  - Inclusive Jets
  - t-quark distributions ($p_\perp$, y) ?

- **Light flavour separation** at medium- & small-x
  - Low-mass Drell-Yan
  - Z rapidity distribution
  - W(+jets) asymmetry

- **Strangeness & Heavy Flavours**
  - $W + c$
  - $Z + c$, $\gamma + c$
  - $Z + b$

... and if we could have them as **APPLGRID or FastNLO grids** ...
that would be really sweet! ;)