PDFs in the light of the LHC data

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24th Rencontres de Blois - Particle Physics & Cosmology May 27 - June 1, 2012

Parton Distribution Functions What are they? – Definition

Consider a process with a single hadron in the initial state



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The cross section for such a process can be written (Factorization Theorem) as

$$d\sigma = \sum_{a} \int_{0}^{1} \frac{d\xi}{\xi} D_{a}(x,\mu^{2}) d\hat{\sigma}_{a}\left(\frac{x}{\xi},\frac{\hat{s}}{\mu^{2}},\alpha_{s}(\mu^{2})\right) + O\left(\frac{1}{Q^{p}}\right)$$



Parton Distribution Functions What are they? - DGLAP evolution

• Parton Distribution Functions are non-perturbative objects and their value at given x and Q² cannot be computed in QCD Perturbation Theory (Lattice?)

No. 1. Statement of the State Continues of

• ... but the scale dependence of PDFs is governed by the DGLAP evolution equations

$$\frac{\partial q_i(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_s(\mu^2)}{2\pi} \Big[P_{qq}(x) \otimes q_i(x,\mu^2) \Big] + \frac{\alpha_s(\mu^2)}{2\pi} \Big[P_{qg} \otimes g(x,\mu^2) \Big]$$
$$\frac{\partial g(x,\mu^2)}{\partial \ln \mu^2} = \frac{\alpha_s(\mu^2)}{2\pi} \Big[P_{gq}(x) \otimes \sum_i \Big(q_i(x,\mu^2) + \overline{q}_i(x,\mu^2) \Big) \Big] + \frac{\alpha_s(\mu^2)}{2\pi} \Big[P_{gg} \otimes g(x,\mu^2) \Big]$$

• ... where the splitting functions (P_{ij}) can be computed in Perturbation Theory and are known up to NNLO

[LO – Dokshitzer; Gribov, Lipatov; Altarelli, Parisi (1977)]
[NLO – Floratos, Ross, Sachrajda; Gonzalez-Arroyo, Lopez, Yndurain; Curci, Furmanski, Petronzio (1981)]
[NNLO – Moch, Vermaseren, Voqt (2004)]

Parton Distribution Functions Why do we care?



The PDF fitting game The players

Collaboration	Authors	arXiv		
ABM	S. Alekhin, J. Blümlein, S. Moch	1105.5349, 1101.5261, 1107.3657, 0908.3128, 0908.2766,		
CTEQ/TEA	M. Guzzi J. Huston, HL. Lai, P. Nadolsky, J. Pumplin, D. Stump, CP.Yuan	1108.5112, 1101.0561, 1007.2241, 1004.4624, 0910.4183, 0904.2424, 0802.0007,		
GJR	M. Glück, P. Jimenez-Delgado, E. Reya	1003.3168, 0909.1711, 0810.4274,		
HERAPDF	HI and ZEUS Collaborations	1107.4193, 1006.4471, 0906.1108,		
MSTW	A. Martin, J. Stirling, R. Thorne, G. Watt	1107.2624, 1006.2753, 0905.3531, 0901.0002,		
NNPDF	R. D. Ball, V. Bertone, F. Cerutti, L. Del Debbio, S. Forte, AG, N. P. Hartland, J. I. Latorre, J. Rojo, M. Ubiali	1110.2483, 1108.2758, 1107.2652, 1103.2369, 1102.3182, 1101.1300, 1005.0397, 1002.4407, 0912.2276, 0906.1958,		

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The PDF fitting game Present status of PDF fits

	DATASET	PERT. ORDER	HQ TREATMENT	αs	PARAM.	UNCERT.
ABM11	DIS Drell-Yan	NLO NNLO	FFN (BMSN)	Fit (multiple values available)	6 indep. PDFs Polynomial (25 param.)	Hessian ($\Delta \chi^2$ =1)
CT10	Global	LO NLO NNLO	GM-VFNS (S-ACOT)	External (multiple values available)	6 indep. PDFs Polynomial (26 param.)	Hessian ($\Delta \chi^2$ =100)
JR09	DIS Drell-Yan Jets	NLO NNLO	FFN VFN	Fit	5 indep. PDFs Polynomial (15 param.)	Hessian ($\Delta \chi^2$ =1)
HERAPDF1.5	DIS (HERA)	NLO NNLO	GM-VFNS (TR)	External (multiple values available)	5 indep. PDFs Polynomial (14 param.)	Hessian ($\Delta \chi^2$ =1)
MSTW08	Global	LO NLO NNLO	GM-VFNS (TR)	Fit (multiple values available)	7 indep. PDFs Polynomial (20 param.)	Hessian $(\Delta \chi^2 \sim 25)$
NNPDF2.1/2.3	Global	LO NLO NNLO	GM-VFNS (FONLL)	External (multiple values available)	7 indep. PDFs Neural Nets (259 param.)	Monte Carlo

Comparing Parton Luminosities

Let us first compare parton luminosities at the LHC (7 TeV)

$$\Phi_{ij} = \frac{1}{s} \int_{\tau}^{1} \frac{dx'}{x'} f_i(x', M_X^2) f_j(\tau / x', M_X^2)$$



Plots by G.Watt (arXiv:1106.5788)



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Comparing predictions for LHC Benchmark processes

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LHC data will soon be accurate enough to distinguish between predictions from different PDF sets

Comparing predictions for LHC Benchmark processes

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LHC data will soon be accurate enough to distinguish between predictions from different PDF sets



Comparing predictions for LHC Benchmark processes

Going beyond inclusive quantities and looking at **differential distributions** adds even **more information**

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LHC data are testing previously untested assumptions and fine details of PDF fits





PDFs for the LHC A "strange" story ...

- In a recent publication (arXiv:1203.4051)
 ATLAS performed a QCD analysis of
 HERA-I and ATLAS W/Z data
- Strange sea PDF roughly equal to the u and d quark sea PDFs, at odds with predictions from most PDF sets
- Strangeness is one place where different sets differ most
- Strange PDFs parametrized with only two
 free parameters
- •We repeated the analysis within the **NNPDF framework** (using a substantially more flexible strange parametrization)







A "strange" story ...

- Compare NNPDF2.1, NNPDF2.3-noLHC, and NNPDF2.3 sets with various datasets: global, HERA+ATLAS-WZ, collider-only
- HERA+ATLAS-WZ (and collider-only) fit: central value consistent with ATLAS analysis, but substantially larger PDF uncertainties
- Possible signs of "tension" between fixed target (NuTeV/CCFR) and collider data

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A "strange" story ...



- PDF uncertainties in ATLAS determination of strangeness probably seriously underestimated
- ... but LHC data begin to provide constraints on strangeness and hint at a possible "tension" with fixed-target data
- Upcoming W+charm measurement will shed more light on the issue



NNPDF2.3 – Inclusion of LHC data in global fits

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NLO	NNPDF2.3 noLHC	NNPDF2.3	
NMCpd	0.93	0.94	
NMC	1.62	1.65	
SLAC	1.27	1.26	
BCDMS	1.24	1.25	
HERA-I	1.03	1.02	
CHORUS	1.15	1.14	
NuTeV	0.42	0.42	
DYE605	0.78	0.81	
DYE866	1.20	1.21	
CDFWASY	1.60	1.60	
CDFZRAP	1.71	1.65	
DOZRAP	0.61	0.61	
ATLAS-WZ	1.41	1.30	
CMS-WEASY	1.60	1.05	
LHCb-WZ	1.13	1.07	
CDFR2KT	0.76	0.79	
DOR2CON	0.78	0.79	
ATLAS-JETS-2010	1.31	1.25	

- Compare the quality of the fit to LHC data before and after inclusion in the global fit
- Including LHC data in the fit improves the quality of their description, w/o deteriorating quality of the fit to other datasets
- Moderate impact of the LHC data, supporting consistency of the global fit framework
- Fit quality is comparable at NLO and NNLO, thought the former marginally better

NNPDF2.3 – Inclusion of LHC data in global fits

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NNLO	NNPDF2.3 noLHC	NNPDF2.3
NMCpd	0.93	0.95
NMC	1.58	1.62
SLAC	1.02	1.01
BCDMS	1.31	1.32
HERA-I	1.07	1.04
CHORUS	1.12	1.12
NuTeV	0.49	0.57
DYE605	0.82	0.82
DYE866	1.33	1.33
CDFWASY	1.67	1.69
CDFZRAP	1.87	1.90
DOZRAP	0.64	0.64
ATLAS-WZ	1.80	1.41
CMS-WEASY	1.19	0.95
LHCb-WZ	1.20	1.11
CDFR2KT	0.75	0.73
DOR2CON	0.83	0.81
ATLAS-JETS-2010	1.26	1.21

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NNPDF2.3 – Inclusion of LHC data in global fits

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- NNPDF2.3 is the first global fit including LHC data
 * ATLAS, CMS & LHC-b W/Z data
 * ATLAS inclusive jet data
- Reduction on uncertainty in large-x gluon (ATLAS jet data)
- Reduction on uncertainties on light quark distributions both at small- and large-x (W/Z data)
- Changes in light flavour PDFs shape after due to inclusion of LHC W/Z data: handle on flavour separation





Collider-only fits, are we there yet?

It is the fit we would love to have

• Only high energy data: minimize the effects of higher-twist contributions

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- Only proton data: no assumptions based on models for nuclear corrections
- How does a fit including only HERA DIS, Tevatron W/Z and inclusove jet and LHC data compares to global fits?
- Gluon distribution is very well constrained both at small-x (HERA) and large-x (Tevatron/LHC jets)
- PDF combinations sensitive to light flavour separation have much larger uncertainties in the collider-only fit
 (missing constraints from fixed target DIS/DY data)





Collider-only fit? More data are coming!

More inclusive jet (and dijet) data



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Constraining the medium/large-x gluon



Collider-only fit? More data are coming!



Low-mass Drell-Yan



High mass W production



(CAVEAT: needs to be turned from a search into a measurement)

Constraining light quark flavour separation

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Collider-only fit? More data are coming!



Conclusions & Outlook

 Parton distribution Functions are an essential ingredient in predictions of observables at the LHC experiments

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- The use of different methods and techniques in the extraction of PDFs guarantees the solidity of predictions and a thorough understanding of the differences and assumptions
- LHC data will soon (and indeed already do) discriminate between predictions from different PDF sets
- Measurements at the LHC will soon (and indeed already do) provide valuable information to further constrain PDFs

