Status of parton distributions and impact on the Higgs

Daniel de Florian
Dpto. de Física - FCEyN- UBA

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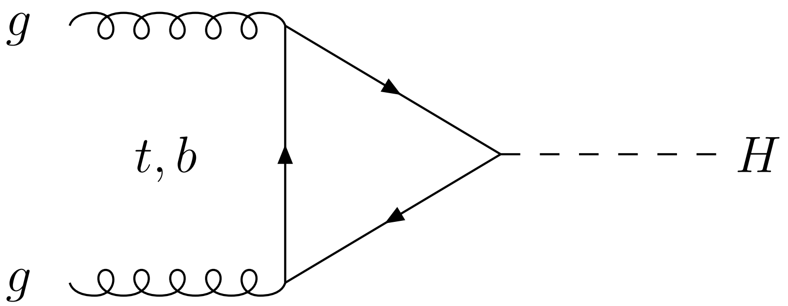
Departamento de Física Juan José Giambiagi
Facultad de Ciencias Exactas y Naturales Universidad de Buenos Aires

- Introduction to PDFs

- Summary of available fits

- Comparison of PDFs

- Impact (and issues) on Higgs Cross section :
  gg channel for inclusive cross section



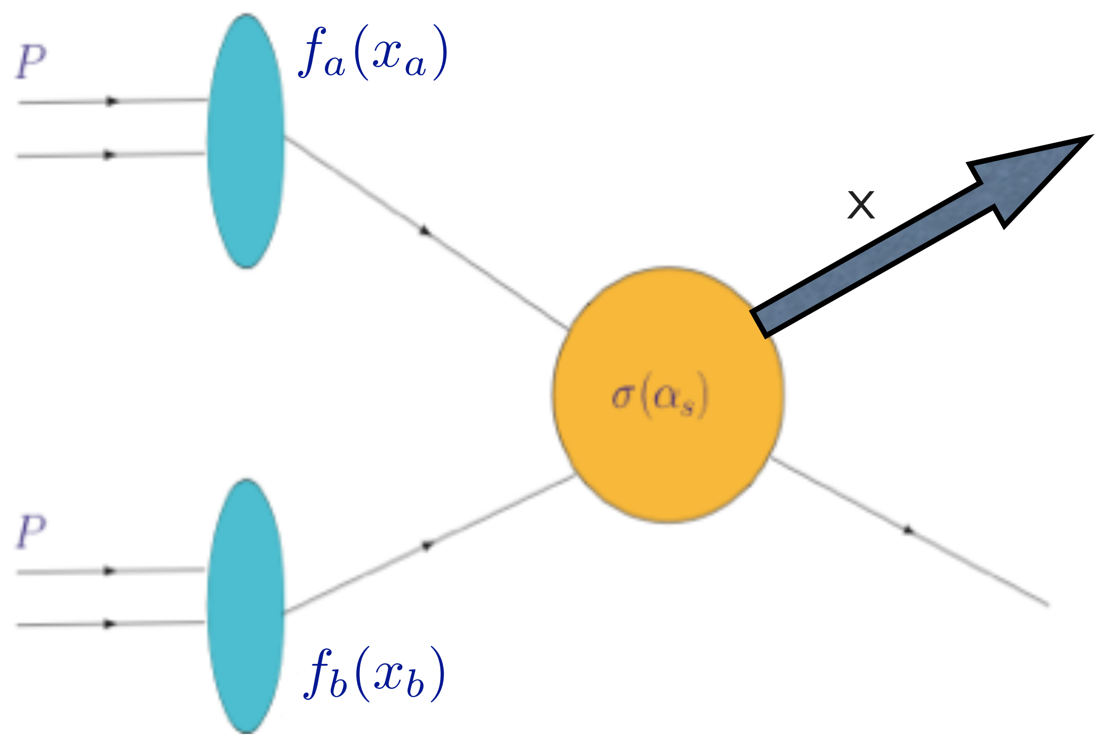
PDFs

Main ingredient of any high-energy observable in Hadronic Colliders

non-perturbative parton distributions

$$d\sigma = \sum_{ab} \int dx_a \int dx_b \, f_a(x_a, \mu_F^2) f_b(x_b, \mu_F^2) \times d\hat{\sigma}_{ab}(x_a, x_b, Q^2, \alpha_s(\mu_R^2)) + \mathcal{O}\left(\left(\frac{\Lambda}{Q}\right)^m\right)$$

perturbative partonic cross-section



Partonic cross-section: expansion in $\alpha_s(\mu_R^2) \ll 1$ $\quad d\hat{\sigma} = \alpha_s^n \, d\hat{\sigma}^{(0)} + \alpha_s^{n+1} \, d\hat{\sigma}^{(1)} + \ldots$

Expression relies on factorization theorem : HT, mass corrections, etc. not trivial

PDFs are universal !

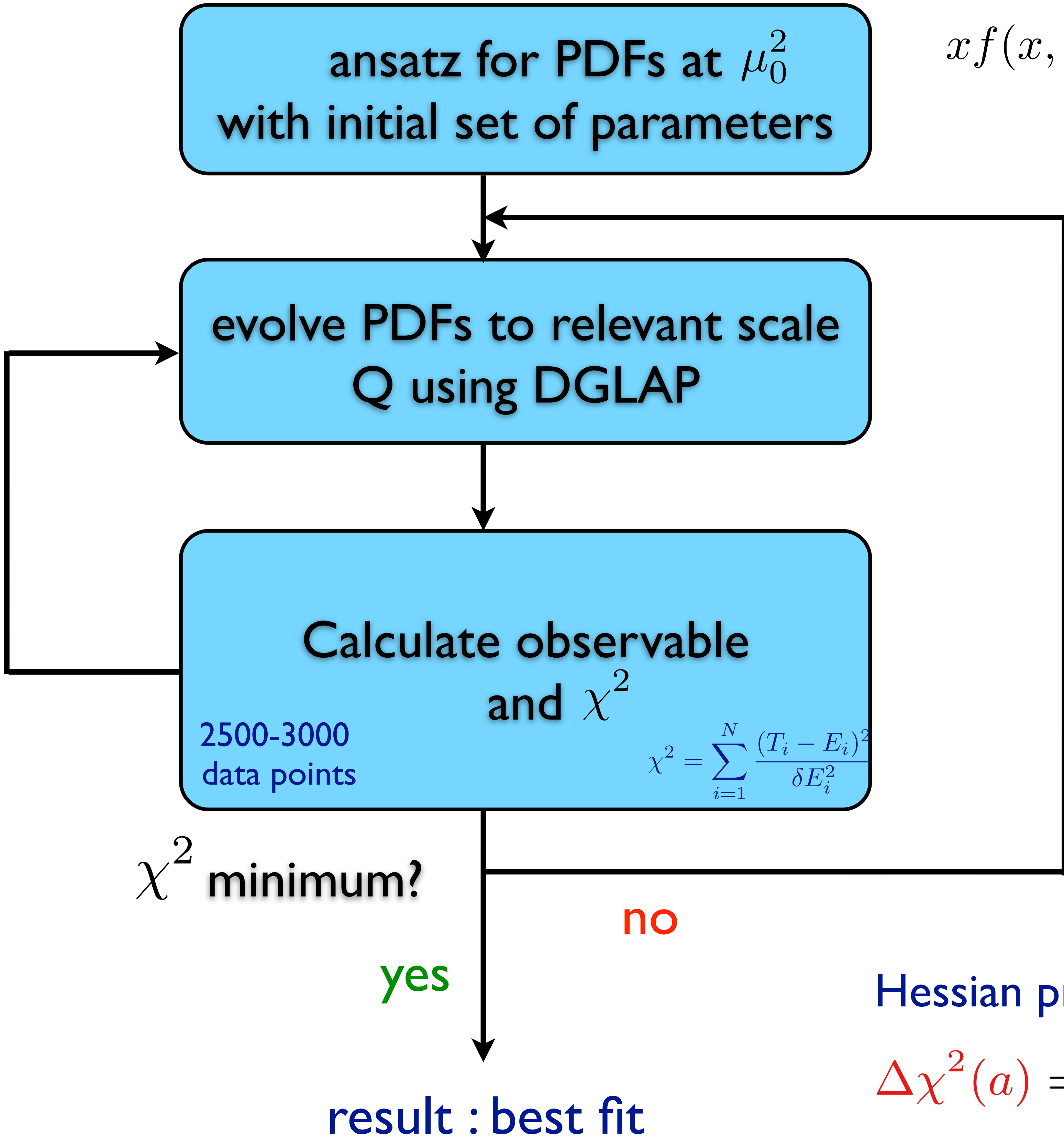
- Include all observables where pQCD is under control : each one helps to constrain a combination of pdfs at certain kinematics

	Process	Subprocess	Partons	x range
Fixed target : *lp* and DY	$\ell^\pm \{p,n\} \to \ell^\pm X$	$\gamma^* q \to q$	$q, \bar{q}, g$	$x \gtrsim 0.01$
	$\ell^\pm n/p \to \ell^\pm X$	$\gamma^* d/u \to d/u$	d/u	$x \gtrsim 0.01$
	$pp \to \mu^+\mu^- X$	$u\bar{u}, d\bar{d} \to \gamma^*$	$\bar{q}$	$0.015 \lesssim x \lesssim 0.35$
	$pn/pp \to \mu^+\mu^- X$	$(u\bar{d})/(u\bar{u}) \to \gamma^*$	$\bar{d}/\bar{u}$	$0.015 \lesssim x \lesssim 0.35$
	$\nu(\bar{\nu}) N \to \mu^-(\mu^+) X$	$W^* q \to q'$	$q, \bar{q}$	$0.01 \lesssim x \lesssim 0.5$
	$\nu N \to \mu^-\mu^+ X$	$W^* s \to c$	s	$0.01 \lesssim x \lesssim 0.2$
	$\bar{\nu} N \to \mu^+\mu^- X$	$W^* \bar{s} \to \bar{c}$	$\bar{s}$	$0.01 \lesssim x \lesssim 0.2$
HERA	$e^\pm p \to e^\pm X$	$\gamma^* q \to q$	$g, q, \bar{q}$	$0.0001 \lesssim x \lesssim 0.1$
	$e^+ p \to \bar{\nu} X$	$W^+ \{d, s\} \to \{u, c\}$	d, s	$x \gtrsim 0.01$
	$e^\pm p \to e^\pm c\bar{c} X$	$\gamma^* c \to c,\ \gamma^* g \to c\bar{c}$	$c,\ g$	$0.0001 \lesssim x \lesssim 0.01$
	$e^\pm p \to \text{jet} + X$	$\gamma^* g \to q\bar{q}$	g	$0.01 \lesssim x \lesssim 0.1$
Tevatron	$p\bar{p} \to \text{jet} + X$	$gg, qg, qq \to 2j$	g, q	$0.01 \lesssim x \lesssim 0.5$
	$p\bar{p} \to (W^\pm \to \ell^\pm \nu) X$	$ud \to W, \bar{u}\bar{d} \to W$	$u, d, \bar{u}, \bar{d}$	$x \gtrsim 0.05$
	$p\bar{p} \to (Z \to \ell^+\ell^-) X$	$uu, dd \to Z$	d	$x \gtrsim 0.05$

MSTW

Traditional approach

PDFs obtained by global fit : χ^2 minimization



$$x f(x, \mu_0^2) = A\, x^{\alpha} (1-x)^{\beta} \times \mathbf{function}(x)$$

20-30 parameters

$$\frac{f_i(x, \mu_F^2)}{d \ln \mu_F^2} = \sum_j P_{ij}(x, \alpha_s(\mu_F^2)) \otimes f_j(x, \mu_F^2)$$

Splitting functions
known up to NNLO

Vogt, Moch, Vermaseren

Hessian provides estimate of uncertainties

$$\Delta\chi^2(a) = \chi^2 - \chi_0^2 = \sum_{i,j} H_{ij} \delta a_i \delta a_j + \cdots$$

provide 40/50 pdfs to compute uncertainties for any observable

Neural Network approach

NNPDF, Ball et al

- Construct a set of MonteCarlo replicas of the original data set where the replicas fluctuate about central data

- Split data sets into training and validation sets

- Fit to the data replicas obtaining PDF replicas

- PDFs generated using a neural net to find the best fit. Eliminates largely dependence on parameterization. Still includes pre-processing factor to constrain kinematic limits

$$f(x,\mu_0^2) = A\,x^{\alpha}(1-x)^{\beta}\,NN(x)$$

- Statistical definition of mean value and standard deviation for observable

$$\langle \mathcal{F}[\{q\}]\rangle = \frac{1}{N_{\rm rep}}\sum_{k=1}^{N_{\rm rep}} \mathcal{F}[\{q^{(k)}\}] \qquad \sigma_{\mathcal{F}} = \left(\frac{1}{N_{\rm rep}-1}\sum_{k=1}^{N_{\rm rep}}\left(\mathcal{F}[\{q^{(k)}\}] - \langle\mathcal{F}[\{q\}]\rangle\right)^2\right)^{1/2}$$

$$N_{\mathbf{rep}} = 100\ \mathbf{or}\ 1000$$

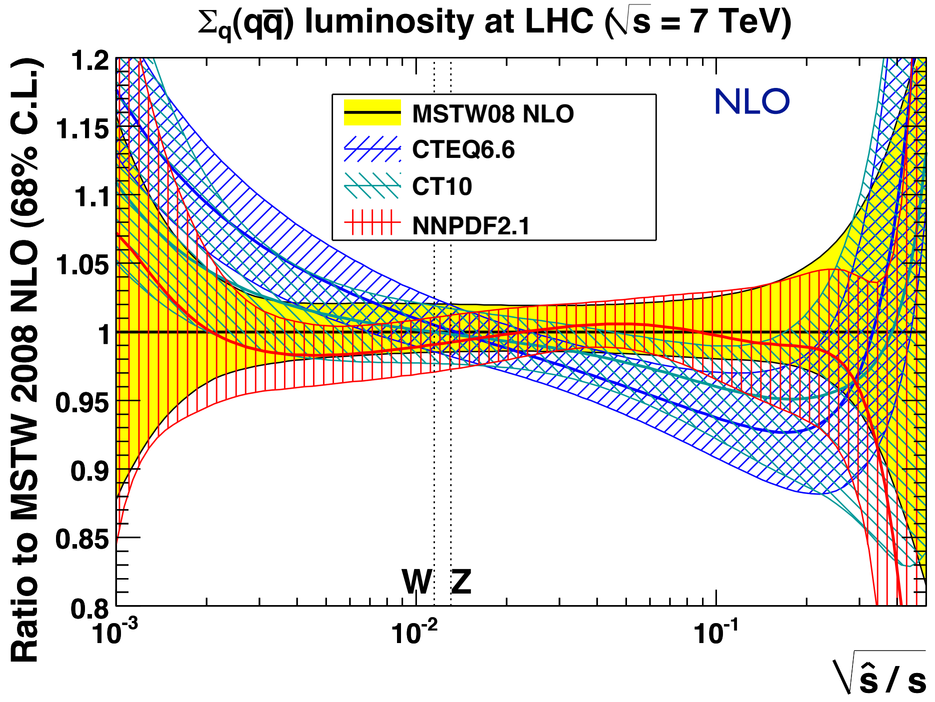
set	order	data	$\alpha_s(M_Z)$	uncertainty	HQ	
MSTW 2008	NNLO	global	fitted (+ external variations)	Hessian (dynamical tolerance)	GM-VFN (ACOT +TR')	Martin, Stirling, Thorne, Watt
CT10	NLO	global combined HERA	external (several values & older fit)	Hessian (dynamical tolerance)	GM-VFN (SACOT-X)	CTEQ, Lai et al.
NNPDF 2.1	NEW NNLO	global combined HERA	external (several values & recent fit)	Monte Carlo (pdf replicas)	GM-VFN (FONLL)	NNPDF, Ball et al.
AB(K)M	NNLO	DIS+DY(f.t.)	fitted	Hessian	FFN +matching	Alekhin, Blümlein, Klein, Moch
(G)JR	NNLO	DIS+DY(f.t.)+ some jet	fitted	Hessian	FFN (VFN massless)	Glück, Jimenez Delgado, Reya
HERA PDF	NNLO	only DIS HERA	external	Hessian	GM-VFN (ACOT +TR')	H1 & Zeus collaborations

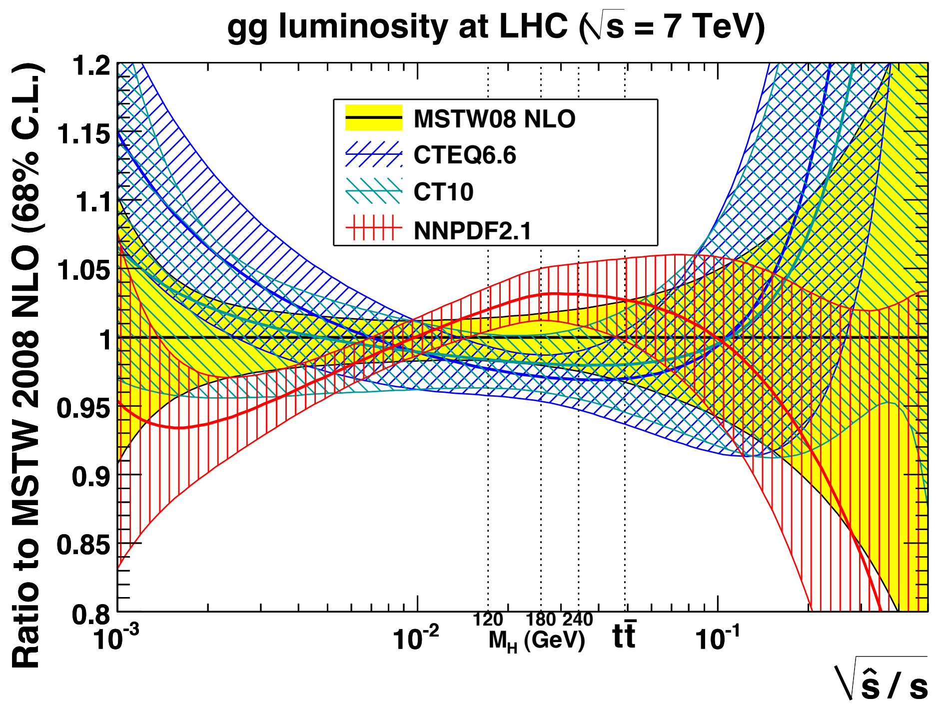
Each group one provides a number of sets to compute central values and pdfs, pdf+coupling uncertainties

Luminosities LHC @ 7 TeV

plots from G.Watt

$\mu_F^2 = \hat{s}$





Three global fits in reasonable agreement ***but*** deviations sometimes as large as uncertainties (not well understood why!)

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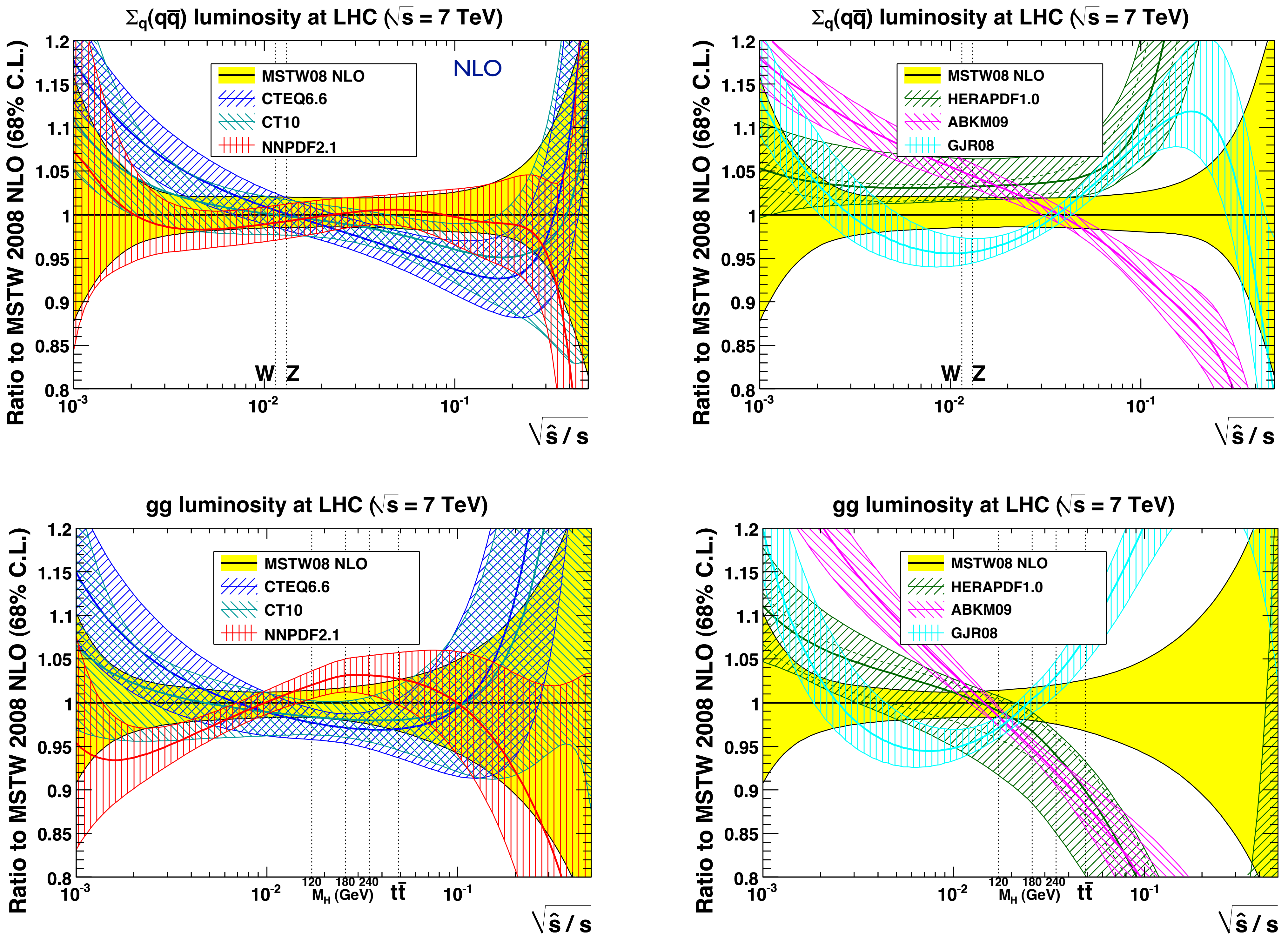

Three global fits in reasonable agreement ***but*** deviations sometimes as large as uncertainties (not well understood why!)

much bigger differences for non-global pdfs!

PDF4LHC recommendation for Higgs

- @ NLO Compute uncertainties using global MSTW & CT & NNPDF
- Obtain the envelope of all 68% c.l. bands : NLO uncertainty

supplemented with $\Delta\alpha_s(M_Z) = \pm 0.0012\,(\pm 0.002)$ at 68% (90%) c.l.

Envelope to partially account for TH uncertainties (assumptions)

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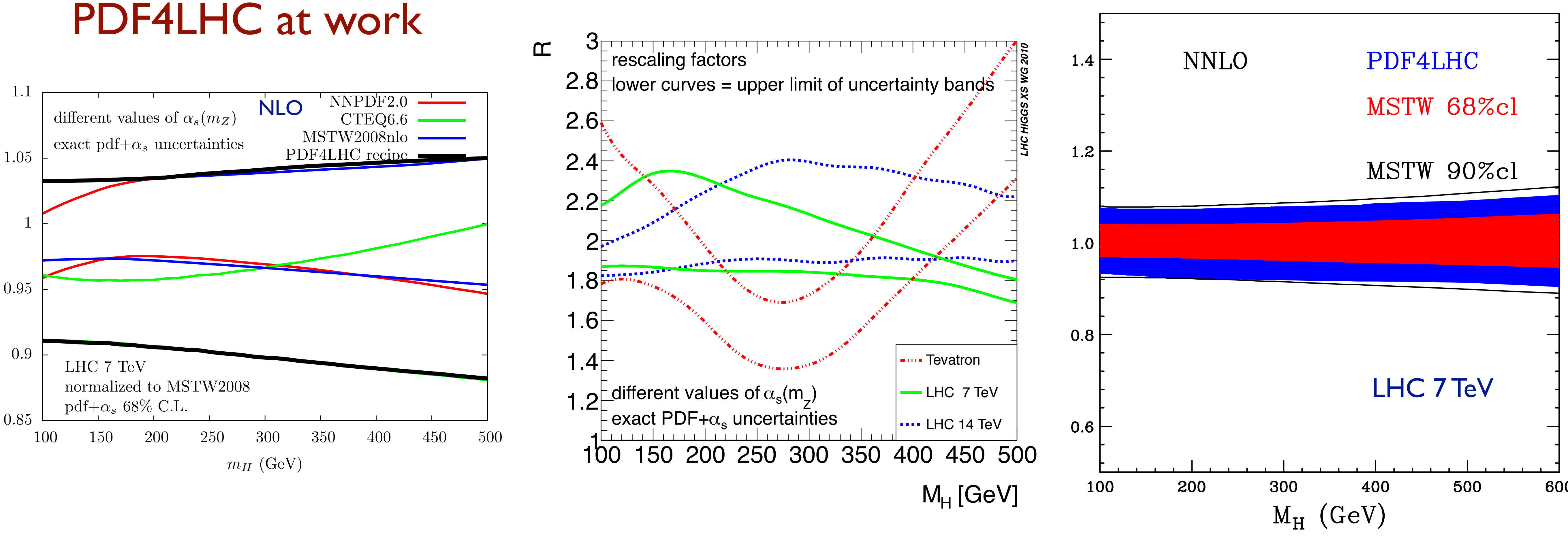
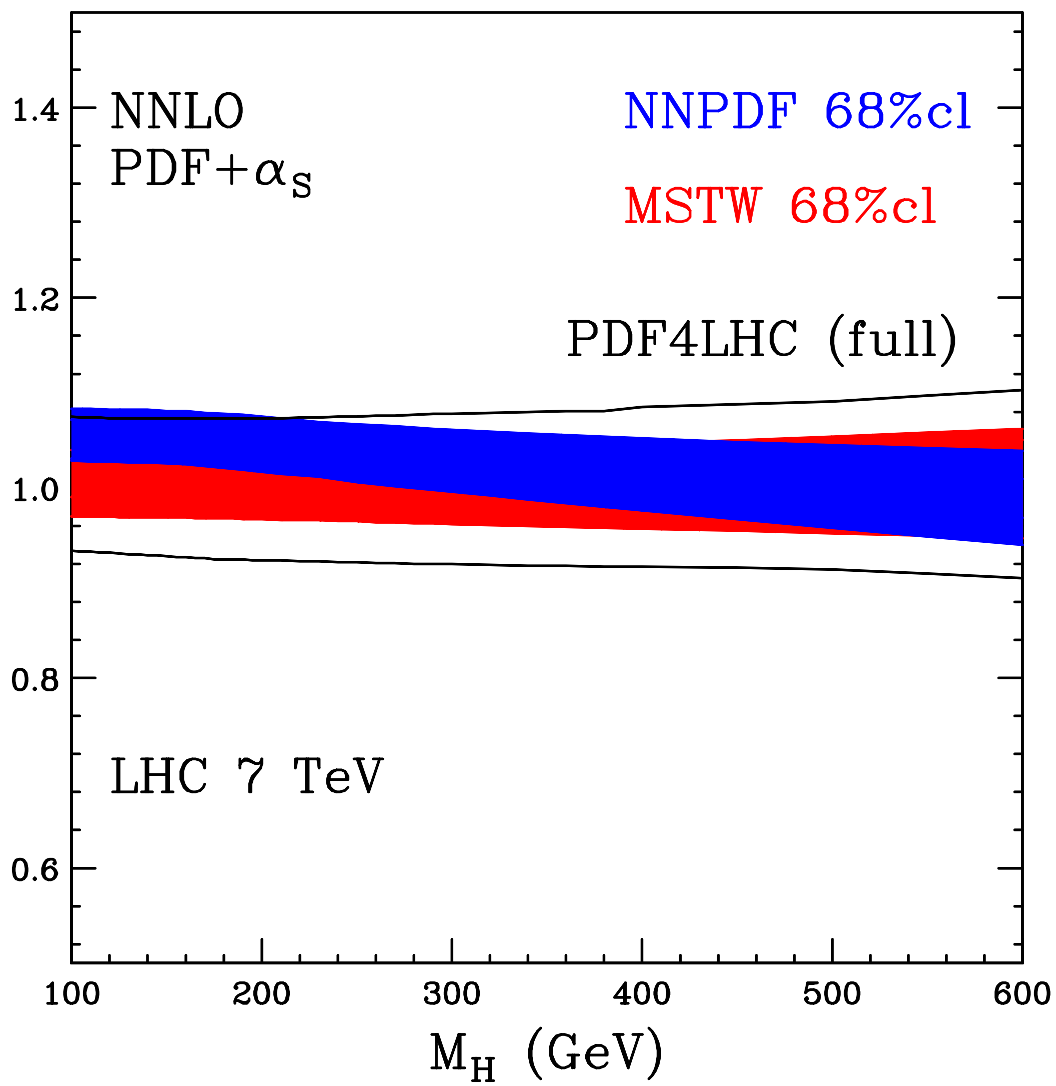
Envelope to partially account for TH uncertainties (assumptions)

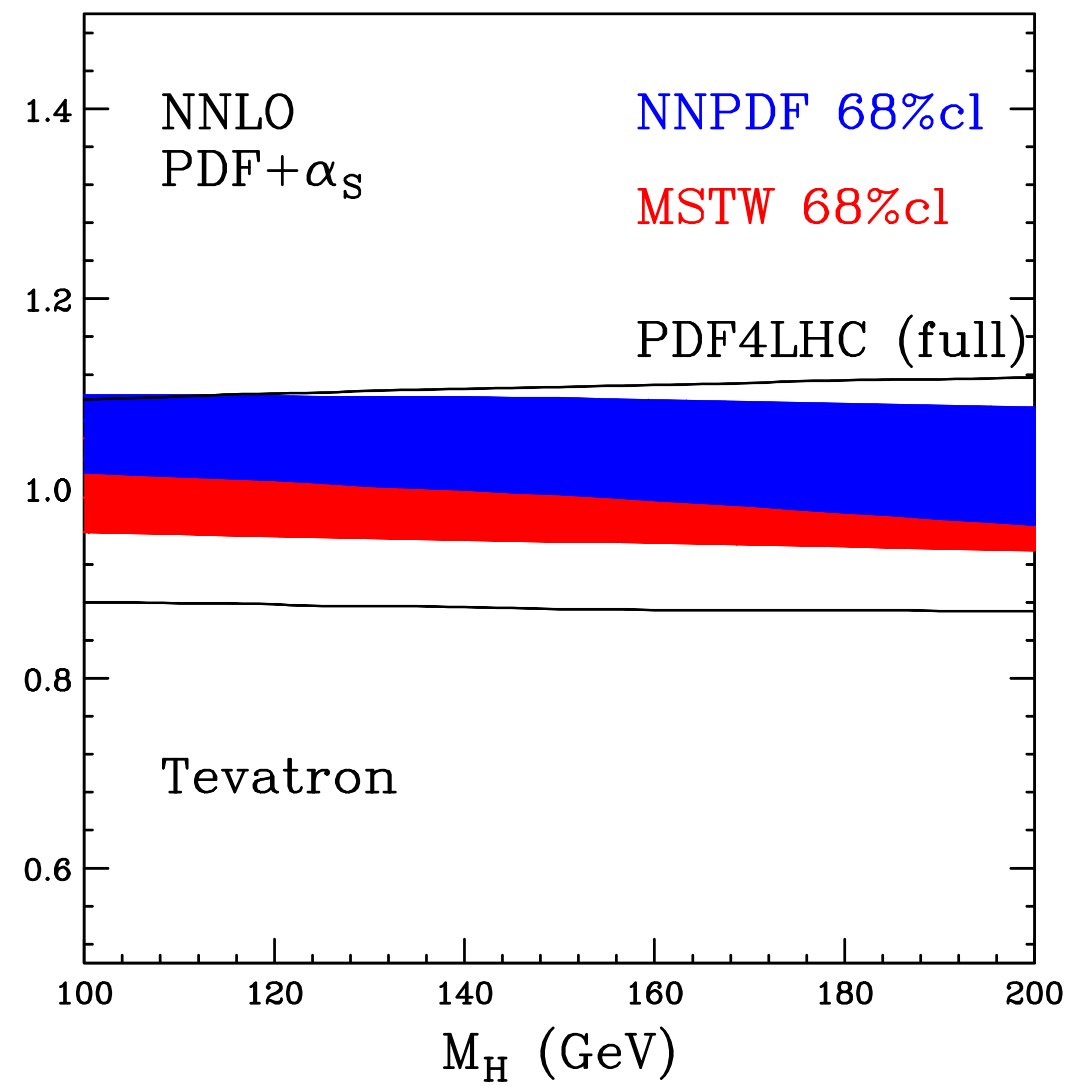
- Take the ratio of NLO-envelope to MSTW-NLO and rescale band at NNLO

PDF4LHC at work



PDF4LHC at work 2 : NNLO with MSTW and NNPDF





NNLO supports PDF4LHC prescription : stability from NLO
CTEQ NNLO coming soon

Of course, any time there is a prescription/recommendation

there should be criticism !

Baglio, Djouadi, Godbole
ABM&JR

Uncertainties might be substantially underestimated by PDF4LHC prescription : use all available sets

Example: ABM + JR
@ Tevatron

ABM vs MSTW
at 160 GeV

-30% (>5 sigma)

M_H (GeV)	ABM10 [8]	ABKM09 [9]	JR [10]	MSTW08 [11]	HERAPDF [12]
100	1.438 ± 0.066	1.380 ± 0.076	1.593 ± 0.091	1.682 ± 0.046	1.417
110	1.051 ± 0.052	1.022 ± 0.061	1.209 ± 0.078	1.265 ± 0.038	1.055
115	0.904 ± 0.047	0.885 ± 0.055	1.060 ± 0.072	1.104 ± 0.034	0.917
120	0.781 ± 0.042	0.770 ± 0.050	0.933 ± 0.067	0.968 ± 0.031	0.800
125	0.677 ± 0.038	0.672 ± 0.045	0.823 ± 0.062	0.851 ± 0.029	0.700
130	0.588 ± 0.034	0.589 ± 0.041	0.729 ± 0.058	0.752 ± 0.026	0.615
135	0.513 ± 0.031	0.518 ± 0.037	0.647 ± 0.054	0.666 ± 0.024	0.541
140	0.449 ± 0.028	0.456 ± 0.034	0.576 ± 0.050	0.591 ± 0.022	0.479
145	0.394 ± 0.025	0.403 ± 0.031	0.514 ± 0.047	0.527 ± 0.020	0.424
150	0.347 ± 0.023	0.358 ± 0.028	0.461 ± 0.044	0.471 ± 0.018	0.377
155	0.306 ± 0.020	0.318 ± 0.026	0.413 ± 0.041	0.421 ± 0.017	0.336
160	0.271 ± 0.019	0.283 ± 0.024	0.371 ± 0.039	0.378 ± 0.016	0.300
165	0.240 ± 0.017	0.253 ± 0.022	0.335 ± 0.036	0.341 ± 0.014	0.269
170	0.213 ± 0.015	0.226 ± 0.020	0.302 ± 0.034	0.307 ± 0.013	0.241
175	0.190 ± 0.014	0.203 ± 0.019	0.274 ± 0.032	0.278 ± 0.012	0.217
180	0.169 ± 0.013	0.182 ± 0.017	0.248 ± 0.030	0.251 ± 0.012	0.195
185	0.151 ± 0.012	0.164 ± 0.016	0.225 ± 0.028	0.228 ± 0.011	0.176
190	0.136 ± 0.011	0.148 ± 0.015	0.205 ± 0.027	0.207 ± 0.010	0.159
200	0.109 ± 0.009	0.121 ± 0.013	0.170 ± 0.024	0.172 ± 0.009	0.131

Potentially big concern for Higgs exclusion limits

Why so different Higgs cross sections? : gluons and coupling constant

One big issue: coupling constant

- affects cross-section
- strong correlation with pdfs

World average : PDG (S. Bethke) $\alpha_s(M_Z) = 0.1184 \pm 0.0007$

uncertainty most probably larger but not more than 0.002

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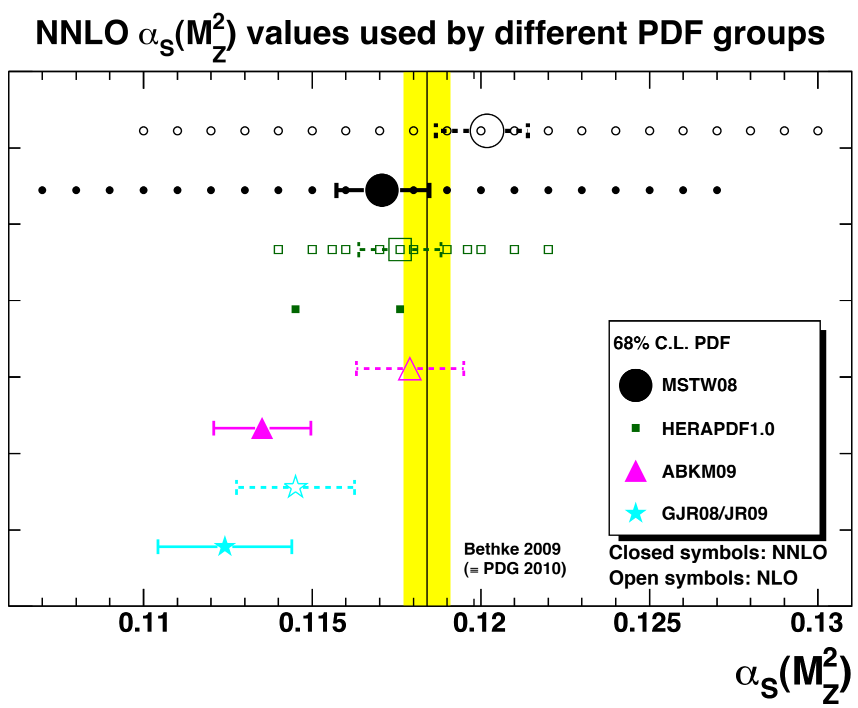
What about pdf sets?



partially responsible for the disagreement

	NLO	NNLO
MSTW	$0.1202^{+0.0012}_{-0.0015}$	0.1171 ± 0.0014
CTEQ	0.1180 ± 0.0019	
NNPDF	0.1191 ± 0.0006	
ABM	0.1179 ± 0.0016	0.1135 ± 0.0014
(G)JR	0.1145 ± 0.0018	0.1124 ± 0.0020

only experimental errors

- Results from global fits agree with world average, large differences with non-global
- DIS only-fits prefer smaller coupling? Challenged by recent analyses: only BCDMS? •NNPDF-MSTW
- Thorne and Watt : Dis-only fits spoil gluon behavior at large x
- Jets stabilize result towards world average NNPDF-Thorne, Watt
- HERA also finds large value 0.1176

PDF4LHC recommendation : use for each fit the corresponding $\alpha_s(M_Z)$ and consider uncertainty $\Delta\alpha_s(M_Z) = \pm 0.0012\,(\pm 0.002)$ at 68% (90%) c.l.

- ABM claims wrong use of NMC data as responsible for both gluons and coupling

$$\frac{d^2\sigma}{dx\,dQ^2} \simeq \frac{4\pi\alpha^2}{x\,Q^4}\left[1-y-\frac{y^2/2}{1+R(x,Q^2)}\right]F_2(x,Q^2)$$

R and higher-twist

✓ ABM : Use cross section instead of F_2 .Wrong procedure reproduce features from other global fits (and Higgs cross section)

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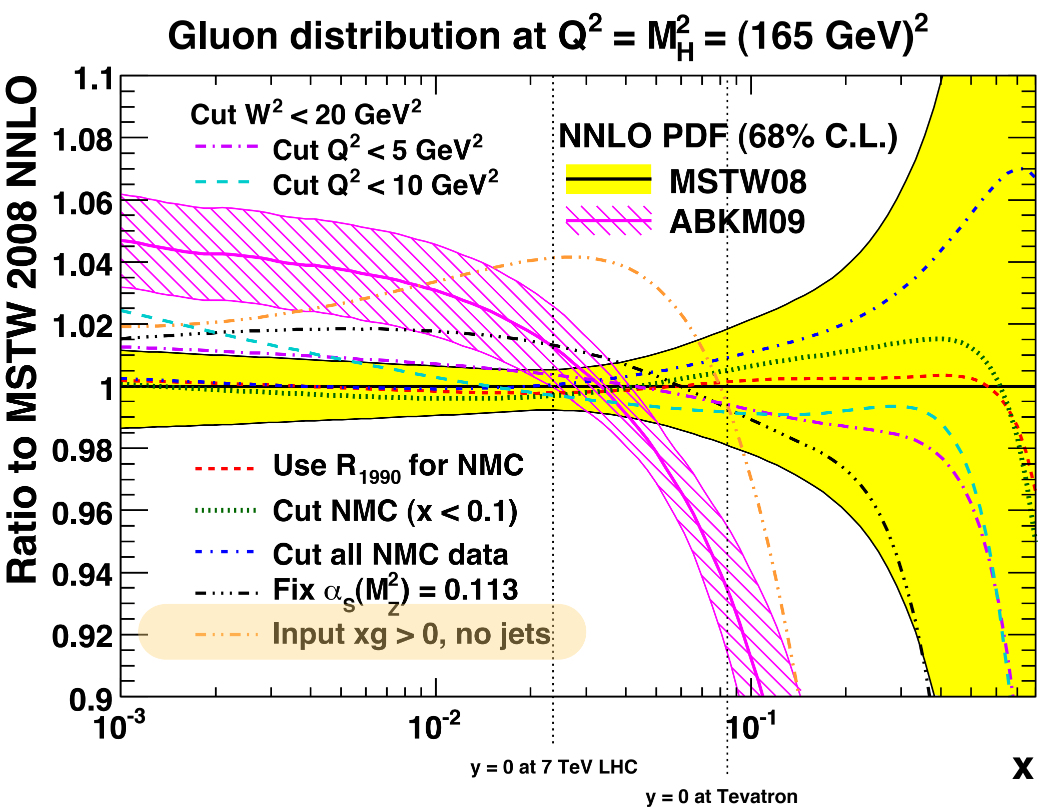
Thorne, Watt

- TW tried using different versions of NMC data and find small effect for gluon and coupling

- NNPDF finds also very small effect



Issue still remains open : Lack of jet data might be main responsible?

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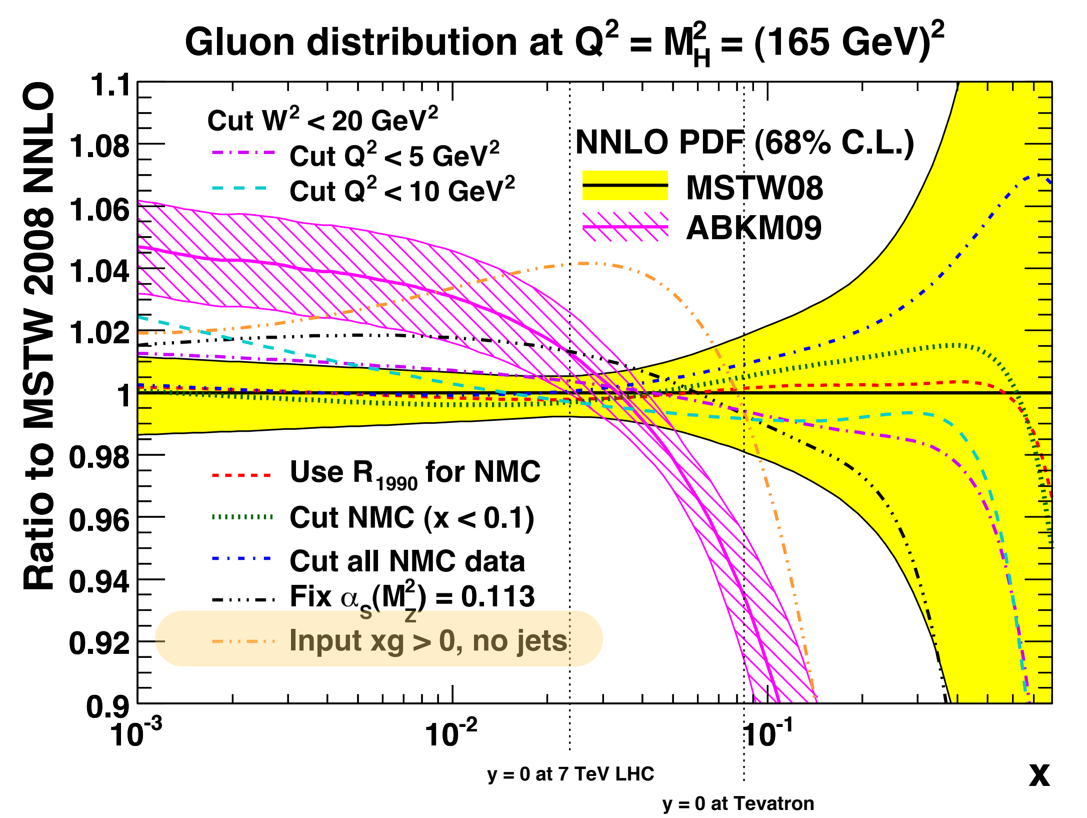


Issue still remains open : Lack of jet data might be main responsible?

• ABM claims Tevatron data not essential for Higgs (find ~ 15% increase)

JETS

Interesting exercise by R.Thorne and G.Watt (2011)

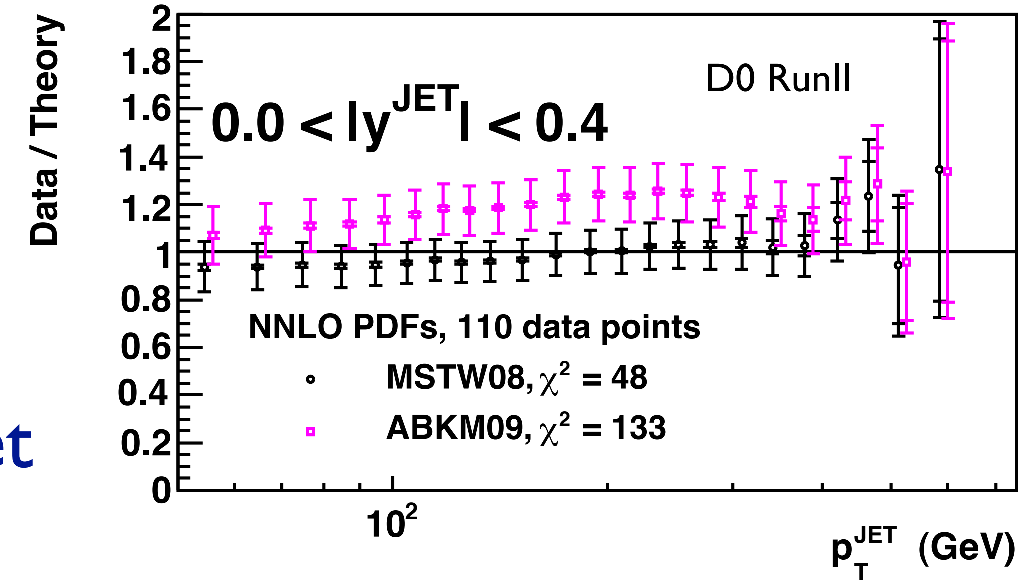
Check how well PDFs reproduce jet Tevatron data

CDF Run II inclusive jet data using k_T algorithm (76 points)

$$\chi^2/N_{\text{pts.}} < 0.83 \text{ within } 90\% \, C.L.$$

NLO PDF (with NLO $\hat{\sigma}$)	$\mu = p_T/2$	$\mu = p_T$	$\mu = 2p_T$
MRST04	1.06 (0.59)	0.94 (0.31)	0.84 (0.31)
MSTW08	**0.75** (0.30)	**0.68** (0.28)	0.91 (0.84)
CTEQ6.6	1.25 (0.14)	1.66 (0.20)	2.38 (0.84)
CT10	1.03 (0.13)	1.20 (0.19)	1.81 (0.84)
NNPDF2.1	**0.74** (0.29)	**0.82** (0.25)	1.23 (0.69)
HERAPDF1.0	2.43 (0.39)	3.26 (0.66)	4.03 (1.67)
HERAPDF1.5	2.26 (0.40)	3.05 (0.66)	3.80 (1.66)
ABKM09	1.62 (0.52)	2.21 (0.85)	3.26 (2.10)
GJR08	1.36 (0.23)	0.94 (0.13)	**0.79** (0.36)

no jet



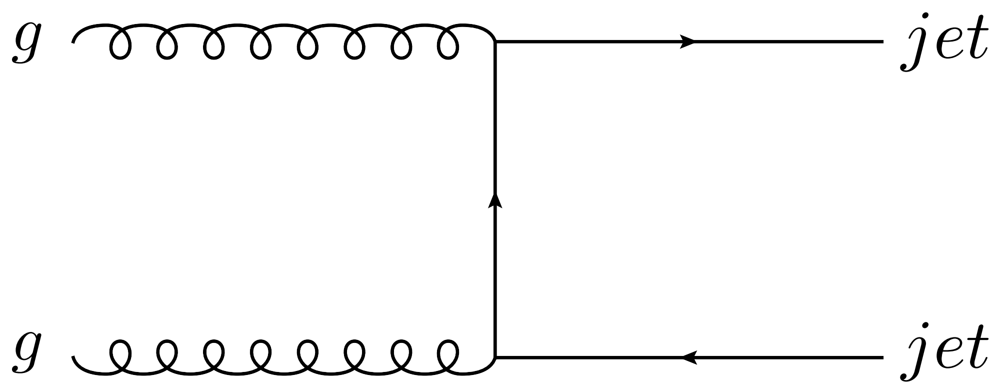
- only central predictions (no band comparison)
- ✓ better agreement with New HERAPDFs

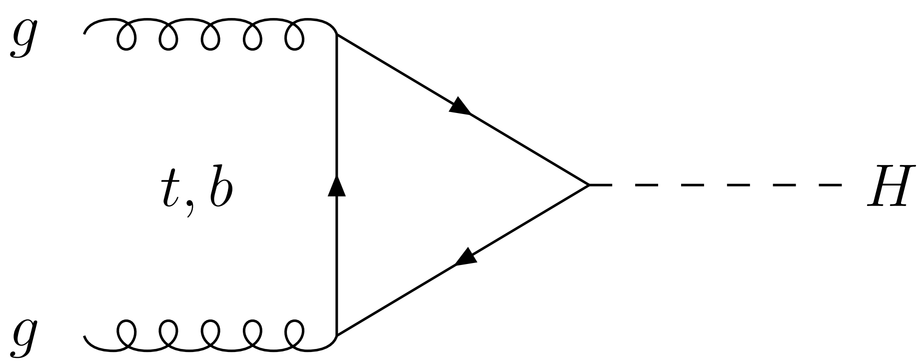
Message from TW : only global analysis provide accurate distributions and uncertainties
No acceptable description of jet data from non-global sets

JETS

PV: Any PDF should reproduce jet data if being used for Higgs

Closest observable to Higgs in terms of Luminosity, kinematics and power of coupling!





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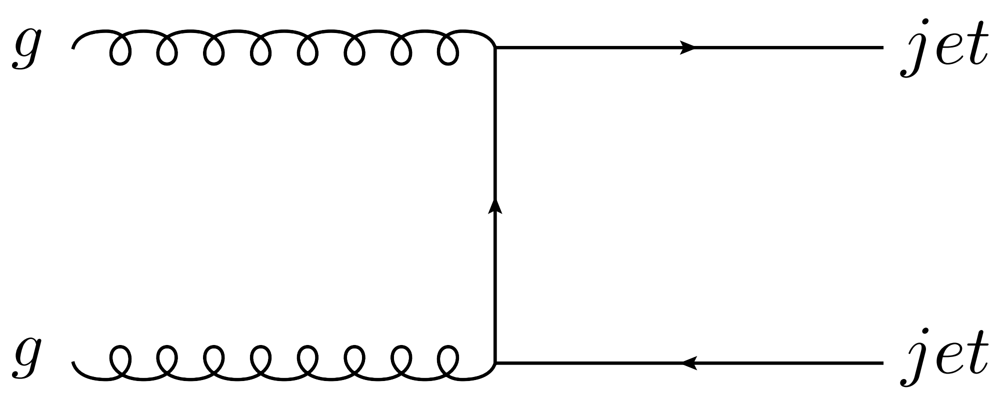
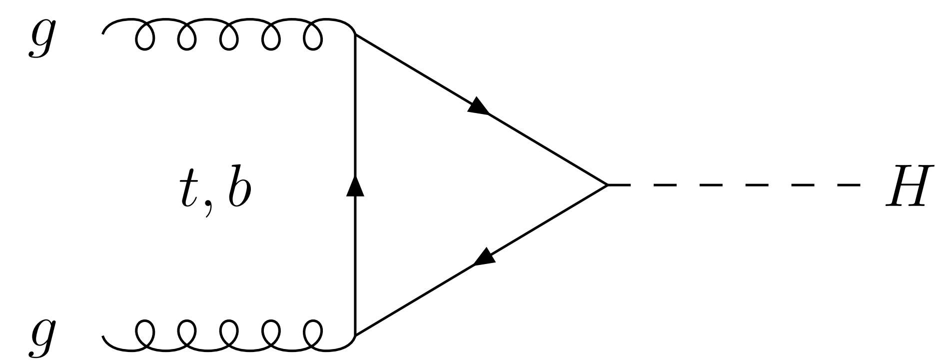




Now, jets are not so trivial!

- Jets at NNLO? use NLO or NLO +Threshold corrections
  soft corrections are small (few %), depend on definition of threshold

Owens, Kidonakis
DdeF, Vogelsang

- Sizable scale dependence (TH uncertainty)
- Comparison subtle because of large correlations in systematic uncertainties
- Dijet more complicated (no NNLO-threshold corrections available)
- Run I vs Run II tension in data

not using Run II jets → up to 100% change in gluon at large x Thorne, Watt

Conclusions

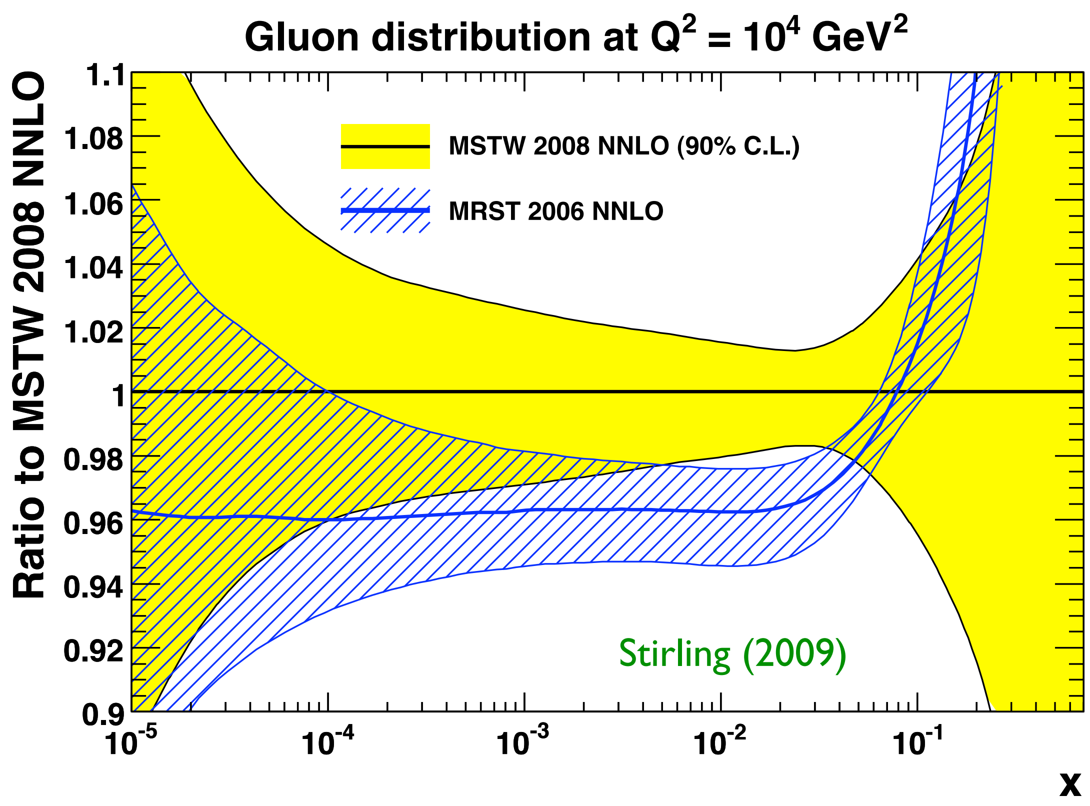
- Everything looks pretty solid and coming LHC data will help to constrain PDFs much better!

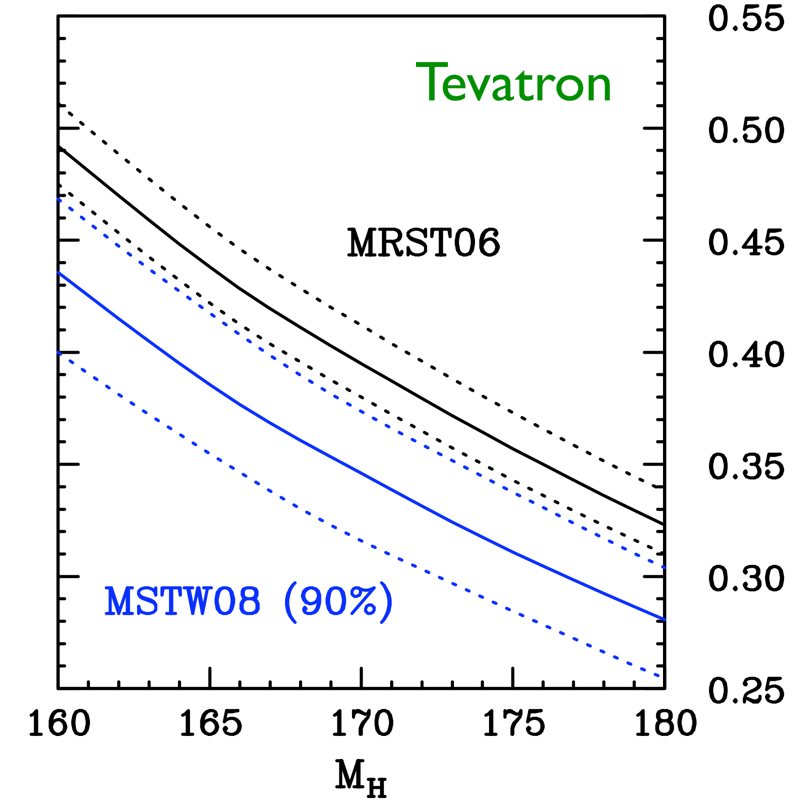
- PDFs play a role in setting exclusion limits for Higgs, but limit can not depend of pdf set used

- We know recent examples (e.g. MRST-06 vs MSTW-08) where TH improvements produced considerable change in PDFs (and Higgs cross section)

  Do not expect such big modification in the future. But to be safer, I would recommend try PDF4LHC prescription with larger uncertainty to leave room for possible TH/EXP improvements (mostly on jets!)

Example: MSTW 2008 vs MRST 2006





2006 analysis did not provide a reliable estimate of uncertainties in large x gluon distribution due to issue in parametrization (DIS to $\overline{\text{MS}}$ scheme transformation)

Do not expect such a big modification in the future

Some questions/Comments/Conclusions

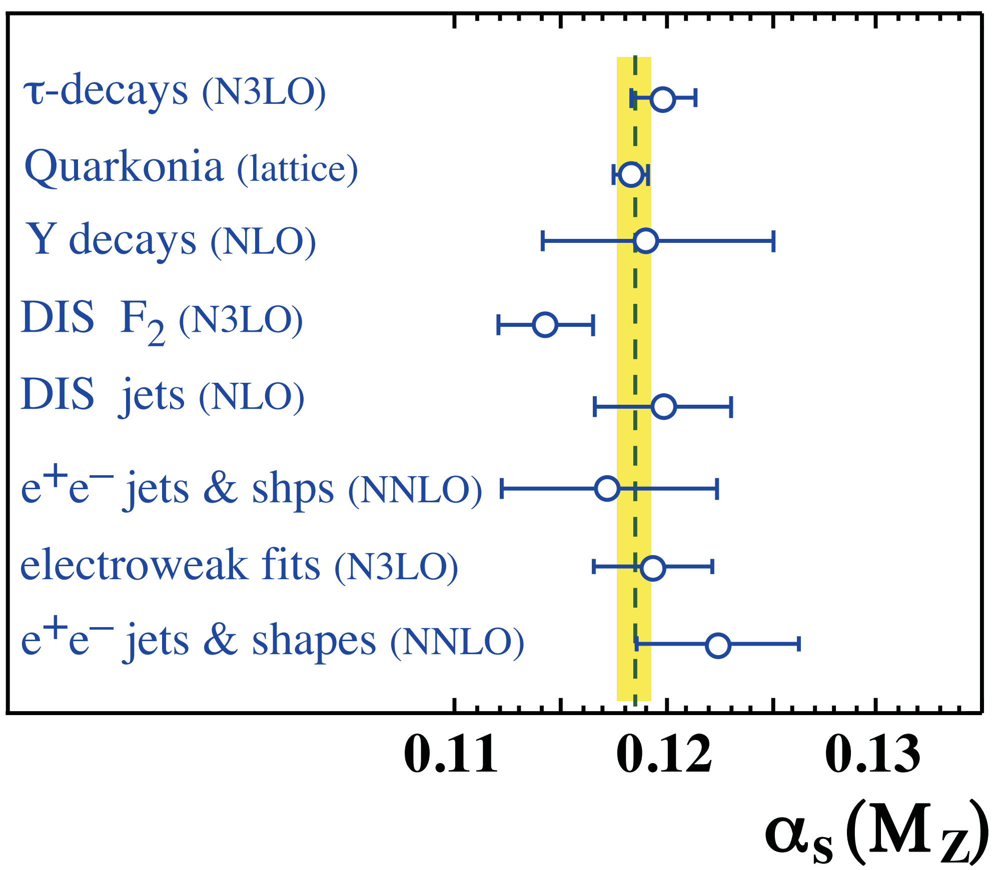
- So far, only experimental errors considered

  Some TH (assumptions) uncertainties estimated by "envelope" prescription

  Baglio et al $\Delta\alpha_s^{TH} = \pm 0.002$ might be incorporated directly on the analysis

  central values **MSTW : 0.117**
  NNPDF : 0.119

- Coupling constant and World average : mixing of perturbative orders



World average PDG (S. Bethke)

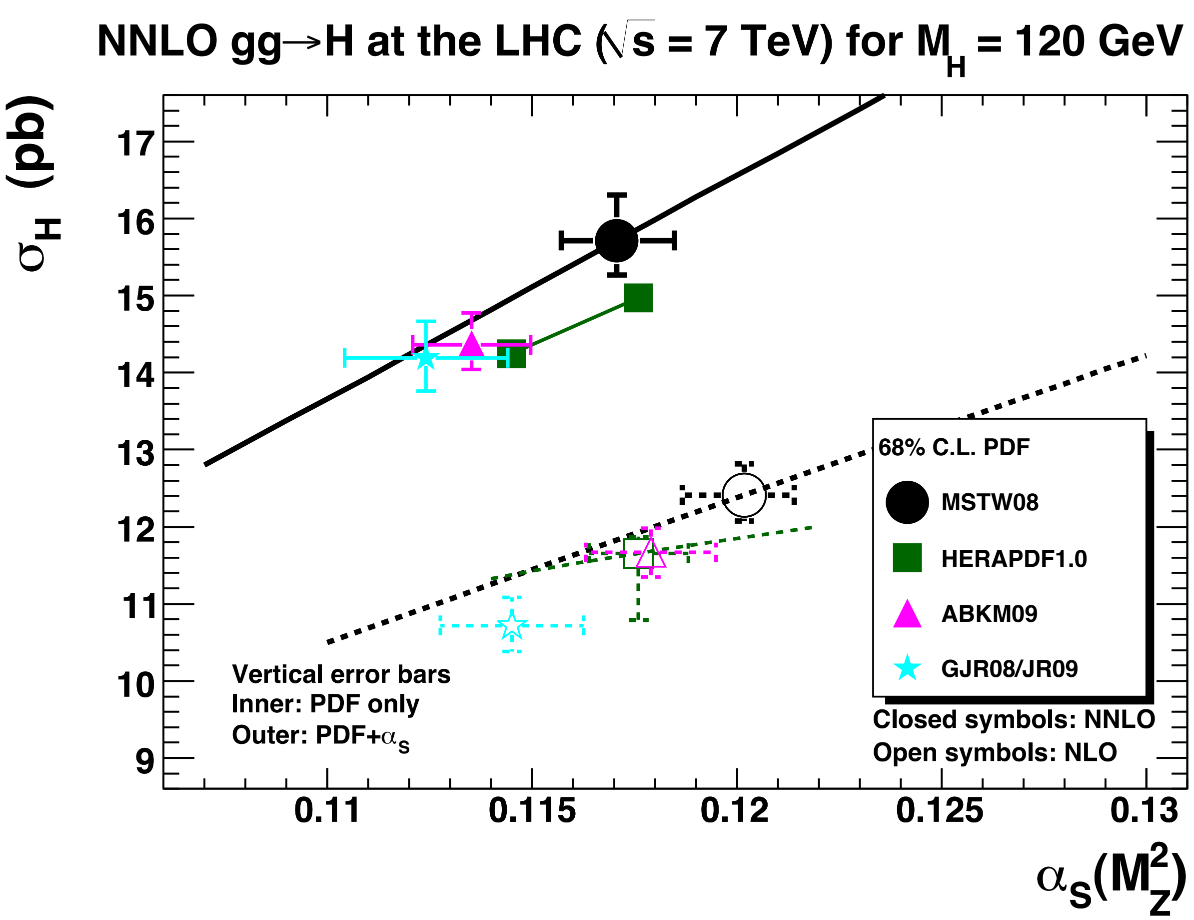
$\alpha_s(M_Z) = 0.1184 \pm 0.0007$

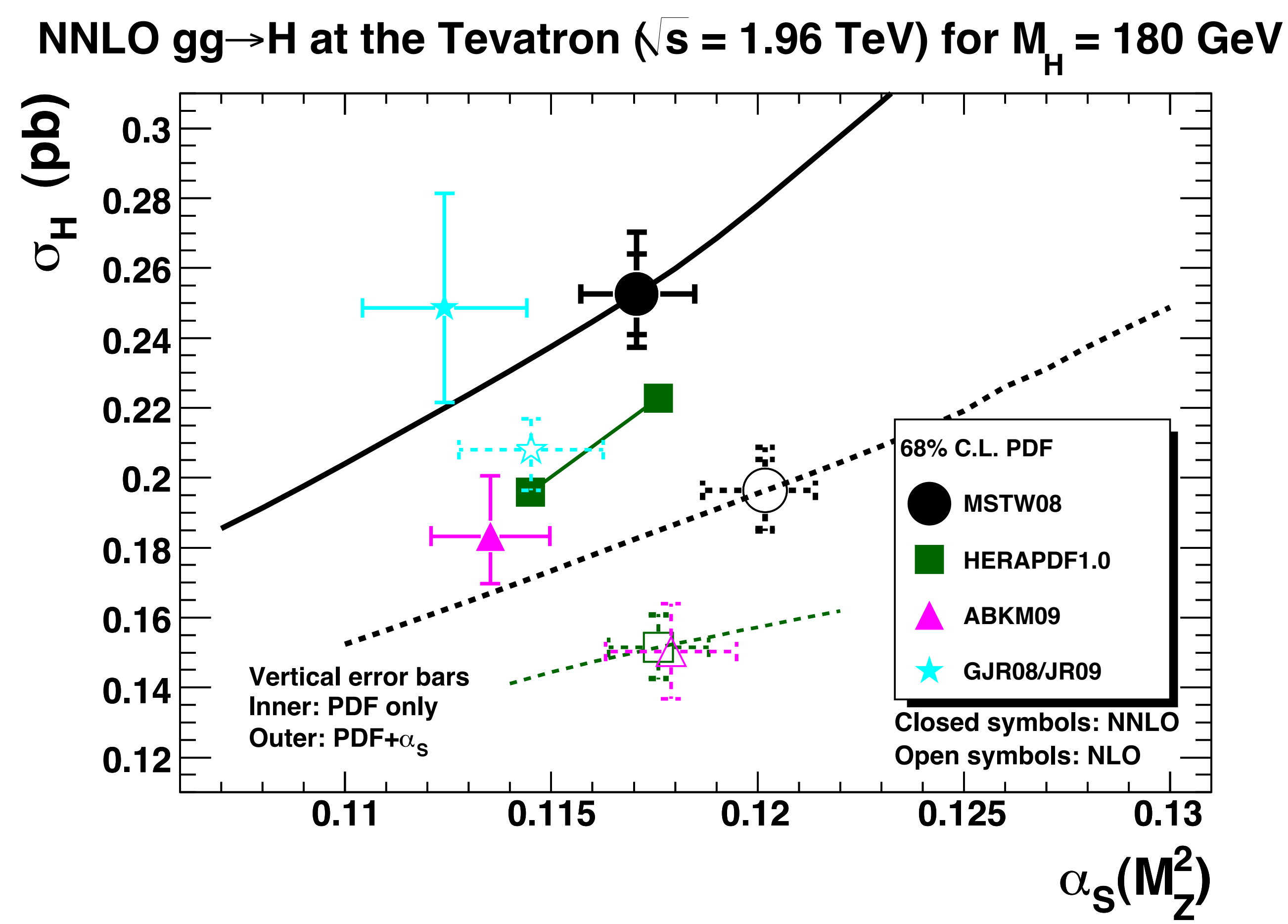
only EW & tau (N3LO)
$\alpha_s(M_Z) = 0.1209 \pm 0.0013$

PDF4LHC recommendation $\Delta\alpha_s(M_Z) = \pm 0.0012\,(\pm 0.002)$ at 68% (90%) c.l.

PDFs provide sets obtained with different values of $\alpha_s(M_Z)$

Sizable effect in uncertainties





Results in better agreement when evaluated at same value: coupling main source of discrepancy at LHC but not enough at Tevatron

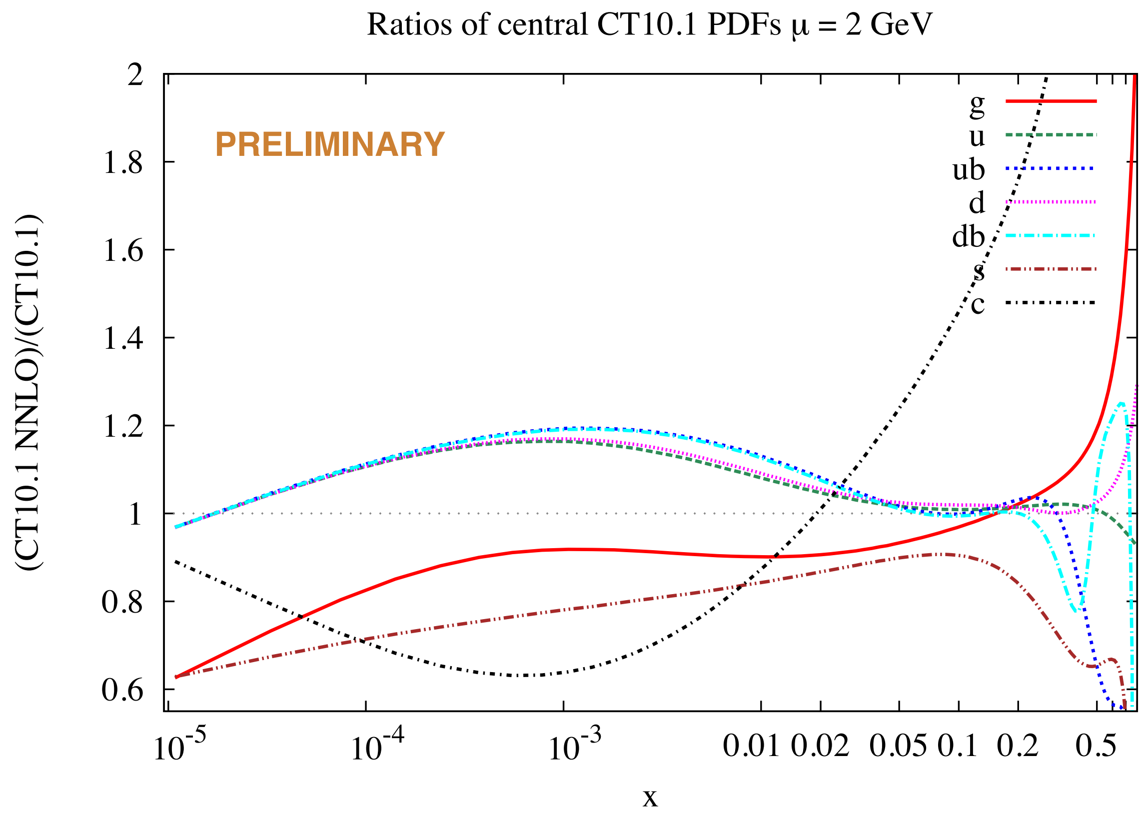
Some issues:

- **Selection of data**
  - which observables (no prompt photon)
  - "incompatible" data sets (W lepton asymmetries)
  - open bins/combined data (Hera)
- **Weights for some experiments**
  - enhance the relevance of some data set
  - enhance some "parton distribution"
  - reduce effect of inconsistent data sets
- **"Aesthetic" requirements**
  - unphysical behavior of pdfs at $x=0$ and 1 : penalty terms
- **Theoretical issues**
  - HQ treatment and masses
  - Parametrization of pdfs
  - Selection of factorization/renormalization scales
  - TH improvements for some observables (resummation)
  - Solution of evolution equations and precision (speed!)
  - α_s from fit or external value? which value/uncertainty?
- **Uncertainties**
  - what is 1sigma in a global fit? $\Delta\chi^2 = ?$

Future

HERA PDF can include Tevatron and LHC data

CT 10.1 with NNLO



from P. Nadolsky

ABM 10 : includes Tevatron jets and improvement in HQ thresholds

NNPDF 2.2 will soon include LHC data (W lepton asymmetry)