The Higgs and the PDFs: to be or not to be[a]

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1. **Higgs production at the Tevatron**
2. **The PDF and other uncertainties**
3. **Combination and implications**
4. **Questions to experts**
5. **Conclusion**

[a] **J. Baglio and AD, JHEP 1010 (2010) 064; arXiv:1003.4266**
J. Baglio, AD, S. Ferrag and R. Godbole, arXiv:1101.1832

1. Higgs production at the Tevatron

- $M_H \gtrsim 140$ GeV : $gg \to H$

(with $H \to WW^* \to \ell\ell\nu\nu$)

LO: already at one loop

exact NLO: K $\approx$2 (1.7)

EFT NLO : good approx.

QCD: EFT NNLO : K $\approx$3 (2)

EFT NNLL : $\approx +$10% (5%)

EFT NLO EW: $\approx \pm$ very small

exact NLO EW$\approx \pm$ a few %

EFT NNLO QCD+EW: a few %

- $M_H \lesssim 140$ GeV : $q\bar{q} \to HV$

$q\bar{q} \to HW/HZ \to b\bar{b} + \ell\nu/\ell\ell, \nu\bar{\nu}$

LO : $\equiv \sigma(V^*) \times BR(V^* \to VH)$

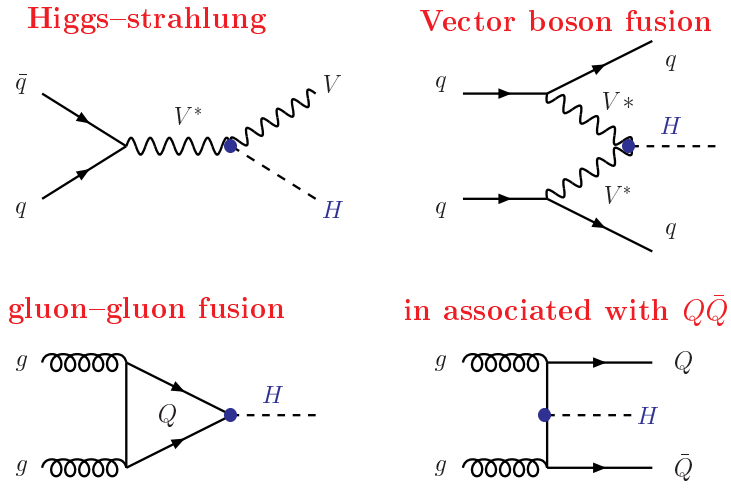
exact NLO QCD : K $\approx$1.4

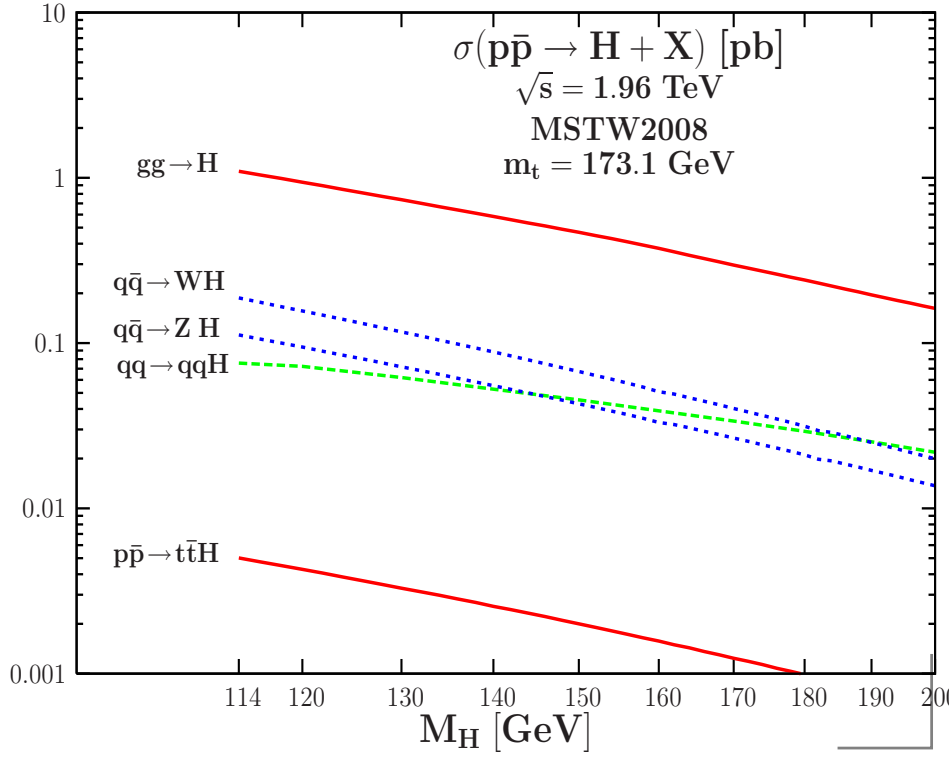
exact NNLO QCD : K $\approx$1.5

exact NLO EW :$\approx -$5%

In practice combine ggH+HZ/HW

- $p\bar{p} \to Hqq$: **bkg. too high.**
- $p\bar{p} \to Htt$: **rates too low.**





2. Theory uncertainties: higher orders

- **K factors extraordinarily large!**

Good: Tevatron sensitive to the Higgs!
Bad: perturbation almost jeopardized...
Ugly: higher orders (HO) important?

- **HO guessed by varying scales** μ_R, μ_F **around central** $\mu_0 = \frac{1}{2} M_H$:

$$\mu_0/\kappa \leq \mu_R, \mu_F \leq \kappa \mu_0$$

– When HO small $\kappa = 2$ enough
– When HO large, $\kappa = 3$ appropriate

$\Delta^{\mu}\sigma_{NNLO} \approx \pm 20\%$ ($\lesssim$ 10% in CDF/D0)

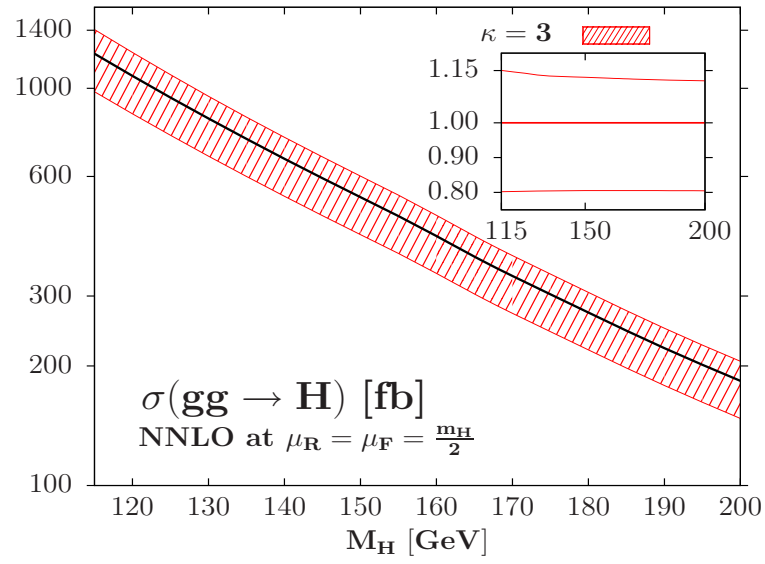
- Also a $\approx$ 5% uncertainty from EFT...
- σ_{NNLO} broken into jet pieces:

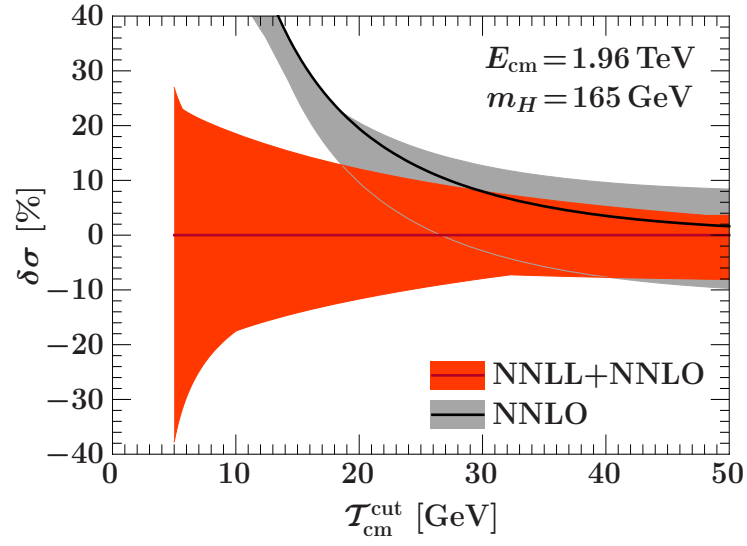
$$\sigma_{tot} = \sigma_{H+0j} + \sigma_{H+1j} + \sigma_{H+\geq 2j}$$

– Impact of jet-veto on σ_{H+0j} huge!
– NNLL resummation of large logs

$\Rightarrow$ leads to a $\approx 20\%$ uncertainty...

Are NNLO PDFs fine for this job?





Berger et al, arXiv:1012:4480

2. Theory uncertainties: PDFs and α_s

- **PDF uncertainties via Hessian method**

$\Rightarrow$ 5–10% PDF error smaller than diffs.

– For MSTW: we chose 90%CL errors

– We will now ignore non NNLO PDFs...

- **Pb: $\sigma_{\rm LO} = \mathcal{O}(\alpha_s^2)$,..., $\sigma_{\rm NNLO} = \mathcal{O}(\alpha_s^4)$**

and $\alpha_s(M_Z^2)$=0.1171$\pm$0.0034 (90%CL)

use MSTW combined PDF+α_s uncertainty

$\Rightarrow$ better agreement but not enough....

- **Also difference in α_s values large**

can be accounted by a theory uncertainty?

$\Rightarrow$ $\Delta^{\rm th}\alpha_s \approx 0.002$ (NNLO/MSTW)

include all: PDF+$\Delta^{\rm exp}\alpha_s \oplus$PDF+$\Delta^{\rm th}\alpha_s$

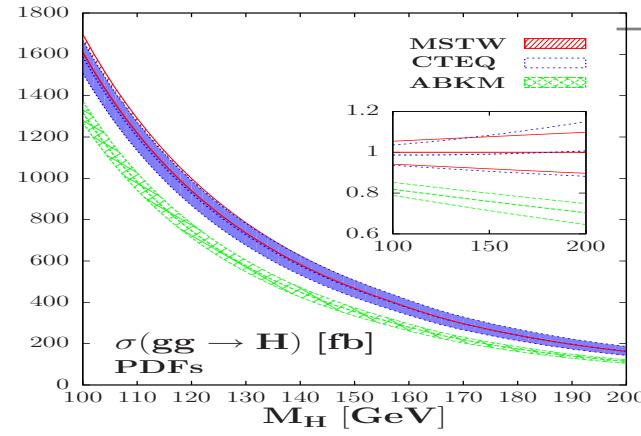
overlap of MSTW/ABKM bands is OK...

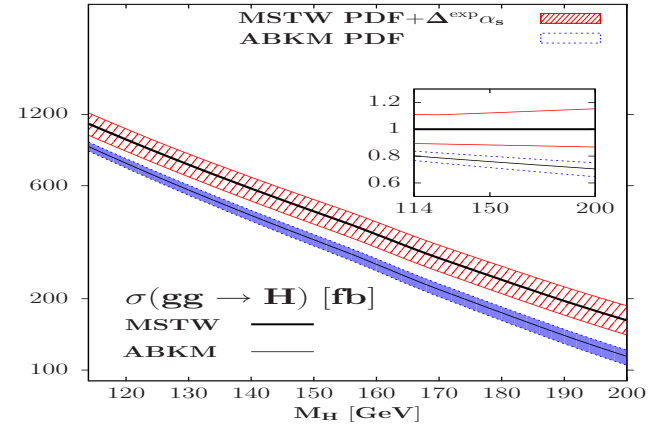
- **At the end of the day, taking MSTW:**

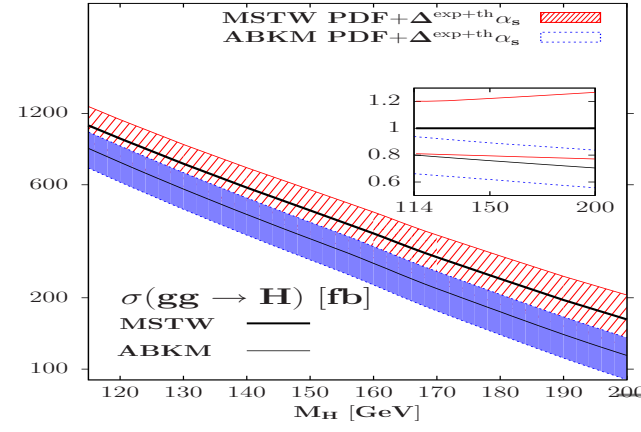
ΔPDF+α_s $\approx$15% at 90%CL

exactly what one gets with PDF4LHC reco.

envelope $\equiv$ theory uncertainty?







2. Theory uncertainties: PDF normalisation

Let us come to inter–PDF differences

4 NNLO sets: MSTW, ABKM, HERA, GJR

what happens to the normalisation?

$\Rightarrow$ extremely large differences!!

is the difference also a measure of the PDF (theoretical) uncertainty?

[Note: ABM claim on NMC data: reconcile MSTW and ABKM/HERA?]

?PDF uncertainties underestimated?

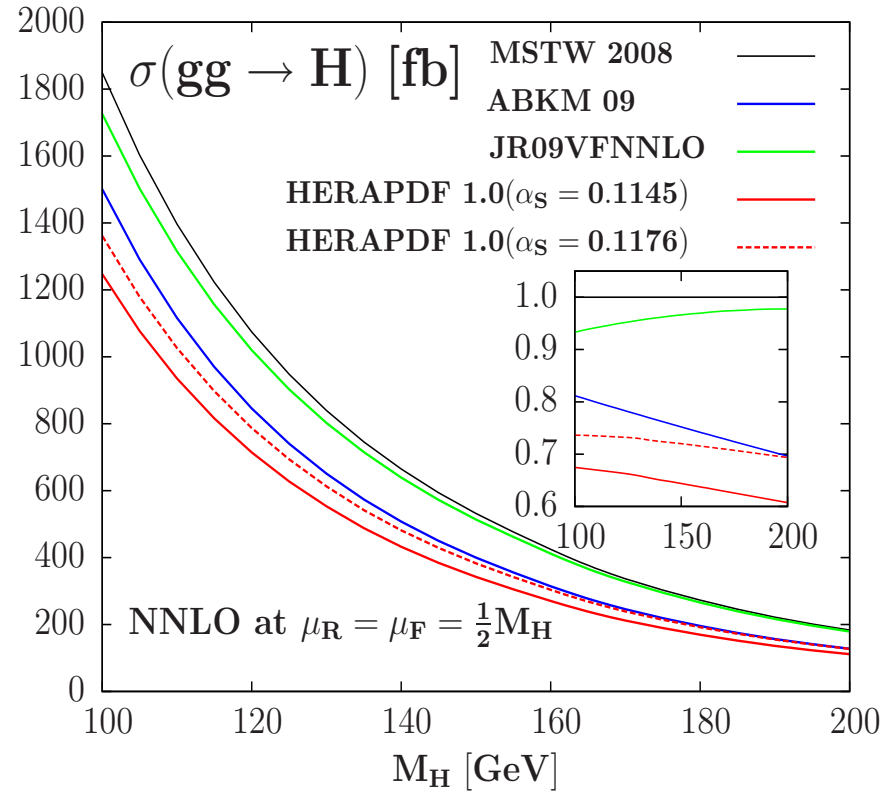
?Some PDFs are to be thrown away?

you experts need to agree!

This is a crucial issue as depending on the choice of PDF in $gg \to H$

Higgs@160 GeV dead or alive!

[impact less drastic at the lHC]



3. Combined uncertainties

Crucial issue: how to combine TH errors?

CDF: 18% (scale) $\oplus$ 12 % (PDF) $\approx$ 20%.

D0 : even smaller, 10%, total uncertainty

– scale and EFT pure theory errors (flat)

– PDF error gaussian with Hessian method

What about the theory uncertainty?

Proposal: apply ΔPDF+α_s on $\min^{\max}\sigma(\mu)$

[also: Cacciari, Mangano et al. (2008)]

includes (small) scale-PDFs correlations?

$\Rightarrow$ last word $\approx \pm$40% total uncertainty!

Even exp. PDF: flat+gaussian not obvious

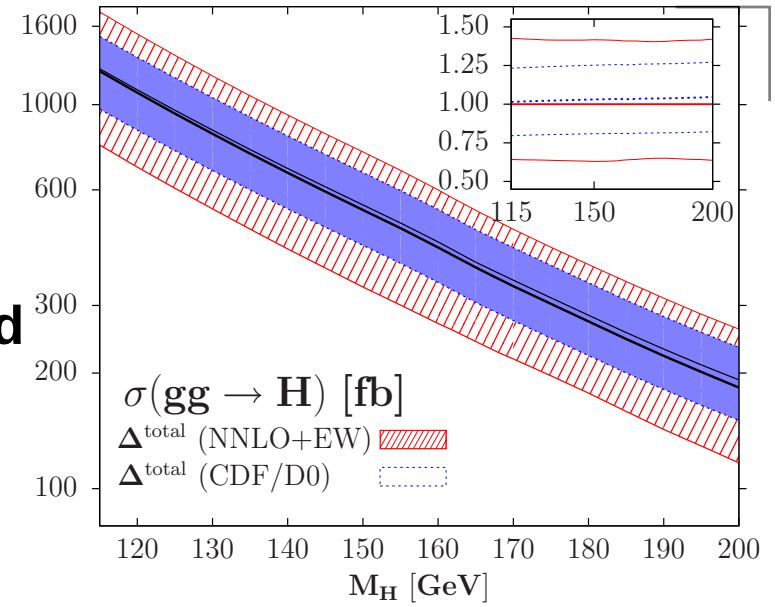
LHC Higgs xsWG recommends $\rightarrow$linear

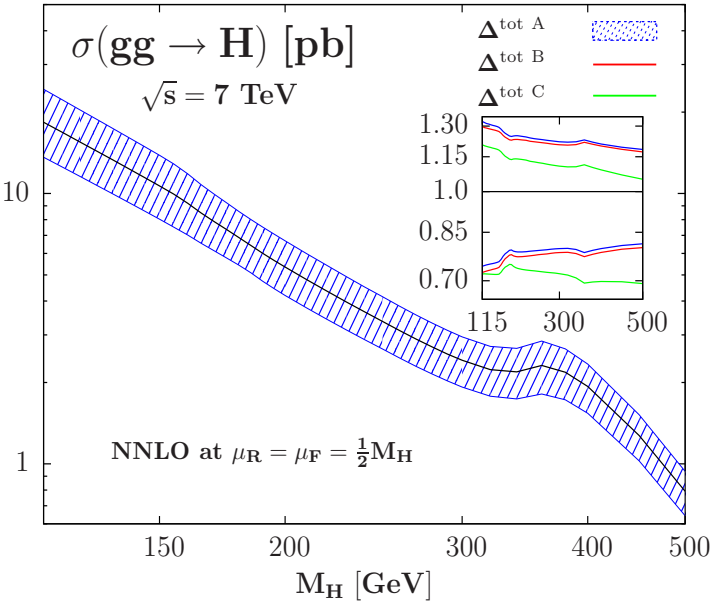
one then gets a $\approx$ 5% # uncertainty!

can we consider # as due to correlation?

If not, is there another way to do it?

Also: how # should be treated (option C).





3. Combination and implications

In Moriond 2010: simple/naive approach
no impact of small CDF/D0 error on limit
40% error $\Rightarrow$ change of normalisation
not "professional" $\Rightarrow$ not accepted

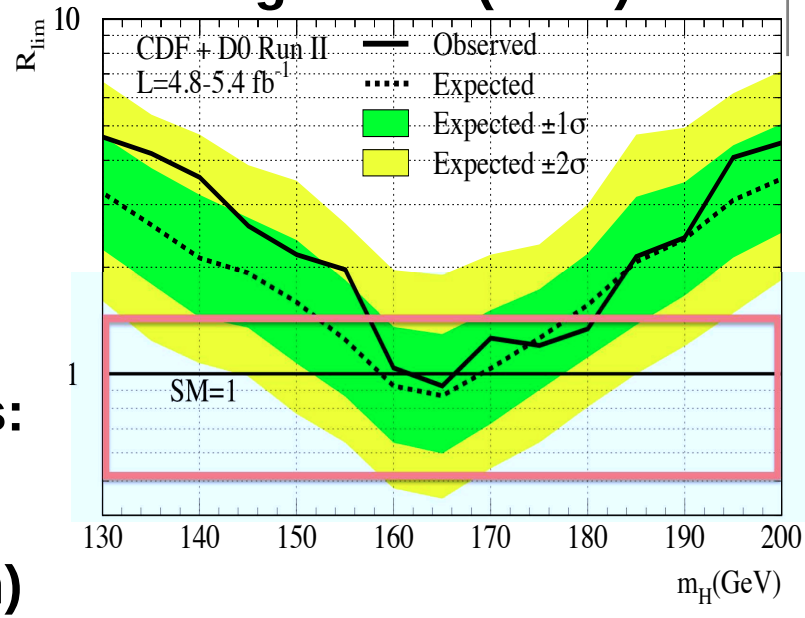
Recent exercise: reproduce CDF results
– with NN/shapes+same analysis 30%OK

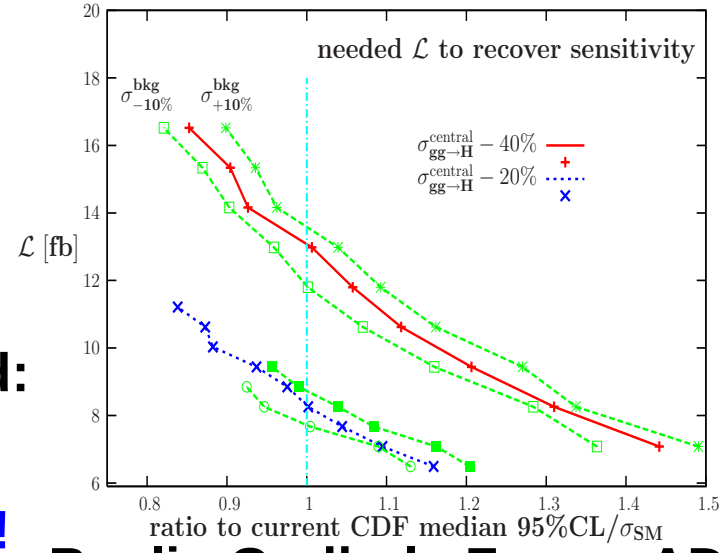
Assume three scenarios for uncertainties:
– $\sigma^{\rm NNLO}_{\rm gg\to H}$ – 20% (full theory uncertainty)
– $\sigma^{\rm NNLO}_{\rm gg\to H}$ – 40% (HERAPDF normalisation)
– Change WW bkg by $\pm$10% (HERAPDF)
(anti-correlation between $\rm q\bar{q}$ and gg..).
Calculate needed $\mathcal{L}$ to recover sensitivity

Factor $\gtrsim 2$ needed in worst scenario!

Conclusions: naive same as sophisticated:
– CDF/D0 limit disappears completely
– Exclusion limit depends on chosen PDF!

Baglio+AD (2010)





Baglio,Godbole,Ferrag,AD

4. Questions to the PDF experts

As basic users, we are (not only) a little bit confused.

There are too many conflicting statements in this whole business:

- **J. Rojo: non-global PDF sets: poor description of jet data.**
  – Dangerous to use non-global PDF sets for LHC phenomenology.
  – Some groups (CT10, MSTW) report tensions (does this means disagreement in normal language?) with other datasets especially with nuclear DIS data. Problem with nuclear corrections? (HERA?)
- **M. Buehler (D0): A comparison of high ET Tevatron data with ABKM09 and HERAPDF shows large disagreement.**
- **MSTW: the inclusion of Tevatron jet data does reduce the fractional uncertainty on the high-x gluon, albeit not dramatically (small?)**
- **S. Moch: the impact of Tevatron jet data on the mid to high-x gluon PDF is generally small**
- **S. Alekhin: ABKM describes jet data better than the truly global fits based on the Run II data??**
- **G. Tonelli (CMS): the precision of the measurement is good enough to provide new inputs to global PDF fits (disagreement with MSTW ?)**
- **G. Hesketh (D0): the (D0) dijet mass distribution still shows some tension with latest PDF (CTEQ, MSTW) fits....**
- **V. Radescu (ZEUS): HERAPDF1.5 provides a reasonable agreement even with D0 lepton asymmetry for which global fits have difficulties.**

4. Questions to the PDF experts

Let us make a recapitulation of the "users" frequently asked questions:

- **What should we do for resummation (and also EW) corrections?**
- **What about the theoretical uncertainties in observables in fits?**
- **What about the issue of α_s (e.g. DIS vs PDG) in the PDF fits?**
- **How should one add scale and PDFs uncertainties (correlations?)**

(also, need to clarify issue of experimental+theoretical uncertainties)

- **What are the Tevatron (Run I and Run II) data really saying?**
- **More precisely, are the use of non–global fits really dangerous?**
- **Are low Q^2 corrections (target mass, nuclear effects, etc...) under control at the level of precision in DIS data and theory calculations?**
- **What about the impact of fixed target (NMC?) data?**
- **Does LHC already has something to say?**
- **Correlation between signal and background due to PDFs?**
- **Is one correctly evaluating the PDF uncertainties in the high precision measurements done at hadron colliders ($M_W, \sigma(t\bar{t}), \ldots$)**

5. Conclusion

Crucial issues in particular for Higgs: a matter of life and death...

(although PDFs are not the only issue contrary to some belief)

We are all relying on you to give us a clear picture....