Revisiting the constraints on the Higgs sector from the Tevatron [a]

Abdelhak Djouadi

(U. Paris-Sud / CERN TH)

1. Higgs production at the Tevatron

2. The theoretical uncertainties

3. Combination and implications

4. The Higgs in SUSY theories

5. Conclusion

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[a] J. Baglio and AD, JHEP 1010 (2010) 064; arXiv:1003.4266
J. Baglio, AD, S. Ferrag and R. Godbole, arXiv:1101.1832
J. Baglio and AD, arXiv:1012.2748, arXiv:1012.0530

1. Higgs production at the Tevatron

• $M_H \gtrsim 140$ GeV : $gg \to H$

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

LO[a] already at one loop

exact NLO[b] : $K \approx 2$ (1.7)

EFT NLO[c]: good approx.

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

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

EFT NLO EW[f]: $\approx \pm$ very small

exact NLO EW[g]: $\approx \pm$ a few %

EFT NNLO QCD+EW[h]: a few %

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[a] Georgi et al., Ellis et al, Wilczek

[b] AD+Spira+Graudenz+Zerwas (exact)

[c] AD, Spira, Zerwas; Dawson (EFT)

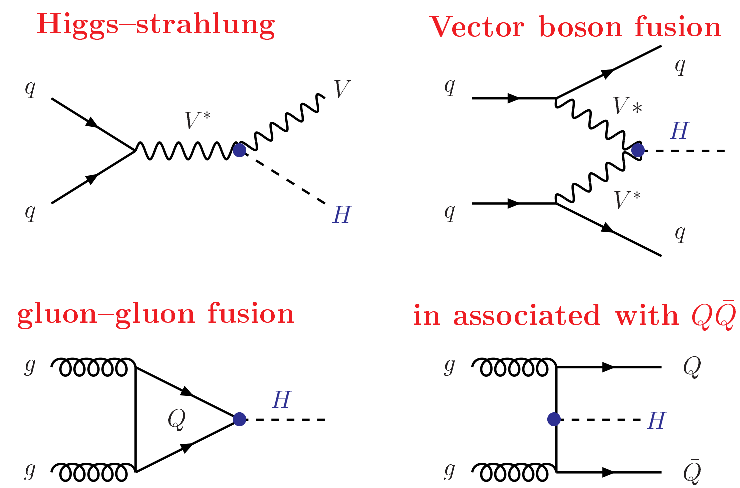
[d] Harlander+Kilgore, Anastasiou+Melnikov Ravindran+Smith+van Neerven

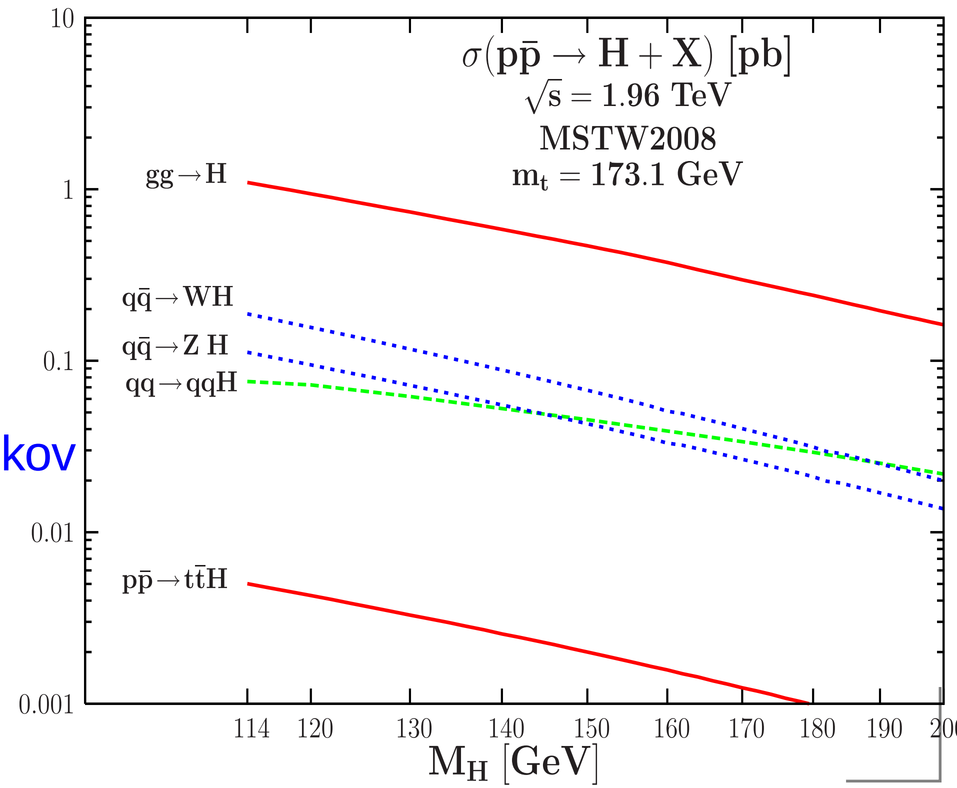
[e] Catani+de Florian+Grazzini+Nason

[f] AD+Gambino; Degrassi et al.

[g] Actis+Passarino+Sturm+Uccirati

[h] Anastasiou+Boughezal+Pietriello





1. Higgs production at the Tevatron

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

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

LO[a]: $\equiv \sigma(\mathrm{V^*}) \times \mathrm{BR}(\mathrm{V^*} \to \mathrm{VH})$

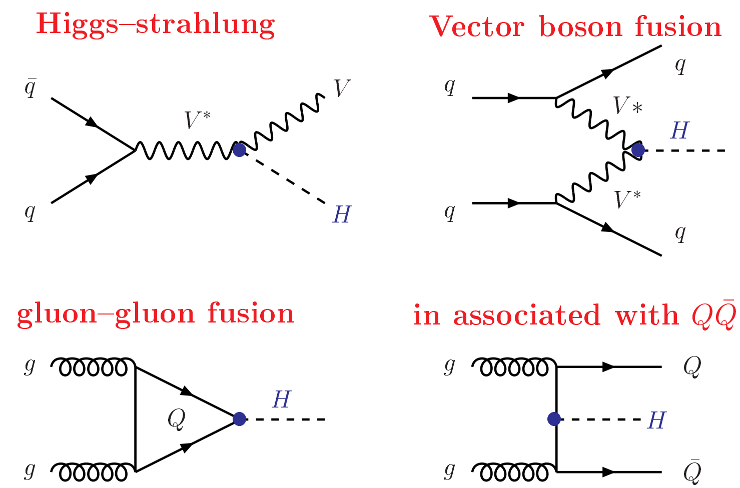
exact NLO QCD[b] : $\mathrm{K} \approx$1.4

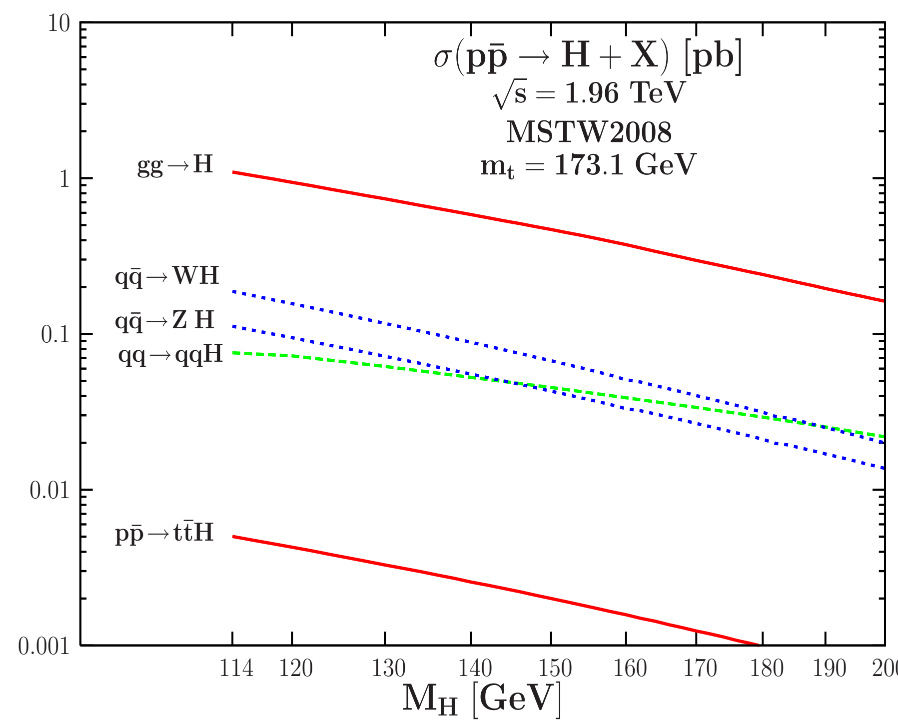
exact NNLO QCD[c]: $\mathrm{K} \approx$1.5

exact NLO EW[d] :$\approx -$5%

In practice combine ggH+HZ/HW

- $\mathrm{p\bar{p} \to Hqq}$: bkg. too high.
- $\mathrm{p\bar{p} \to Ht\bar{t}}$: rates too low.





[a] Glashow+Nanopoulos+Yildiz
[b] Altarelli et al; Han+Willenbrock
[c] Brein+AD+Harlander
[d] Ciccolini+Dittmaier+Krämer

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** $\mu_{\mathbf{R}}, \mu_{\mathbf{F}}$ **around central** $\mu_{\mathbf{0}} = \frac{1}{2}\mathbf{M_H}$**:**

$$\mu_{\mathbf{0}}/\kappa \leq \mu_{\mathbf{R}}, \mu_{\mathbf{F}} \leq \kappa\mu_{\mathbf{0}}$$

- **When HO small** $\kappa = 2$ **enough**
  Guess from $\sigma_{\mathbf{LO}}$ **and** $\sigma_{\mathbf{NLO}}$ **bands**

$\kappa = 4$ **(LO) and** $\kappa = 3$ **(NLO) needed.**

$\boldsymbol{\kappa = 3 \Rightarrow \Delta^{\mu}\sigma_{\mathbf{NNLO}} \approx \pm 20\%}$

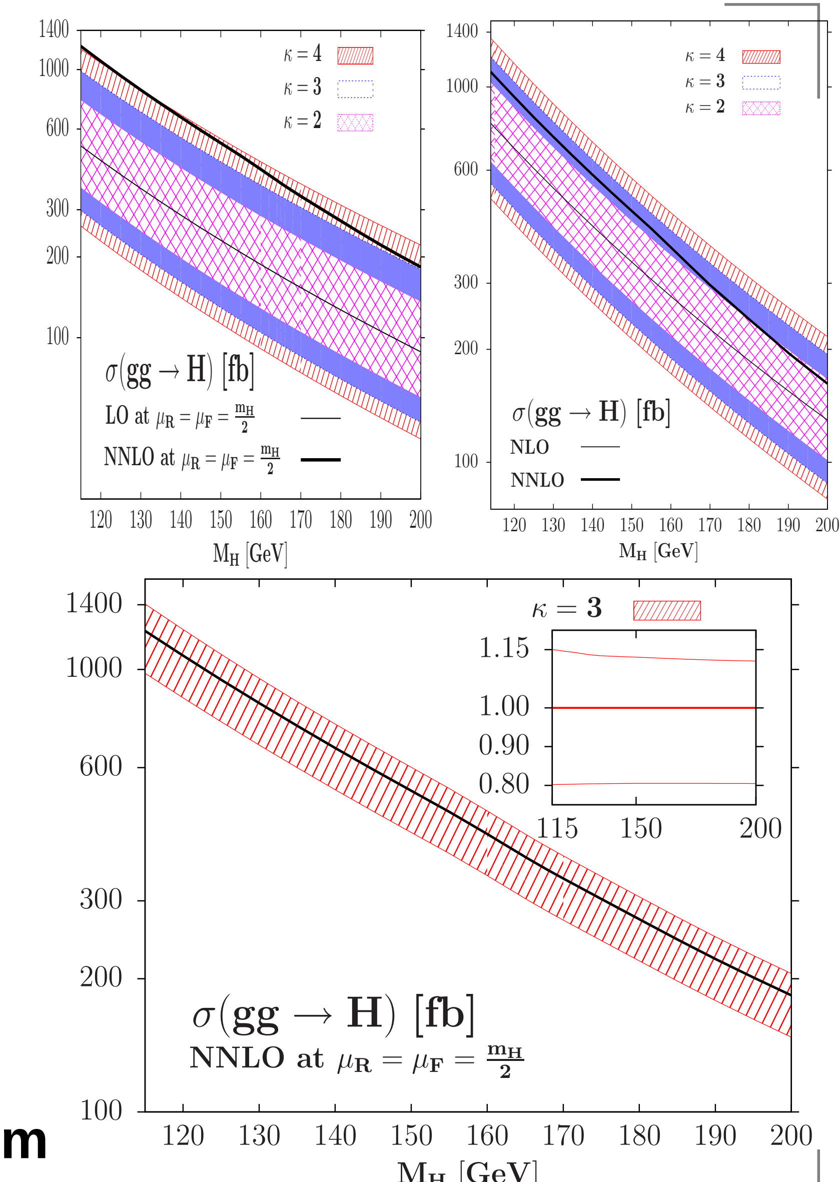
(compared to less than 10% by CDF/D0)

- $\sigma_{\mathbf{NNLO}}$ **broken into jet pieces:**

$\sigma_{\mathbf{tot}}$**=**$\sigma_{\mathbf{H+0j}(\mathbf{7}\%)}$**+**$\sigma_{\mathbf{H+1j}(\mathbf{25}\%)}$**+**$\sigma_{\mathbf{H+2j}(\mathbf{50}\%)}$

$\boldsymbol{\Delta^{\mu}\sigma_{\mathbf{tot}} \approx 17\%}$ **(as found by CDF/D0)**

- **Impact of jet-veto huge: severe problem**
  C. Berger et al, arXiv:1012:4480 [hep-ph]

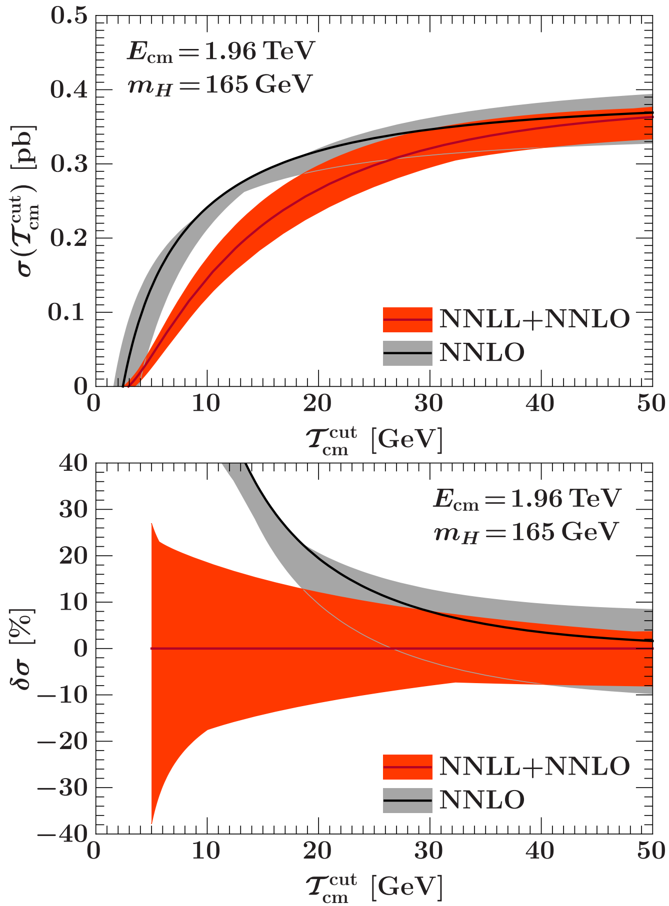


2. Theory uncertainties: higher orders

Jet veto: introduces large double logs in $\sigma_{\mathrm{H+0j}}$ to be resummed.
$\tau_{\mathrm{cm}}^{\mathrm{cut}}$ cut similar to $\mathrm{p_T^{cut}}$ on jet: huge impact (also at the LHC).

Backup

Results for the Tevatron



Compare NNLL+NNLO to NNLO only

- Fixed-order expansion is not reliable in 0-jet region at small $\mathcal{T}_{\mathrm{cm}}$
- Summation of jet-veto logarithms is necessary for reliable predictions and estimation of uncertainties
- Scale uncertainty at NNLL+NNLO is $10 - 20\%$

Current Tevatron Higgs limits

- Lower central value partly accounted for by parton shower
- Theory uncertainty $\sim 20\%$ much larger than currently used 7%

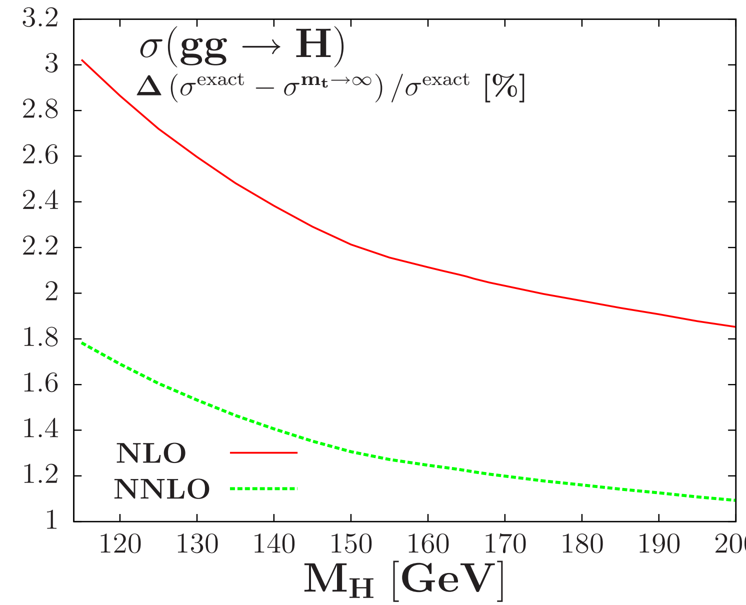
Frank Tackmann (MIT) | Higgs Production with a Jet Veto at NNLL+NNLO | 2011-02-18 | 22 / 17

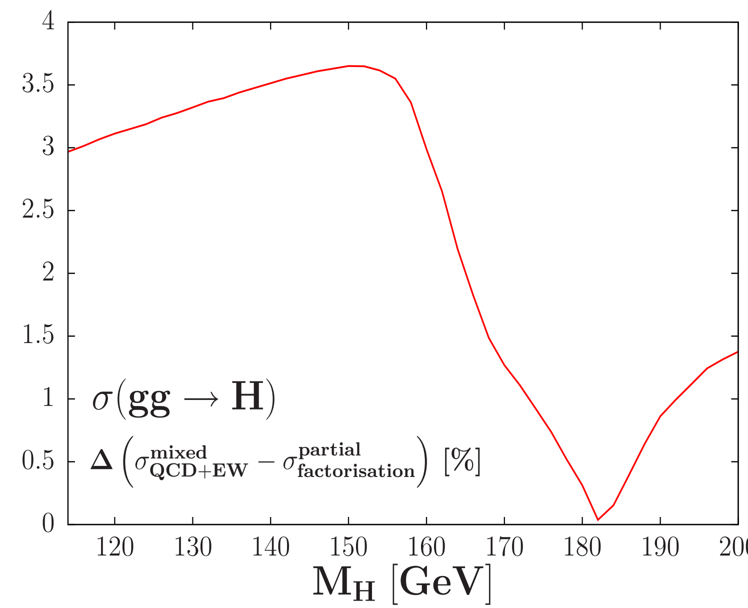
2. Theory uncertainties: EFT approach beyond NLO

To simplify (hard!) NNLO calculation
EFT approach where $M_{loop} \gg M_H$
$\Rightarrow$ effective two–loop calculation

- **Good for top loop (R. Harlander...)**
  provided that exact m_t, m_b in σ_{LO}
- **Not good for b–loop ($\approx$ 10% at LO)**
  estimate from NLO (exact/EFT) $\longrightarrow$ few %
- **b–loop: m_b^{pole} or $m_b^{\overline{MS}}(m_b)$?**
  renormalization scheme dep. $\longrightarrow$ few %
- **Mixed EW+QCD RadCor at NNLO:**
  EFT approach with $M_{W/Z} \gg M_H$
  Contrib. $\equiv$ to EW NLO in $\#$ schemes
  partial vs complete factor. $\longrightarrow$ few %

total EFT uncertainty of $\mathcal{O}(5\%)$
ignored by CDF/D0 collaborations





2. Theory uncertainties: PDFs and α_s

- PDF uncertainties via Hessian method

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

- 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)

better agreement but not enough......

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

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

overlap of MSTW/ABKM bands OK

$\Rightarrow\ \gtrsim$ 15% error ($\approx$ 5% PDF alone)

However, also other sets: ABKM, HERA,

GJR, which are also at NNLO, so we try:

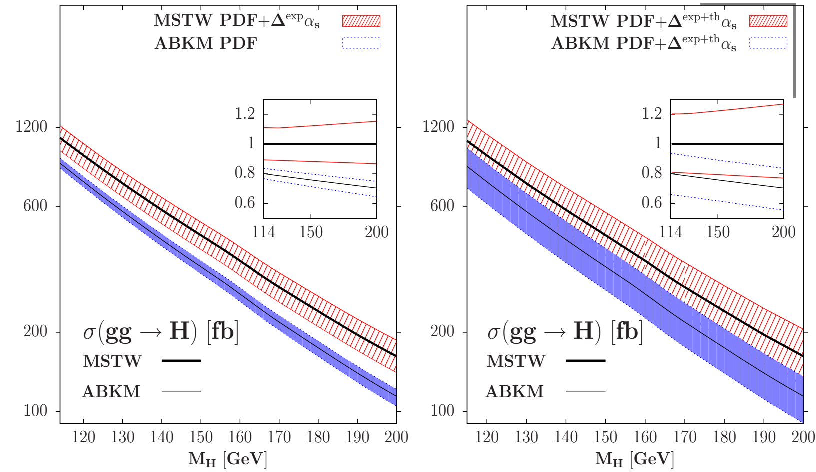
$\Rightarrow$ extremely large differences!!

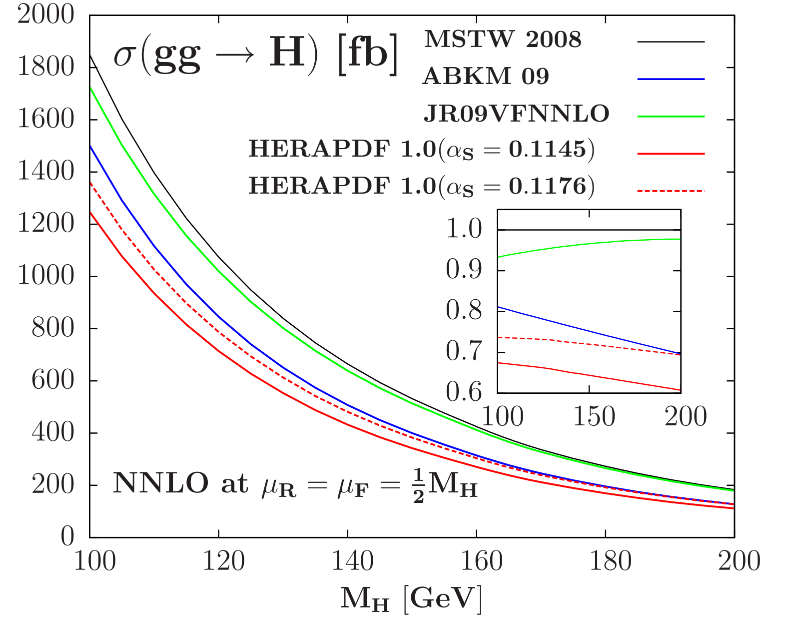
is also a measure of the PDF (TH) error!

?PDF uncertainties underestimated?

?Some PDFs are to be thrown away?

Experts need to agree!

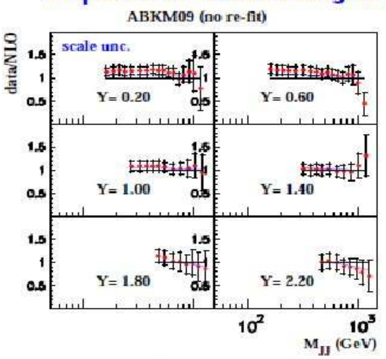


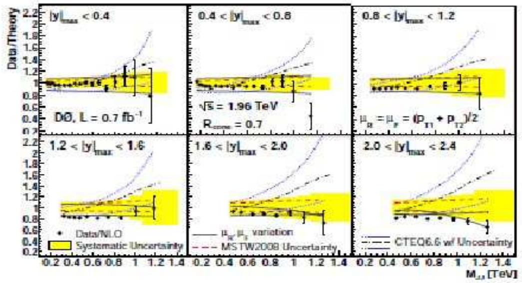


Note: ABM claim on NMC data:
reconcile MSTW and ABKM/HERA?

2. The devils advocate: why not ABKM/HERAPDF?

Impact of Tevatron jet data

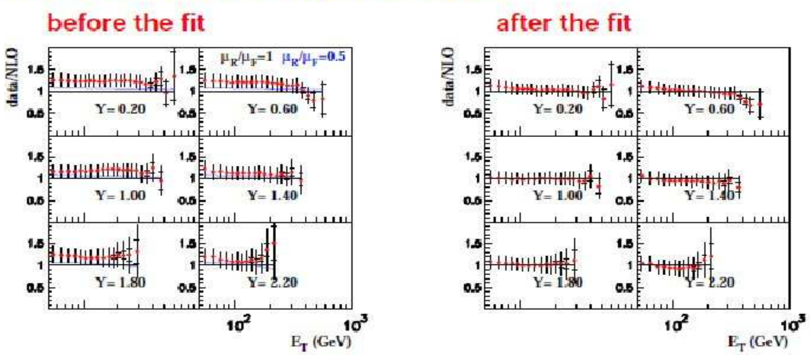




- NLO ABKM09 predictions compared to D0 Run II dijet data (D0 coll. '10)
  - 5-flavor PDFs generated from the 3-flavor ones $\mu_r = \mu_f = M_{JJ}$
    Alekhin, Blümlein, S.M. '10
- Impact of the data on ABKM PDFs is marginal
- ABKM provides very good description of Run II jet data

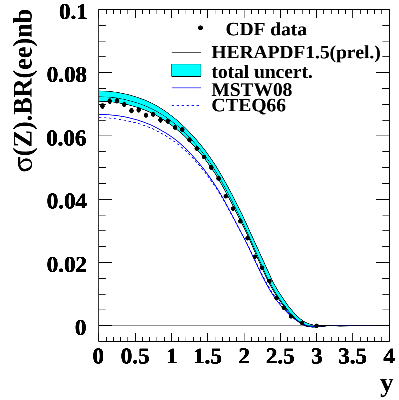
Sven-Olaf Moch Higgs production and fixed-target DIS data – p.8

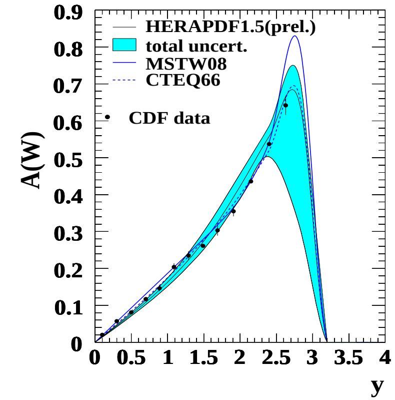
Inclusion of Tevatron jet data in fit

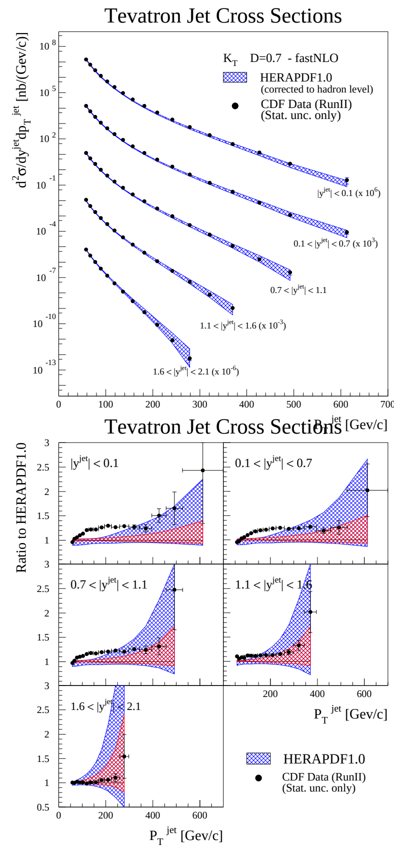


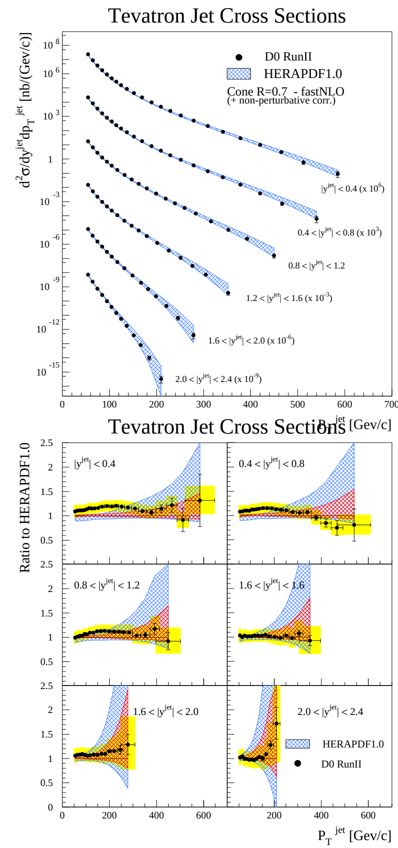
- NLO variant of ABKM09 fit with D0 Run II data included (inclusive midpoint algorithm) Alekhin, Blümlein, S.M. '10
  - 3-flavor PDFs for DIS, 5-flavor PDFs for jets, $\mu_f = E_T$
  - for D0 data: $\chi^2 = 104/110 \longrightarrow$ jet data compatible with others
  - uncertainty due to missing NNLO corrections

Sven-Olaf Moch Higgs production and fixed-target DIS data – p.9







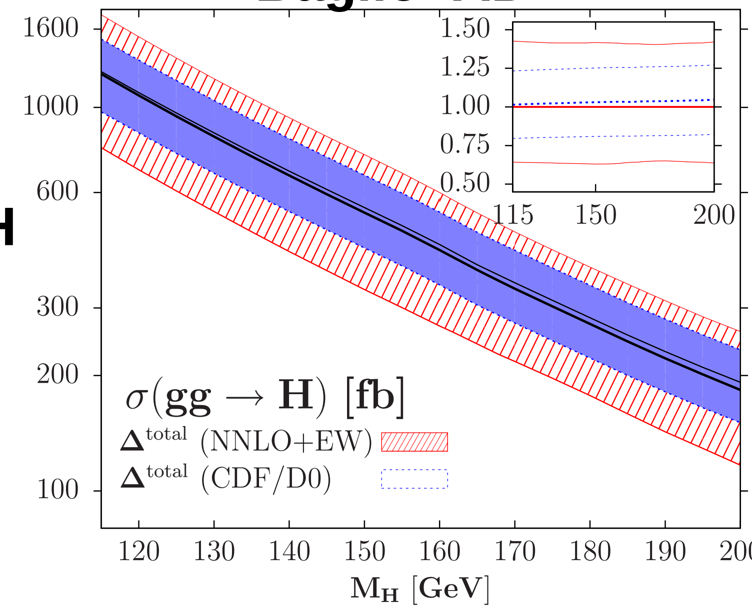


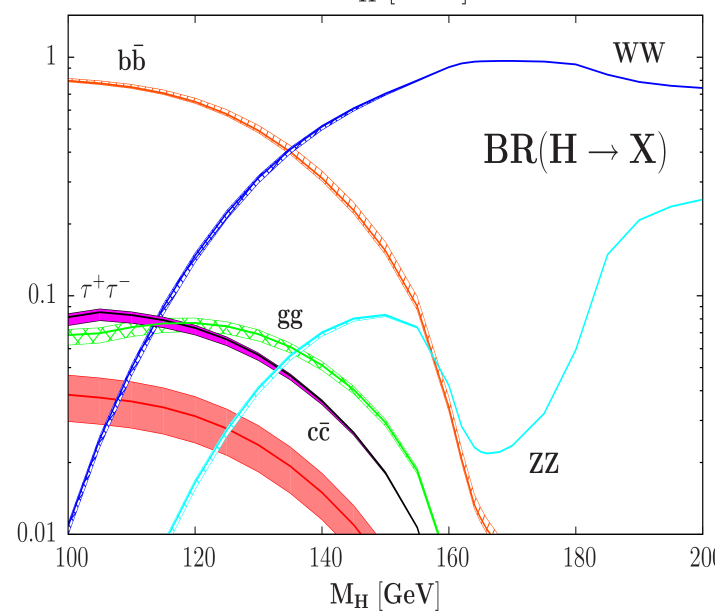
3. Combined uncertainties

Crucial issue: how to combine TH errors?
CDF: 18% (scale) $\oplus$ 12 % (PDF) $\approx$ 20%.
– scale and EFT pure theory errors (flat)
– PDF Gaussian with Hessian but not if TH
Proposal: apply ΔPDF+α_s on $^{\max}_{\min}\sigma(\mu)$
[also: Cacciari, Mangano et al. (2008)]
includes (small) scale-PDFs correlations
add linearly also small EFT uncertainty
last word $\approx$ $\pm$40% total uncertainty!

Even exp. PDF: flat+gaussian not obvious
LHC Higgs xsWG recommends $\longrightarrow$linear
CDF/D0 $\Rightarrow$ 18%+12%(+5%)=35%$\approx$40%!
[Uncertainty on σ not enough: BRs!
errors from $\Delta m_b, \Delta m_c, \Delta\alpha_s, \Delta\mu$,
for M_H $\approx$120–150 GeV: 5–10% error
on BR: $H \to b\bar{b}$ and $H \to WW^*$.]

Baglio+AD





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

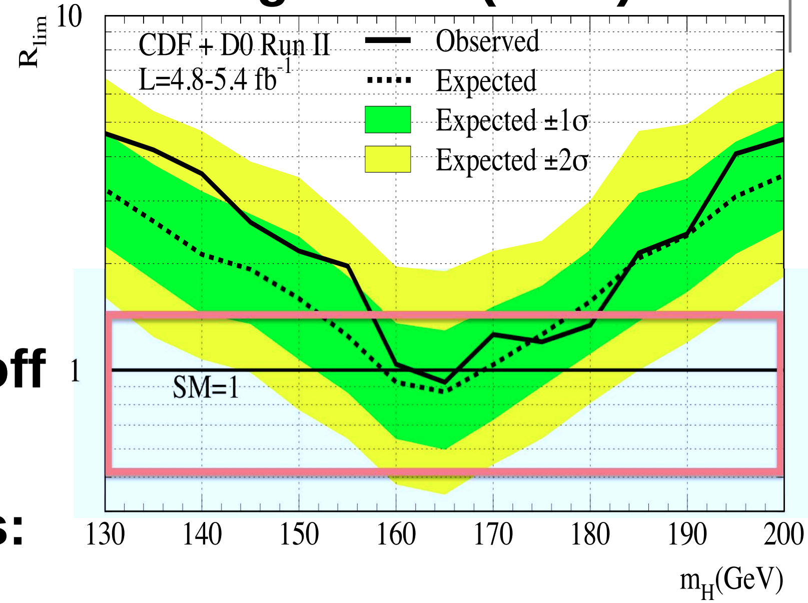
Recent exercise: reproduce CDF results
– without NN and shapes: a factor of 10 off
– with NN/shapes+same analysis 30%OK

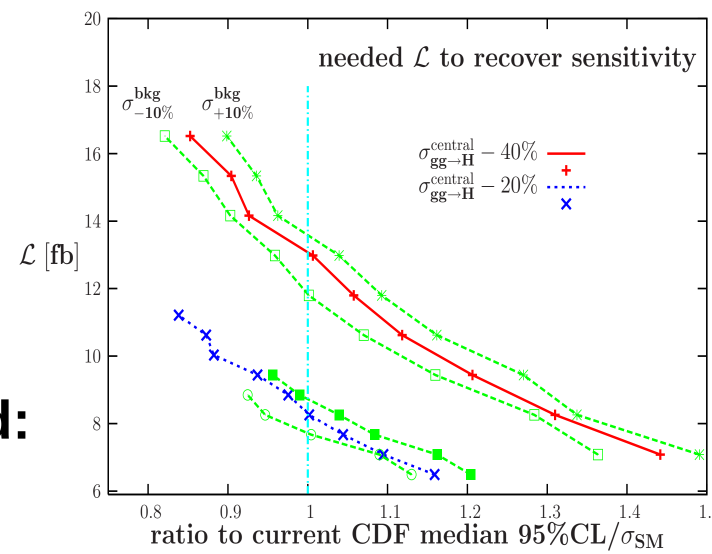
Assume three scenarios for uncertainties:
– $\sigma^{\rm NNLO}_{gg\to H}$ – 20% (full theory uncertainty)
– $\sigma^{\rm NNLO}_{gg\to H}$ – 40% (HERAPDF normalisation)
– Change WW bkg by $\pm$10% (HERAPDF)

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. The Higgs in SUSY theories

In MSSM, 5 Higgses: $\mathrm{h, H, A, H^{\pm}}$

SUSY$\longrightarrow$ 2 parameters: $\mathrm{M_A}, \tan\beta$

Most of time $\mathrm{h \equiv H_{SM}, H \equiv A}$

At Tevatron (lHC) good chances

for Φ=H/A at very high tanβ with

$$\sigma\left({}^{\mathbf{gg\to\Phi\to\tau^+\tau^-}}_{\mathbf{b\bar{b}\to\Phi\to\tau^+\tau^-}}\right) \propto \mathbf{2tan^2}\beta\times\mathbf{10\%}$$

But again, very large uncertainties:

scale, scheme, PDFs, $\Delta\mathrm{m_b}$, SUSY...

$\Rightarrow \pm 30-40$ theoretical uncertainty

Latest CDF/DO combined analysis:

claims that $\tan\beta \gtrsim 30$ excluded

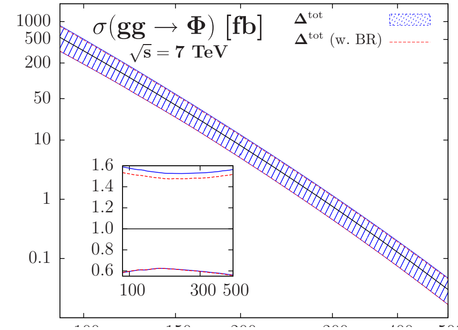
in the range $\mathrm{M_A = 100-200}$GeV

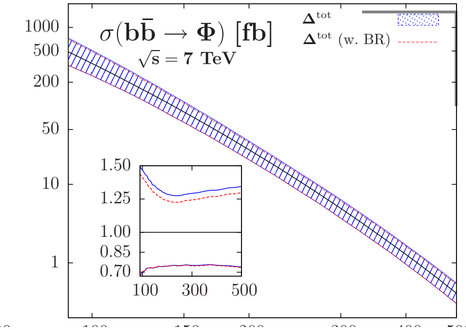
– SUSY effects cancel in $\sigma\times\mathrm{BR}$

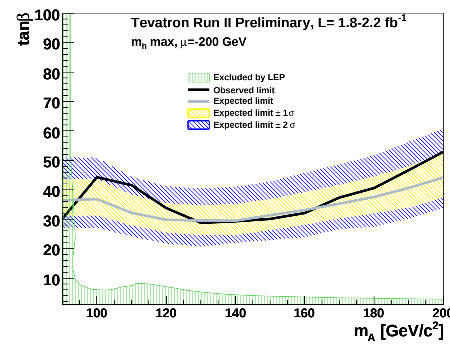
– incorrect normalisation (-30%)

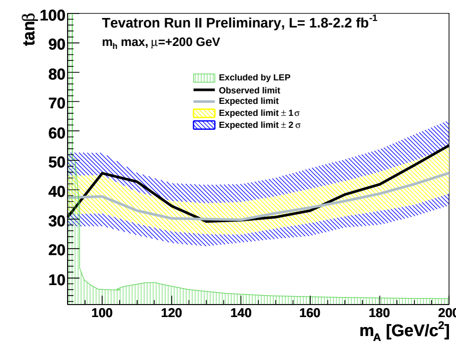
– no theory uncertainties at all

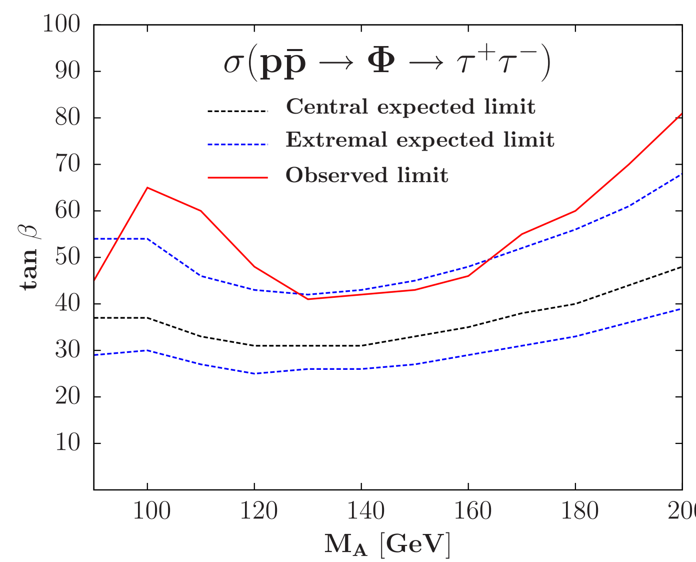
Done properly: only $\tan\beta \gtrsim 50$ out.











5. Conclusion

For the moment we are (unfortunately) in the Higgs exclusion mood:
Watch out: not exclude (at 95%CL) something you can discover later!

- **Large corrections, large uncertainties from higher orders**
- **Large spread in predictions due to PDFs (critical/urgent issue!)**
- **Way of combining theoretical uncertainties crucial ...**

SM Higgs at 165 GeV: half dead, half alive!

The lHC is and will be in the same mood for the next few months:

- **effects less drastic: smaller HO corrections and PDF uncertainties**
- **with linear combination à la LHC HXSWG $\Rightarrow$ 20–30% uncertainty**
- **will start to probe same mass range as Tevatron (this summer?).**

We hope ATLAS/CMS will give us a (non NN) $\sigma \times \mathrm{BR}$ limit so that:
– we can put our own uncertainties
– play with the normalization (new models, updates in PDFs, etc..)

But most important hope: switch quickly to discovery mood or mode!
(where all theses issues will be irrelevant, untill it comes to mesurements.