Higgs at the Tevatron: theoretical predictions and uncertainties

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1. **Higgs production at the Tevatron**
2. **Uncertainties from higher orders/scale**
3. **Uncertainties from the PDFs and α_s**
4. **Uncertainties from effective approach at NNLO**
5. **Combined uncertainties**
6. **Conclusion**
7. **Questions**

1. Higgs production at Tevatron: rates

- $M_H \gtrsim 150$ GeV : $gg \to H$

  exact NLO[a] : $K \approx 2$

  QCD: EFT NNLO[b]: $K \approx 3$

  EFT NNLL[c]: $\approx +10\%$

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

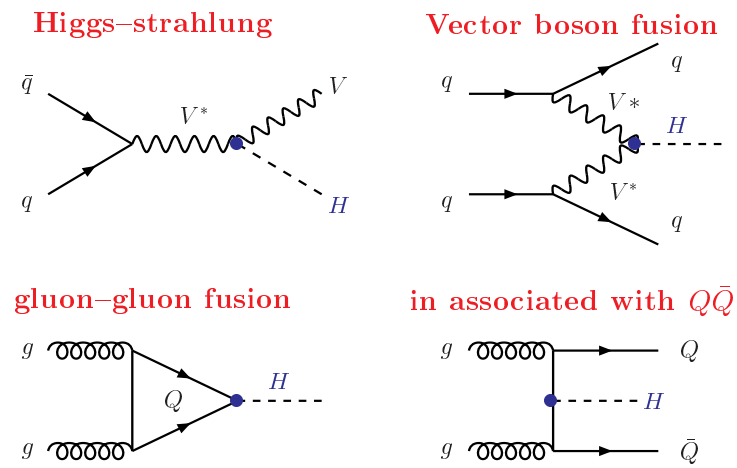
  EFT NNLO QCD+EW[e]: a few %

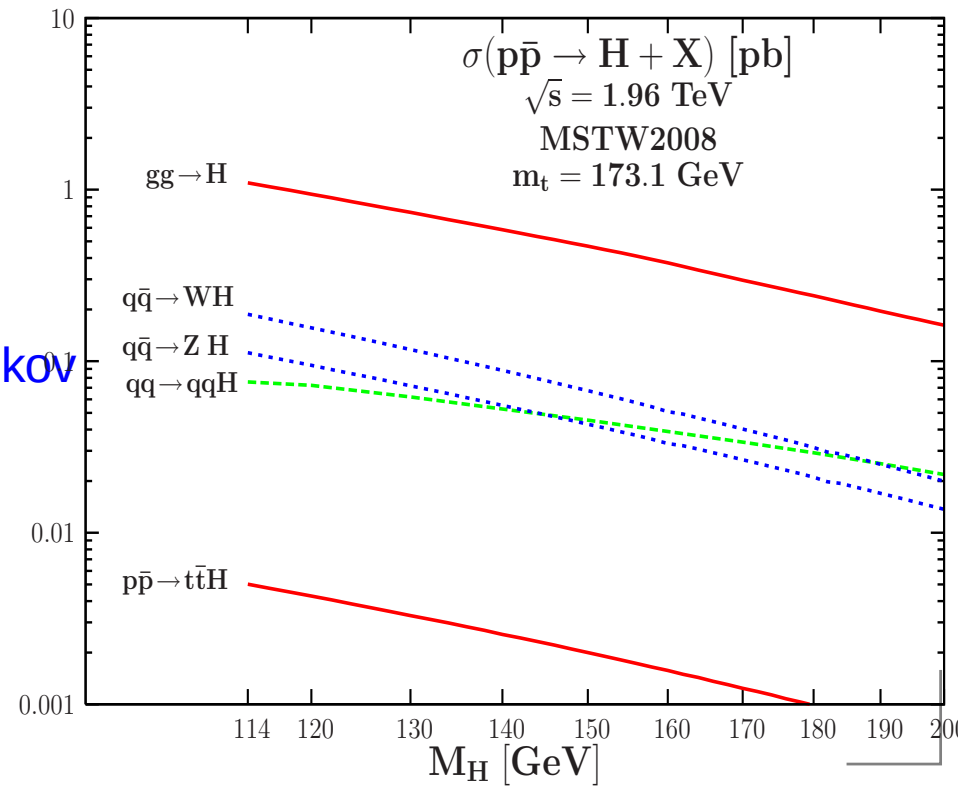
- $M_H \lesssim 150$ GeV : $q\bar{q} \to HV$

  exact NNLO QCD[f]: $K \approx 1.5$

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

[a] AD, Spira, Zerwas; Dawson (EFT)
Spira+AD+Graudenz+Zerwas (exact)
[b] Harlander+Kilgore, Anastasiou+Melnikov
Ravindran+Smith+van Neerven
[c] Catani+de Florian+Grazzini+Nason
[d] Actis+Passarino+Sturm+Uccirati
[e] Anastasiou+Boughezal+Pietriello
[f] Hamberg+van Neerven+Matsuura;
Brein+AD+Harlander
[g] Ciccolini+Dittmaier+Krämer





1. Higgs at Tevatron: focus on gg→H

- **The K factors are extraordinarily large:**

good: this is what makes the Tevatron sensitive to the SM Higgs!

bad: perturbation theory almost jeopardized as $\sigma_{\rm LO} \approx \sigma_{\rm NLO} \approx \sigma_{\rm NNLO}$.

uggly: higher order (HO) corrections might be very important...

- **NNLL corrections known only for inclusive cross section $\sigma_{\rm tot}$:**

– $\sigma_{\rm cuts}$ used experimentally is known only at NNLO[a]: stick to NNLO.

– in fact, NNLO only in EFT approach (no b-loop); exact only at NLO[b].

– K in $\sigma_{\rm tot}$ and $\sigma_{\rm cuts}$ different[c] by $\approx$ 25%: $\mathrm{K}^{\rm nnlo}_{\rm cuts}$=2.6 vs $\mathrm{K}^{\rm nnlo}_{\rm tot}$ =3.3.

- **Other remarks:**

– Starting point of calculation: HIGLU (M. Spira) based on Ref. [b].

– Recent update[d] for $\mathrm{gg} \to \mathrm{H}$ (2009) but not for $\mathrm{p\bar{p}} \to \mathrm{HV}$ (2004).

– Distributions not discussed, see Ref. [c]; no background neither.

– Higgs decays: use latest HDECAY[e] which has EW RC for H→WW.

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[a] Catani+Grazzini (HNNLO), Anastasiou+Melnikov+Petriello (FEHIP)
[b] Spira+AD+Graudenz+Zerwas (exact)
[c] Anastasiou, Dissertori, Grazzini, Stökli, Webber (2009)
[d] de Florian+Grazzini; Anastasiou+Boughezal+Pietriello
[e] AD+Kalinowski+Spira

2. Uncertainties: higher orders and scale variation

Higher orders (HO) guessed by varying μ_R, μ_F arround central scale $\mu_0 = M_H$:

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

(only a guess, not a true measure!)

In general, when small HO, $\kappa = 2$ enough (this is the case for $q\bar{q} \to HV$ e.g.).

Here: $K_{HO} \approx 3$ and PTh almost ruined.

HO beyond NNLL might be still large:

$\Rightarrow$ guess scale domain from σ_{NLO}

For σ_{NLO} band to catch σ_{NNLL} value

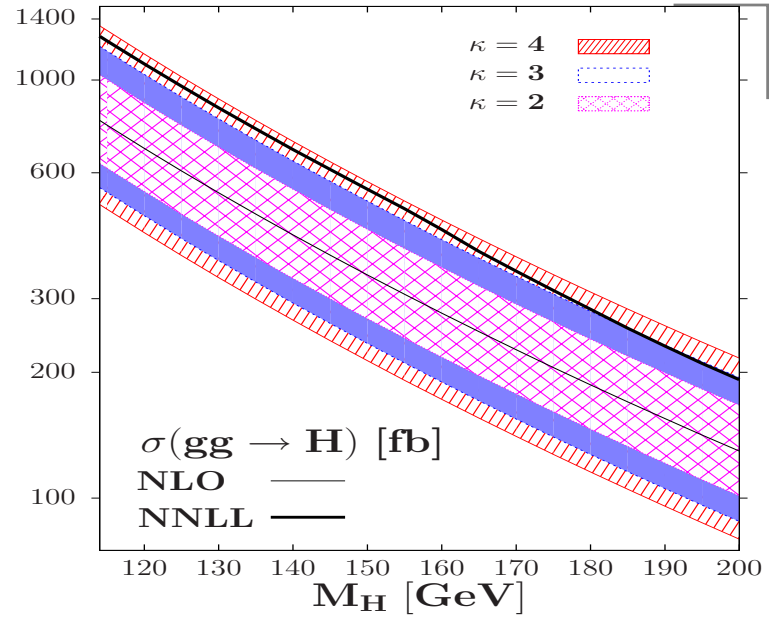
$$\Rightarrow \text{one needs at least } \kappa = 4$$

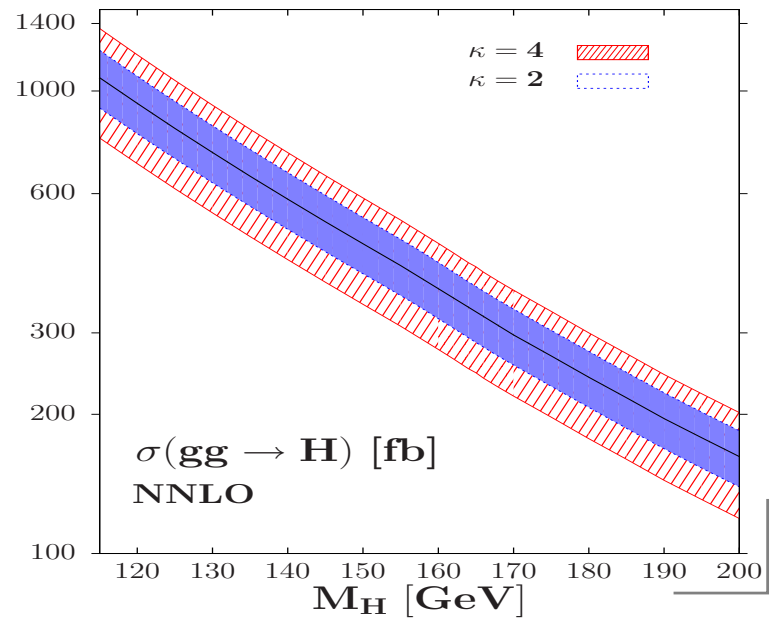
Apply variation with $\kappa = 4$ for σ_{NNLO}

$\approx 25\%$ scale uncertainty on σ_{NNLO}

(compared to $\approx 10\%$ for σ_{NNLL}+$\kappa = 2$)

compensates for 30% diff. K_{cuts} vs K_{tot}





3. Uncertainties: PDFs and α_s

PDF uncertainties estimated using the 2x20 MSTW PDF sets including errors. However, also other sets: CTEQ, ABKM...

$\Rightarrow$ take into account all existing PDF sets

(# is also a measure of the PDF error...)

CTEQ/MSTW and ABKM give 5–10% error

But ABKM has 25% smaller central value!

Pb: $\sigma_{\rm LO} = \mathcal{O}(\alpha_s^2)$,..., $\sigma_{\rm NNLO} = \mathcal{O}(\alpha_s^4)$ and $\alpha_s(M_Z^2) = 0.1171\ ^{+0.0034}_{-0.0034}$ (90%CL)

MSTW has new set up with $\Delta^{\rm exp}\alpha_s$ in.

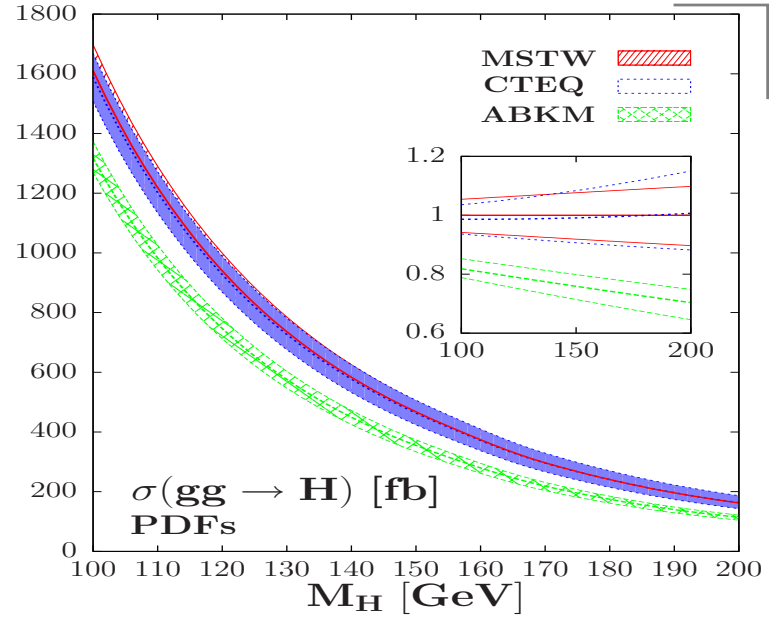
Not enough: also $\Delta^{\rm th}\alpha_s \approx 0.0033$

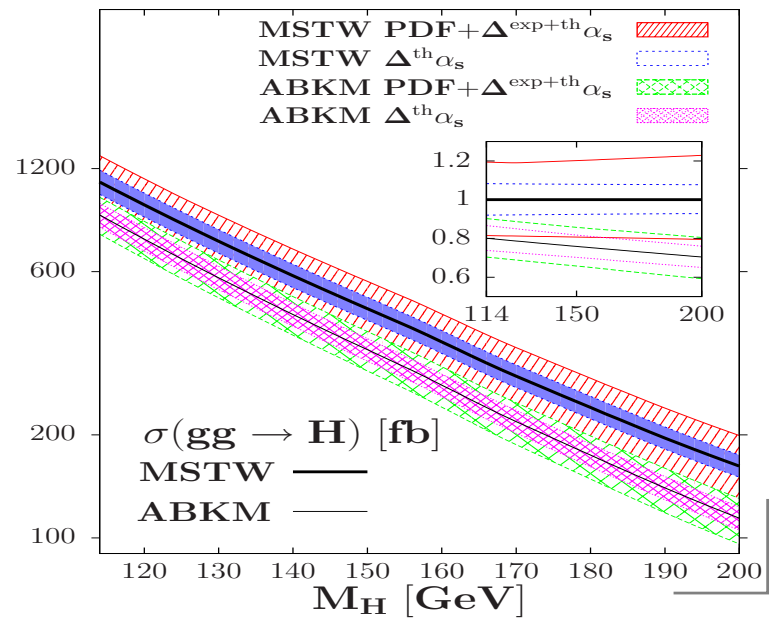
Include all: PDF+$\Delta^{\rm exp}\alpha_s + \Delta^{\rm th}\alpha_s$

MSTW is finally consistent with ABKM.

But total uncertainty is now $\approx$ 20% !

(compared with $\approx$ 5% for PDF alone)





4. Uncertainties: EFT approach at NNLO

To simplify (hard!) NNLO calculation

EFT approach where $\mathrm{M_{loop}} \gg \mathrm{M_H}$

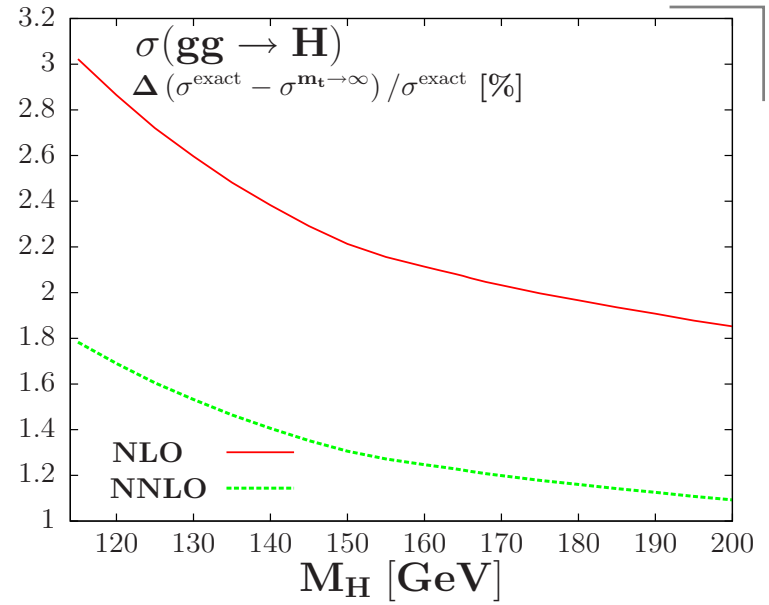
Good for t–loop (see R. Harlander)

Not good for b–loop ($\approx$ 10% at LO)

Estimate error from NLO (known exactly)

$$\Delta_{\mathrm{b}}^{\mathrm{NNLO}} : \frac{\sigma_{\mathrm{exact}}^{\mathrm{NLO}} - \sigma_{\mathrm{EFT}}^{\mathrm{NLO}}}{\sigma_{\mathrm{exact}}^{\mathrm{NLO}}} \times \frac{\mathrm{K_{NLO}}}{\mathrm{K_{NNLO}}}$$

Uncertainty of one to two percent...



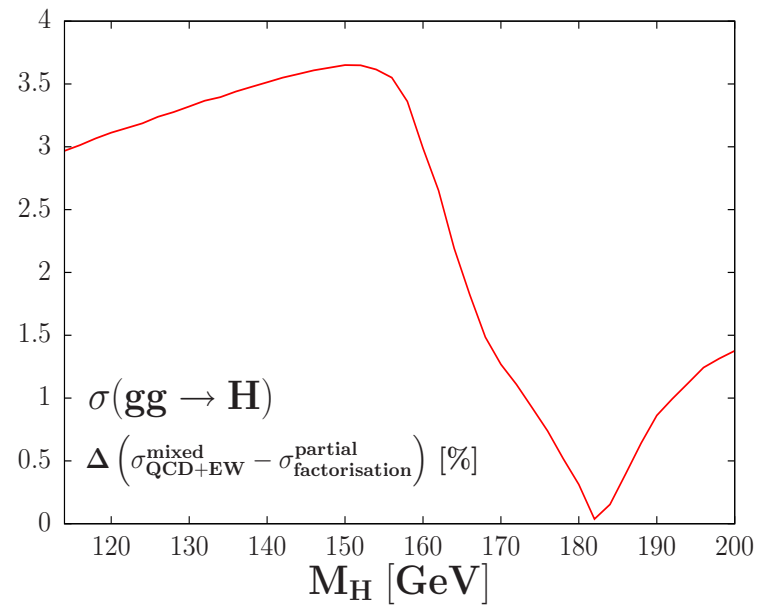
Mixed EW+QCD RadCor at NNLO:

EFT approach with $\mathrm{M_{W/Z}} \gg \mathrm{M_H}$

Contrib. $\equiv$ to EW NLO in $\#$ schemes

$$\Delta_{\mathrm{EW}}^{\mathrm{NNLO}} : \frac{\sigma_{\mathrm{complete\ factor.}}^{\mathrm{NLO-EW}} - \sigma_{\mathrm{partial\ factor.}}^{\mathrm{NLO-EW}}}{\sigma_{\mathrm{complete\ factor.}}^{\mathrm{NLO-EW}}}$$

Uncertainty of a few percent ($\lesssim$ 3.5%)



5. Uncertainties: combination

Next very important issue: how to combine these theoretical errors?

CDF: 10% (scale) + 5% (PDF) = 11%.

D0 : even smaller, 10%, total error.

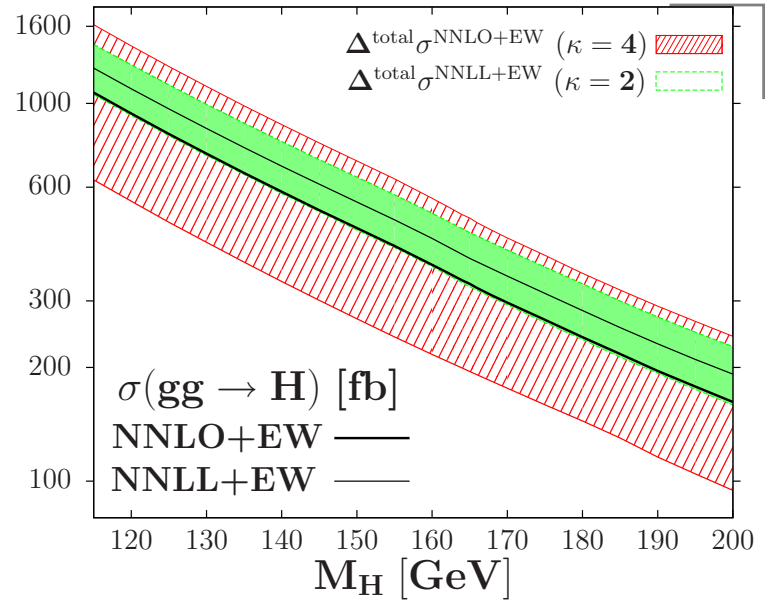
– add scale and PDF not in quadrature

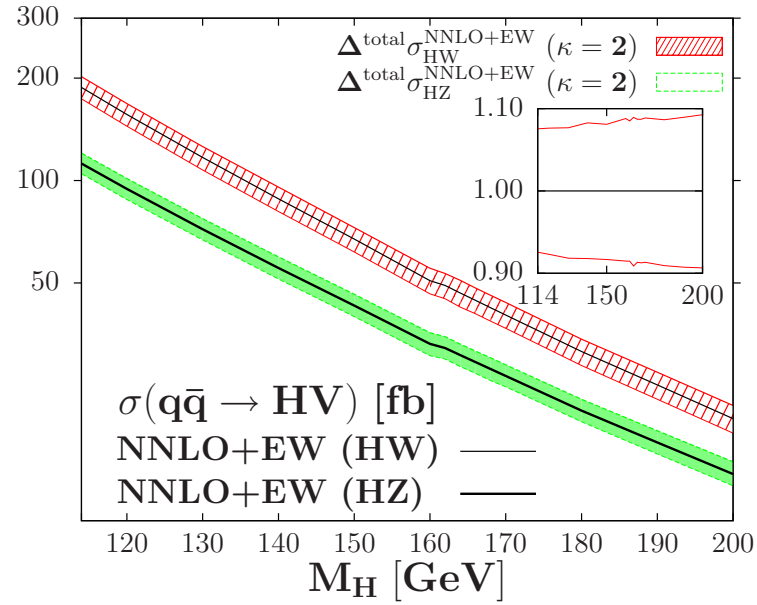
– exp+th error on α_s should be added

Reasonable way: calculate $\mathbf{\substack{max\\min}}\sigma(\mu_{\mathbf{F/R}})$ and apply on them PDF+$\alpha_\mathbf{s}$ errors (and eventually small EFT error)

In $\mathbf{gg \to H}$ $:\approx \pm$40% total uncertainty in the entire M_H range at the Tevatron. Much larger than the $\approx$ 10% of CDF/D0

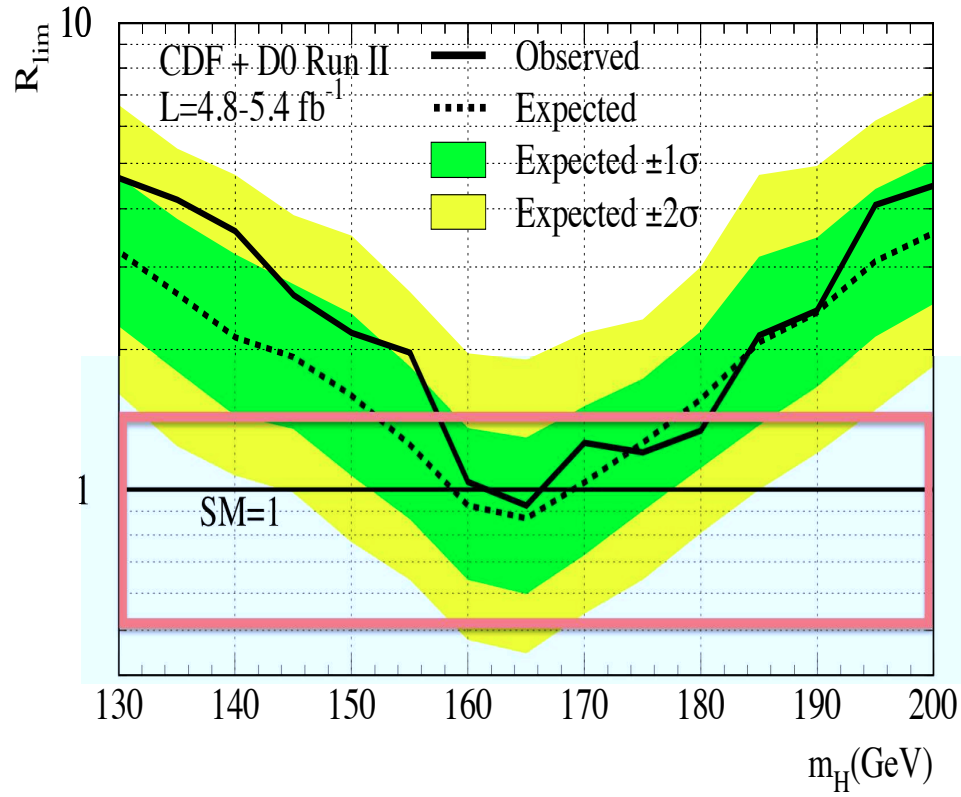
In $\mathbf{p\bar{p} \to HV}$ $:\approx \pm$10% uncertainty smaller than gg$\to$H but x2 CDF/D0 error.





6. Conclusion

- **Performed "state of the art" update of Higgs cross sections at Tevatron.**
- **Investigated all sources of theoretical errors for the two main channels.**
  - $\mathbf{M_H \lesssim 150\ GeV : q\bar{q} \to HV}$**:**
    only a $\approx 10\%$ **error but a factor of two larger than what is used.**
  - $\mathbf{M_H \gtrsim 150\ GeV : gg \to H}$**:**
    a large, $\approx \pm 40\%$**, uncertainty, mainly from scale and PDF+**α_s
  - $\sigma^{NNLO}_{gg\to H}$ **could be a factor of two lower than what is assumed by CDF/D0 analysis for** $p\bar{p} \to H \to W^{(*)}W^{(*)} \to \ell\ell\nu\nu$



- **Need to reconsider 95% CL CDF/D0 exclusion limit 162**$\lesssim M_H \lesssim$**166 GeV.**