Higgs production at the Tevatron: theoretical predictions and uncertainties

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Main production channels

- gluon–gluon fusion and Higgs–strahlung known at NNLO in QCD
- $t\bar{t}H$ known at NLO only
- VBF pushed partly to NNLO in 2010
  (Bolzoni, Maltoni, Moch, Zaro; arXiv:1003.4451)
  but considered in this talk at NLO only ($\sim 0.3\%$ difference)
Higgs production at Tevatron

$M_H \gtrsim 150$ GeV, $gg \to H$ channel
Exact at NLO QCD\(^a\), $K_{\text{NLO}} \sim 2$
Infinite top mass at NNLO QCD\(^b\), $K_{\text{NNLO}} \sim 3$
Exact NLO EW corrections\(^c\),
Effective NNLO mixed QCD-EW\(^d\): $
\simeq \pm$ a few %

$M_H \lesssim 150$ GeV, $p\bar{p} \to HV$ channel
Exact at NNLO QCD\(^e\), $K_{\text{NNLO}} \sim 1.5$
Exact NLO EW corrections\(^f\) $\simeq -5\%$
CKM effects included ($\sim -5\%$)

\(^a\) Dawson (EFT, 1991), Djouadi, Spira & Zerwas (EFT, 1991); Spira, Djouadi, Graudenz, Zerwas (1995)
\(^d\) Anastasiou, Boughezal, Pietriello (2009)
\(^f\) Ciccolini, Dittmaier, Krämer (2003)
Gluon–gluon fusion channel known up to Next-to-Next-to-Leading-Logarithm (NNLL) (Catani, de Florian, Grazzini & Nason (2003)). But here not included because:

- Experimental analysis still at the NNLO
  ⇒ theoretical input should be (for now) at NNLO
- Cross section with cuts (and no resummation) have reduced $K$–factors
  ⇒ should be seen in the NNLO scale uncertainty
- No PDF at the NNLL level until now
  ⇒ calculation slightly inconsistent (Corcella & Magnea (2005))
Scale uncertainty

Higher orders (HO) guessed with $\mu_R, \mu_F$ variation around central $\mu_0 = m_H$

$$\frac{m_H}{\kappa} \leq \mu_R, \mu_F \leq \kappa m_H$$

Small HO $\Rightarrow \kappa = 2$ enough (ex. $q\bar{q} \rightarrow HV$)

Large HO in $gg \rightarrow H$ ($K_{HO} \approx 3$) guess scale domain from $\sigma_{NLO}$: NLO band catches $\sigma_{NNLO}$ $\Rightarrow \kappa = 3$ needed (at least) according to our criterium

NNLO $gg \rightarrow H$: $\approx 20\%$ scale variation

$(\neq 10\%$ assumed by CDF/D0)
PDF and $\alpha_s^{\exp+\text{th}}$ errors

Different sets of PDFs on the market
⇒ different errors on individual PDF
+ different central values
All have $\sim 5 - 7\%$ error, but central ABKM is 25% smaller than MSTW/CTEQ!

Add PDF+$\alpha_s^{\exp}$ correlated error
(MSTW dedicated set)
⇒ $\alpha_s(M_Z) = 0.1171 \pm 0.0034$ (90\%CL) error
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Add $\Delta^{\text{th}} \alpha_s = 0.002$ error with central fixed-$\alpha_s$
MSTW PDF sets
⇒ ABKM is now consistent with MSTW/CTEQ

$\sim 20\%$ final error $\gg 5\%$ PDF alone
Effective theory at NNLO

**NNLO**: easier with $M_{\text{loop}} \gg M_H$

Good for $t$–loop (Marzani et al. 2008, Harlander et al. 2009)
Not for $b$–loop: $\sim 10\%$ error at NLO

$$
\Delta_b^{\text{NNLO}} = \frac{K_{\text{NLO}}}{K_{\text{NNLO}}} \times \frac{\sigma_{\text{exact}}^{\text{NLO}} - \sigma_{\text{EFT}}^{\text{NLO}}}{\sigma_{\text{exact}}^{\text{NLO}}}
$$

Then add $M_b$ uncertainty (on-shell versus $\overline{\text{MS}}$)

$b$–loop uncertainty: $\pm 2 - 3\%$

Exact EW corrections at NLO (Actis et al. 2008)
Effective theory for NNLO mixed QCD–EW, $M_H \ll M_W, Z$ (Anastasiou et al. 2009)

$$
\Delta_{\text{EW}}^{\text{NNLO}} = \frac{\sigma_{\text{mixed}} - \sigma_{\text{NLO EW}}}{\sigma_{\text{mixed}}}
$$

Add at most $\sim \pm 3.5\%$ error
Putting together all the errors

Combining the errors: quadature or linear?
CDF: 10% scale ⊕ 5% PDF = 11% total error
D0: 10% total error

Reasonable way: add in quadature
PDF+∆_{exp+th}^{\alpha_s} on \min_{\max} \sigma(\mu)
and eventually linearly the small EW and b–loop errors

\( gg \rightarrow H: \sim \pm 40\% \gg \sim 10\% \) CDF/D0
\( p\bar{p} \rightarrow HV: \sim \pm 10\% \gg \sim 5\% \) CDF/D0

\( p\bar{p} \rightarrow HV \) much more under control
CDF+D0 exclusion bands?

CDF & D0: excluded $M_H \in [162 - 166] \text{ GeV}$ (Phys. Rev. Lett. 104, 061803 (2010))

But with our errors:

This 95% CL exclusion should therefore be reconsidered.
Higgs production at Tevatron

- The two most important channels have been revisited at Tevatron (minor update for the two others).

How decompositions into 132 and 525 have been thoroughtly studied with all uncertainties: scale, PDF, $\alpha_s$, EFT, $\alpha_{\text{exp} + \text{th}}$.
Summary and conclusion

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- Gluon–gluon fusion has been thoroughly studied with all uncertainties: scale, PDF, $\alpha_s^{\text{exp}+\text{th}}$, EFT

The overall $\approx 40\%$ error on $gg\rightarrow H$ cross section implies that the Tevatron exclusion bands on Higgs mass should be revisited.

Same has also been done at $\ell^+\ell^-$ for gluon–gluon fusion, MSSM study under way.
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- Gluon–gluon fusion has been thoroughly studied with all uncertainties: scale, PDF, $\alpha_s^{\text{exp+th}}$, EFT
- Higgs–strahlung has been revisited with all major uncertainties: scale, PDF, $\alpha_s^{\text{exp+th}}$
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- **The overall $\simeq 40\%$ error on $gg \rightarrow H$ cross section implies that the Tevatron exclusion bands on Higgs mass should be revisited**
- Same has also been done at $\ell\text{HC} = \text{LHC@7 TeV and 1 fb}^{-1}$ for gluon–gluon fusion, MSSM study under way
Backup: $gg \rightarrow H$ at the LHC@7 TeV

**Combination**: same exercise as at Tevatron

**Final error in $gg \rightarrow H$:** $\sim -25\%, \sim +30\%$

much more under control than at Tevatron ($\sim -40\%, +50\%$ error).