Precise Predictions for Higgs Production Beyond the SM

Radja Boughezal

ITP, University of Zurich

Planck 2010: From the Planck Scale to the ElectroWeak Scale

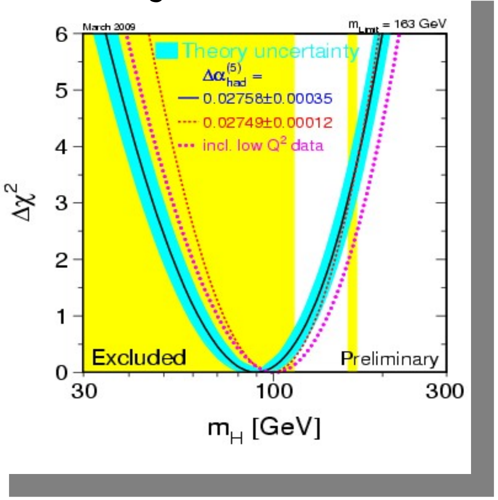
CERN, 1st June 2010

Current Limits on the SM Higgs Mass

Combined efforts from direct searches and theoretical predictions were needed to set tighter limits on MH

- Current fit of electroweak parameters by LEP EW-working group predicts:

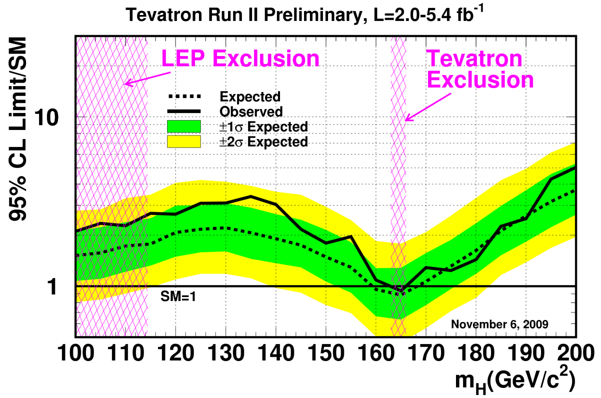
$$M_H = 87^{+35}_{-26}\, GeV$$



LEP EW working group August 2009

- Upper bound (from precision EW measurements) and lower bound (direct searches at LEP) at 95% CL (SM Higgs):

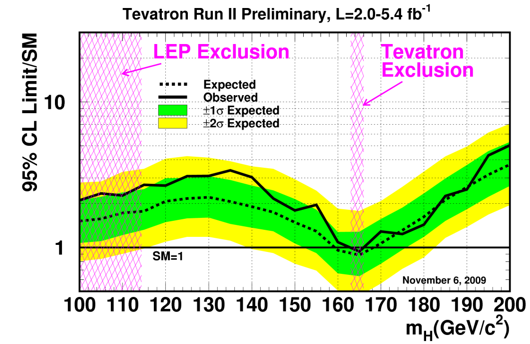
$$M_H < 157\, GeV$$
$$M_H > 114\, GeV$$



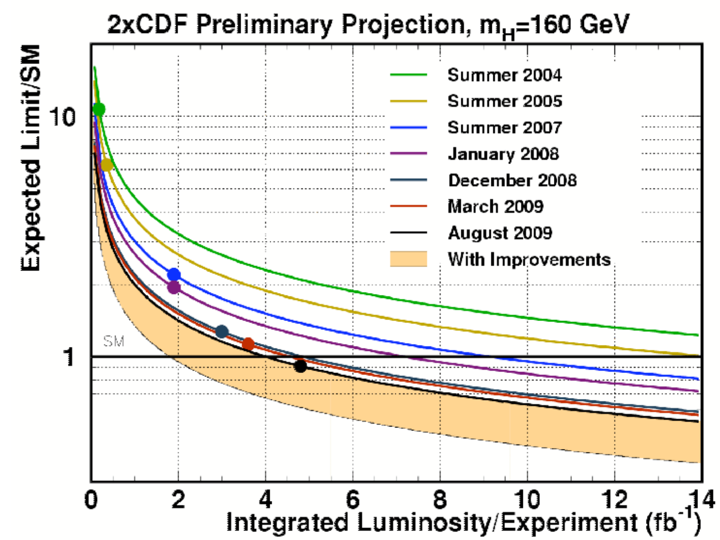
- Combined results from CDF and D0 excluded MH in the range 162-166 GeV at 95% CL arXiv:1001.4162

- Tevatron exclusion is based mostly on the gluon fusion process gg → H → WW

Great results from CDF and D0 in both low and high mass sectors



- SM Higgs exclusion in the range 162-166 GeV @ 95% CL
- Tevatron now exploring remaining parameter space: expected exclusion range 159-169 GeV
- further improvements: more data, increased acceptances, Control over systematics



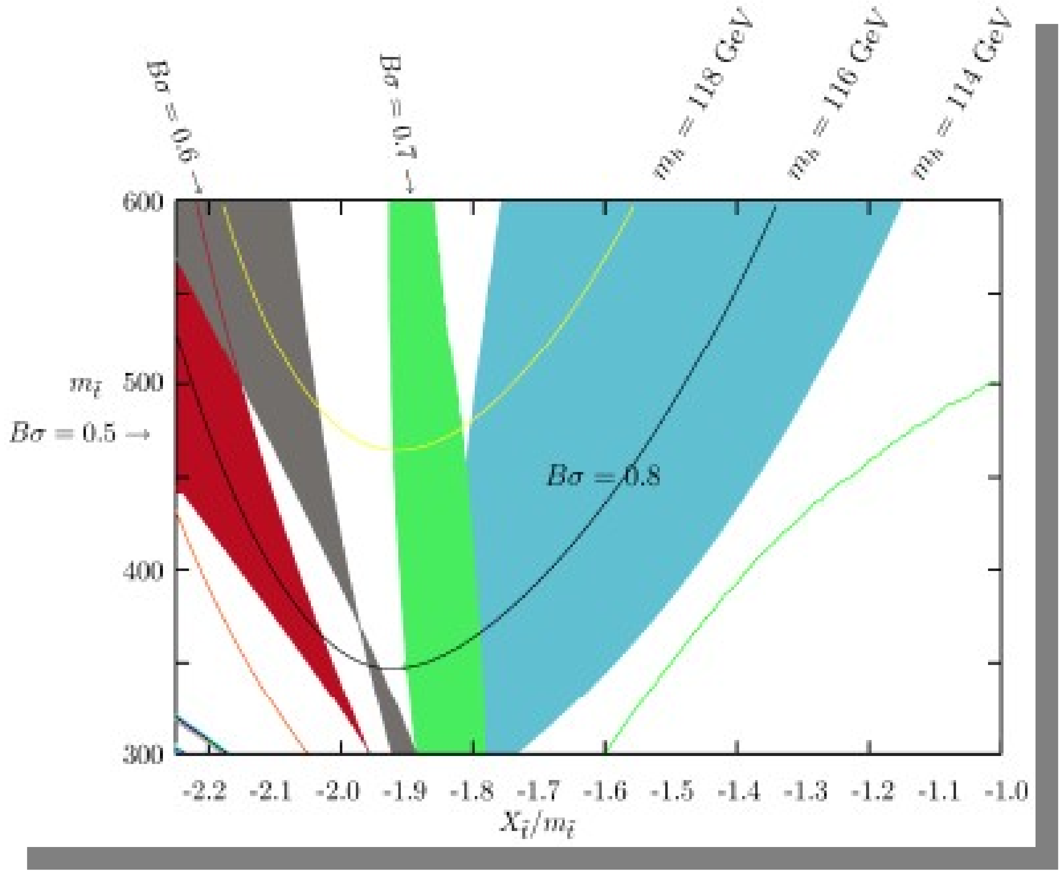
- On the theory side: theory errors have become small enough not to wash out BSM effects

Can we use these results to understand or indirectly exclude new physics?

Higgs Beyond the SM

MSSM Low, Shalgar 2009

$$g\,g \rightarrow h \rightarrow \gamma\,\gamma$$



The Higgs can be very different in models beyond the SM

Example Studies:

Color Octet scalars and 4th generation effects on the cross section in the $gg \rightarrow H$ process

Details can be found in arXiv:1003.2046 & arXiv:1003.4677

Color Octet scalar effects in $gg \rightarrow H$

- Transforms as $(8,1)_0$ under $SU(3) \times SU(2) \times U(1)$

$$\mathcal{L}^{full} = \mathcal{L}_{SM} + \mathrm{Tr}\left[D_\mu S D^\mu S\right] - m_S'^2\, \mathrm{Tr}\left[S^2\right] - g_s^2\, G_{4S}\, \mathrm{Tr}\left[S^2\right]^2 - \lambda_1 H^\dagger H\, \mathrm{Tr}\left[S^2\right]$$
$$-\lambda_h \left(H^\dagger H - \frac{v^2}{2}\right)^2 .$$

- Arise in theories with universal extra dimensions and in technicolor models
- Primary decays expected to be into tt or bb depending on mS
- Can be searched for at Tevatron by looking for four b-jet final state, BUT direct search is difficult due to large QCD background
- Can indirectly search for it using the influence of the scalar on Higgs production xsection

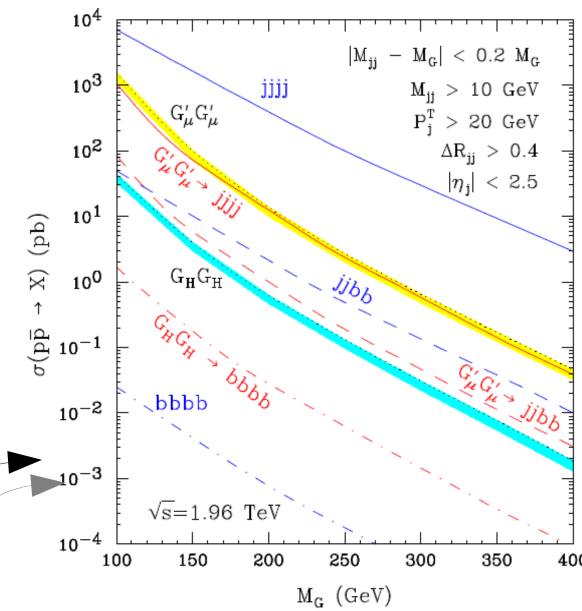
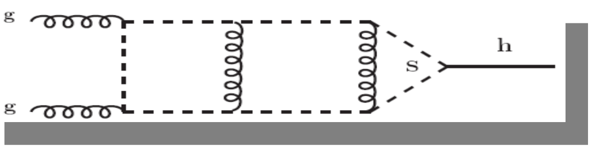


Figure 3: Tevatron cross sections for pair production of spin-1 (G'_μ) and spin-0 (G_H) octets and for backgrounds, as a function of octet mass. Four-jet final states with 0, 2 and 4 b-tags are shown (for both signal and background) as solid, dashed, and dot-dashed lines respectively, for given cuts. Dotted lines represent signal cross sections without cuts, with uncertainties indicated by shaded bands.

Dobrescu, Kong, Mahbubani (2007)

Color Octet scalar effects in gg → H

Need to calculate



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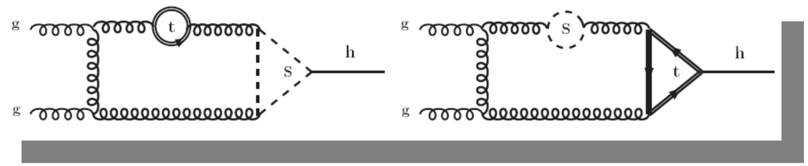

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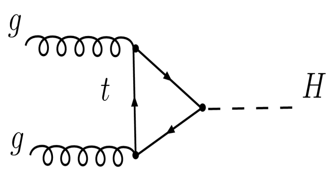
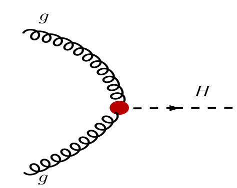
- Search reach at Tevatron estimated to be 280 GeV   Dobrescu, Kong, Mahbubani (2007)
- LEP and Tevatron indicate that Higgs, if it exists, is light
- This allows for an effective theory approach, without the top and the scalar:



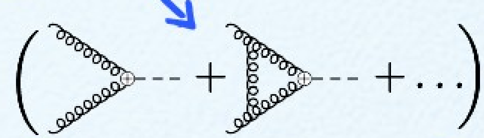
$2M_{heavy} > M_{Higgs}$

$C(\alpha_s, M_t)$ X



$$\mathcal{L}_{eff} = -\frac{\alpha_S}{4v} C\, H G^a_{\mu\nu} G^{a\mu\nu}$$

$$\left(C_0 + \left(\frac{\alpha_s}{\pi}\right) C_1 + \left(\frac{\alpha_s}{\pi}\right)^2 C_2 + \ldots\right)$$



Model dependent (top quark + anything)

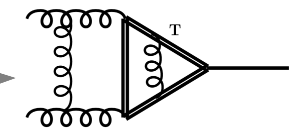
QCD only

Color Octet scalar effects in gg → H: the Wilson coefficient

The NNLO Wilson coefficient for the adjoint scalar

$$C_1 = C_{TTH} + C_{SSH} + C_{TS}$$

$$C_{TTH} = -\frac{a'}{3} - \frac{11\,a'^2}{12} + a'^3\left[\frac{1}{864}\left(-2777 + 684\,L_T\right) + \frac{1}{288}\left(67 + 64\,L_T\right)\,n_l\right]$$



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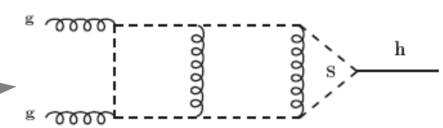
$$\begin{aligned} C_{SSH} = & -\frac{\lambda_1 v^2}{2\,m_S^2}\left\{\frac{a'}{4} + a'^2\left[\frac{33}{16} + \frac{5\,G_{4S}}{8}\right] + a'^3\left[n_l\left(\frac{-101}{288} + \frac{7\,L_S}{24}\right)\right.\right. \\ & + G_{4S}^2\left(\frac{-35}{16} + 5\,L_S\right) + \frac{9\,L_S\left(-43 + 8\,x^2\right)}{64} - \frac{3\left(76 - 3895\,x^2 + 257\,x^4\right)}{1024\,x^2} \\ & - G_{4S}\left(\frac{-705}{64} + \frac{575\,L_S}{96} + \frac{5\ln(x)}{24}\right) + \frac{3\left(76 + 37\,x^2 + 86\,x^4 + 225\,x^6\right)}{2048\,x^3}\times \\ & \left(\mathrm{Li}_3(x) - \mathrm{Li}_3(-x)\right) \\ & + \ln^2(x)\left\{-\frac{-228 + 41\,x^2 - 192\,x^4 + 675\,x^6}{2048\left(-1 + x\right)x^2\left(1 + x\right)} + \frac{3\left(76 + 37\,x^2 + 86\,x^4 + 225\,x^6\right)}{4096\,x^3}\times\right. \\ & \left.\left(\ln(1 + x) - \ln(1 - x)\right)\right\} \\ & \left.\left. + 3\ln(x)\left\{\frac{76 - 111\,x^2 + 159\,x^4}{1024\,x^2} - \frac{76 + 37\,x^2 + 86\,x^4 + 225\,x^6}{2048\,x^3}\left(\mathrm{Li}_2(x) - \mathrm{Li}_2(-x)\right)\right\}\right]\right\}. \end{aligned} \qquad (3.22)$$



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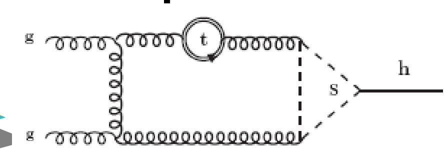

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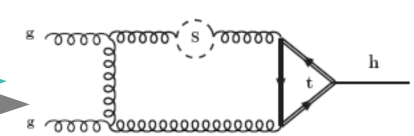
$$\begin{aligned} C_{TS} = a'^3 & \left[\frac{9\,L_S\,x^2}{8} - \frac{2052 + 1075\,x^2 + 1755\,x^4}{9216\,x^2}\right. \\ & + \ln(x)\left\{\frac{684 + 409\,x^2 + 1431\,x^4}{3072\,x^2} - \frac{3\left(76 + 37\,x^2 + 86\,x^4 + 225\,x^6\right)}{2048\,x^3}\left(\mathrm{Li}_2(x) - \mathrm{Li}_2(-x)\right)\right\} \\ & + \ln^2(x)\left\{-\frac{-228 + 41\,x^2 - 192\,x^4 + 675\,x^6}{2048\left(-1 + x\right)x^2\left(1 + x\right)} + \frac{3\left(76 + 37\,x^2 + 86\,x^4 + 225\,x^6\right)}{4096\,x^3}\times\right. \\ & \left.\left.\left(\ln(1 + x) - \ln(1 - x)\right)\right\} + \frac{3\left(76 + 37\,x^2 + 86\,x^4 + 225\,x^6\right)}{2048\,x^3}\left(\mathrm{Li}_3(x) - \mathrm{Li}_3(-x)\right)\right] \end{aligned} \qquad (3.23)$$



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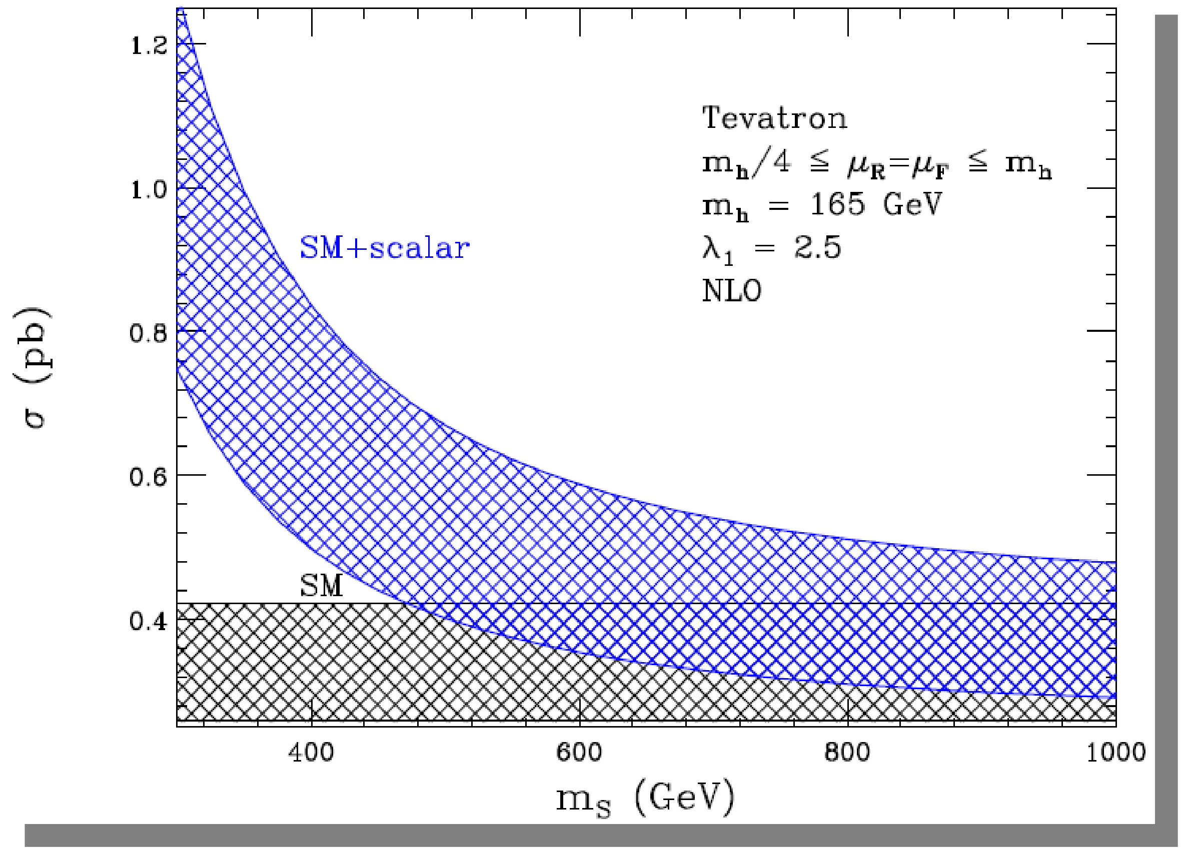
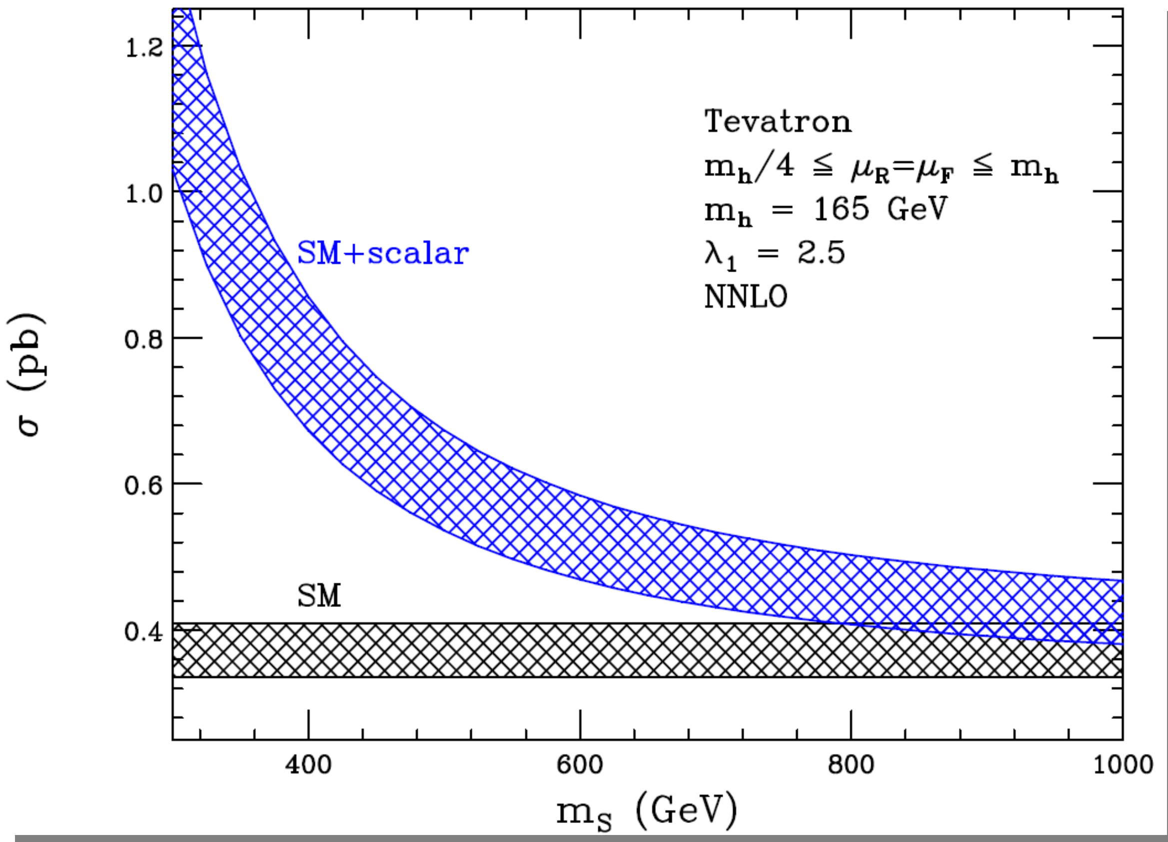
Tevatron: NLO



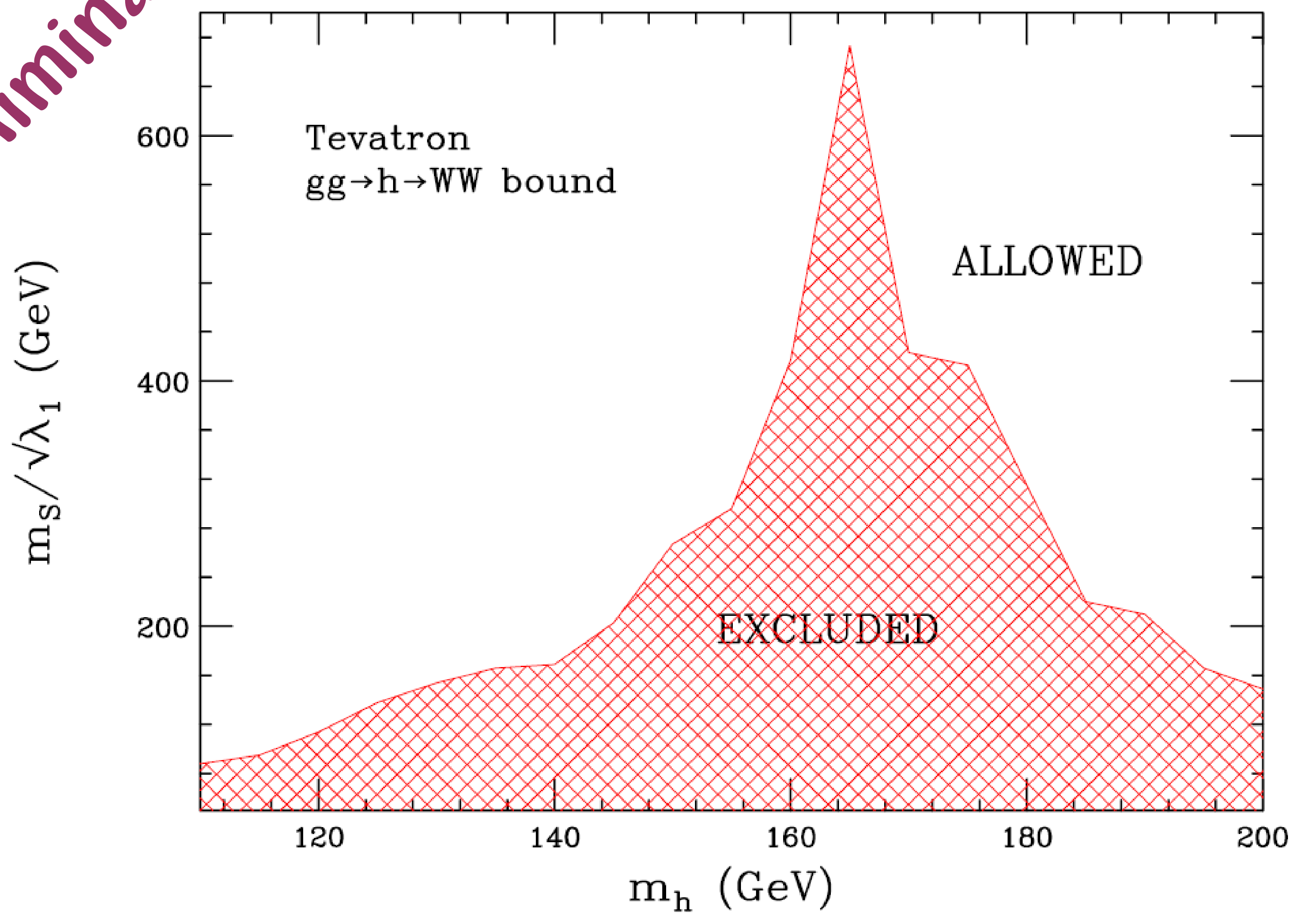
Tevatron: NNLO



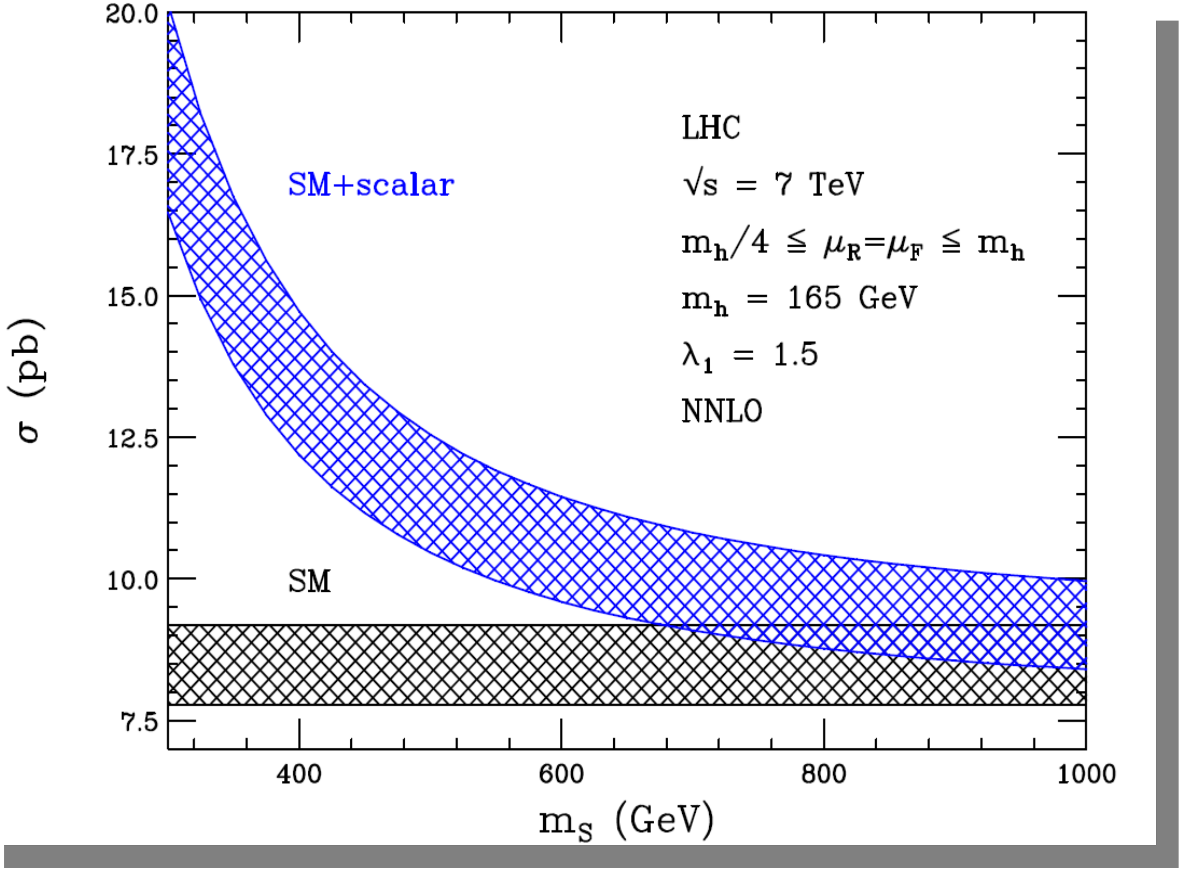
Only at NNLO a precise prediction is obtained → need NNLO for the indirect searches !

Using Tevatron data

Preliminary



LHC



20.0
17.5
15.0
12.5
10.0
7.5
400
600
800
1000
σ (pb)
m_S (GeV)
SM+scalar
SM
LHC
√s = 7 TeV
m_h/4 ≦ μ_R=μ_F ≦ m_h
m_h = 165 GeV
λ_1 = 1.5
NNLO

Fourth generation effects in $gg \to H$

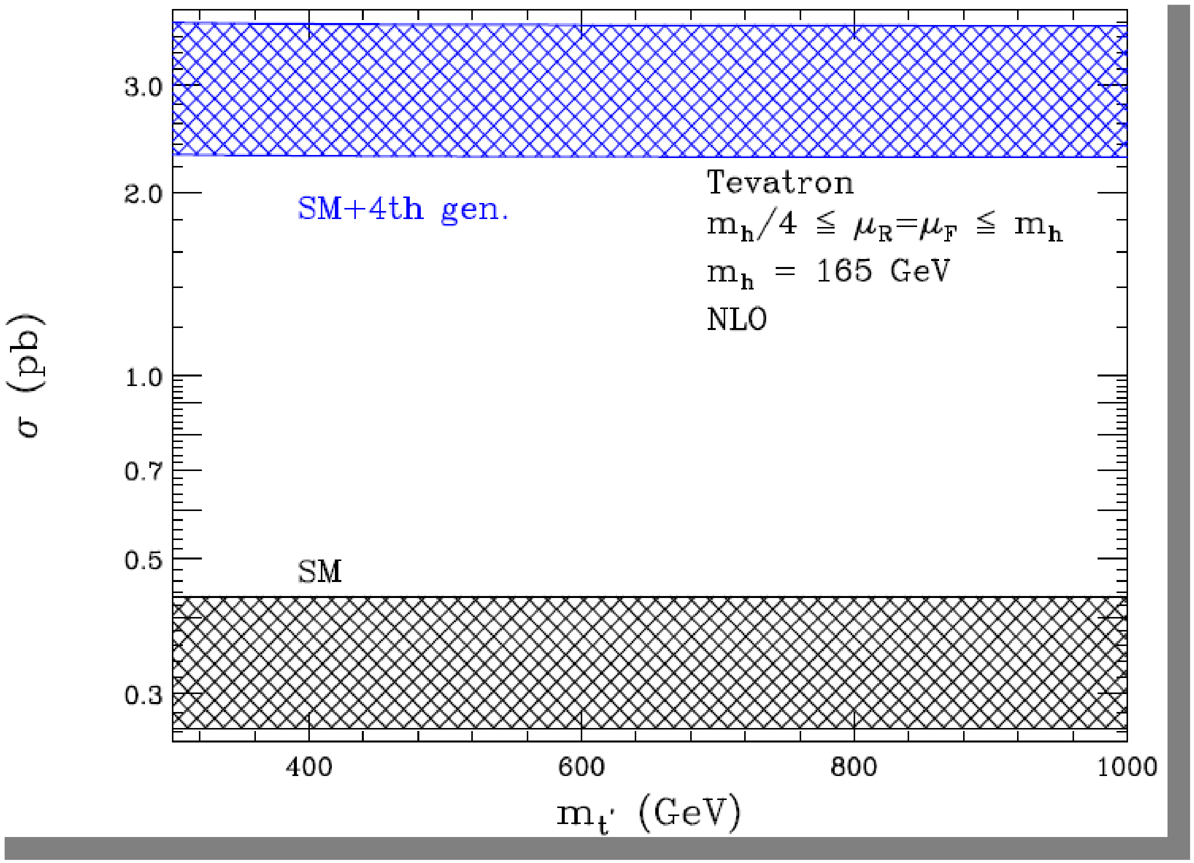
- An other experimental benchmark: fourth generation with masses larger than the SM 3 generations

  - a natural extension to the SM that can be tested with Higgs boson searches at the Tevatron
  - Precision measurements of Z boson decay width (LEP, SLD,...) excluded models with neutrino mass eigenstate less than 45GeV. A heavier fourth generation is not yet excluded

- Consider QCD corrections to $gg \to H$ using a heavy doublet of quarks (T', B') in addition to the usual QCD particles

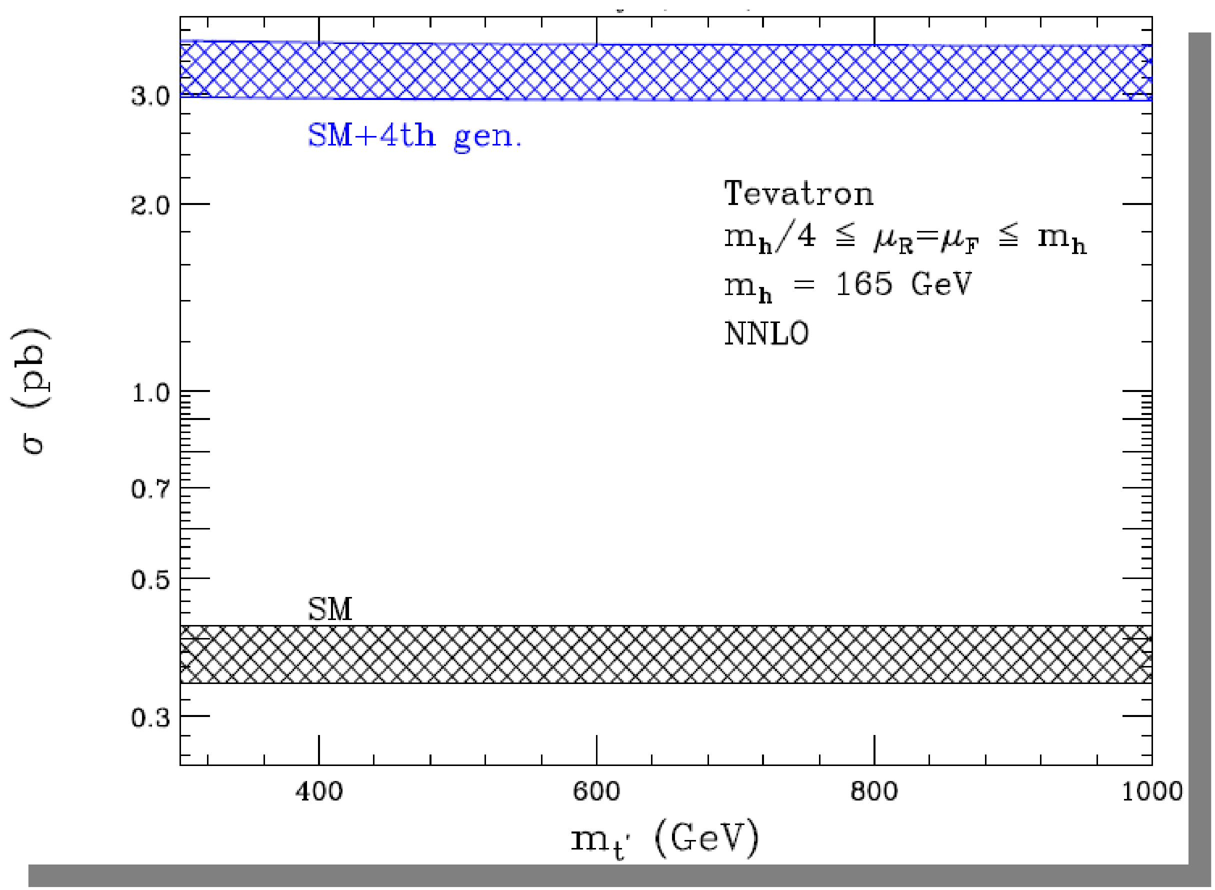
Fourth generation effects in gg → H : NLO @ Tevatron

Effect for mT′=mB′



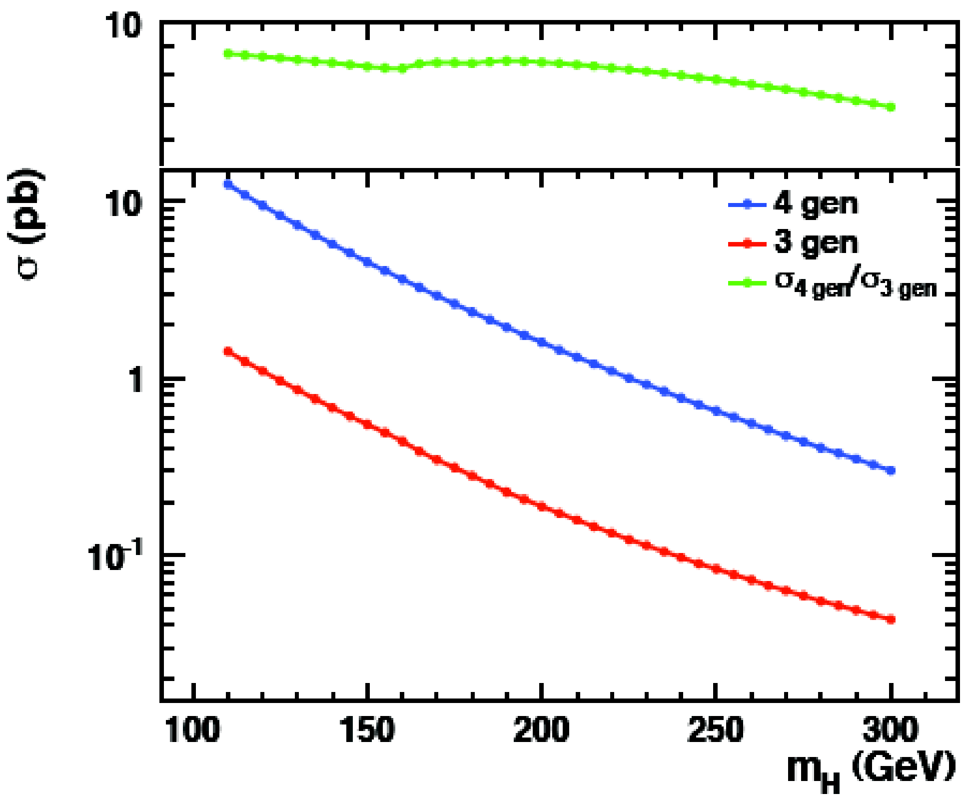
Fourth generation effects in gg → H : NNLO @ Tevatron

Effect for mT'=mB'



Only at NNLO the theoretical uncertainty is significantly reduced

Higgs production cross section



$$m_T - m_B = 50\,\mathrm{GeV} + 10\log\left(\frac{m_H}{115\,\mathrm{GeV}}\right)\,\mathrm{GeV}$$

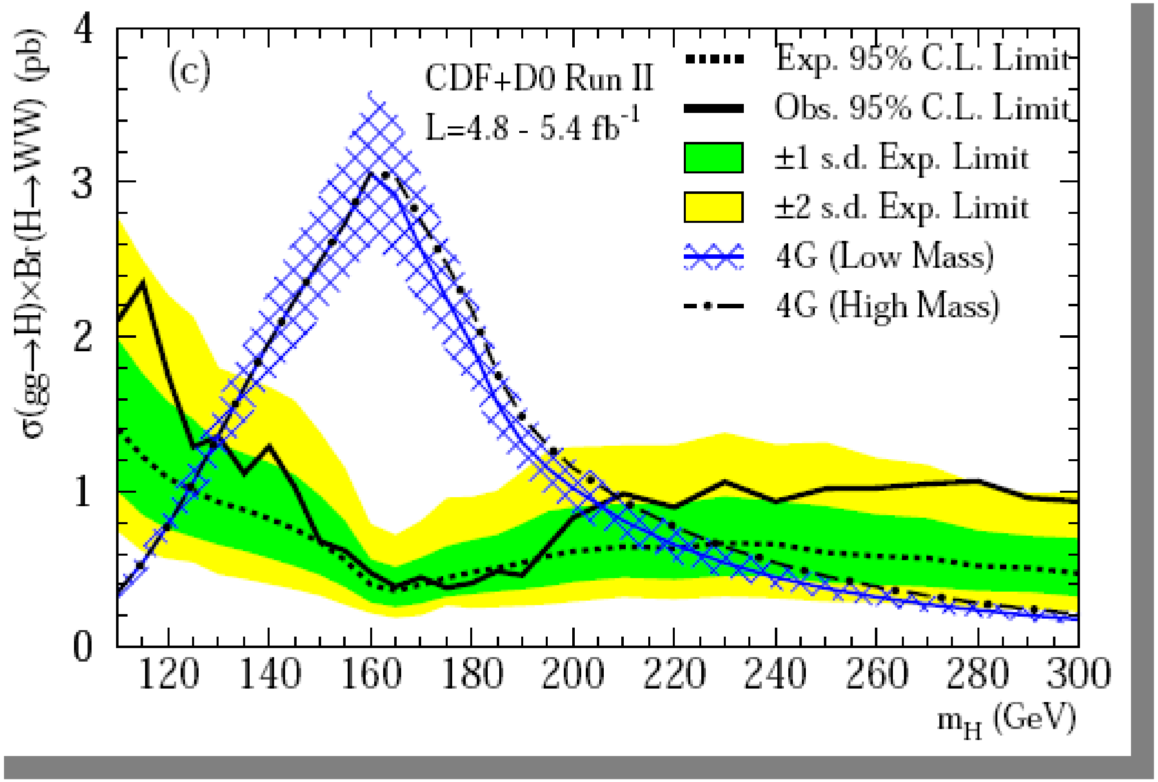
Permitted by constraints from EW precision tests

Plot for mB=400GeV

- Enhancement over the SM production cross section varies between 7 and 9 depending on mH
- Our result is used by the Tevatron collaborations in their new constraints on mH

New Tevatron exclusion

arXiv:1005.3216: CDF & D0 collaborations



Assuming the existence of a 4th generation of fermions with large masses, a SM-like Higgs boson in the mass range 131-204 GeV is excluded

Summary

- New physics that affects the observation of the Higgs boson is a priority to study

→ Need BSM predictions with the a precision that matches the experimental accuracy

- provided NNLO predictions for two classes of extensions to the SM using $gg \to H$

colored adjoint scalars and a fourth generation of quarks

- deviations from SM cross section are large enough to allow their exclusion within the Tevatron and LHC reach or their use to set limits on mH

Backup slides

Deviations of 4th generation xsection from SM

$$\Delta^{SM} = 100\frac{\sigma^{NNLO;(t,B,T)} - 9\sigma^{NNLO;(t)}}{9\sigma^{NNLO;(t)}}$$

m_H(GeV)	$\sigma_{(1)}(fb)$	$\Delta^{SM}_{(1)}\%$	$\sigma_{(2)}(fb)$	$\Delta^{SM}_{(2)}\%$	$\frac{\delta\sigma}{\sigma}(\text{pdf}+\alpha_s)\%$	$\frac{\delta\sigma}{\sigma}(\text{scale})\%$
110	12384	-2.4 %	12308	-2.9 %	+12% , −11%	+12% , −8%
115	10798	-3.0 %	10725	-3.5 %	+12% , −11%	+12% , −8%
120	9449.9	-3.6 %	9384.3	-4.1 %	+12% , −11%	+12% , −8%
125	8298.8	-4.2 %	8240.0	-4.8 %	+12% , −12%	+12% , −8%
130	7314.0	-4.8 %	7258.7	-5.5 %	+12% , −12%	+12% , −8%
135	6465.1	-5.5 %	6414.2	-6.1 %	+12% , −12%	+12% , −8%
140	5731.4	-6.1 %	5684.1	-6.8 %	+13% , −12%	+12% , −8%
145	5094.6	-6.8 %	5050.4	-7.5 %	+13% , −12%	+12% , −8%
150	4540.5	-7.4 %	4498.5	-8.2 %	+13% , −12%	+12% , −8%
155	4055.6	-8.1 %	4017.6	-8.9 %	+13% , −12%	+12% , −8%
160	3630.2	-8.1 %	3595.1	-8.9 %	+13% , −13%	+12% , −8%
165	3253.7	-6.3 %	3220.7	-7.2 %	+14% , −13%	+12% , −8%
170	2924.1	-5.7 %	2893.2	-6.7 %	+14% , −13%	+12% , −8%
175	2633.9	-5.8 %	2604.4	-6.8 %	+14% , −13%	+12% , −8%
180	2376.7	-5.9 %	2348.9	-6.9 %	+14% , −13%	+12% , −8%
185	2147.2	-5.1 %	2121.5	-6.2 %	+15% , −13%	+12% , −8%
190	1943.9	-4.7 %	1919.7	-5.9 %	+15% , −14%	+12% , −8%
195	1763.2	-4.9 %	1740.2	-6.1 %	+15% , −14%	+12% , −8%
200	1601.8	-5.2 %	1580.0	-6.5 %	+15% , −14%	+12% , −8%
205	1457.5	-5.6 %	1436.7	-7.0 %	+16% , −14%	+12% , −8%
210	1328.1	-6.1 %	1308.4	-7.5 %	+16% , −14%	+12% , −8%
215	1212.0	-6.7 %	1193.2	-8.1 %	+16% , −14%	+12% , −8%
220	1107.7	-7.3 %	1089.6	-8.8 %	+16% , −15%	+12% , −8%
225	1013.6	-7.9 %	996.33	-9.5 %	+17% , −15%	+12% , −8%
230	928.61	-8.6 %	912.21	-10 %	+17% , −15%	+12% , −8%
235	852.00	-9.3 %	836.33	-11 %	+17% , −15%	+12% , −8%
240	782.52	-10 %	767.44	-12 %	+17% , −15%	+12% , −8%
245	719.64	-11 %	705.19	-13 %	+18% , −15%	+12% , −8%
250	662.60	-11 %	648.81	-13 %	+18% , −16%	+12% , −8%
255	610.74	-12 %	597.51	-14 %	+18% , −16%	+12% , −8%
260	563.53	-13 %	550.90	-15 %	+19% , −16%	+12% , −8%
265	520.60	-14 %	508.52	-16 %	+19% , −16%	+12% , −8%
270	481.49	-15 %	469.93	-17 %	+19% , −16%	+12% , −8%
275	445.86	-16 %	434.72	-18 %	+20% , −16%	+12% , −8%
280	413.24	-17 %	402.68	-19 %	+20% , −17%	+12% , −8%
285	383.56	-18 %	373.28	-20 %	+20% , −17%	+12% , −8%
290	356.39	-19 %	346.53	-21 %	+21% , −17%	+12% , −8%
295	331.53	-20 %	322.04	-22 %	+21% , −17%	+12% , −8%
300	308.70	-21 %	299.71	-23 %	+21% , −17%	+12% , −8%

Table 1: The NNLO cross-section for Higgs production via gluon fusion at the TEVATRON. $\sigma_($ corresponds to $m_B = 300$GeV and $\sigma_{(2)}$ to $m_B = 400$GeV. The mass of the fourth generation u quark is given by Eq. (5.1). The percent difference from the Standard Model result $\Delta^{SM}_{(i)}$ define in Eq. (5.5) is also presented.