NLO QCD corrections to $Wb\bar{b}$ production at the Tevatron

Fernando Febres Cordero

LoopFest V, SLAC, June 2006

- Motivations (Tevatron searches of Light Higgs and Single Top)
- Calculation (Virtual and Real pieces with $m_b \neq 0$)
- Results (theoretical uncertainties, $m_{b\bar{b}}$ distributions)
- Impact of non-zero bottom quark mass
- Summary

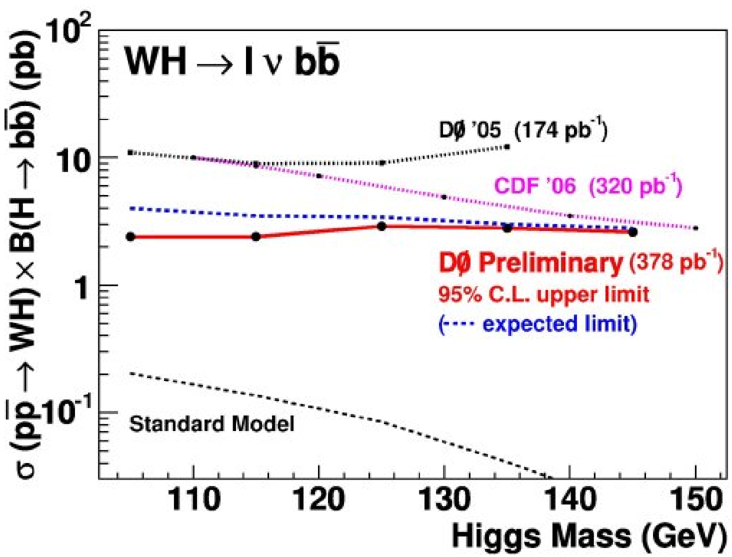
in collaboration with [hep-ph/0606102]

Laura Reina and Doreen Wackeroth

Two important challenges at the Tevatron $p\bar{p}$ collider

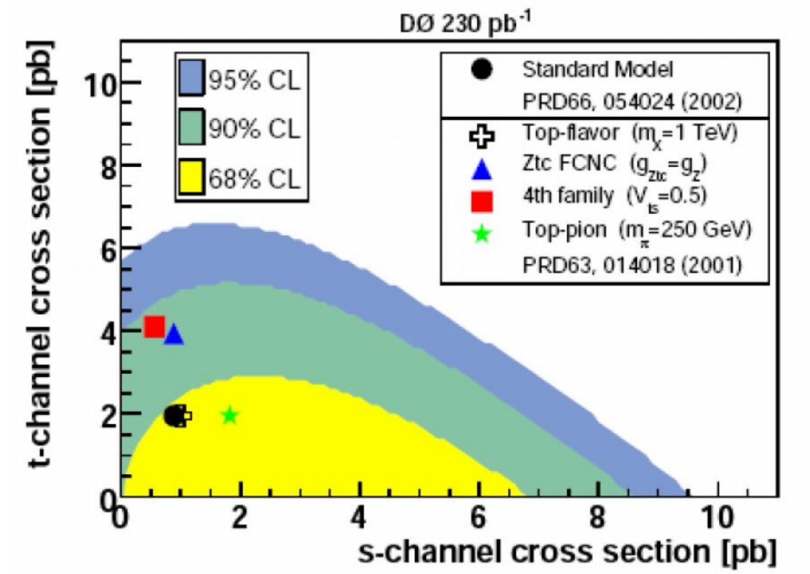
Around 1.5 fb^{-1} total integrated luminosity accumulated (up to 0.1 fb^{-1} per week at the end of Run II)

Light Higgs Boson Searches



March 2006 Results by DZero and CDF collaborations

Single Top Production



Presented at PHENO 2006 by DZero collaboration

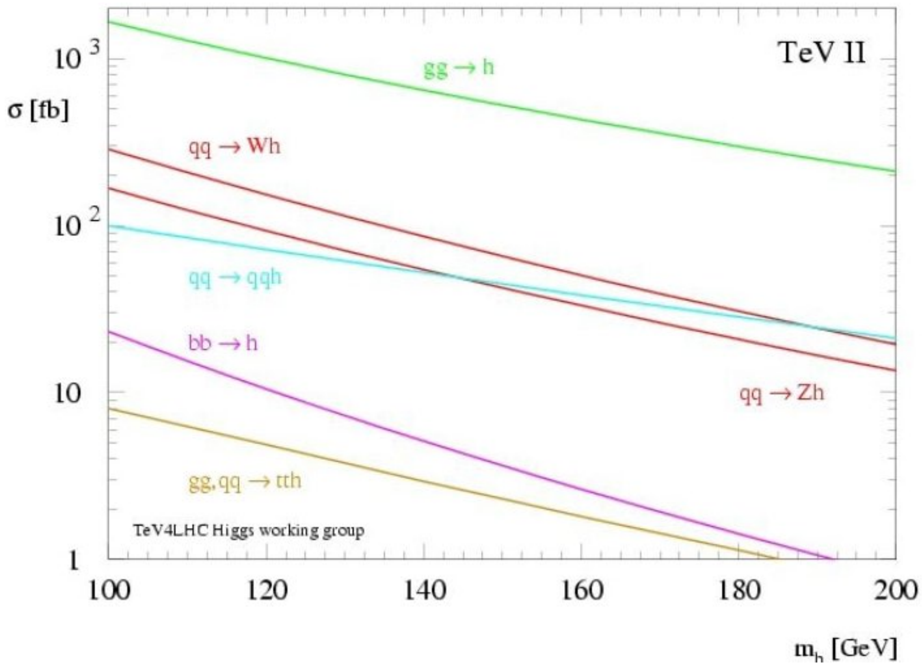
⟶ Constraints on cross section of associated production of a SM Higgs and W still far from expected value. Single Top production close to observation!

⟶ QCD $Wb\bar{b}$ production main background for both processes

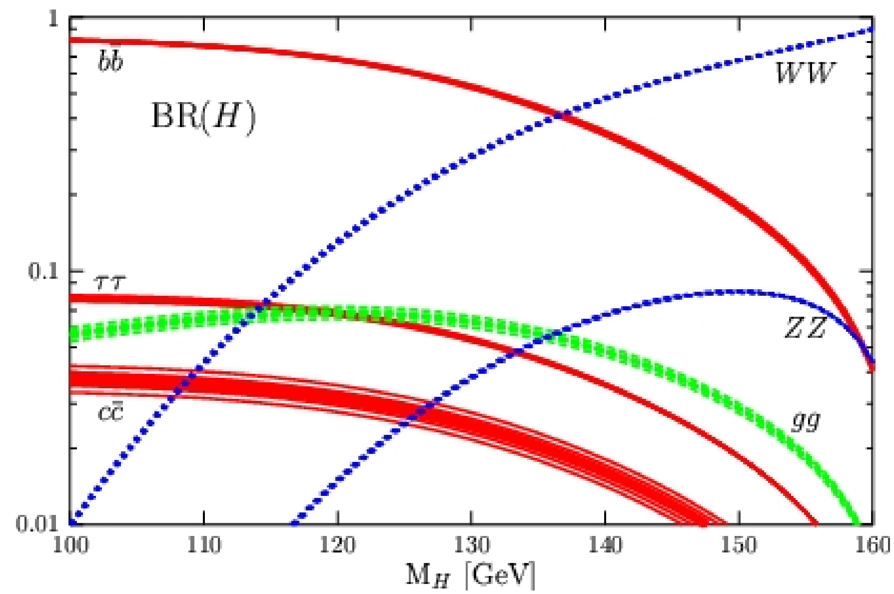
⟶ LHC planned to start operation by late 2007. Tevatron searches will complement the LHC search for a light SM Higgs, specially in the low mass range.

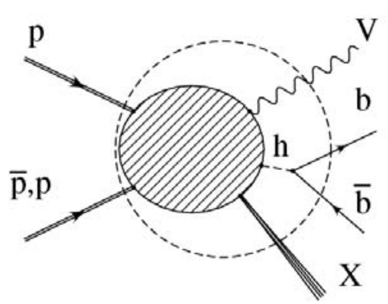
Associated production of SM Higgs with weak vector bosons

→ Cross sections for SM Higgs production @ Tevatron



→ SM Higgs decay branching ratios



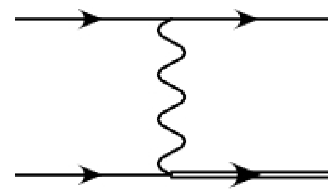


⟶ NNLO QCD corrections have been calculated for the signal [O.Brien, A.Djouadi and R.Harlander, 2004]

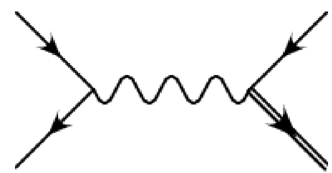
⟶ $O(\alpha)$ EW corrections have been calculated for the signal [M.L.Ciccolini, S.Dittmaier and M.Kramer, 2003]

SM Single Top production

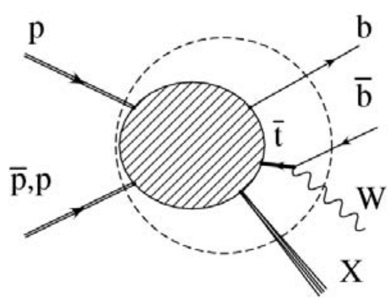
LO diagrams for s and t channels (with $t \to Wb$ almost 100% in the SM):



(a)



(b)



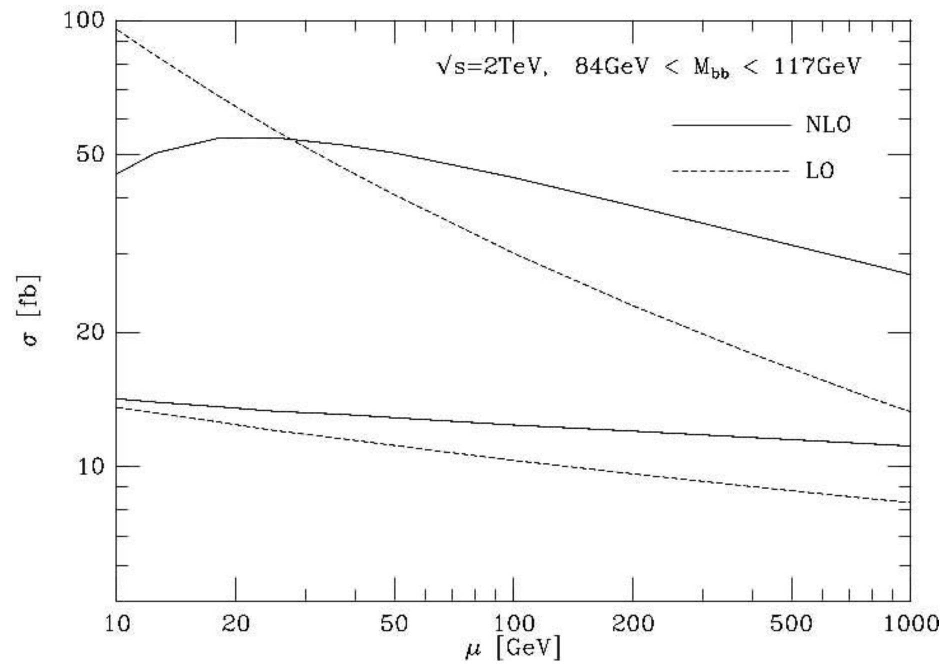
$\longrightarrow$ NLO QCD corrections have been thoroughly studied [T.Stelzer, Z.Sullivan and S.Willenbrock, 1998; B.W.Harris, E.Laenen, L.Phaf, Z.Sullivan and S.Weinzierl, 2002; ...]

$\longrightarrow$ NLO EW corrections have been calculated for the (SM and MSSM) signal [M.Beccaria, G.Macorini, F.M.Renard and C.Verzegnassi, 2006]

$Wb\bar{b}$ production most important background for s-channel Single Top production, but also for t-channel background when one b-jet is mistagged.

$Wb\bar{b}$ production

- NLO calculation in $m_b = 0$ approximation available in MCFM [J.Campbell and R.K.Ellis]: [R.K.Ellis and S.Veseli, 1998]



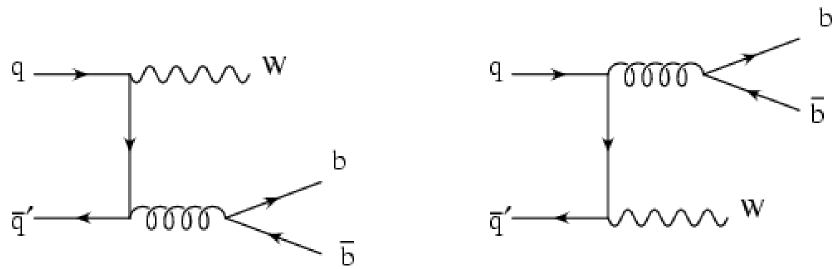
$\longrightarrow$ Kinematical cuts were imposed in the massless approximation in order to simulate mass effects:

- $p^T_{b,\bar{b}} > m_b$,
- $(p_b + p_{\bar{b}})^2 > 4m_b^2$.

$\longrightarrow$ Error on the differential cross section from $m_b = 0$ approximation expected to be small ($\sim 10\%$ from LO estimates), is difficult to quantify due to non trivial contribution of m_b coming from phase space and matrix elements.

NLO calculation of $Wb\bar{b}$ production with full m_b effects

LO Feynman diagrams:



On-shell W

α_s corrections to $d\sigma$:

$\longrightarrow$ Virtual diagrams interfered with born

$\longrightarrow$ Real emission of extra parton

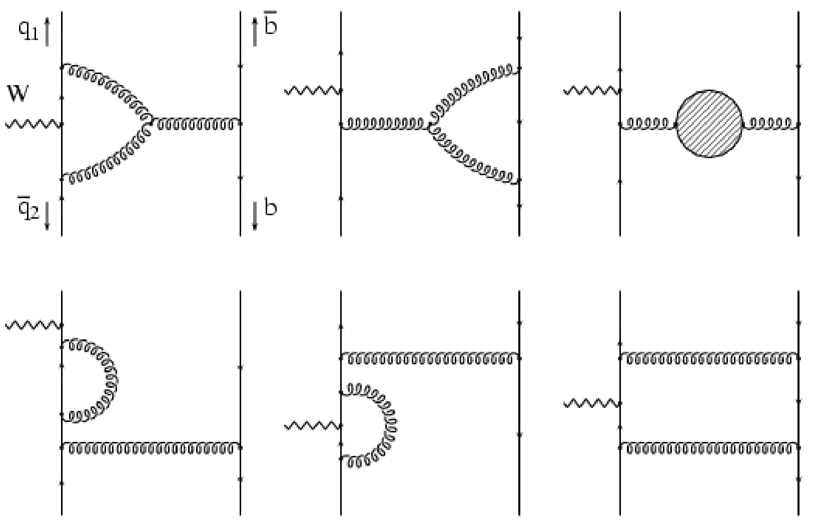
$\longrightarrow$ For the Wqq' vertex we take the following CKM matrix elements: $V_{ud} = V_{cs} = 0.975$ and $V_{us} = V_{cd} = 0.222$, while neglect contribution of the third generation (suppressed by corresponding PDFs or CKM matrix elements).

$\longrightarrow$ PDF: for LO results we use 1-loop evolution of α_s and CTEQ6L, while for NLO results 2-loop evolution of α_s and CTEQ6M.

$\longrightarrow$ Mass Values: We use for the weak boson $M_W = 81.410$ GeV, a fixed bottom-quark mass $m_b = 4.62$ GeV and fixed top-quark mass $m_t = 174$ GeV (entering through virtual corrections).

Virtual corrections

Sample of loop diagrams:



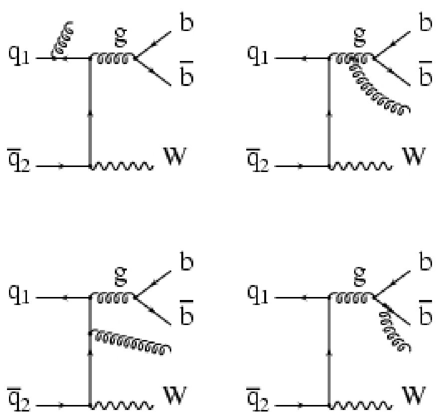
- We use dimensional regularization and $\overline{MS}$ renormalization scheme.
- Tensor integrals reduced analytically to scalar integrals and organized to avoid spurious divergences.
- Scalar integrals dealt with standard techniques; two massive boxes not in the literature were calculated explicitly.

- After introducing counterterms we obtain UV finite amplitudes.
- Remaining divergences, of IR nature, are proportional to the Born and cancel with Real part after convoluting with renormalized PDFs.
- Finite pieces finally are interfered with the Born amplitude.

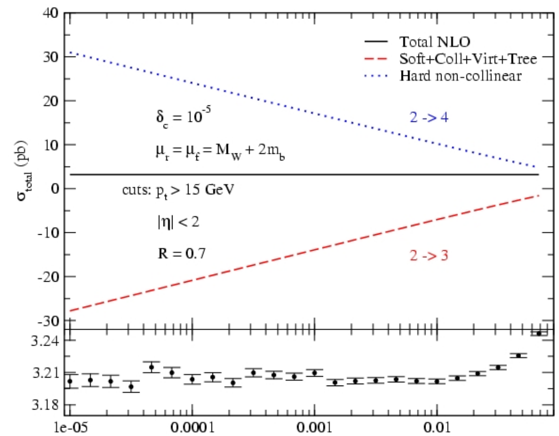
Real corrections

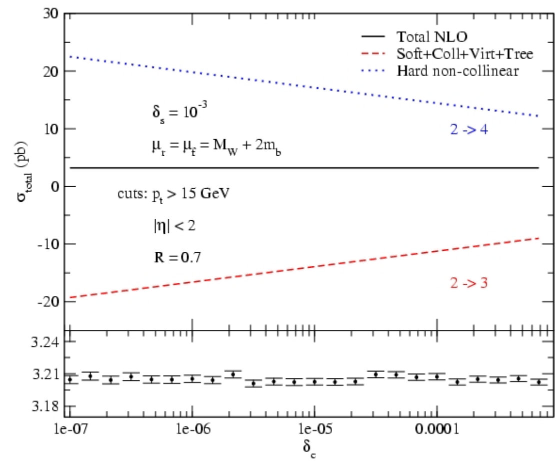
⟶ Phase Space Slicing (PSS) used to extract IR divergences: we checked independence of final result of δ_s and δ_c.

Sample of diagrams with extra parton:



$q\bar{q}' \to Wb\bar{b}g$ and $qg \to Wb\bar{b}q'$ contributions





⟶ After convoluting the virtual plus real contributions with the renormalized PDFs, IR divergences cancel.

Jet Algorithm

Having a fully differential cross section allows to implement any experimental cut to calculate total cross sections and distributions. We have produced data for the Tevatron ($\sqrt{s} = 1.96$ TeV) using the k_T jet algorithm with pseudo-cone size $R = 0.7$.

This allows to study the following phenomenological cases:

$\longrightarrow$ Inclusive Cross Section: Events with two $(b + \bar{b})$ or three $(b + \bar{b} + j)$ jets resolved contribute to the cross section.

$\longrightarrow$ Exclusive Cross Section: Only events with two $(b + \bar{b})$ jets resolved contribute to the cross section.

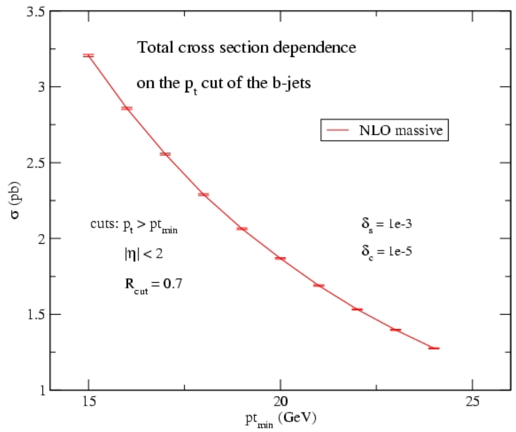
This is the same convention used by MCFM (all following massless results have been obtained using this program).

Experimental Cuts

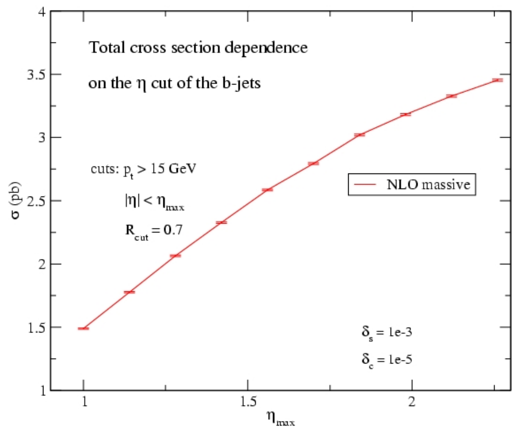
We also apply the following experimental cuts:

- Transverse momentum of the b-jets: $p_t > p_{t\ min}$ (15 GeV) for both b and $\bar{b}$ jets.
- Pseudorapidity: $|\eta| < \eta_{max}$ (2) for both b and $\bar{b}$ jets.
- We require both b-jets are tagged.
- If a jet passes p_t and η cuts we say it's resolved.

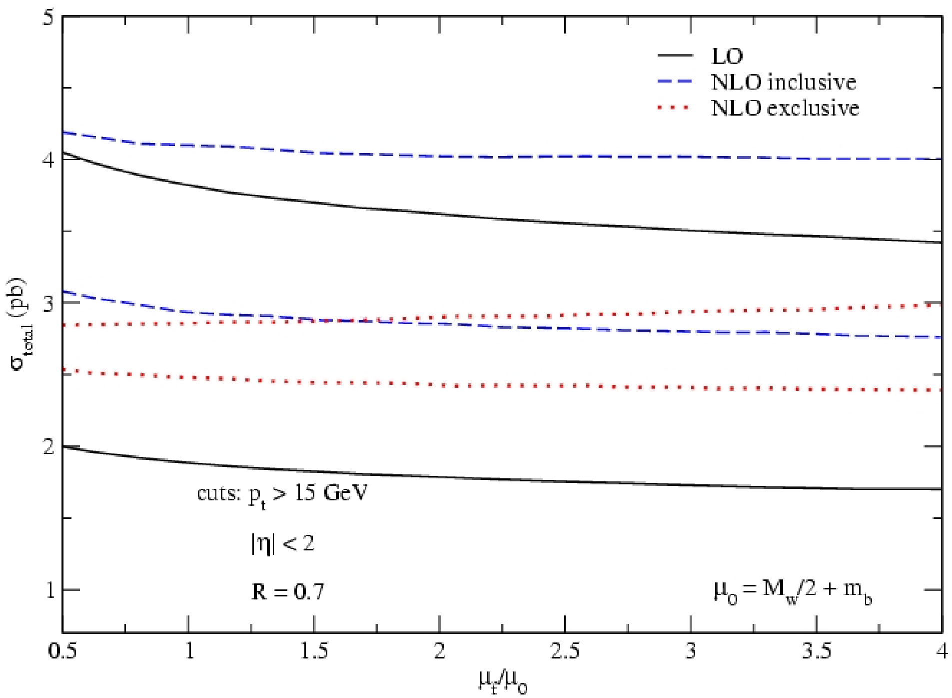
p_t cut impact (inclusive case):



η cut impact (inclusive case):



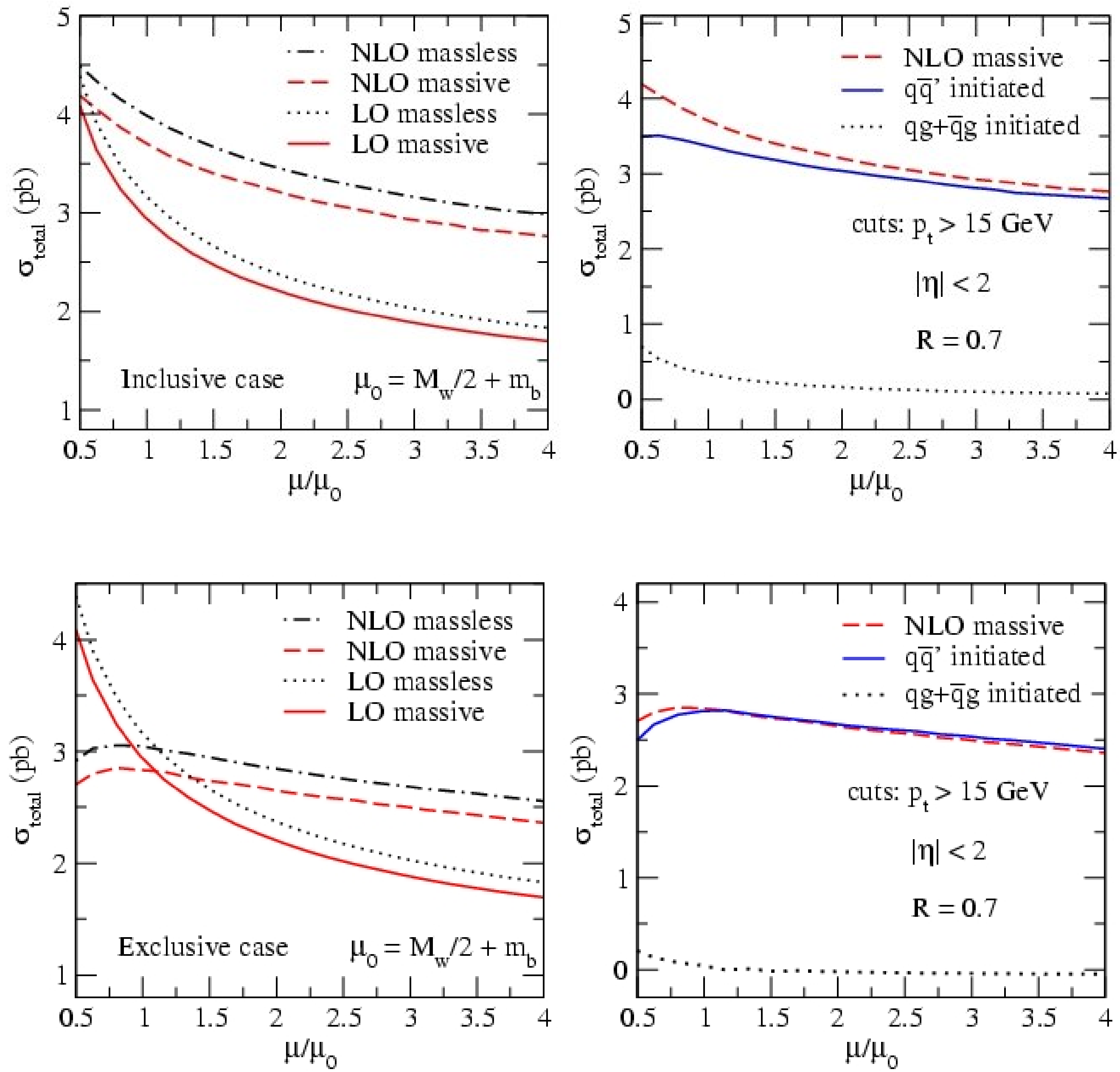
Scale Dependence and Theoretical Uncertainty



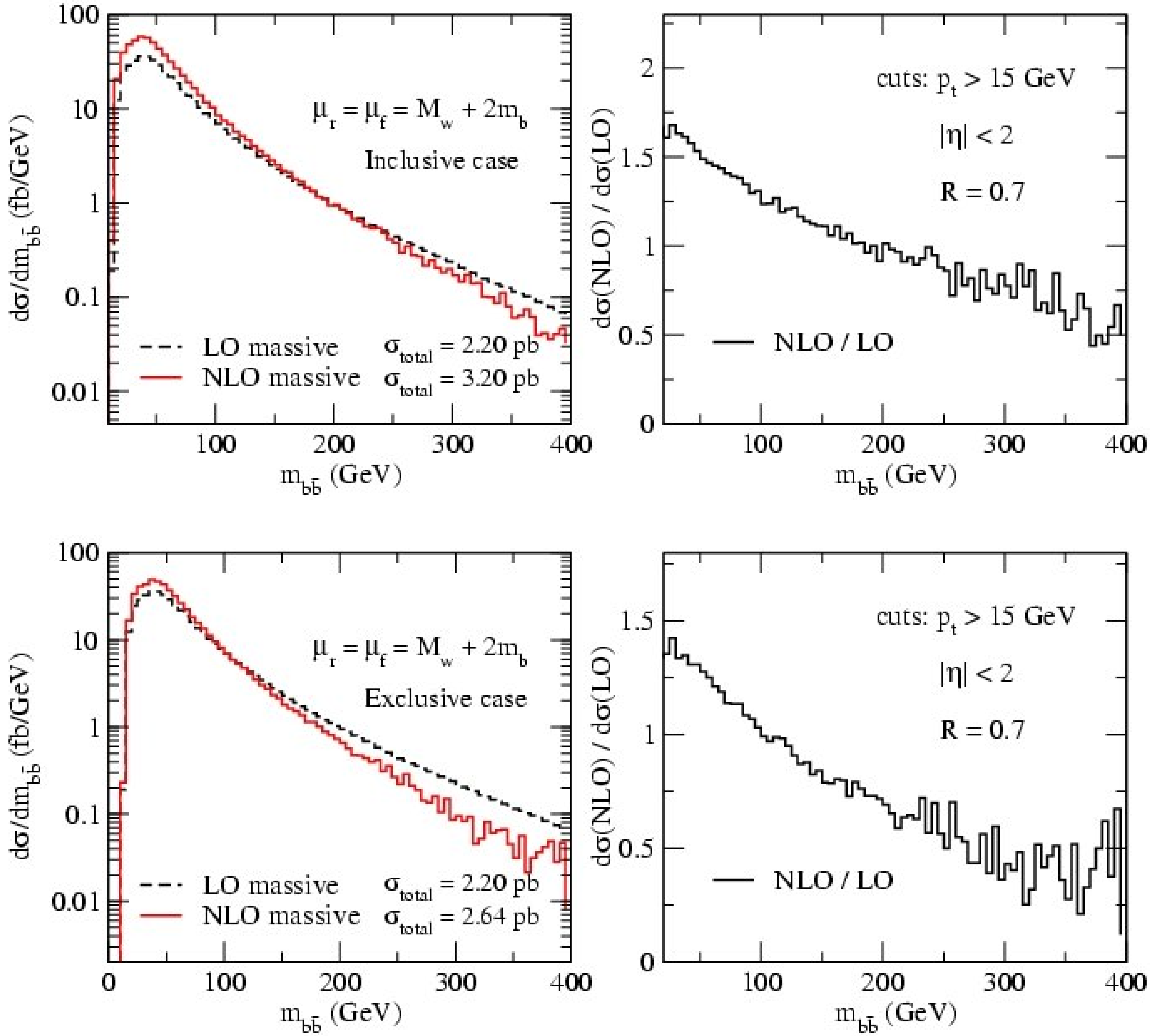
⟶ Bands obtained by varying both μ_R and μ_F between $\mu_0/2$ and $4\mu_0$ (with $\mu_0 = m_b + M_W/2$).

- LO uncertainty $\sim 40\%$.
- Inclusive NLO uncertainty $\sim 20\%$.
- Exclusive NLO uncertainty $\sim 10\%$.

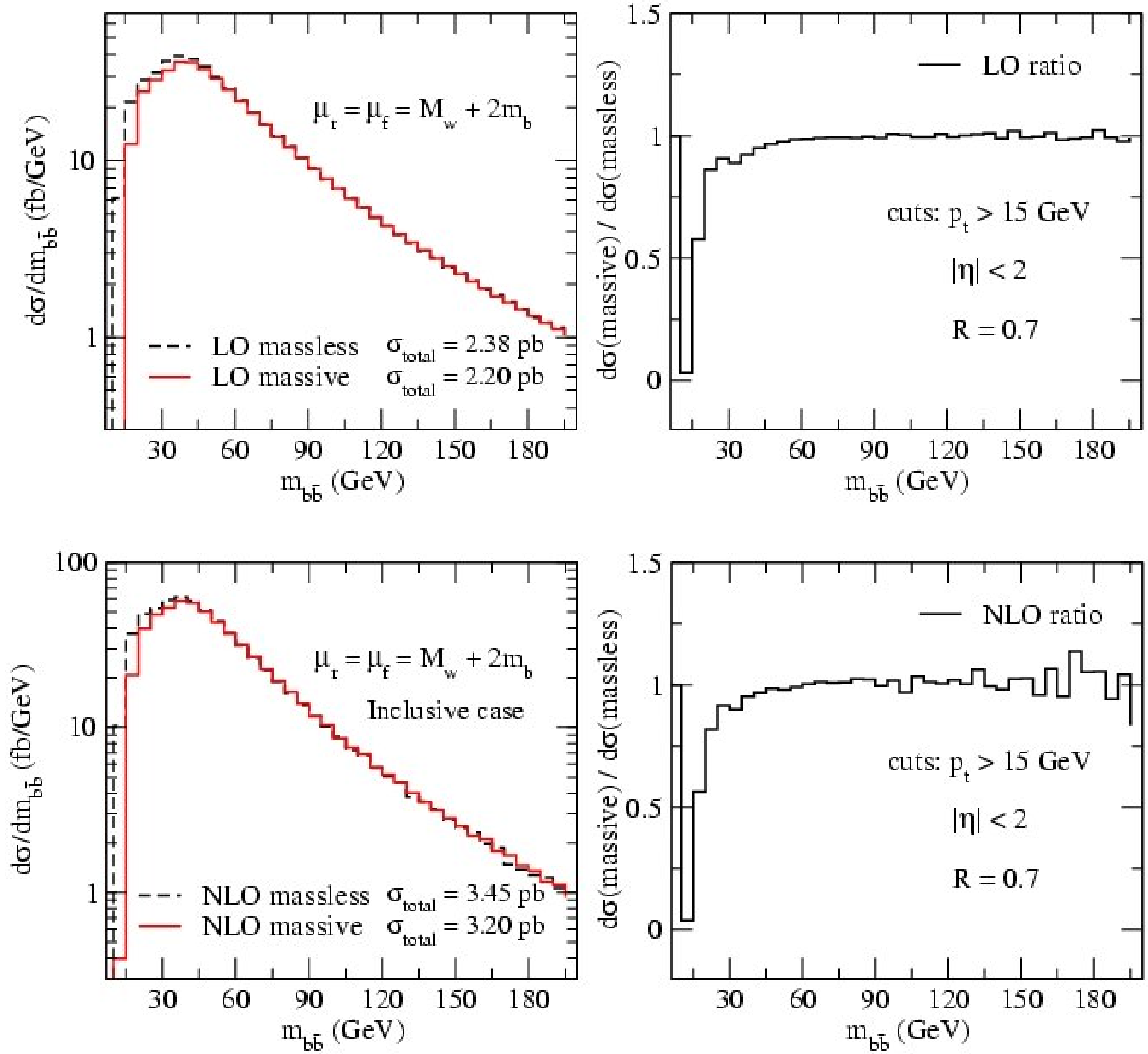
Scale Dependence for massive and massless calculations



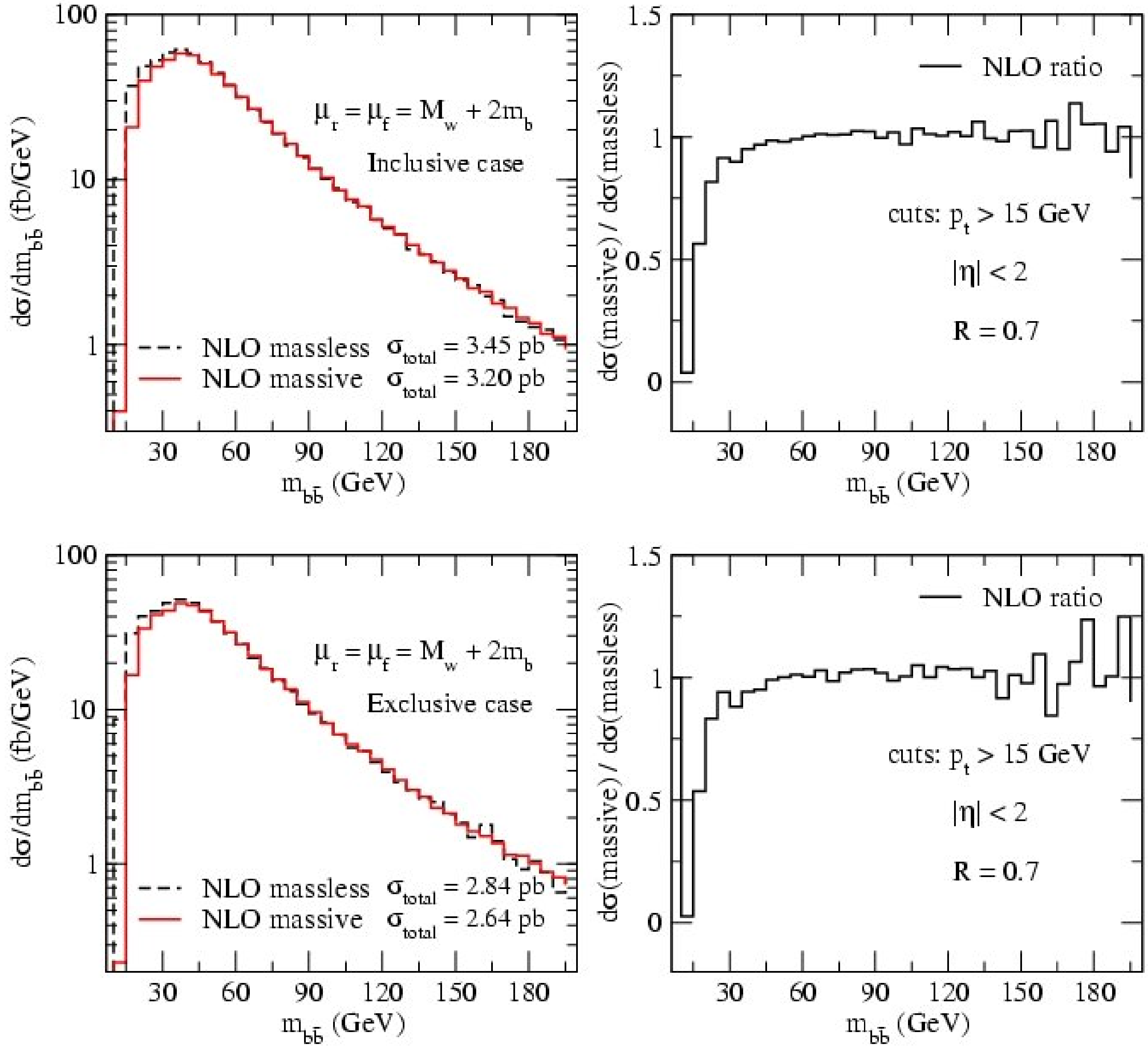
$m_{b\bar{b}}$ distributions: LO-NLO comparison



$m_{b\bar{b}}$ distributions: massive-massless comparison



$m_{b\bar{b}}$ distributions: massive-massless comparison (cont.)



Summary

- We have calculated the NLO QCD radiative corrections to the production of a W with two massive b-jets.

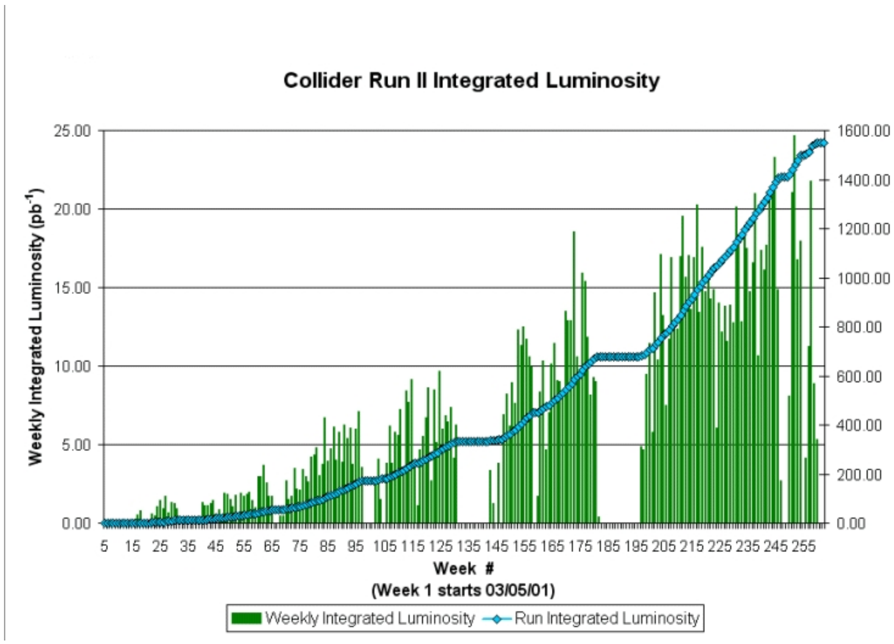
- We observe considerable reduction of the theoretical uncertainty on the total cross section with respect to the LO calculation, allowing for better predictions of backgrounds to important processes like vector boson associated Higgs production and Single Top production.

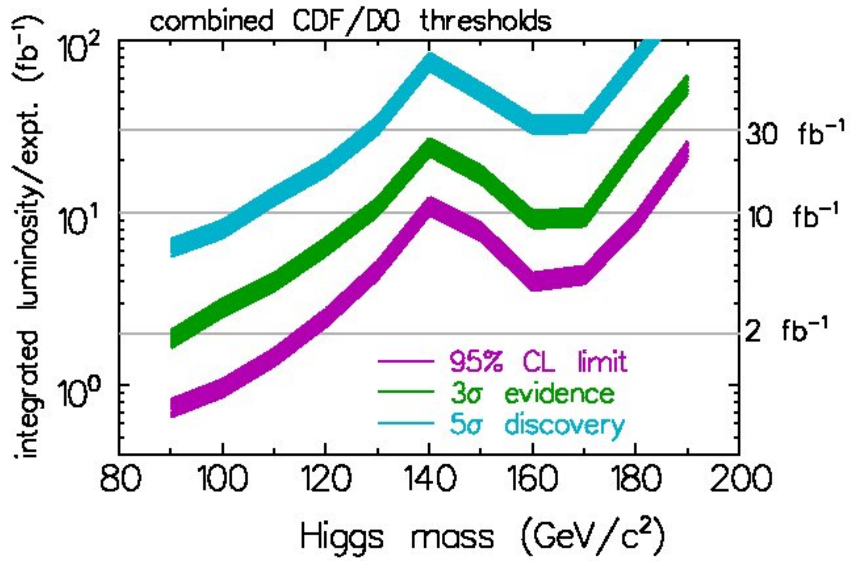
- Mass effects reduce by $\sim 8\%$ the total cross section, affecting mostly the low invariant mass region of the $b - \bar{b}$ pair (below ~ 60 GeV).

- Given the variety of experimental analyses involved both in the search of HW associated production and Single Top production, it is important to assess the impact of m_b over the entire kinematical reach of the process, including complete NLO QCD corrections.

- We are working to produce the $Z + b\bar{b}$ counterpart of this calculation.

Back up slide - Tevatron Higgs searches





Back up slide - LHC Higgs searches