Backgrounds to Tevatron Higgs production

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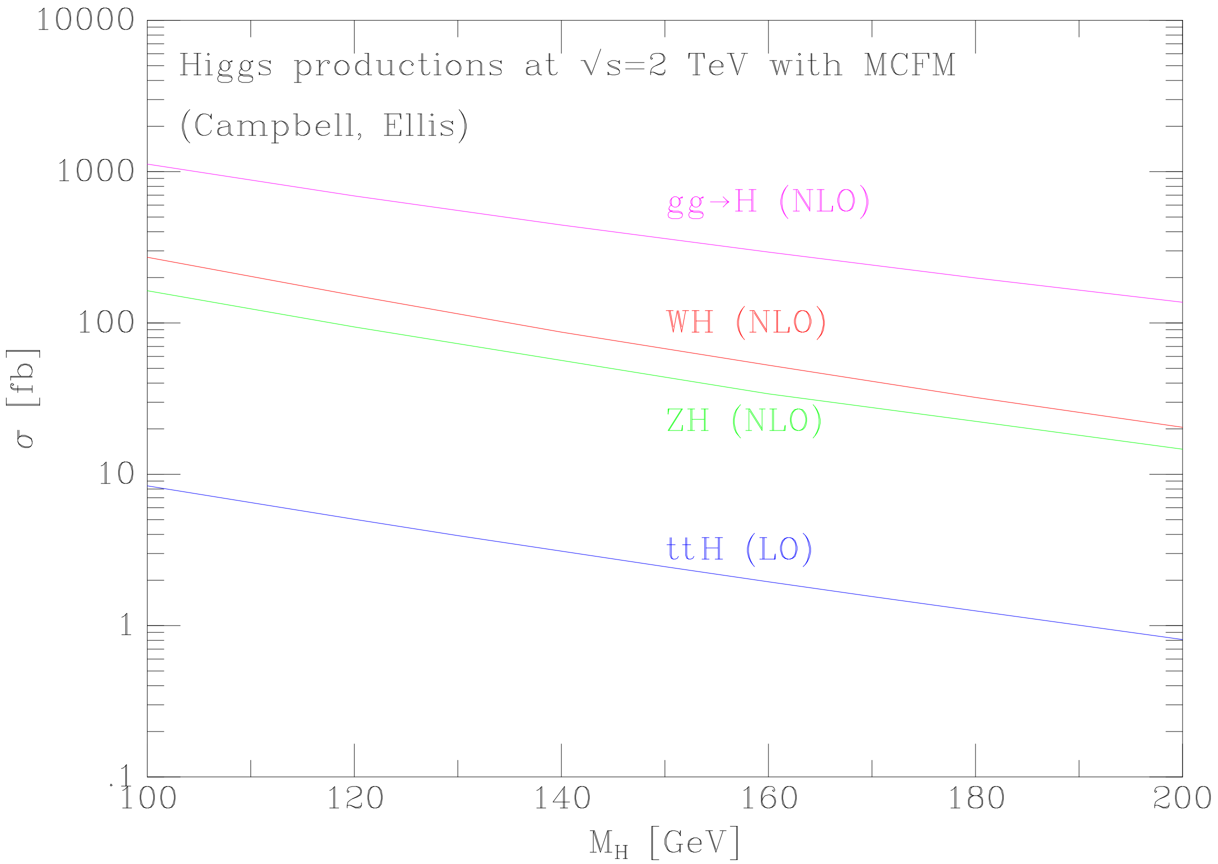
Higgs production at 2 TeV

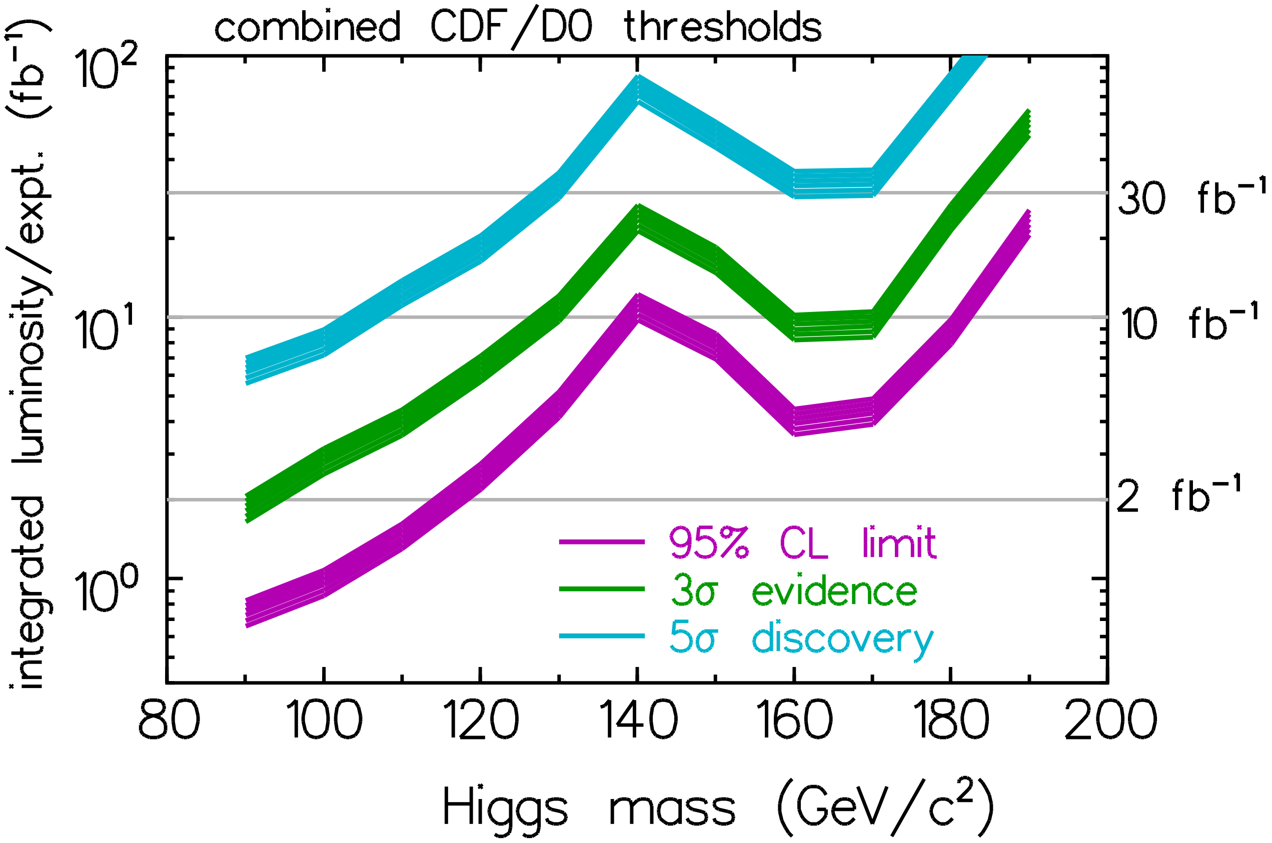


- Higgs cross sections are not so small at the Tevatron.
- Issue of background is crucial.
- This talk will consider SM physics backgrounds.

Scope of the talk

- Aim is to provide the most accurate NLO information on signals and backgrounds, so that relative rates and shapes of cross sections are predicted.
- NLO calculations only contain partial effects of parton showering. For the heavy objects considered here this may be a good approximation.
- No detector effects on backgrounds. So a full assessment of the Higgs reach will not be possible.
- These are preparatory studies which will inform the more complete analysis to be performed when the run II data becomes available.

Higgs working group results



- Does this contain the most accurate theoretical information?
- $t\bar{t}H$ not included (4.1σ effect for $M_H = 120$GeV and 15fb^{-1}/expt).

Synopsis of Talk

- Description of the NLO program MCFM.
- Backgrounds to WH production (low mass Higgs).
- Backgrounds to ZH production.(low mass Higgs)
- Backgrounds to l^+l^- +missing energy signature (high mass Higgs)
- No MCFM studies yet of $t\bar{t}H$ production, (largest background $t\bar{t}$ + 2 jets)

MCFM Philosophy

- The Tevatron Run II will be sensitive to processes at the femtobarn level.
- Particularly interesting are final states involving heavy quarks, leptons and missing energy.
- Standard model processes which result in these final states often include W, Z or Higgs. Data samples may not be large enough to determine SM backgrounds experimentally.
- MCFM aims to provide a unified description of such processes at NLO accuracy.
- The extension to NLO is made possible in many cases by the recent calculations of virtual matrix elements involving a vector boson and four partons.

MCFM Process List

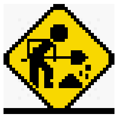
Included at NLO	
$p\bar{p} \to W^{\pm}/Z$	$p\bar{p} \to W^{+} + W^{-}$
$p\bar{p} \to W^{\pm} + Z$	$p\bar{p} \to Z + Z$
$p\bar{p} \to W^{\pm}/Z + H$	$p\bar{p} \to W^{\pm}/Z + 1$ jet
$p\bar{p} \to W^{\pm} + g^{\star}\,(\to b\bar{b})$	$p\bar{p} \to Z + b\bar{b}$

- Various leptonic and/or hadronic decays of the bosons are included as further sub-processes.
- Where applicable Z includes the Z/γ^* interference, (important e.g. for trilepton signatures).
- MCFM v1.0 may be downloaded from

`http://www-theory.fnal.gov/people/campbell/mcfm.html`

Processes included in MCFM at LO (including vector boson and top decays).

- $p\bar{p} \to t\bar{t}$
- $p\bar{p} \to t\bar{b}$ (single top production)
- $p\bar{p} \to qt\bar{b}$ (single top production, W gluon fusion)
- $p\bar{p} \to t\bar{t}H$

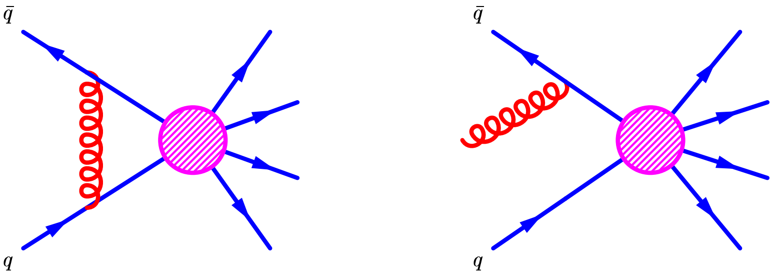


Processes which are under construction at NLO

- $p\bar{p} \to W^{\pm} + 2$ jet
- $p\bar{p} \to Z/\gamma^{*} + 2$ jet

Monte Carlo Ingredients - 1

- Helicity amplitudes for the virtual and real ME's

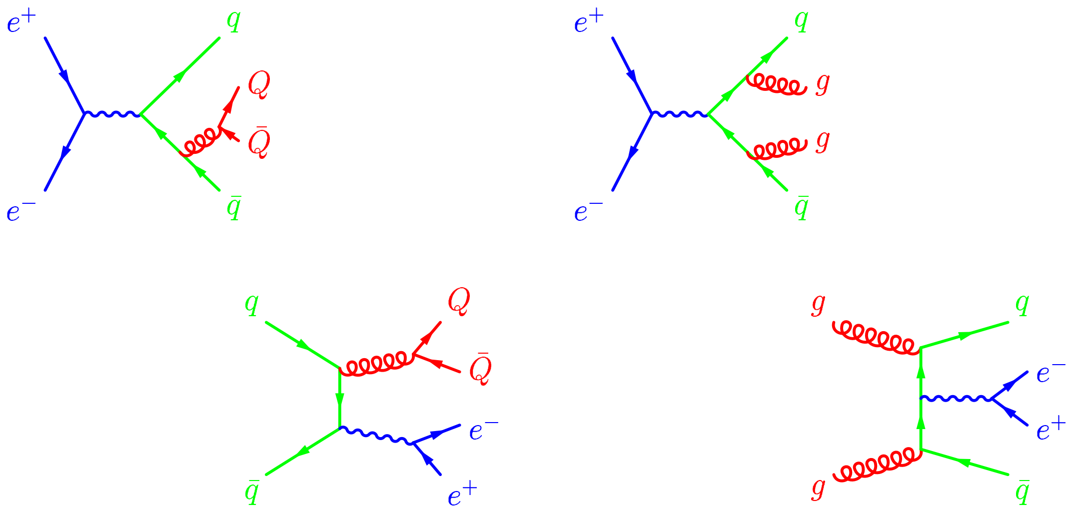


m-parton process

$(m+1)$-parton process

- Many of the NLO matrix elements are obtained by crossing the ones calculated for $e^+e^- \to 4$ jets.

Bern, Dixon, Kosower and Weinzierl, Nucl. Phys. **B489** (1997) 3
Glover and Miller, Phys. Lett. **B396** (1997) 257
Campbell, Glover and Miller, Phys. Lett. **B409** (1997) 503



Monte Carlo Ingredients - 2

- Singular pieces of the real matrix elements must be identified and cancelled by an appropriate set of counter-terms. ERT, Nucl.Phys.**B178** (1981) 421
- MCFM uses the dipole method to cancel the infrared divergences between real and virtual contributions.
  Catani and Seymour, Nucl. Phys. **B485** (1997) 291

$$\begin{aligned}\sigma^{m+1}_{real} &= \int_{(m+1)} (d\sigma_{real} - d\sigma_{counter}) + \int_{(m+1)} d\sigma_{counter} \\ &= (\text{integrable terms}) + \sum_{dipoles} \int_m d\sigma \otimes \int_1 dV_{dipole}\end{aligned}$$

where the 1-dimensional integral over the dipoles leads to soft and collinear divergences (poles in ϵ).

- These poles manifestly multiply m-parton ME's and may be cancelled against poles from the loop diagrams.

Higgs search using MCFM

- Studies using LO Monte Carlos and other event generators show that for a Higgs in the mass range of 100-130 GeV, the most promising channels for discovery at Run II are associated Higgs production.

Stange, Marciano, Willenbrock, Phys. Rev. **D49** (1994) 1354, **D50** (1994) 4491

$$p\bar{p} \longrightarrow W(\rightarrow e\nu)H(\rightarrow b\bar{b})$$

$$p\bar{p} \longrightarrow Z(\rightarrow \nu\bar{\nu}, \ell\bar{\ell})H(\rightarrow b\bar{b})$$

- Mass range interesting in the light of hints from SUSY.
- Backgrounds for the WH signal:

$$\begin{aligned} p\bar{p} &\longrightarrow W\, g^\star(\rightarrow b\bar{b}) \\ p\bar{p} &\longrightarrow W\, Z/\gamma^\star(\rightarrow b\bar{b}) \end{aligned}$$

$$\begin{aligned} p\bar{p} &\longrightarrow t(\rightarrow bW^+)\bar{t}(\rightarrow \bar{b}W^-) \\ p\bar{p} &\longrightarrow W^{\pm *}(t(\rightarrow bW^+)\bar{b}) \\ qg &\longrightarrow q't(\rightarrow bW^+)\bar{b} \end{aligned}$$

Cuts for a WH study

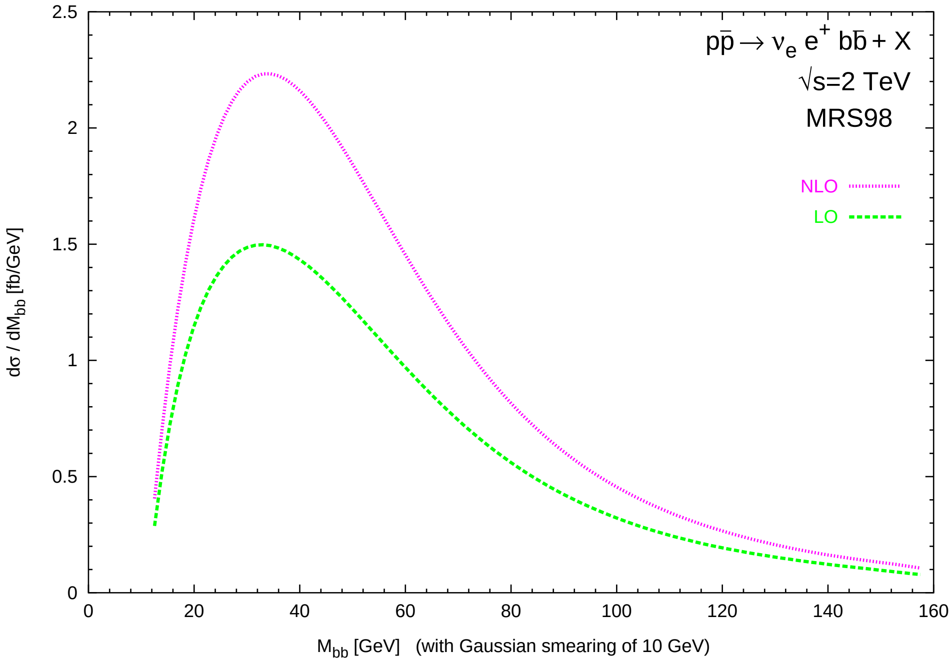
- Use a set of “standard” cuts from the literature

$$\begin{array}{rcl} |p_b^T|, |p_{\bar{b}}^T| & > & 15 \text{ GeV} \\ |y_b|, |y_{\bar{b}}| & < & 2\ , \\ |p_e^T|, |p_\nu^T| & > & 20 \text{ GeV} \\ |y_e| & < & 2.5\ , \\ |p_{jet}^T| & > & 20 \text{ GeV} \\ |y_{jet}| & < & 2\ , \\ R_{b\bar{b}}, R_{eb}, R_{e\bar{b}} & > & 0.7 \\ |\cos\theta_{b\bar{b}}| & < & 0.8 \end{array}$$

- $\theta_{b\bar{b}}$ is the scattering angle of the $b\bar{b}$ system in the Collins-Soper frame
- MRS98 parton distribution functions

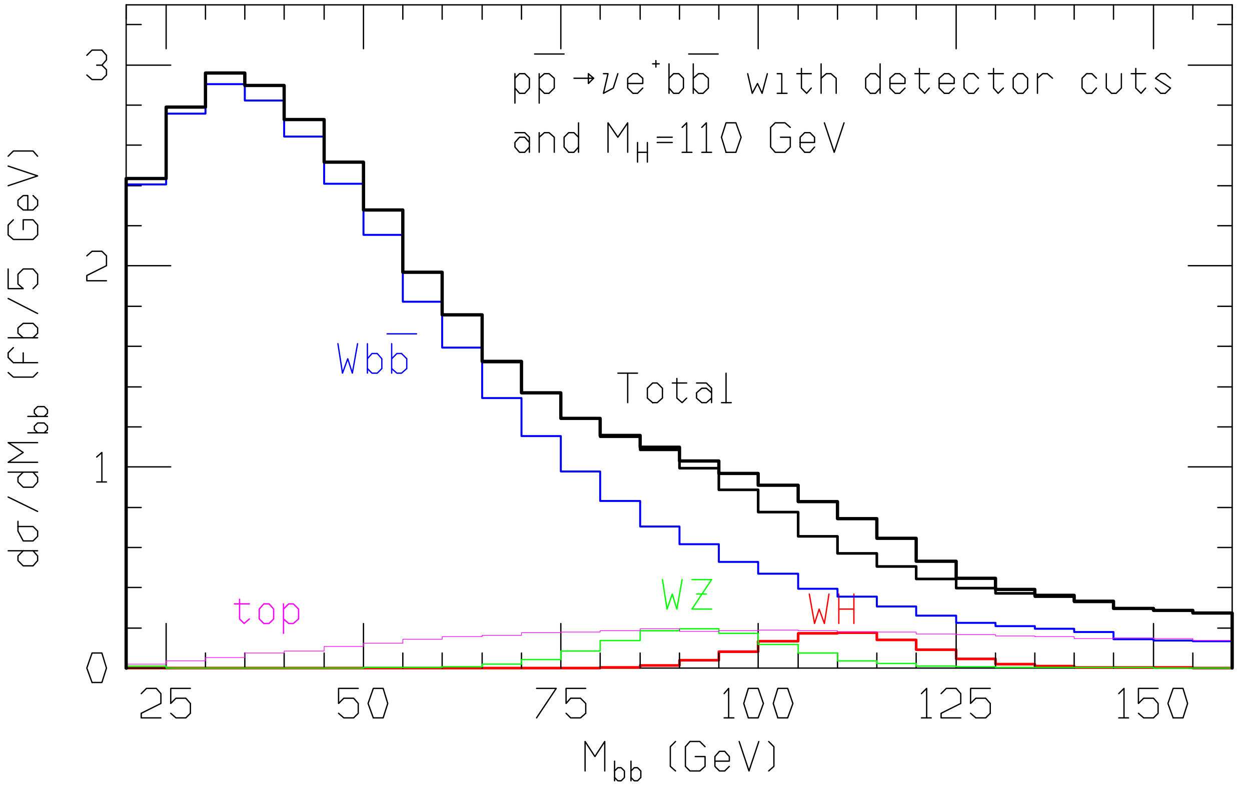
$m_{b\bar{b}}$ mass distribution

- Examine the $m_{b\bar{b}}$ mass distribution of the largest background at LO and NLO and a scale of 100 GeV



- We see that the actual shape changes very little and the K-factor is around 1.5

Signal and Backgrounds for $m_H = 110$ GeV



- Double b-tagging efficiency of $\epsilon_{b\bar{b}} = 0.45$
- We have to understand a cocktail of backgrounds, both in normalization and shape. ($WZ \equiv WH$).

Signal and backgrounds at 2 TeV

- We take a resolution of $\Delta = 0.1 \times m_H$ and integrate signal and background over the range

$$m_H - \sqrt{2}\Delta < m_{b\bar{b}} < m_H + \sqrt{2}\Delta$$

M_H [GeV]	100	110	120	130
$W^\pm H(\to b\bar{b})$	8.8	6.4	4.2	2.5
$W^\pm g^*(\to b\bar{b})$	22.9	20.3	16.8	14.2
$W^\pm Z(\to b\bar{b})$	6.7	4.3	2.0	1.0
$t(\to bW^+)\bar{t}(\to \bar{b}W^-)$	4.2	4.7	4.9	5.0
$W^{\pm *}(t(\to bW^+)\bar{b})$	5.3	6.0	6.2	6.2
$q' t(\to bW^+)$	3.1	3.2	2.9	2.6
Total B	42.1	38.5	32.9	28.8
S/B	0.21	0.17	0.13	0.09
$S/\sqrt{B}$	1.36	1.03	0.73	0.47

Conclusions on WH channel

- Tau-decay in the $t\bar{t}$ channel is not properly implemented, and may result in an under-estimate of this background
- Our analysis confirms the rates used in the SUSY Higgs study for the WH channel.

ZH Study

- Similar cuts to WH. Cut also on the missing transverse energy and the azimuthal angles between the direction of the missing energy and the b jets:

$$\begin{aligned} E_T^{miss} &> 35\ \mathrm{GeV} \\ \Delta\phi(E_T^{miss}, jets) &> 0.5 \end{aligned}$$

Caveat

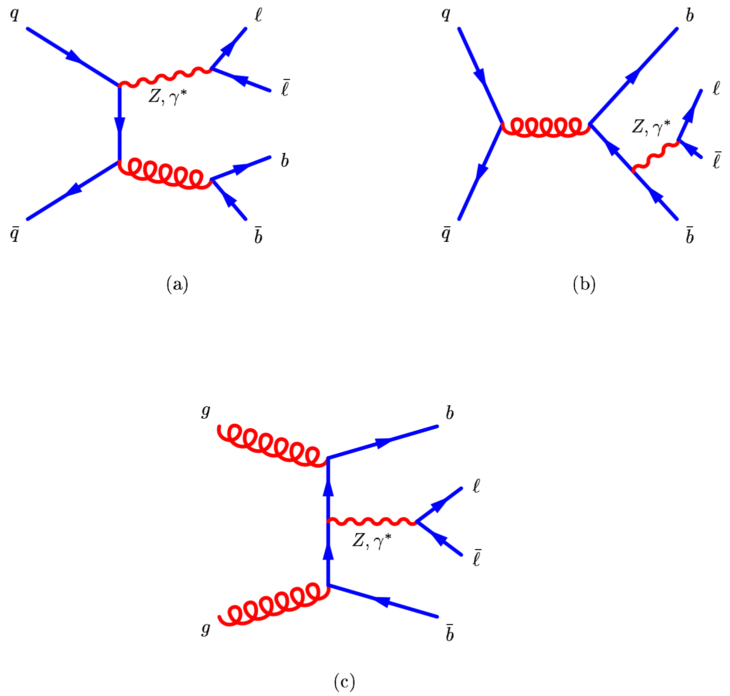
- A further background to the ZH study could be from ordinary ($p\bar{p} \to b\bar{b}$) events which also contain sufficient missing energy - for example, from a jet that is outside the acceptance region or hits a crack in the detector
- Since the total cross-section for this process is $\sim$ 9 orders of magnitude above the femtobarn signal, even the very

small number of events that might fall into this category could be significant

- It is unlikely that even a full shower Monte Carlo would provide a reliable estimate of such a background, much less our NLO Monte Carlo
- Ultimately, we shall have to rely on data to assess the importance of such effects

Results for $Zb\bar{b}$

- New results include radiative corrections, relevant for a further Higgs search in the channel ZH.
- The required matrix elements are very similar to the $Wb\bar{b}$ case,



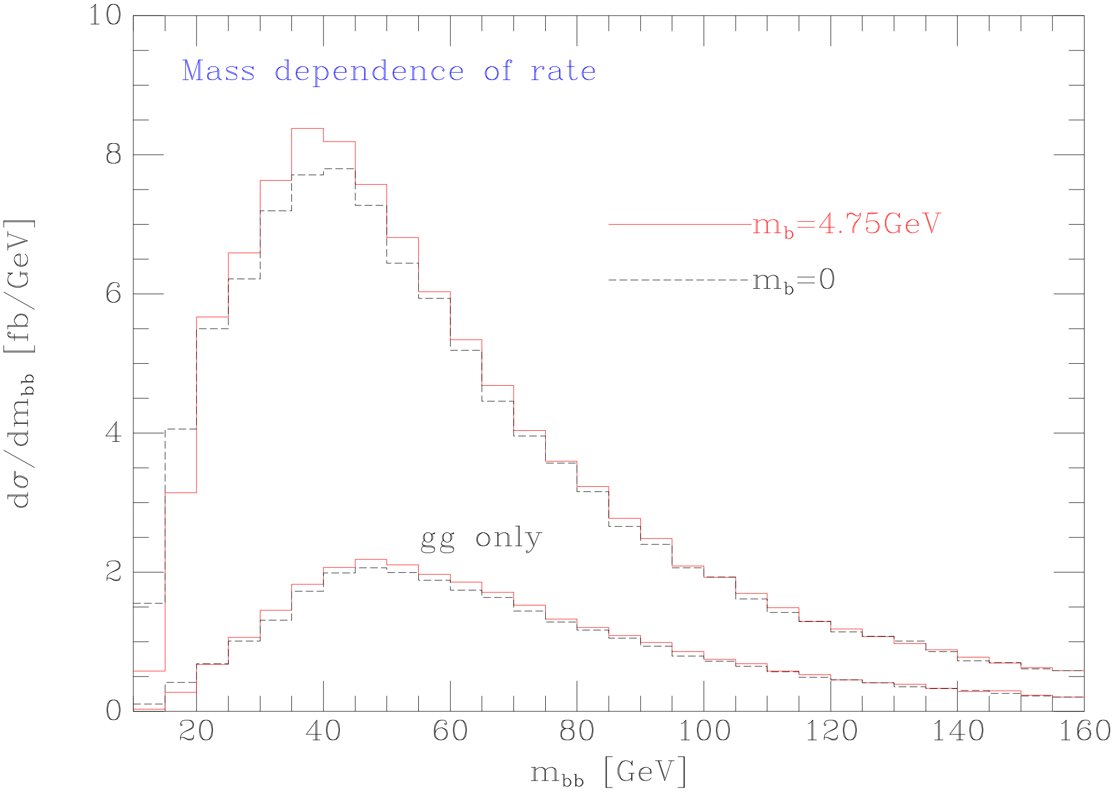
(a) (b)

(c)

with additional contributions from gg initial states.

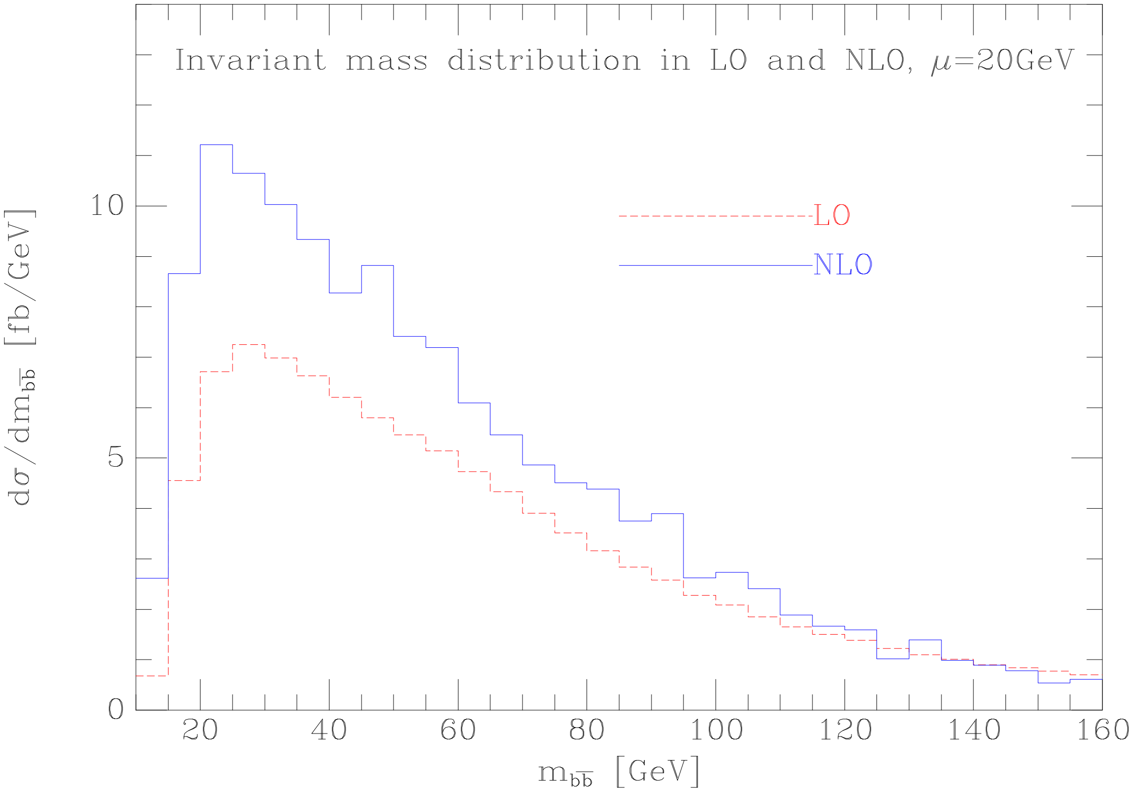
The gg sub-process in LO

- A $b\bar{b}$ pair with a large invariant mass can be produced by the gg initial state process, without off-shell propagators.
- Test of $m_b = 0$ approximation



$m_{b\bar{b}}$ mass distribution for $Zb\bar{b}$

- For a ‘conventional’ scale of 100 GeV, there is a large K-factor in the region of interest, around 1.8.

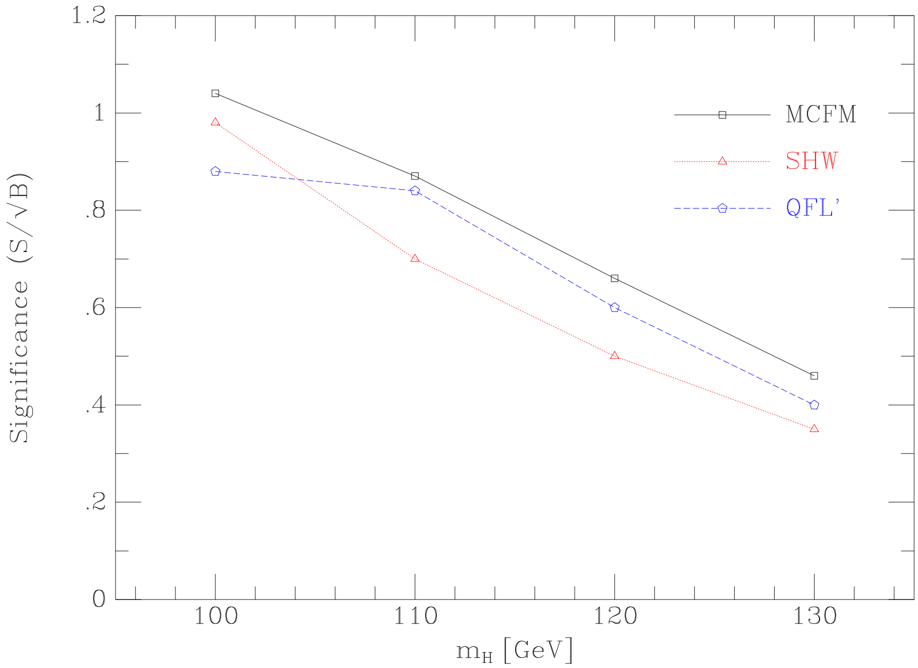


- The entire distribution is changed both in shape and normalization - perhaps suggesting that this scale choice is no longer appropriate (→ new gg processes).

Z Channel: Signal and backgrounds

2 TeV				
M_H [GeV]	100	110	120	130
$Z^0(\to \nu\bar{\nu})H(\to b\bar{b})$	5.8	4.4	2.9	1.8
$Z^0(\to \nu\bar{\nu})g^*(\to b\bar{b})$	12.6	11.6	10.3	8.6
$Z^0(\to \nu\bar{\nu})Z(\to b\bar{b})$	9.6	6.1	3.0	1.3
$W^{\pm *}(t(\to bW^+)\bar{b})$	0.6	0.7	0.7	0.7
$q't(\to bW^+)$	0.2	0.1	0.1	0.1
Total B	23.0	18.5	14.1	10.7
S/B	0.25	0.24	0.21	0.17
$S/\sqrt{B}$	1.21	1.02	0.77	0.55

Significance compared with SUSY Higgs study



- MCFM overestimates significance because of lack of detector effects (misidentification of leptons).
- Susy Higgs study overestimates significance because of underestimate of $Zb\bar{b}$ background. Our guess is that this could be a 20% effect.

Higher mass Higgs

Basic idea (Han, Turcot, Zhang): exploit the $H \to W^*W$ decay in the higher mass region.

- Signal processes

$gg \to H \to WW^*$
$ZH \to ZWW^*$
$WH \to WWW^*$

- Experimental signatures

l^+l^- + missing energy $(\nu\bar{\nu})$
$l^\pm l^\pm jj$
$l^\pm l^\mp l'^\pm$

- Main backgrounds $WW, WZ, t\bar{t}$

MCFM Results on High-mass Higgs

- The only experimental signature which can be usefully analysed in MCFM is l^+l^- + missing energy. (This is the most significant according to HTZ)

Signal (m_H)	140	150	160	170	180	190
$\sigma_{\rm cuts}$ (fb)	4.36	5.32	6.12	5.15	3.90	2.47
$\sigma_{\rm total}$ (pb)	0.181	0.206	0.215	0.180	0.143	0.0976

Background	WW	$t\bar{t}$	ZZ	WZ
$\sigma_{\rm cuts}$ (fb)	185	9.55	2.48	10.4
$\sigma_{\rm total}$ (pb)	13.0	6.82	1.56	3.96

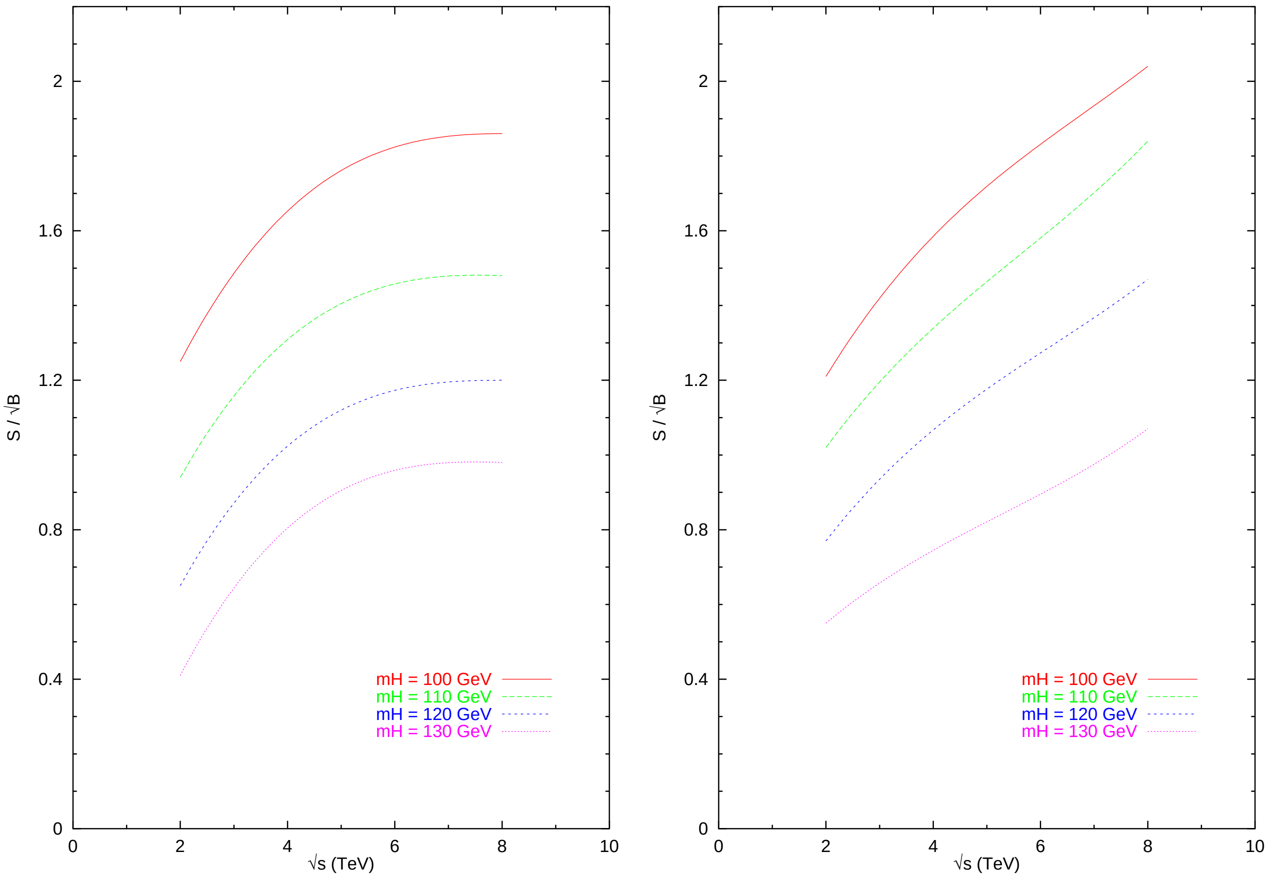
Table 1: Signal and background cross-sections for a Higgs search with di-lepton final states. The total cross sections (without leptonic decays from the vector bosons) are also shown.

Comparison with HTZ

- We find that all the backgrounds due to the di-boson processes are larger than in Han,Turcot and Zhang (HTZ) because we have normalized to the $O(\alpha_s)$ cross-sections which are about 30% bigger than the Born cross-sections..
- Our signal cross sections are also larger than HTZ by about 20%; the net effect on $S/\sqrt{B}$ may be small.
- We do not know exactly what the $gg \to H$ rate is (in the light of estimate of NNLO corrections by Harlander).
- The background from the WZ-class of events is twice as big as in HTZ because of our inclusion of the $W\gamma^*$ contribution.

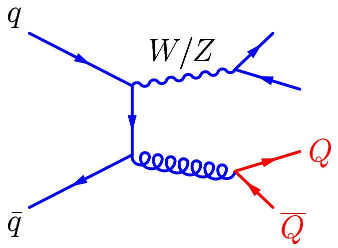
Signal and backgrounds beyond 2 TeV

- $S/\sqrt{B}$ as a function of collider energy for the WH (left) and ZH (right) processes

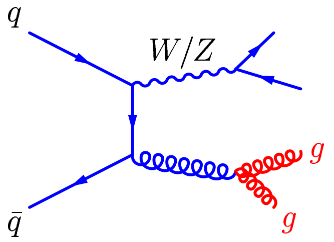


$W + 2$ jets: work in progress

- View the $W + 2$ jets process as an extension of the $Wb\bar{b}$ and $Zb\bar{b}$ calculations already performed:
  - $Wb\bar{b}$ – part of $q\bar{q} \rightarrow W + q'\bar{q}'$



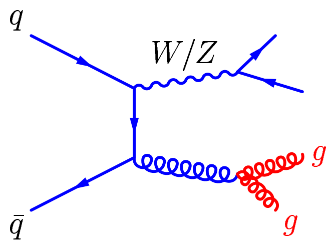
  - $Zb\bar{b}$ – contains $gg \rightarrow Z + q\bar{q}$ + crossings



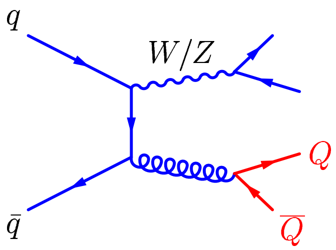
- There are extra parton configurations that we must count.
- The real radiation diagrams have extra singularities due to more configurations of soft/collinear gluons and collinear quark pairs.

$W + 2$ jets at lowest order

- Separate the diagrams by colour structure:

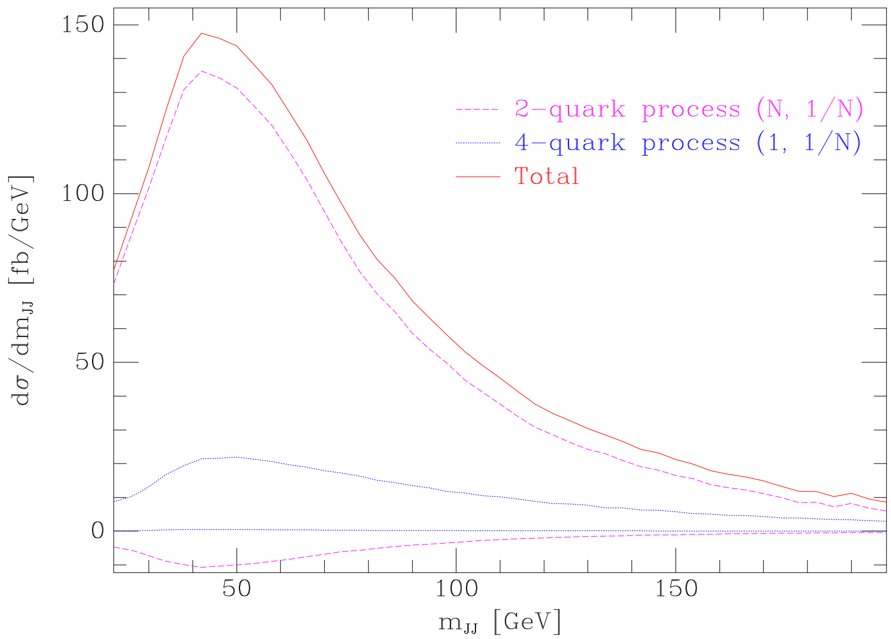


$$\propto N,\ 1/N$$



$$\propto 1,\ 1/N \times \delta_{qQ}$$

- Typical distribution, standard set of cuts:



$W + 2$ jets: strategy

$$|\mathcal{M}_{NLO}(Vq\bar{q}gg)|^2 \sim 1 \longleftarrow \text{Near completion}$$

$$+\frac{1}{N^2}$$

$$+\frac{1}{N^4}$$

$$|\mathcal{M}_{NLO}(Vq\bar{q}Q\bar{Q})|^2 \sim \frac{1}{N} \longleftarrow \text{Next target}$$

$$+\frac{1}{N^3}$$

$$+\frac{1}{N^2} \times \delta_{qQ}$$

$$+\frac{1}{N^4} \times \delta_{qQ}$$

- Emphasis on $W + 2$ jet first

Conclusions

- $Wb\bar{b}$ background has approximate K factor already included in Susy-Higgs analysis.
- $Zb\bar{b}$ background is modified significantly (new class of diagrams). We believe that the significance will be less than the Susy-Higgs working group estimate.
- Our work underscores the importance of having an experimental determination of the $Zb\bar{b}$ and $Wb\bar{b}$ background, by relating them to $Vb\bar{b}$ events at lower $m_{b\bar{b}}$ or $V+$ 2jet events.
- We find that the rates used in the (HTZ) analysis too low, but the radiative corrections lead to little net change in $S/\sqrt{B}$.
- More luminosity is the panacea for all background ills.