

# Weak effects in top pair and bottom pair production at Hadron colliders

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LoopFest VI, Fermilab Chicago, April 2007

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# Outline

- Motivation and Status of NLO calculations
- Methods and Consistency
- Results
- Conclusion and Outlook

# Why weak effects in hadronic collisions ?

- Hadron colliders
  - provide high energy events
  - corresponding experiments measure at 5-10% accuracy

## Theory: NLO corrections

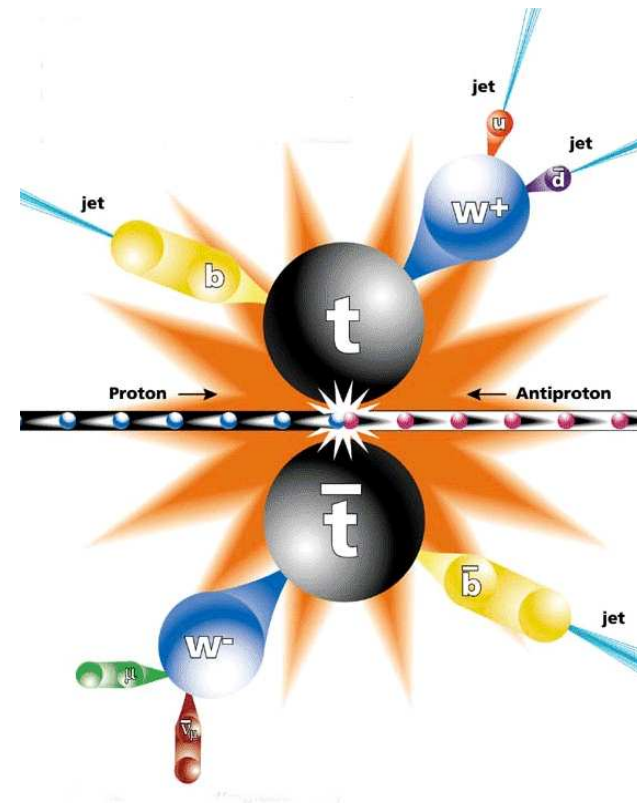
- QCD-corrections are dominant
- weak corrections
  - smaller coupling:  $\alpha < \alpha_s$
  - but large logarithms: Sudakov Logarithms

$$\ln^2 \left( \frac{E_{cm}}{M_w} \right), \ln \left( \frac{E_{cm}}{M_w} \right)$$

(Sudakov 1954)  
(Kühn, Penin, Smirnov 1999)  
(Ciafaloni, Comelli 1999)  
(Denner, Pozzorini 2001)

# Top quark pair production

- completes the fermion sector of the SM
- probes physics at highest mass scale ( $m_{\text{top}} \simeq 172.7 \text{ GeV}$ )
- but still not very well measured
- questions:
  - how is the mass generated ?
  - elementary particle ?

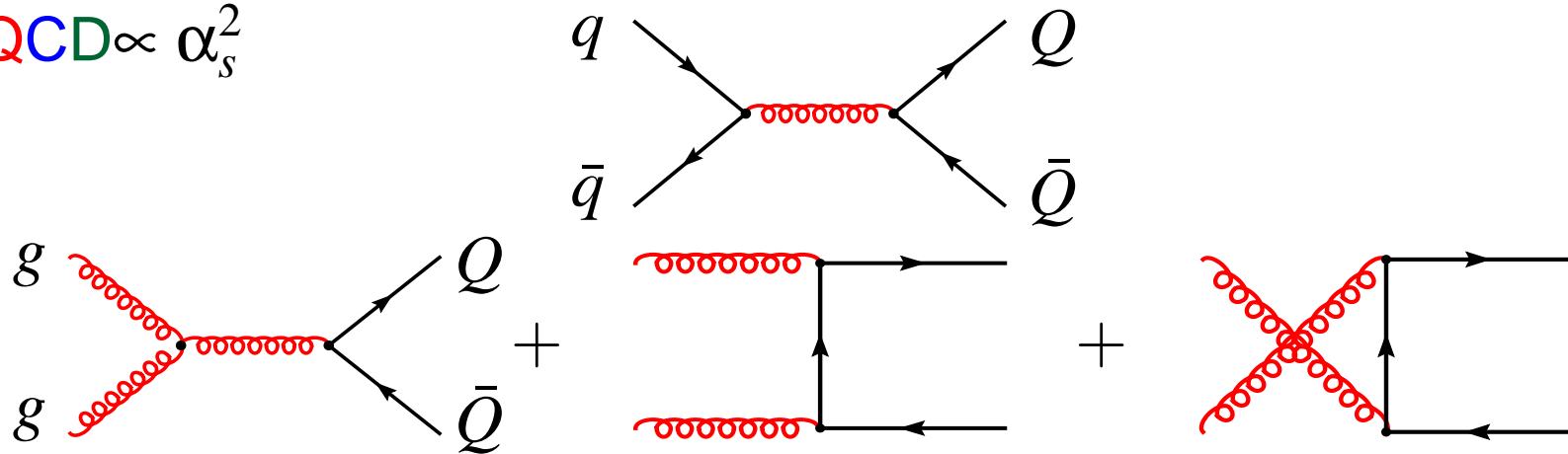


# Bottom quark pair production

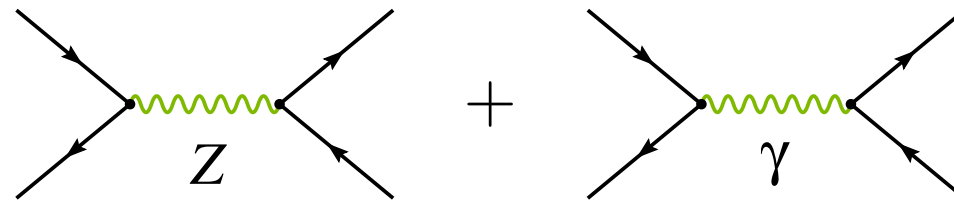
- studying di-jet events with well separated  $b$  quarks  
( $m_b = 0$ ,  $p_T > 50$  GeV)
- lifetime of  $B$ -mesons allows  $b$ -tagging
- testing the SM at high  $p_T$ 
  - Sudakov-Logarithms become important
- background process

# Heavy quark pair production at hadron colliders

- $\text{QCD} \propto \alpha_s^2$



- electroweak  $\propto \alpha^2 \ll \alpha_s^2$



- no mixed contributions ( $\alpha_s \alpha$ ) at leading order

# NLO calculations for top pair production

- QCD-corrections ( $t\bar{t}$ )

(Dawson, Ellis, Nason 1988)  
(Beenakker, Kuijf, Neerven, Smith 1989)  
(Bernreuther, Brandenburg, Si, Uwer 2004)

- $t\bar{t} + j$  @ NLO

(Dittmaier, Uwer, Weinzierl)

- weak corrections ( $\alpha_s^2 \alpha$ )

(Beenakker et al 1994)

- first complete calculation

(J.H. Kühn, A.S., P. Uwer 2005)  
(W. Bernreuther, M. Fuecker, Z.G. Si 2005)  
(J.H. Kühn, A.S., P. Uwer 2006)  
(W. Bernreuther, M. Fuecker, Z.G. Si 2006)

- not in agreement with

(Moretti et al 2006)

# NLO calculations for bottom pair production

- QCD-corrections ( $\alpha_s^3$ )

(Dawson, Ellis, Nason 1988)  
(Beenakker, Kuijf, Neerven, Smith 1989)

- weak corrections ( $\alpha_s^2 \alpha$ )

(Moretti et al 2003)

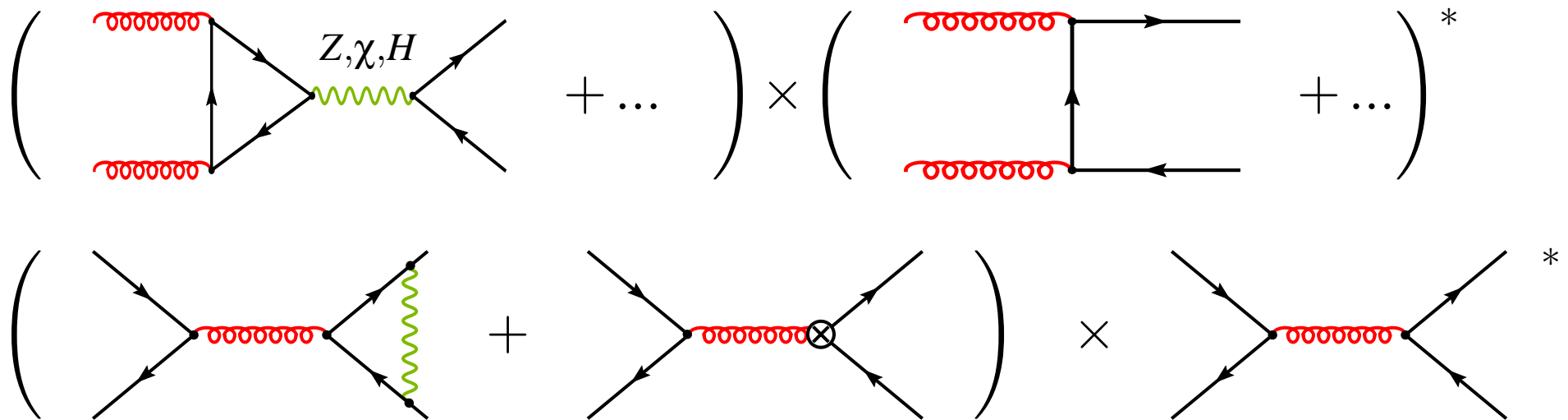
- no differential distributions
- no analytic results

- calculation: compare massive with massless results

- take top calculation
- $m_t \leftrightarrow m_b$
- adjust couplings

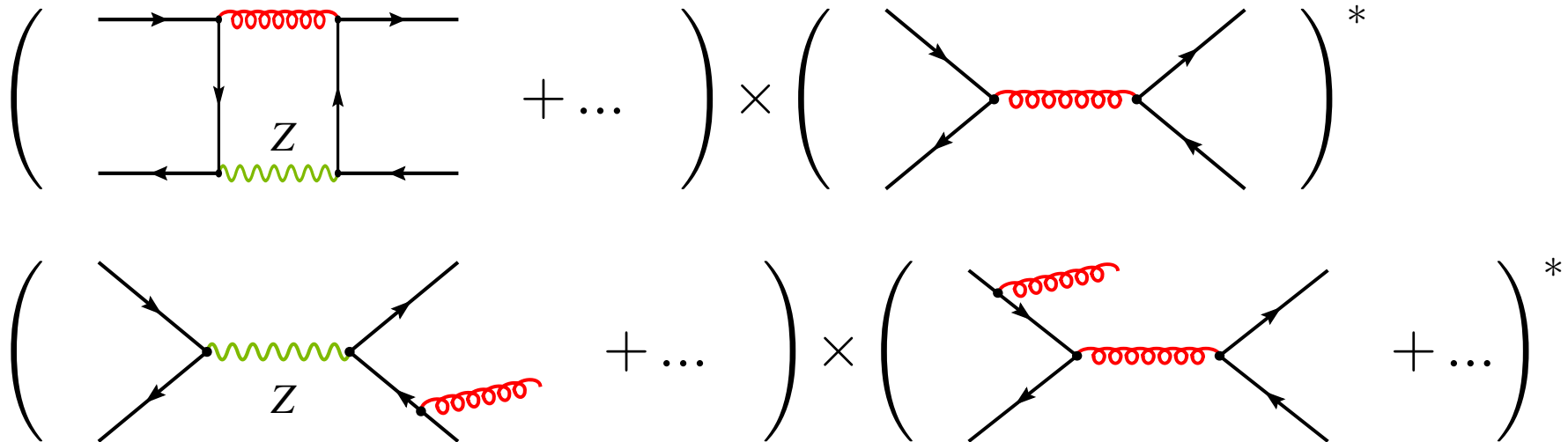
# Methods ( $t\bar{t}$ )

- calculation in Feynman-Gauge:  $Z, W, \chi, \phi, H$
- Passarino-Veltman reduction
- on-shell renormalisation
  - no coupling constant renormalisation is needed



# Methods ( $t\bar{t}$ )

## ● IR-divergent contributions



## ● IR-singularities

- phase-space-slicing

(Giele, Glover 1992)  
(Giele, Glover, Kosower 1993)

- (dipole-) subtraction method ✓

(Frixione, Kunszt, Signer 1995)  
(Catani, Seymour 1996)  
(Nason, Oleari 1998)  
(Catani, Dittmaier, Seymour, Trocsányi 2002)

# Consistency: $t\bar{t}$ -calculation

## ● internal tests

- cancellation of the IR singularities ✓
- diagram-specific properties ✓

## ● cross checks

- independent calculation by Peter Uwer ✓
- parallel work ✓

(W. Bernreuther, M. Fückler, Z.G. Si)

## ● components in literature ✓

(Beenakker et al 1994)

(Grzadkowski, Kühn 1987)

(Kniehl, Kühn 1989)

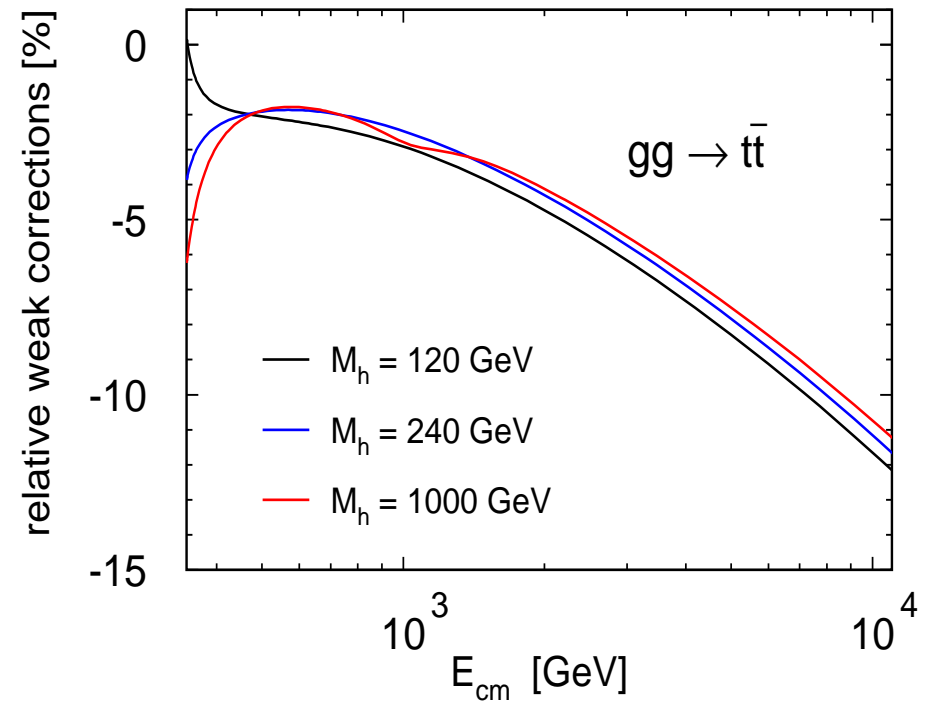
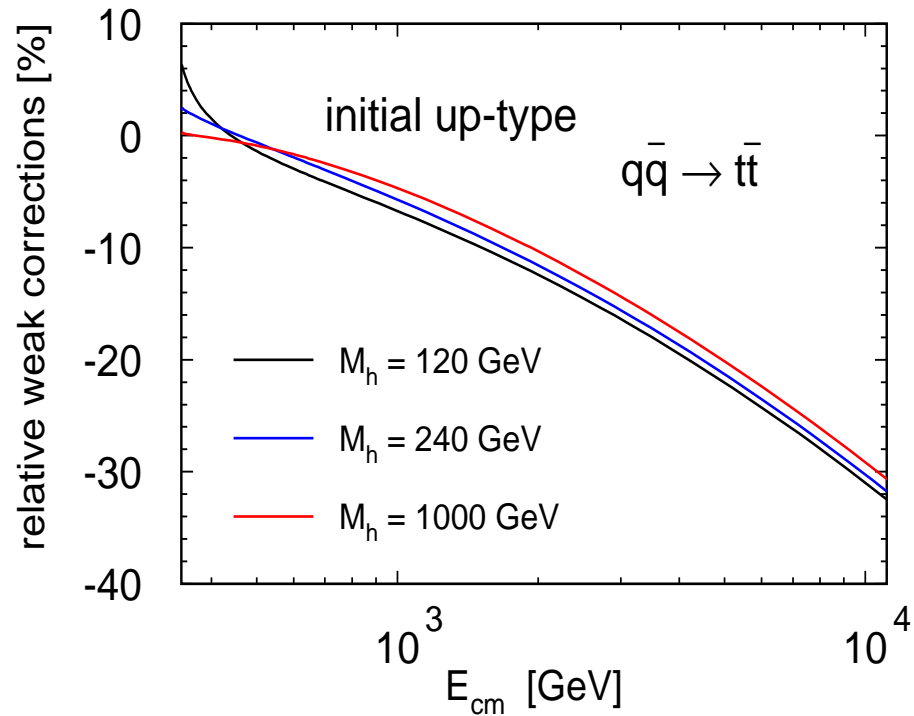
(Jezábek, Kühn 1993)

# Status of $b\bar{b}$ production

- calculation for gluon fusion channel
  - comparison with massive results ✓
- IR **finite** parts for quark induced corrections
  - comparison with massive results ✓
- IR **divergent** parts for quark induced corrections
  - in progress

# Partonic results for $t\bar{t}$ production

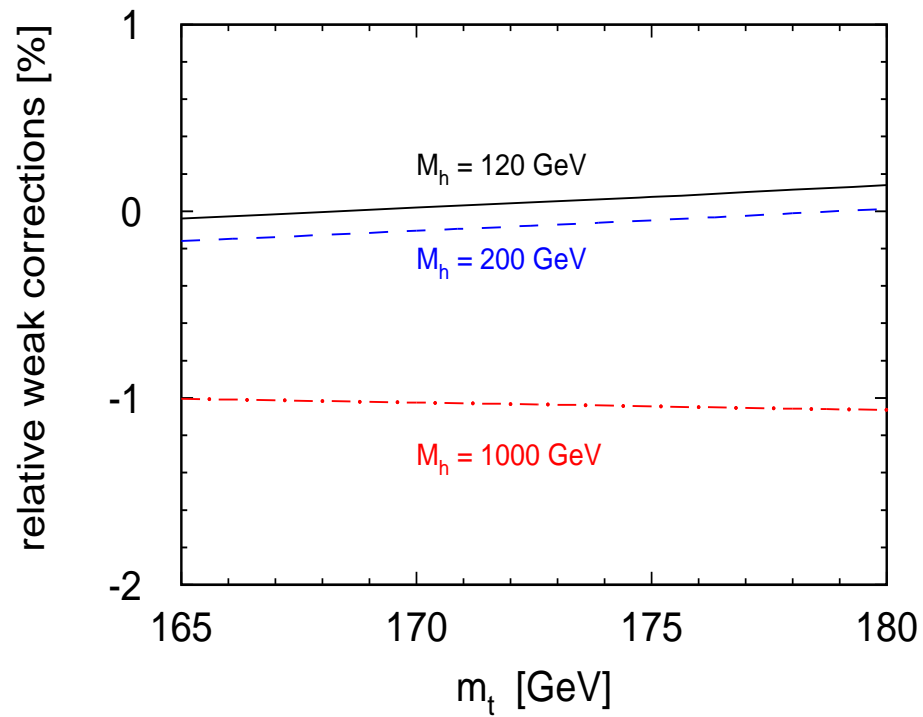
- analytic results
- partonic cross section



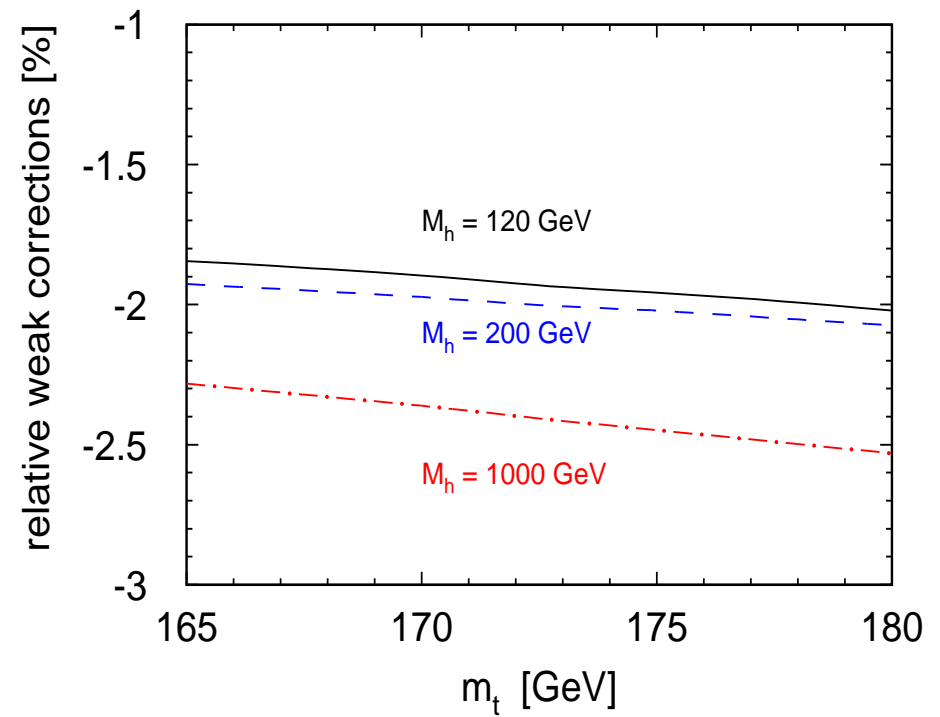
# Total hadronic cross section for $t\bar{t}$

● small corrections

## TEVATRON



## LHC

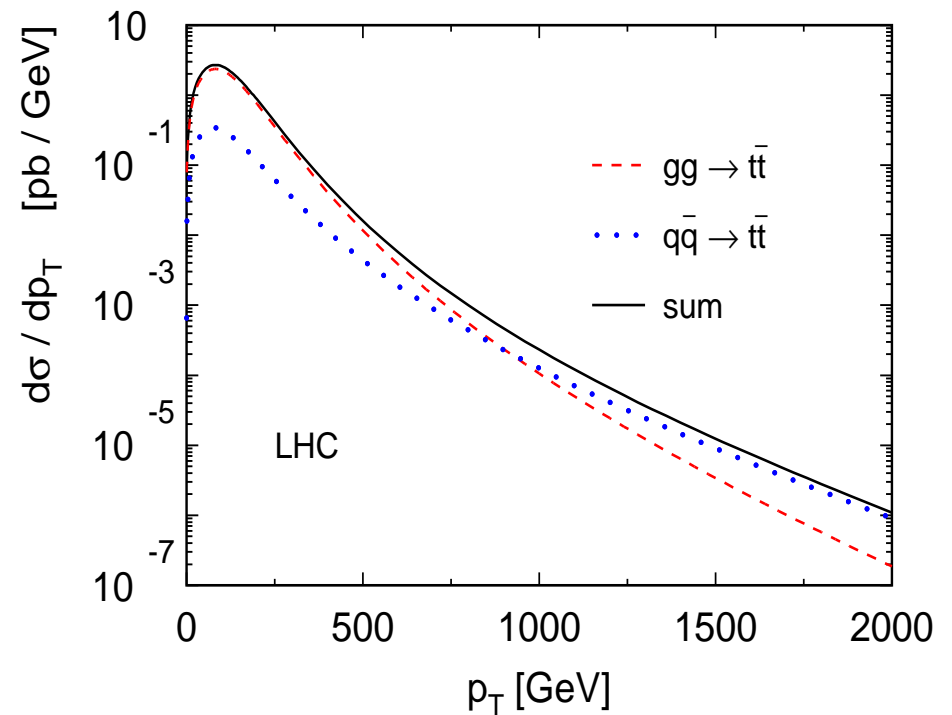
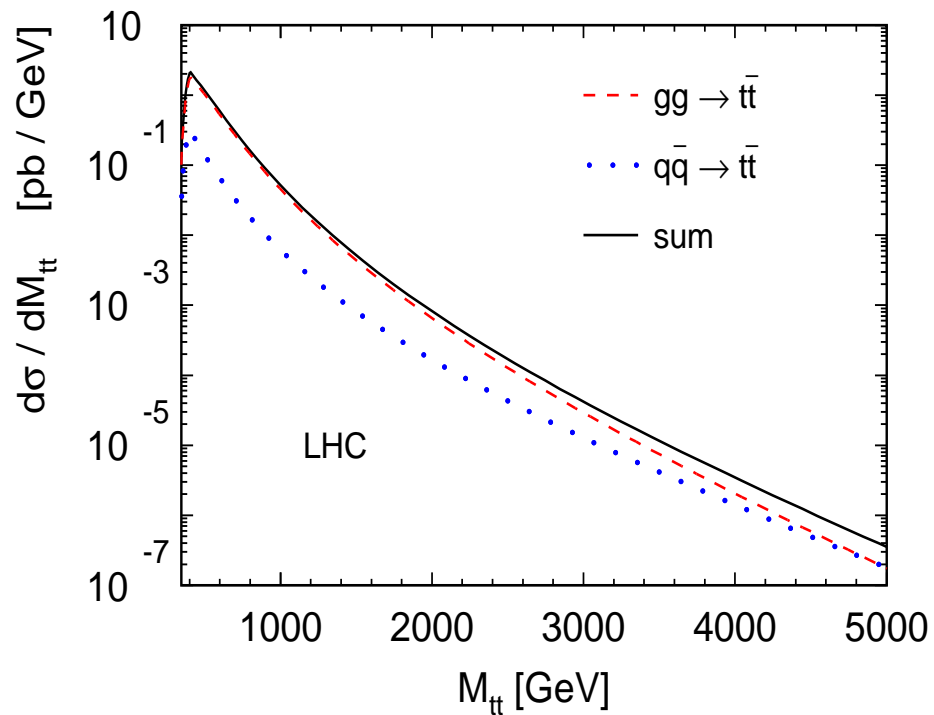


# $t\bar{t}$ production at LHC

## ● leading order distributions

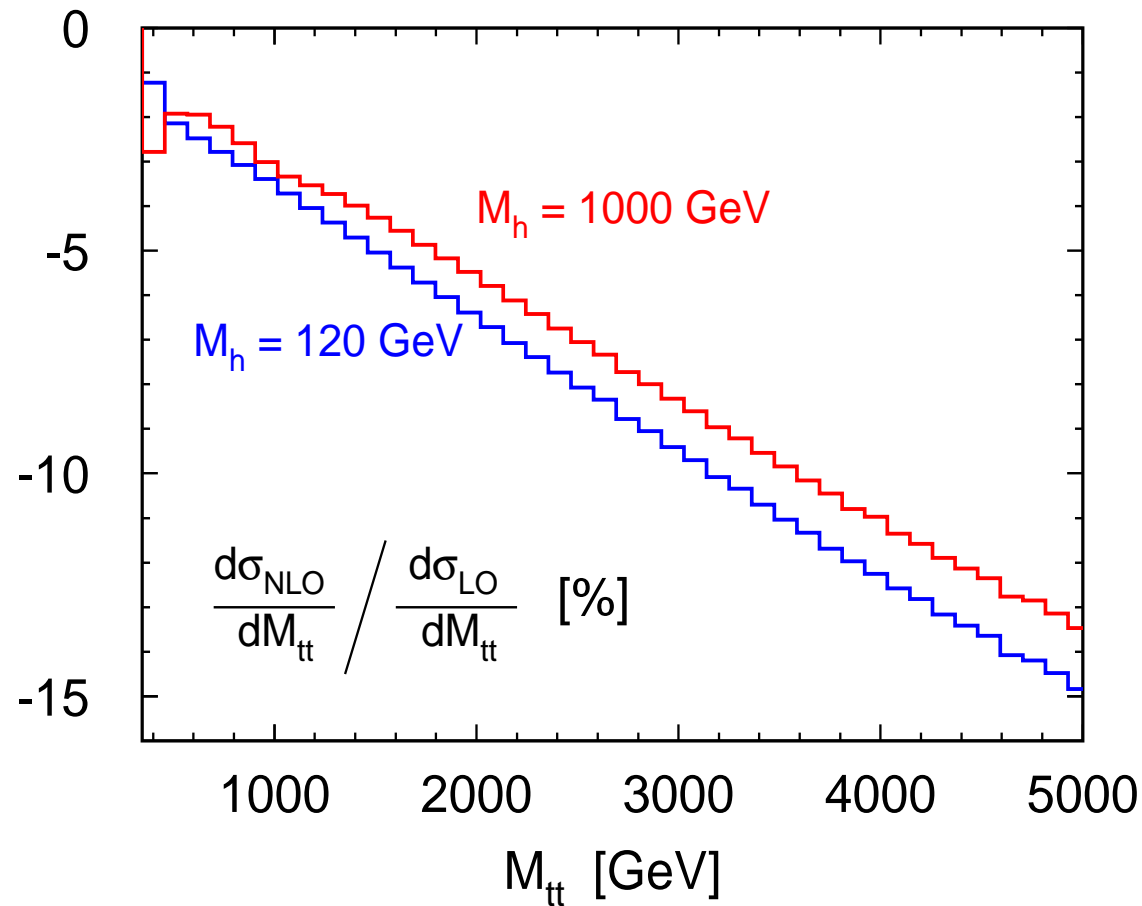
● invariant  $t\bar{t}$ -mass:  $M_{t\bar{t}}$

● transverse momentum of the top quark:  $p_T$



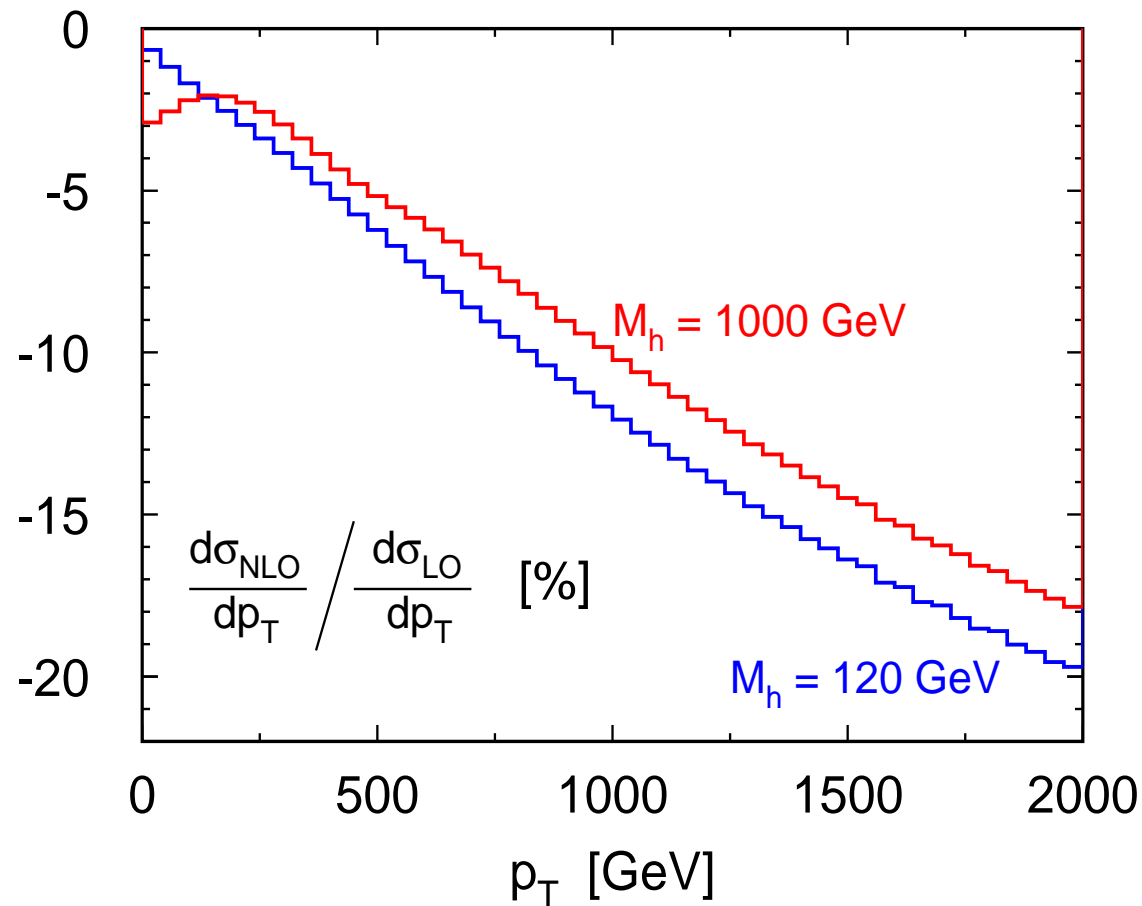
# $t\bar{t}$ production at LHC

- relative corrections to  $\frac{d\sigma}{dM_{t\bar{t}}}$

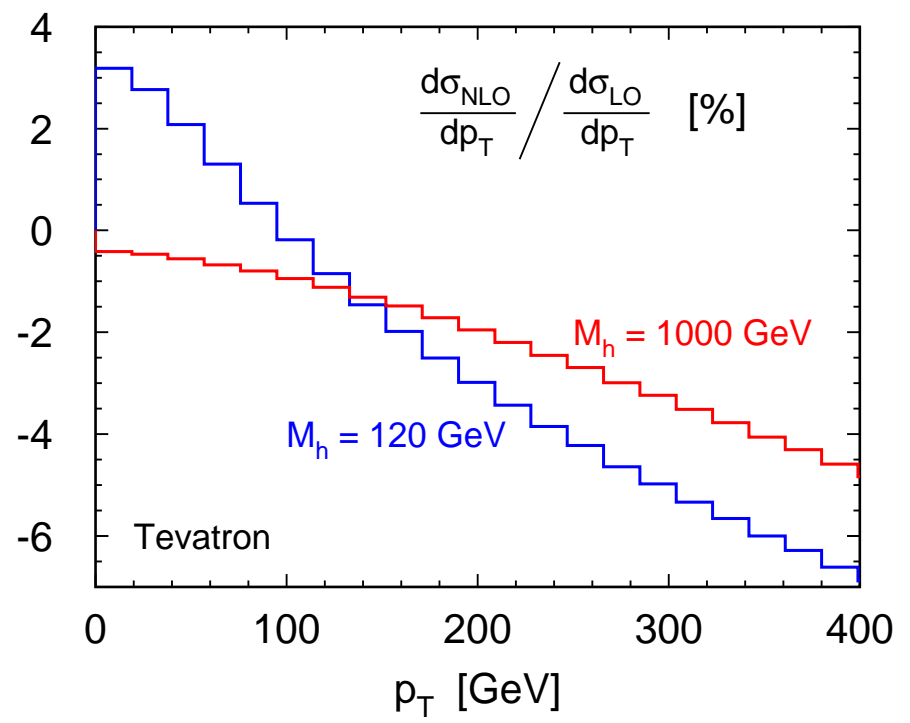
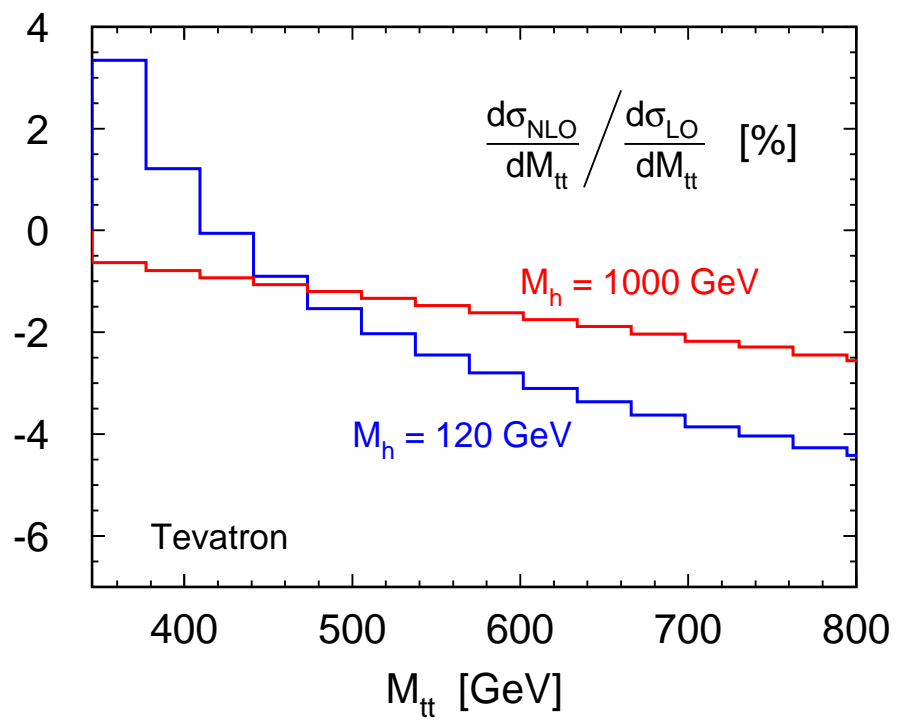


# $t\bar{t}$ production at LHC

- relative corrections to  $\frac{d\sigma}{dp_T}$



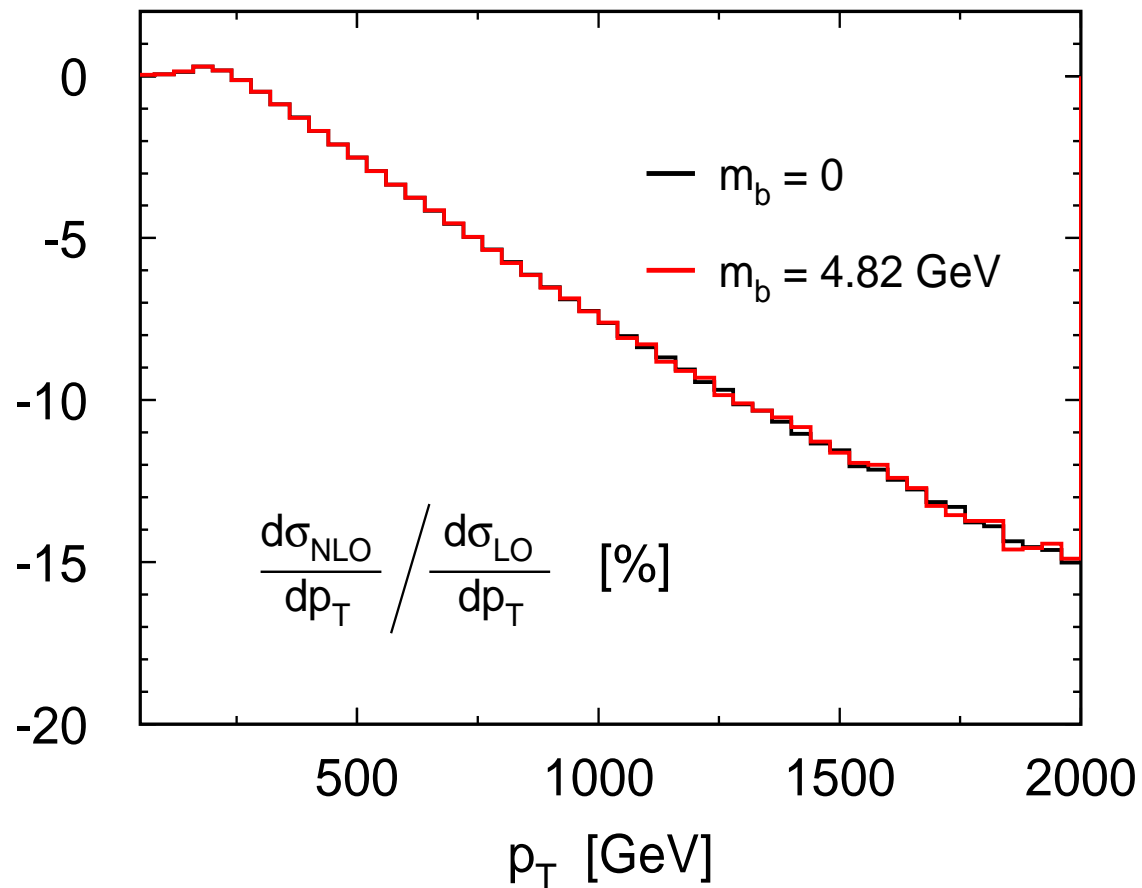
# t $\bar{t}$ production at Tevatron



# $b\bar{b}$ production at LHC

● Preliminary

●  $q\bar{q}$ -boxes + real corrections are not included

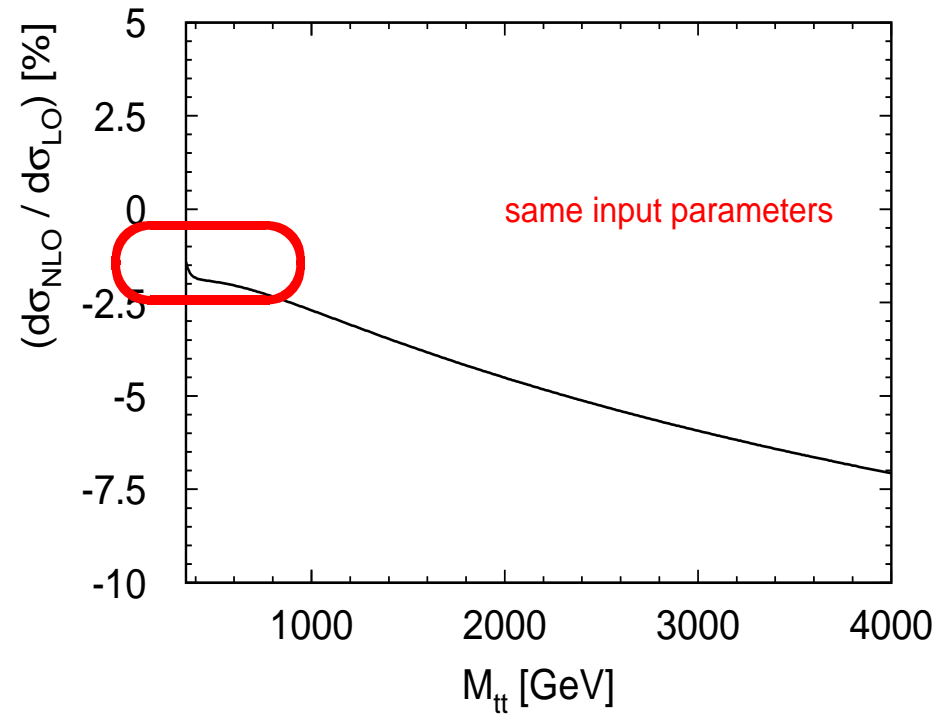
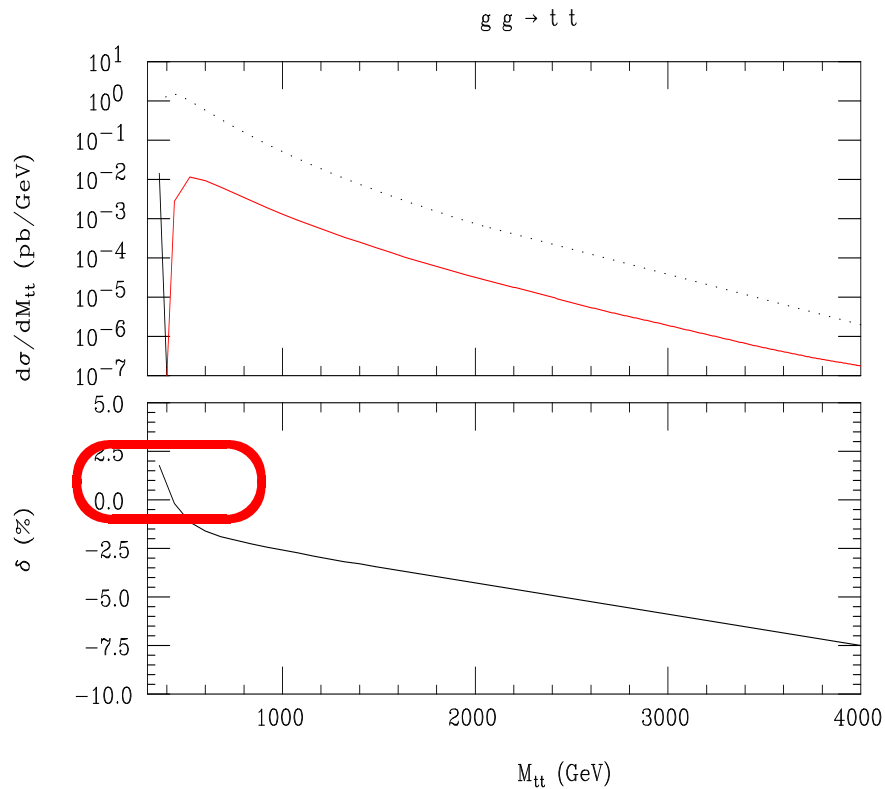


## Conclusion and Outlook

- weak effects are very important in heavy quark pair production at LHC
  - small corrections to the total cross section
  - large effects for differential distributions (10-15 % )
- first consistent calculation for  $t\bar{t}$  production (analytic results)
- massless  $b$ -jet pair production in progress

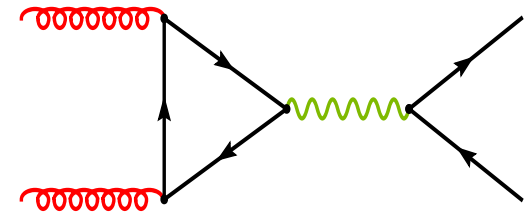
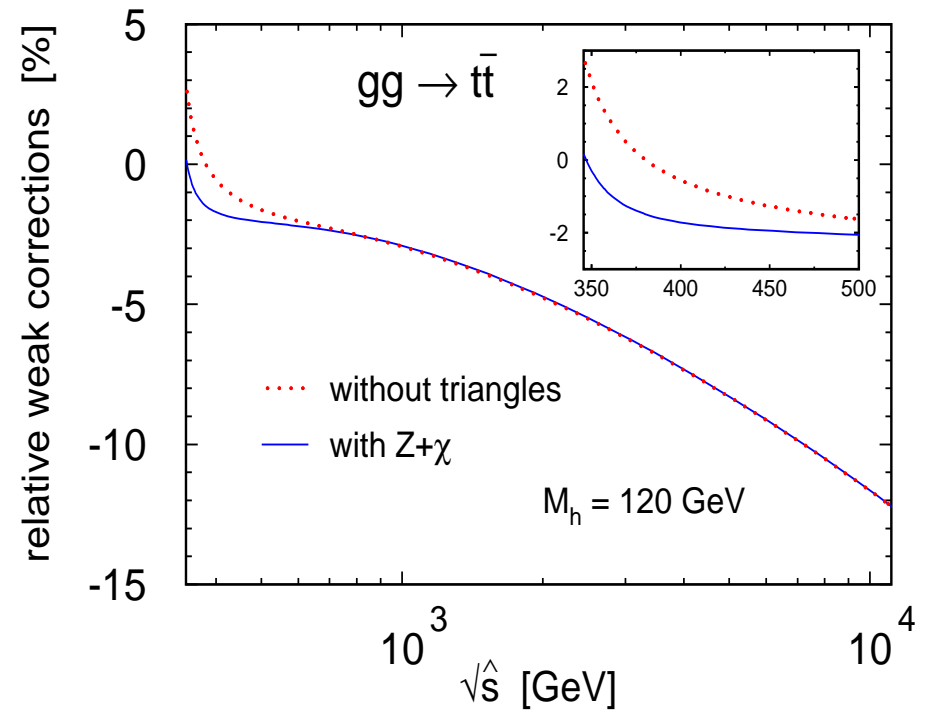
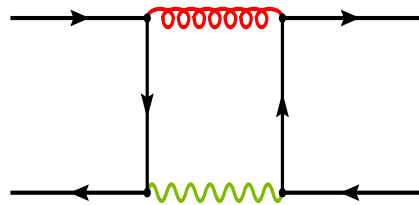
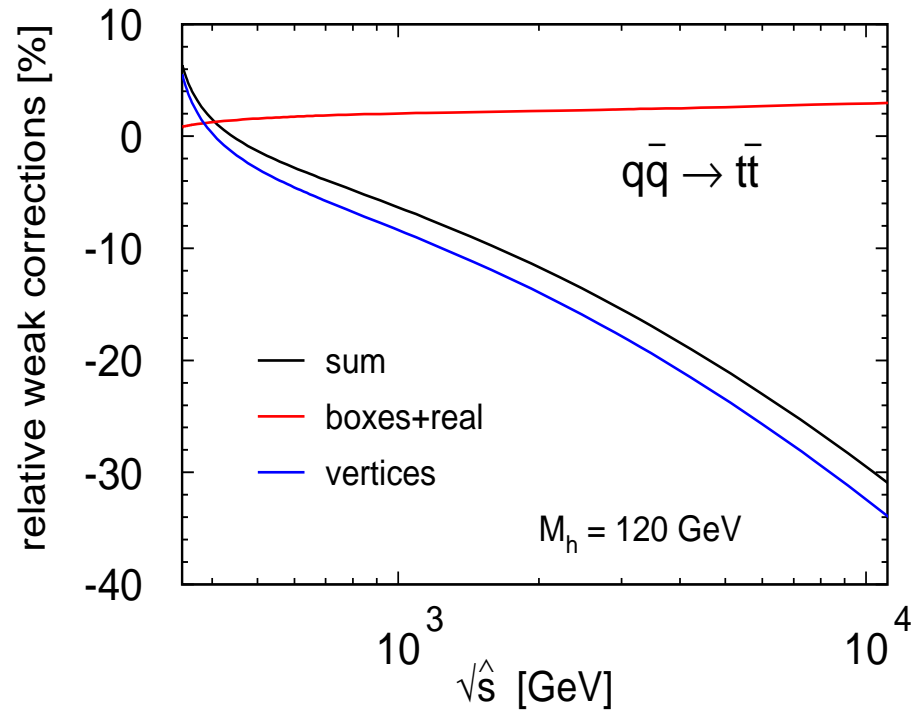
# Comparison with Moretti et al 2006

## ● gluon-induced corrections



# Comparison with Beenakker et al 1994

## ● Partonic results



# Scale Dependence for $t\bar{t}$ production

●  $\mu = \mu_R = \mu_F$

