

Weak effects in top quark pair production at LHC

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In collaboration with Johann H. Kühn and Peter Uwer

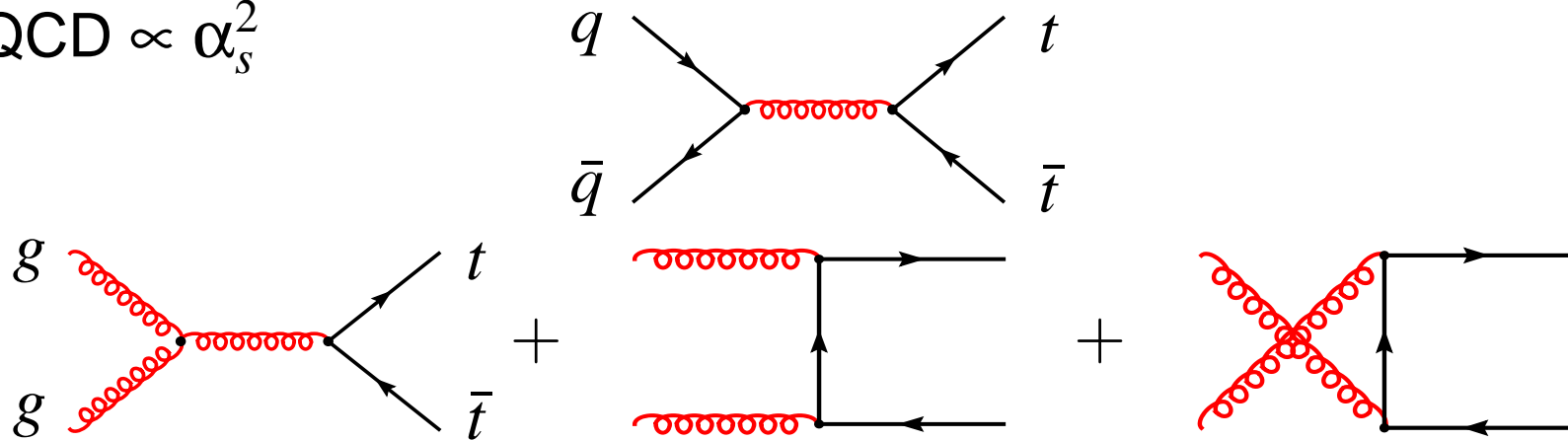
Top physics

- heaviest fundamental fermion known ($m_{\text{top}} \simeq 172.7 \text{ GeV}$)
 - test of the Standard Model at high energies
 - sensitive to new physics
 - how is the mass generated ? Higgs mechanism ?
 - top quark really an elementary particle?
- TEVATRON and LHC: direct measurements

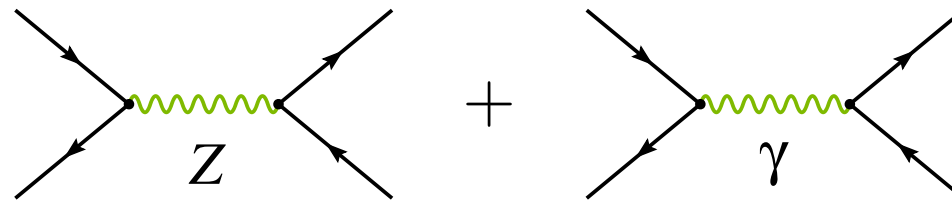
precise predictions from the theory

Top production at hadron colliders

- QCD $\propto \alpha_s^2$



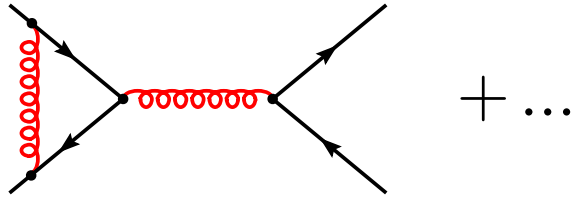
- electroweak $\propto \alpha^2 \ll \alpha_s^2$



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

NLO calculations for top pair production

- QCD corrections α_s^3



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

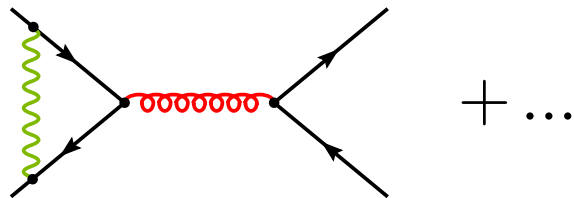
- next step weak corrections $\alpha_s^2 \alpha > \alpha^2$

(Beenakker et al 1994)

- but missing pieces !

- first complete calculation of order $\alpha_s^2 \alpha$ for $t\bar{t}$ -production

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

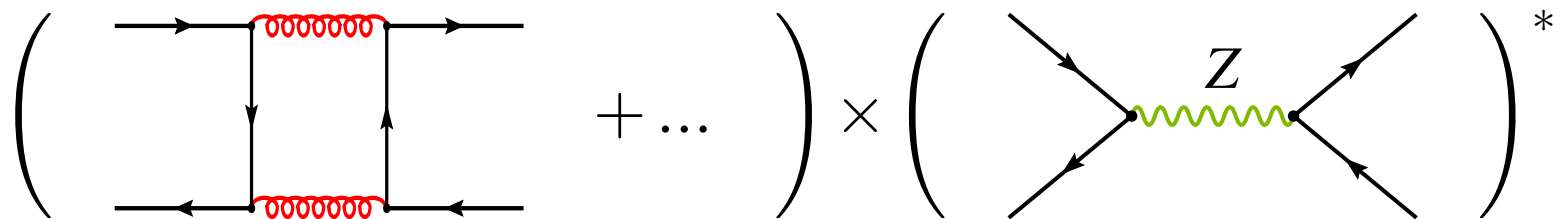
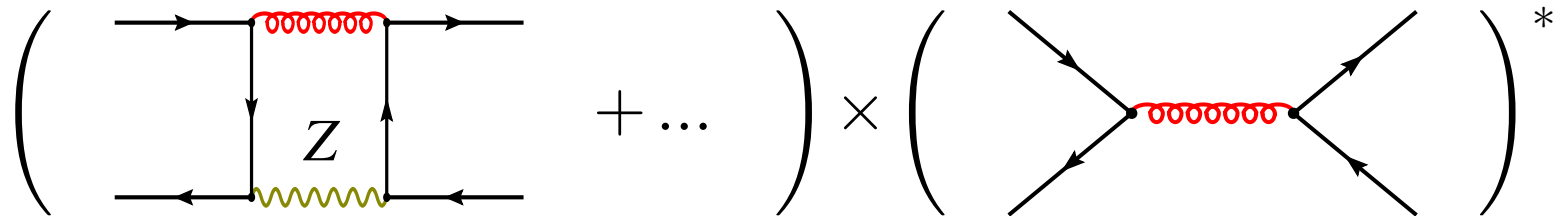


- gluon induced corrections in disagreement with Moretti et al 2006 !

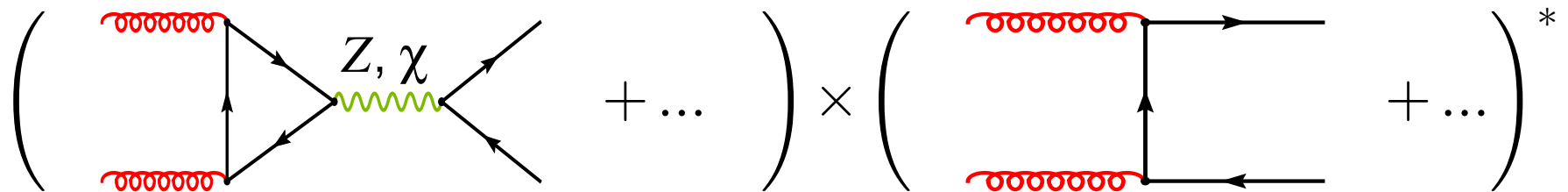
Corrections of order $\alpha\alpha_s^2$

● not calculated by (Beenakker et al 1994)

● $q\bar{q} \rightarrow t\bar{t}$

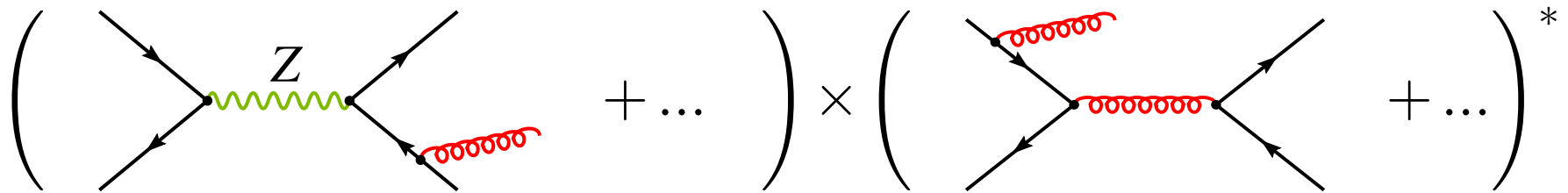


● $gg \rightarrow t\bar{t}$



Methods

- Passarino Veltman tensor reduction
- on-shell renormalisation
- real corrections to $q\bar{q} \rightarrow t\bar{t}$



- two methods to handle IR singularities
 - phase-space-slicing
 - (dipole) subtraction method ✓

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

(Frixione, Kunszt, Signer 1995)
(Catani, Seymour 1996)
(Nason, Oleari 1998)
(Phaf, Weinzierl 2001)

(Catani, Dittmaier, Seymour, Trocsányi 2002)

Consistency

- internal checks

- cancellation of the IR-poles $q\bar{q} \rightarrow t\bar{t}$ ✓
- other properties ✓

- cross checks

- independent calculation by Peter Uwer ✓
- parallel work ✓

(W. Bernreuther, M. Fückler, Z.G. Si)

- partial comparison with literature ✓

(Beenakker et al 1994)

(Grzadkowski, Kühn 1987)

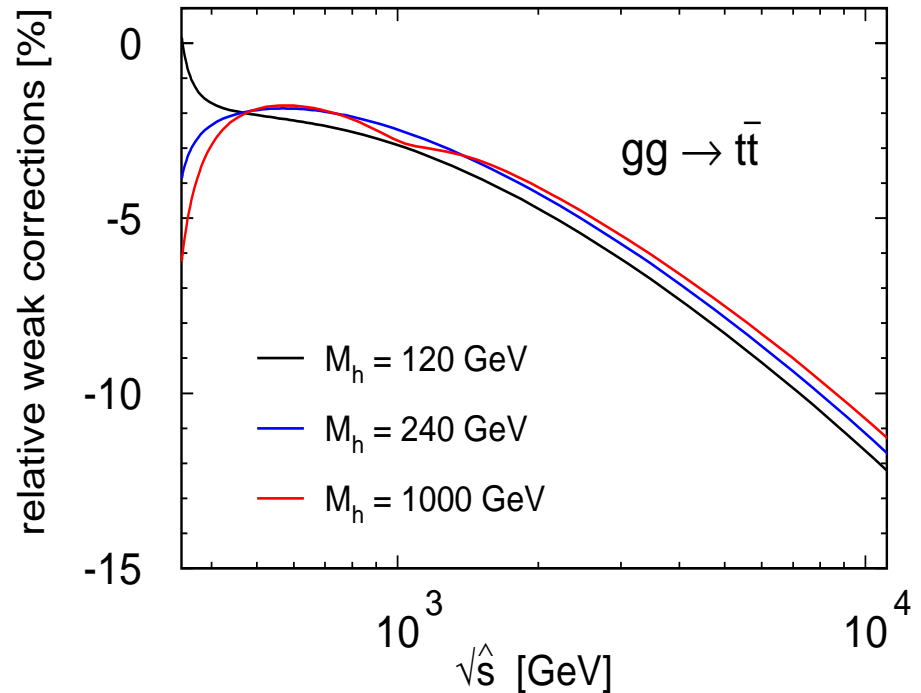
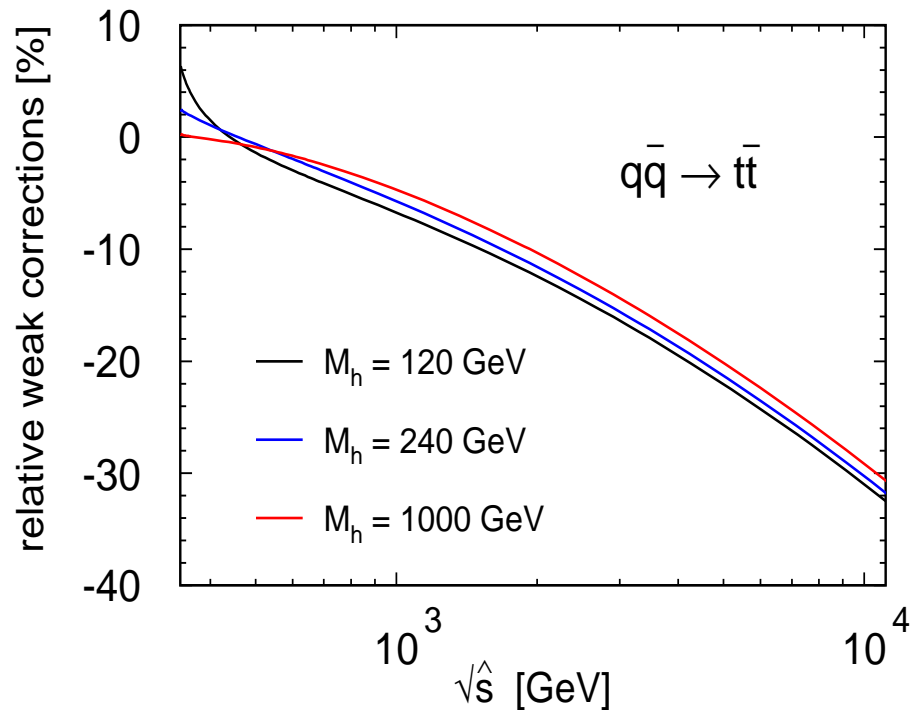
(Kniehl, Kühn 1989)

(Jezábek, Kühn 1993)

- gluon induced process: no agreement with Moretti et al 2006

Partonic results

- results are in analytical form

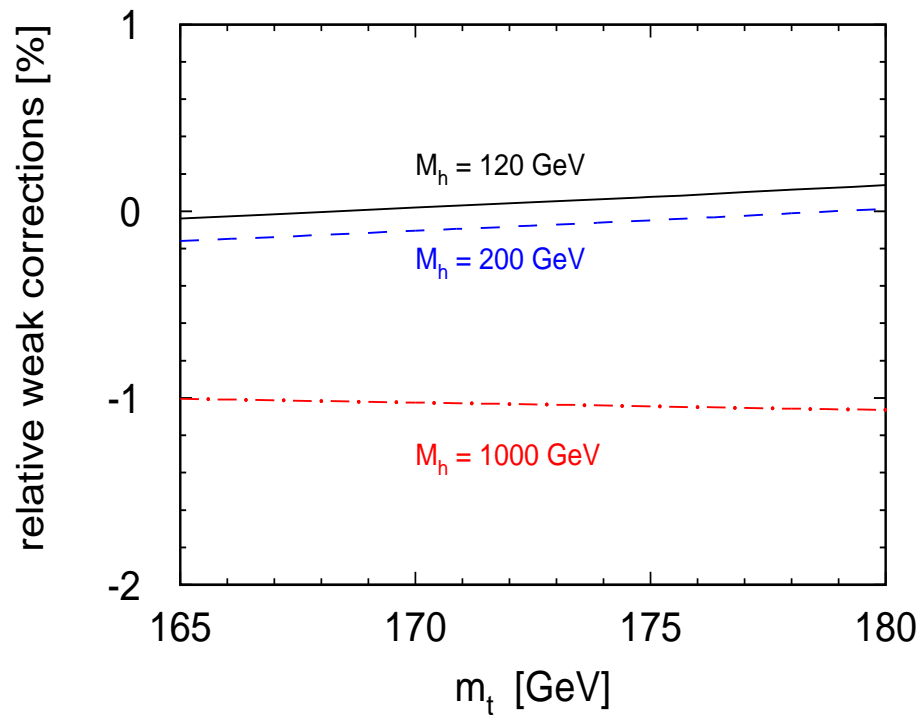


- high energy behaviour \rightarrow Sudakov Logarithms (Sudakov 1954)
(Kühn, Penin, Smirnov 1999)
(Ciafaloni, Comelli 1999)

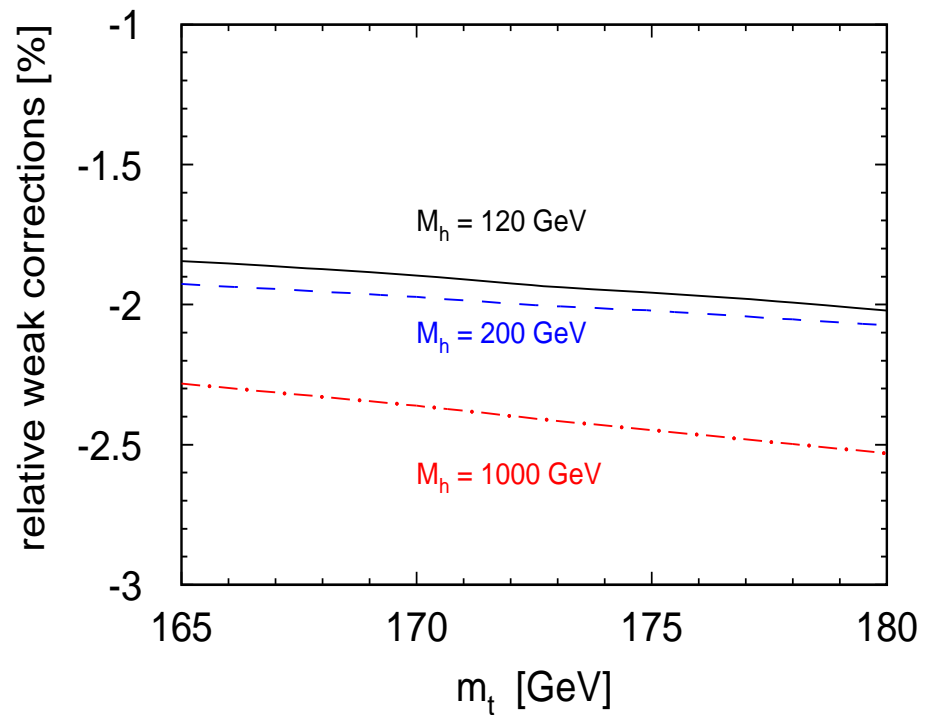
Hadronic total cross section

- small contributions to the total cross section

TEVATRON

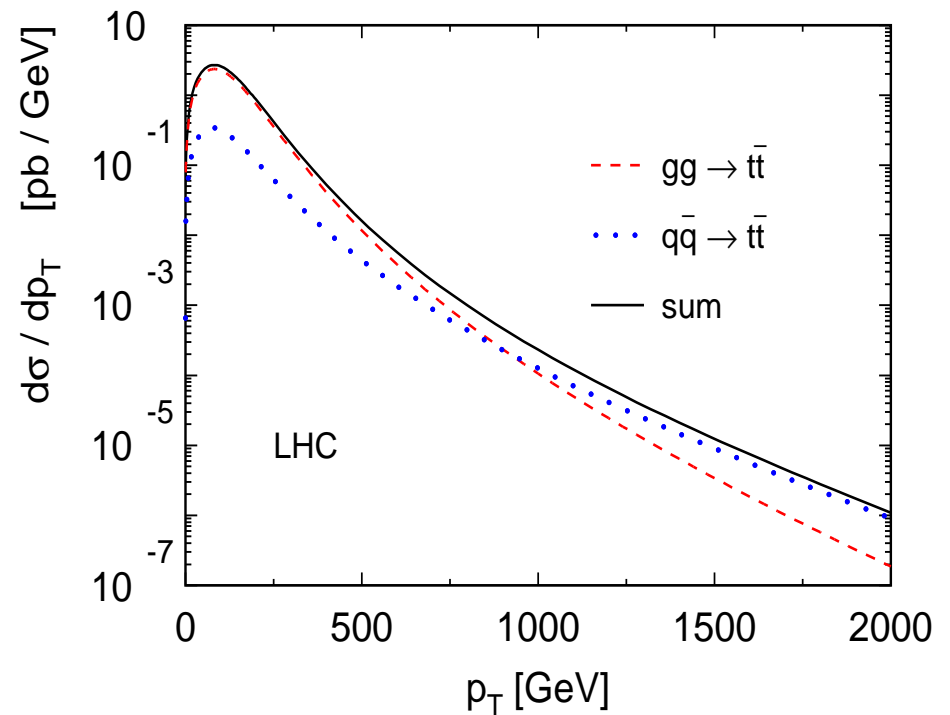
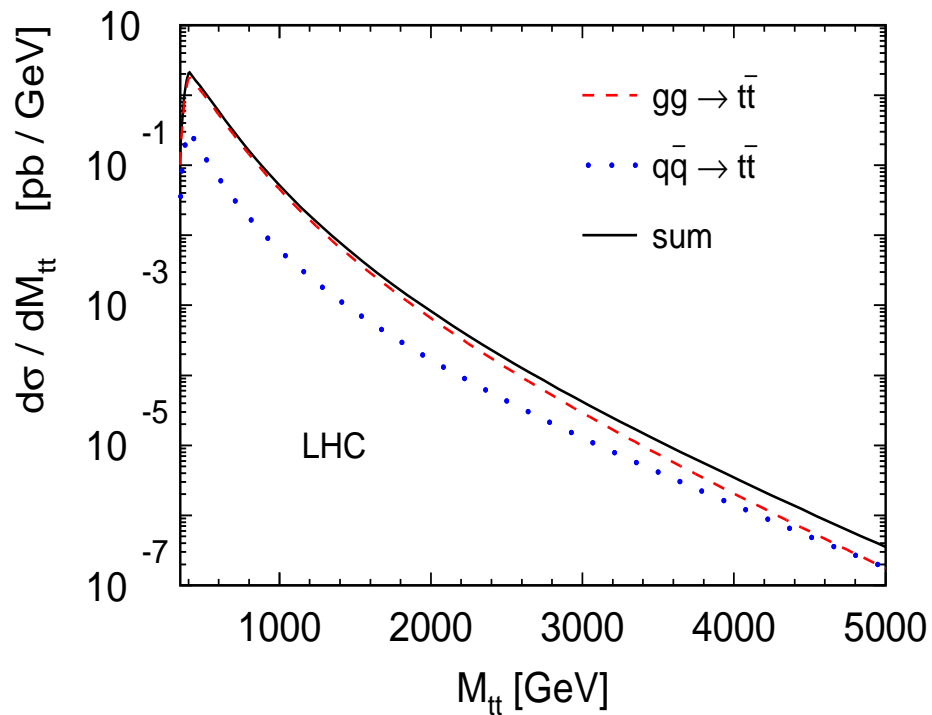


LHC



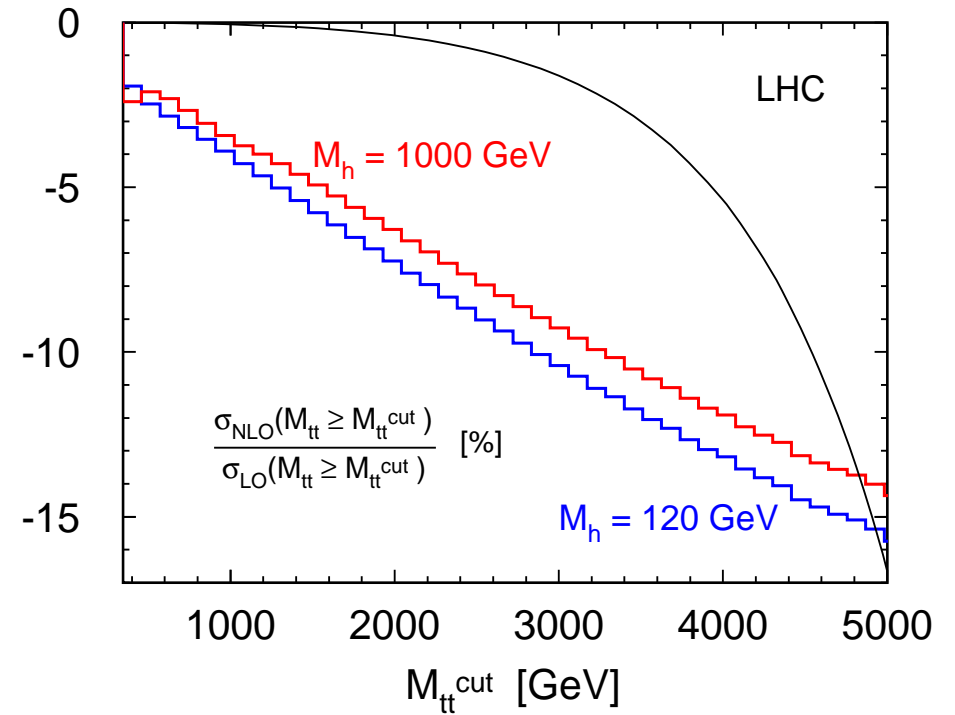
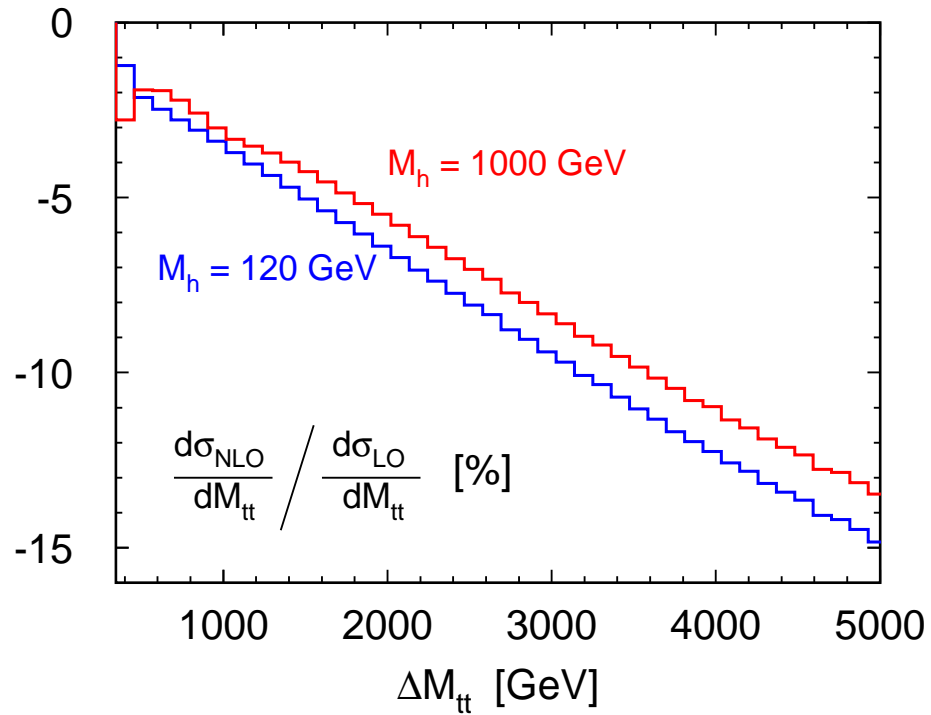
Hadronic Results for LHC

- Leading order distributions
- invariant top quark pair mass: $M_{t\bar{t}}$
- transverse momentum of the top quark: p_T



Hadronic Results for LHC

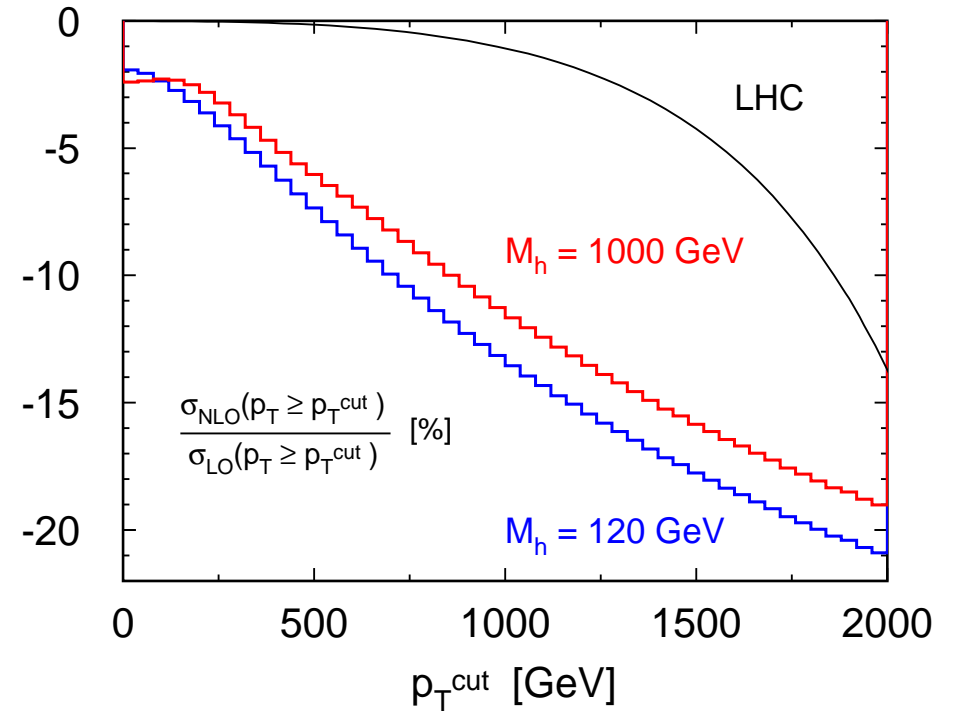
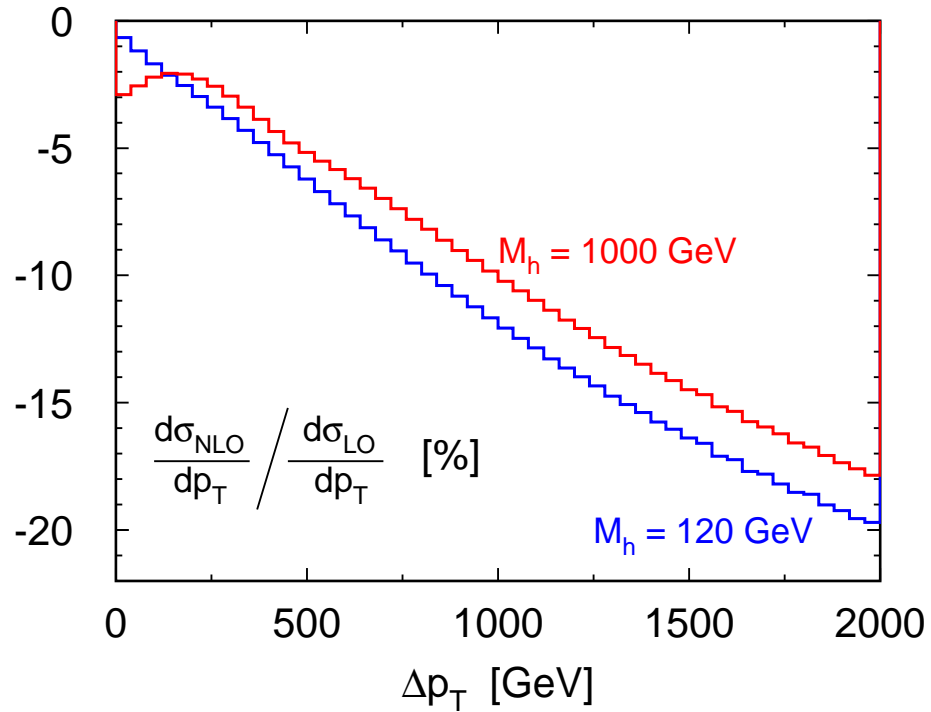
● relative corrections to $M_{t\bar{t}}$



$$\int \mathcal{L} dt = 200\text{fb}^{-1}$$

Hadronic Results for LHC

● relative corrections to p_T

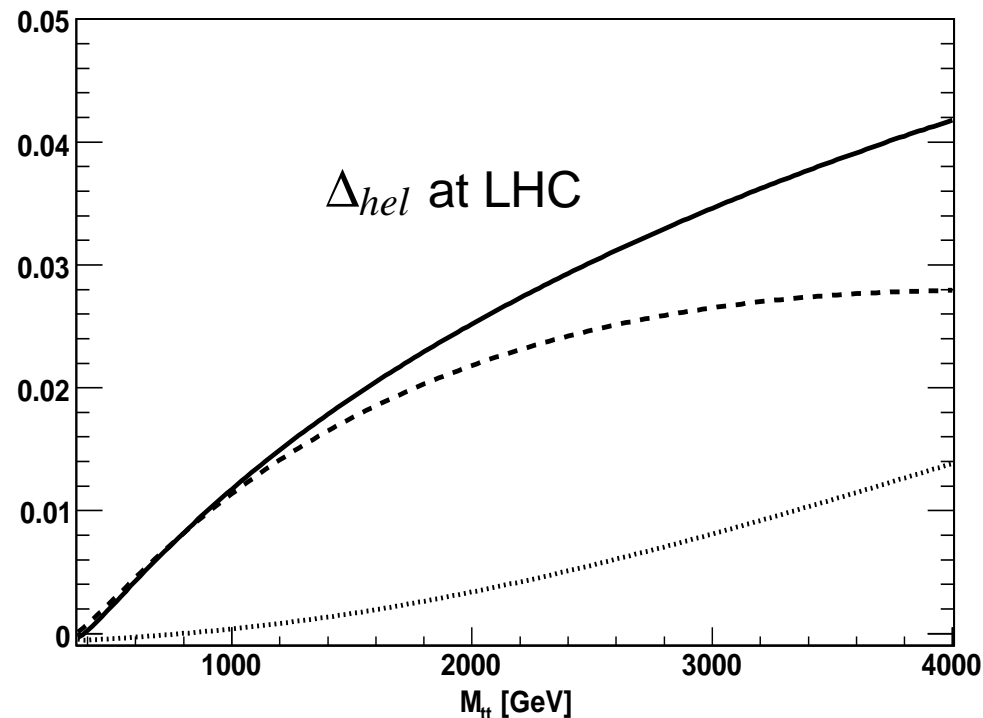


$$\int \mathcal{L} dt = 200\text{fb}^{-1}$$

- Weak corrections \rightarrow P-violating spin asymmetries, especially t (and \bar{t}) polarization along helicity axis.

- Consider PV single t spin asymmetry $+$, $-$ refer to t helicity

$$\Delta_{hel} = \frac{1}{N} \left(\frac{d\sigma_+}{dM_{t\bar{t}}} - \frac{d\sigma_-}{dM_{t\bar{t}}} \right) \quad (\Delta_{hel} \text{ is equal to double } t\bar{t} \text{ spin asymmetry } \frac{d\sigma_{+-}}{dM_{t\bar{t}}} - \frac{d\sigma_{-+}}{dM_{t\bar{t}}})$$



- $\Delta_{hel} \rightarrow$ leptonic asymmetries in $\ell\ell$ and $\ell + j$ channels:

$$pp, p\bar{p} \rightarrow t\bar{t}X \rightarrow \ell^+ + X:$$

- Angular distribution:

$$\frac{1}{\sigma} \frac{d\sigma}{d\cos\theta_+} = \frac{1}{2} (1 + B \cos\theta_+)$$

with

$$\theta_+ = \angle(\ell^+, t), \quad B = c_\ell \int dM_{t\bar{t}} \Delta_{hel} / \sigma_{t\bar{t}}$$

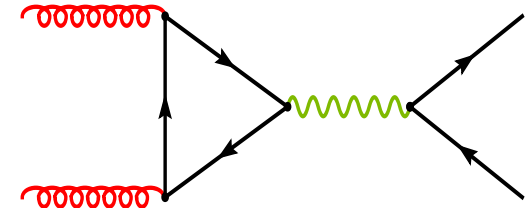
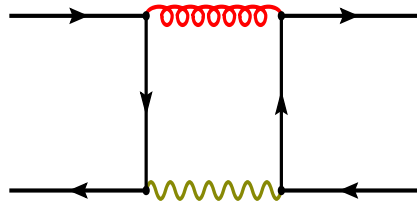
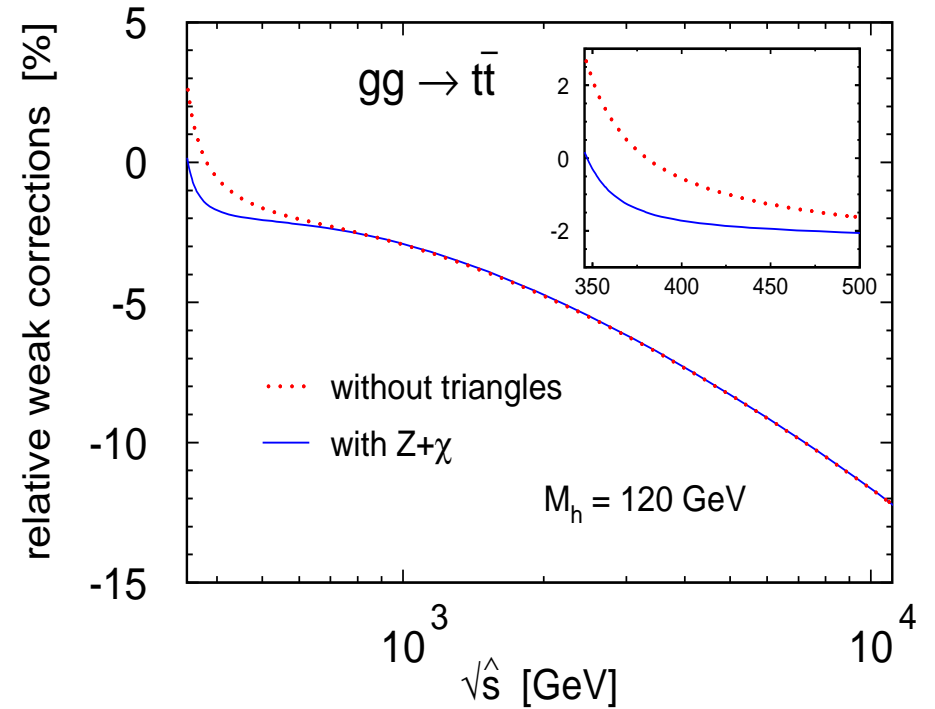
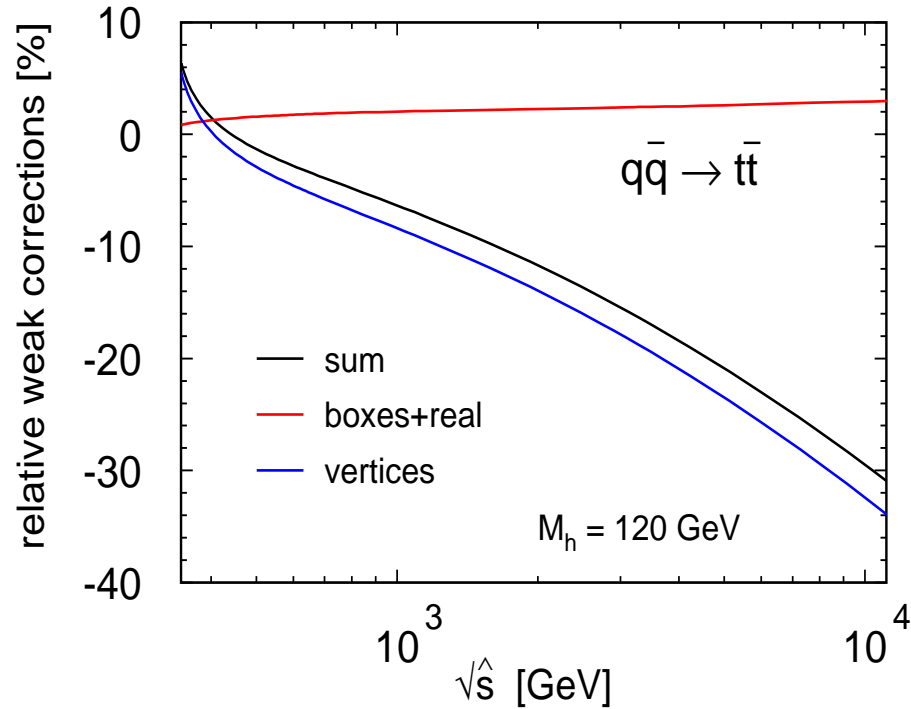
$$|B|_{SM} \leq 2\% \text{ at LHC for events with minimum } M_{t\bar{t}} \leq 1.5 \text{ TeV}$$

Summary

- corrections of order $\alpha_s^2\alpha$ to top quark pair production are known analytically
- small contribution to the total cross section
- **10 – 15%** corrections for $M_{t\bar{t}}$ and p_T distributions
- SM predictions for spin observables (W. Bernreuther, M. Fücker, Z.G. Si)

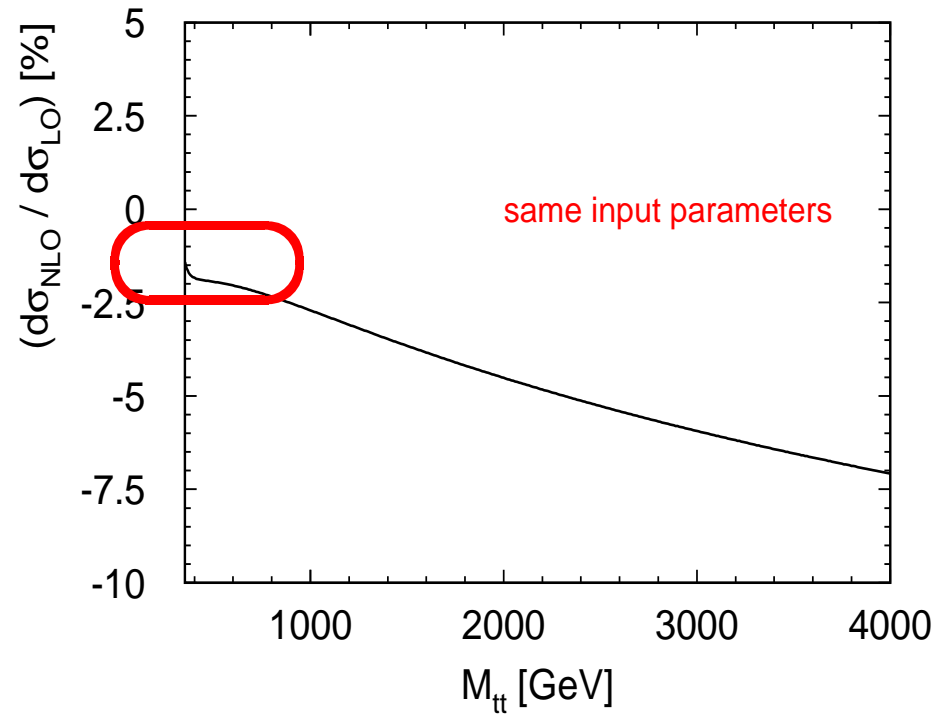
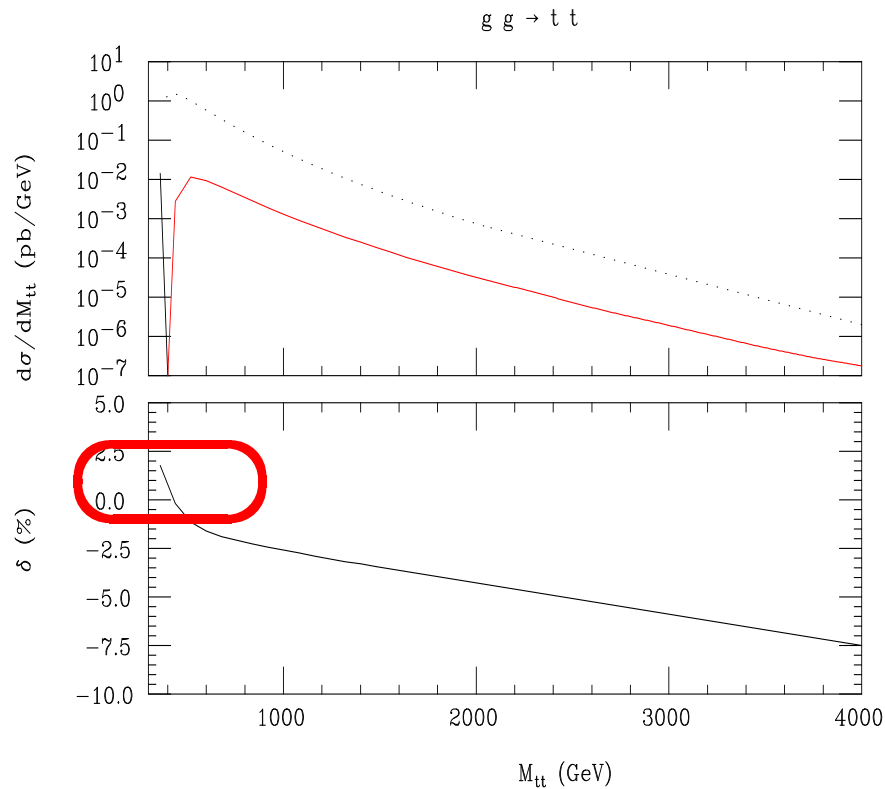
Partonic results

● missing pieces



Comparison with Moretti et al 2006

● gluon induced contributions



Hadronic results for TEVATRON

