

Recent progress in theoretical predictions for top-pair phenomenology

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Introduction

A good theoretical understanding of top-pair production is crucial for many analyses at Tevatron and LHC, be the top a *signal* (\rightarrow precise measurement of top quark properties) or a *background* in New Physics searches (\rightarrow Higgs production in VBF, SUSY...)

Top-pair phenomenology has been widely investigated since many years with impressive progress in several directions (NLO, NNLO, resummation...)

In this talk I will focus on a few (quite recent) selected topics which exemplify current improvement at NLO accuracy in the description of three benchmark processes:

- $t\bar{t} + X$
- $t\bar{t} + 1 \text{ jet} + X$
- $t\bar{t} + 2 \text{ jets} + X$

I. $t\bar{t} + X$

I. Results in the narrow-width approximation

Factorizable NLO QCD corrections to $t\bar{t}$ production with full spin correlations

↪ Investigation of QCD-induced spin correlations in double angular distributions

Bernreuther, Brandenburg, Si and Uwer (2004)

↪ Flexible Monte Carlo implementation, fully differential level

Melnikov and Schulze (2009)

Effects of mixed QCD-EW (NLOW) corrections to $t\bar{t}$ production

Bernreuther, Fücker and Si (2005-2008)

↪ Study of observables for top-spin induced correlations; charge asymmetries
for top quark and charged leptons at NLOW

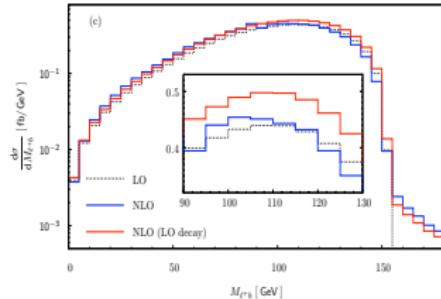
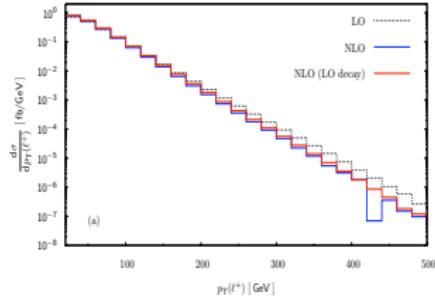
Bernreuther and Si (2010)

QCD-induced spin correlations are visible at Tevatron and LHC. Weak
interaction contributes up to several percent in certain kinematical regions

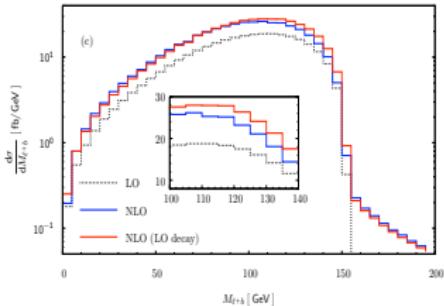
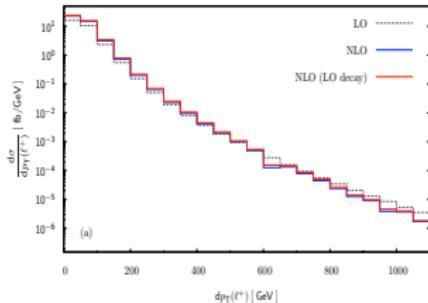
Impact of NLO QCD corrections to top quark production and decay

$(pp(p\bar{p}) \rightarrow t\bar{t} \rightarrow \ell^+\nu\ell^-\bar{\nu}bb)$

Melnikov and Schulze, 0907.3090 [hep-ph]



Tevatron

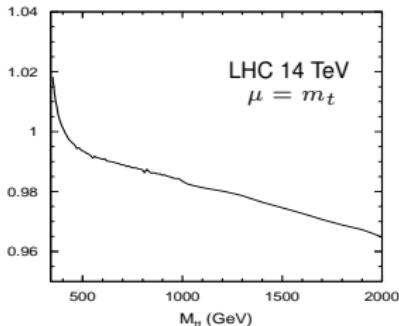


LHC
10 TeV

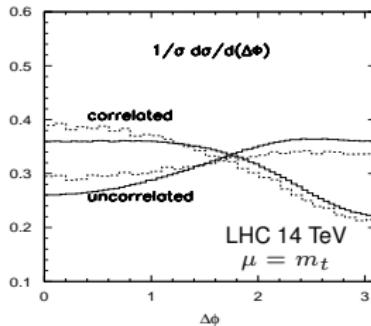
Effects of mixed weak-QCD corrections to $t\bar{t}$ production \times decay

Bernreuther and Si, 1003.3926 [hep-ph]

Ratio NLOW'/NLO'



Azimuthal angle distribution ($\ell\ell$)



Charge and $t\bar{t}$ asymmetry

	Tevatron ($(t\bar{t})$ correlated))			Tevatron ($(t\bar{t})$ uncorrelated))		
μ	$m_t/2$	m_t	$2m_t$	$m_t/2$	m_t	$2m_t$
A (NLO')	0.053	0.048	0.044	0.053	0.047	0.043
A (NLOW')	0.054	0.049	0.046	0.054	0.049	0.046
$A^{\#}$ (NLO')	0.074	0.068	0.062	0.075	0.067	0.061
$A^{\#}$ (NLOW')	0.078	0.071	0.066	0.077	0.070	0.065
A^t (NLO')	0.038	0.033	0.031	0.037	0.033	0.030
A^t (NLOW')	0.039	0.034	0.032	0.038	0.035	0.032
$A^{t\bar{t}}$ (NLO')	0.047	0.042	0.038	0.050	0.045	0.041
$A^{t\bar{t}}$ (NLOW')	0.048	0.044	0.040	0.052	0.047	0.043

$$A^\ell = \frac{\int_{y>0} N_{\ell+}(y) - \int_{y>0} N_{\ell-}(y)}{\int_{y>0} N_{\ell+}(y) + \int_{y>0} N_{\ell-}(y)}$$

$$A^{\ell\ell} = \frac{\int N(\Delta y_\ell > 0) - \int N(\Delta y_\ell < 0)}{\int N(\Delta y_\ell > 0) + \int N(\Delta y_\ell < 0)}$$

$$A^{t\bar{t}} = \frac{\int N(\Delta y > 0) - \int N(\Delta y < 0)}{\int N(\Delta y > 0) + \int N(\Delta y < 0)}$$

II. Beyond the narrow-width approximation

Complete off-shell effects to $t\bar{t}$ production at NLO QCD

↪ non-factorizable, single-resonant, non-resonant

Two independent calculations with per-mille agreement:

- $pp(p\bar{p}) \rightarrow W^+W^-b\bar{b} \rightarrow e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}$

Denner, Dittmaier, Kallweit and Pozzorini (2010)

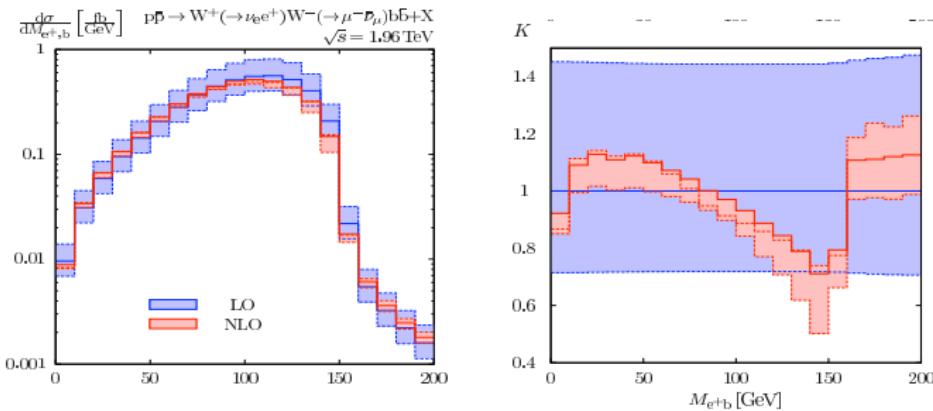
- $pp(p\bar{p}) \rightarrow e^+\nu_e\mu^-\bar{\nu}_\mu b\bar{b}$

GB, Czakon, van Hameren, Papadopoulos and Worek (2010)

With inclusive cuts, finite-width effects on the integrated cross section
are small (within $\sim 1\%$) both at the Tevatron and the LHC

Invariant mass of the positron– b -jet system (M_{e+b}) at the Tevatron

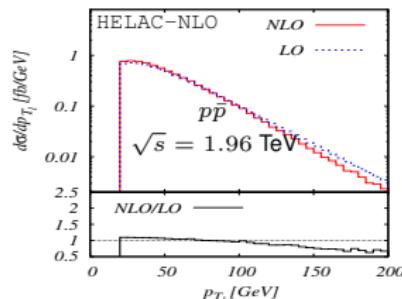
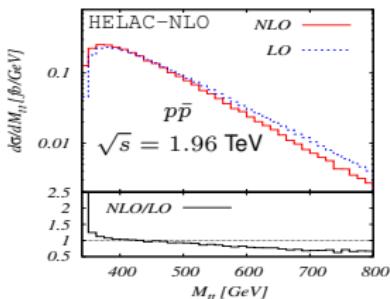
Denner, Dittmaier, Kallweit and Pozzorini, 1012.3975 [hep-ph]



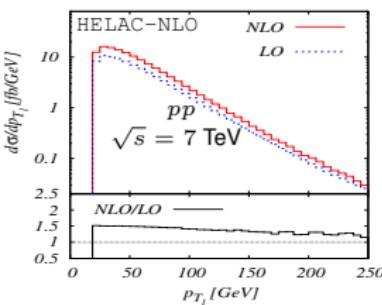
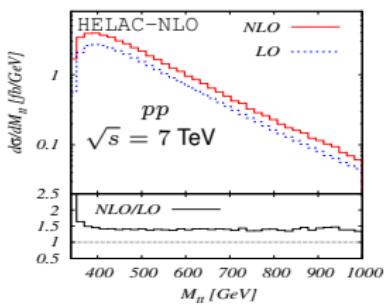
Residual scale uncertainty $\sim 9\%$ at both Tevatron and LHC

Invariant mass of the $t\bar{t}$ system and p_T of the charged leptons

GB, Czakon, van Hameren, Papadopoulos and Worek, 1012.4230 [hep-ph]



Tevatron



LHC
7 TeV

Moderate K -factor at Tevatron, but also more relevant shape distortions w.r.t LHC

II. $t\bar{t} + 1 \text{ jet} + X$

Status

Complete phenomenological studies at NLO QCD

- $pp(p\bar{p}) \rightarrow t\bar{t}j$
Dittmaier, Uwer and Weinzierl (2008)
- $pp(p\bar{p}) \rightarrow t\bar{t}j \rightarrow \ell\nu\ell\nu b\bar{b}j/\ell\nu j_1 j_2 b\bar{b}j$ (with LO top decays)
Melnikov and Schulze (2010)

First results of NLO+PS matching recently started to appear!

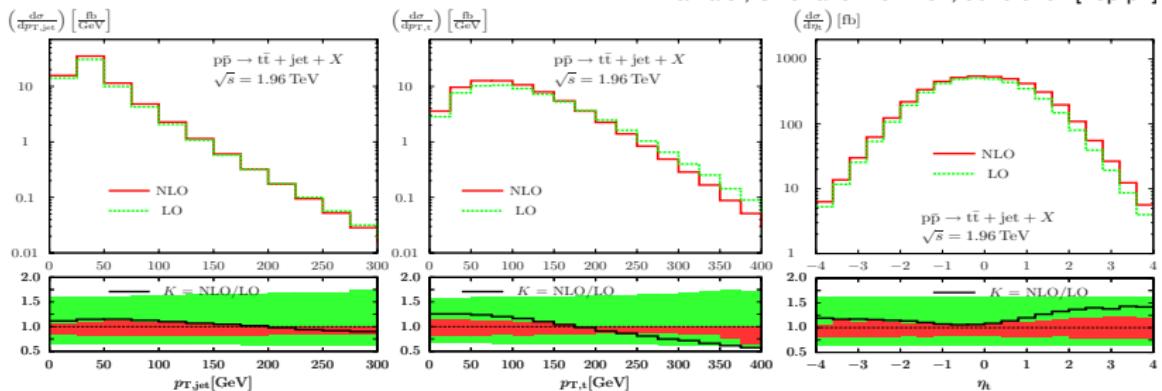
↪ Two calculations based on the POWHEG method

Kardos, Papadopoulos and Trocsanyi (2011)

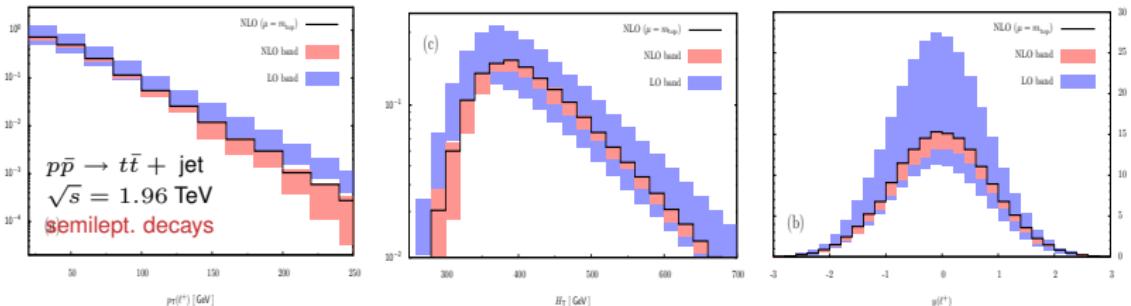
Alioli, Moch and Uwer (in progress)

NLO QCD corrections to $t\bar{t}$ production: focus on the Tevatron case

Dittmaier, Uwer and Weinzierl, 0810.0452 [hep-ph]



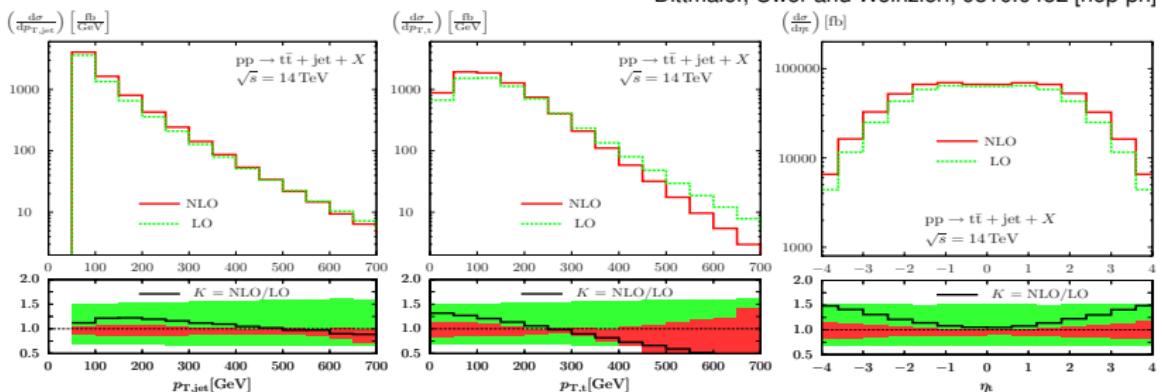
Melnikov and Schulze, 1004.3284 [hep-ph]



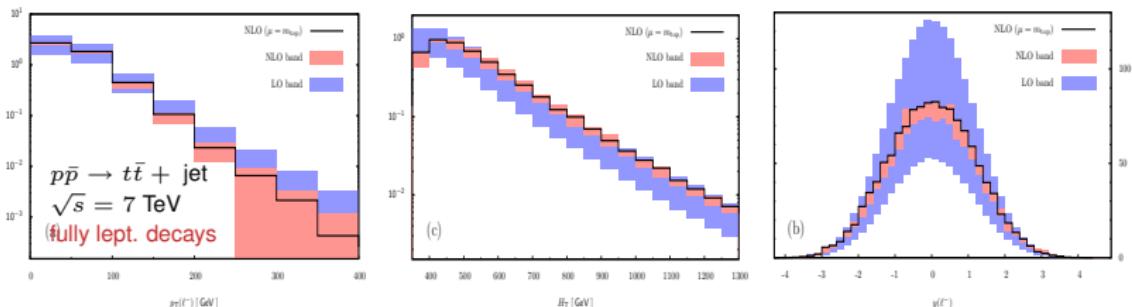
Top quark asymmetry significantly decreased at NLO

NLO QCD corrections to $t\bar{t}j$ production: the LHC case

Dittmaier, Uwer and Weinzierl, 0810.0452 [hep-ph]



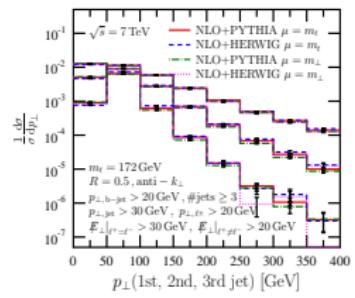
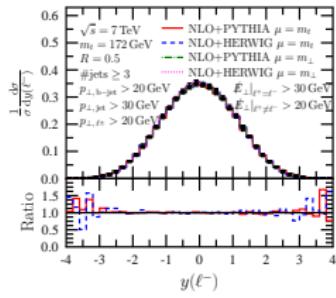
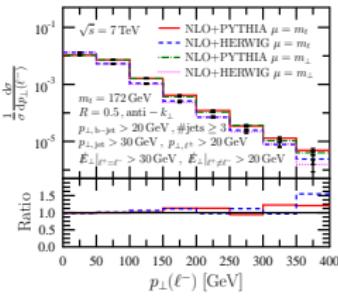
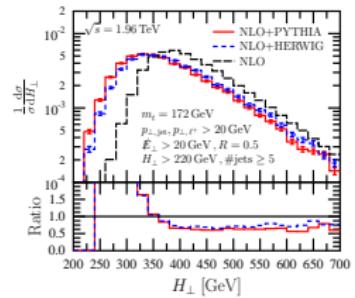
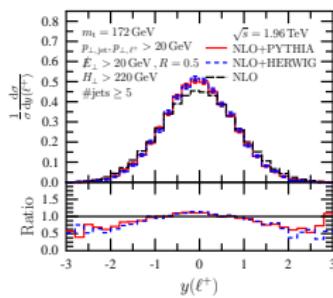
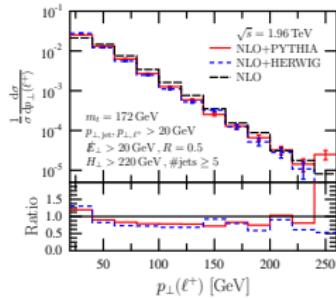
Melnikov and Schulze, 1004.3284 [hep-ph]



The ratio $\sigma(t\bar{t}j)/\sigma(t\bar{t})$ at NLO is about 47%, 22%, and 7% for jet- p_T cuts of 50 GeV, 100 GeV and 200 GeV respectively

NLO+PS matching with POWHEG

Kardos, Papadopoulos and Trocsanyi, 1101.2672 [hep-ph]



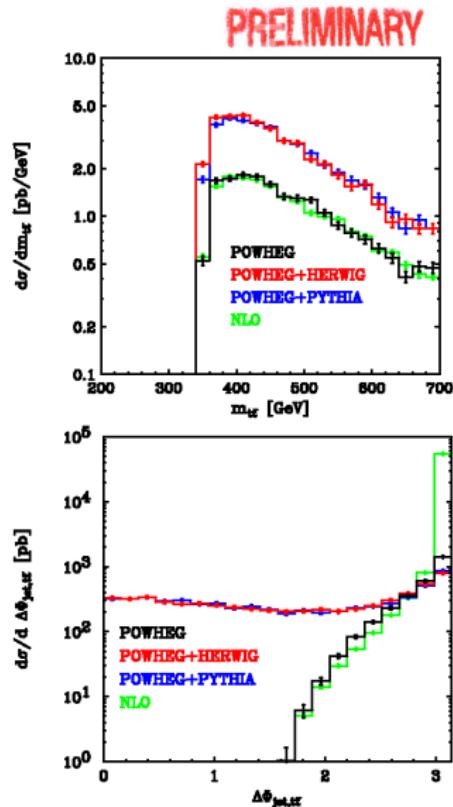
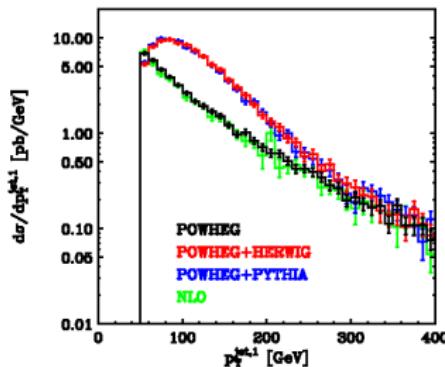
Visible showering effects in rapidity and H_T distributions

Shapes rather robust against different scale choices

NLO+PS matching with POWHEG

from S. Alioli's talk, Workshop on Heavy Particles at the LHC (Jan 2011)

MATCHING WITH SHOWER



- Results for LHC show more marked differences after shower also for inclusive observables
- Different jet cut: $p_T^{\text{jet}} > 50$ GeV
- Similar behaviour for exclusive observables sensible to shower effects

III. $t\bar{t} + 2 \text{ jets} + X$

Status

One of the current frontiers in the field of associated top production at NLO

Focus on the special case $pp \rightarrow t\bar{t}b\bar{b}$:

- Two NLO QCD calculations with per-mille agreement

Bredenstein, Denner, Dittmaier and Pozzorini (2009)

G.B. Czakon, Papadopoulos, Pittau and Worek (2009)

- Detailed phenomenological study with different kinematical setups

Bredenstein, Denner, Dittmaier and Pozzorini (2010)

More recently, the first complete results on $pp \rightarrow t\bar{t}jj$ at NLO QCD have also started to appear

G.B. Czakon, Papadopoulos and Worek (2010)

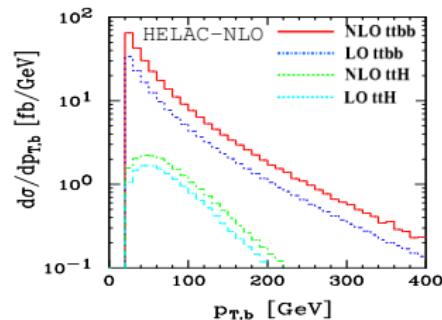
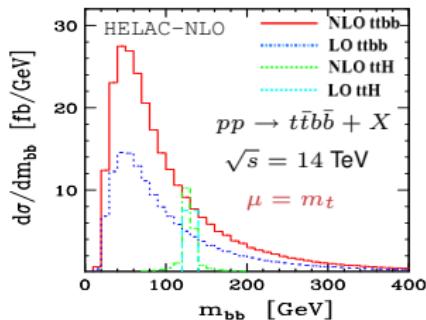
Top quarks treated as stable particles, no decay implemented yet

Some results on $pp \rightarrow t\bar{t}b\bar{b}$ at NLO QCD:

QCD background vs Higgs signal $t\bar{t}H(H \rightarrow b\bar{b})$

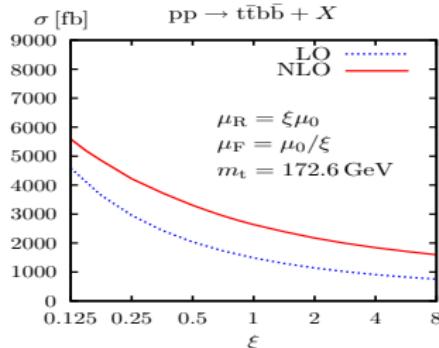
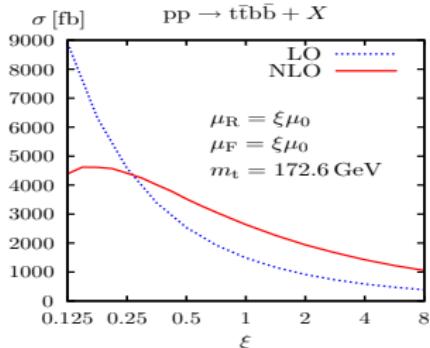
G.B. Czakon, Papadopoulos, Pittau, Worek, arXiv: 0907.4723 [hep-ph]

G.B. Czakon, Garzelli, Papadopoulos, Pittau, Worek, arXiv:1003.1241 [hep-ph]



Scale dependence of the QCD background

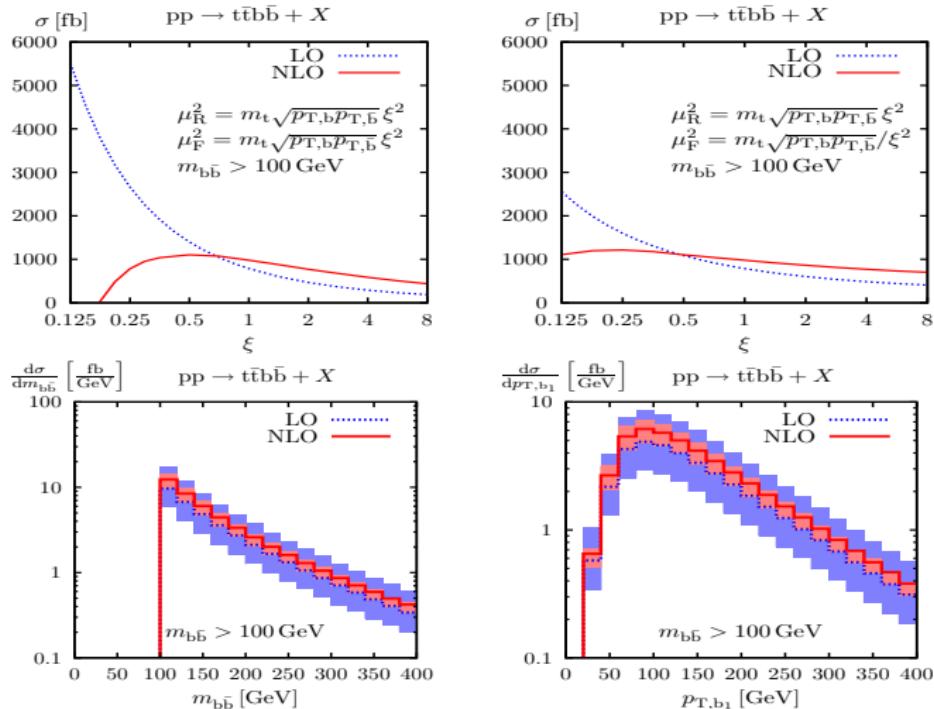
Bredenstein, Denner, Dittmaier and Pozzorini, 0905.0110 [hep-ph]



With fixed-scale choice, QCD corrections to $t\bar{t}b\bar{b}$ are large ($\sim 77\%$ at the central scale)

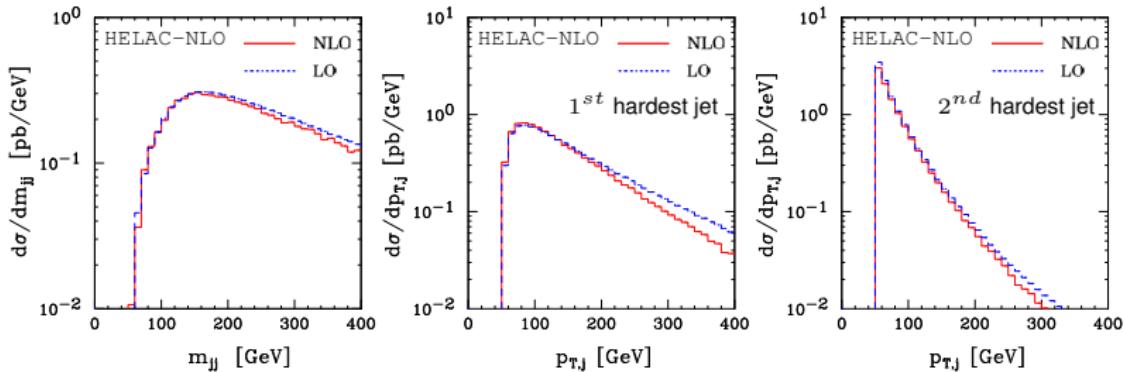
Improved convergence adopting dynamical scale: $\mu^2 = m_t \sqrt{p_{T,b} p_{T,\bar{b}}}$

Bredenstein, Denner, Dittmaier and Pozzorini, 1001.4006 [hep-ph]



Complete NLO QCD corrections to $pp \rightarrow t\bar{t}jj$

G.B, Czakon, Papadopoulos, Worek, arXiv:1002.4009 [hep-ph]



- QCD corrections determine a shift of -11% compared to LO
- residual scale uncertainty $\sim 13\%$
- tiny corrections in the dijet invariant mass, up to at least $m_{jj} = 200$ GeV
- much larger effects in jet p_T distributions, especially in the high- p_T region

Summary

The investigation of top-pair production and related phenomenology at **NLO** has reached in the last years a quite sophisticated level...

	FO Inclusive	FO Exclusive		PS matching
		NWA	Full	
$t\bar{t}$	✓	✓	✓	✓
$t\bar{t}j$	✓	✓	✗	✓
$t\bar{t}jj$	✓	✗	✗	✗

...but there is lot of room for new developments!