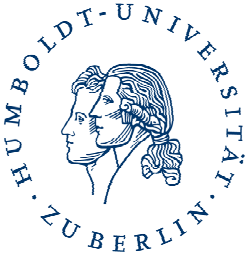


Electroweak corrections in top physics: 1) Top-quark pair production

Peter Uwer

Humoldt-Universität
zu Berlin

Content

Two talks on EW:

Davide's talk: ttV, ttH, single top-quark production,
Charge asymmetry in tt,

This talk:

- Focus on top-quark pair production
- Main aspect: are we sensitive to EW corrections in run 2?

Outline:

1. Introduction
2. Weak corrections to top-quark pair production
3. QED corrections to top-quark pair production
4. Summary

To constrain weak couplings better use single-top and top-quark decays

Why are EW corrections important ?

- In the SM top-quark decays weakly
- EW corrections maybe relevant aiming for ultimate precision:

Naïve power counting: $(\alpha_s \approx 0.1, \alpha \approx 0.01)$

	α_s^0	α_s^1	α_s^2	α_s^3	α_s^4
α^0	—	—	100%	10%	1%
α^1	—	10%	1%	*	*
α^2	1%	*	*	*	*

QCD, MSTW2008NNLO
100% | 49 % | 17 %
Theory uncertainty ~3%

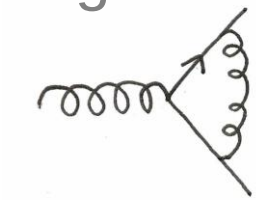
Further suppressed by PDF's

Further suppressed: qq fraction, charges,
→ per mille level contribution

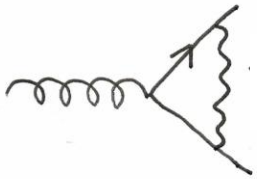
- Threshold enhancement due to attractive Yukawa interaction, sensitive to ttH coupling, difficult to measure

Why are EW corrections important ?

- Weak corrections can be enhanced at high energies due to Sudakov logs:



Soft and coll. Singularities,
→ 1/ε poles, canceled by real corrections



Potential sing. regularized by gauge boson masses

$$\rightarrow \log^2(p_\perp/M_W), \log^2(p_\perp/M_Z)$$

(no theoretical need to include real corrections, "different final state")

Incl. quantities often dominated by "threshold" region → Sudakov enhancement not important, large effects possible in differential distributions at large momentum transfer

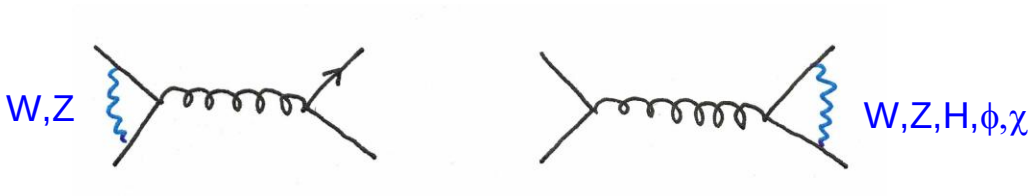
- Relevant for new physics searches using observables which vanish in plain QCD due to parity conservation (→ top-quark polarization)

Sample diagrams

Photonic corrections and weak corrections can be treated separately

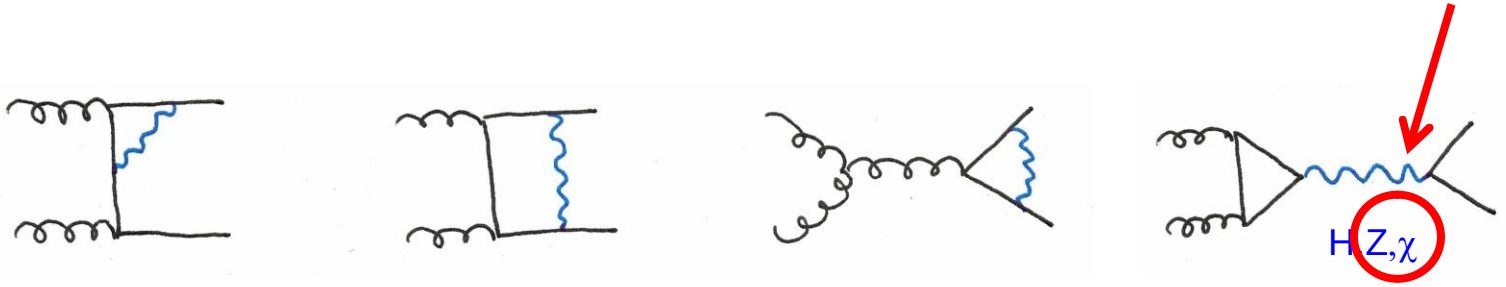
Weak corrections to qq→tt:

[Beennakker, Denner, Hollik, Mertig, Sack, Wackeroth '94, Bernreuther, Fücker, Si '05,'06, Moretti, Nolten, Ross '06, Kühn,Scharf,PU '05,'06,'14]



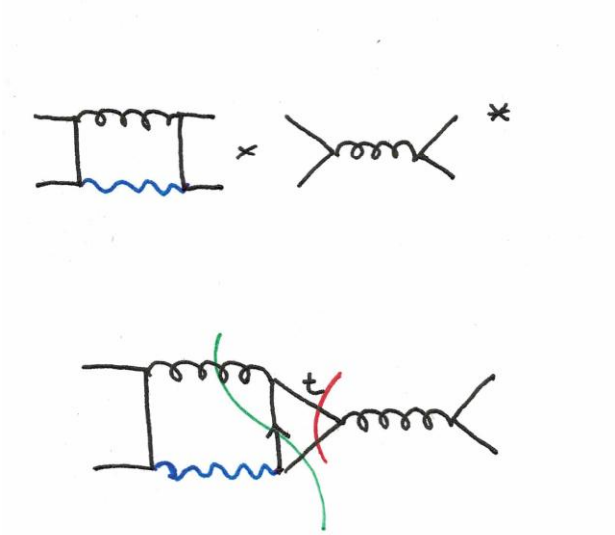
Not considered in Beenakker et al

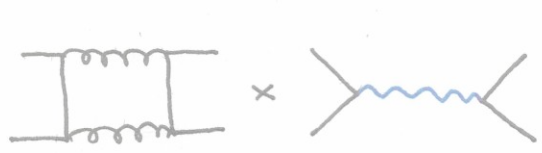
Weak corrections to gg→tt:

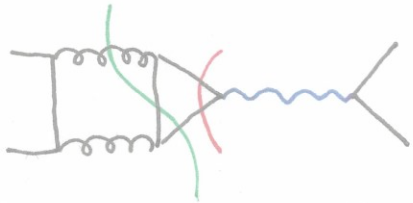


IR divergent box contributions

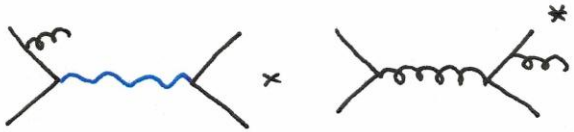
Virtual contributions:







Real contributions:



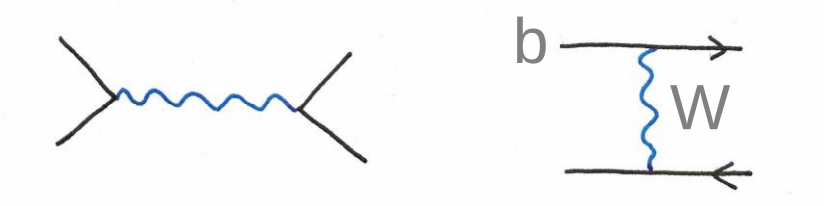
No Sudakov enhancement, small correction further suppressed through gg dominance at LHC

Note: qq ←→ gg mixture depends on energy!

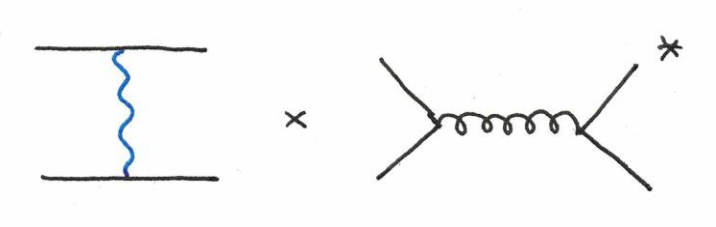
Further corrections without Sudakov enhancement

- bb→tt in 5-flavour scheme

[Bernreuther, Fücker, Si '06,'08]

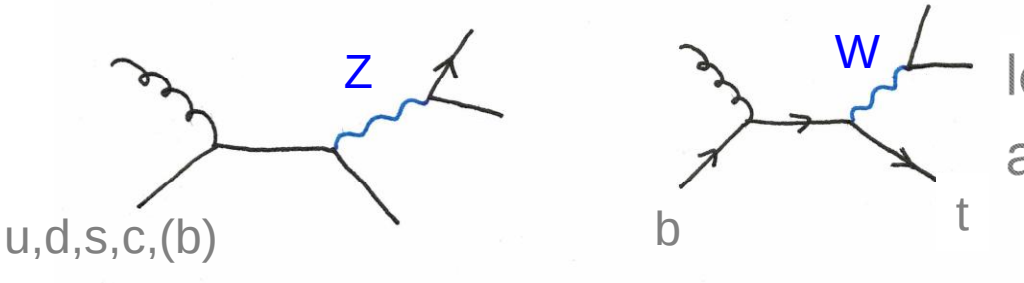


Leads to $\alpha\alpha_s$ contribution:



Not forbidden by color, suppressed however through b-PDF

- qg → ttq

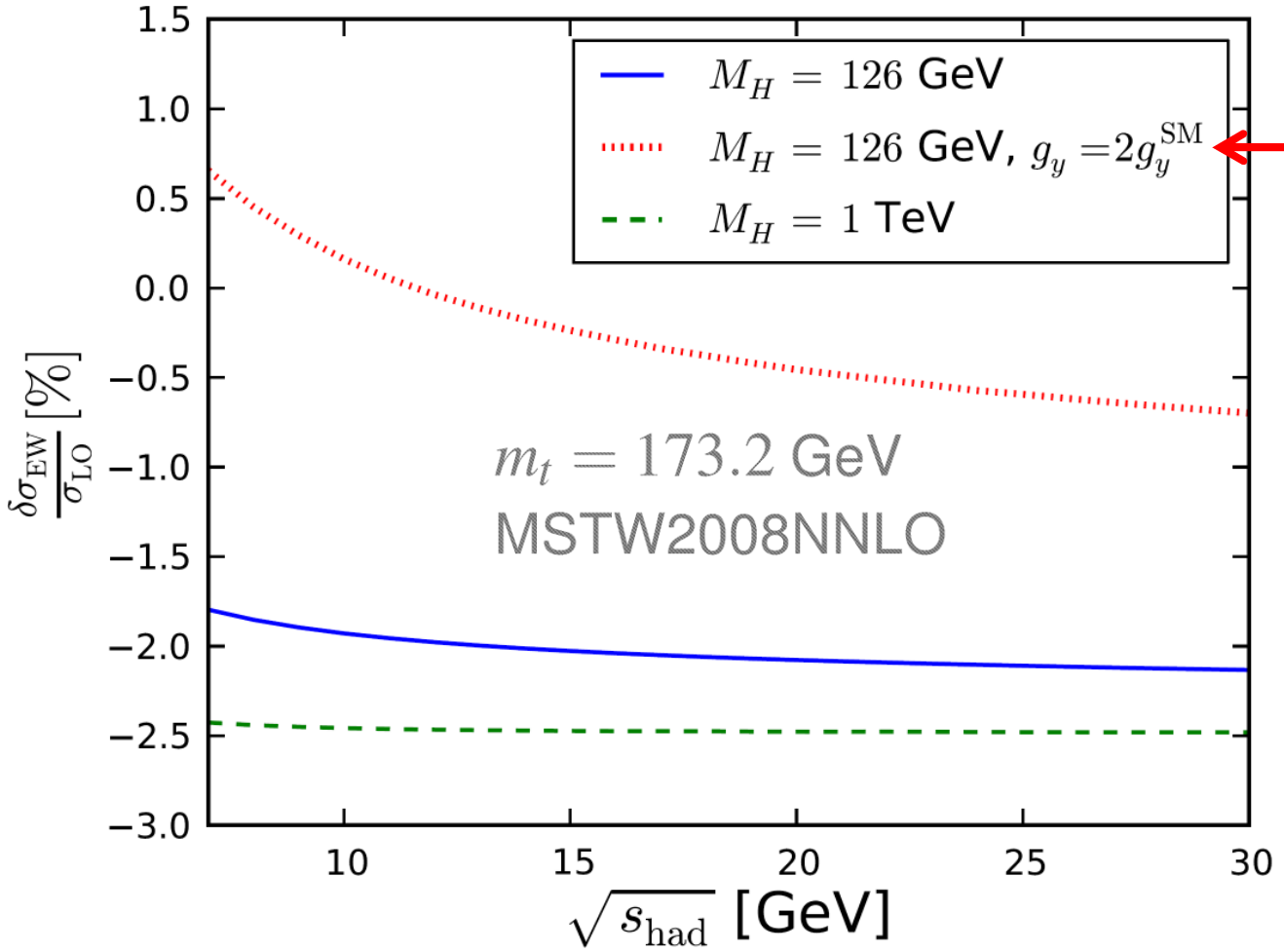


leads to $\alpha\alpha_s^2$ and $\alpha^2\alpha_s$ contr.

→ Tiny contribution to cross sections, can be relevant for dedicated spin observables

Weak corrections — inclusive cross section

[Kühn,Scharf,PU '14]



For illustration only!

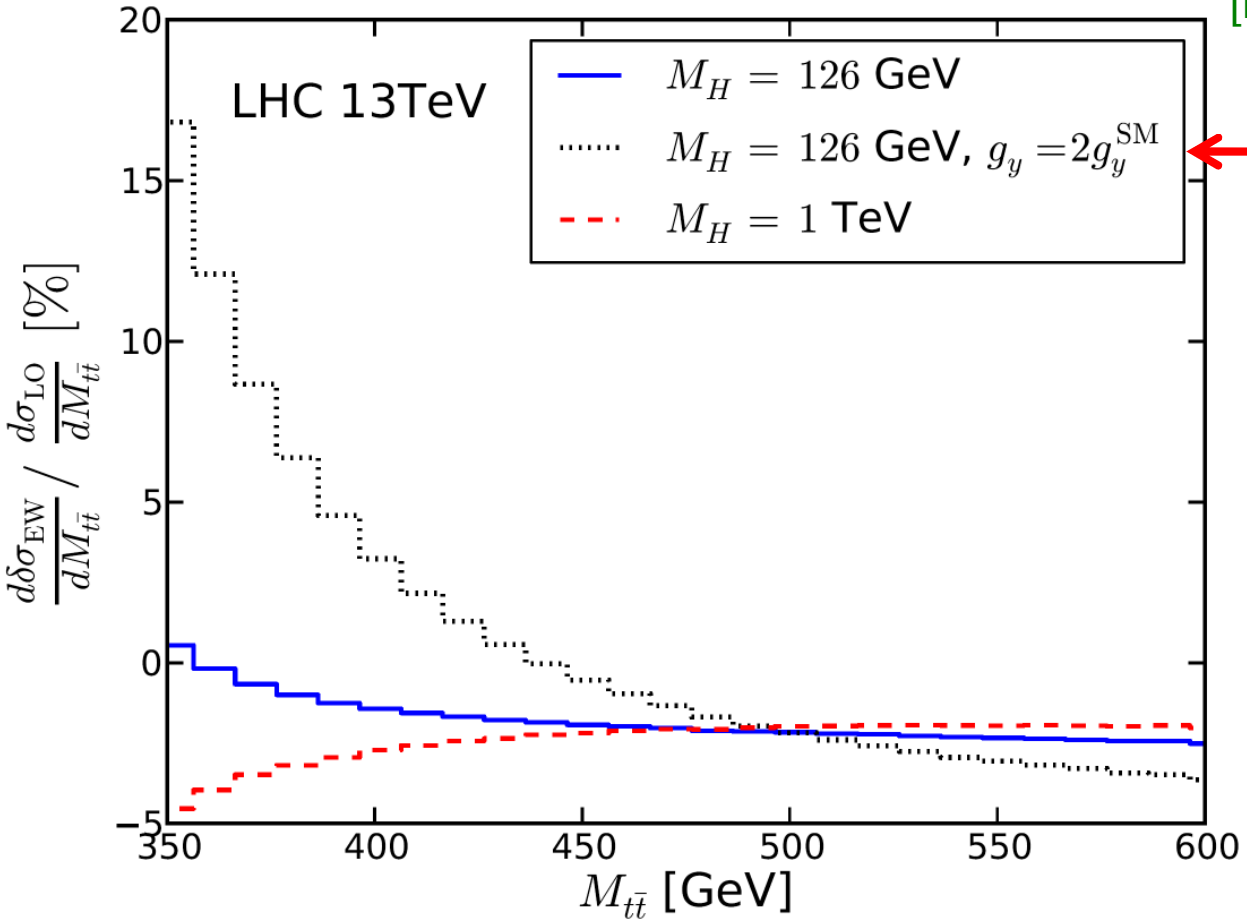
Similar results: [Beenakker et al], [Bernreuther, Fücker, Si] [Moretti,Nolten,Ross]

Note: Normalized to LO cross section !

Weak corrections — distributions

Threshold enhancement due to attractive Yukawa interaction

[Kühn,Scharf,PU '14]



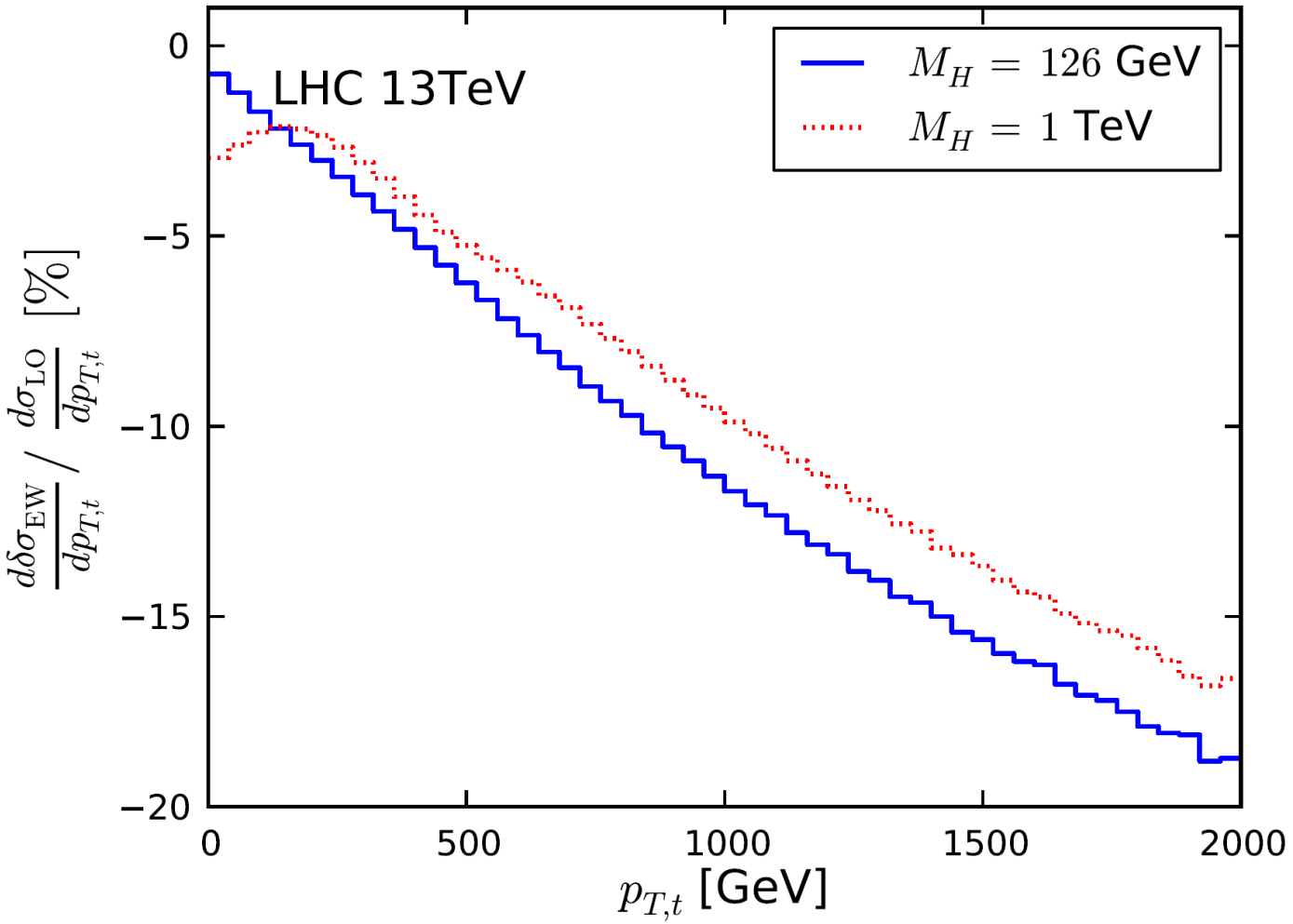
For illustration only!

$$\frac{\delta\sigma_{\rm EW}^{13\rm TeV}}{\sigma_{\rm LO}}(m_{t\bar{t}} < 2M_t + 50{\rm GeV}) = (-3.753 + 3.08 g_Y^2)\%$$

Most likely experimentally not accessible due to limited precision

Weak corrections — distributions

[Kühn,Scharf,PU '14]



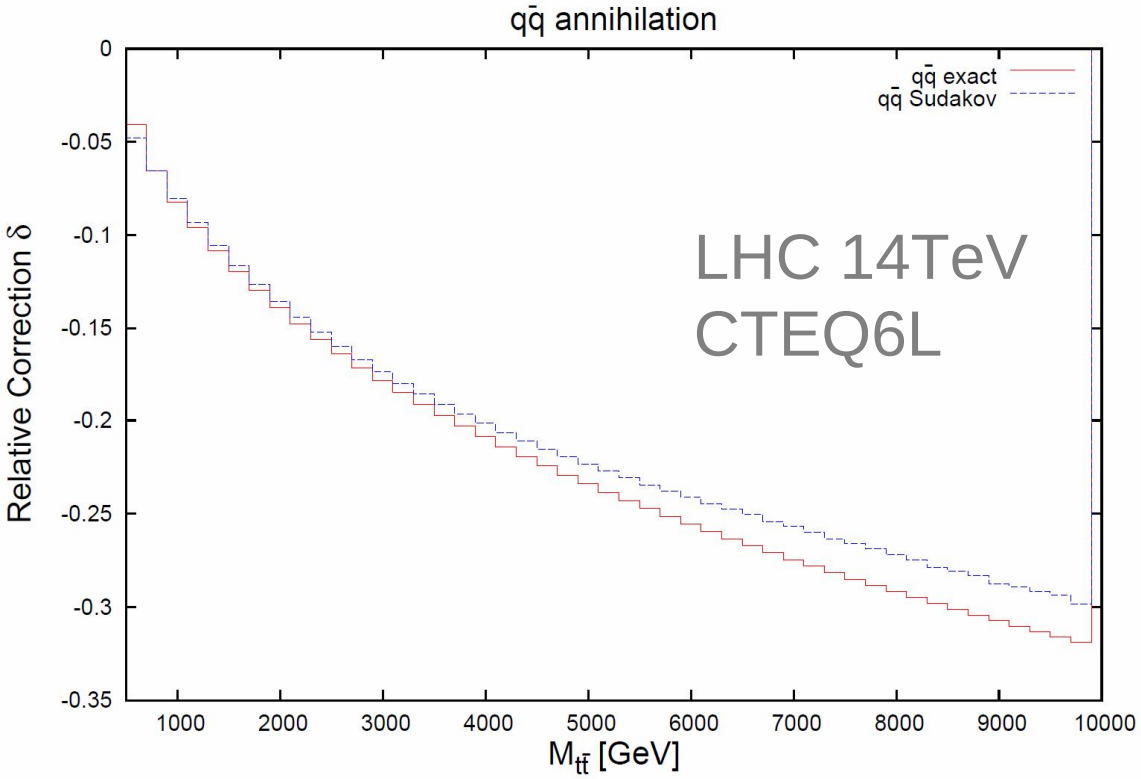
Similar results: [Beenakker et al], [Bernreuther, Fücker, Si] [Moretti,Nolten,Ross]

Difference: most up-to-date input, impact on predictions very small

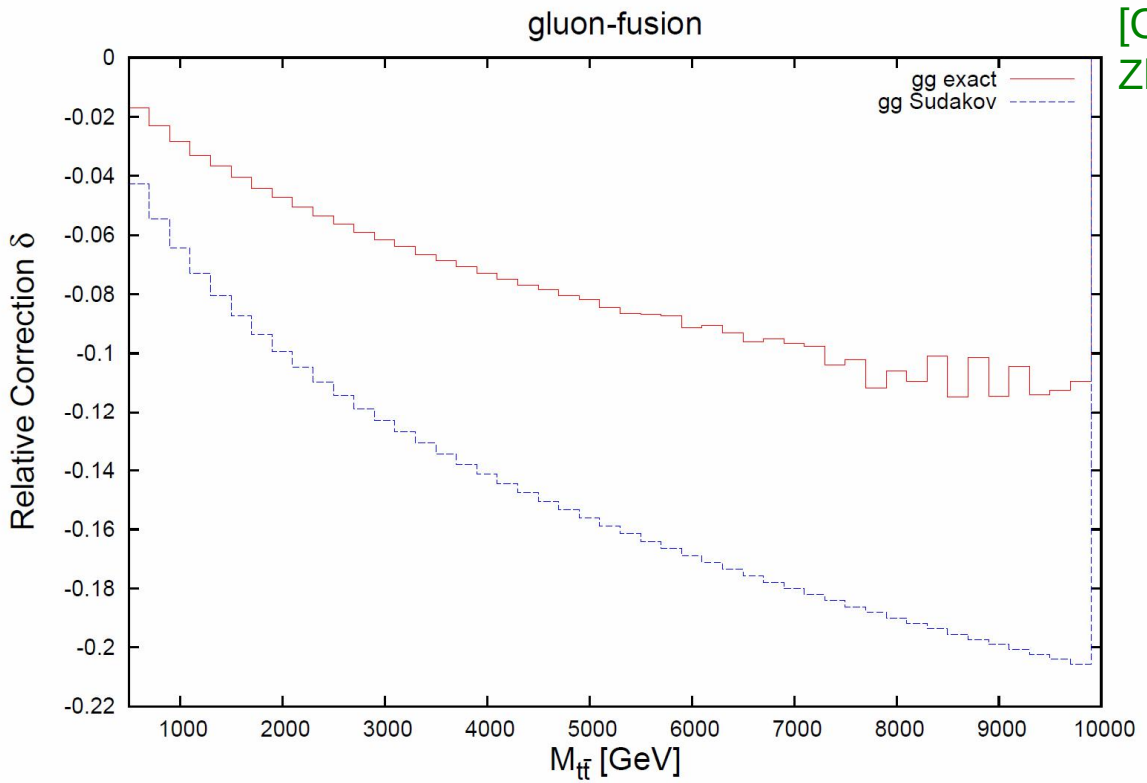
Recent developments: (E)W corrections in MCFM

- Corrections available for exp. analysis [Campbell, Wackeroth, Zhou '15]

  (2→2 contributions also available in Hathor, see also recent developments [Chiesa, Greiner, Tramontana (Gosam) '15, Denner et al (Recola) '14, Madgraph5_aMC@NLO]
- Comparison with Sudakov approximation:



Recent developments: (E)W corrections in MCFM



[Campbell, Wackeroth, Zhou '15]

LHC 14TeV, CTEQ6L

→ Reasonable approximation in case of qq

→ more complicated angular dependence in gg not well modeled

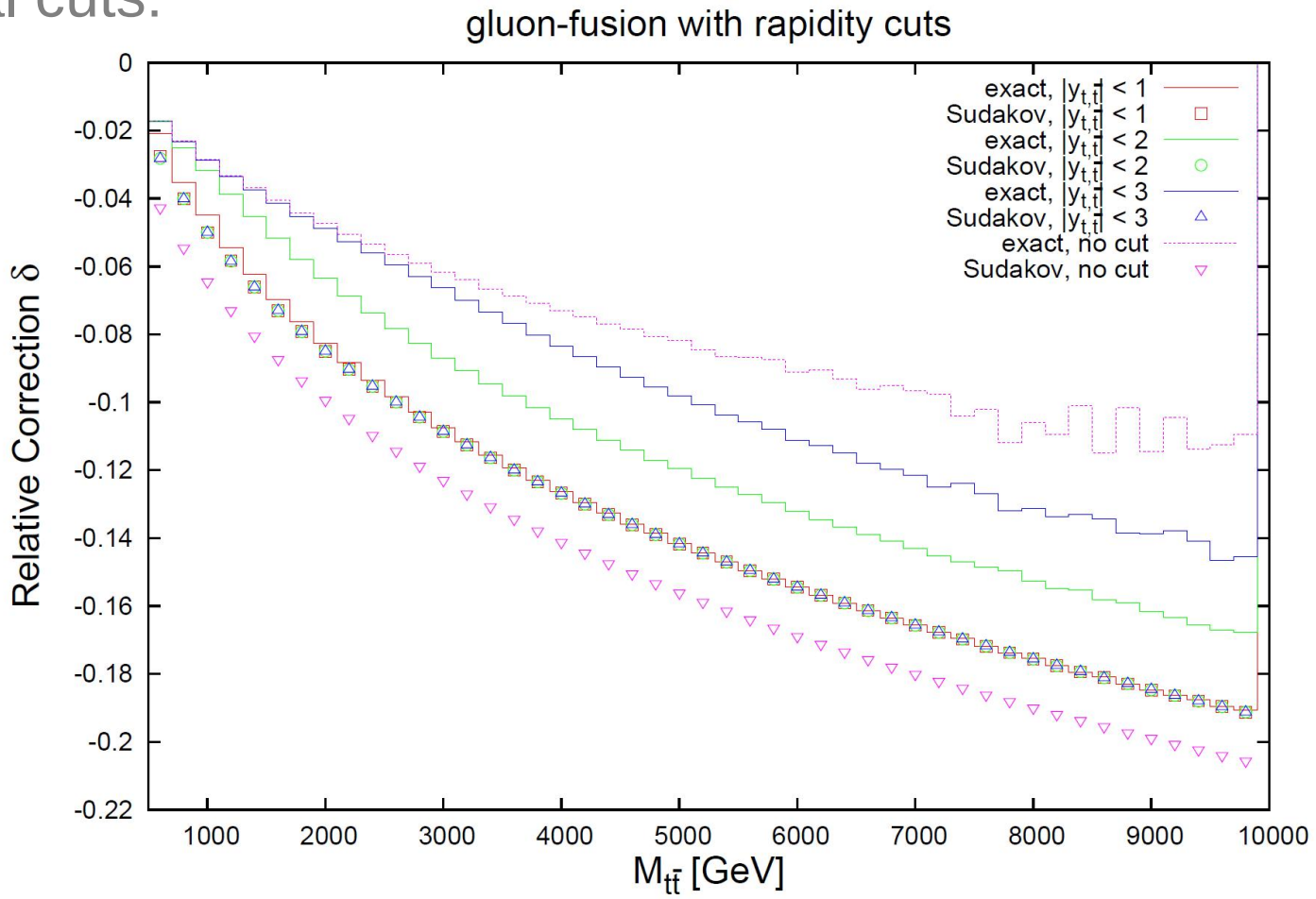
(Sudakov limit in gg requires $|\hat{t}|$ or $|\hat{u}|$ to be large

see also [Kühn,Scharf,PU '15])

Recent developments: (E)W corrections in MCFM

[Campbell, Wackeroth, Zhou '15]

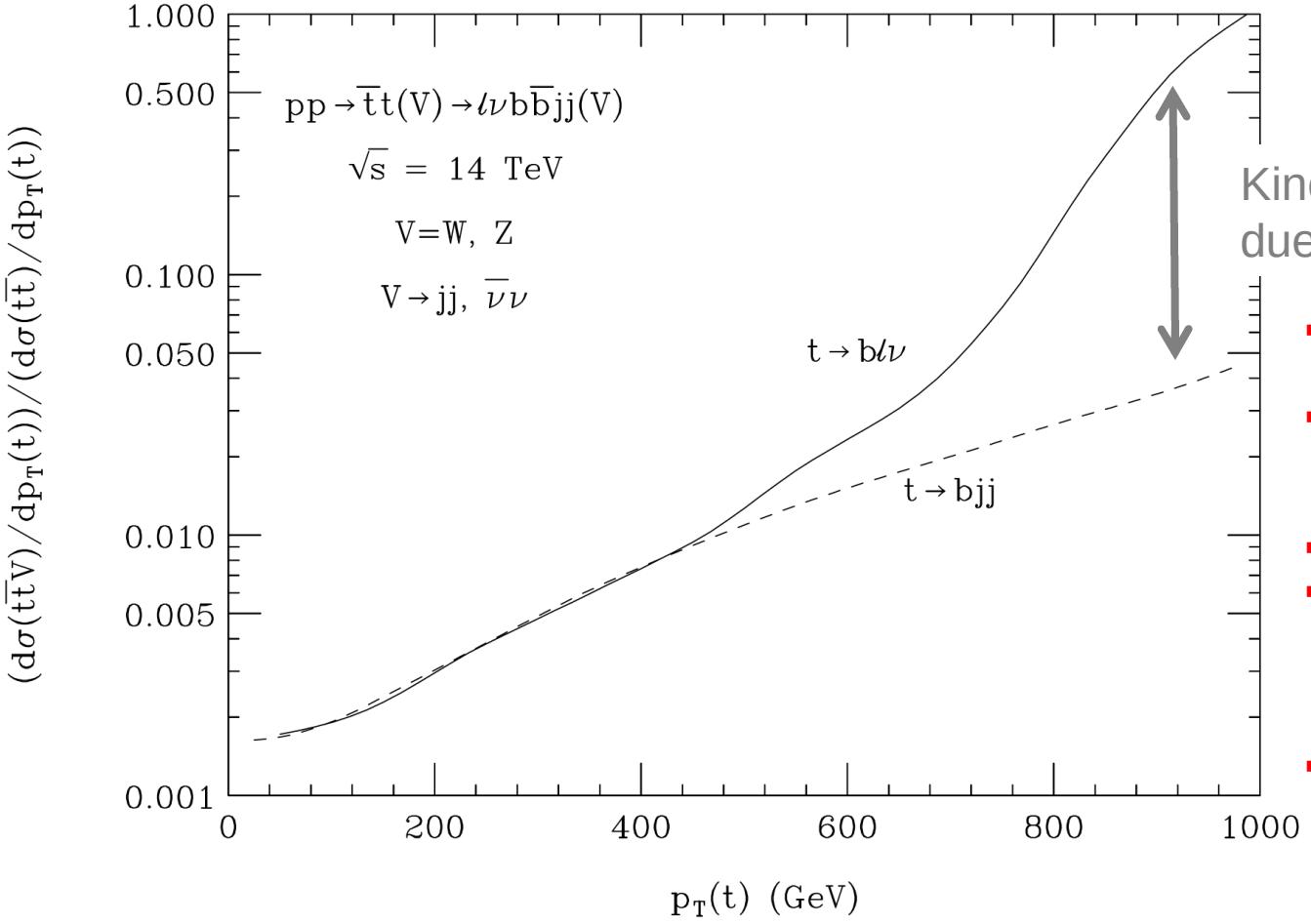
→ Accuracy of Sudakov approximation can be improved by additional cuts:



→ Reliable approximation in central region

What about real corrections ?

[Baur '06]



Kinematical effect due to separation cut

- Semileptonic final states
- Both b-quarks are assumed to be tagged
- N(j)>=2
- Only one charged lepton (suppression of ttV with V=W→lν, V=Z→ll)
- Only tt resonant diagrams

→Possible cancellation at high momentum transfer
Study should be redone using up-to-date setup

QED corrections — inclusive cross section

[Hollik, Kollar '08]

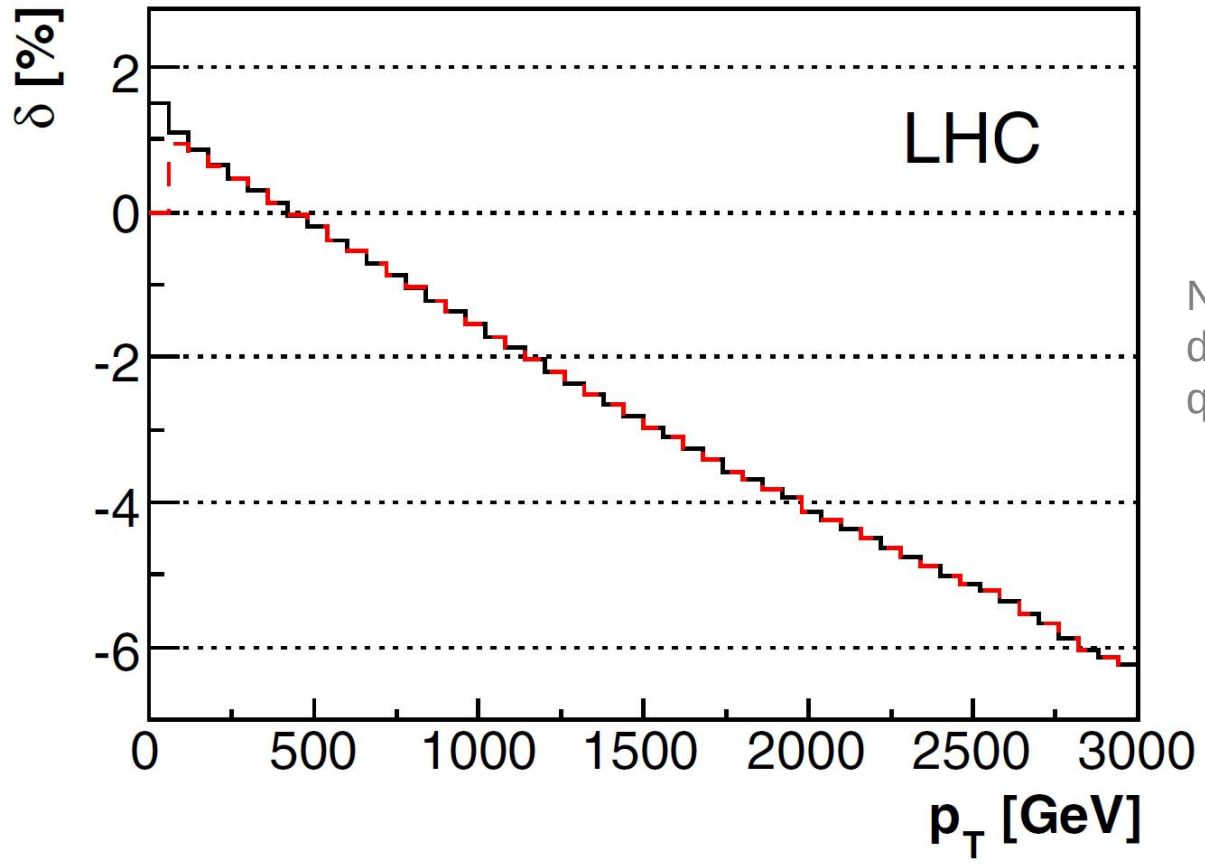
Process	σ_{tot} without cuts [pb] Born	Correction	σ_{tot} with cuts [pb] Born	Correction
$u\bar{u}$	34.25	−1.41	18.64	−0.770
$d\bar{d}$	21.61	−0.228	11.54	−1.68
$s\bar{s}$	4.682	−0.0410	2.253	−0.0304
$c\bar{c}$	2.075	−0.0762	0.9630	−0.0446
gg	407.8	2.08	213.6	0.524
$g\gamma$		4.45		2.29
pp	470.4	4.78	247.0	1.80

MRST2004 PDF set, LHC 14 TeV, DIS scheme, $\mu_F = 2m_t$

- Corrections of one percent, consistent with naïve estimate
- Large contribution from $g\gamma$ (competing effects: PDF ←→ α α_s)
- Strong cancellations between qq (<0) and gg/$g\gamma$ (>0)
- Possible cancellation between weak and photonic corrections
- PDF uncertainty of $g\gamma$ contribution?

QED corrections — distributions

[Hollik, Kollar '08]



Neg. corrections due to qq contribution

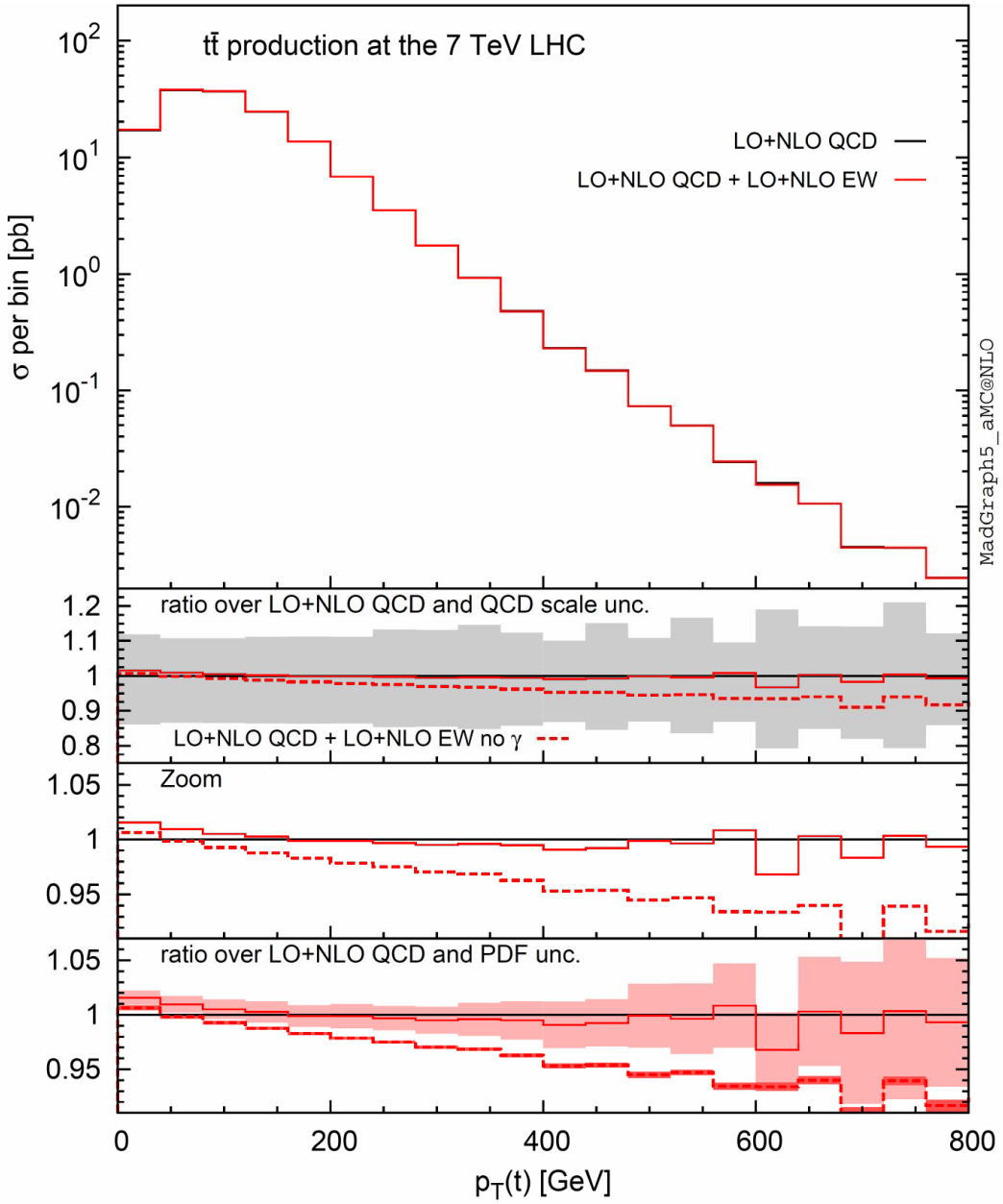
- Sizeable corrections due to logarithmically enhanced final state radiation not cancelled by virtual corrections in case of non-inclusive quantities

QED corrections – remarks

Further studies required:

- Impact of updated PDF's i.e. NNPDF, CTEQ14QED
- Uncertainty of the photon induced contributions
- Alternative scale setting
  - Phase space dependent scale
  - $\mu = m_t$
- Impact of different factorization schemes
  - DIS versus MS

Impact of photon PDF



Preliminary,
Plot provided by [Davide Pagani and Marco Zaro]

NNPDF2.3QED

Solid: full EW including contribution with photons in the initial state

Dashed: full EW without γ in the initial state

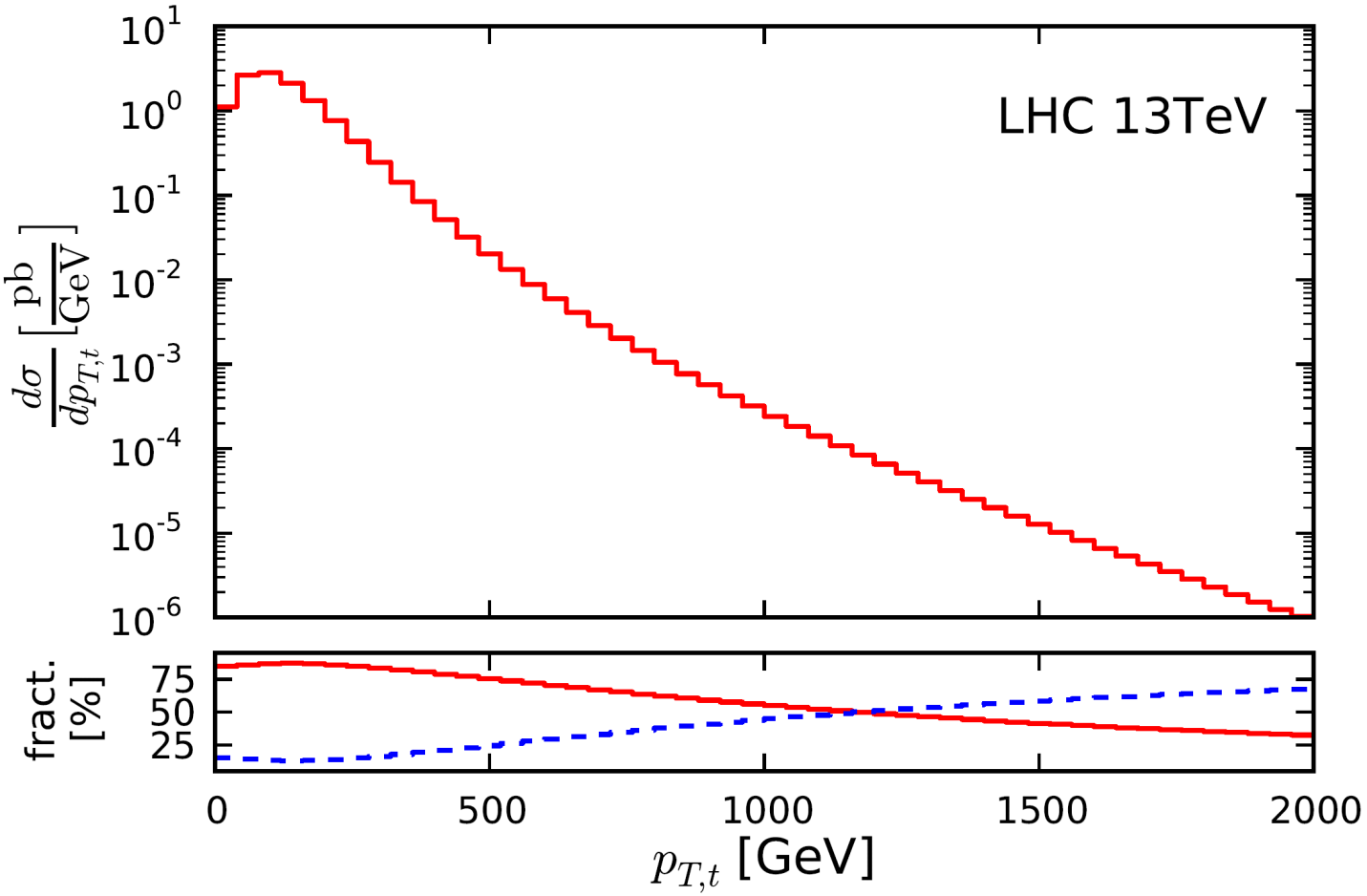
Band: PDF uncertainty

Summary

- Weak corrections to incl. cross section O(1-2%)
- Large negative corrections to distributions at large momentum transfer (-15% for pt=1.5TeV) from weak corrections
- However: possible cancellations between weak corrections and photonic/real corrections
- QED corrections reduce effects (for p_T < 800 GeV) however at the price of introducing “large” pdf uncertainties, what happens for p_T > 800 GeV ?
- Improvements on Photon PDF’s ?

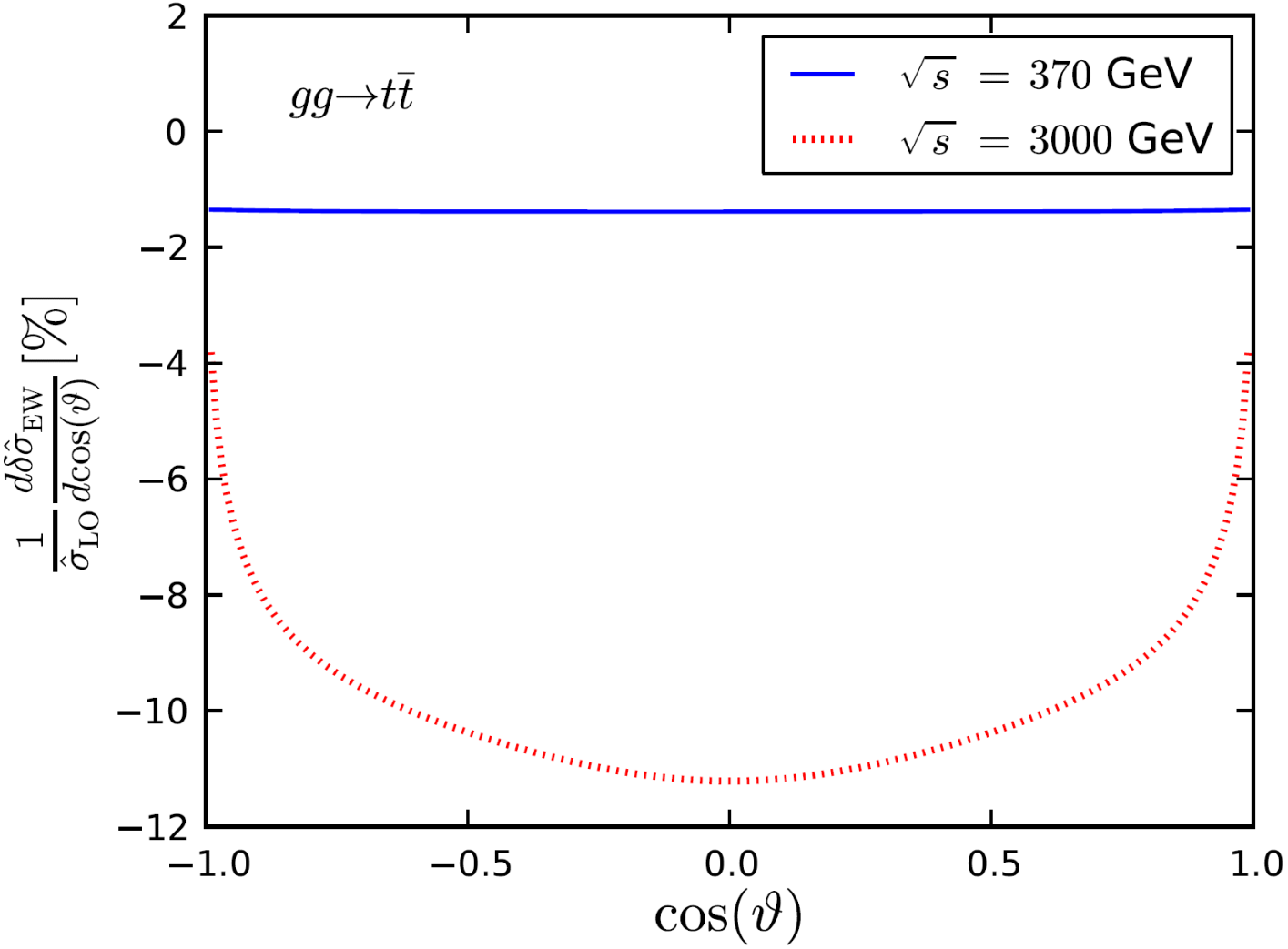
gg/qq fraction as function of pt

[Kühn,Scharf,PU '14]



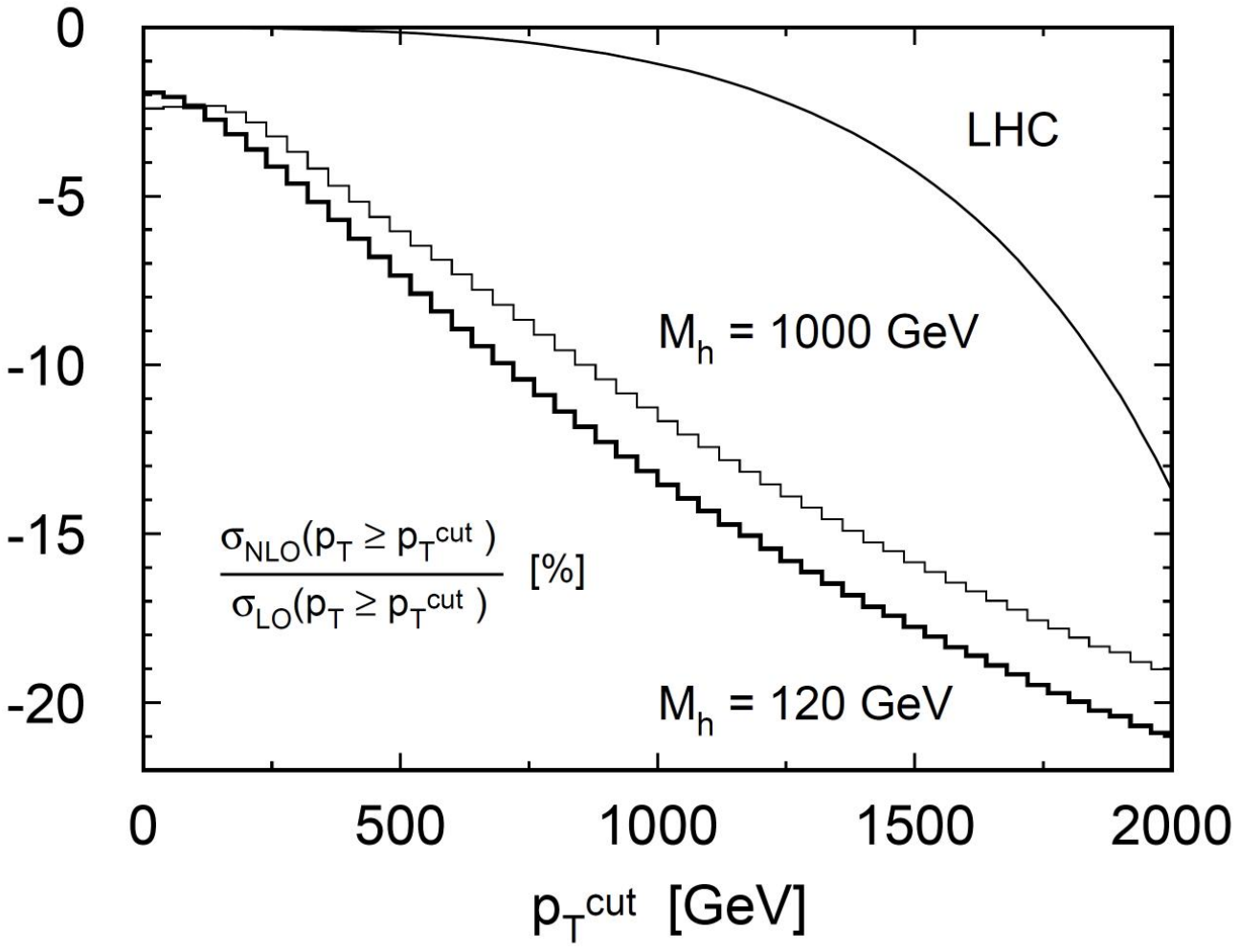
Weak corrections at the parton level

[Kühn,Scharf,PU '14]



Rough estimate of statistical uncertainties

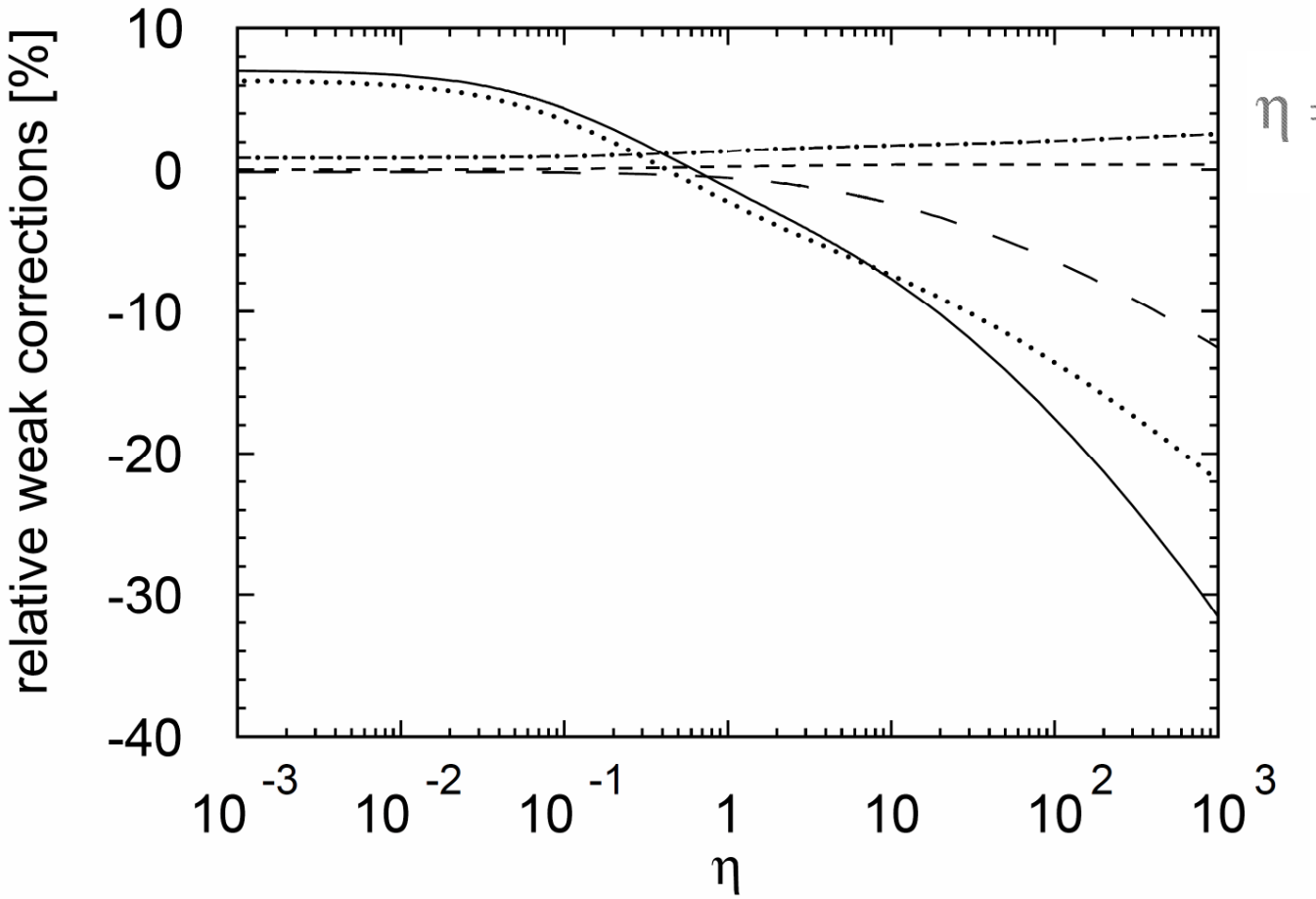
[Kühn,Scharf,PU '06]



LHC 14 TeV, 200 1/fb, no tagging efficiencies taken into account

Weak effects in qq at parton level

[Kühn,Scharf,PU '05]



$$\eta = \frac{s}{4m_t^2} - 1$$

Figure IV.3: Different contributions to the electroweak corrections for incoming up-quarks: Initial vertices (long-dashed), final vertices (dotted), EW-box (dash-dotted), QCD-box (dashed). The sum is shown as a full line.

Weak effects in gg at parton level

[Kühn,Scharf,PU '06]

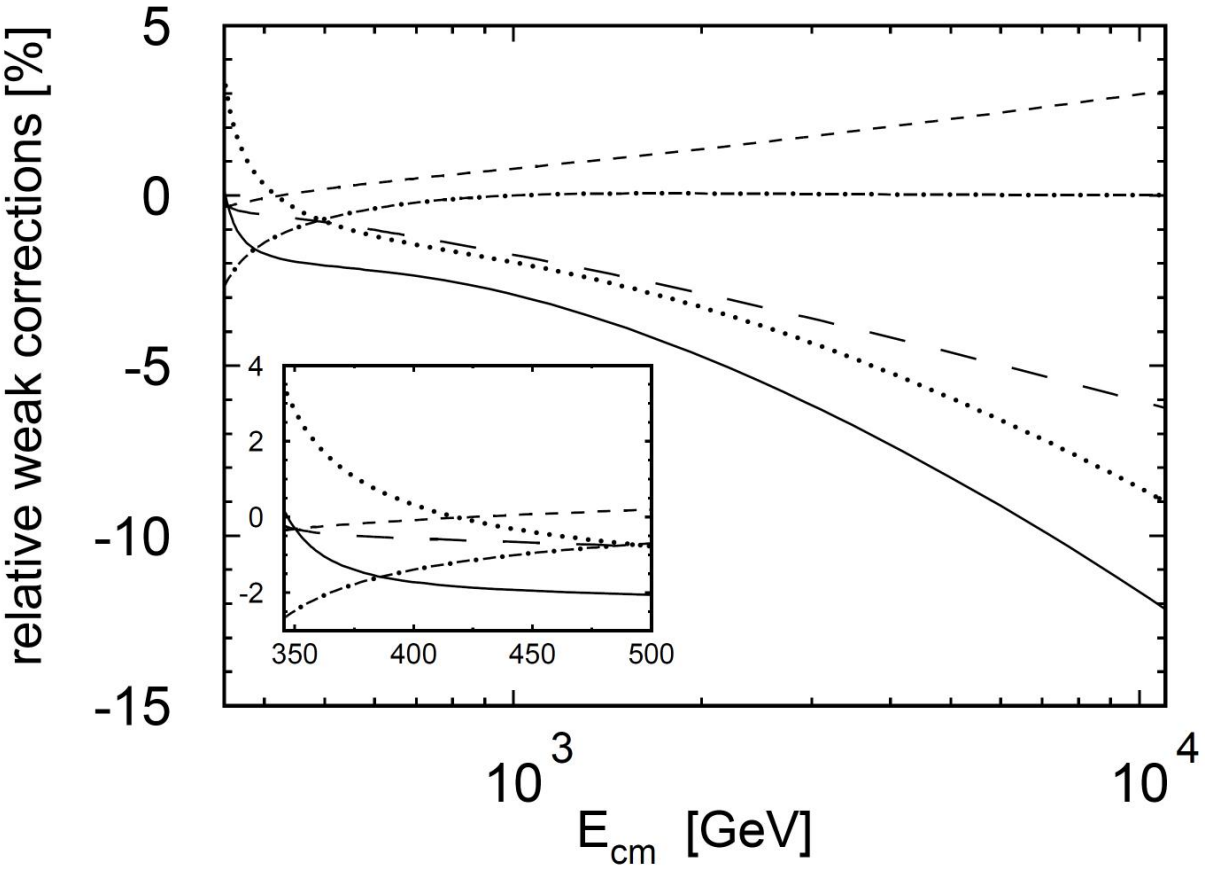


Figure III.1: Different contributions to the electroweak corrections: Vertices (long-dashed), self-energies (dashed), boxes (dotted), triangles (dash-dotted). The sum is shown as full line.