Weak effects in *b*-jet and di-jet production at Hadron Colliders

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Outline

- Motivation & Leading order processes
- Next-to-leading order corrections $O(\alpha_s^2\alpha)$
- Results & Conclusion

Why weak effects in hadronic collisions ?

- Hadron Colliders
  - Provide high energy events
  - Many observables will be measured with 5-20% accuracy

Theory: NLO corrections

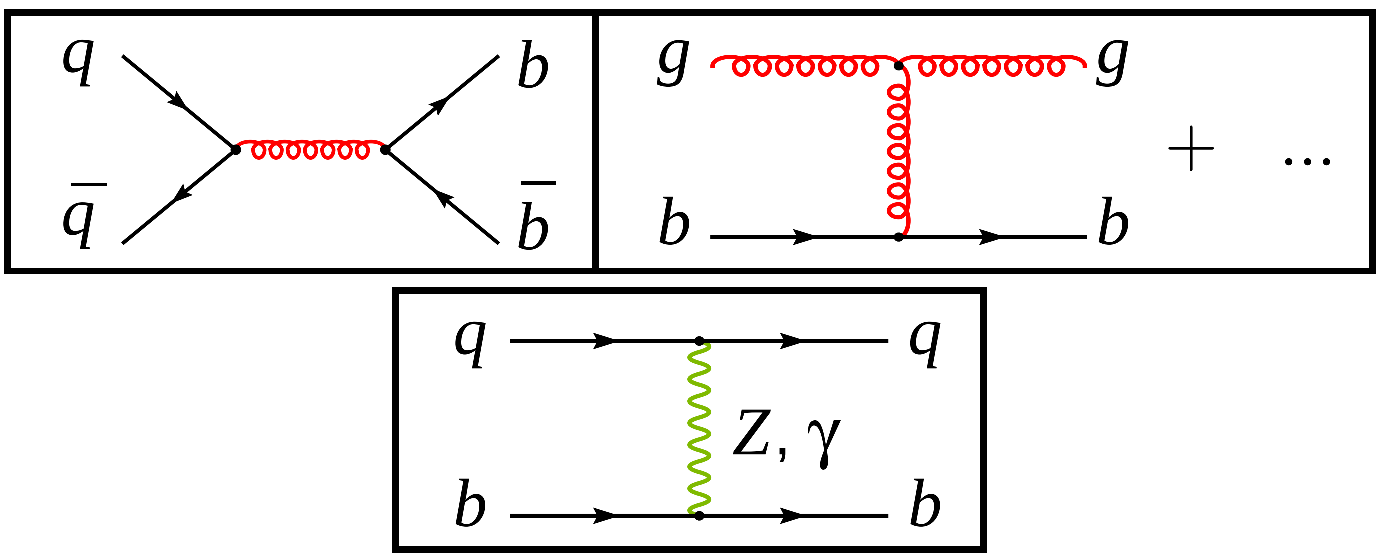
- QCD-corrections are important
- (Electro-) Weak corrections
  - Smaller coupling: $\alpha < \alpha_s$
  - Large logarithms: Sudakov Logarithms

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

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

Bottom jet production

- Bottom-quark ($m_b = 0$)
  - Events with well separated partons ($\mathrm{p_T} > 50$ GeV)
  - Background process ($t\bar{t}$, SUSY)
  - Testing the SM at high $\mathrm{p_T}$
- b-jet production at Hadron Colliders

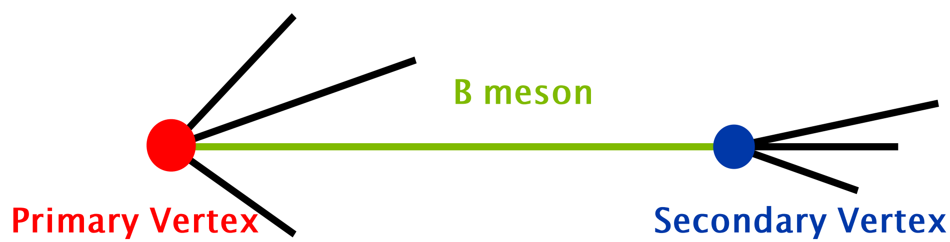


Bottom jet production

- QCD, Mixed and Electroweak contributions

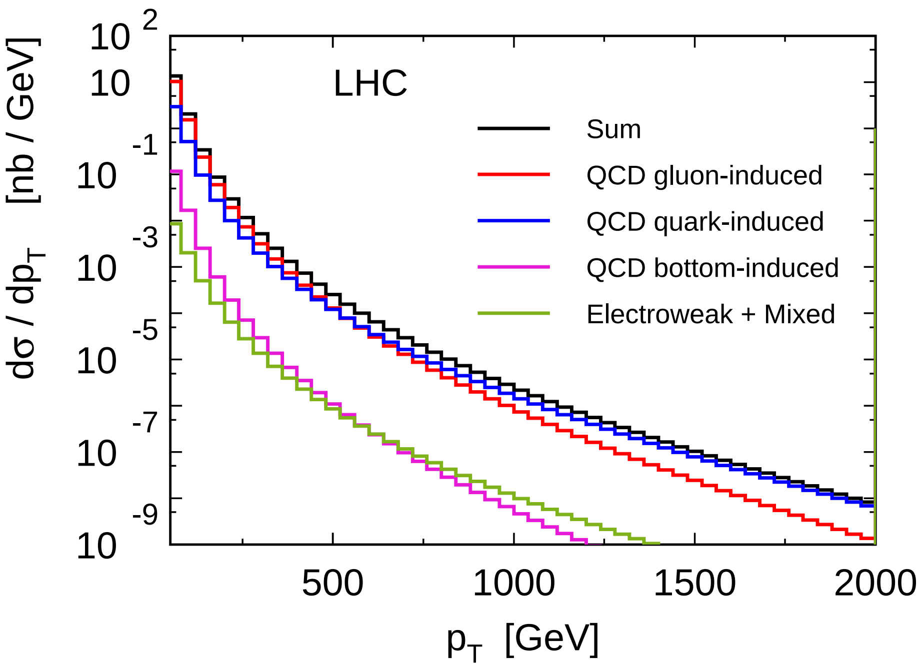
initial state	single b-tag	
quark-induced	$qb \to qb$, $q\bar{b} \to q\bar{b}$, $\bar{q}b \to \bar{q}b$, $\bar{q}\bar{b} \to \bar{q}\bar{b}$	$q\bar{q} \to b\bar{b}$
gluon-induced	$gb \to gb$, $g\bar{b} \to g\bar{b}$	$gg \to b\bar{b}$
pure bottom-induced	$b\bar{b} \to b\bar{b}$, $bb \to bb$, $\bar{b}\bar{b} \to \bar{b}\bar{b}$	
	double b-tag	

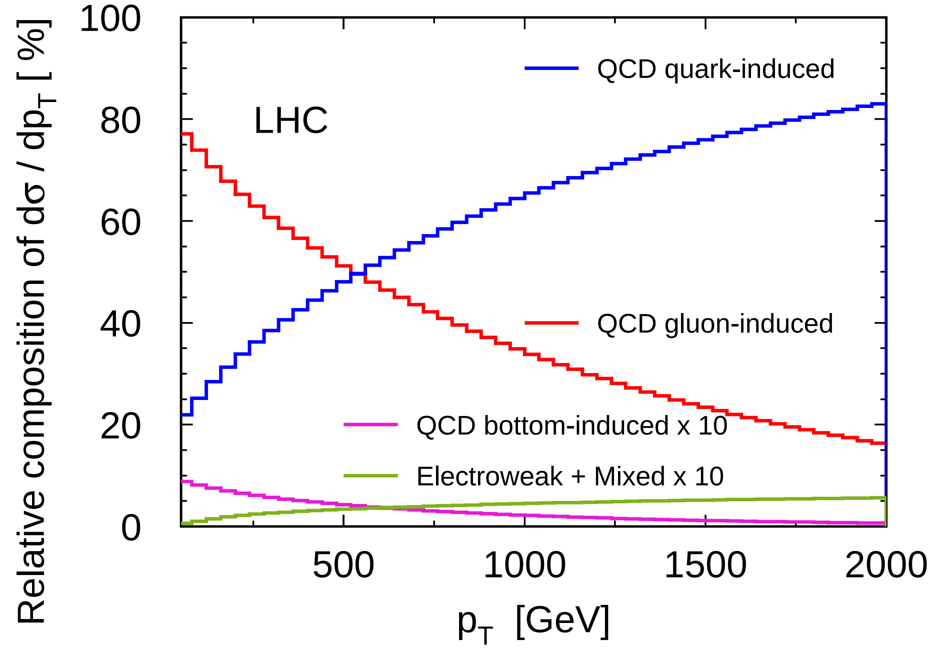
- Experimentally
  - Lifetime of B mesons $\propto 1.5 \times 10^{-12} s$
  - Decay length allows b-jet identification



Bottom jet production

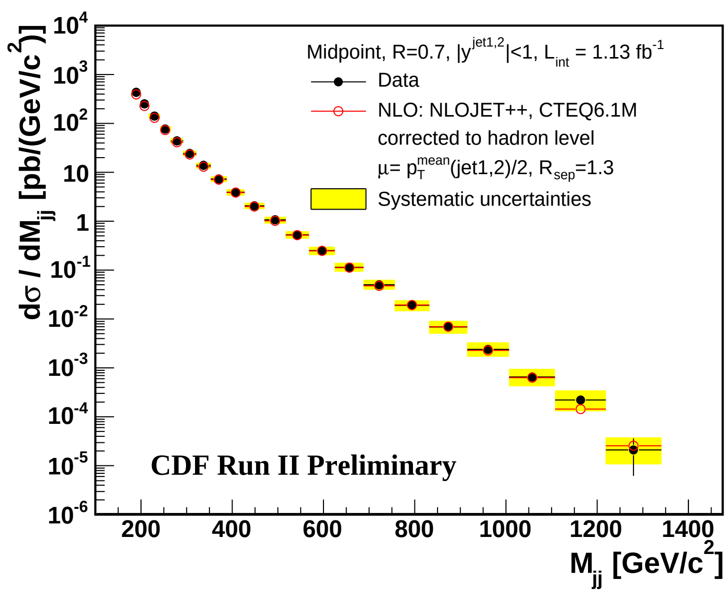
- p_T-distribution at leading order
  - Single b-tag





Di-jet production

- Gluon- & light quark-jets ($m_u = m_d = m_s = m_c = 0$)
  - Well separated jets $p_T > 50$ GeV
  - Indirect new physics search, e.g. Z'
- Experimentally
  - Tevatron: Di-jet-Masses up to 1 TeV
  - LHC: Di-jet-Masses up to several TeV

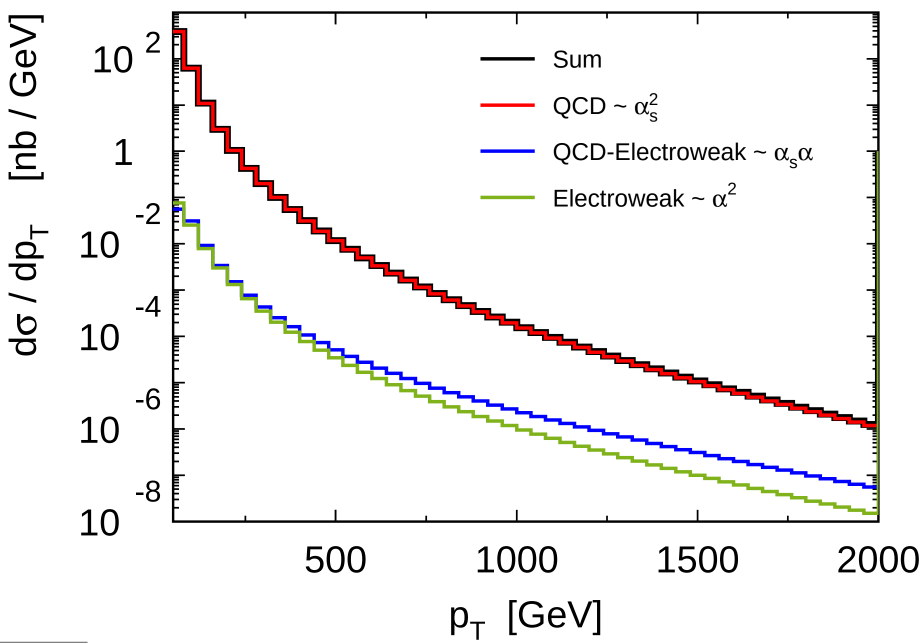


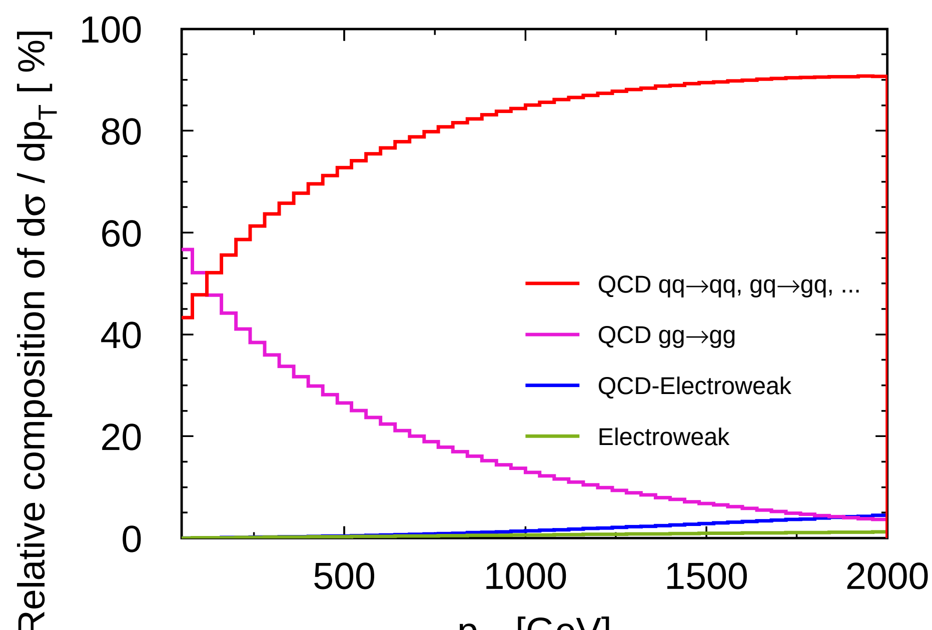
Di-jet production

- Partonic processes

	α_S^2	$\alpha_S\alpha$	α^2
Processes with external Gluons			
$gg \to gg$, $gg \to q\bar{q}$, $gq \to gq$, $g\bar{q} \to g\bar{q}$, $q\bar{q} \to gg$	✓	—	—
Processes with external Quarks only			
$q\bar{q} \to q'\bar{q}'$, $q\bar{q}' \to q\bar{q}'$, $qq' \to qq'$, $\bar{q}'\bar{q} \to \bar{q}'\bar{q}$	✓	✓	✓
$q\bar{q} \to q\bar{q}$, $qq \to qq$, $\bar{q}\bar{q} \to \bar{q}\bar{q}$	✓	✓	✓

- p_T-distribution at leading order

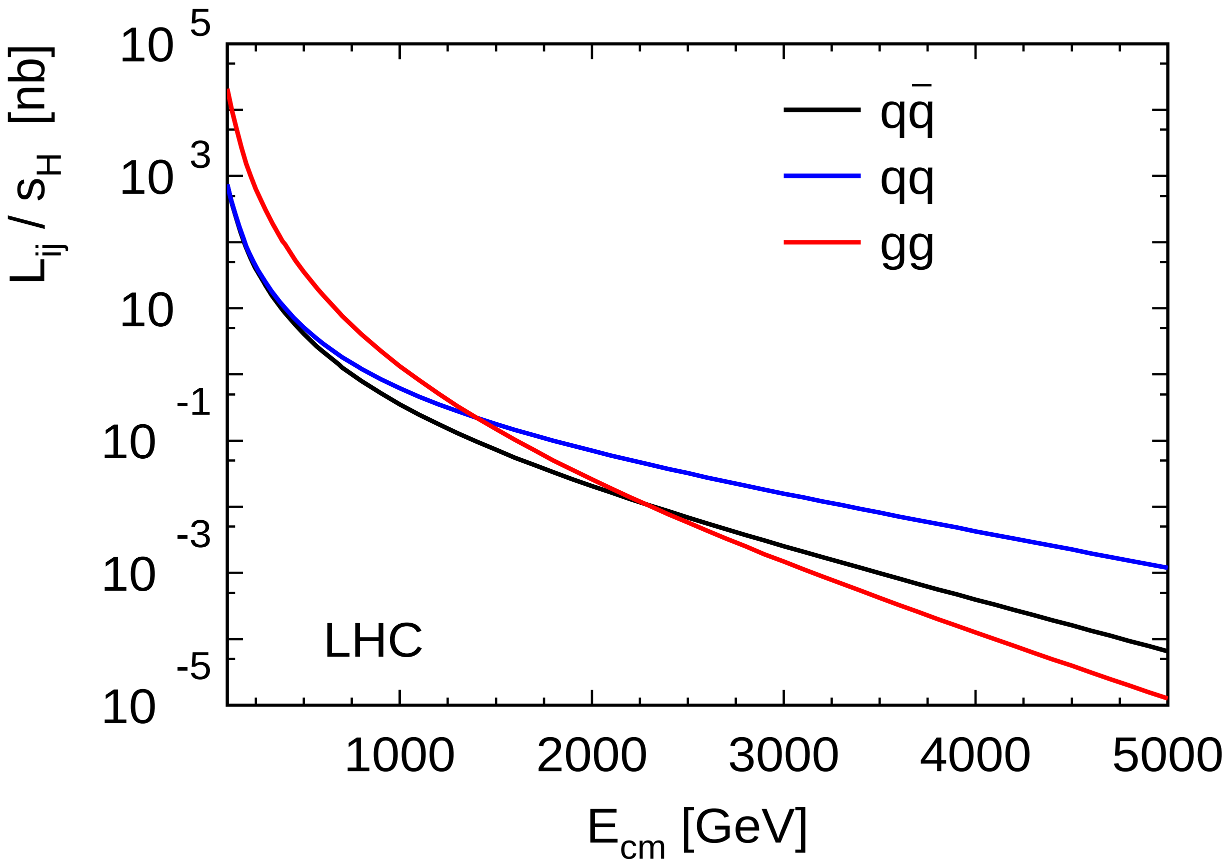




Parton luminosity at the LHC

- Leading order PDF's:
  - Define luminosity function:

$$L_{ij}(\tau,\mu_F) = \int_\tau^1 \frac{1}{x_1} f_{i,p}(x_1,\mu_F) f_{j,p}(\frac{\tau}{x_1},\mu_F) \quad \text{with } \tau = \frac{E_{cm}^2}{S}$$



Status of NLO calculations

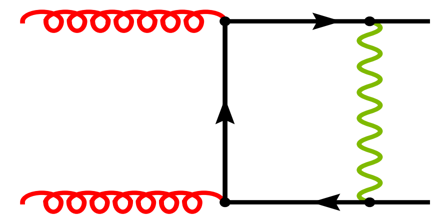
- b-jet production
  - QCD corrections $O(\alpha_s^3)$ (Dawson, Ellis, Nason 1988) (Beenakker, Kuijf, Neerven, Smith 1989) (Frixione, Mangano 1997)
  - $b\bar{b}$ production $O(\alpha_s^2\alpha)$ (Moretti et al 2003)
- Di-jet production
  - QCD corrections $O(\alpha_s^3)$ (Ellis, Sexton 1985) (Aversa et al 1988, 1991)
  - Weak corrections $O(\alpha_s^2\alpha)$ (Moretti et al 2006)

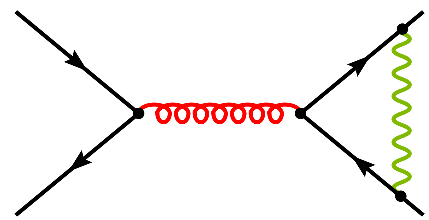
General Remarks about NLO

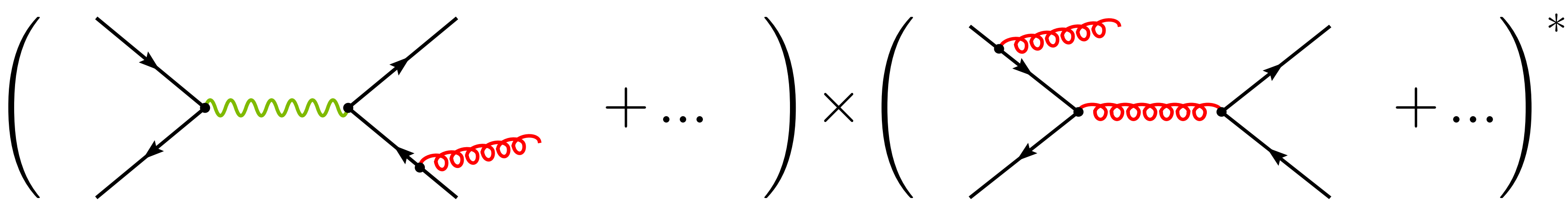
- Consider only weak corrections $\longrightarrow$ neglecting photonic contributions
  - Gauge invariant subset
  - Photonic contributions involve no Sudakov Logarithms
- b-jet production
  - $O(\alpha)$ corrections to LO α_s^2 processes: Z, W, ϕ
- Di-jet production
  - $O(\alpha)$ corrections to LO α_s^2 processes: Z, W
  - $O(\alpha_s)$ corrections to LO $\alpha_s \alpha$ processes

Methods: Overview

- Passarino-Veltman reduction
- Renormalisation
  - Weak corrections: Wave function only
  - QCD-corrections: $\overline{\text{MS}}$ scheme
- Real corrections
  - Dipole Subtraction (Catani, Seymour 1996)
  - Phase Space Slicing (Harris, Owens 2002)





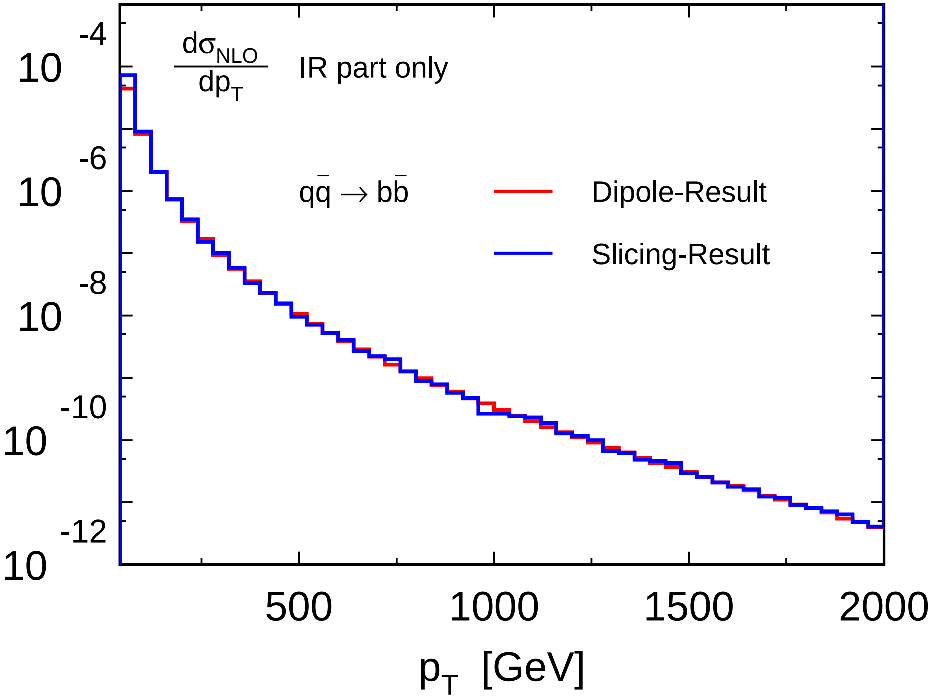


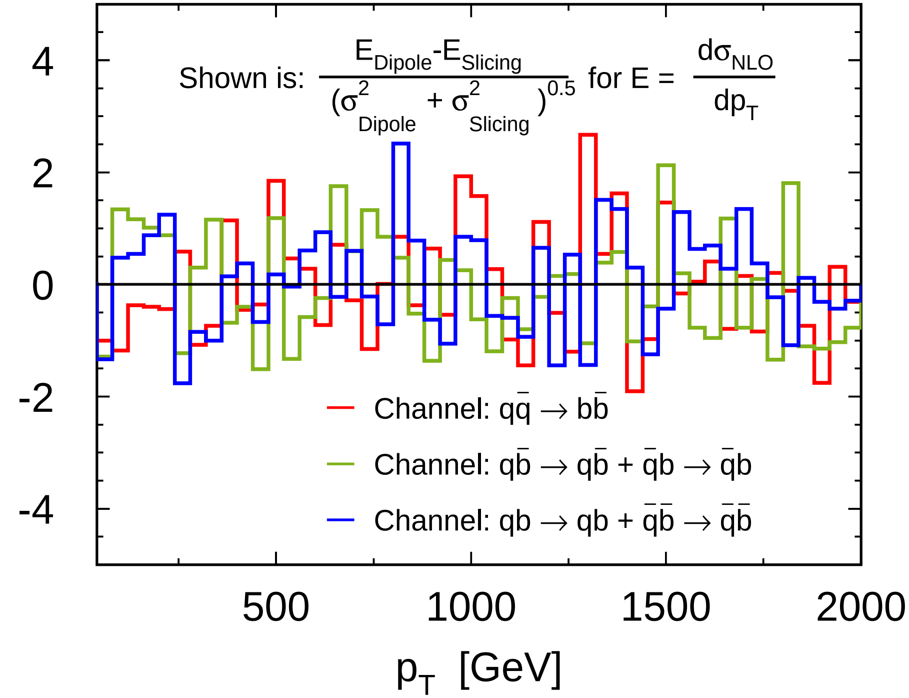
Consistency

- b-jet production
  - Cancellation of the IR and UV poles, ... ✓
  - Crossing symmetries ✓
  - Comparison between Slicing- and Dipole-Method ✓
- Di-jet production
  - Cancellation of the IR and UV poles, ... ✓
  - Crossing symmetries ✓
  - Comparison between Slicing- and Dipole-Method (✓)

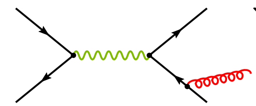
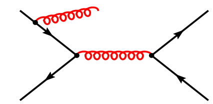
Consistency

- Comparison between Slicing- and Dipole-Method: *b*-jet production





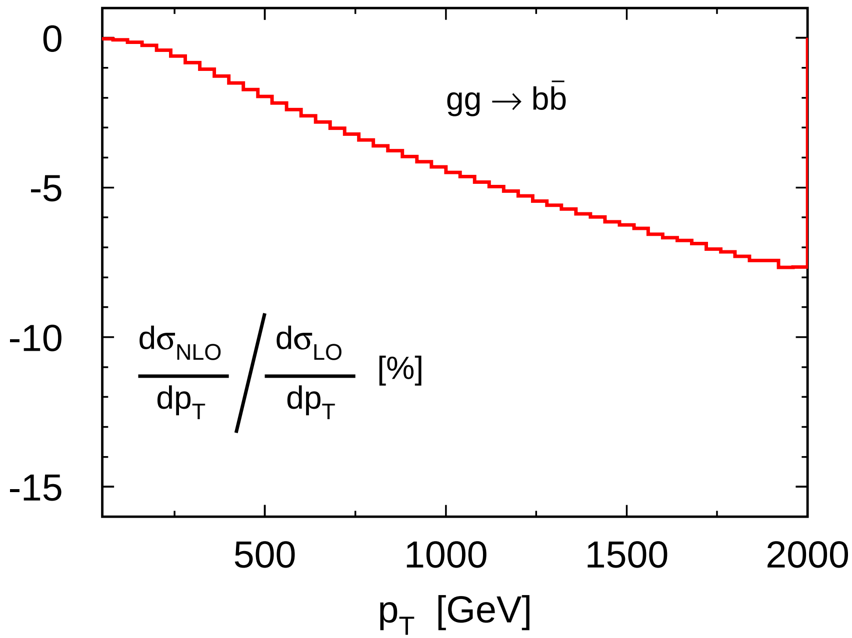
Analytic Result: Example

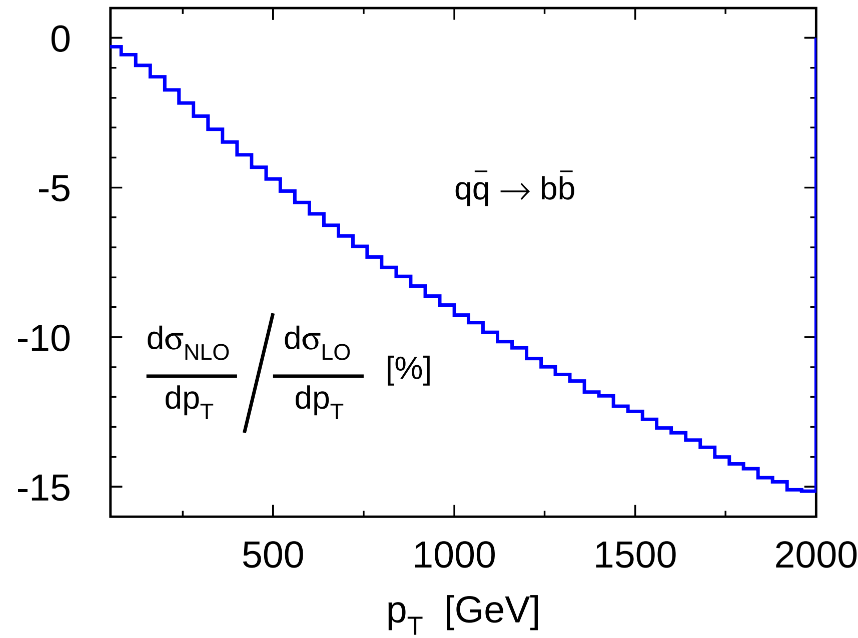
- Real corrections for $q\bar{q} \to b\bar{b}g$ $\Bigg($  $\Bigg) \times \Bigg($  $\Bigg)^*$

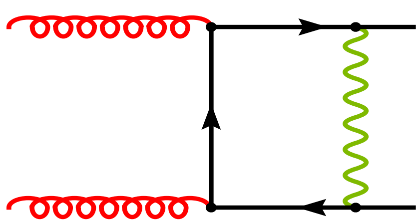
$$
\begin{aligned}
\frac{1}{4}\frac{1}{N^2}\sum_{\text{Spin}}\sum_{\text{Colour}}\left|M^{q\bar{q}\to b\bar{b}g}\right|^2 \quad &= \quad \alpha_s^2\alpha(4\pi)^3\frac{N^2-1}{N^2} \\
&\times \quad \Big(g_v^q g_v^b(t_1^2+t_2^2+u_1^2+u_2^2) - g_a^q g_a^b(t_1^2+t_2^2-u_1^2-u_2^2)\Big) \\
&\times \quad \frac{1}{s}\;\frac{1}{s-m_Z{}^2}\;\frac{1}{s+t_1+t_2+u_1+u_2}\;\frac{1}{s+t_1+t_2+u_1+u_2+m_Z{}^2} \\
&\times \quad \frac{1}{s+t_1+u_1}\;\frac{1}{s+t_2+u_1}\;\frac{1}{s+t_1+u_2}\;\frac{1}{s+t_2+u_2} \\
&\times \quad \Big(2s^2+(t_1+t_2+u_1+u_2)(2s-m_Z{}^2)\Big) \\
&\times \quad \Big((t_1+t_2-u_1-u_2)s^2+((t_1+t_2)^2-(u_1+u_2)^2)s \\
&+ \quad (t_1+t_2+u_1+u_2)(t_1t_2-u_1u_2)\Big)
\end{aligned}
$$

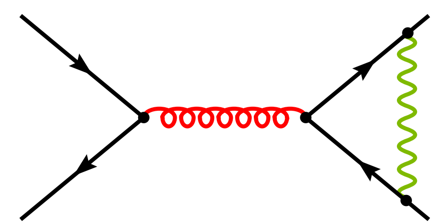
Partonic Results

- Consider relative corrections to $gg \to b\bar{b}$ and $q\bar{q} \to b\bar{b}$





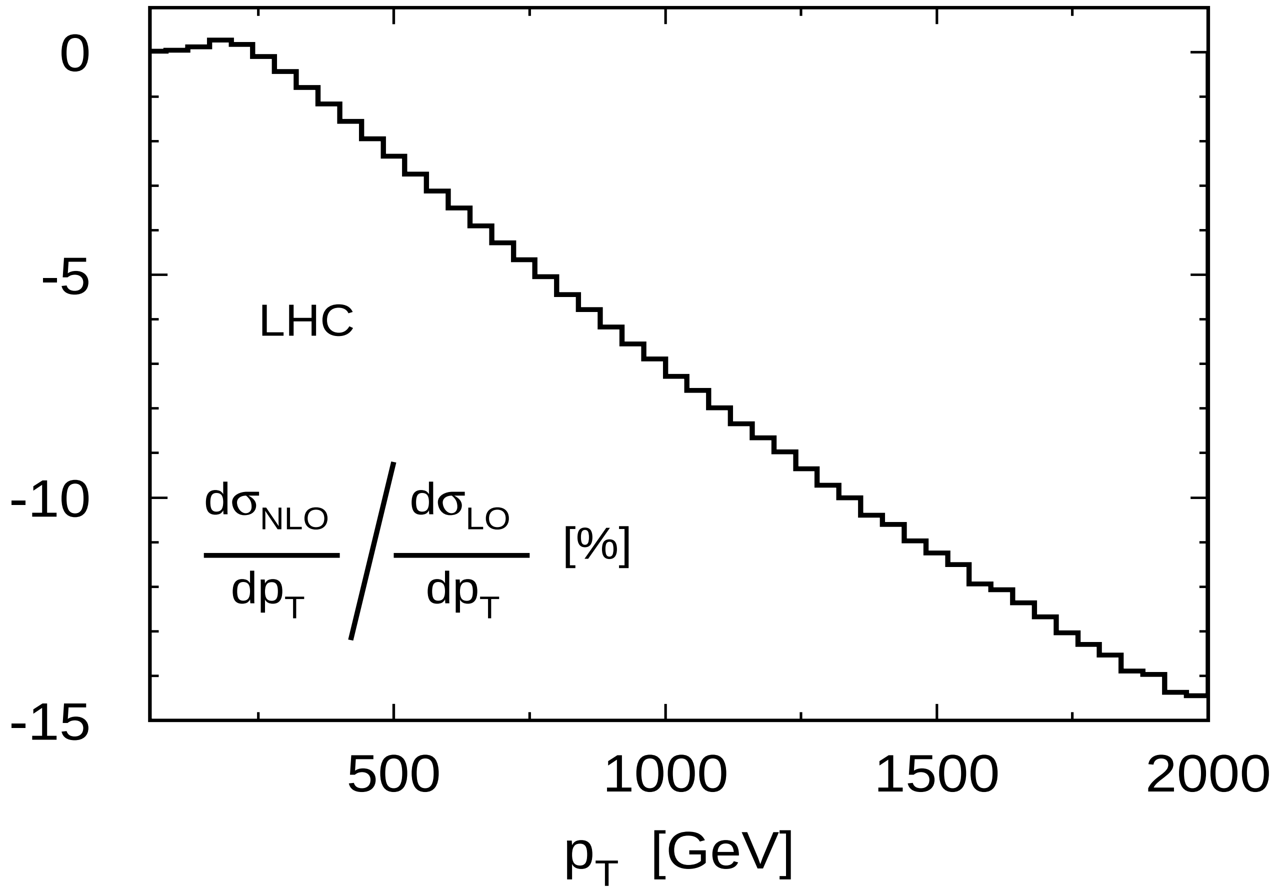




- Quark-induced processes receive larger corrections

b-jet production at the LHC

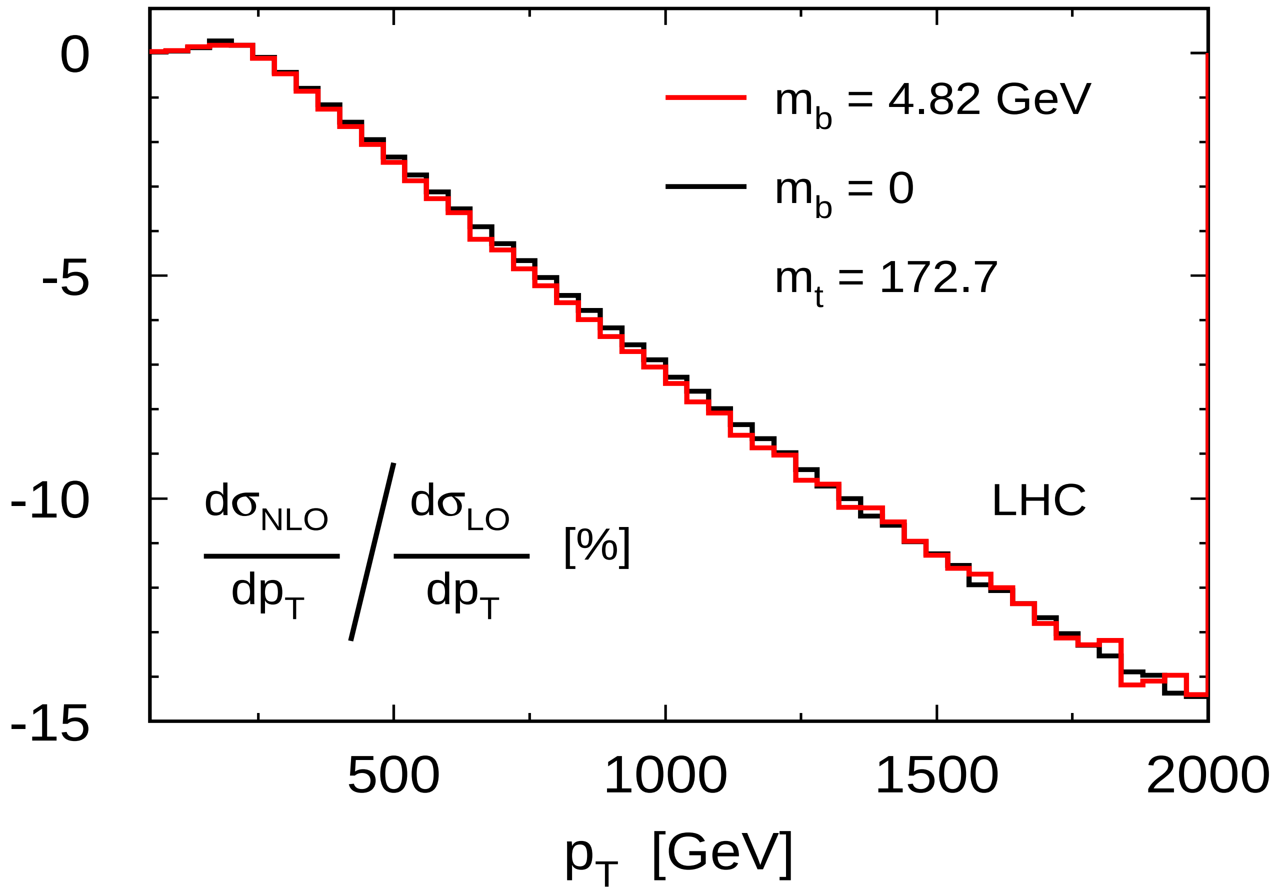
- Relative corrections to p_T: double *b* tag



b-jet production at the LHC

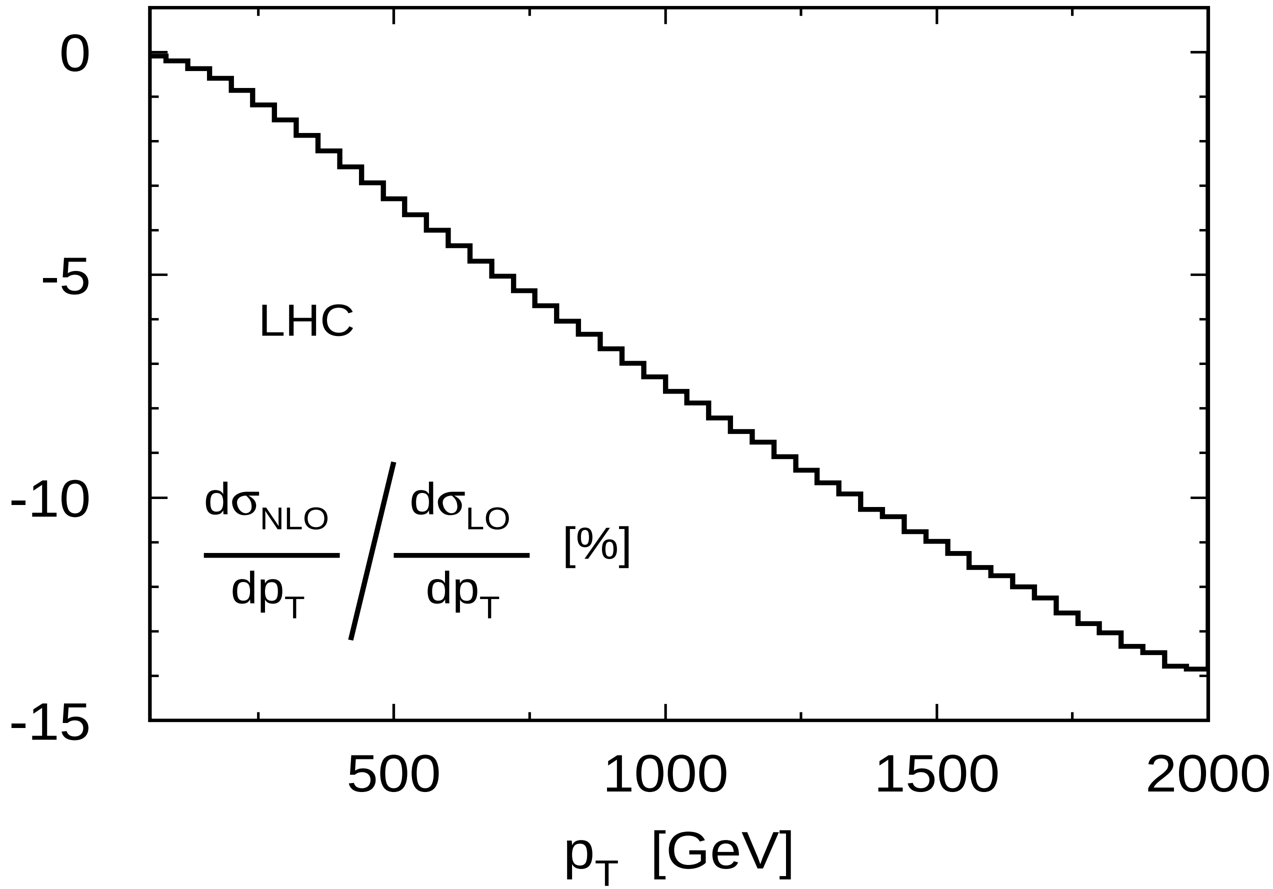
- Relative corrections to p_T: double *b* tag
  - Comparison between massive and massless calculation

(Kühn, A.S., Uwer 2006)



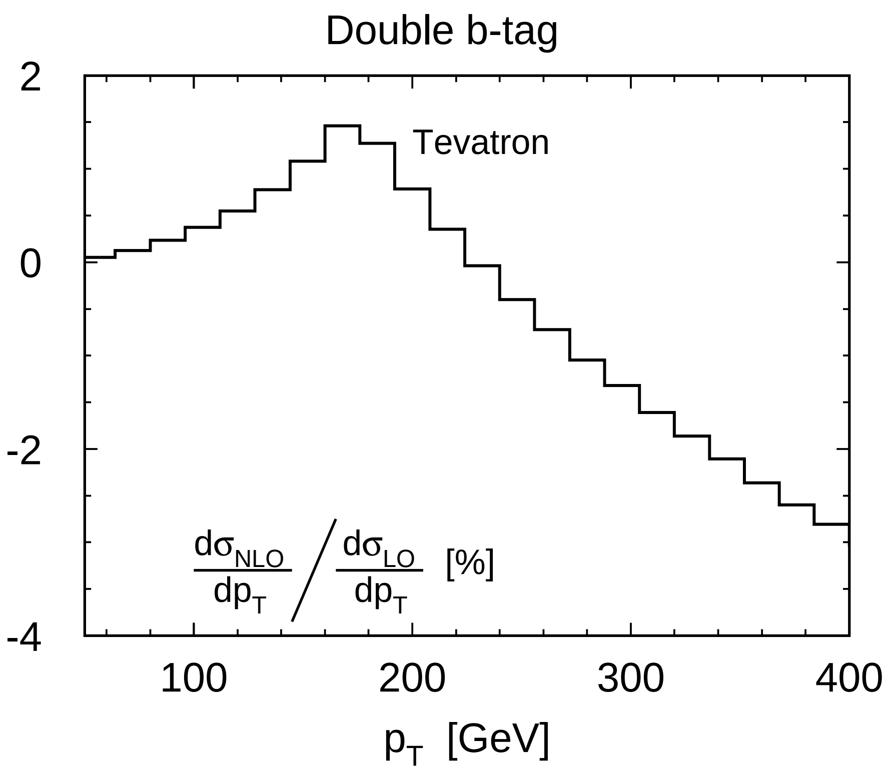
b-jet production at the LHC

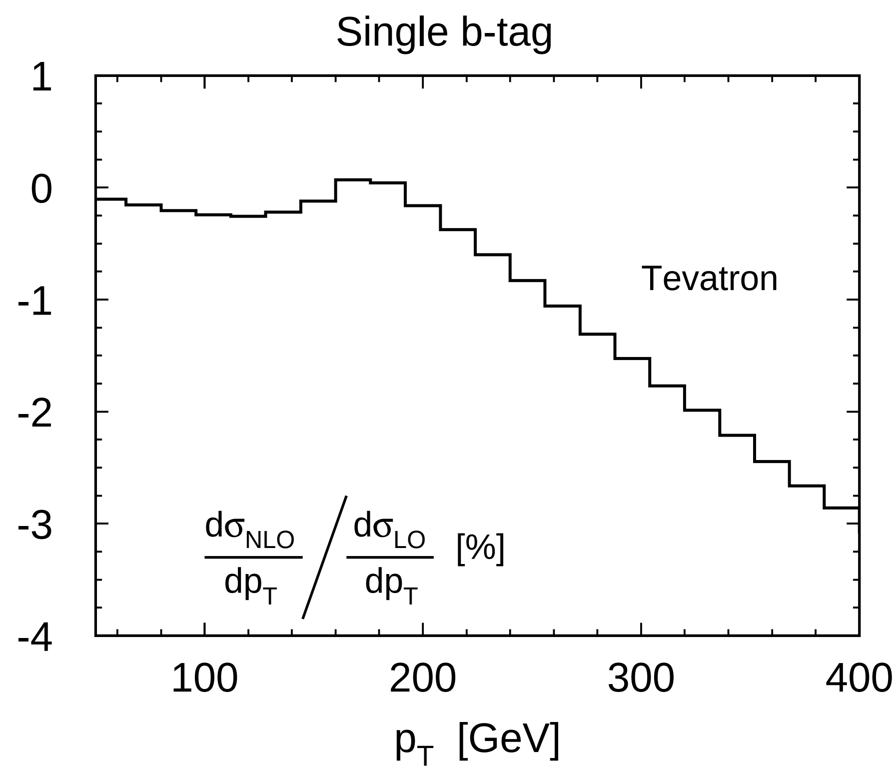
- Relative corrections to p_T: single *b* tag



b-jet production at the Tevatron

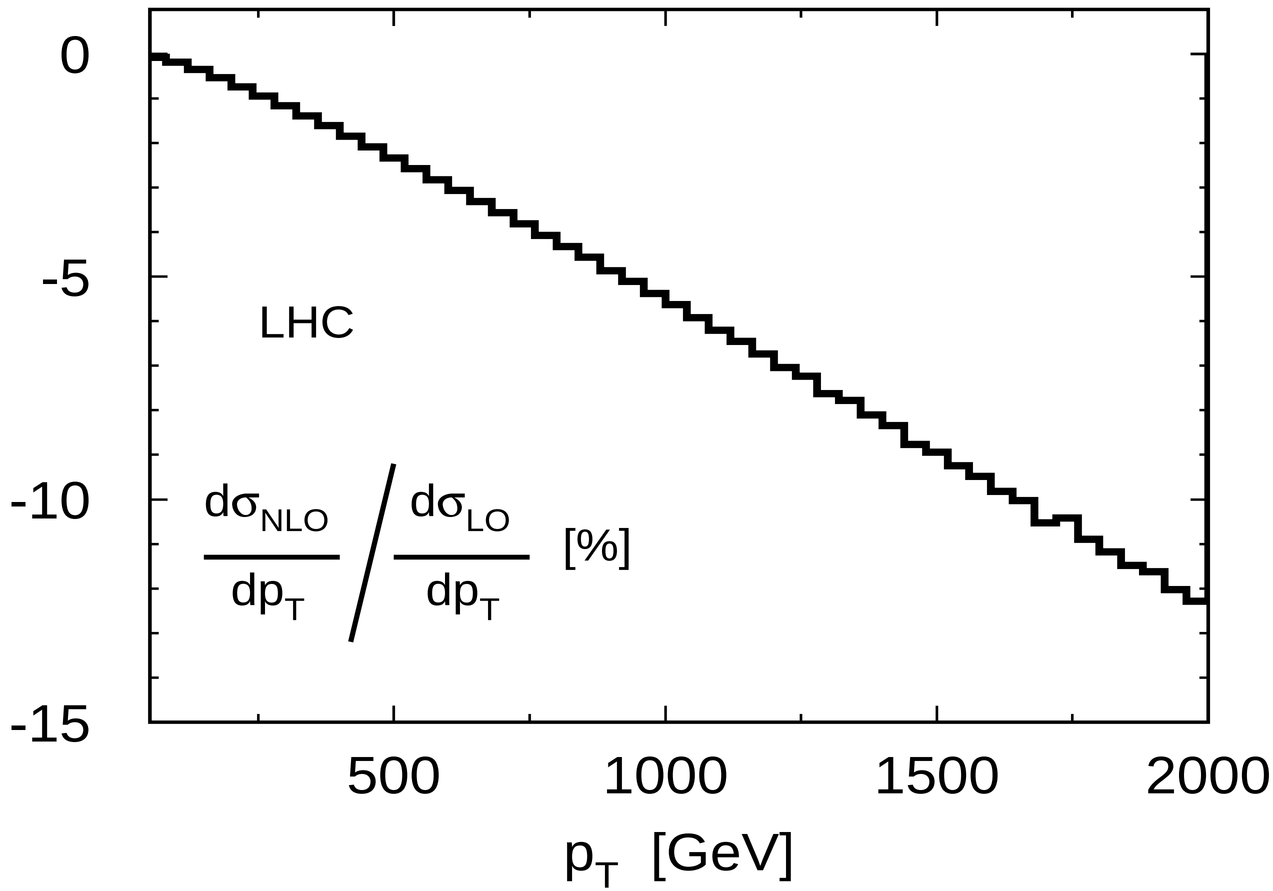
- Relative corrections to p_T





Di-jet production at the LHC

- Preliminary Result



Conclusion

- Weak corrections have impact to $\mathrm{p_T}$-distribution
  - b-jet production: $\propto 10 - 15\%$
  - di-jet production (preliminary): $\propto 8 - 12\%$
  - Analytic results for further studies