NLO corrections to $W + \gamma$ production at the LHC

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Albert-Ludwigs-Universität Freiburg

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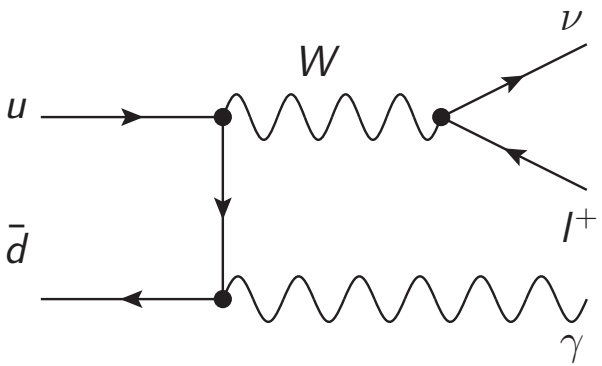
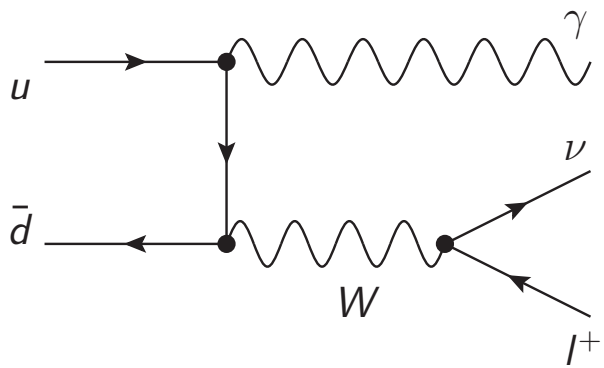
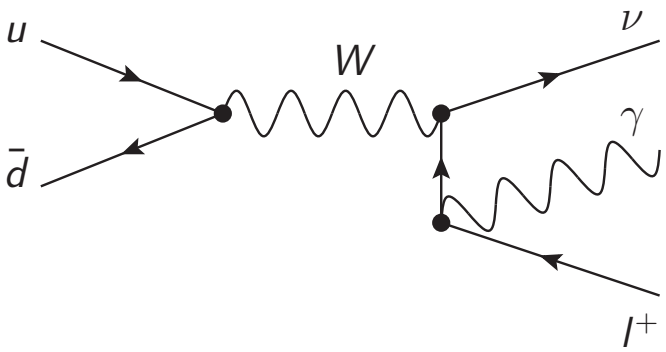
Content

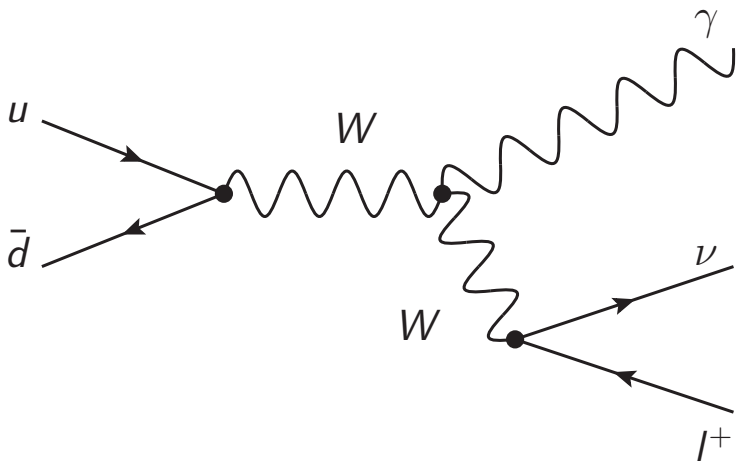
Motivation and Overview

Motivation









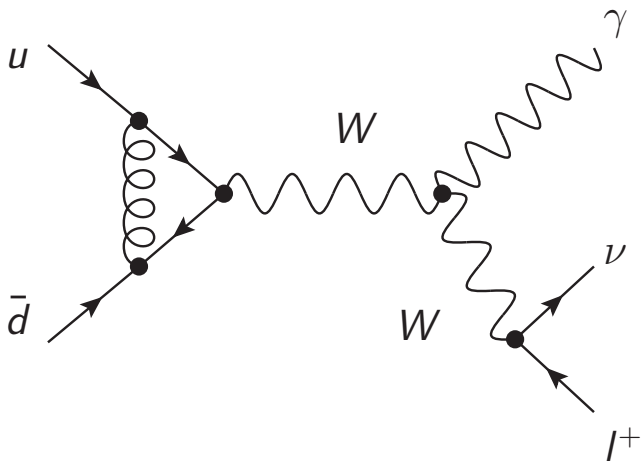
- testing Standard Model
- studying anomalous couplings
- background for new physics

Overview

QCD corrections

- @NLO:
  - MCFM [Campbell, Ellis, Williams]
  - VBFNLO [Zeppenfeld et al.]
- NNLO calculation to $Z + \gamma$

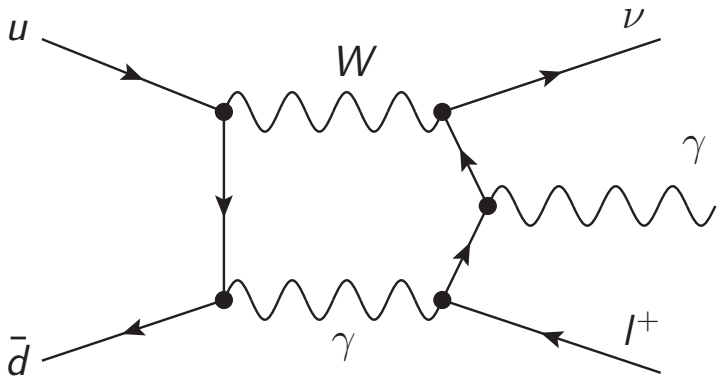
  [Grazzini, Kallweit, Rathlev, Torre '13]



EW corrections

- $q\bar{q}$-channel in Leading Pole Approximation (POLE)

  [Accomando, Denner, Meier '06]
- inclusion of all off-shell effects
- photon induced contributions
- non-collinear-safe observables



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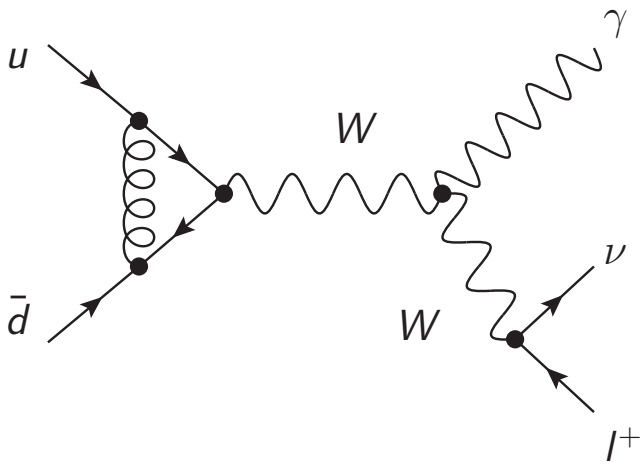

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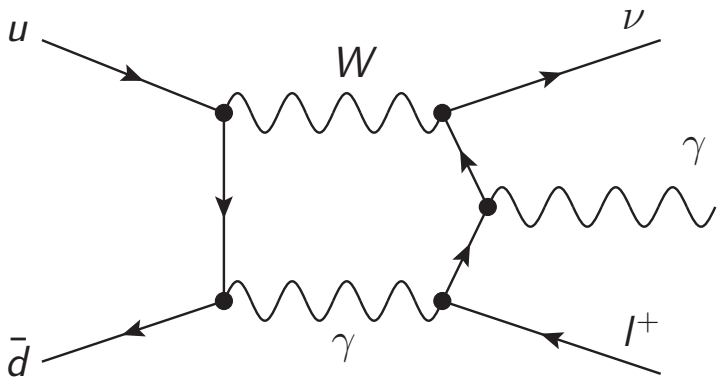

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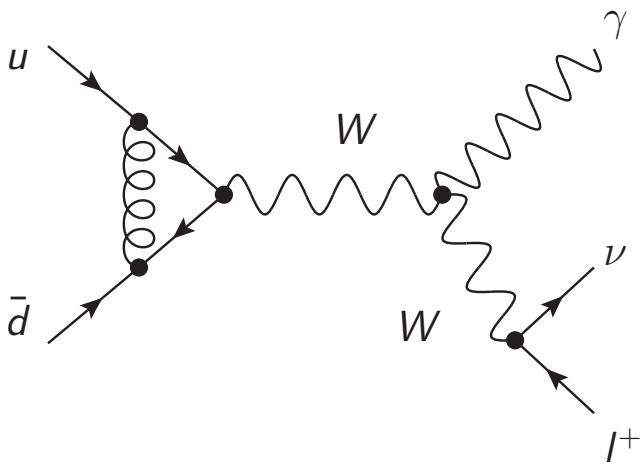

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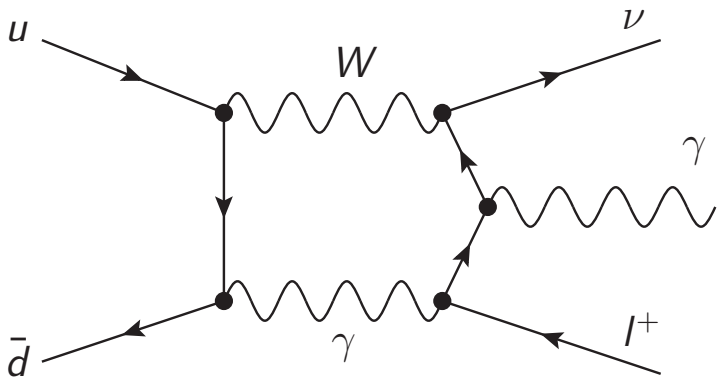

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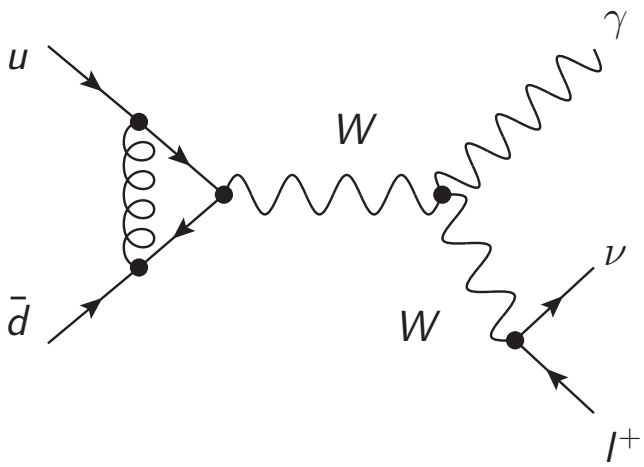

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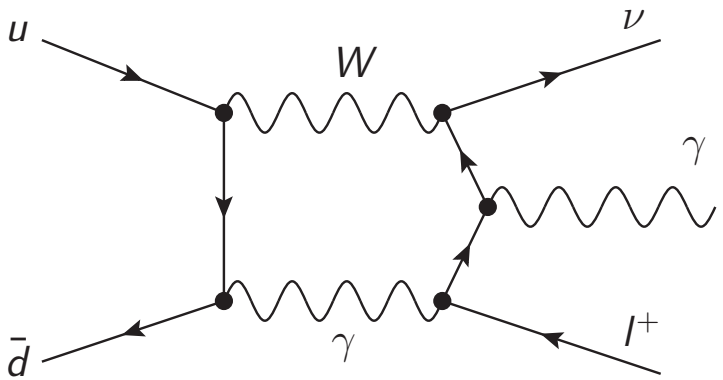

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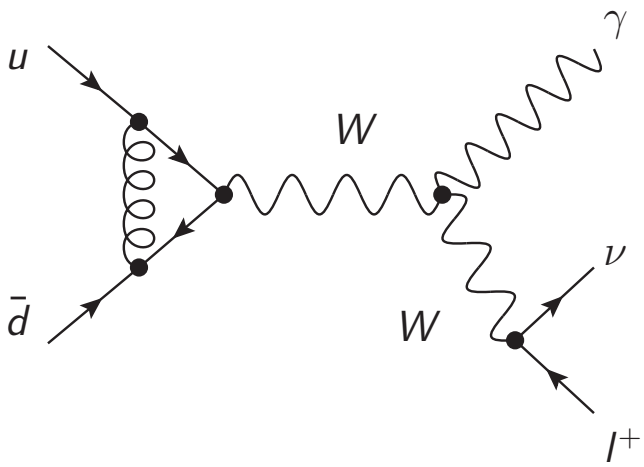

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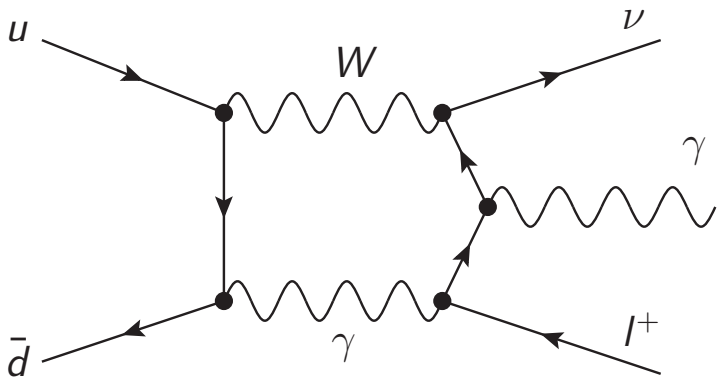

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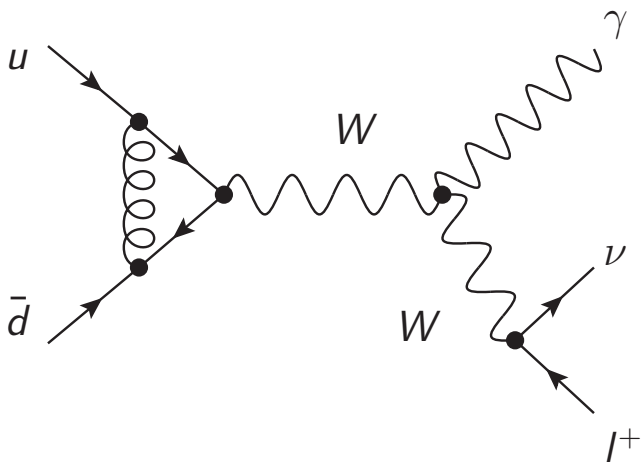

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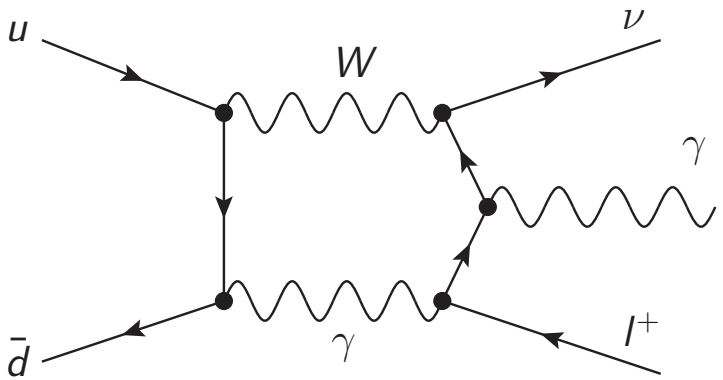

Calculation of QCD and EW Corrections at NLO

Types of divergences at NLO

UV divergences

- originate from virtual corrections
- compensated by renormalization

IR (soft/collinear) divergences

- appear in real and virtual corrections
- complete cancellation of soft singularities between real and virtual corrections
- after cancellation of collinear singularities, collinear IS singularities remain
  - $\rightarrow$ process independent factorization
  - $\rightarrow$ absorbed by redefinition of PDFs

Dipole Subtraction

$$\hat{\sigma}^{NLO} = \int_{m+1} \mathrm{d}\sigma^R + \int_m \mathrm{d}\sigma^V + \int_m \mathrm{d}\sigma^C$$

$$= \int_{m+1} \left[\mathrm{d}\sigma^R - \mathrm{d}\sigma^A\right] + \int_{m+1} \mathrm{d}\sigma^A + \int_m \mathrm{d}\sigma^V + \int_m \mathrm{d}\sigma^C$$

$$= \int_{m+1} \underbrace{\left[\mathrm{d}\sigma^R(\hat{s}) - \mathrm{d}\sigma^A(\hat{s})\right]}_{\text{finite}} + \int_m \underbrace{\left[\mathrm{d}\sigma^V(\hat{s},\epsilon) + \mathrm{d}\sigma^B(\hat{s}) \otimes \mathbf{I}(\epsilon)\right]_{\epsilon=0}}_{\text{finite}}$$

$$+ \int_0^1 \mathrm{d}x \int_m \underbrace{\left[\mathrm{d}\sigma^B(x\hat{s}) \otimes (\mathbf{P} + \mathbf{K})(x)\right]_{\epsilon=0}}_{\text{finite}}$$

Dipole Subtraction formalisms

- QCD dipoles [Catani, Seymour '97]
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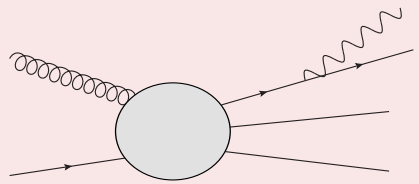
Problems

- overlap of $W + \gamma$ and $W + \text{jet}$ in collinear photon-jet configuration
  $\rightarrow$ aim: find well defined separation of $W + \gamma$ and $W + \text{jet}$
- collinear singularity between photon and quark-jet
  $\rightarrow$ aim: compensate collinear singularity



Solution: democratic clustering & fragmentation function

- collinear photon-jet configuration is merged to one jet (democratic clustering) [Glover, Morgan 1994]
- using energy fraction $z_\gamma = \frac{E_\gamma}{E_\gamma + E_{\text{jet}}}$ of the photon inside the jet to discriminate between $W + \gamma$ and $W + \text{jet}$
  $\rightarrow$ if $z_\gamma < z_c$, event belongs to $W + \text{jet}$
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- fragmentation function introduced by [Glover, Morgan '94] and measured at LEP [ALEPH '96]

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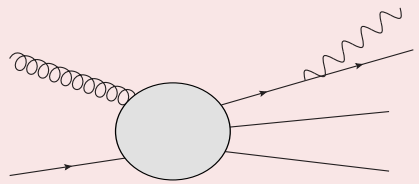

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Quark-to-Photon Fragmentation Function

$$\mathrm{d}\sigma^{\mathrm{frag}}(z_c) = \mathrm{d}\sigma^{0} \int_{z_c}^{1} \mathrm{d}z_\gamma \left\{ D_{q\to\gamma}^{\mathrm{ALEPH}}(z_\gamma, \mu_\mathrm{F}) + e^2 Q_q^2 P_{ff}(1-z_\gamma) \left[\ln\left(\frac{m_q^2}{\mu_\mathrm{F}} z_\gamma^2 \right) + 1 \right] \right\}$$

Compensation of collinear divergence by fragmentation function

Dipole subtraction:

$$\begin{aligned} &\mathrm{d}\sigma^{\mathrm{R}}(z_c) + \mathrm{d}\sigma^{\mathrm{frag}}(z_c) \\ &= \underbrace{\left[\mathrm{d}\sigma^{\mathrm{R}}(z_c) - \mathrm{d}\sigma^{\mathrm{sub}}(z_c)\right]}_{\text{finite}} + \underbrace{\mathrm{d}\sigma^{\mathrm{sub}}(z_c) + \mathrm{d}\sigma^{\mathrm{frag}}(z_c)}_{\text{finite}} \end{aligned}$$ [Dittmaier, Kabelschacht, Kasprzik '08]

One-cut-off slicing:

$$\mathrm{d}\sigma^{\mathrm{R}}(z_c) + \mathrm{d}\sigma^{\mathrm{frag}}(z_c) = \mathrm{d}\sigma_{\mathrm{fin}}^{\mathrm{R}}(z_c; s_{\mathrm{cut}}) + \underbrace{\mathrm{d}\sigma_{\mathrm{coll}}^{\mathrm{R}}(z_c; s_{\mathrm{cut}}) + \mathrm{d}\sigma^{\mathrm{frag}}(z_c)}_{\text{finite}}$$ [Giele, Glover '92]

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Numerical Results

Setup

- Cuts and event selection taken from Atlas and CMS measurements.
- Center-of-mass energy $\sqrt{s} = 14\,\mathrm{TeV}$.

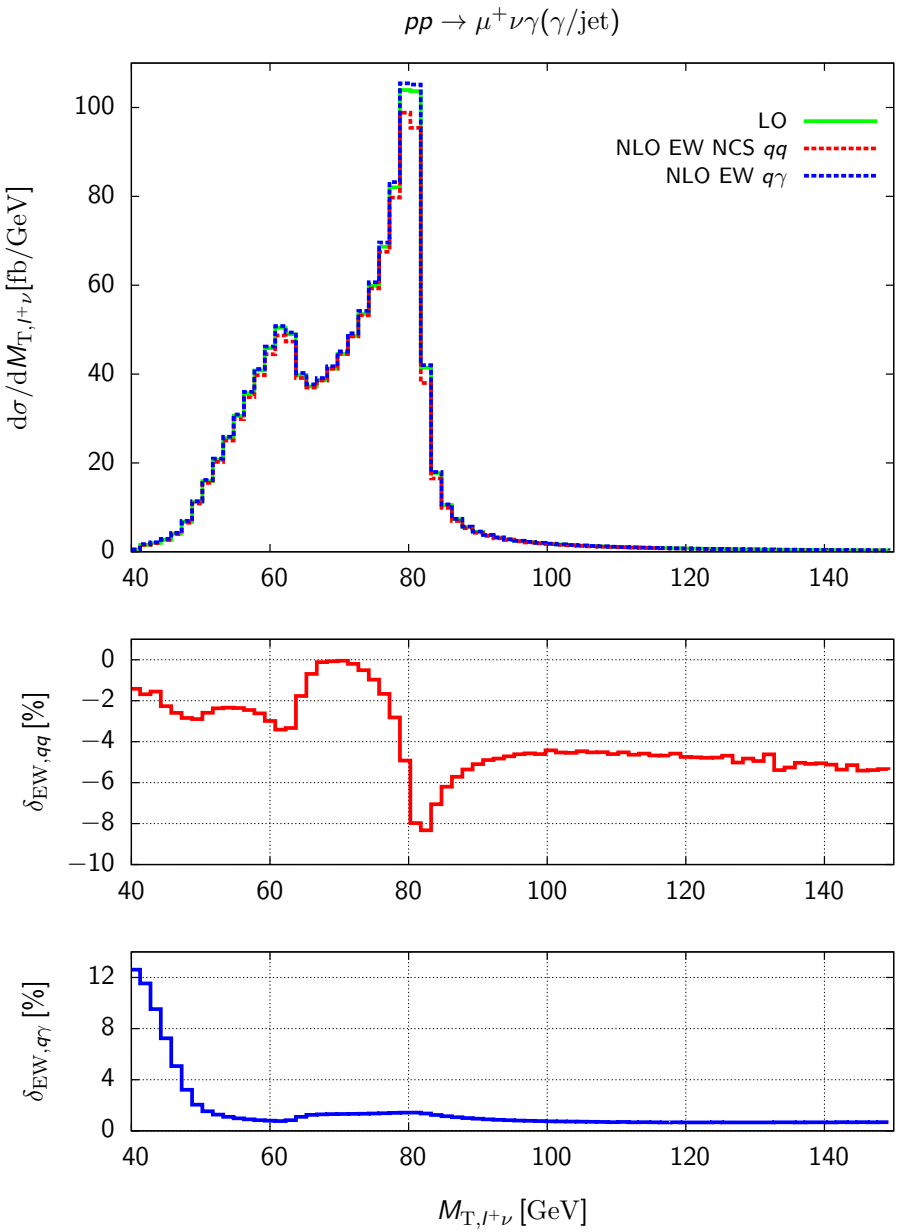
basic cuts

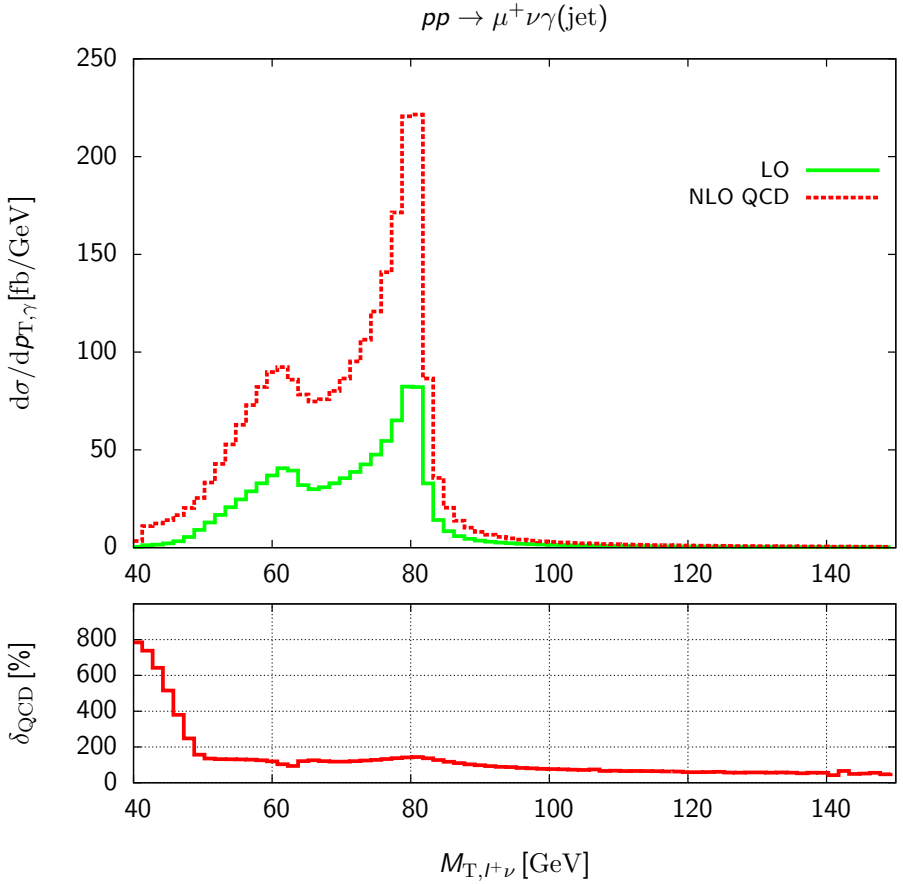
- $P_{\mathrm{T},l} > 25\,\mathrm{GeV}$
- $\not{P}_{\mathrm{T}} > 25\,\mathrm{GeV}$
- $R_{l\gamma} > 0.7$
- $M_{\mathrm{T},l\nu} > 40\,\mathrm{GeV}$
- $|\eta_{l^+}| < 2.5$, $|\eta_\gamma| < 2.5$

event selection

- jet defined by:
  $P_{\mathrm{T,had}} > 100\,\mathrm{GeV}$
  $z_{\mathrm{had}} > 10\%$
- photon defined by:
  $P_{\mathrm{T},\gamma} > 15\,\mathrm{GeV}$
  $z_\gamma > 90\%$

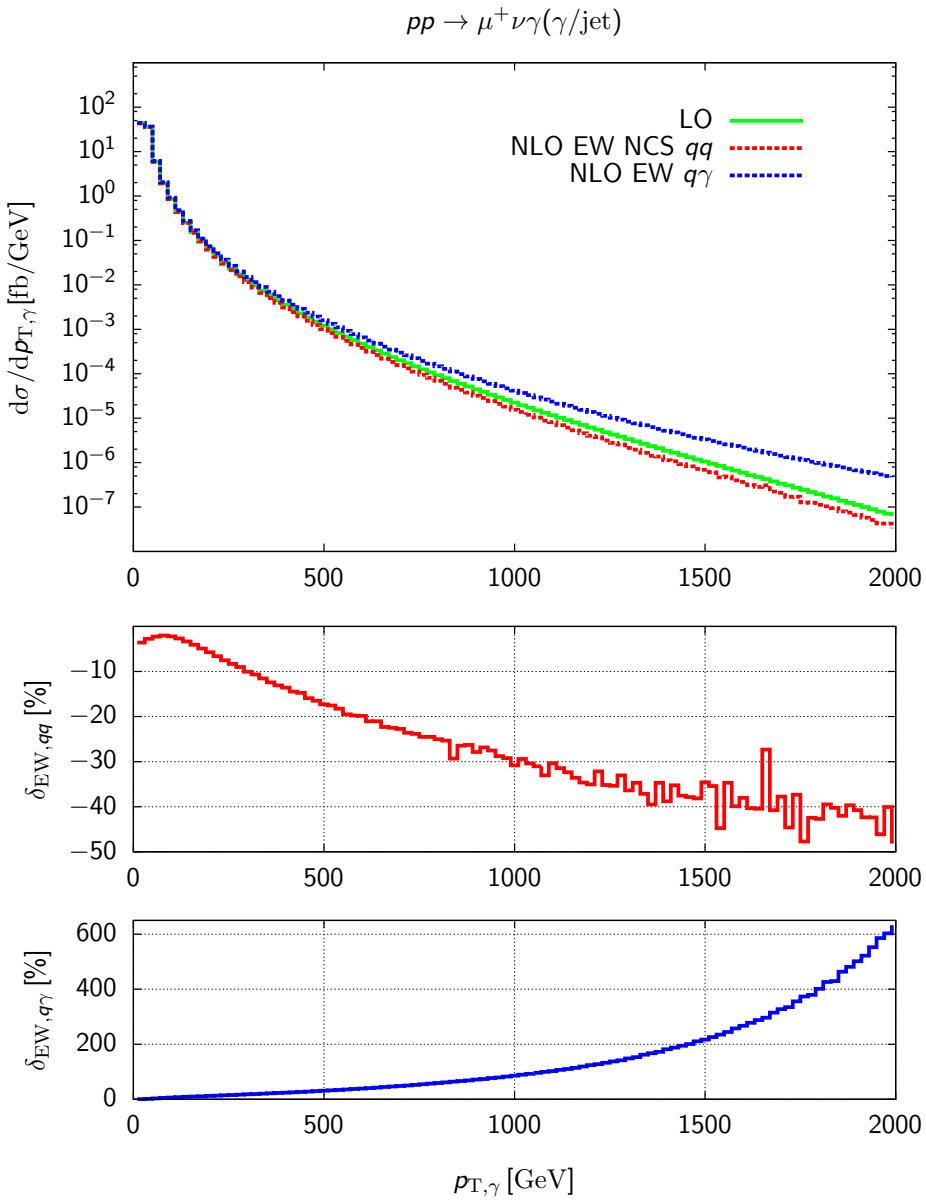
Transverse mass of the lepton–neutrino pair

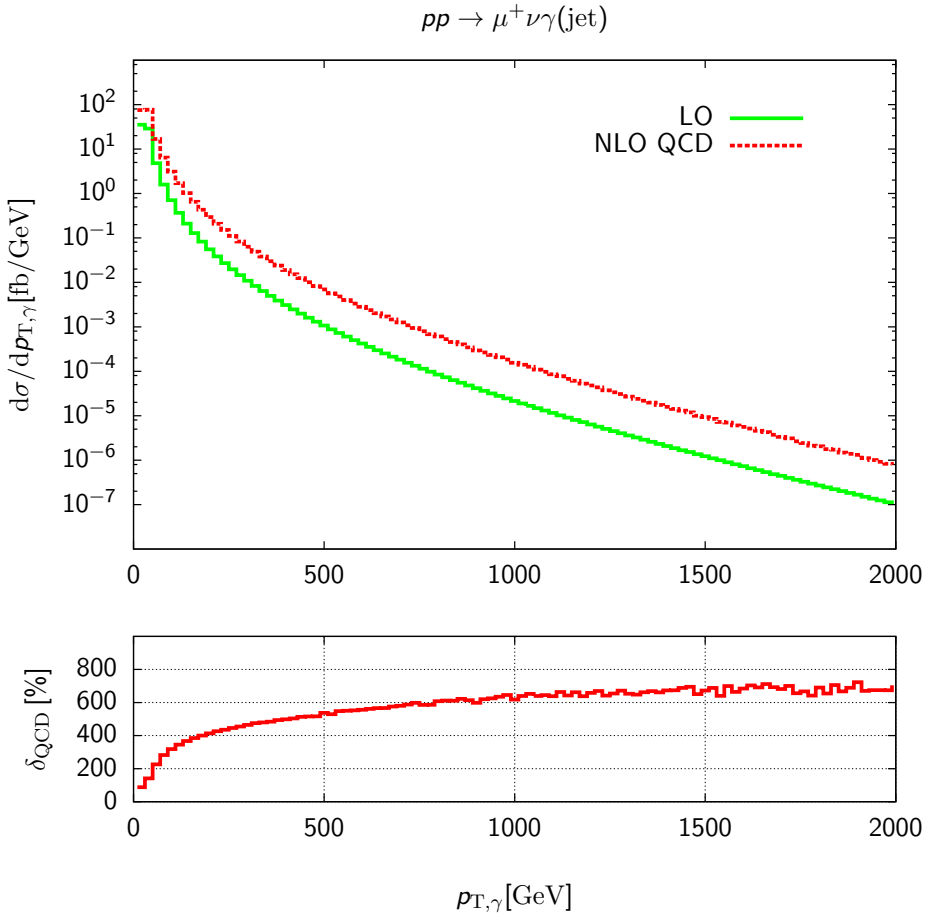




- EW corrections up to -8%
- QCD corrections ca. 150% in resonance region

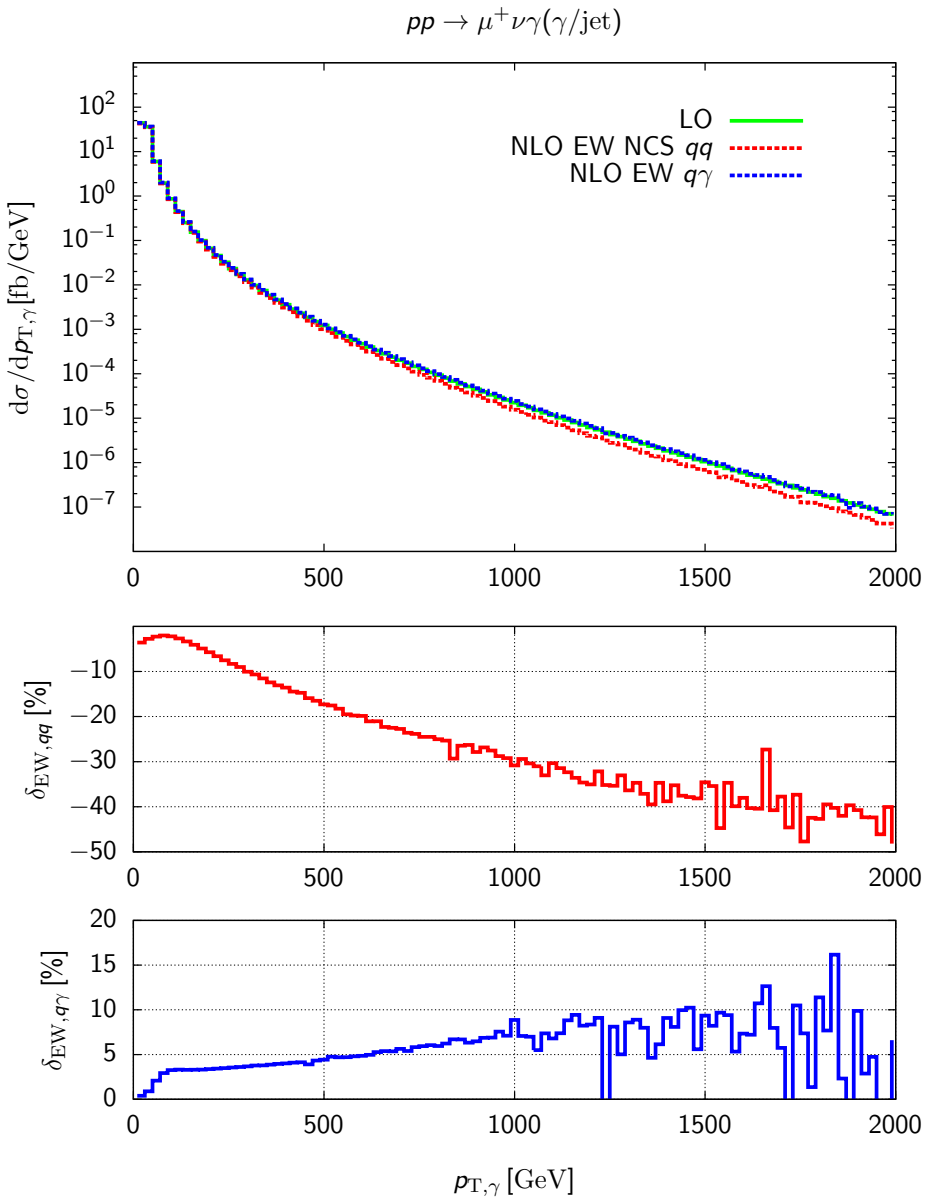
Transverse momentum of the photon

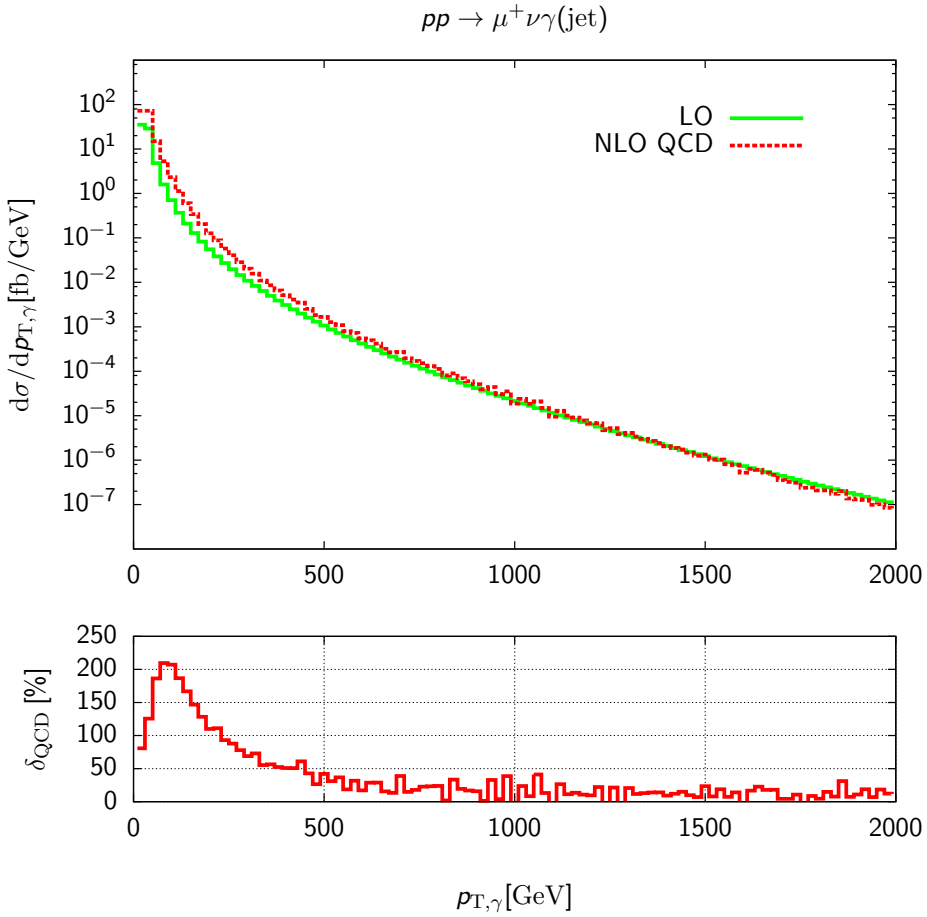




- Large QCD corrections.
- Large corrections from $q\gamma$ channel $\rightarrow$ impose jet veto.

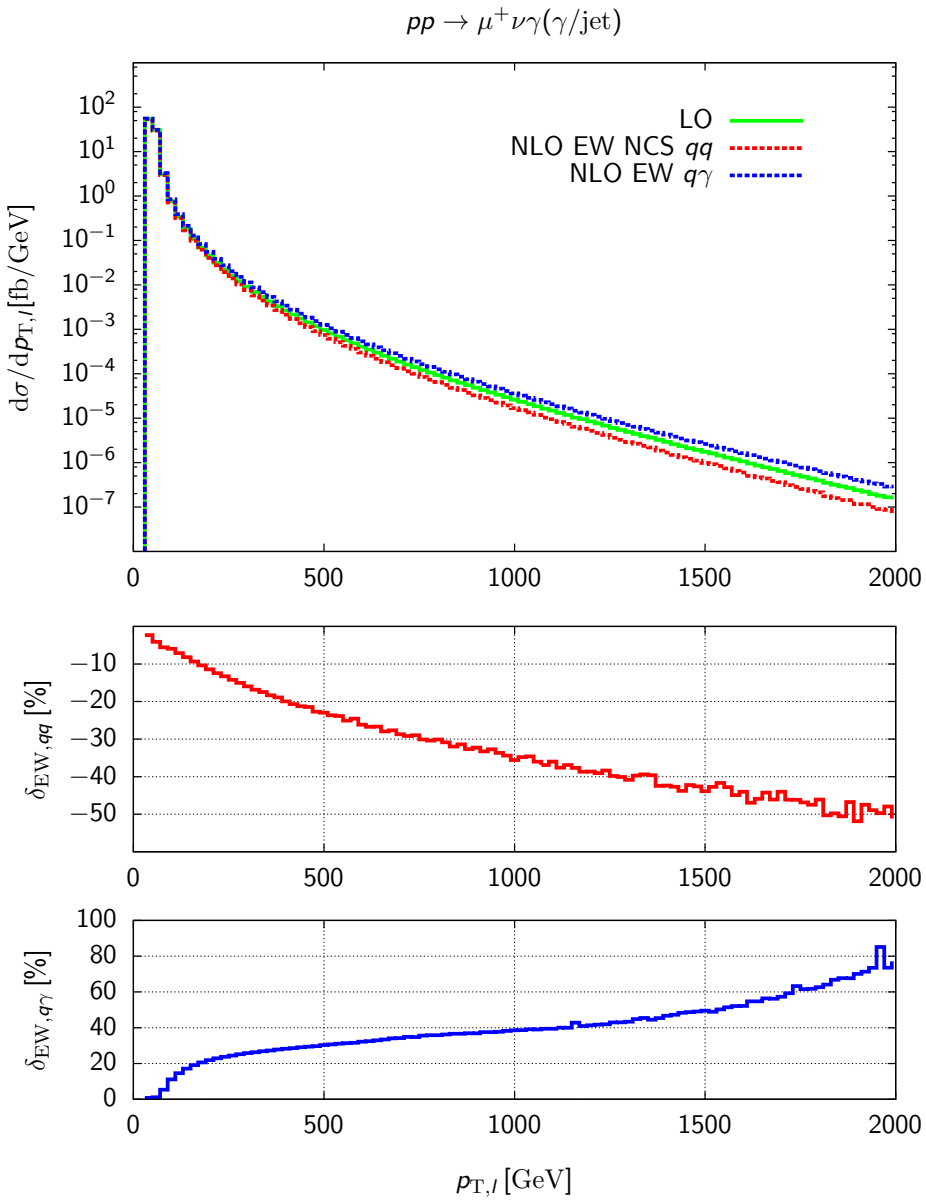
Transverse momentum of the photon with jet-veto

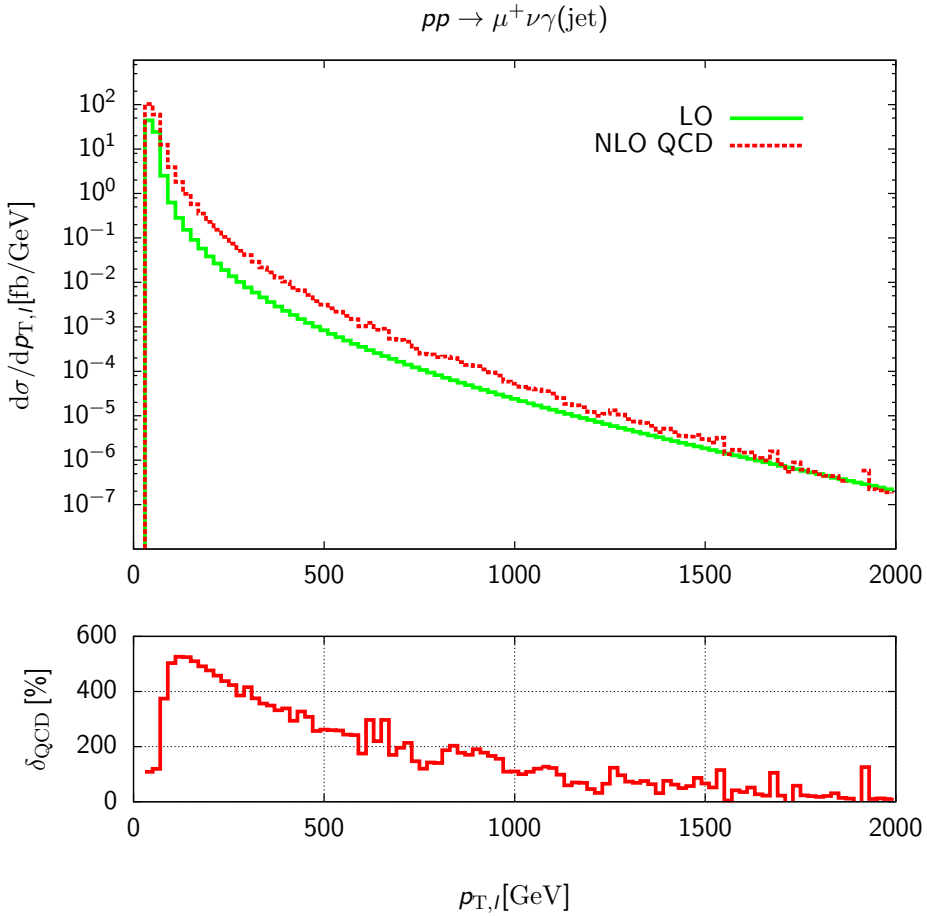




- QCD & γ-induced corrections small in high P_{T} tail.
- EW corrections dominate.

Transverse momentum of the charged lepton





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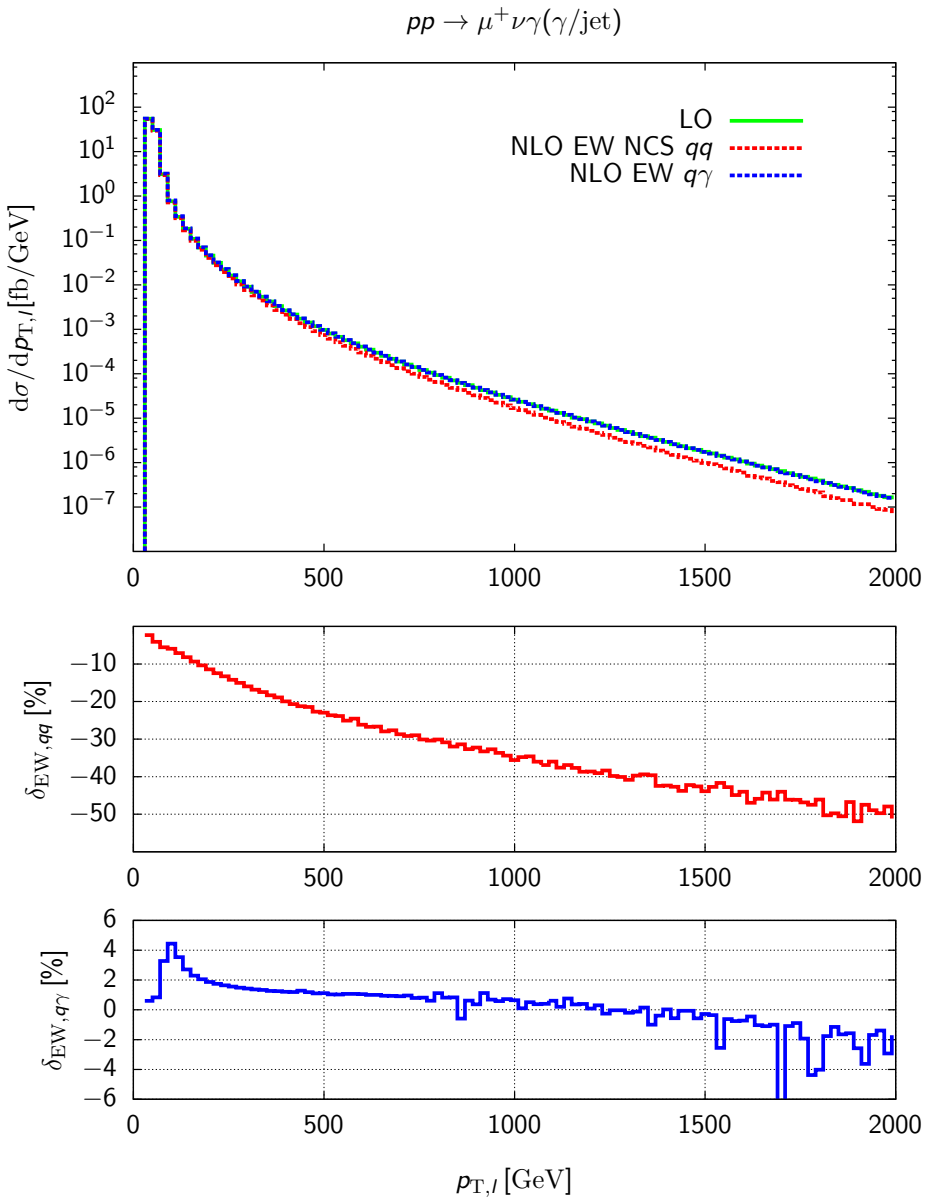
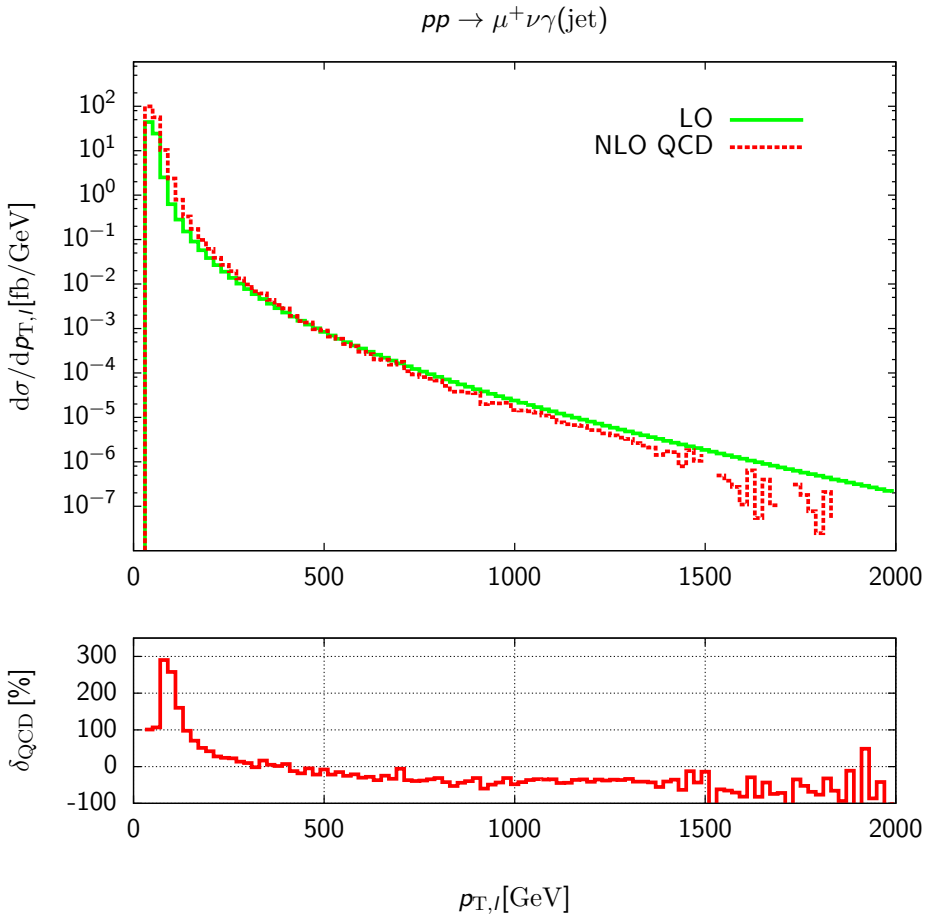
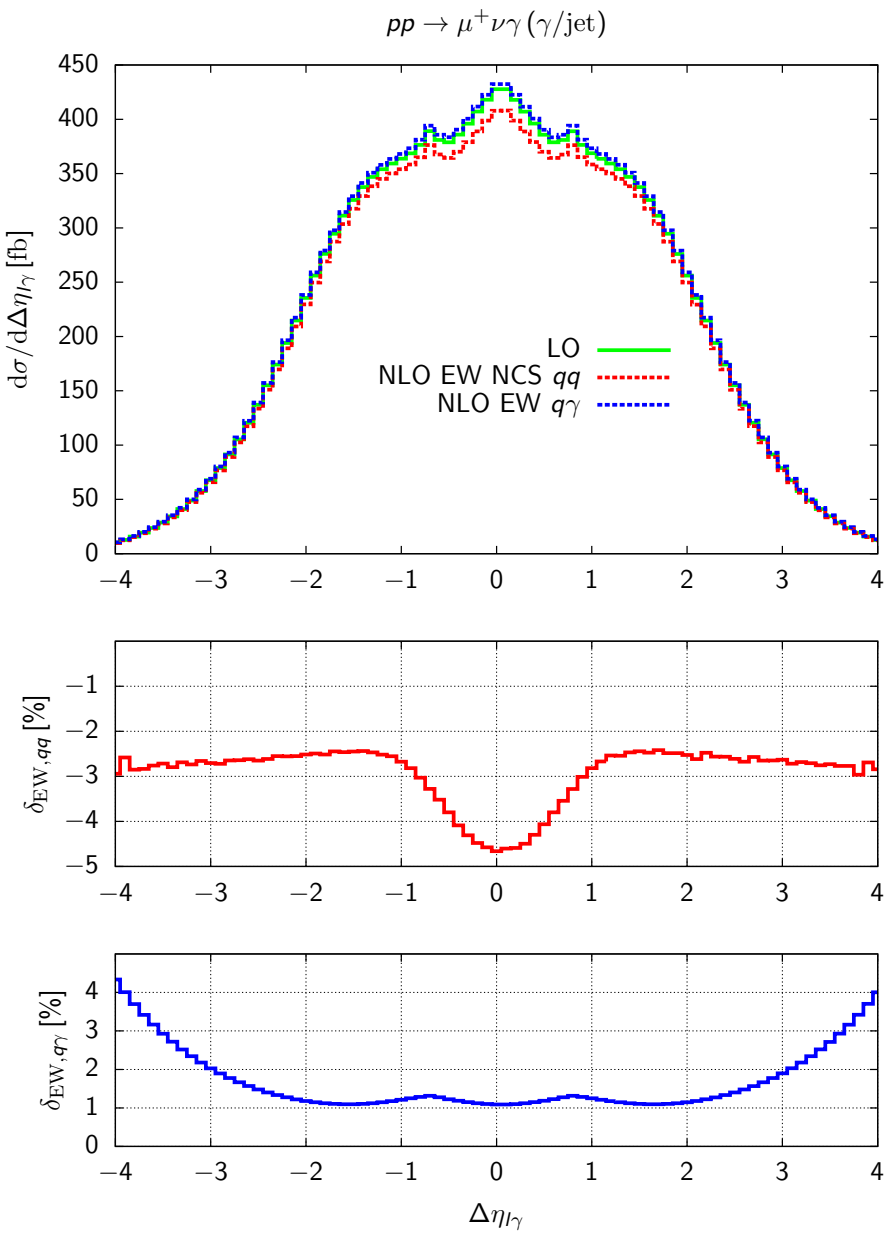
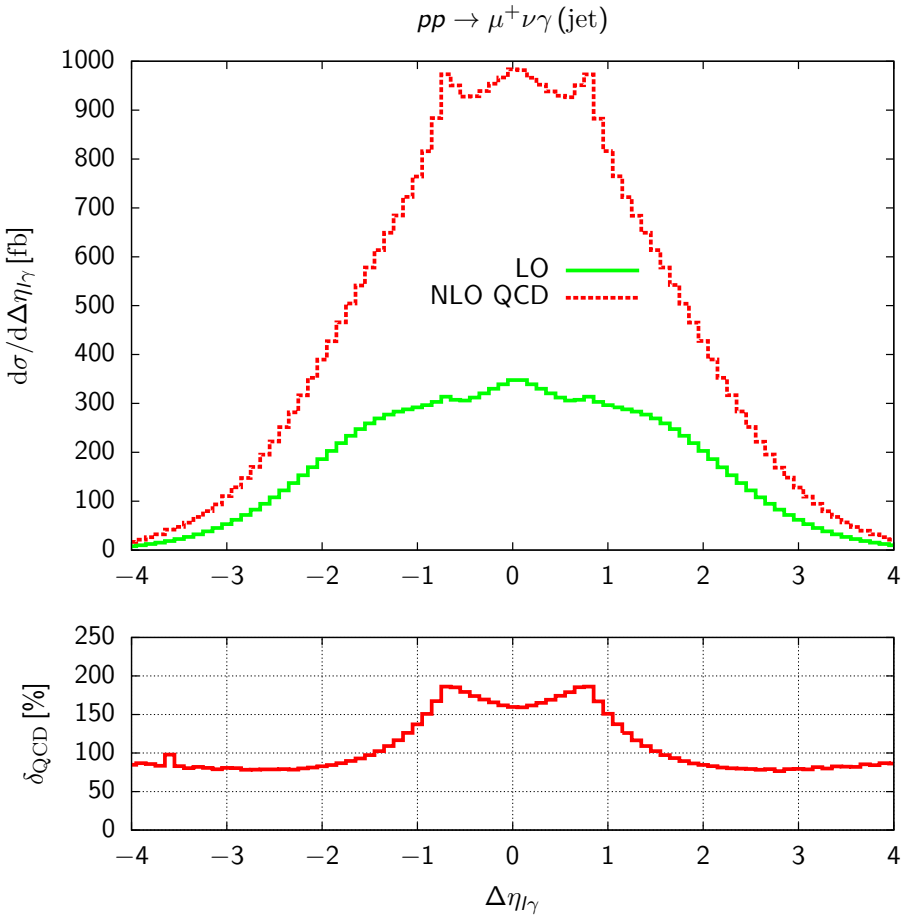




- QCD corrections are negative.
- EW corrections of the same order as QCD corrections.

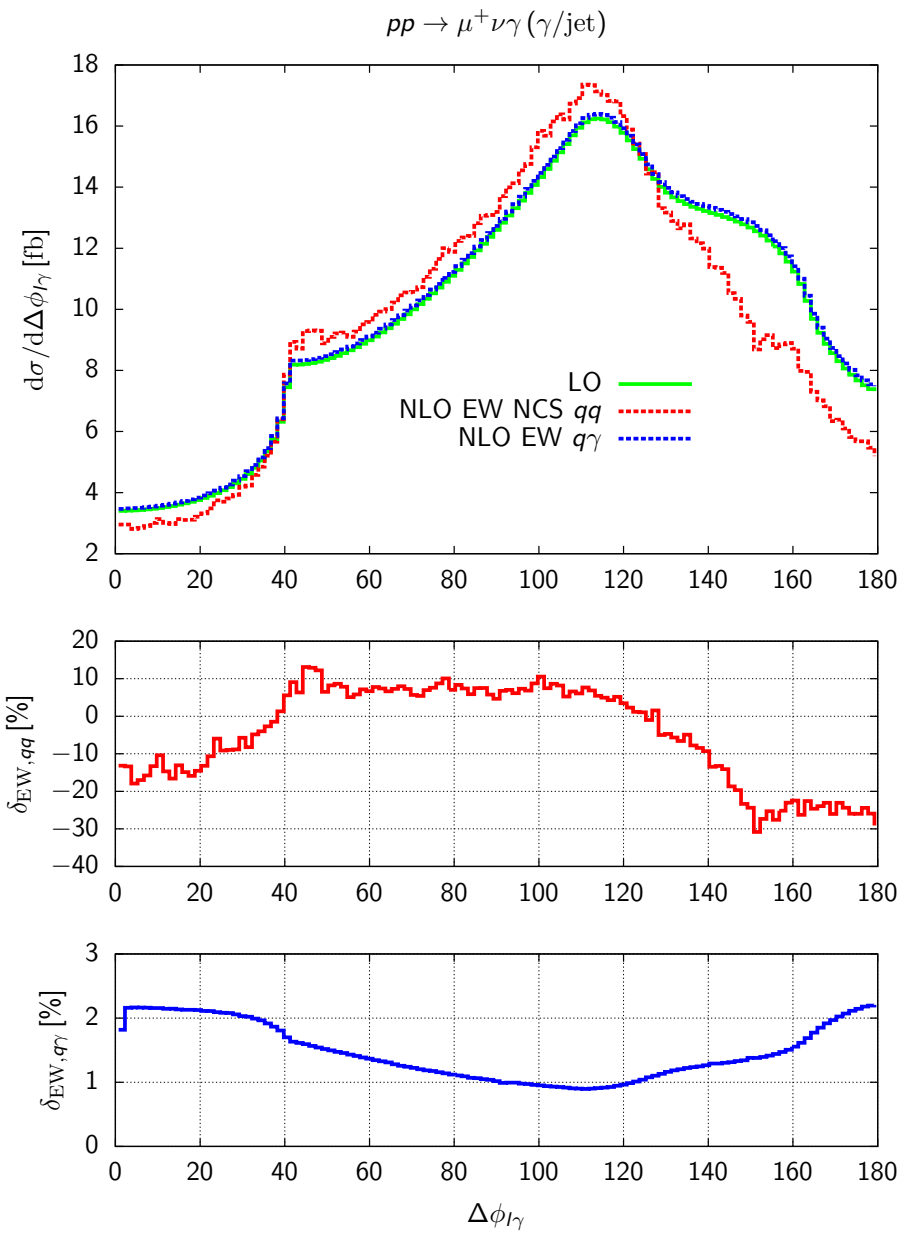
Rapidity difference between charged lepton and photon

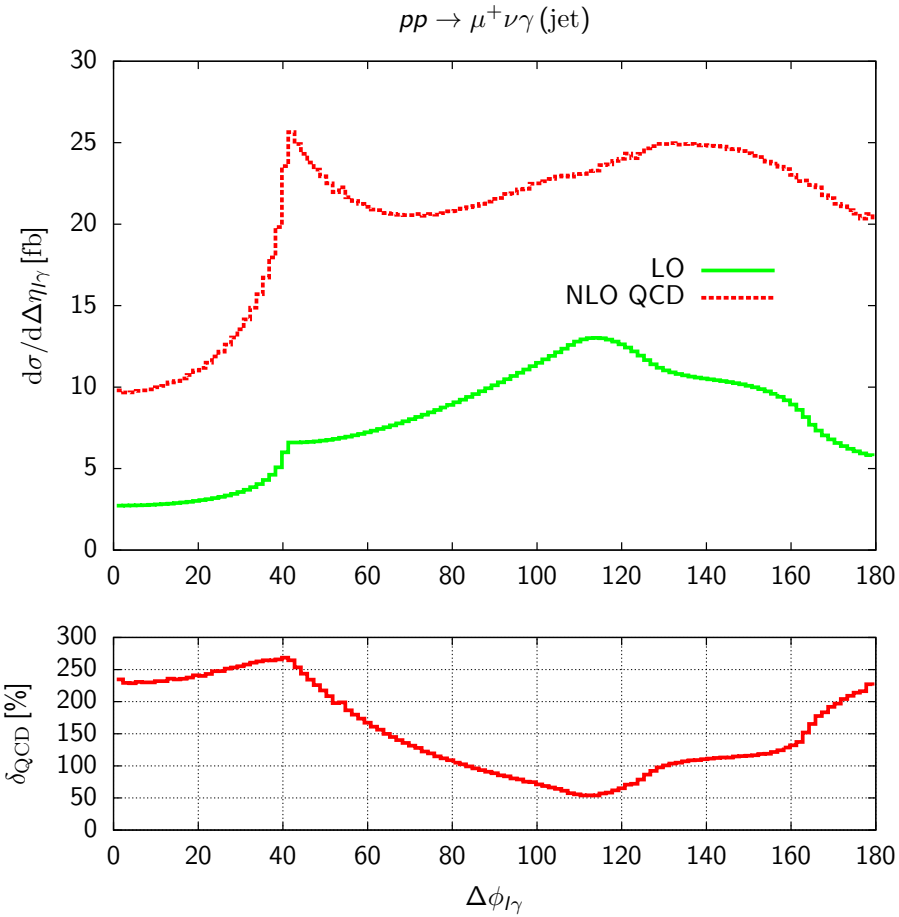




- Moderate shape distortion by EW corrections.
- Large shape distortion by QCD corrections.

Angular difference between charged lepton and photon





- No shape distortion by EW corrections.
- Large shape distortion by QCD corrections.

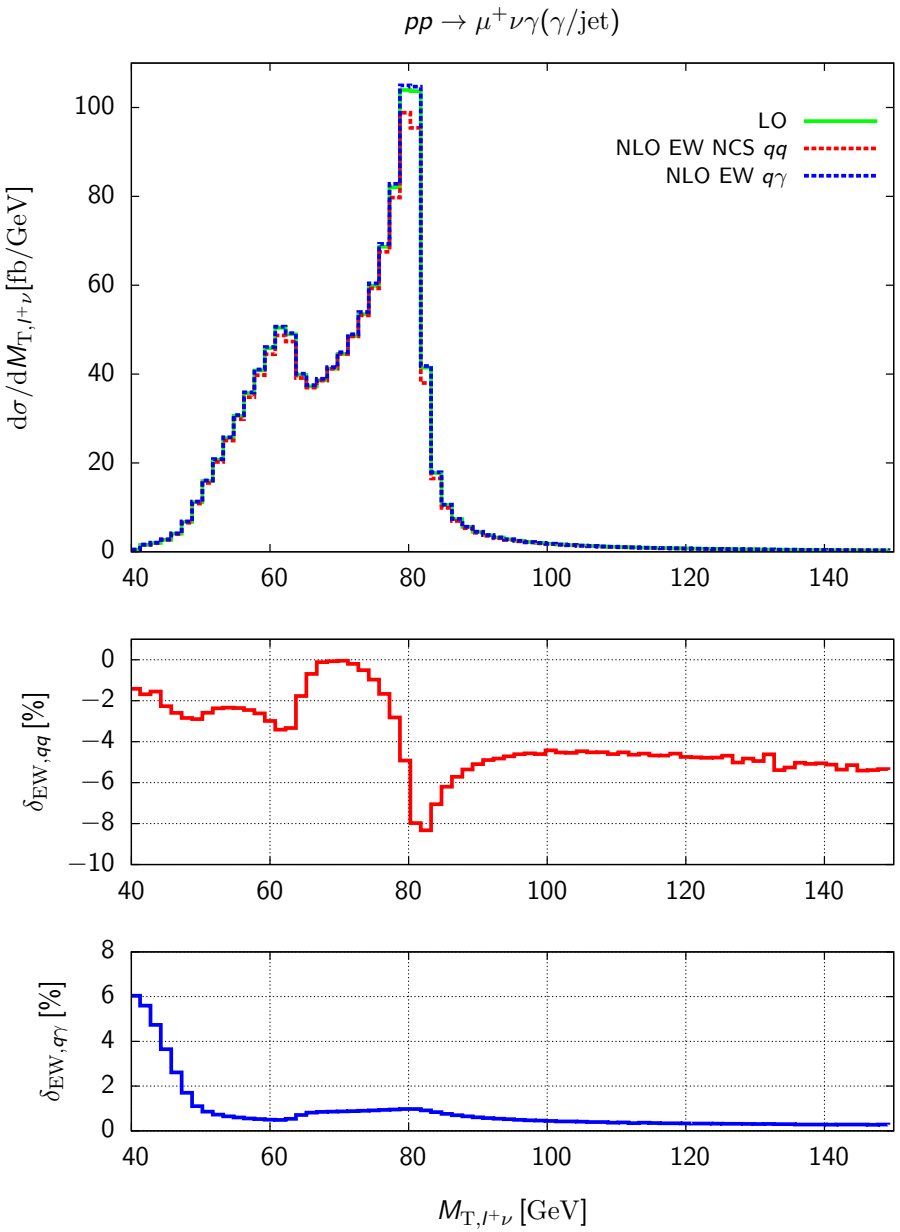
Conclusions and Outlook

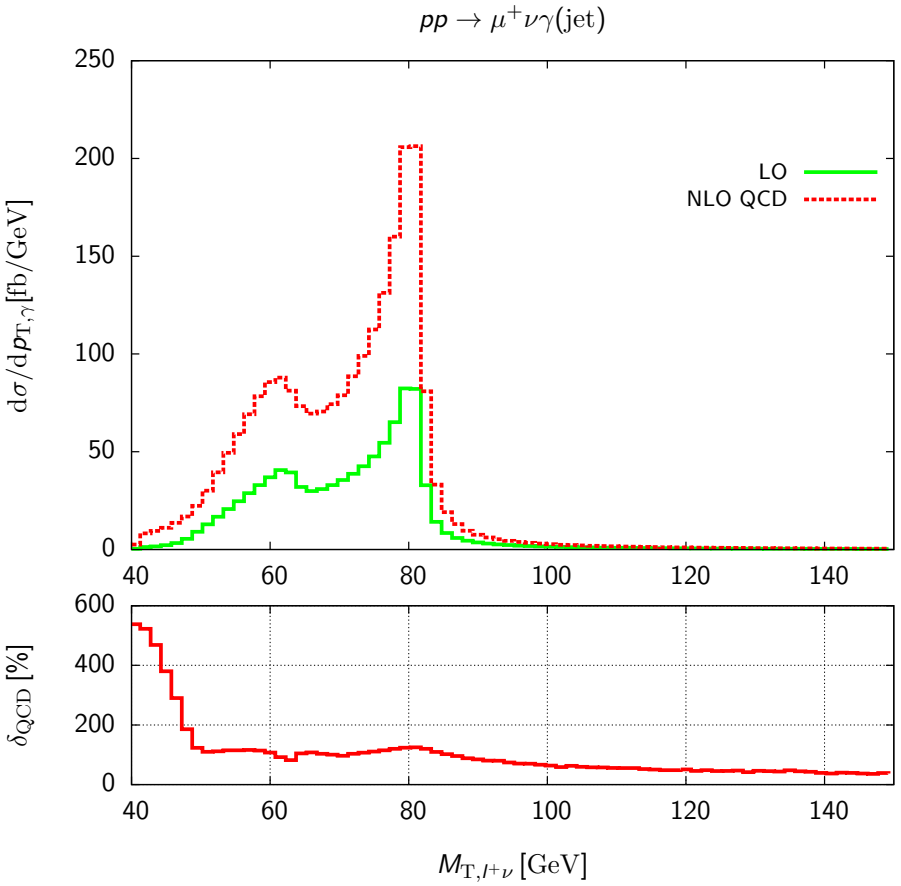
- full calculation of NLO corrections to $W + \gamma$ production
  - inclusion of all off-shell effects
  - photon-induced contributions included
  - provide calculation of non-collinear-safe observables
  - well defined separation between $W + \gamma$ and $W + \mathrm{jet}$
- huge QCD corrections

  $\rightarrow$ NNLO QCD corrections needed to lower scale uncertainty
- sizeable EW corrections in P_{T} distributions with and without jet-veto
- Outlook:
  - implementation of anomalous couplings
  - calculation of NLO corrections to $Z + \gamma$ (important background to Higgs-production)

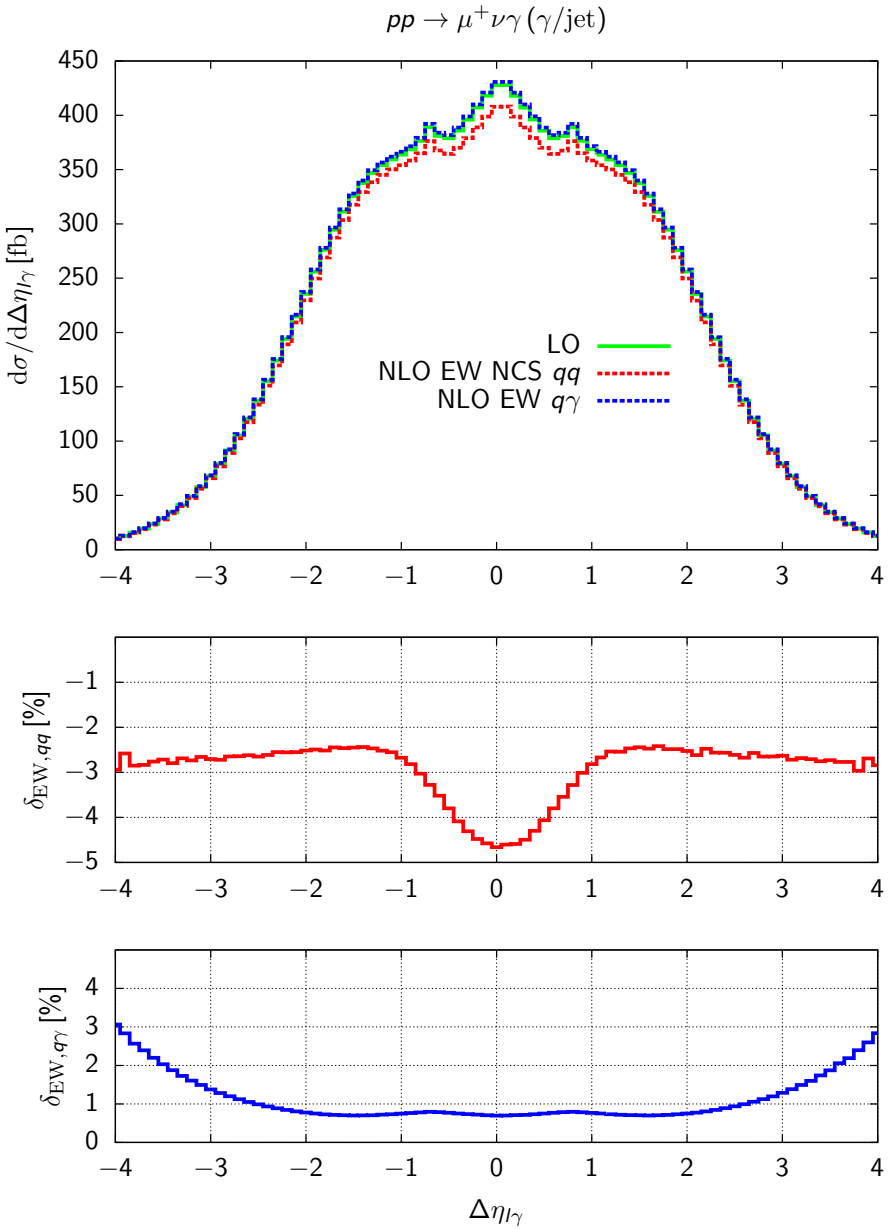
Thank you for your attention!

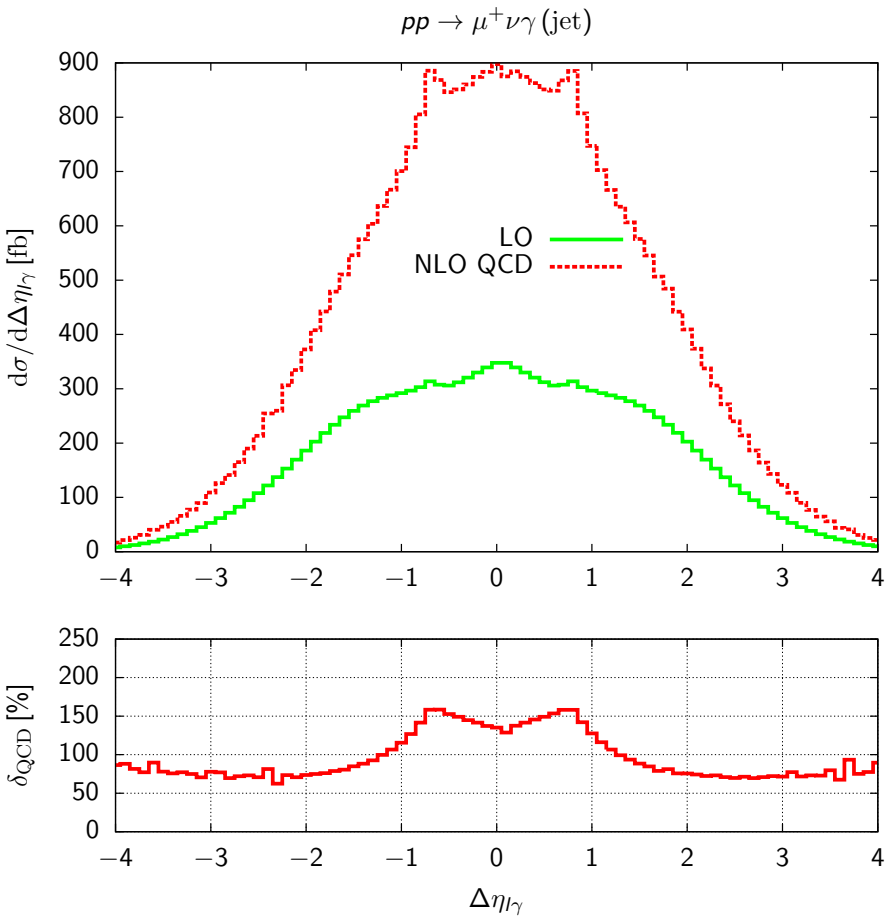
Transverse mass of the lepton–neutrino pair with jet-veto



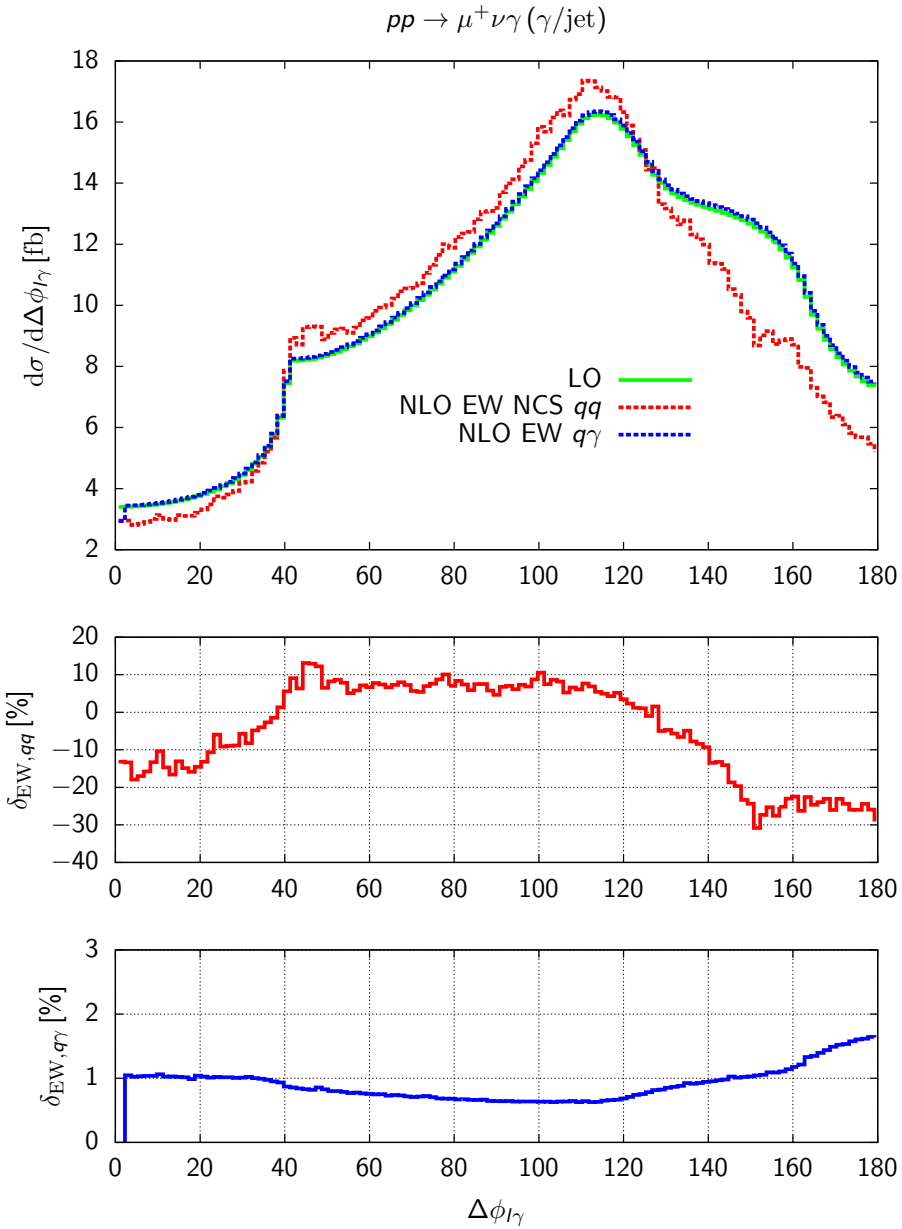


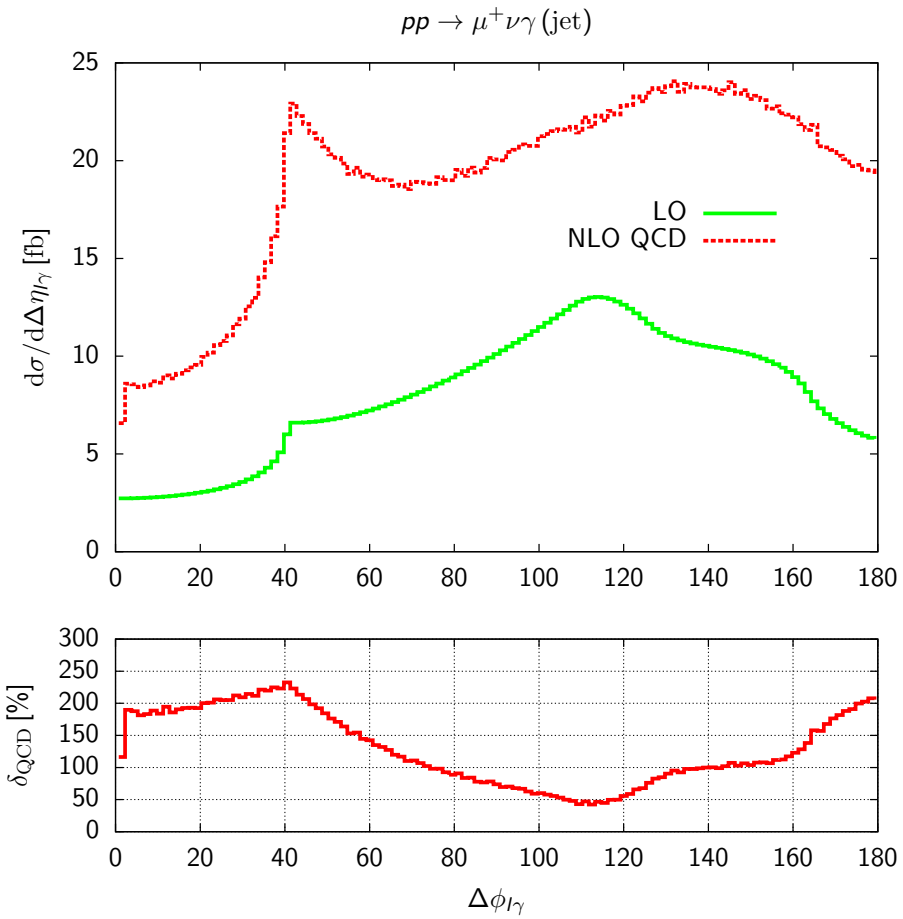
Rapidity difference with jet-veto





Angular difference with jet-veto





Frixione Isolation Cut

Definition of Frixione isolation cut

All events with $R_{\mathrm{jet},\gamma} < R_0$ have to respect

$$p_{\mathrm{T,jet}} < \varepsilon\, p_{\mathrm{T},\gamma} \left(\frac{1 - \cos\left(R_{\mathrm{jet},\gamma}\right)}{1 - \cos\left(R_0\right)} \right) \text{ [Frixione 1998]}, \qquad \varepsilon \approx \frac{1 - z_c}{z_c}$$

Properties

- all IR divergences ($R_{\mathrm{jet},\gamma} \to 0$ and $p_{\mathrm{T},\gamma} \to 0$) caused by the photon are excluded
- soft and collinear ($p_{\mathrm{T,jet}} \to 0$) jet emission is treated inclusively