Radiative Corrections to Di-Photon + 1 Jet Production

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with

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HIGGS + 1 JET $\to \gamma\gamma$ + 1 JET

A leading order parton level study (CompHEP) at 30 fb^{-1} at LHC

Abdullin et al. hep-ph/9805341

- event selection cuts

$$\begin{cases} \text{2 isolated photons with} & p_{\gamma T} \geq 40 \text{ GeV} & |\eta_\gamma| \leq 2.5 \\ \text{1 jet with} & E_{\text{jet}T} \geq 30 \text{ GeV} & |\eta_{\text{jet}}| \leq 4.5 \\ \text{photon-photon distance} & \Delta R_{\gamma\gamma} \geq 0.3 & \\ \text{jet-photon distance} & \Delta R_{\gamma\text{jet}} \geq 0.3 & \end{cases}$$

- $M_{\gamma\gamma}$ bin $\quad \Delta M_{\gamma\gamma} = \begin{cases} 3.25 \text{ GeV} & \text{ATLAS} \\ 2.0 \text{ GeV} & \text{CMS} \end{cases}$

  photon identification efficiency 73 %

- $\sqrt{\hat{s}} \geq 300$ GeV is used in order to improve S/B

  ➥ for $M_{\mathrm{H}} = 120$ GeV, $\quad S/\sqrt{B} = \begin{cases} 6.2 & \text{ATLAS} \\ 7.0 & \text{CMS} \end{cases}$

HIGGS + 1 JET $\to \gamma\gamma$ + 1 JET

A hadron level study (CompHEP & PYTHIA) at 30 fb^{-1}

Zmushko ATLAS Note 2002

- event selection cuts: same as in Abdullin et al., but for $\Delta R_{\gamma \rm jet} \geq 0.4$
- $M_{\gamma\gamma}$ bin $\Delta M_{\gamma\gamma} = 3.64$ GeV
  photon identification efficiency 80 %
- no K factor included for the signal
- S/B increases with $\sqrt{\hat{s}}$ $\rightarrow$ $\sqrt{\hat{s}} \geq 300$ GeV is used
- $S/\sqrt{B}$ is roughly independent of $\sqrt{\hat{s}}$

  ➥ for $M_{\rm H} = 120$ GeV, $S/\sqrt{B} \; = \; 4.9$

Caveat: background (and thus $S/\sqrt{B}$) depends on the evolution scale for PYTHIA parton showering: $Q^2 = 0.5 M_{\gamma\gamma}^2 + p_{\rm T}^2$

Signal: Higgs + 1 Jet

Several sources for the inclusive Higgs production at high transverse momentum or with an associated jet

- Higgs + 1 Jet via Gluon Fusion — de Florian, Grazzini, Kunszt 99
- Weak-Boson Fusion: $qq \to qqH$ — Campbell, Ellis; Figy, Oleari, Zeppenfeld 03
- Associated Weak-Boson Production: HW, HZ — Han, Willenbrok 92

They are all known at NLO, and are all included in MCFM Campbell, Ellis

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Background: $\gamma\gamma$ + 1 Jet

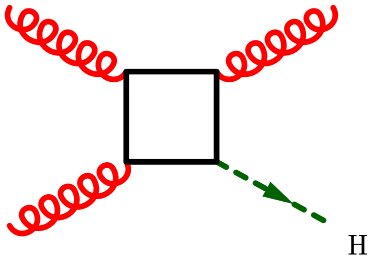
- QCD Production of $pp \longrightarrow \gamma\gamma + 1$ Jet — Maltoni, Nagy, Trocsanyi, VDD 03
- ElectroWeak Production of $pp \longrightarrow \gamma\gamma + 1$ Jet

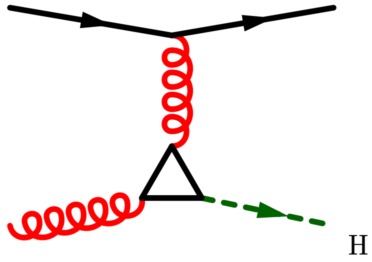
They are known at NLO

Higgs + 1 Jet via Gluon Fusion

Leading Order

$\mathcal{O}(\alpha_s^3)$





☛ 1-loop $gg \to gH \quad qg \to qH \quad +$ crossings

Higgs + 1 Jet via Gluon Fusion

Leading Order

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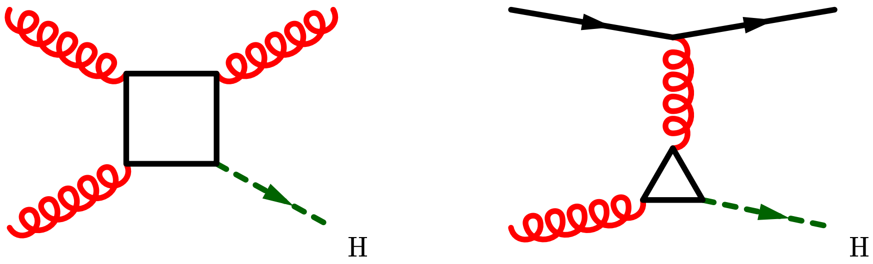
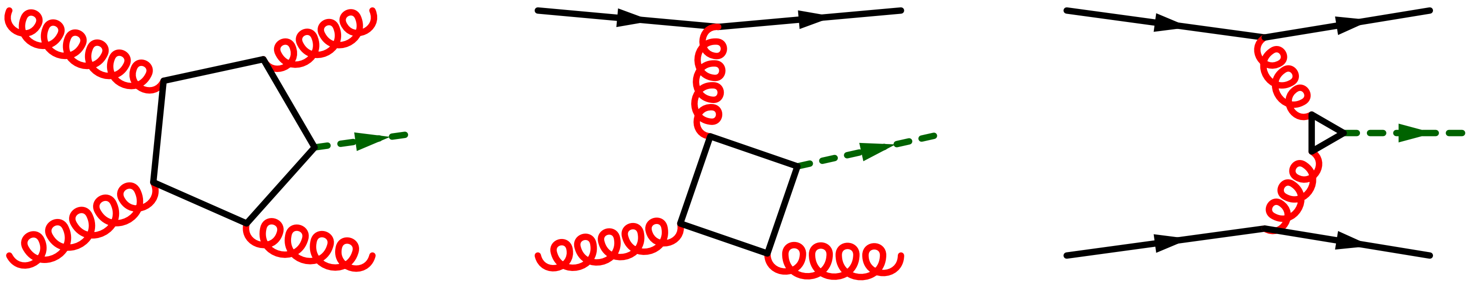


- 1-loop $\quad gg \to gH \quad qg \to qH \quad + \quad$ crossings

NLO corrections

$\mathcal{O}(\alpha_S^4)$

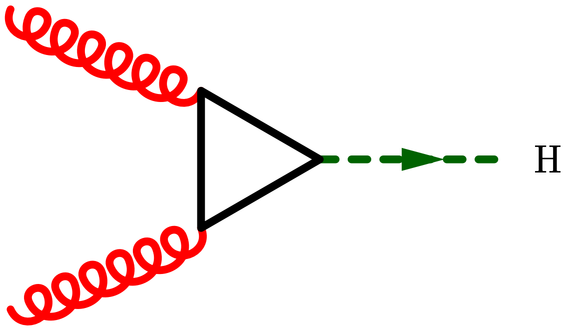
- 1-loop $\quad gg \to ggH \quad qg \to qgH \quad qQ \to qQH \quad + \quad$ crossings



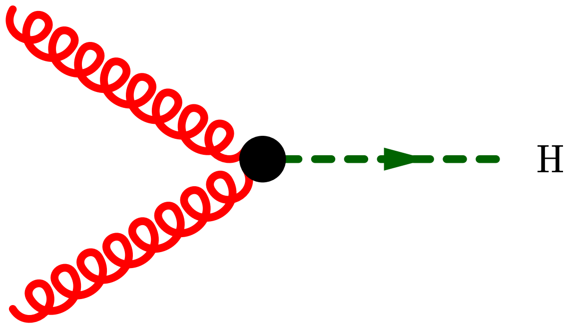
Kilgore, Oleari, Schmidt, Zeppenfeld, VDD 01

- 2-loop $\quad gg \to gH \quad qg \to qH \; + \;$ crossings $\quad$ is at present unknown

THE LARGE TOP-MASS LIMIT



$$\xrightarrow{M_{\mathrm{H}} \ll 2M_t}$$



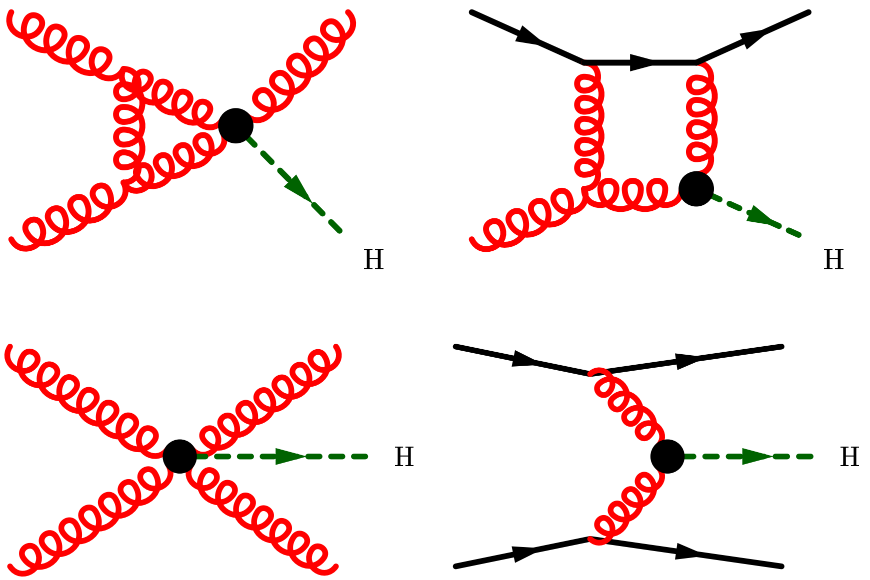
☛ for Higgs + 1 jet, the large $\boldsymbol{M_t}$ limit is accurate if $M_{\mathrm{H}} \ll 2M_t$ and $p_{\mathrm{T}} \ll M_t$

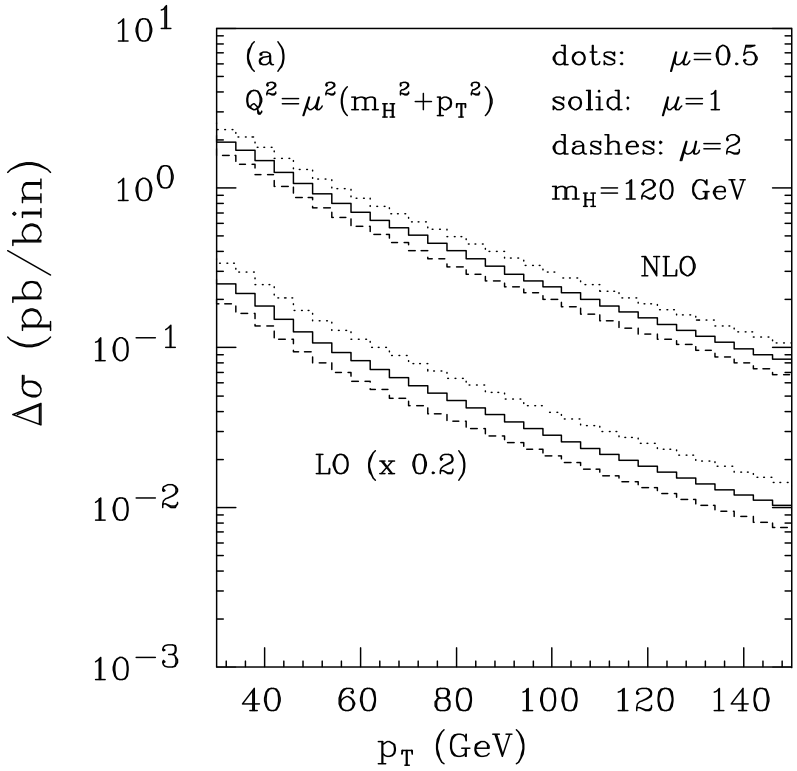
Higgs + 1 Jet in the large M_t limit

NLO corrections $\mathcal{O}(\alpha_S^4)$

- 1-loop $gg \to gH \quad qg \to qH \quad +$ crossings
- tree $gg \to ggH \quad qg \to qgH \quad qQ \to qQH \quad +$ crossings

de Florian, Grazzini, Kunszt hep-ph/9902483



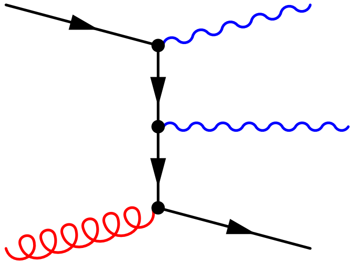


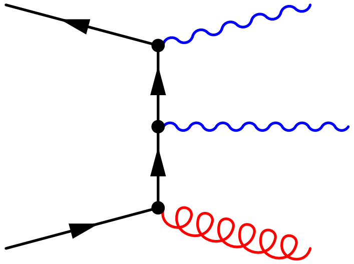
- large K factor: $K_\infty^{\rm NLO} \simeq 1.6$
- variation of $\mu_R = \mu_F = \mu = 0.5 \to 2$: $\pm 35\%$ at LO; $\pm 20\%$ at NLO

Background: $\gamma\gamma$ + 1 Jet

Leading Order

$\mathcal{O}(\alpha_s \alpha_{\rm em}^2)$



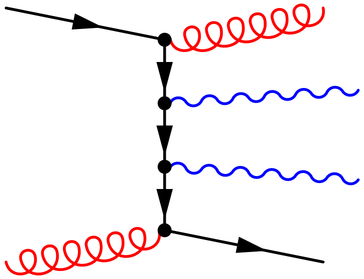


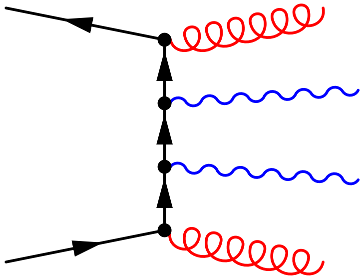
☛ tree $\quad qg \to q\gamma\gamma \qquad q\bar{q} \to g\gamma\gamma$

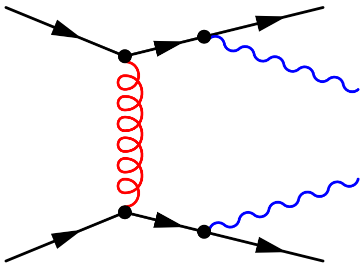
NLO corrections

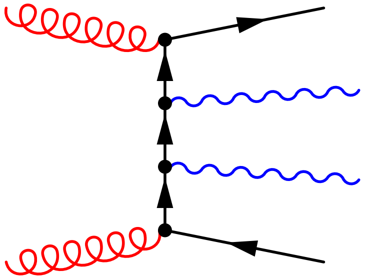
$\mathcal{O}(\alpha_s^2 \alpha_{\rm em}^2)$

☛ tree $\quad qg \to qg\gamma\gamma \qquad q\bar{q} \to gg\gamma\gamma \qquad qq \to qq\gamma\gamma \qquad gg \to q\bar{q}\gamma\gamma$

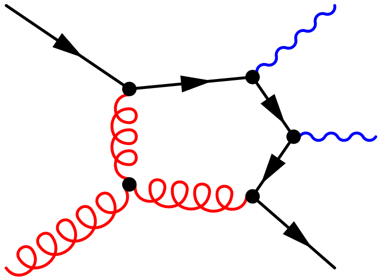


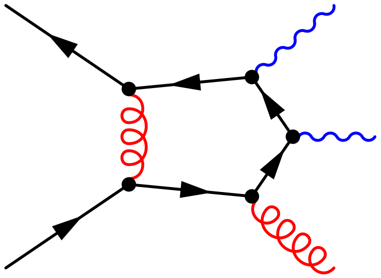






☛ 1-loop $\quad qg \to q\gamma\gamma \qquad q\bar{q} \to g\gamma\gamma$

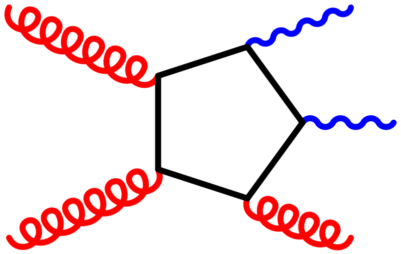




Background: $\gamma\gamma + 1$ Jet

NNLO corrections

$\mathcal{O}(\alpha_s^3 \alpha_{\mathrm{em}}^2)$



☛ not known, except for $gg \to g\gamma\gamma$, which is effectively a leading order term.

$gg \to g\gamma\gamma$ is about 20% of $qg \to q\gamma\gamma$ at leading order

de Florian, Kunszt 99

Balazs, Nadolsky, Schmidt, Yuan 99

NLO Corrections to $\gamma\gamma + 1$ Jet

Maltoni, Nagy, Trocsanyi, VDD hep-ph/0303012

- event selection cuts

$$\begin{cases} \text{2 isolated photons and 1 jet with} & p_{\mathrm{T}} \geq 40\ \mathrm{GeV} \quad |\eta| \leq 2.5 \\ \text{jet cone size} & R_{\mathrm{jet}} = 1 \\ \text{jet-photon distance} & \Delta R_{\gamma\mathrm{jet}} \geq 1.5 \\ \text{photon-photon transverse momentum} & p_{\gamma\gamma\mathrm{T}} \geq 40\ \mathrm{GeV} \end{cases}$$

- Standard photon isolation

hadronic energy allowed inside the cone of radius R_γ is

$$E_{\mathrm{T}} \leq E_{\mathrm{T,max}} \quad \text{with} \quad E_{\mathrm{T,max}} = \#\ \mathrm{GeV}, \quad \text{or} \quad \epsilon\, p_{\gamma\mathrm{T}}$$

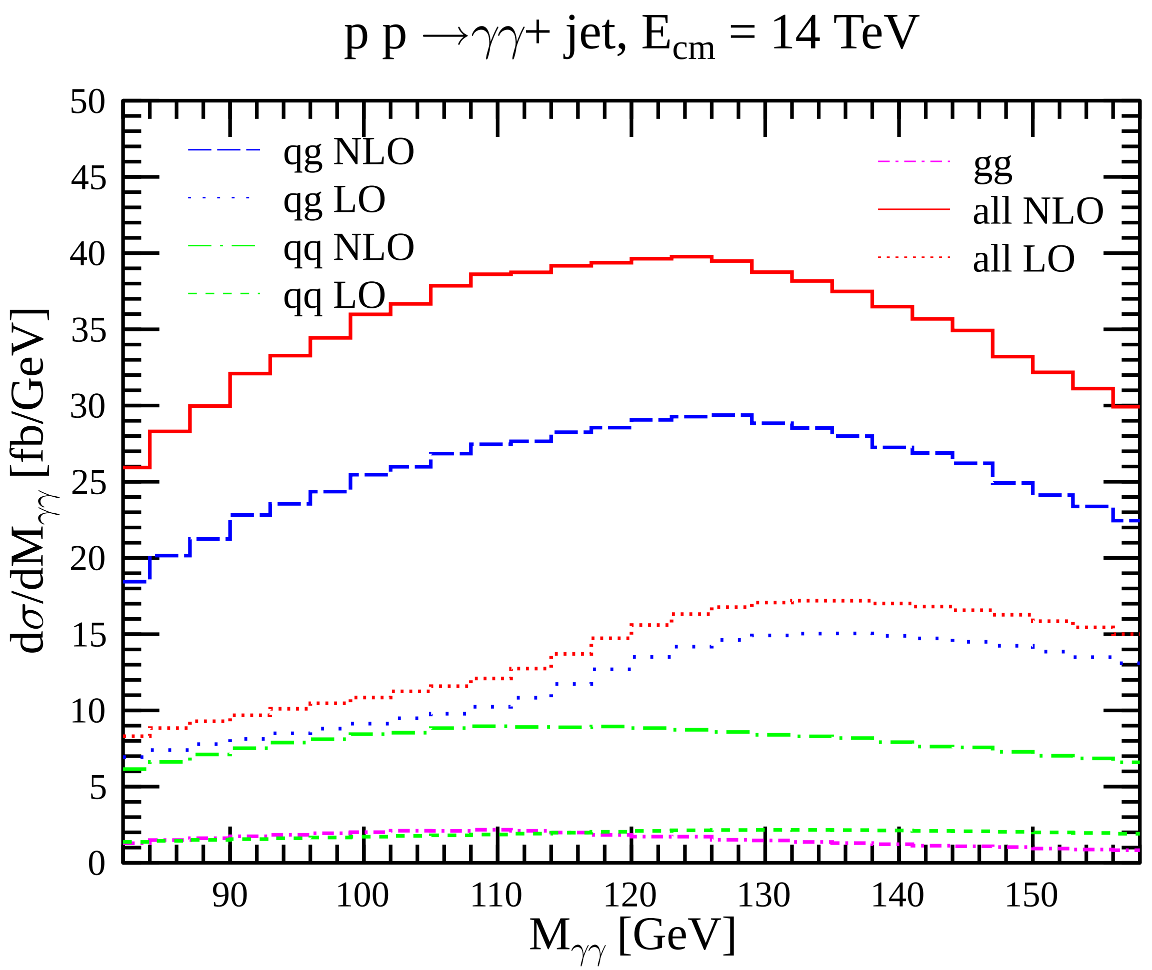
- Smooth (Frixione) photon isolation

hadronic energy allowed inside the cone of radius $r < R_\gamma$ is

$$E_{\mathrm{T}} \leq E_{\mathrm{T,max}} \left(\frac{1 - \cos r}{1 - \cos R_\gamma} \right)^n \qquad (\text{we take} \quad n = 1)$$

Frixione's photon isolation avoids fragmentation

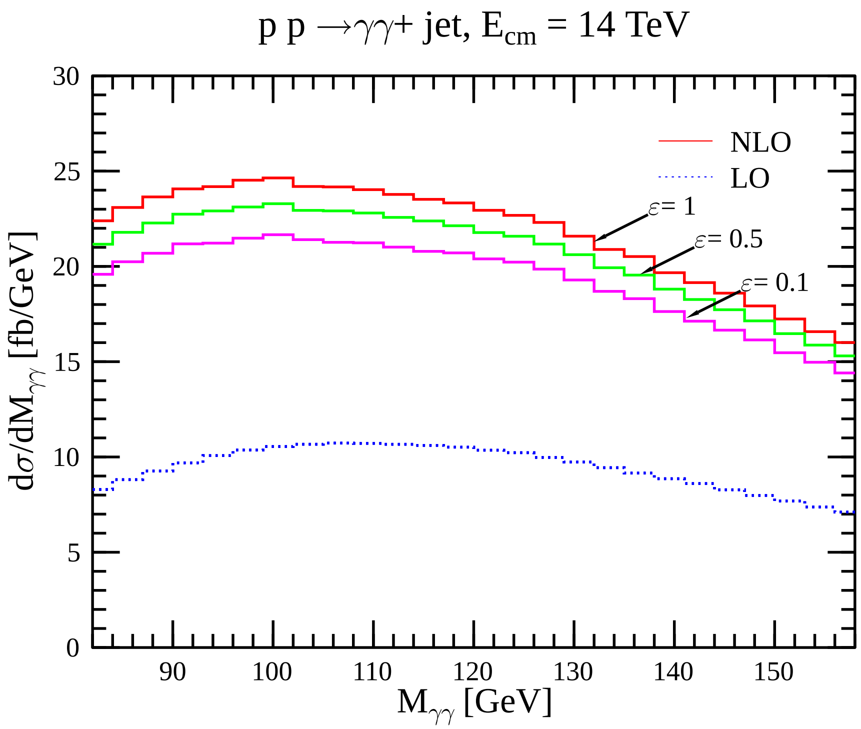
Invariant Mass of the Di-Photon Pair

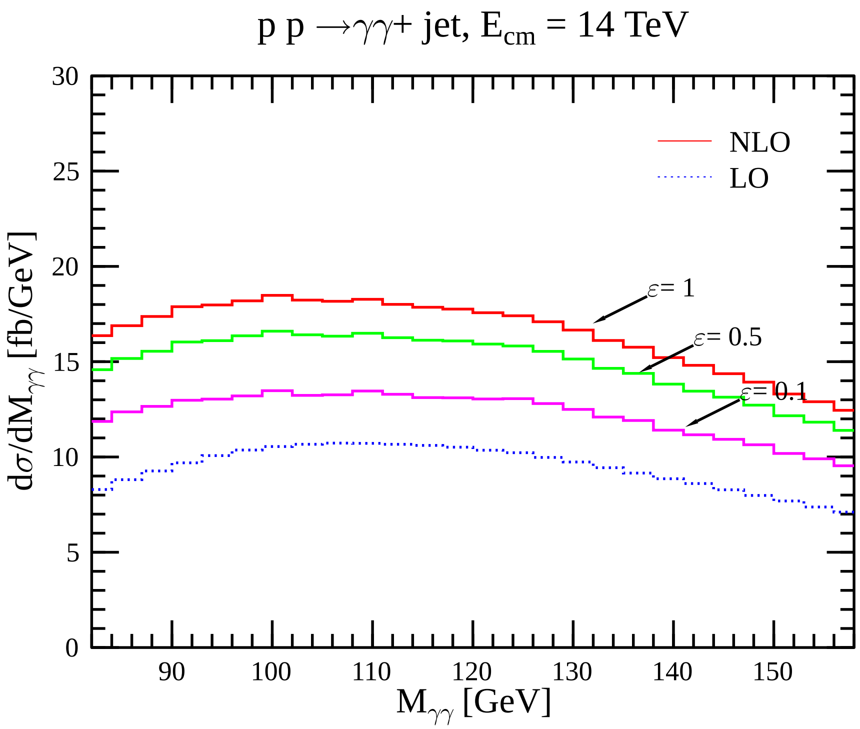


☛ Photon isolation $R_\gamma = 0.4$ and $\epsilon = 0.5$

Dependence of $M_{\gamma\gamma}$ on R_γ and ϵ

Dependence of the invariant mass distribution of the photon pair on the photon isolation parameters



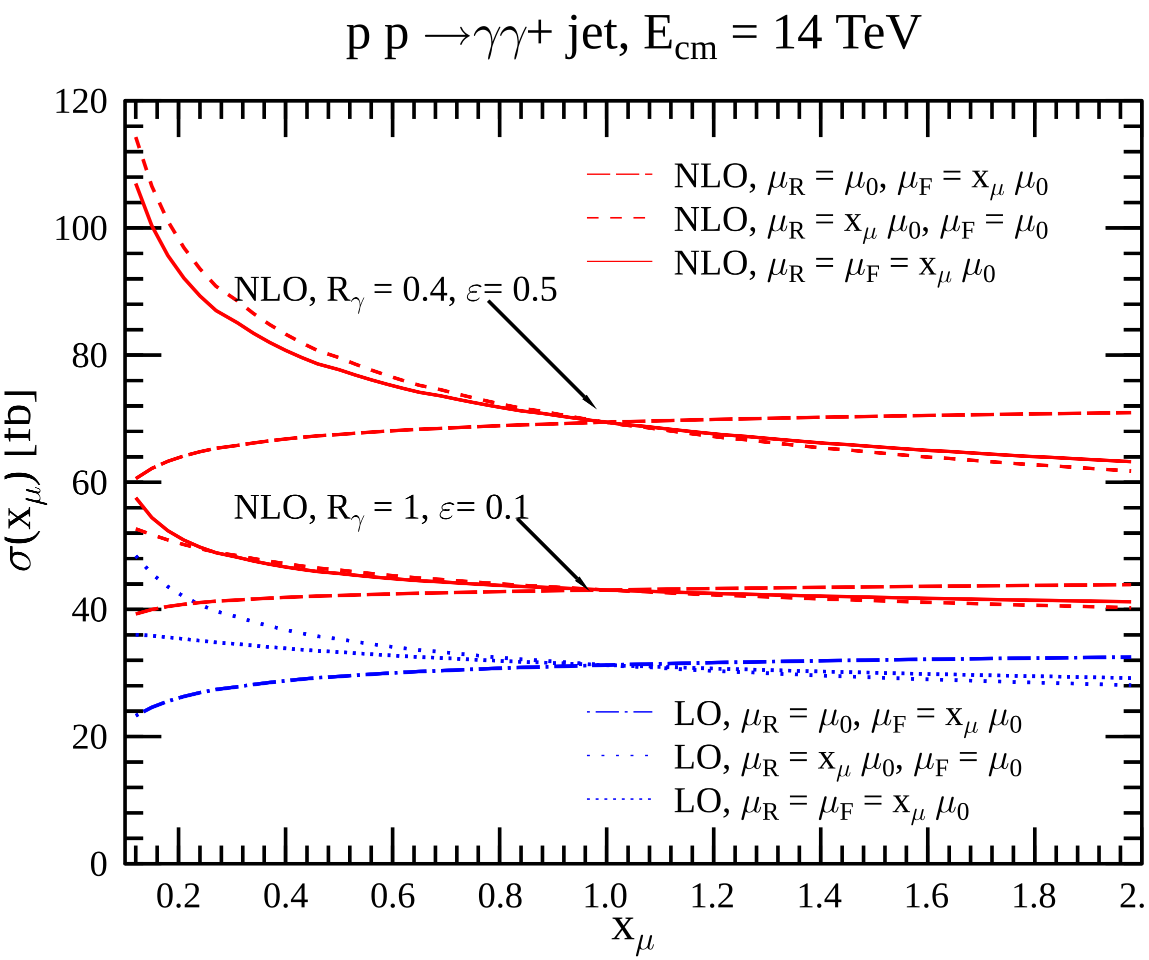


☛ Photon isolation $R_\gamma = 0.4$ $R_\gamma = 1$

➥ large corrections (with a K factor > 2) for $R_\gamma = 0.4$

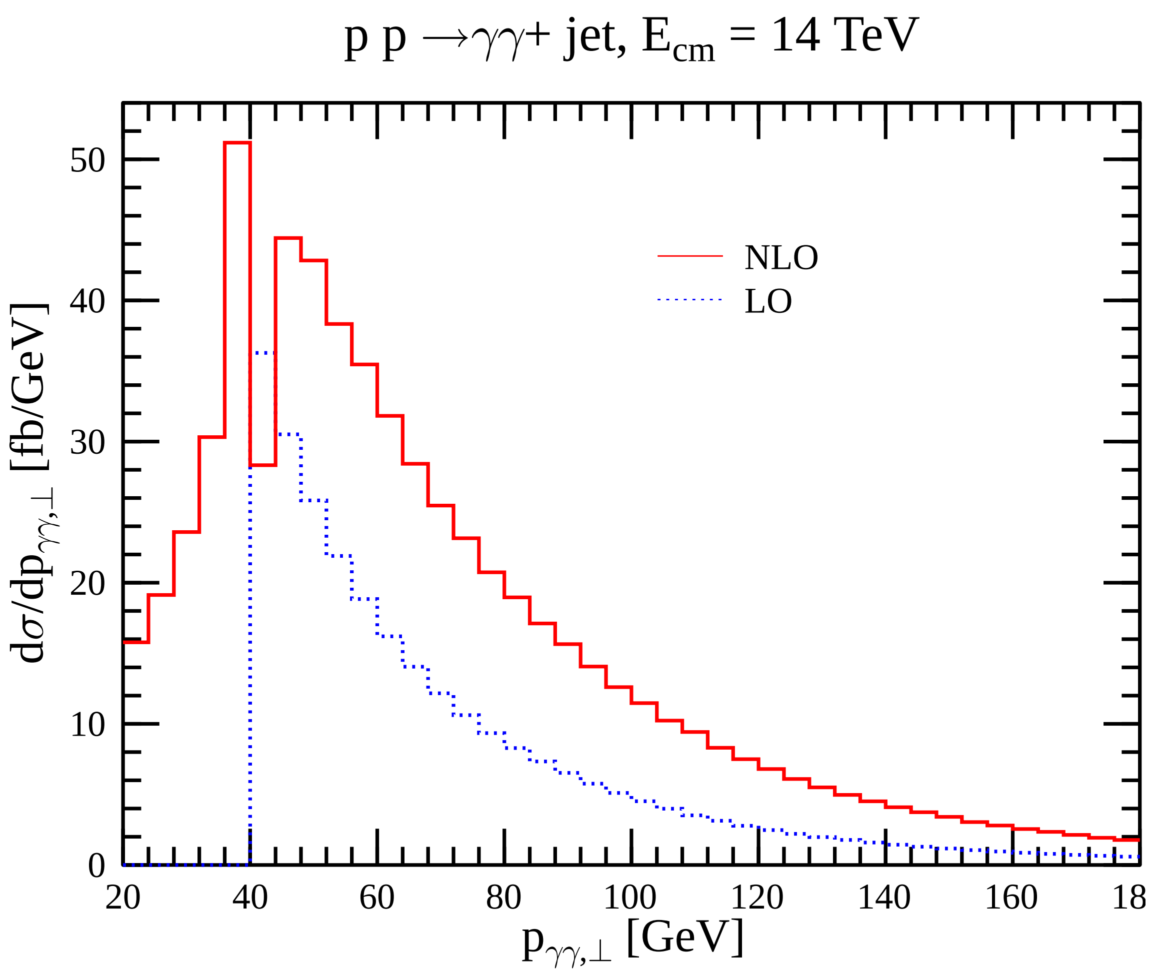
DEPENDENCE ON μ_R, μ_F

Dependence of the cross section on the renormalization and factorization scales in a bin of $118.5\,\mathrm{GeV} \leq M_{\gamma\gamma} \leq 121.5\,\mathrm{GeV}$



- Reference value for μ_R and μ_F: $\mu_0^2 = \left(M_{\gamma\gamma}^2 + p_{\mathrm{jetT}}^2\right)/4$
  - for $R_\gamma = 0.4$ the scale dependence increases at NLO

TRANSVERSE MOMENTUM DISTRIBUTION OF $\gamma\gamma$



☛ Photon isolation $R_\gamma = 0.4$ and $\epsilon = 0.5$

❋ Note opening of the phase space: C-parameter effect

➥ leading order rates should not be multiplied by K factors

Conclusions

- We have presented the NLO corrections to $\gamma\gamma + 1$ Jet production
- a small isolation cone, $R_\gamma = 0.4$, results in
  - more than $100\,\%$ correction $\rightarrow$ K factor > 2
  - a larger residual scale dependence at NLO than at leading order

Conclusions

- We have presented the NLO corrections to $\gamma\gamma + 1$ Jet production
- a small isolation cone, $R_\gamma = 0.4$, results in
  - more than $100\,\%$ correction $\rightarrow$ K factor > 2
  - a larger residual scale dependence at NLO than at leading order

Open Questions

- We have used Frixione's photon isolation, which has been analysed in
  - polarised pp collisions — Frixione, Vogelsang 99
    prompt γ production in $\gamma\gamma$ collisions — Fontannaz, Guillet, Heinrich 01
  - LEP data on prompt γ production — OPAL hep-ex/0305075
  - an ATLAS simulation — Wielers ATL-PHYS-2002-004

  but not in hadron collider experiments, so far