RADIATIVE CORRECTIONS
TO
DI-PHOTON + 1 JET PRODUCTION

VITTORIO DEL DUCA

I.N.F.N. TORINO

WITH

F. MALTONI, Z. TRÒCSÀNYI, Z. NAGY

MONTE CARLO WORKSHOP CERN, JULY 9 2003

HIGGS + 1 JET → $\gamma\gamma$ + 1 JET

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

Abdullin et al. hep-ph/9805341

☛ event selection cuts

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

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

photon identification efficiency $\quad$ 73 %

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

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

HIGGS + 1 JET $\rightarrow \gamma\gamma$ + 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 $\Delta R_{\gamma\mathrm{jet}} \geq 0.4$
- ☛ $M_{\gamma\gamma}$ bin $\Delta M_{\gamma\gamma} = 3.64$ GeV
  photon identification efficiency 80 %
- ☛ no K factor included for the signal
- ☛ S/B increases with $\sqrt{\hat{s}}$ → $\sqrt{\hat{s}} \geq 300$ GeV is used
- ☛ $S/\sqrt{B}$ is roughly independent of $\sqrt{\hat{s}}$

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

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

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

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

BACKGROUND: $\gamma\gamma$ + 1 JET

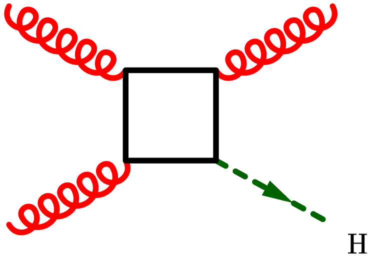
- QCD Production of $pp \to \gamma\gamma + 1$ Jet — Maltoni, Nagy, Trocsanyi, VDD 03
- ElectroWeak Production of $pp \to \gamma\gamma + 1$ Jet

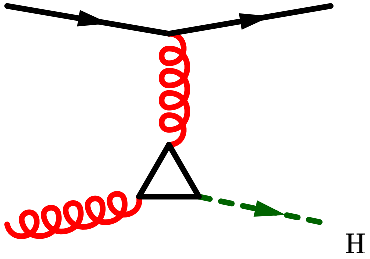
They are known at NLO

HIGGS + 1 JET VIA GLUON FUSION

LEADING ORDER

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



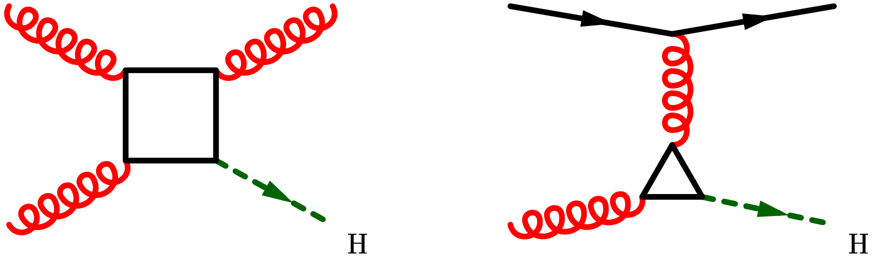


- ☛ 1-loop $gg \to gH$ $qg \to qH$ $+$ crossings

HIGGS + 1 JET VIA GLUON FUSION

LEADING ORDER

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

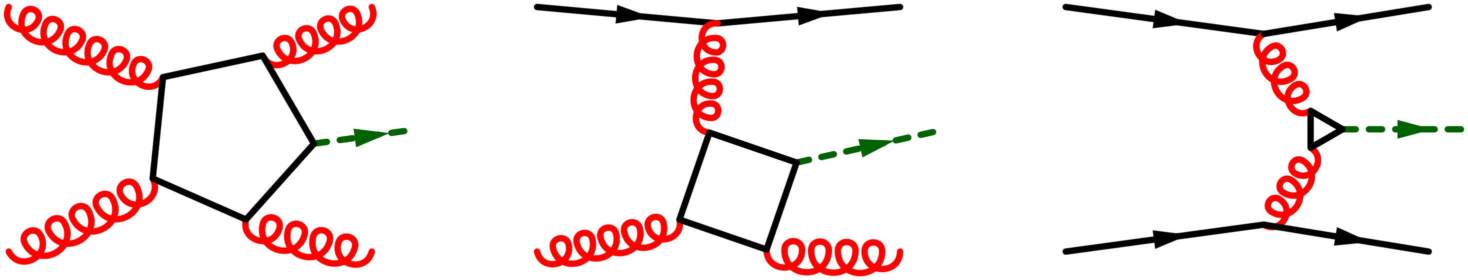


- 1-loop $gg \to gH \quad qg \to qH \quad +$ crossings

NLO CORRECTIONS

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

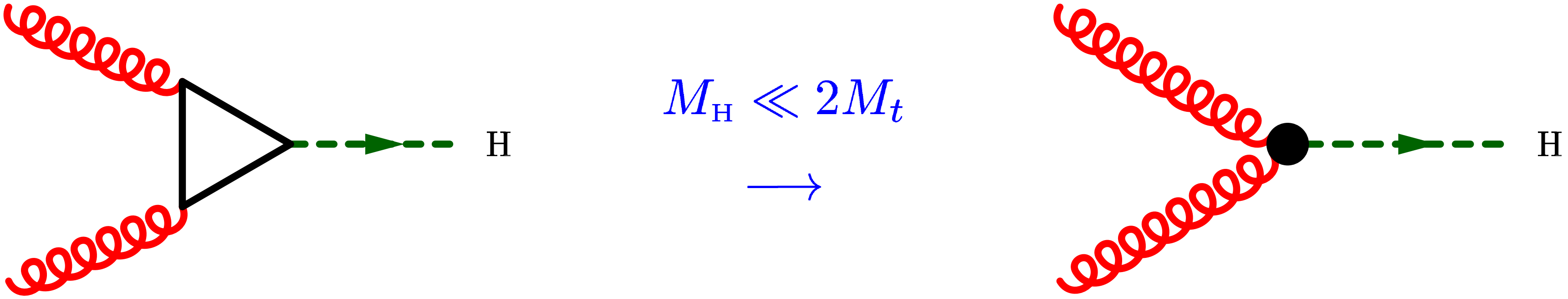
- 1-loop $gg \to ggH \quad qg \to qgH \quad qQ \to qQH \quad +$ crossings



Kilgore, Oleari, Schmidt, Zeppenfeld, VDD 01

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

THE LARGE TOP-MASS LIMIT



$$M_{\mathrm{H}} \ll 2M_t \quad \longrightarrow$$

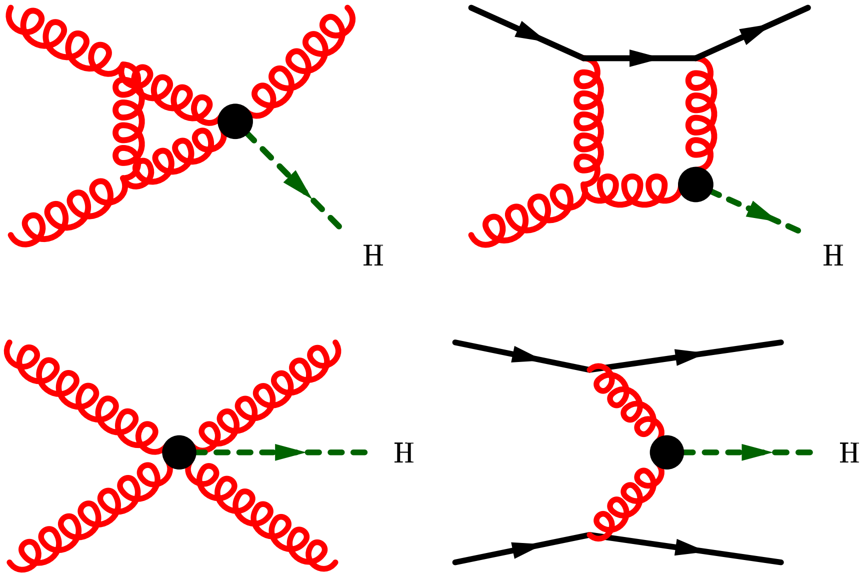
- for Higgs + 1 jet, the large $\boldsymbol{M_t}$ limit is accurate if $M_{\mathrm{H}} \ll 2M_t$ and $p_{\mathrm{T}} \ll M_t$

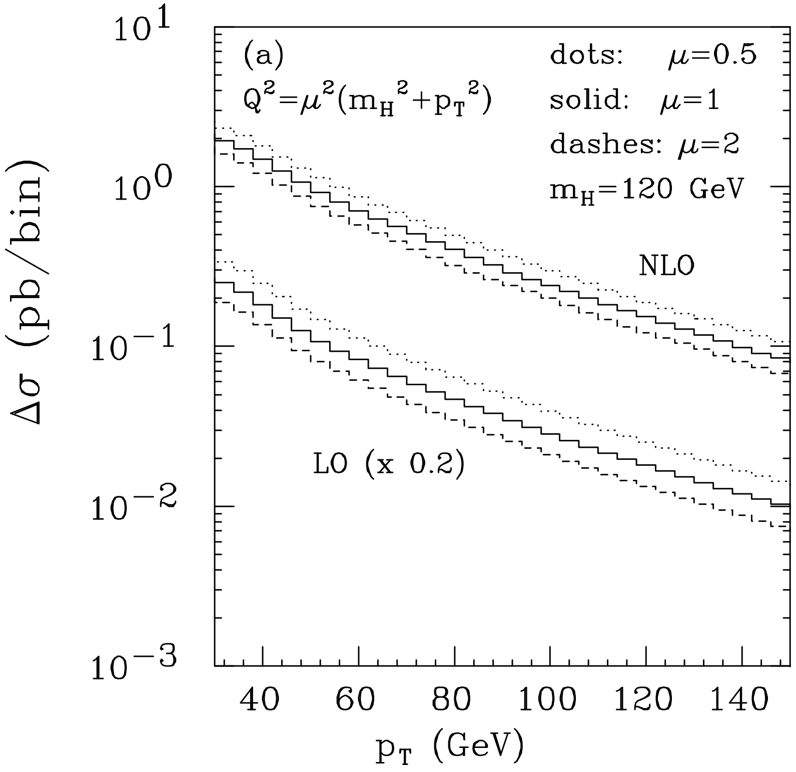
HIGGS + 1 JET IN THE LARGE M_t LIMIT

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

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

de Florian, Grazzini, Kunszt hep-ph/9902483



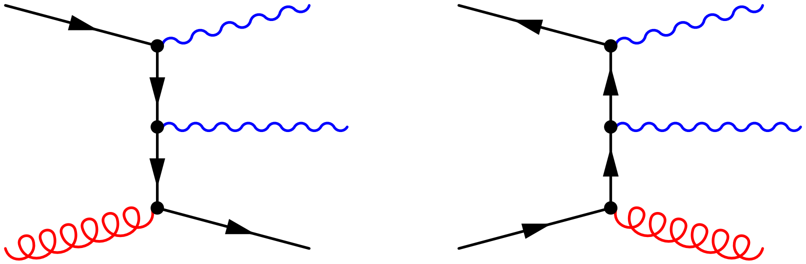


- large K factor: $K_\infty^{\text{NLO}} \simeq 1.6$
- variation of $\mu_R = \mu_F = \mu = 0.5 \to 2$: $\pm 35\%$ at LO; $\pm 20\%$ at NLO

BACKGROUND: $\gamma\gamma + 1$ JET

LEADING ORDER

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

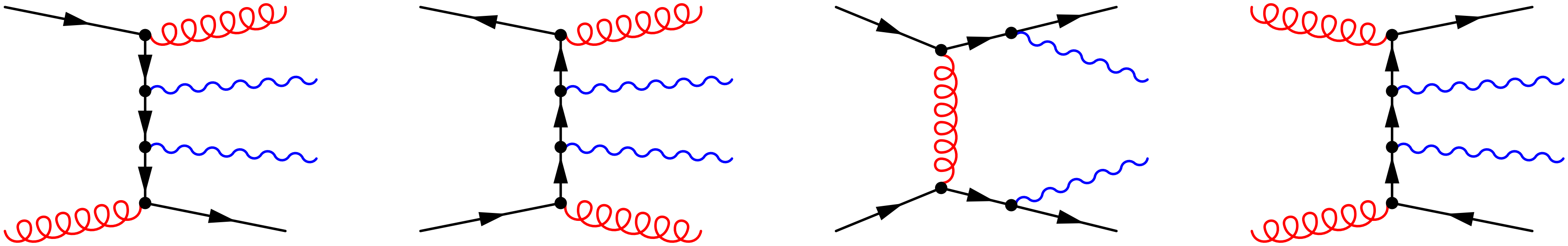


☛ tree $qg \to q\gamma\gamma$ $q\bar{q} \to g\gamma\gamma$

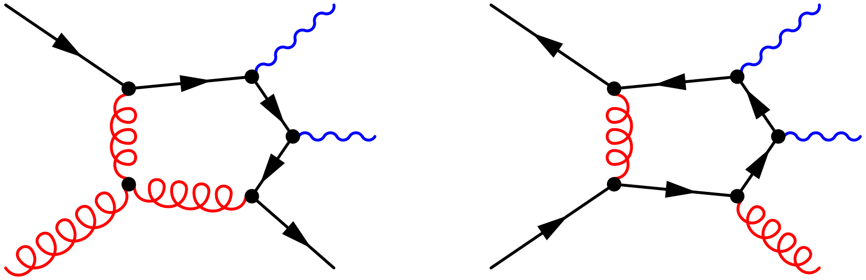
NLO CORRECTIONS

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

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



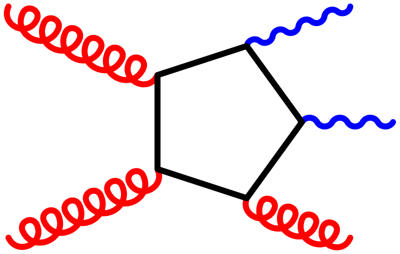
☛ 1-loop $qg \to q\gamma\gamma$ $q\bar{q} \to g\gamma\gamma$



BACKGROUND: $\gamma\gamma + 1$ JET

NNLO CORRECTIONS

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



☛ 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

2 isolated photons and 1 jet with	$p_{\mathrm{T}} \geq 40$ GeV	$\lvert\eta\rvert \leq 2.5$
jet cone size	$R_{\mathrm{jet}} = 1$	
jet-photon distance	$\Delta R_{\gamma\mathrm{jet}} \geq 1.5$	
photon-photon transverse momentum	$p_{\gamma\gamma\mathrm{T}} \geq 40$ GeV	

- Standard photon isolation

  hadronic energy allowed inside the cone of radius R_γ is

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

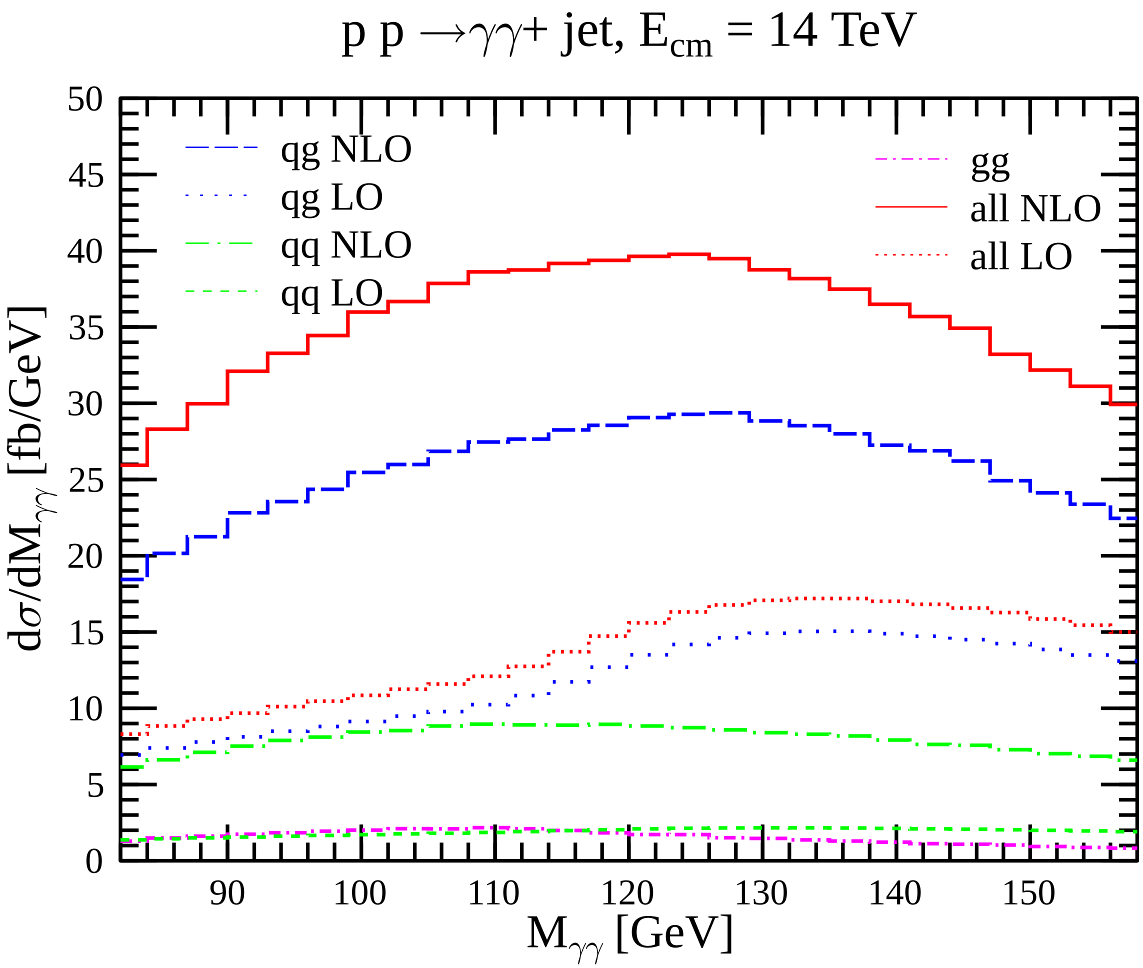
- Smooth (Frixione) photon isolation

  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

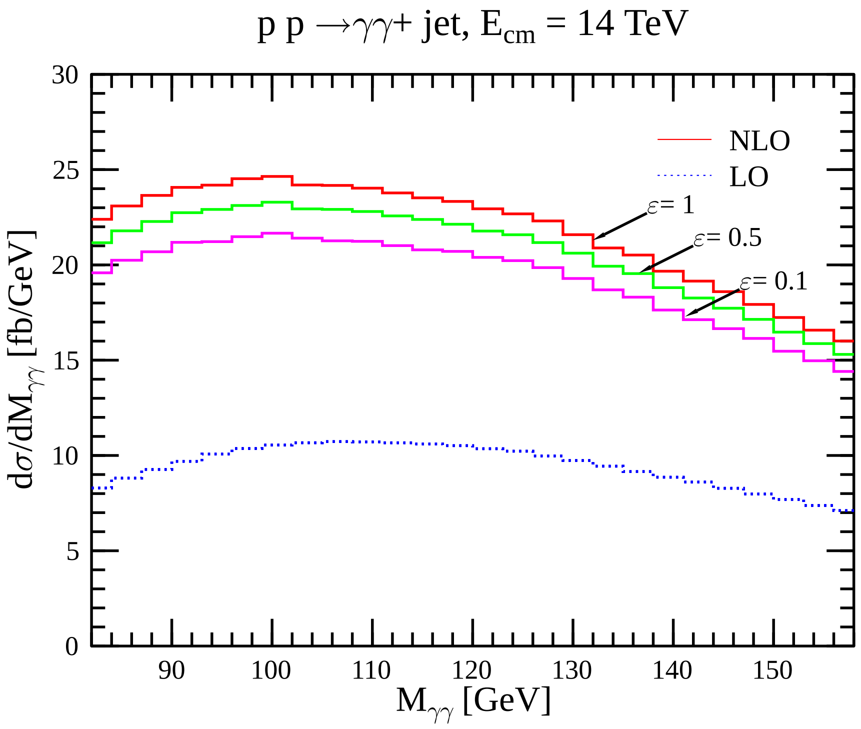
INVARIANT MASS OF THE DI-PHOTON PAIR

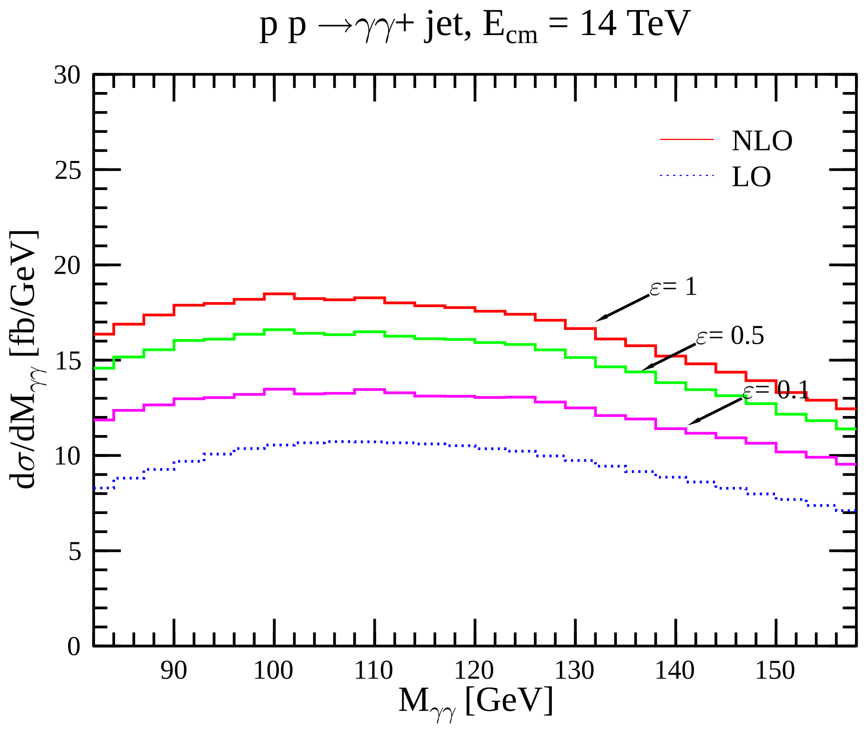


☛ Photon isolation $R_\gamma = 0.4$ and $\epsilon = 0.5$

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



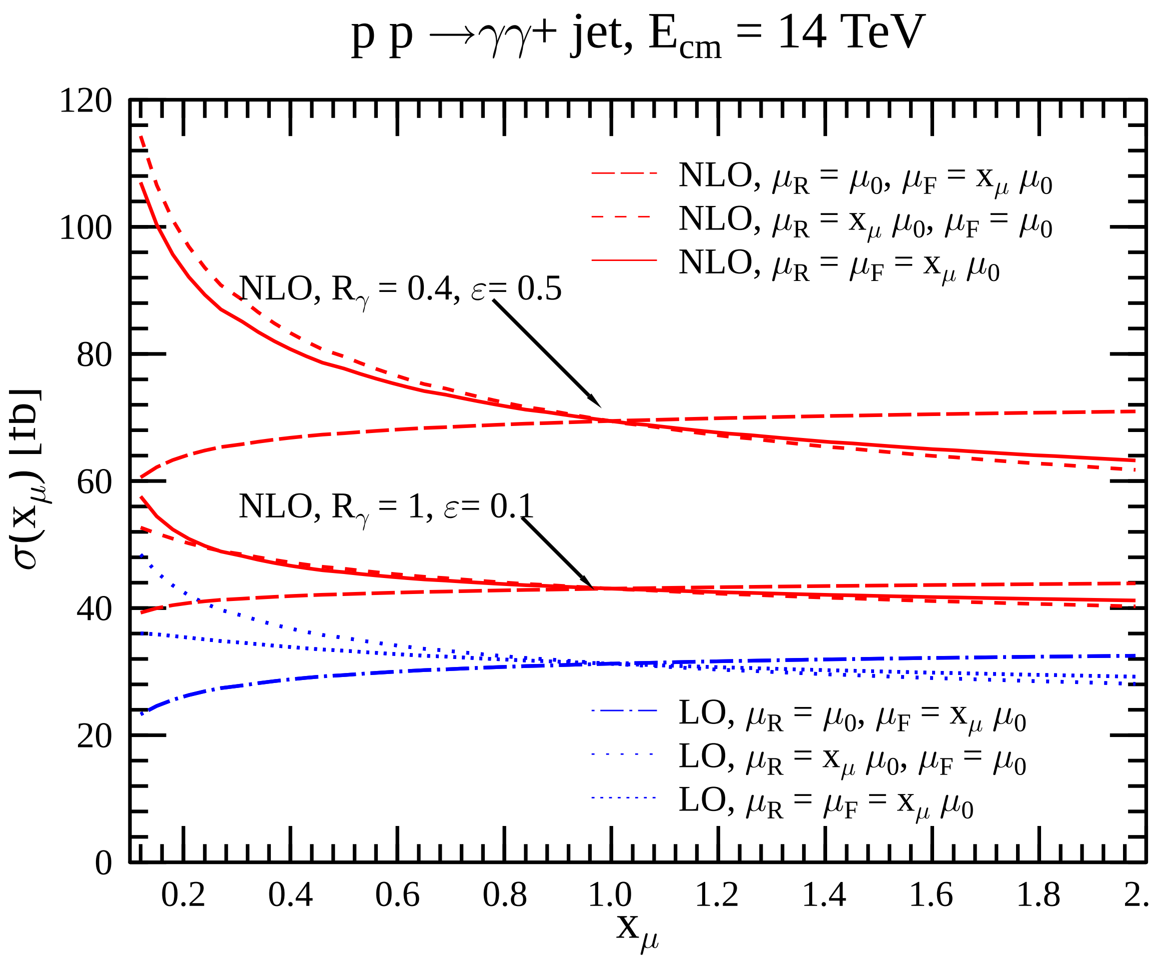


☛ Photon isolation $R_\gamma = 0.4$ $R_\gamma = 1$

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

DEPENDENCE ON μ_R, μ_F

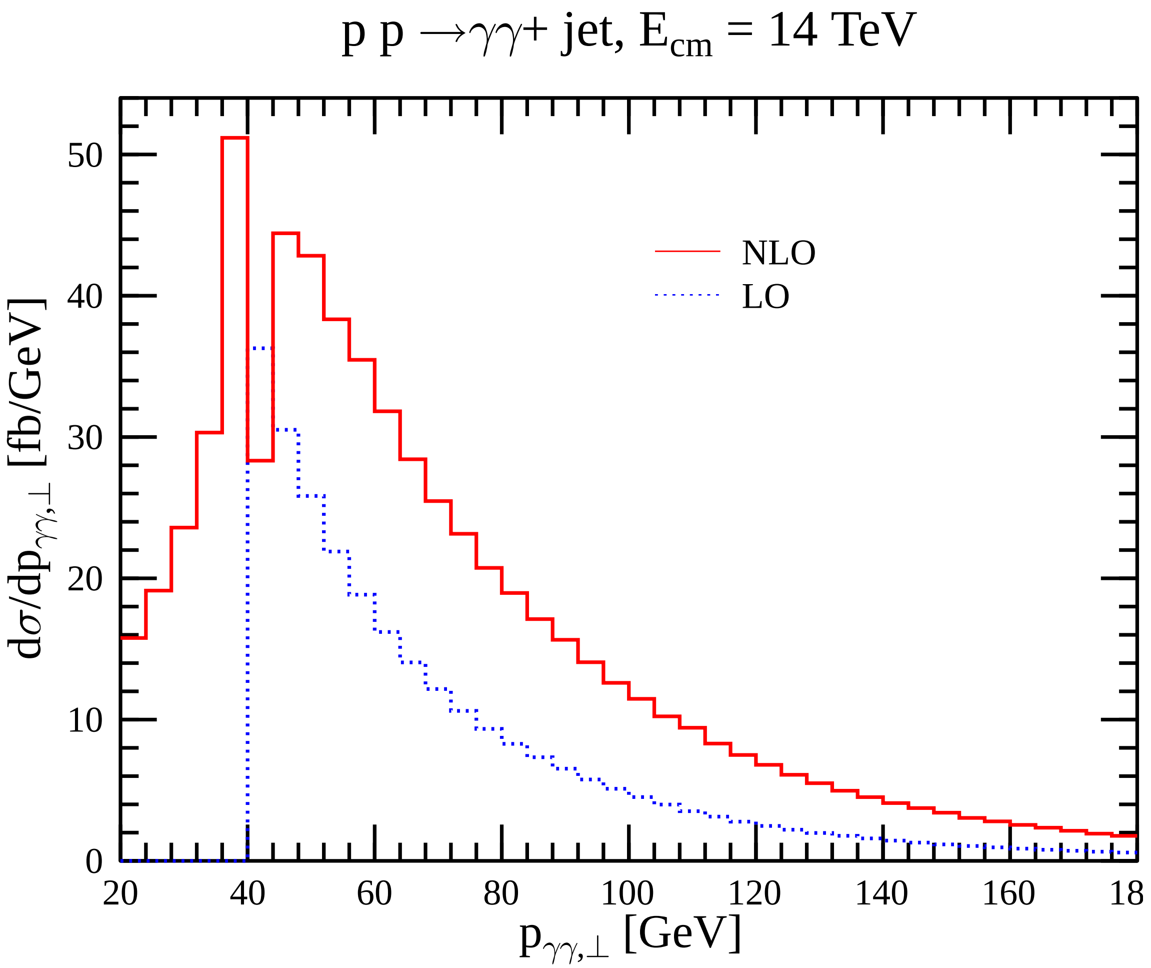
Dependence of the cross section on the renormalization and factorization scales in a bin of $118.5\,\mathrm{GeV} \leq M_{\gamma\gamma} \leq 121.5\,\mathrm{GeV}$



☛ 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 → 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 prompt γ production in $\gamma\gamma$ collisions	Frixione, Vogelsang 99 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