Top-quark effects in $gg \to \gamma\gamma$ at NLO QCD

Xiaoran Zhao[1]

with Fabio Maltoni(UCLouvain&U. Bologna), Manoj K. Mandal(U. Padova)

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[1]Centre for Cosmology, Particle Physics and Phenomenology (CP3)
Université catholique de Louvain, Belgium

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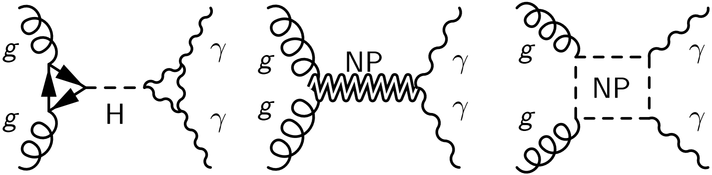
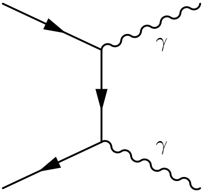
The $\gamma\gamma$ channel

- Clean finalstate at LHC
- One main channel for Higgs discovery, and study Higgs properties
- Important channel for searching various kind of new physics, e.g.
  - New scalar or spin-2 resonance
  - Multiple resonances from extra-dimension/clockwork models
  - Peak-dip structures due to new particles in loops



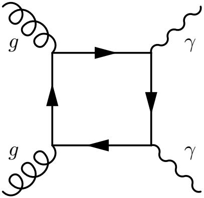
Theoretical status

- LO $q\bar{q} \to \gamma\gamma$
- NLO known since 2000 T. Binoth, J.P. Guillet, E. Pilon, M.Werlen'EPJC(16)311
- NNLO recently S. Catani, L. Cieri, D. deFlorian, G. Ferrera, M. Grazzini'PRL(108)072001, J.M. Campbell, R.K. Ellis, Y. Li, and C. Williams'JHEP(2016)07148 M. Grazzini, S. Kallweit, M. Wiesemann'EPJC(78)537

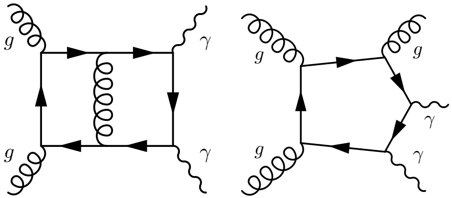


The loop-induced gluon fusion $gg \to \gamma\gamma$:

- Formally part of NNLO
- Anomalously large due to gluon-gluon luminosity.
- Separately gauge-invariant and IR finite.
- Can be treated as a standalone channel.



gluon fusion into diphoton: NLO status



- Formally part of NNNLO corrections to $q\bar{q} \to \gamma\gamma$.
- NLO known for massless quarks only. Z. Bern, L. J. Dixon, C. Schmidt'PRD66,074018

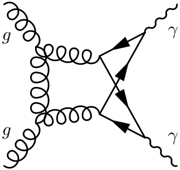
The top quark contribution is missing! How large could it be? Naively counting electric charge:

$$\frac{\sigma(6F)}{\sigma(5F)} = \frac{(\sum_{6F} Q_f^2)^2}{(\sum_{5F} Q_f^2)^2} \approx 1.86$$

Calculation framework

$$d\sigma^{\rm NLO} = d\sigma^{\rm LO} + d\sigma^{\rm V} + d\sigma^{\rm R} + d\sigma^{\rm C}$$

- Madgraph5_aMC@NLO and Recola2 for $gg \to \gamma\gamma g$, $gq \to \gamma\gamma q$, $q\bar{q} \to \gamma\gamma g$ amplitudes J. Alwall, et.al'JHEP(2014)07079 A. Denner, J.N. Lang, S. Uccirati'CPC(224)346
- Dipole subtraction for IR divergences S. Catani, M.H. Seymour'NPB(485)291
- Main challenge: the two-loop virtual amplitude $gg \to \gamma\gamma$



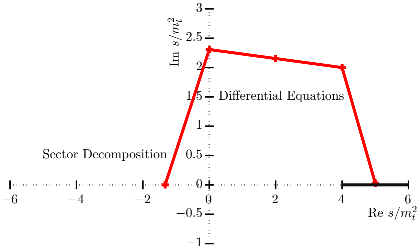
Massless case known since 2001 Z. Bern, A. De Freitas, L.J. Dixon JHEP(2001)09037

Massive case remains unknown, only some master integrals known analytically(mainly planar)

Numerical methods developed M.K. Mandal, XZ'arXiv:1812.03060

$$I = \int \prod_{i=1}^{L} \mathrm{d}^d k_i \frac{1}{\prod_{j=1}^{N} D_j^{a_j}}$$

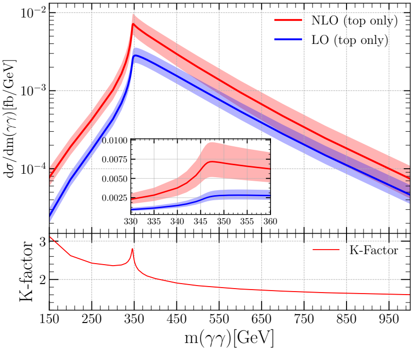
$$\frac{\partial I(x;\epsilon)}{\partial x_i} = J_i(x;\epsilon) I(x;\epsilon)$$



With integrate-by-parts(IBP) reduction, differential equations(DE) can be obtained:

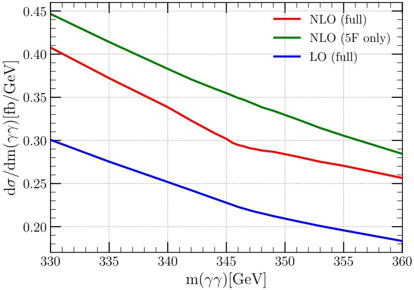
- Numerical methods for DE work well
- But it needs an initial condition
- Adopt the sector decomposition(SD) method T. Binoth, G. Heinrich'NPB(585)741
- SD: low efficiency in the physical region,
- but very well in the Euclidean region
- DE: analytically continue it to the physical region

Firstly we consider the case that only including the top quark contribution:



- Tiny cross section in low energy region,
- The cross section peaks around top pair threshold
- Huge NLO corrections, decrease as $m(\gamma\gamma)$ increases
- Threshold region enhanced due to Coulomb gluon effects.

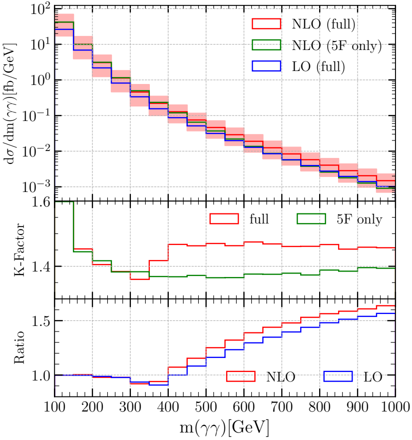
Threshold behavior



The threshold region

- Including the top quark decreases the cross section
- Slope changes more visible at NLO.
- Possibility of extracting the top quark mass here.

Differential cross section



- Negligible effects below top pair threshold
- Decrease the cross section at the threshold region
- Larger K-factor above the threshold region.
- As $m(\gamma\gamma)$ increases, slowly approaching naive six-flavour limit(≈ 1.86)

Conclusion

- NLO corrections to $gg \to \gamma\gamma$
- Including both light quarks and the top quark
- Numerical methods for the two-loop massive amplitudes
- Large NLO corrections for the top quark contribution
- More visible slope changes below and above top pair threshold
- Further enhancement beyond threshold region