Simulation of diphoton (+ jet) production by GR@PPA

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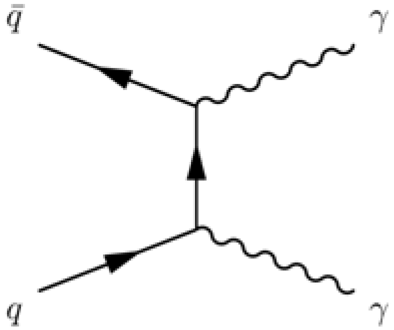
A digest of

S. Odaka and Y. Kurihara, *Consistent simulation of non-resonant diphoton production at hadron collisions with a custom-made parton shower*, arXiv:1203.4038 [hep-ph]

Non-resonant diphoton ($\gamma\gamma$) production at hadron collisions

Important background for the Higgs-boson search/study

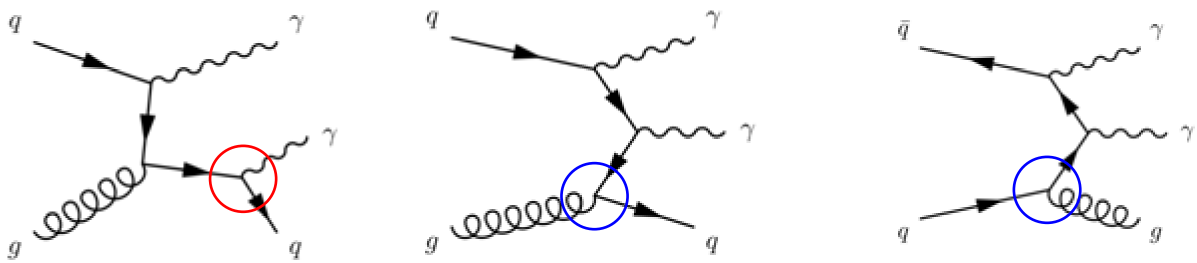
Easier than the direct-photon production to generate,
because the lowest order does not include colored particles
in the final state.



$\gamma\gamma$ + jet

Very large contribution → large NLO correction

Need to include them for realistic simulations



$qg \to \gamma\gamma + q$

$q\bar{q} \to \gamma\gamma + g$

May become large due to the large gluon density

A final-state QED divergence together with initial-state QCD divergences

We have a tool for regularizing the initial-state QCD divergences.

S. Odaka and Y. Kurihara, Comput. Phys. Commun. 183 (2012) 1014; arXiv:1107.4467 [hep-ph]

Jet matching in GR@PPA

- Subtract the divergent leading-log (LL) component from the matrix elements (MEs) of radiative (1-jet) processes.
- Restore the subtracted LL components by combining non-radiative (0-jet) processes to which a parton shower (PS) is applied.
  - The leading terms in LL-PS is identical to the subtracted components.
  - The multiple radiation in PS regularizes the divergence.
- PS radiations are limited by a certain energy scale (μ_{PS}) → limit the subtraction by the same scale: the limited leading-log (LLL) subtraction.
- The LL components are shared between 0-jet and 1-jet processes.

We have extended this method to the final-state QED divergence.

A final-state PS has been developed for regularizing the divergence, a QCD/QED-mixed PS supplemented with a fragmentation function.

The PS has the capability of enforcing hard (energetic) photon radiation.

GR@PPA simulation

14-TeV LHC condition with CTEQ6L1 PDF
Parton showers are fully applied to both initial and final states,
with a backward-evolution PS (QCDPSb) for the initial state.

Fragmentation process

The forced γ-radiation PS is applied to $qg \to \gamma q$ events.

Other processes: $\gamma\gamma$, $\gamma\gamma + q$, $\gamma\gamma + g$

Simultaneously generated by GR@PPA.
The LLL subtraction is applied to $\gamma\gamma + q$ and $\gamma\gamma + g$ for jet matching: the final-state QED subtraction together with the initial-state QCD subtraction.

Generated events are passed to PYTHIA 6.425 (old PS) to simulate lower-Q^2 phenomena down to the hadron level.

The selection is applied to the hadron-level events.

Kinematical cut

two γ's in $|\eta| < 2.5$
$p_T(\gamma_1) > 40$ GeV/c, $p_T(\gamma_2) > 25$ GeV/c
$\Delta R_{\gamma\gamma} > 0.4$, and $80 < m_{\gamma\gamma} < 140$ GeV/c^2

Isolation cut

$E_{T,\mathrm{iso}} < 15$ GeV with $R_{\mathrm{iso}} = 0.4$

Jet matching in diphoton production

Divergent LL radiations are separated into soft/hard components by μ_{ISR} and μ_{FSR}.

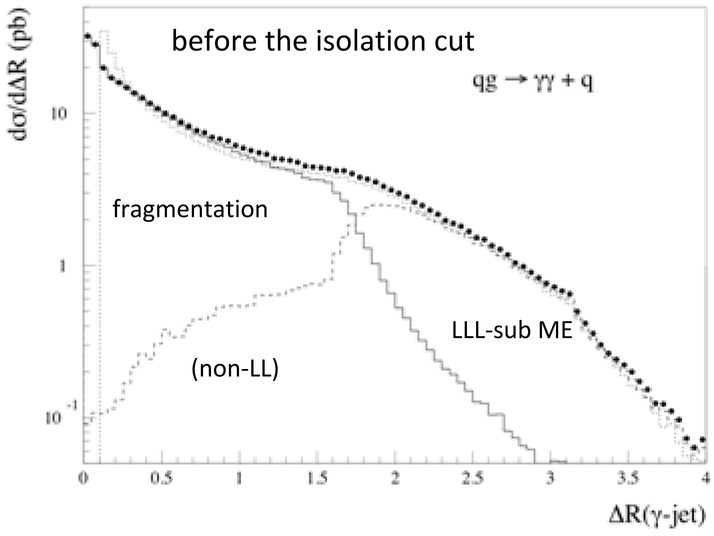
- Soft components: PS applied to non-radiative processes
- Hard components: MEs for radiative processes

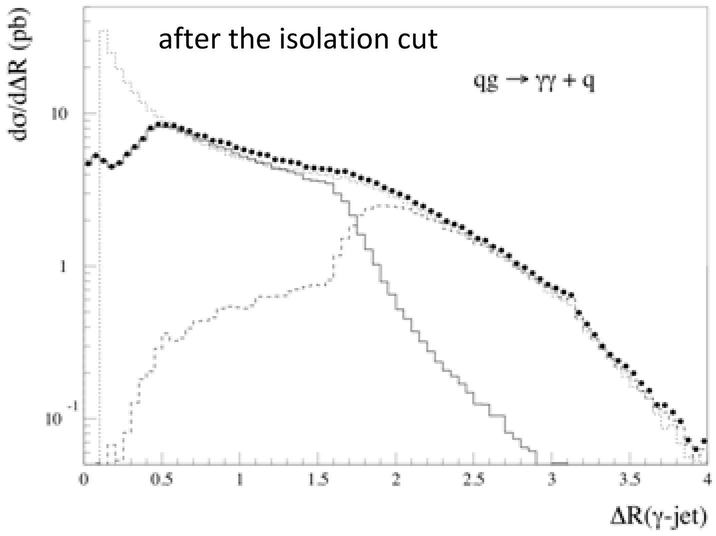
The boundaries are usually in visible regions.

- A good matching can be achieved if the boundaries are consistently defined, and if the PS kinematics are appropriately defined.

The figures show the sharing of the final-state QED radiation.

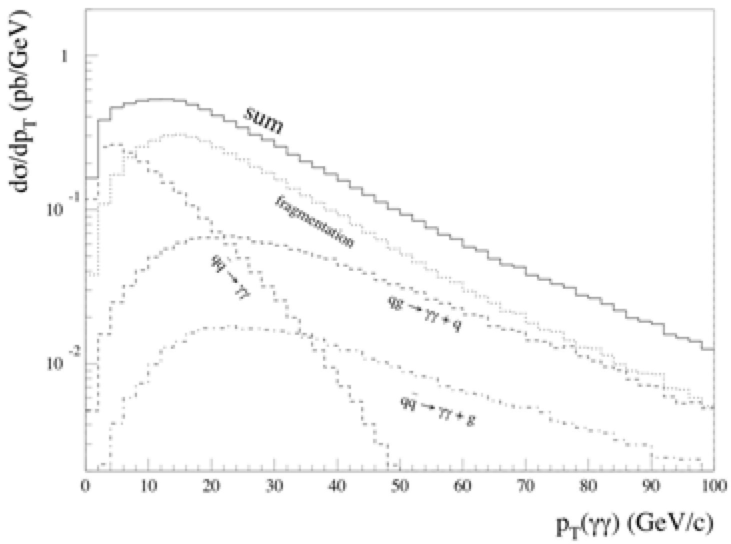
- A good matching between the soft/hard simulations.
- A substantial non-LL component remains after the LLL subtraction.





Combined result

	σ (pb)	fraction (%)
$\gamma\gamma$	4.16	23
$\gamma\gamma + q$	3.28	18
$\gamma\gamma + g$	0.93	5
fragmentation	9.71	54
total	18.1	

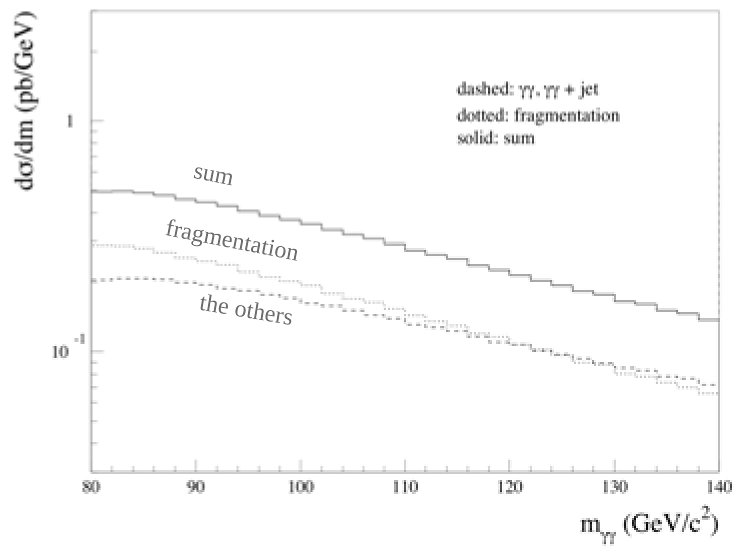


The lowest-order contribution is smaller than 1/4.
The total $qg \to \gamma\gamma + q$ contribution is more than 70%.

This composition is not physically meaningful.

The above is the result when we separate the LL radiations at p_T of non-radiative $\gamma\gamma$ or γq events.

However, the dominance of $qg \to \gamma\gamma + q$ is a characteristic feature of diphoton production at hadron collisions.



Comparison with RESBOS and DIPHOX

GR@PPA (histogram): 18.1 pb

RESBOS w/o $gg \to \gamma\gamma$ (filled): 15.6 pb

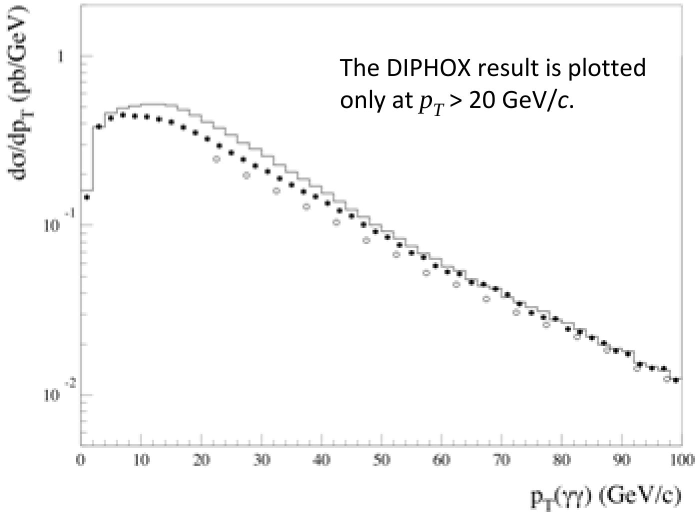
DIPHOX "direct" + LO "one frag." (open):
w/o $gg \to \gamma\gamma$ and "two frag."
13.7 pb

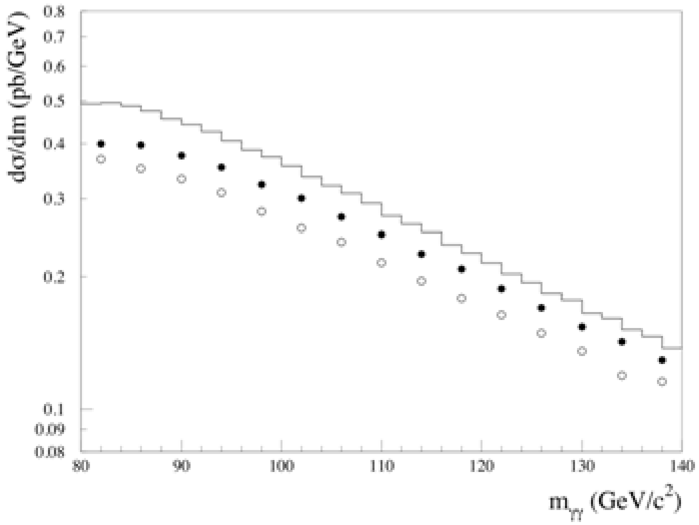
A reasonable agreement.

The difference can be attributed to the difference in the simulation level, and that in the isolation cut.

RESBOS rejects the whole LL component at $\Delta R(\gamma\text{-jet}) < R_{\rm iso}$ for the regularization.

See arXiv:1203.4038 for further discussions.





Summary

- An event generator for diphoton (+ jet) production has been developed in the framework of GR@PPA.
  - The LLL subtraction for initial-state QCD divergences has been extended to the final-state QED divergence.
  - A QCD/QED-mixed PS has been developed for regularizing the subtracted divergence; small-Q^2 radiations are supplemented using a fragmentation function.
  - The PS has the capability of enforcing hard-photon radiation.
  - The PS is applied to $qg \to \gamma q$ events to generate another photon from q (fragmentation process).
- The generated events can be passed to PYTHIA for simulating the events down to the hadron level.
  - The isolation cut can be applied to the hadron-level events.
  - The events can be further fed to detector simulations.
- The event generation was tested for the 14-TeV LHC condition with a typical Higgs-search condition.
  - The lowest-order contribution is smaller than 1/4, while the total $qg \to \gamma\gamma + q$ contribution is larger than 70%.
  - A reasonable agreement with RESBOS and DIPHOX.
- See arXiv:1203.4038 for the details.

Additional materials

A hybrid simulation

LLL-subtracted radiative processes: $\gamma\gamma + q$ and $\gamma\gamma + g$

parton-level simulation/analysis

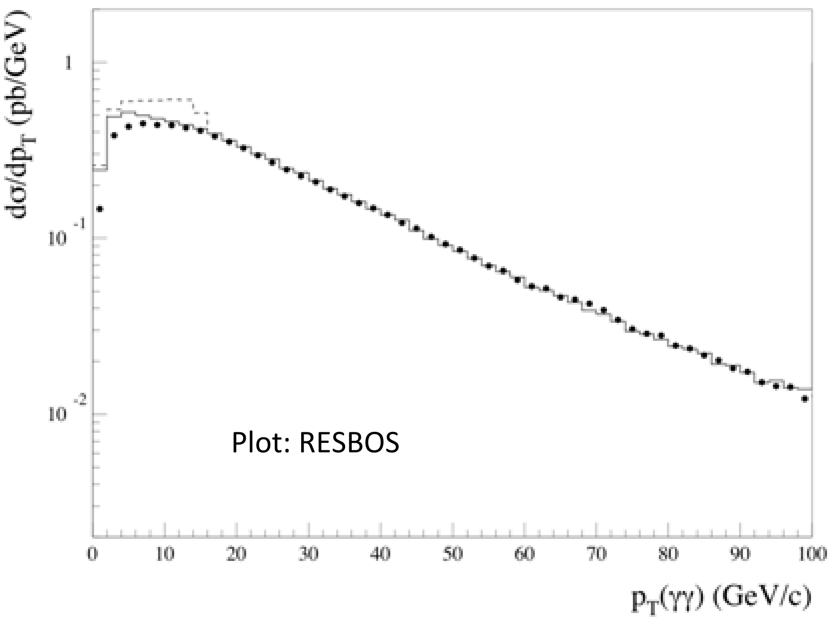
Fragmentation process

reconstruct the parton-level $\gamma\gamma + q$ by turning-on the FSR (forced PS)

parton-level analysis

Lowest-order $\gamma\gamma$

full simulation, and analysis at the hadron level



Reject all fragmentation events at $\Delta R(\gamma\text{-jet}) < 0.4$ (RESBOS style)

⇨ solid histogram: nearly complete agreement with RESBOS at $p_T(\gamma\gamma) > 10$ GeV/c

$\sigma = 16.5$ pb → The calculations are reasonably done both in GR@PPA and RESBOS.

Allow fragmentation events having small $E_{T,\mathrm{iso}} < 15$ GeV

⇨ dashed histogram: a step-like enhancement at $p_T(\gamma\gamma) < 15$ GeV/c

$\sigma = 18.1$ pb → Smeared to produce the difference in the previous slide.

Comparison with PYTHIA PS

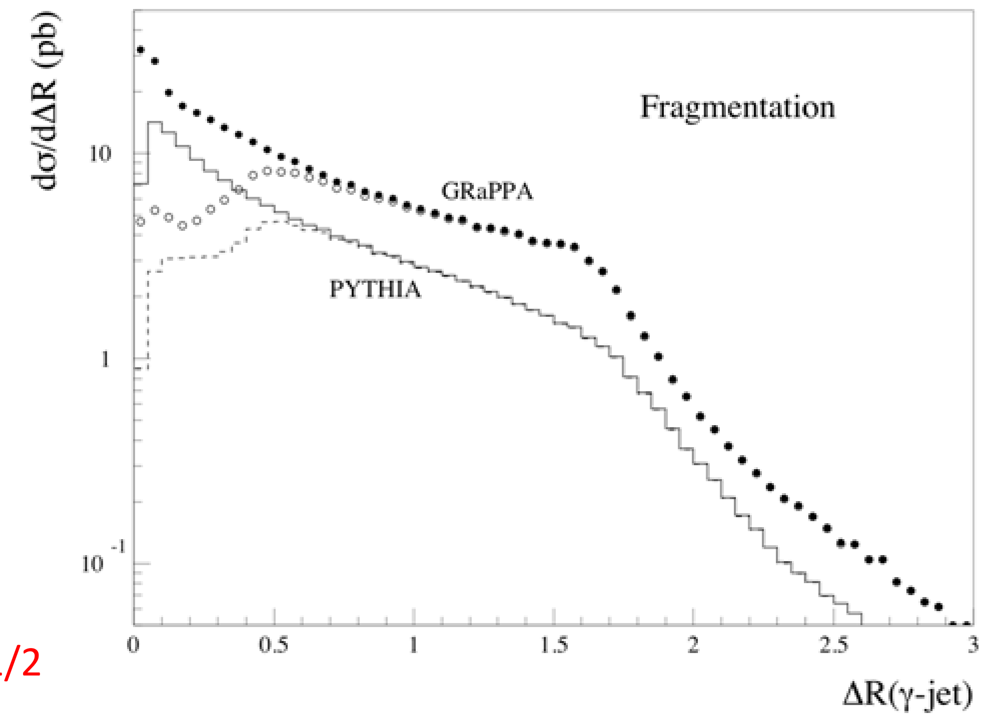
arXiv:1105.5847: a study by using the PYTHIA PS

Not good result.
Why?

GR@PPA
- filled: w/o isolation cut
- open: w/ isolation cut

PYTHIA
- 6.425; old PS (PYSHOW)
- solid: w/o isolation cut
- dashed: w/ isolation cut

The PYTHIA prediction is about 1/2 of the GR@PPA result.



The PYTHIA new PS cannot be used for photon-radiation simulation.

The performance of PYTHIA8 is under investigation.