Diphoton isolation studies

Leandro Cieri
La Sapienza - Università di Roma
Outline

- Introduction
- Isolation criteria (IC)
- IC comparison (NLO)
- Les Houches accord ("tight" isolation accord)
- Examples
- Summary

In collaboration with D. de Florian
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In collaboration with D. de Florian
Why is diphoton production important?

It is a channel that we can use to check the validity of perturbative Quantum Chromodynamics (pQCD)

- Collinear factorization approach
- $K_T$ factorization approach
- Soft gluon logarithmic resummation techniques

It constitutes an irreducible background for new physics searches

- Universal Extra Dimensions
- Randall-Sundrum ED
- Supersymmetry
- New heavy resonances
Why is diphoton production important?

It is a channel that we can use to check the validity of perturbative Quantum Chromodynamics (pQCD)
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It constitutes an irreducible background for new physics searches

**Irreducible background**
- In studies and searches for a low mass Higgs boson decaying into photon pairs
The search for the SM Higgs boson

All these motivations are strengthened by the spectacular observation of a new neutral boson (M~125 GeV)

Photon production

When we deal with the production of photons we have to consider two production mechanisms:

**Direct component**: photon directly produced through the hard interaction

**Fragmentation component**: photon produced from non-perturbative fragmentation of a hard parton (analogously to a hadron)

Calculations of cross sections with photons have additional singularities in the presence of QCD radiation. (i.e. When we go beyond LO)

**Fragmentation function**: to be fitted from data
Photon production

Two mechanisms for photon production

Direct (point-like)

Direct and double resolved (collinear fragmentation)

Separation between them not-physical in general (beyond LO)

Collinear divergence

Cancelled by fragmentation
Photon production

Experimentally photons must be isolated
Isolation reduces fragmentation component

Experimentalist may choose:

$$\sum_{\delta < R_0} E_T^{had} \leq \epsilon_\gamma p_T^{\gamma}$$

$$\sum_{\delta < R_0} E_T^{had} \leq E_T^{max}$$

Using conventional isolation, only the sum of the direct and fragmentation contributions is meaningful.

But there is a way to isolate and make the direct cross section physical (Infrared safe)

**Smooth cone Isolation**


Soft emission allowed arbitrarily close to the photon

$$\chi(\delta) = \epsilon_\gamma E_T^{\gamma} \left( \frac{1 - \cos(\delta)}{1 - \cos(R_0)} \right)^n$$

- no quark-photon collinear divergences
- no fragmentation component (only direct)
- direct well defined by itself

$$E_T^{had}(\delta) \leq \chi(\delta) \text{ such that } \lim_{\delta \to 0} \chi(\delta) = 0$$
\[
\chi(\delta) = \left( \frac{1 - \cos(\delta)}{1 - \cos(R_0)} \right)^n \leq 1
\]

**Standard**
\[
E_T^{had}(\delta) \leq E_T^{had}_{max}
\]

**Smooth**
\[
E_T^{had}(\delta) \leq E_T^{had}_{max} \chi(\delta)
\]

- No quark-photon collinear divergences
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- Direct contribution well defined
$\chi(\delta) = \left( \frac{1 - \cos(\delta)}{1 - \cos(R_0)} \right)^n \leq 1$

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**Smooth**

$$E_T^{had}(\delta) \leq E_T^{had \ max} \chi(\delta)$$

$$E_T^{had}(\delta) \leq E_T^{had \ max}$$
No quark-photon collinear divergences
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The smooth cone isolation criterion is more restrictive than the standard one

\[ \sigma_{Fr\text{ix}}\{R, E_T \text{ max}\} \leq \sigma_{Stand}\{R, E_T \text{ max}\} \]

(both theoretically and experimentally)
In real life... how much different?

**NLO comparison (Standard vs. Smooth)**

<table>
<thead>
<tr>
<th>$E_{T_{\text{max}}}^{\text{had}}$</th>
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DIPHOX → (Direct + Fragmentation)[NLO]


- **Standard** $E_T^{\text{had}}(\delta) \leq E_{T_{\text{max}}}^{\text{had}}$
- **Smooth** $E_T^{\text{had}}(\delta) \leq E_{T_{\text{max}}}^{\text{had}} \chi(\delta)$
- No quark-photon collinear divergences
- No fragmentation contribution (only direct)
- Direct contribution well defined

**References**

- MCFM: J. M. Campbell, R. K. Ellis, and C. Williams (2011)
- gamma2MC: Bern, Dixon and Schmidt (2011)
In real life... how much different?

NLO comparison (Standard vs. Smooth)  \( R_0=0.4 \quad n=1 \)

\[
\chi(\delta) = \left( \frac{1 - \cos(\delta)}{1 - \cos(R_0)} \right)^n \leq 1
\]

Standard
\[
E_T^{\text{had}}(\delta) \leq E_T^{\text{had}}_{\text{max}}
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Standard Smooth
No quark-photon collinear divergences
No fragmentation contribution (only direct)
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In real life... how much different?

NLO comparison (Standard vs. Smooth) Ro=0.4 n=1

DIPHOX → Direct + Fragmentation
But the effects of the fragmentation could appear strongly in kinematical regions far away from the back-to-back configuration.....
The calculation of fragmentation contributions is very difficult:

We can find calculations in which the fragmentation component is considered at one perturbative level less, than the direct component.

For the next slides: [For the all the cases we use the same set of isolation parameters]
Diphoton production $\sqrt{s} = 8$ TeV  
CTEQ6M $\mu_F = \mu_R = M_{\gamma\gamma}$

$p_T^{\gamma \text{hard}} \geq 40$ GeV  
$p_T^{\gamma \text{soft}} \geq 30$ GeV

$100$ GeV $\leq M_{\gamma\gamma} \leq 160$ GeV  
$|\eta^\gamma| \leq 2.5$  
$R_{\gamma\gamma} \geq 0.45$

full NLO Cone (DIPHOX) vs Cone with LO fragmentation vs NLO Smooth

$E_T^{\text{had max}} = \epsilon p_T^{\gamma}$  
$\epsilon = 0.05$

$L.C$, D. de Florian 2013
Diphoton production \( \sqrt{s} = 8 \text{ TeV} \) CTEQ6M \( \mu_F = \mu_R = M_{\gamma \gamma} \)

\[
p_T^{\gamma\text{hard}} \geq 40 \text{ GeV} \quad 100 \text{ GeV} \leq M_{\gamma \gamma} \leq 160 \text{ GeV} \quad |\eta^{\gamma}| \leq 2.5 \quad R_{\gamma \gamma} \geq 0.45
\]

full NLO Cone (DIPHOX) vs Cone with LO fragmentation vs NLO Smooth

\[
E_{T\text{max}}^{\text{had}} = \epsilon p_T^{\gamma} \quad \epsilon = 0.05
\]

\[
E_{T\text{max}}^{\text{had}} = 4 \text{ GeV}
\]

L.C , D. de Florian 2013
Same Features for all distributions

Smooth cone @NLO ~ Cone @ NLO 1-2 %

Cone + LO fragmentation component worse than 5%

L.C , D. de Florian 2013
In some cases, using LO fragmentation component can make things look very strange...

Standard cone isolation → DIPHOX
In cases, using LO fragmentation component can make things look very strange...

**Standard cone isolation → DIPHOX**

**CMS [ 7 TeV ]**

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<th>$\sum E_T^{\text{had}}$</th>
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Standard cone isolation → DIPHOX

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Tighter criteria

Direct component increasing
While the definition of “tight enough” might slightly depend on the particular observable (that can always be checked by a lowest order calculation), our analysis shows that at the LHC isolation parameters as $E_T^{\max} \leq 5 \text{ GeV} \ (\text{or } \epsilon < 0.1)$, $R \sim 0.4$ and $R_{\gamma \gamma} \sim 0.4$ are safe enough to proceed.

This procedure would allow to extend available NLO calculations to one order higher (NNLO) for a number of observables, since the direct component is always much simpler to evaluate than the fragmentation part, which identically vanishes under the smooth cone isolation.
Considering that NNLO corrections are of the order of 50% for diphoton cross sections and a few 100% for some distributions in extreme kinematical configurations, it is far better accepting a few % error arising from the isolation (less than the size of the expected NNNLO corrections and within any estimate of TH uncertainties!) than neglecting those huge QCD effects towards some ”more pure implementation” of the isolation prescription.

Recently, some calculations use the smooth cone isolation criteria to arrive at the highest level of accuracy:

- **Zγ production [NNLO]**: M. Grazzini, S. Kallweit, D. Rathlev, A. Torre (2013)
- **γγ + (up to) 3Jets [NLO]**: S. Badger, A. Guffanti, V. Yundin (2013)
- **γγ production [NNLO]**: S. Catani, L. Cieri, D. de Florian, G. Ferrera, and M. Grazzini (2011)
Summary

Cross section with “smooth” isolation, is a lower bound for cross section with standard isolation.

Sizeable NNLO corrections to the \( \gamma \gamma \) mass distribution

Other calculations use the “smooth” isolation to reach the highest level of accuracy: \( Z \gamma \) production, \( \gamma \gamma + 2\text{Jets} \), etc.

We have to be aware, that inconsistent results could appear, if we use the fragmentation component at one perturbative level less than the direct component.

Pragmatic accord (LH 2013): it is far better accepting a few % error arising from the isolation, than neglecting those huge QCD effects towards some, "more pure implementation" of the isolation prescription.
Thank you!!!
Backup slides