Inclusive and Isolated Photon Productions at Large Transverse Momenta

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Outline

1. Inclusive photon production: direct and fragmentation
2. High order correction to large-p_T photon production
3. Isolation condition for large-p_T photons
4. Isolation condition for large-p_T photons at SPD NICA

Inclusive photon production: direct and fragmentation

Inclusive production

$$p + p \to \gamma + X$$

Direct production in LO CPM

$$q + g \to \gamma + q$$

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

$$\sigma^{dir} \sim \Phi_{g/p}(x_1, \mu) \otimes \hat{\sigma}(\alpha\alpha_s) \otimes \Phi_{q/p}(x_2, \mu)$$

Fragmentation production in LO CPM

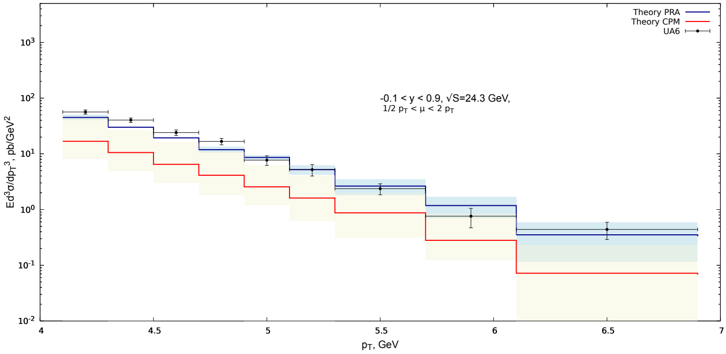
$$q + g \to q + g, \;\; \text{with } q \to q + \gamma_{||}$$

$$\sigma^{frag} \sim \Phi_{g/p}(x_1, \mu) \otimes \hat{\sigma}(\alpha_s^2) \otimes F_{q\to\gamma}(\mu, z = p_\gamma/p_q) \otimes \Phi_{q/p}(x_2, \mu)$$

$$F_{q\to\gamma}(\mu, z) \sim \alpha \times \ln\left(\frac{\mu}{\mu_0}\right), \qquad \mu \sim p_{Tq}, \qquad \text{DGLAP}$$

Prompt (direct + fragmentation) photon production in LO CPM

Transverse momentum spectrum in LO CPM and in TMD/KT-factorization (it is coincide with NLO* CPM). Data from CERN-UA6 Collaboration (1998).



High order correction to large-p_T photon production

Real NLO corrections in direct production

$$q + g \to q + g + \gamma$$

It is divergent when $p_q || p_\gamma$ plus it has double counting with LO fragmentation production. We need to use some subtraction scheme.

NLO fragmentation production

$$q + g \to q + g + g \text{ with } q \to q + \gamma_{||}$$

It has huge number of subprocesses which contribute in photon fragmentation production. The subtraction scheme becomes very complicated.

High order correction to large-p_T photon production

Single photon production in NNLO CPM

- X. Chen, T. Gehrmann, N. Glover, M. Höfer and A. Huss, "Isolated photon and photon+jet production at NNLO QCD accuracy," JHEP **04** (2020), 166 doi:10.1007/JHEP04(2020)166 [arXiv:1904.01044 [hep-ph]].

For single-photon production at the LHC:

$$K_{LO} \simeq 3.0, \qquad K_{NLO} \simeq 1.5, \qquad K_{NNLO} \simeq 1.0$$

Diphoton production in NNLO CPM

- S. Catani, L. Cieri, D. de Florian, G. Ferrera and M. Grazzini, "Diphoton production at hadron colliders: a fully-differential QCD calculation at NNLO," Phys. Rev. Lett. **108** (2012), 072001 [erratum: Phys. Rev. Lett. **117** (2016) no.8, 089901] doi:10.1103/PhysRevLett.108.072001.
- J. M. Campbell, R. K. Ellis, Y. Li and C. Williams, "Predictions for diphoton production at the LHC through NNLO in QCD," JHEP **07** (2016), 148 doi:10.1007/JHEP07(2016)148.

High order correction to large-p_T photon production

Three-photon production in NNLO CPM

- H. A. Chawdhry, M. L. Czakon, A. Mitov and R. Poncelet, *NNLO QCD corrections to three-photon production at the LHC* JHEP **02** (2020), 057 doi:10.1007/JHEP02(2020)057
- S. Kallweit, V. Sotnikov and M. Wiesemann, *Triphoton production at hadron colliders in NNLO QCD* Phys. Lett. B **812** (2021), 136013 doi:10.1016/j.physletb.2020.136013.

For theree-photon production at the LHC, $\sqrt{s} = 8$ TeV (ATLAS):

$$K_{LO} \simeq 5.0, \qquad K_{NLO} \simeq 1.9, \qquad K_{NNLO} \simeq 1.3$$

K-factors at SPD NICA

At SPD NICA $p_{T\gamma} \simeq 4 - 6$ GeV and $\alpha_s^{NICA} > \alpha_s^{ATLAS}$. We estimate more large values of K_{LO} and K_{NLO} in photon production at SPD NICA than at LHC, where $p_{T\gamma} > 50$ GeV.

How these gentlemen have did NNLO calculation ?

THEY STUDY ISOLATED PHOTON PRODUCTION

Isolation condition for large-p_T photons

Cone condition in experiment (ATLAS)

$$R_{i\gamma} = \sqrt{(\phi_i - \phi_\gamma)^2 + (\eta_i - \eta_\gamma)^2}$$

$$\eta_\gamma = y_\gamma = -\ln\tan(\theta/2)$$

Separation of isolated photons:

- $R_{i\gamma} \geq R_0 = 0.4$ and there are no correlation between photon and final partons (jets)
- At $R_{i\gamma} < R_0$ the non-photonic energy (E_T) in events should be smaller than E_T^{ISO}.

$$E_T^{ISO} = \epsilon E_T^\gamma + 4.8 \text{ GeV}, \qquad \epsilon = 0.042$$

Isolation condition for large-p_T photons

Cone condition in calculations

In LO CPM for $2 \to 2$ suprocesses, the cone condition is trivial, $\phi_q - \phi_\gamma = 2\pi$.

In NLO CPM for $2 \to 3$ subprocesses, the events with $R_{q\gamma} < R_0$ may be interpreted as *fragmentation* production. To regularize collinear singularities we can use *Frixione* phenomenological approach:

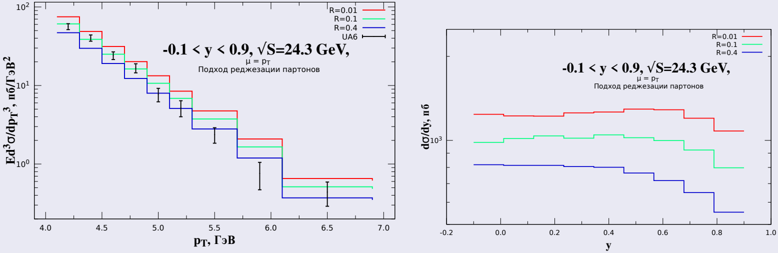
$$E_{qT} < E_T^{ISO} \left(\frac{1 - \cos(R_{q\gamma})}{1 - \cos(R_0)} \right)^n, \qquad n = 1 - 2$$

S. Frixione, Isolated photons in perturbative QCD, Phys. Lett. B ***429*** *(1998), 369-374 doi:10.1016/S0370-2693(98)00454-7 [arXiv:hep-ph/9801442 [hep-ph]].*

In TMD/KT-factorization (PRA), the isolation condition should be used already for LO calculation for $2 \to 2$ subprocesses in which initial partons have transverse momenta and $\Delta\phi_{q\gamma}$ may be equal to zero (see Fig. 1).

Isolation condition for large-p_T photons

R-dependence for isolated photon production at $\sqrt{s} = 24.3$ GeV



Isolation condition for large-p_T photons

Isolated photons at the PHENIX RICH and twist-3 predictions

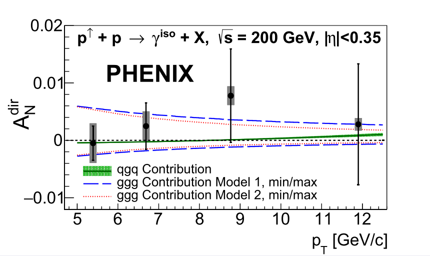


FIG. 2. Transverse single-spin asymmetry of isolated direct photons measured at midrapidity $|\eta| < 0.35$ in $p^{\uparrow}+p$ collisions at $\sqrt{s} = 200$ GeV. An additional scale uncertainty of 3.4% due to the polarization uncertainty is not shown.

arXiv:2102.13585v2 [hep-ex] 20 Aug 2021: *Probing gluon spin-momentum correlations in transversely polarized protons through midrapidity isolated direct photons in $p^{\uparrow}p$ collisions at $\sqrt{s} = 200$ GeV.*

Isolation condition for large-p_T photons

Isolation conditions for photons at the PHENIX

Additionally, direct photon candidates have to pass an isolation cut, which further reduces the contribution of decay photons [23]. Ref. [1] estimates that the contribution of the next-to-leading-order fragmentation photons to the isolated direct photon sample is less than 15% for photons with $p_T > 5$ GeV/c. The photon isolation cut requires that the sum of the particles' energy surrounding the photon in a cone of radius $r = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} <$ 0.4 radians be less than 10% of the candidate photon's energy: $E_{\text{cone}} < E_\gamma \cdot 10\%$. To be included in the cone sum energy, E_{cone}, an EMCal cluster must have energy larger than 0.15 GeV and a charged track needs to have a momentum above 0.2 GeV/c. To provide a more inclusive sample of the particles surrounding the photon, the clusters and tracks that are included in the E_{cone} sum are only required to pass a minimum set of quality cuts. The charged track veto cut is still used to ensure charged particles are not double counted by the energy that they deposit in the EMCal. The shower-shape cut is not applied to EMCal clusters to ensure that neutral hadrons and charged hadrons that were not reconstructed as charged tracks can still contribute to E_{cone}.

Isolation condition for large-p_T photons

Isolated photon production versus inclusive production

- High order calculations can be done simply
- Decay photons are suppressed additionally
- Fragmentation production contribution can be minimized

Isolation conditions for photons at SPD NICA

$$R = 0.4 \quad ??$$
$$E_T^{ISO} = \quad ? \text{ or } E_{cone} = ***\% E_\gamma$$

Thank you for your attention!