Measurement of isolated-photon plus jet production at $\sqrt{s}$ =13 TeV with the ATLAS detector.

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Outline:

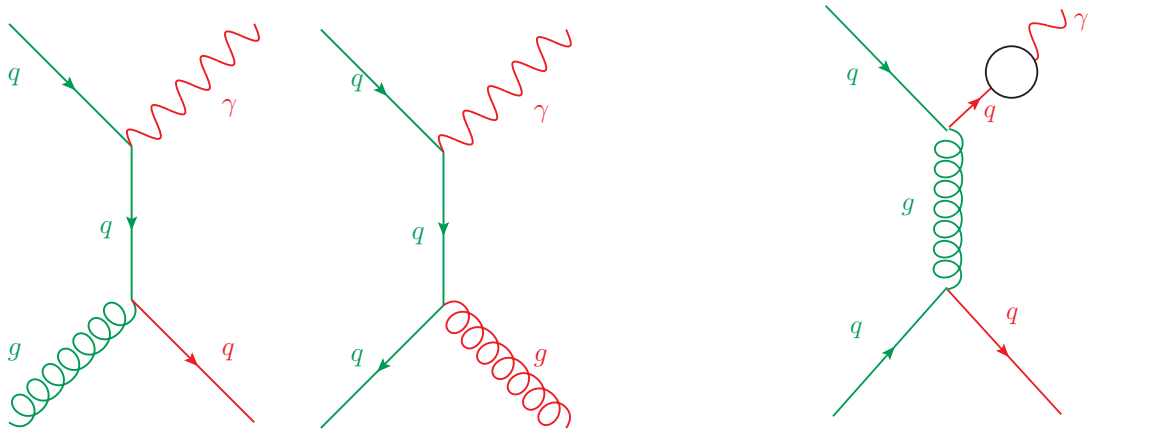
- ★ **Prompt photon plus jet production at LHC**
- ★ **Photons in ATLAS**
- ★ **Background subtraction**
- ★ **NLO QCD predictions**
- ★ **Results**
- ★ **Summary**

Prompt photon plus jet production at LHC

PROMPT PHOTONS

Photons not coming from hadron decays

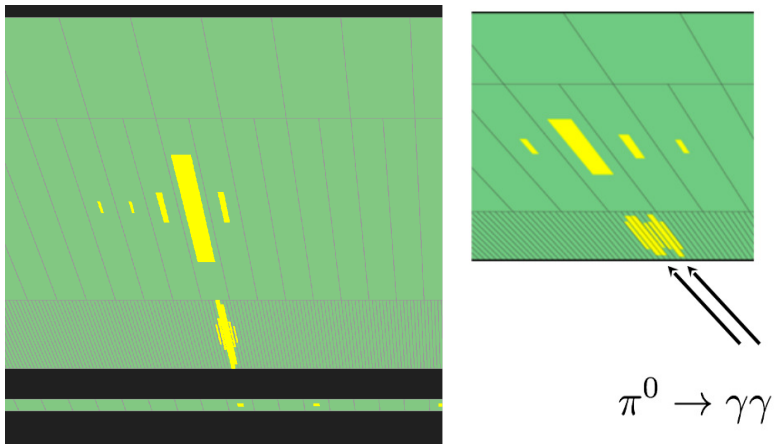
DIRECT **FRAGMENTATION**



- Test of pQCD with a hard colorless probe.
  ↪ Aid to understand SM background to BSM processes (e.g.: Searches for new phenomena with photon+jet events).
  ↪ Useful for MC tunning.
- Study of the dynamics of the 2→2 hard process at 13 TeV (for the first time!).
  ⋆ Understanding of the fragmentation component (wide angle photon radiation)
- Photon also copiously produced inside jets (background).
  ↪ Photon isolation is crucial for background rejection. It also suppresses the contribution from the fragmentation component.
- Previous ATLAS publications (at 7 and 8 TeV)

▸ Phys. Rev. D **85** (2012) 092014 ▸ Nucl. Phys. B **875** (2013) 483 ▸ Nucl. Phys. B 918 (2017) 257

Photons in ATLAS



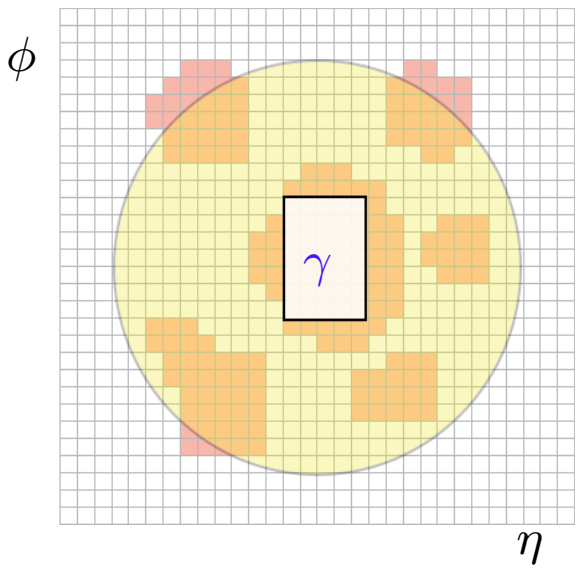
- Photon candidates are reconstructed from clusters of energy in the EM calorimeter (Lead-liquid Argon)

  ↪ Unconverted and converted photons ($\gamma \to e^+e^-$ in the passive material in front of the calorimeter) are considered

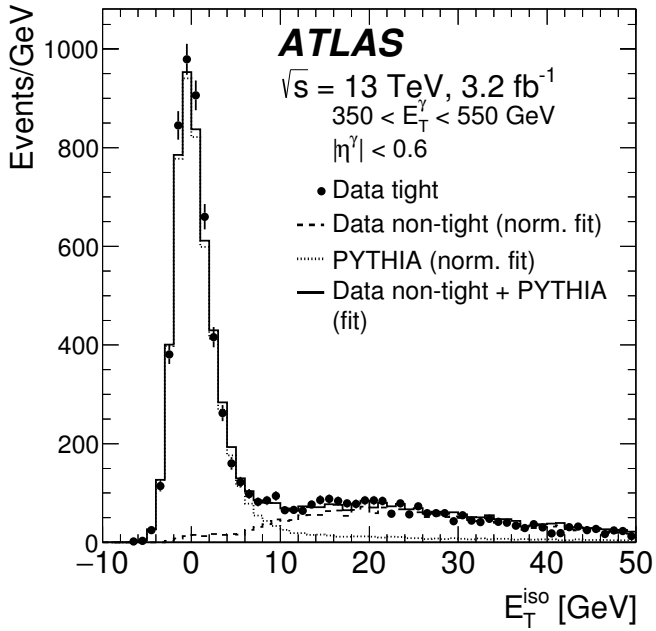
- The fine granularity of the first layer of the EM calorimeter is used to characterise the shower shapes of the deposits and exploited to discriminate between signal and background photons.

- The isolation transverse energy, E_T^{iso}, is computed from topological clusters (EM and HAD) in a cone of $R = 0.4$ excluding the area centered ($\Delta\eta \times \Delta\phi = 0.125 \times 0.175$) on the photon cluster.

  ↪ Corrected for photon leakage into the cone and pile-up and underlying event effects in a event-by-event basis (jet-area method)



Background subtraction

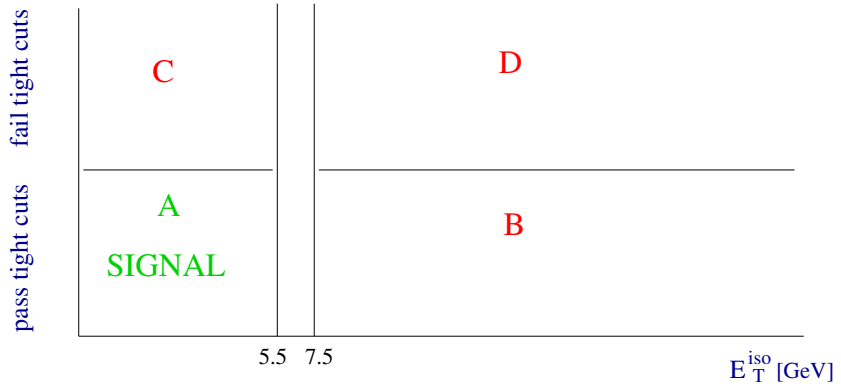


→ Clear signal observed after applying tight and isolation requirements

→ But residual background contamination remains in the signal region

→ $E_{\mathrm{T}}^{\mathrm{iso}}$ shifted in MC to describe the peak observed in data

- Data-driven background subtraction:
  → 2D-sideband method used in the γ_{ID} vs. E_T^{iso} plane
  → The leading loose' photon is classified into one of the four regions in the plane



Assuming no correlation between E_T^{iso} and γ_{ID} for the background and accounting for the signal leakage fractions, ϵ_i (from MC).The final signal yield is extracted using:

$$N_A^{\mathrm{sig}} = N_A - (N_C - \epsilon_C N_A^{\mathrm{sig}}) \frac{(N_B - \epsilon_B N_A^{\mathrm{sig}})}{(N_D - \epsilon_D N_A^{\mathrm{sig}})}$$

NLO QCD predictions

JetPhox

- Full fixed-order NLO pQCD predictions for direct and fragmentation contribution.
- MMHT2014 parametrisations of proton PDF ($\alpha_s(m_Z)$ =0.120) and BFGII set of fragmentation functions.
- Non-perturbative correction factors estimated with special Pythia samples.

NLO Sherpa

- Parton-level calculations for $\gamma + 1, 2$ jets at NLO and $\gamma + 3, 4$ jets at LO suplemented with parton shower.
- Only direct contribution (Frixione's isolation at ME level).
- NNPDF3.0NNLO PDF ($\alpha_s(m_Z)$ =0.118).

Theoretical uncertainties

The considered theoretical uncertainties are:

- The uncertainty due to missing orders.
- The uncertainty due to the imperfect knowledge of the proton PDF.
- The α_s-induced uncertainty.
- The uncertainties on the non-perturbative corrections.

Fiducial cross section

- The fiducial cross section in the phase space given by the cuts summarized in the table has been measured.

Phase-space region
Requirements on photons
$E_{\mathrm{T}}^{\gamma} > 125$ GeV, $\lvert\eta^{\gamma}\rvert < 2.37$ (excluding $1.37 < \lvert\eta^{\gamma}\rvert < 1.56$)
$E_{\mathrm{T}}^{\mathrm{iso}} < 4.2 \cdot 10^{-3} \cdot E_{\mathrm{T}}^{\gamma} + 10$ GeV
Requirements on jets
anti-k_{t} algorithm with $R = 0.4$
$p_{\mathrm{T}}^{\mathrm{jet-lead}} > 100$ GeV, $\lvert y^{\mathrm{jet-lead}}\rvert < 2.37$
$\Delta R^{\gamma-\mathrm{jet}} > 0.8$

$$\sigma_{\mathrm{meas}} = 300 \pm 10\ (\mathrm{exp.})\ \pm 6\ (\mathrm{lumi.})\ \mathrm{pb}$$

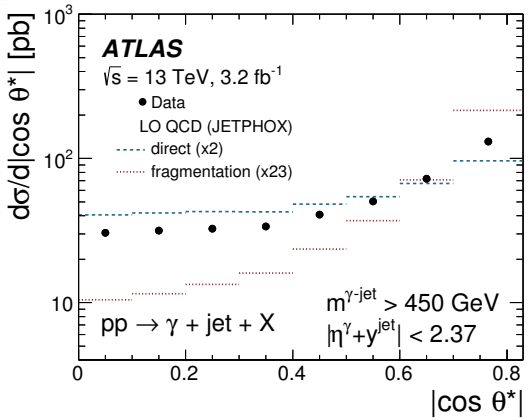
- Predictions from JetPhox and Sherpa NLO consistent with the measured fiducial cross section within experimental and theoretical uncertainties:

$$\sigma_{\mathrm{JetPhox}} = 291^{+25}_{-21}(\mathrm{scale\ unc.})\ ^{+2}_{-3}\ (\mathrm{PDF\ unc.})\ ^{+4}_{-5}\ (\alpha_s\ \mathrm{unc.})\ \pm 6\ (\mathrm{non\text{-}perturb.})\ \mathrm{pb}$$

$$\sigma_{\mathrm{SherpaNLO}} = 319^{+54}_{-45}(\mathrm{scale\ unc.})\ \pm 3\ (\mathrm{PDF\ unc.})\ ^{+10}_{-11}\ (\alpha_s\ \mathrm{unc.})\ \mathrm{pb}$$

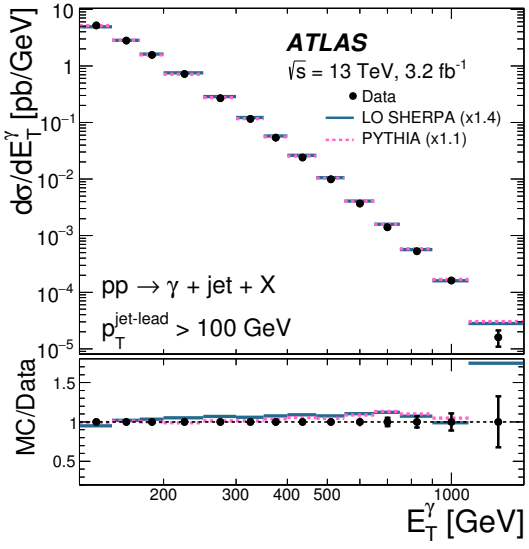
t-channel quark exchange

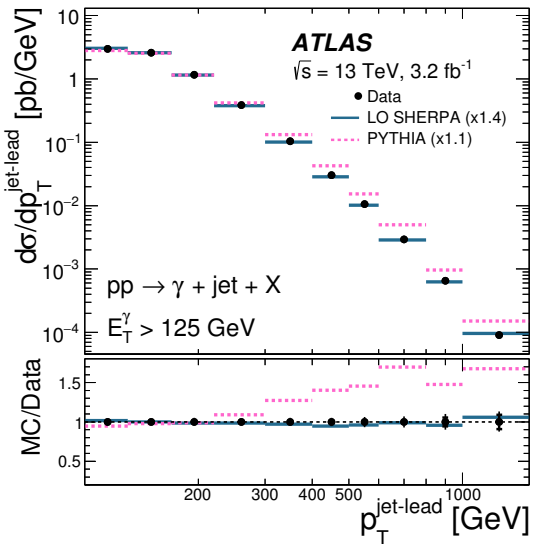
- $\mathrm{d}\sigma \propto (1 - \lvert\cos\theta^{\star}\rvert)^{-2s}$ when $\lvert\cos\theta^{\star}\rvert \to 1$; s is the spin of the t-channel exchanged particle.
- Comparison of the measured $\lvert\cos\theta^{\star}\rvert$ distribution to LO predictions for direct and fragmentation contributions exhibits a clear dominance of the t-channel quark exchange (direct contribution).

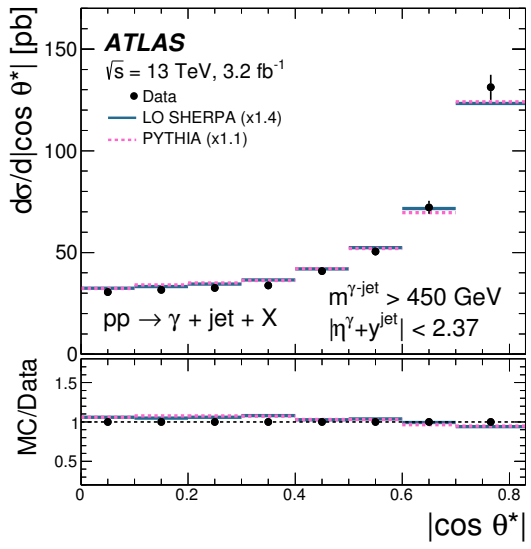


Results

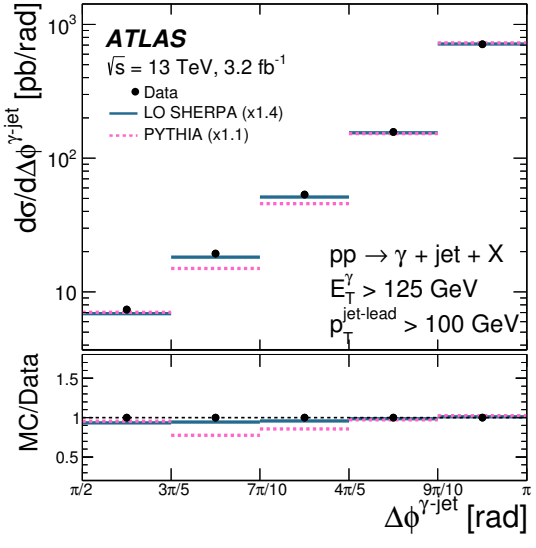
- Comparison of the measured cross sections to LO SHERPA (multileg) and PYTHIA

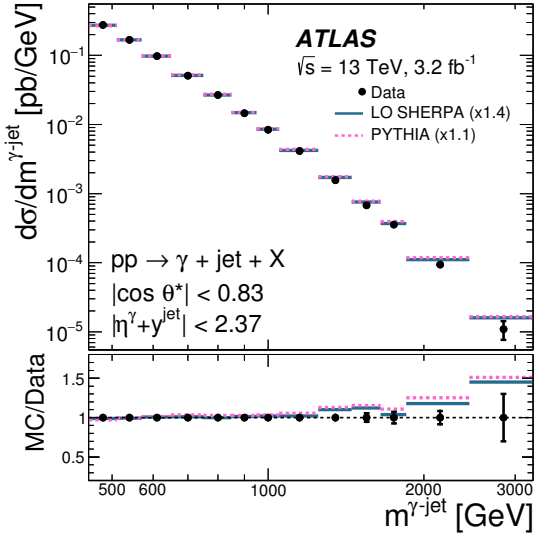






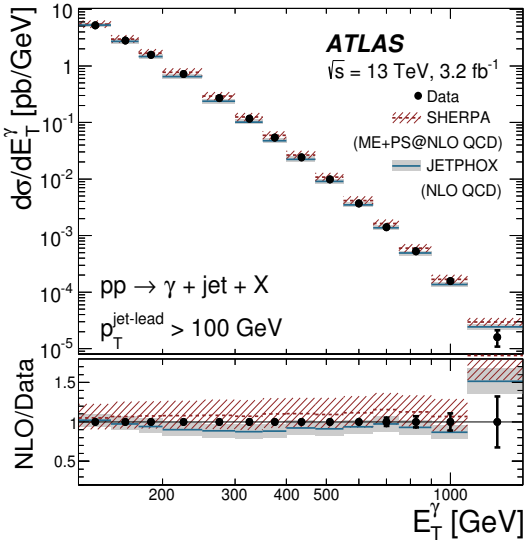
- Values up to 1.5 TeV accessible for E_T^{γ} and $p_T^{\mathrm{jet-lead}}$.
- $\frac{d\sigma}{dm^{\gamma-jet}}$ measured from 450 GeV up to 3.25 TeV.
- The LO SHERPA and PYTHIA predictions normalized to data provide an adequate description of the shape of the distributions, except PYTHIA in the tail of $p_T^{\mathrm{jet-lead}}$

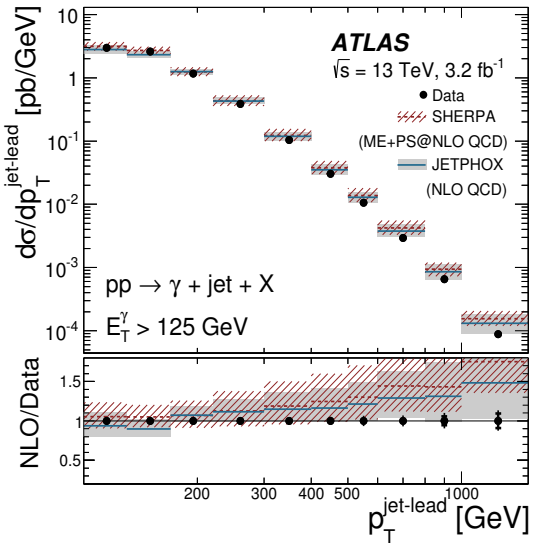


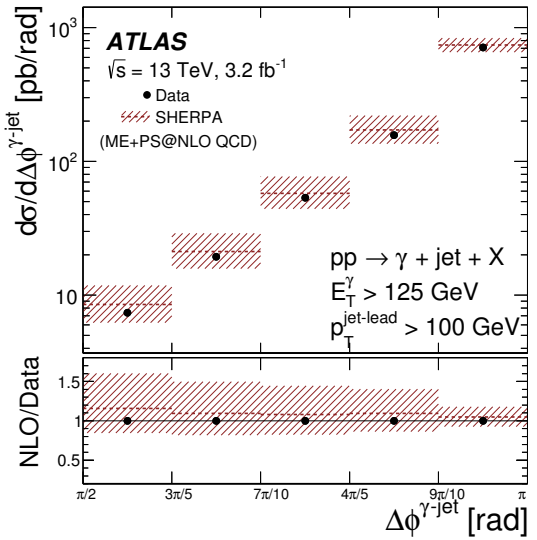


Results

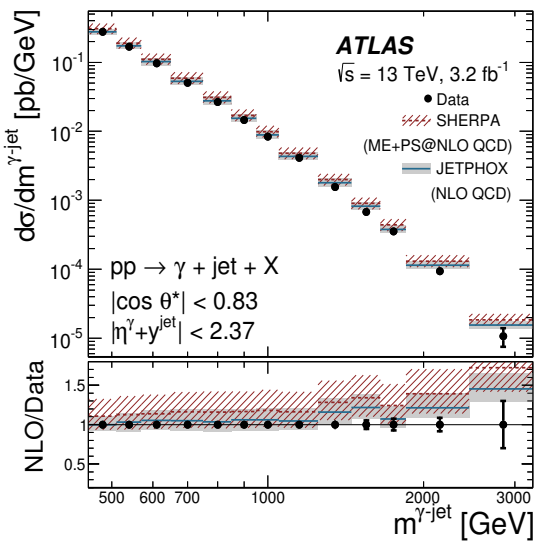
- Comparison of NLO QCD predictions of SHERPA (+ PS) and JETPHOX (corrected for non-perturbative corrections) to the measured cross sections unfolded to particle level.

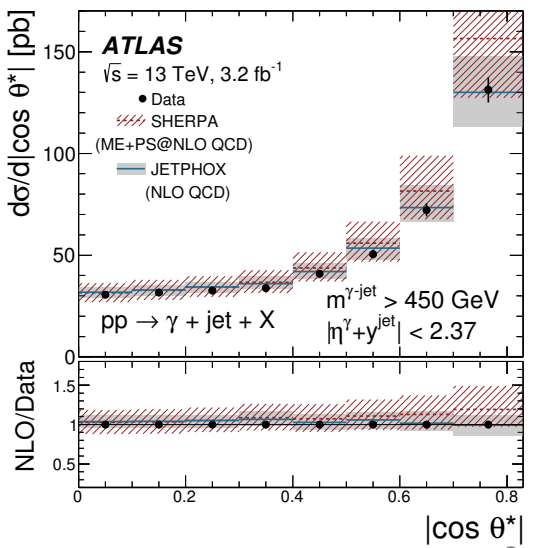






- Both describe the data within the theoretical and experimental uncertainties (dominated by the jet energy scale).
- In most of the regions of the phase space the theoretical uncertainties dominate (lead by the missing higher orders uncertainty).





Summary

- First measurements of isolated photon plus one jet production at 13 TeV have been shown.
- Differential cross sections measured as function of five observables: E_T^{γ}, $p_T^{\mathrm{jet-lead}}$, $\Delta\phi^{\gamma-jet}$, $m^{\gamma-\mathrm{jet}}$ and $|\cos\theta^{\star}|$.
- Measurements have been compared to the tree-level plus parton shower calculations of SHERPA and PYTHIA, which describe adequately the shape of the distributions with the exception of the high $p_T^{\mathrm{jet-lead}}$ region by PYTHIA
- Measurements have been compared to the predictions of fixed-order NLO QCD from JETPHOX (direct+fragmentation) and multileg NLO QCD plus parton showers from SHERPA (direct only; $\gamma + 1, 2$ jets at NLO and $\gamma + 3, 4$ jets at LO). Both describe the data within the theoretical uncertainties (much larger than the experimental uncertainties).
- SHERPA, thanks to the inclusion of NLO for $\gamma + 1, 2$ jets and LO for $\gamma + 3, 4$ jets, is the only one providing a meaningful prediction for $d\sigma/d\Delta\phi^{\gamma-jet}$ and describes the data.
- The measured $d\sigma/d|\cos\theta^{\star}|$ increases as $|\cos\theta^{\star}|$ increases. The observed increase is consistent with that predicted by NLO JETPHOX or NLO SHERPA, which is dominated by t-channel quark exchange. The measured dependence is closer to that of LO direct (mediated by quark exchange) than that of LO fragmentation (mediated by gluon exchange).