Prompt photon production in pp scattering: high energy factorization approach

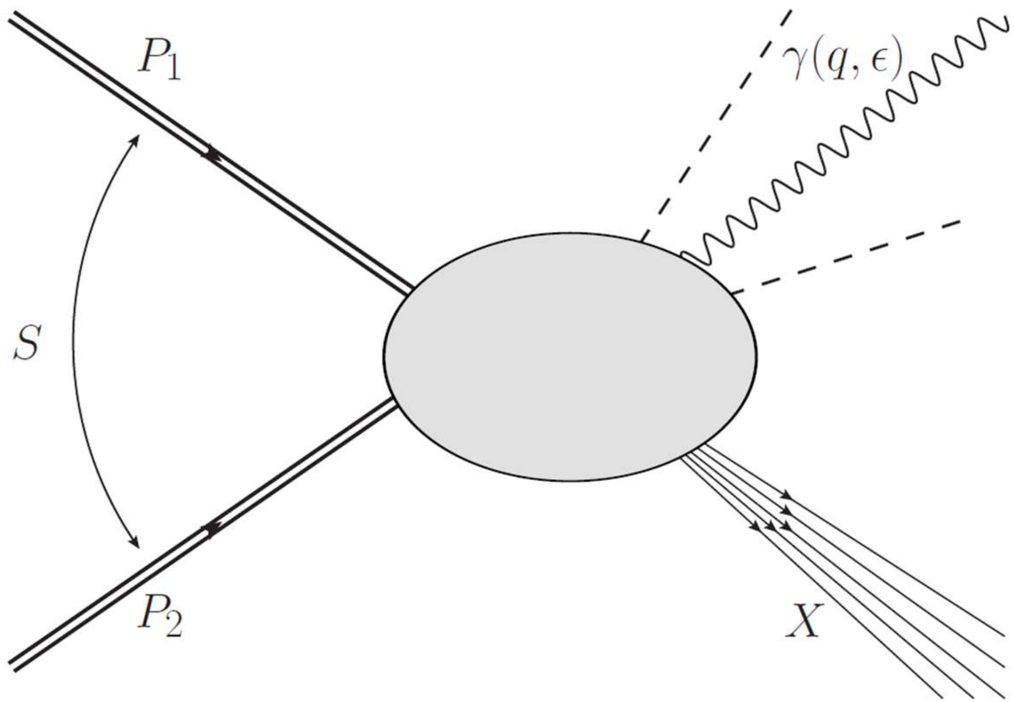
Tomasz Stebel
Institute of Theoretical Physics, Jagiellonian University, Cracow, Poland
with
Krzysztof Golec-Biernat (Institute of Nuclear Physics, Cracow)
Leszek Motyka Institute of Theoretical Physics, Jagiellonian University

Based on:
Phys. Rev. D **103**, 034013 (2021), 2010.00468

NATIONAL SCIENCE CENTRE POLAND
Project is supported by National Science Centre, grant no. 2019/32/C/ST2/00202.

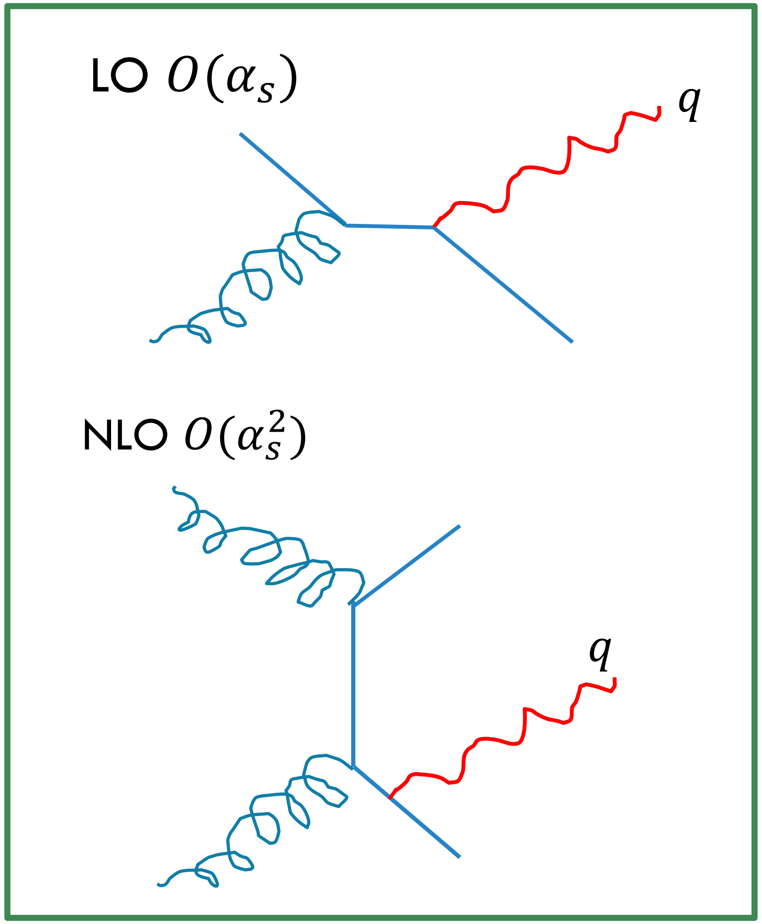
THE PROCESS

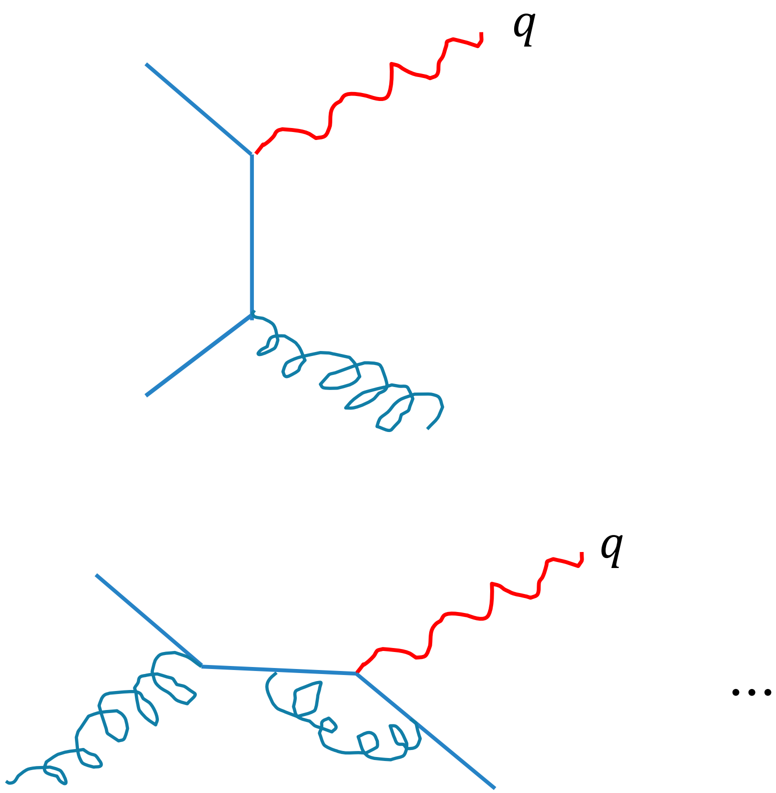
$$q_\gamma = (q_\gamma^+, q_\gamma^-, \boldsymbol{q}_T) = (x_F\sqrt{S}, \boldsymbol{q}_T^2/x_F\sqrt{S}, \boldsymbol{q}_T)$$



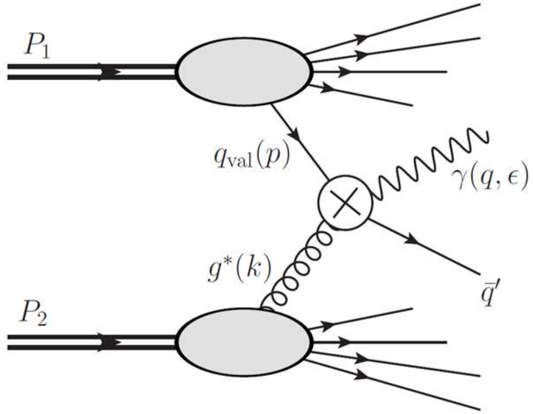
HIGH ENERGY APPROXIMATION

$E \gg$ other scales → Gluon distribution dominates

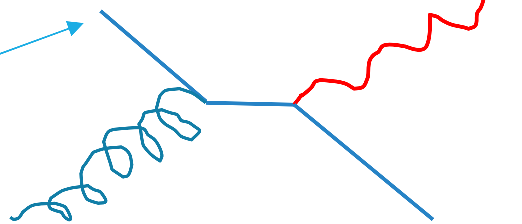




APPROACH qg^* (LO)



k_T-factorization approach (or rather „hybrid”):

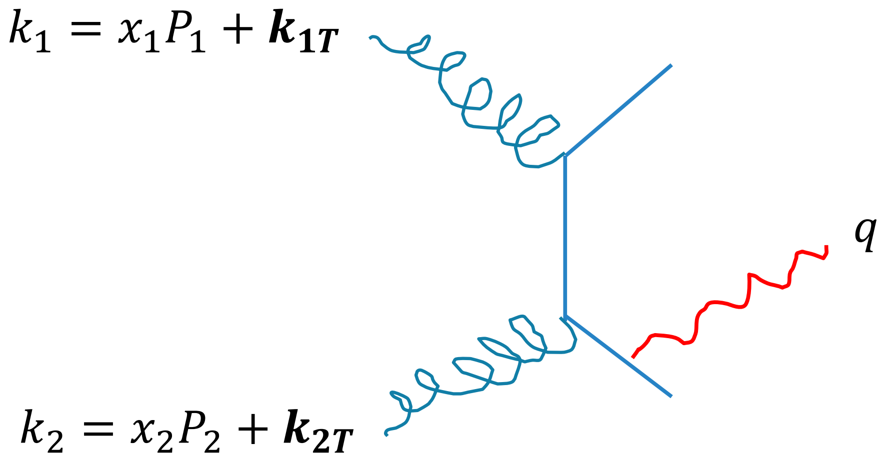


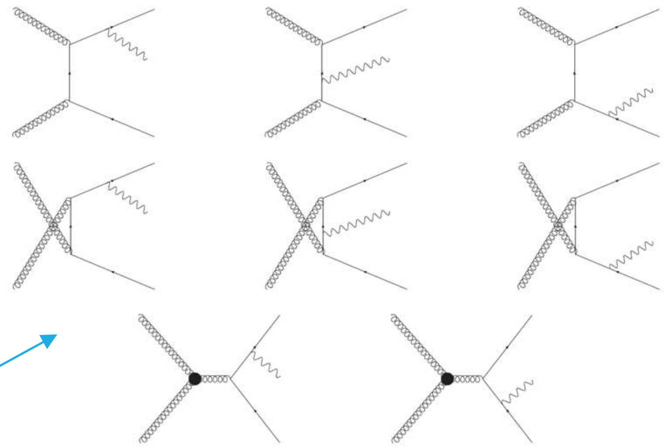
$$\frac{d\sigma^{\gamma}}{dy d^2\boldsymbol{q}_T} = \frac{\alpha_{\rm em}}{3\pi} \int_{x_F}^{1} \frac{dz}{z} \frac{x_F}{z} \sum_{i\in\{f,\bar{f}\}} e_i^2\, q_i\left(\frac{x_F}{z}, \mu_F\right)$$

$$\times \int \frac{d^2\boldsymbol{k}_T}{k_T^2} \alpha_s F_g(x_g, k_T, \mu_F) \frac{\left[1+(1-z)^2\right] z^2 \boldsymbol{k}_T^2}{\boldsymbol{q}_T^2(\boldsymbol{q}_T - z\boldsymbol{k}_T)^2} + (y \to -y)$$

APPROACH $g^* g^*$ („NLO”)

k_T-factorization approach:

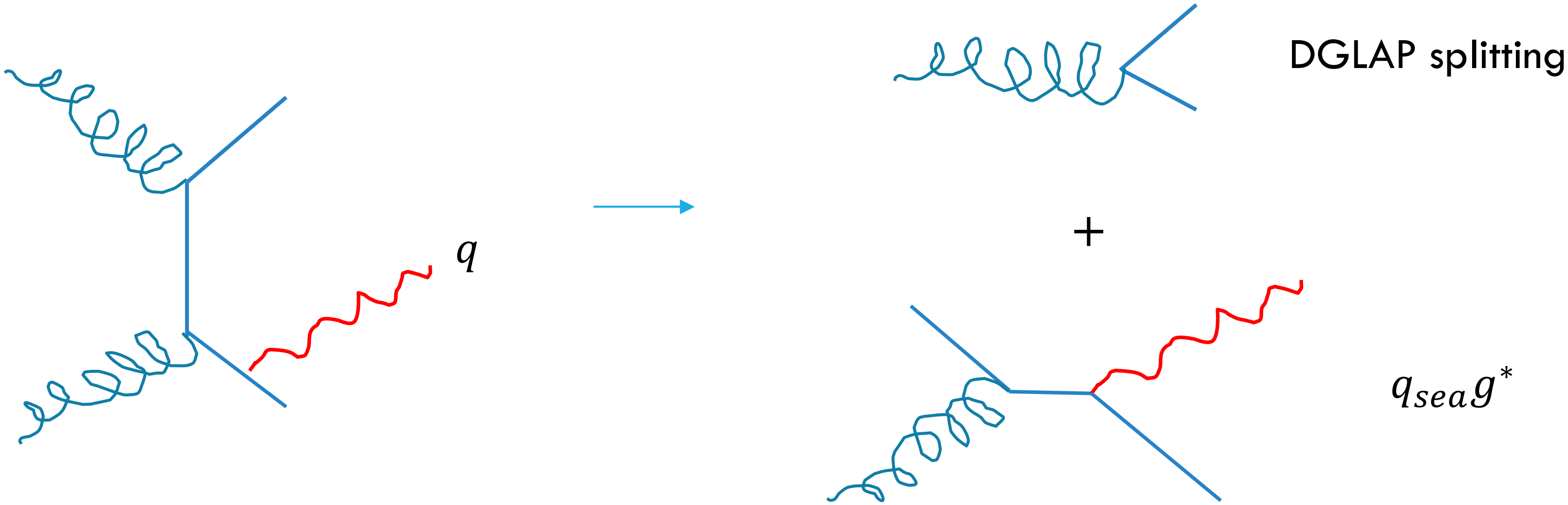




$$d\sigma_\sigma^{(g^*g^*\to q\bar{q}\gamma)} = \int dx_1 \int \frac{d^2\boldsymbol{k}_{1T}}{\pi k_{1T}^2} F_g(x_1, k_{1T}, \mu_F) \int dx_2 \int \frac{d^2\boldsymbol{k}_{2T}}{\pi k_{2T}^2} F_g(x_2, k_{2T}, \mu_F)$$

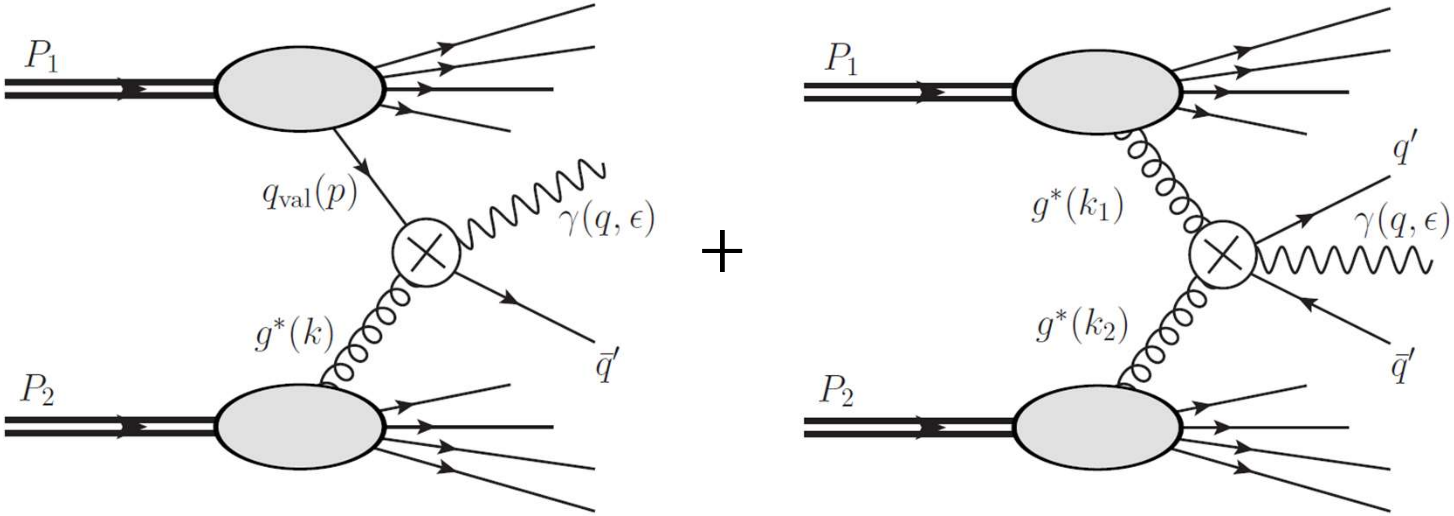
$$\times \; \frac{(2\pi)^4}{2S} \mathcal{H}_\sigma \, dPS_3(k_1 + k_2 \to p_3 + p_4 + q),$$

APPROACH $g^* g^*$ („NLO”)



We need to add the missing $q_{valence} g^*$ contribution

APPROACH $g^* g^* + q_{val} g^*$



$$d\sigma^{\gamma} = d\sigma^{(q_{\rm val} g^* \to q\gamma)} + d\sigma^{(g^* g^* \to q\bar{q}\gamma)}$$

UNINTEGRATED GLUON DISTRIBUTIONS (uPDF)

$$d\sigma_{\sigma}^{(g^*g^*\to q\bar{q}\gamma)} = \int dx_1 \int \frac{d^2\boldsymbol{k}_{1T}}{\pi k_{1T}^2} F_g(x_1, k_{1T}, \mu_F) \int dx_2 \int \frac{d^2\boldsymbol{k}_{2T}}{\pi k_{2T}^2} F_g(x_2, k_{2T}, \mu_F)$$
$$\times \frac{(2\pi)^4}{2S} \mathcal{H}_\sigma \, dPS_3(k_1 + k_2 \to p_3 + p_4 + q),$$

g^*g^* channel

$$\frac{d\sigma^\gamma}{dy d^2\boldsymbol{q}_T} = \frac{\alpha_{\rm em}}{3\pi} \int_{x_F}^1 \frac{dz}{z} \frac{x_F}{z} \sum_{i\in\{f,\bar{f}\}} e_i^2 \, q_i\left(\frac{x_F}{z}, \mu_F\right)$$
$$\times \int \frac{d^2\boldsymbol{k}_T}{k_T^2} \alpha_s F_g(x_g, k_T, \mu_F) \frac{\left[1 + (1-z)^2\right] z^2 \boldsymbol{k}_T^2}{\boldsymbol{q}_T^2 (\boldsymbol{q}_T - z\boldsymbol{k}_T)^2} + (y \to -y)$$

qg^* channel

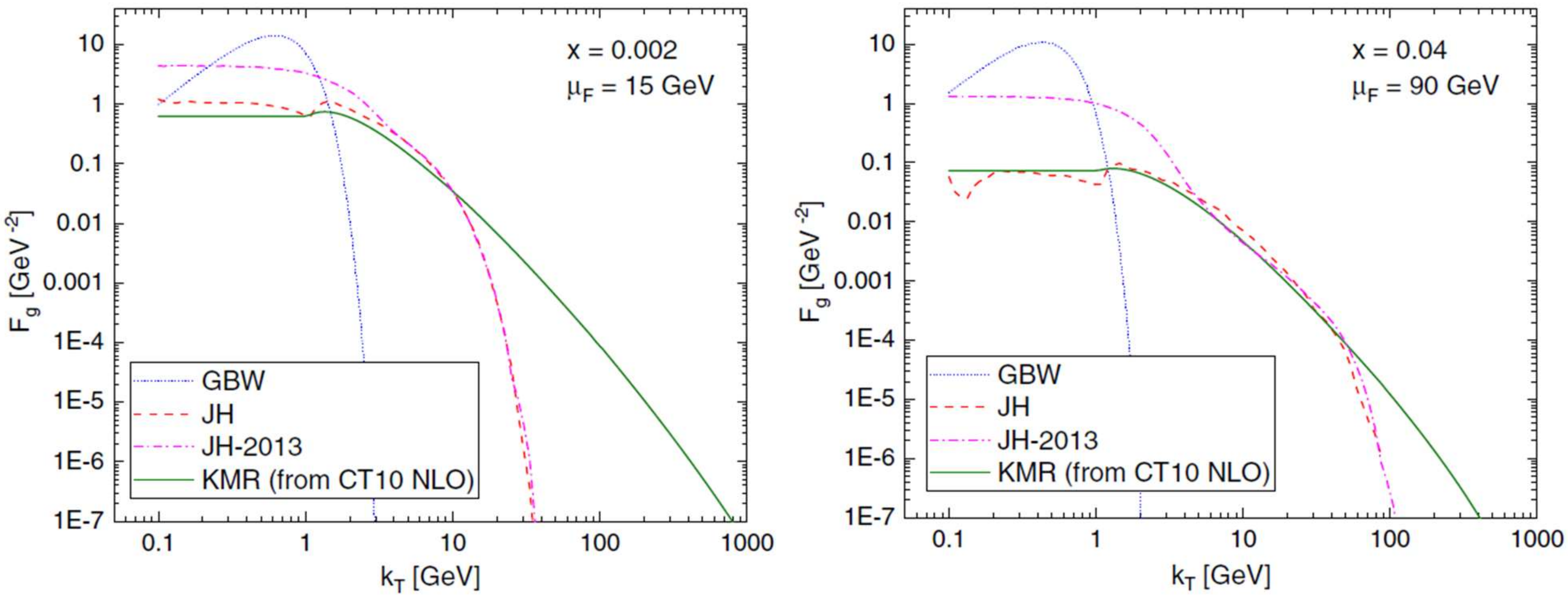
$F_g(x, k_T, \mu_F)$ is nonperturbative quantity and some models are needed.

$$\alpha_s F_g(x, k_T, \mu) = \frac{3\sigma_0}{4\pi^2} \frac{k_T^2}{Q_s^2} \exp(-k_T^2/Q_s^2) \times \left(\frac{1-x}{1-0.01}\right)^7$$

We will use:

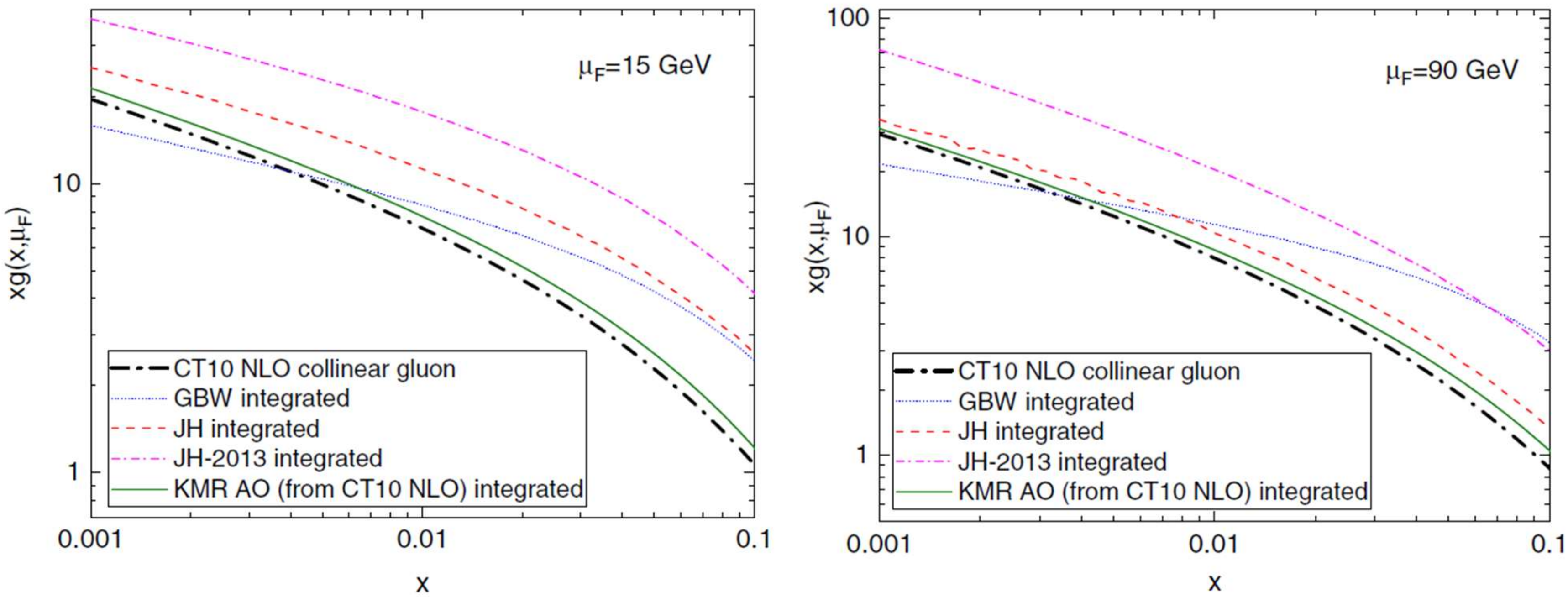
1) Golec-Biernat – Wusthoff (GBW) model (modified at large x)
2) CCFM solution by Jung and Hansson (JH) or Jung and Hautmann (JH-2013)
3) Kimber–Martin–Ryskin (KMR) uPDF

PLOTS OF uPDFs



PLOTS OF INTEGRATED uPDFs

$$\int_0^{\mu_F^2} dk_T^2 \, F_g(x, k_T, \mu_F) = xg(x, \mu_F)$$



DATA FOR ISOLATED PHOTON

We shall use the following data sets:

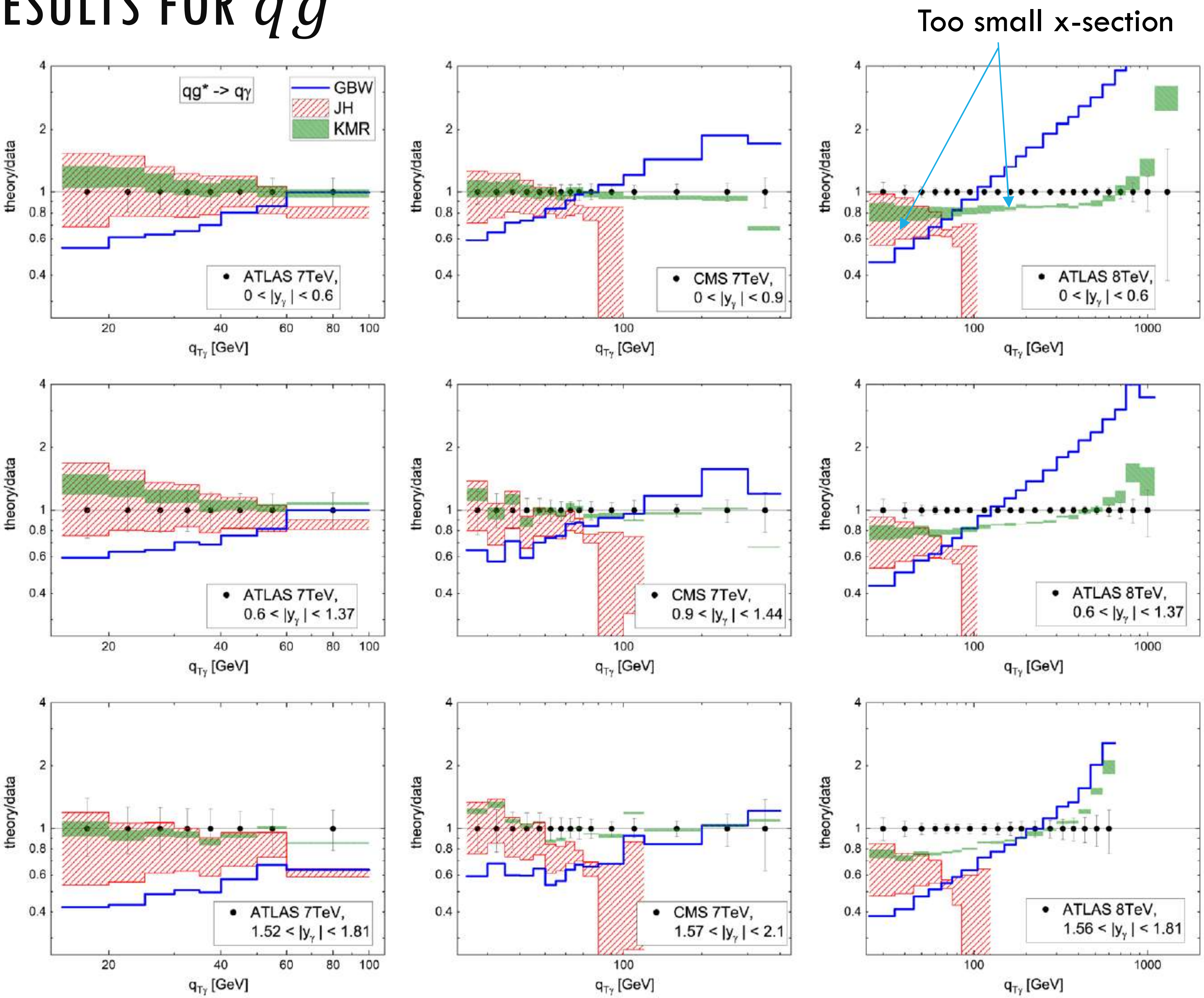
$x \approx 0.002$

- ATLAS data at $\sqrt{S} = 7$ TeV with 15 GeV $< q_T <$ 100 GeV (ATLAS@7TeV)
- CMS data at $\sqrt{S} = 7$ TeV with 25 GeV $< q_T <$ 400 GeV (CMS@7TeV)
- ATLAS data at $\sqrt{S} = 8$ TeV with 25 GeV $< q_T <$ 1500 GeV (ATLAS@8TeV)

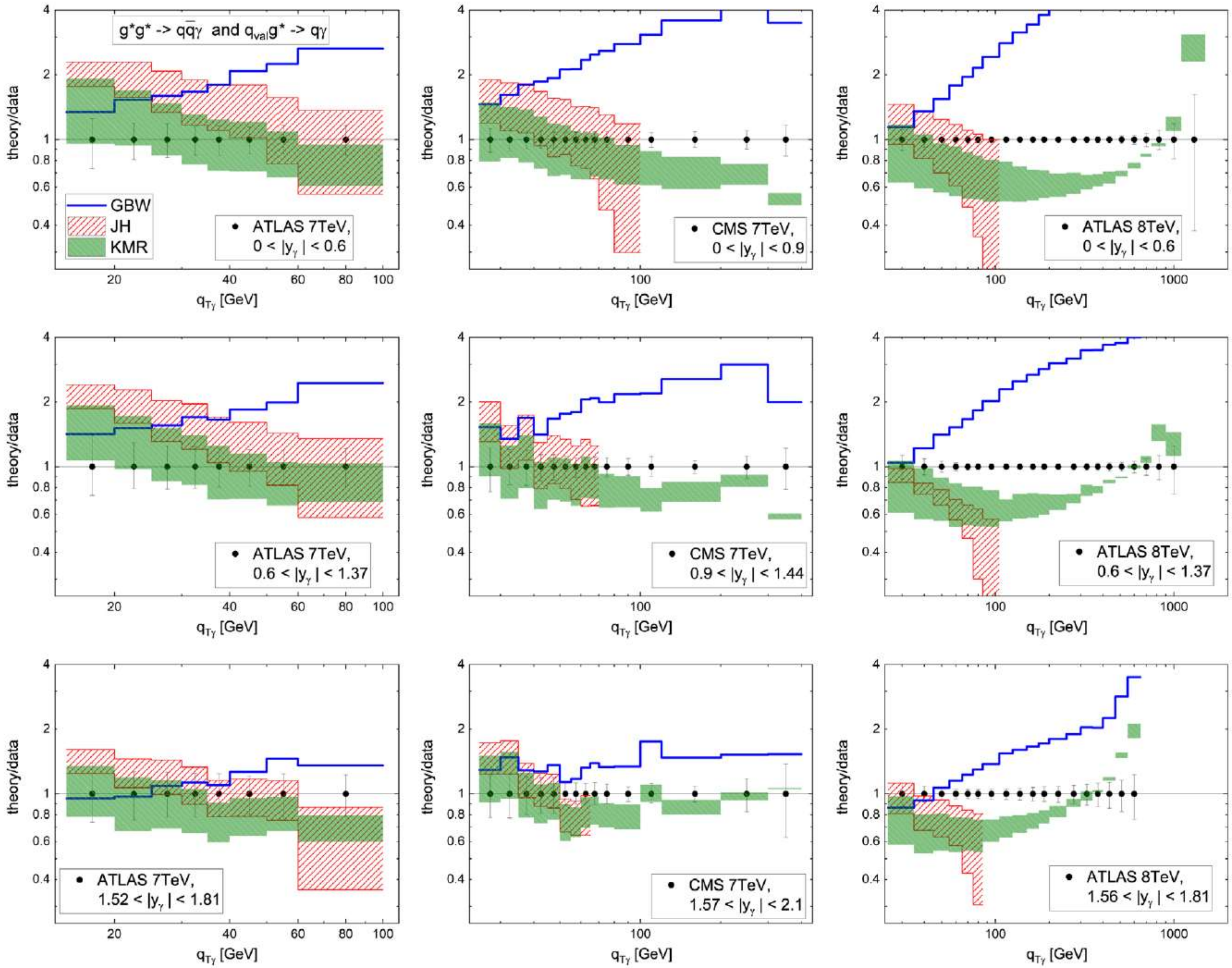
$x \approx 0.2$

These data can test the k_T-factorization framework at different values of x.

RESULTS FOR qg^*



RESULTS FOR $g^* g^* + q_{val} g^*$



SUMMARY

- We calculate cross-section for prompt photon production using k_T-factorization framework.
- We have tested three well-know transverse momentum dependent gluon distributions (GBW, CCFM, KMR)
- Good description of data was obtained, even at high q_T.
- Surprisingly, the $g^* g^*$ channel does not improve the description of data.

THANK YOU!

Backup slides

GOLEC-BIERNAT – WUSTHOFF (GBW) GLUON DISTRIBUTION

$$\alpha_s F_g(x, k_T, \mu) = \frac{3\sigma_0}{4\pi^2} \frac{k_T^2}{Q_s^2} \exp(-k_T^2/Q_s^2)$$

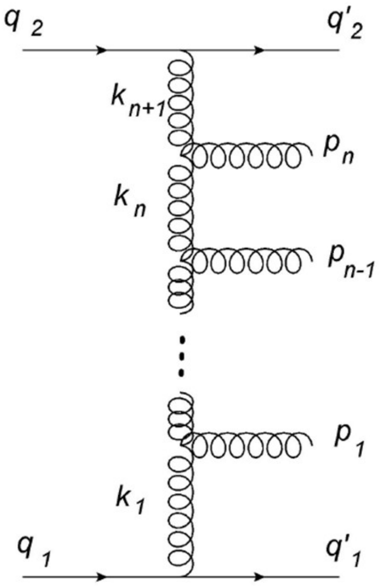
where the the saturation scale $Q_s^2 = (x/x_0)^{-\lambda}$ GeV^2.

The parameters σ_0, x_0, λ were fitted to data with $x < 0.01$.

We introduce additional factor which modifies uPDF at high x:

$$\alpha_s F_g(x, k_T, \mu) = \frac{3\sigma_0}{4\pi^2} \frac{k_T^2}{Q_s^2} \exp(-k_T^2/Q_s^2) \times \left(\frac{1-x}{1-0.01}\right)^7$$

CATANI—CIAFALONI—FIORANI—MARCHESINI (CCFM) EQUATION



CCFM formalism is one the most popular modification of small-x evolution equation (BFKL) for $x \to 1$.

θ_i - emission angle of gluon p_i w.r.t. z axis defined by hadrons' momenta P_1 and P_2

CCFM requires angular ordering: $\theta_i > \theta_{i-1}$.

$$f_g(x, k_T, Q) = f_g^0(x, k_T, Q_0) + \int \frac{d^2\vec{q}}{\pi q^2} \int_x^1 \frac{dz}{z} \theta(Q - zq)\theta(q - Q_0) \frac{\alpha_s(q)}{2\pi} \Delta_S(Q, zq) \times (2N_c) \left[\frac{\Delta_{NS}(k_T, q, z)}{z} + \frac{\theta(1 - z - Q_0/q)}{1 - z} \right] f_g\Big(\frac{x}{z}, |\vec{k}_T + (1 - z)\vec{q}|, q\Big)$$

We use the solution of CCFM by Jung and Hansson (2003), hep-ph/0309009

KIMBER–MARTIN–RYSKIN (KMR)

The main idea is to obtain uPDFs from collinear PDF (DGLAP equation). This is often done by:

$$f_a(x, k_\perp, Q) = \frac{\partial}{\partial \ln k_\perp^2} \left[T_a(Q, k_\perp) D_a(x, k_\perp) \right]$$

where Sudakov formfactor is $T_a(Q, k_\perp) = \exp\left\{ - \int_{k_\perp^2}^{Q^2} \frac{dp_\perp^2}{p_\perp^2} \sum_{a'} \int_0^{1-\Delta} dz z P_{a'a}(z, p_\perp) \right\}$

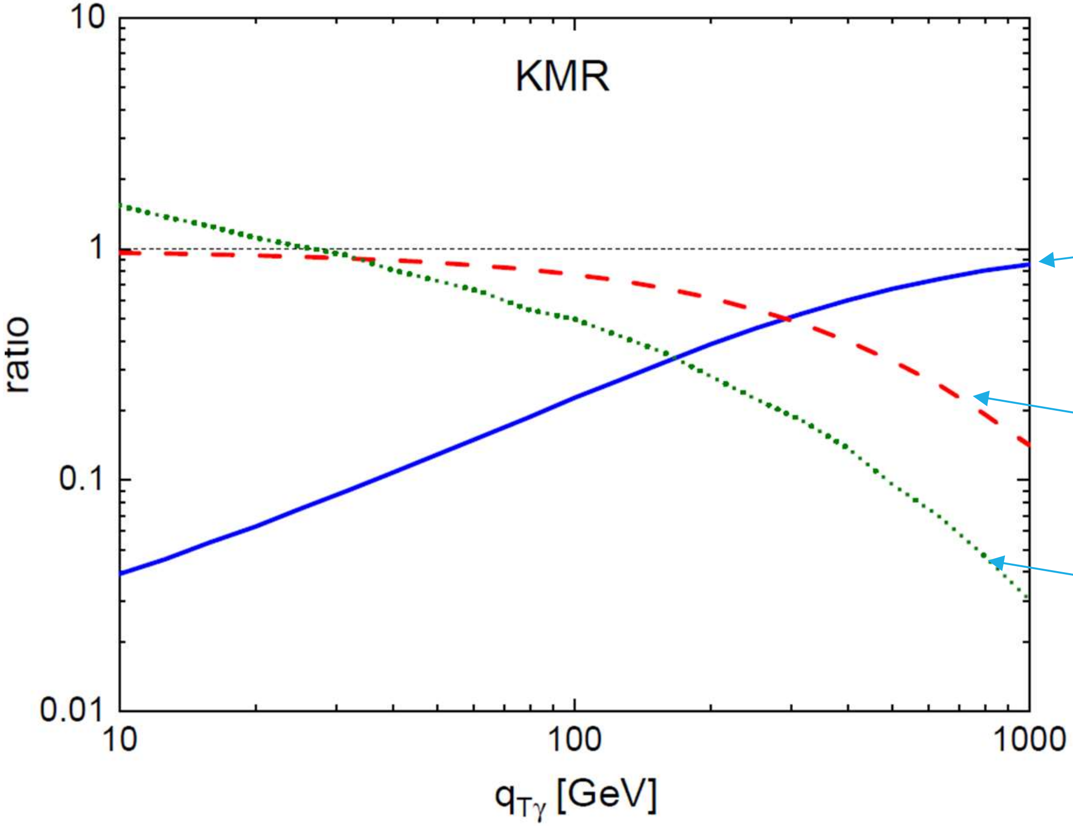
$$\Delta(k_T, Q) = \frac{k_T}{k_T + Q}$$ (angular ordering version of KMR)

It was shown by K. Golec-Biernat and A. Staśto (1803.06246[hep-ph]) that better prescription is:

$$F_g(x, k_T, Q) \equiv \frac{T_a(Q, k_T)}{{k_T}^2} \sum_{a' \in \{f, \bar{f}, g\}} \int_x^{1-\Delta(k_T, Q)} \frac{dz}{z} P_{ga'}(z, k_T)\, D_{a'}\left(\frac{x}{z}, k_T\right)$$

COMPARISON BETWEEN CHANNELS (FOR KMR)

$$\sigma(qg^*) = \sigma(q_{sea}g^*) + \sigma(q_{val}g^*)$$



$$\frac{\sigma(q_{val}g^*)}{\sigma(qg^*)}$$

$$\frac{\sigma(q_{sea}g^*)}{\sigma(qg^*)}$$

$$\frac{\sigma(g^*g^*)}{\sigma(qg^*)}$$