Inclusive production of $f_2(1270)$ tensor mesons at the LHC via gluon-gluon fusion in the k_t-factorization approach

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Krakow, July 28 - August 6, 2020

Contents

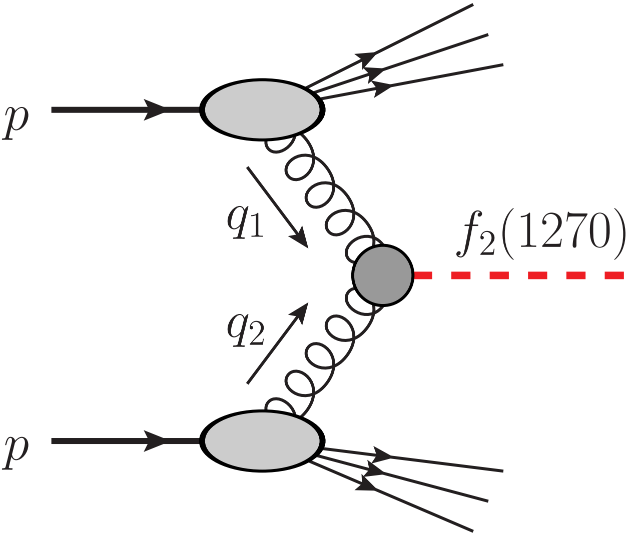
Introduction

- The mechanism of meson production in proton-proton collisions is not fully undersood. The string-model is an option considered e.g. in Phythia. But not all meson production can be explained via string fragmentation.
- The gluon-gluon fusion for η_c and χ_c quarkonium production was shown recently to be the dominant mechanism [1,2].
- In contrast the mechanism of light meson production is not known. Is there gluon-gluon fusion important effect ? Very recently we have considered production of $f_0(980)$ [3] and shown that gluon-gluon fusion is important contribution but not sufficient to describe ALICE data.
- Here we consider inclusive production of tensor $f_2(1270)$ meson.

Our recent paper

[1] I. Babiarz, R. Pasechnik, W. Schäfer and A. Szczurek, JHEP02, 037 (2020).
[2] I. Babiarz, R. Pasechnik, W. Schäfer and A. Szczurek, JHEP06, 101 (2020).
[3] P. Lebiedowicz, R. Maciula and A. Szczurek
, Phys. Lett. **B806** 135475 (2020).
[4] P. Lebiedowicz and A. Szczurek, arXiv:2007.12485.

Introduction



Ewerz-Maniatis-Nachtmann (EMN) vertex

$$\begin{aligned}\Gamma^{(f_2\gamma\gamma)}_{\mu\nu\kappa\lambda}(q_1,q_2) &= 2a_{f_2\gamma\gamma}\,\Gamma^{(0)}_{\mu\nu\kappa\lambda}(q_1,q_2)\,F^{(0)}(Q_1^2,Q_2^2) \\ &\quad - b_{f_2\gamma\gamma}\,\Gamma^{(2)}_{\mu\nu\kappa\lambda}(q_1,q_2)\,F^{(2)}(Q_1^2,Q_2^2)\,, \qquad (1)\end{aligned}$$

with two rank-four tensor functions,

$$\Gamma^{(0)}_{\mu\nu\kappa\lambda}(q_1,q_2) = \Big[(q_1\cdot q_2)g_{\mu\nu} - q_{2\mu}q_{1\nu}\Big]\Big[q_{1\kappa}q_{2\lambda} + q_{2\kappa}q_{1\lambda} - \frac{1}{2}(q_1\cdot q_2)g_{\kappa\lambda}\Big]\,, \qquad (2)$$

$$\begin{aligned}\Gamma^{(2)}_{\mu\nu\kappa\lambda}(q_1,q_2) = &\ (q_1\cdot q_2)(g_{\mu\kappa}g_{\nu\lambda} + g_{\mu\lambda}g_{\nu\kappa}) + g_{\mu\nu}(q_{1\kappa}q_{2\lambda} + q_{2\kappa}q_{1\lambda}) \\ &- q_{1\nu}q_{2\lambda}g_{\mu\kappa} - q_{1\nu}q_{2\kappa}g_{\mu\lambda} - q_{2\mu}q_{1\lambda}g_{\nu\kappa} - q_{2\mu}q_{1\kappa}g_{\nu\lambda} \\ &- [(q_1\cdot q_2)g_{\mu\nu} - q_{2\mu}q_{1\nu}]\,g_{\kappa\lambda}\,, \qquad (3)\end{aligned}$$

Ewerz-Maniatis-Nachtmann (EMN) vertex

To obtain $a_{f_2\gamma\gamma}$ and $b_{f_2\gamma\gamma}$ in (1) we use the values

$$\begin{aligned} &\Gamma(f_2 \to \gamma\gamma) = (2.93 \pm 0.40)\,\mathrm{keV}\,, \\ &\text{helicity zero contribution} \approx 9\% \text{ of } \Gamma(f_2 \to \gamma\gamma)\,. \end{aligned} \tag{4}$$

Using the exp. decay rate

$$\Gamma(f_2 \to \gamma\gamma) = \frac{m_{f_2}}{80\pi}\left(\frac{1}{6} m_{f_2}^6 |a_{f_2\gamma\gamma}|^2 + m_{f_2}^2 |b_{f_2\gamma\gamma}|^2\right), \tag{5}$$

and assuming $a_{f_2\gamma\gamma} > 0$ and $b_{f_2\gamma\gamma} > 0$, we find

$$a_{f_2\gamma\gamma} = \alpha_{\mathrm{em}} \times 1.17\ \mathrm{GeV}^{-3}\,, \tag{6}$$

$$b_{f_2\gamma\gamma} = \alpha_{\mathrm{em}} \times 2.46\ \mathrm{GeV}^{-1}\,, \tag{7}$$

where $\alpha_{\mathrm{em}} = e^2/(4\pi) \simeq 1/137$ is the electr. coupling constant.

Pascalutsa-Pauk-Vanderhaeghen (PPV) vertex

Poppe and Pascalutsa et al. shown that the most general amplitude for the process $\gamma^*(q_1, \lambda_1) + \gamma^*(q_2, \lambda_2) \to f_2(\Lambda)$, describing the transition from an initial state of two virtual photons to a tensor meson f_2 ($J^{PC} = 2^{++}$) with mass m_{f_2} and helicity $\Lambda = \pm 2, \pm 1, 0$, involves five independent structures (invariant amplitudes).

Pascalutsa-Pauk-Vanderhaeghen (PPV) vertex

In the formalism presented by Pascalutsa et al. the $\gamma^*\gamma^* \to f_2(1270)$ vertex is parameterized as

$$
\begin{aligned}
\Gamma^{(f_2\gamma\gamma)}_{\mu\nu\kappa\lambda}(q_1,q_2) \quad = \quad & 4\pi\alpha_{\rm em}\Bigg\{\Bigg[R_{\mu\kappa}(q_1,q_2)R_{\nu\lambda}(q_1,q_2)+\frac{s}{8X}R_{\mu\nu}(q_1,q_2)(q_1-q_2)_\kappa\,(q_1-q_2)_\lambda\Bigg] \\
& \times\frac{\nu}{m_{f_2}}T^{(2)}(Q_1^2,Q_2^2) \\
& +R_{\nu\kappa}(q_1,q_2)(q_1-q_2)_\lambda\left(q_{1\mu}+\frac{Q_1^2}{\nu}q_{2\mu}\right)\frac{1}{m_{f_2}}T^{(1)}(Q_1^2,Q_2^2) \\
& +R_{\mu\kappa}(q_1,q_2)(q_2-q_1)_\lambda\left(q_{2\nu}+\frac{Q_2^2}{\nu}q_{1\nu}\right)\frac{1}{m_{f_2}}T^{(1)}(Q_2^2,Q_1^2) \\
& +R_{\mu\nu}(q_1,q_2)(q_1-q_2)_\kappa\,(q_1-q_2)_\lambda\,\frac{1}{m_{f_2}}T^{(0,T)}(Q_1^2,Q_2^2) \\
& +\left(q_{1\mu}+\frac{Q_1^2}{\nu}q_{2\mu}\right)\left(q_{2\nu}+\frac{Q_2^2}{\nu}q_{1\nu}\right)(q_1-q_2)_\kappa(q_1-q_2)_\lambda\,\frac{1}{m_{f_2}^3}T^{(0,L)}(Q_1^2,Q_2^2)\Bigg\}\,,
\end{aligned}
\tag{8}
$$

Pascalutsa-Pauk-Vanderhaeghen (PPV) vertex

where photons with momenta q_1 and q_2 have virtualities, $Q_1^2 = -q_1^2$ and $Q_2^2 = -q_2^2$, $s = (q_1 + q_2)^2 = 2\nu - Q_1^2 - Q_2^2$, $X = \nu^2 - q_1^2 q_2^2$, $\nu = (q_1 \cdot q_2)$, and

$$R_{\mu\nu}(q_1, q_2) = -g_{\mu\nu} + \frac{1}{X}\left[\nu\left(q_{1\mu}q_{2\nu} + q_{2\mu}q_{1\nu}\right) - q_1^2 q_{2\mu}q_{2\nu} - q_2^2 q_{1\mu}q_{1\nu}\right] \tag{9}$$

$T^{(\Lambda)}(Q_1^2, Q_2^2)$ are the $\gamma^*\gamma^* \to f_2(1270)$ transition form factors for Λ $f_2(1270)$ helicity.For the case of helicity zero, there are two form factors depending on whether both photons are transverse (superscript T) or longitudinal (superscript L). We can express the transition form factors as

$$T^{(\Lambda)}(Q_1^2, Q_2^2) = F^{(\Lambda)}(Q_1^2, Q_2^2)\, T^{(\Lambda)}(0, 0)\,. \tag{10}$$

In the limit $Q_{1,2}^2 \to 0$ only $T^{(0,T)}$ and $T^{(2)}$ contribute.

EMN vs PPV vertices

Comparing the two approaches at both real photons ($Q_1^2 = Q_2^2 = 0$) and at $\sqrt{s} = m_{f_2}$ we found the correspondence

$$4\pi\alpha_{\rm em}\, T^{(0,T)}(0,0) = -a_{f_2\gamma\gamma}\,\frac{m_{f_2}^3}{2}\,, \tag{11}$$

$$4\pi\alpha_{\rm em}\, T^{(2)}(0,0) = -b_{f_2\gamma\gamma}\,2m_{f_2}\,. \tag{12}$$

$g^*g^* \to f_2(1270)$ form factor(s)

$f_2(1270)$ is extended, finite size object and one can expect an additional form factor(s) $F(Q_1^2, Q_2^2)$ associated with the gluon virtualities for the $g^*g^* \to f_2$ vertex. In our work the form factor is parametrized as:

$$F(Q_1^2, Q_2^2) = \frac{\Lambda_M^2}{Q_1^2 + Q_2^2 + \Lambda_M^2}, \tag{13}$$

$$F(Q_1^2, Q_2^2) = \left(\frac{\Lambda_D^2}{Q_1^2 + Q_2^2 + \Lambda_D^2}\right)^2, \tag{14}$$

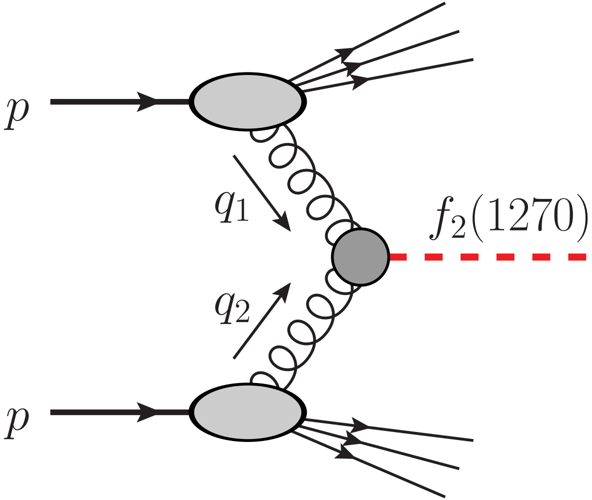
$$F(Q_1^2, Q_2^2) = \frac{\Lambda_1^2}{Q_1^2 + \Lambda_1^2} \frac{\Lambda_1^2}{Q_2^2 + \Lambda_1^2}, \tag{15}$$

$$F(Q_1^2, Q_2^2) = \frac{\Lambda_2^4}{(Q_1^2 + \Lambda_2^2)^2} \frac{\Lambda_2^4}{(Q_2^2 + \Lambda_2^2)^2}, \tag{16}$$

where Λ is a parameter whose value is expected to be close to the resonance mass.

No form factor in earlier work by Jeon et al.

k_t-factorization approach



Rysunek: General diagram for inclusive $f_2(1270)$ production via gluon-gluon fusion in proton-proton collisions.

k_t-factorization approach

The differential cross section for inclusive $f_2(1270)$ meson production via the $g^* g^* \to f_2(1270)$ fusion in the k_t-factorization approach can be written as:

$$\frac{d\sigma}{dy d^2\boldsymbol{p}} = \int \frac{d^2\boldsymbol{q}_1}{\pi \boldsymbol{q}_1^2} \mathcal{F}_g(x_1, \boldsymbol{q}_1^2) \int \frac{d^2\boldsymbol{q}_2}{\pi \boldsymbol{q}_2^2} \mathcal{F}_g(x_2, \boldsymbol{q}_2^2)\, \delta^{(2)}(\boldsymbol{q}_1 + \boldsymbol{q}_2 - \boldsymbol{p}) \frac{\pi}{(x_1 x_2 s)^2} \overline{|\mathcal{M}_{g^* g^* \to f_2}|^2} . \quad (17)$$

Here $\boldsymbol{q}_1$, $\boldsymbol{q}_2$ and $\boldsymbol{p}$ - the transverse momenta of the gluons and the $f_2(1270)$ meson. The f_2 meson is on-shell and $p^2 = m_{f_2}^2$. $\mathcal{M}_{g^* g^* \to f_2}$ is the off-shell matrix element for the hard subprocess and $\mathcal{F}_g$ are the unintegrated gluon distribution functions (UGDFs). The UGDFs depend on gluon longitudinal momentum fractions $x_{1,2} = m_T \exp(\pm \mathrm{y})/\sqrt{s}$ and $\boldsymbol{q}_1^2, \boldsymbol{q}_2^2$ entering the hard process. In principle, they can depend also on factorization scales $\mu_{F,i}^2$, $i = 1, 2$. We assume $\mu_{F,1}^2 = \mu_{F,2}^2 = m_T^2$. Here m_T is transverse mass of the $f_2(1270)$ meson; $m_T = \sqrt{\boldsymbol{p}^2 + m_{f_2}^2}$. The $\delta^{(2)}$ function above can be eliminated by introducing $\boldsymbol{q}_1 + \boldsymbol{q}_2$ and $\boldsymbol{q}_1 - \boldsymbol{q}_2$

k_t-factorization approach

The off-shell matrix element can be written as (we restore the color-indices a and b)

$$\mathcal{M}^{ab} = \frac{q_{1t}^{\mu} q_{2t}^{\nu}}{|\boldsymbol{q}_1||\boldsymbol{q}_2|} \mathcal{M}^{ab}_{\mu\nu} = \frac{q_{1+} q_{2-}}{|\boldsymbol{q}_1||\boldsymbol{q}_2|} n^{+\mu} n^{-\nu} \mathcal{M}^{ab}_{\mu\nu} = \frac{x_1 x_2 s}{2|\boldsymbol{q}_1||\boldsymbol{q}_2|} n^{+\mu} n^{-\nu} \mathcal{M}^{ab}_{\mu\nu} (1$$

with the lightcone components of gluon momenta $q_{1+} = x_1\sqrt{s/2}$, $q_{2-} = x_2\sqrt{s/2}$. Here the matrix-element reads

$$\mathcal{M}_{\mu\nu} = \Gamma^{(f_2\gamma\gamma)}_{\mu\nu\kappa\lambda}(q_{1t}, q_{2t}) \left(\epsilon^{(f_2)\kappa\lambda}(p)\right)^* , \qquad (19)$$

where $\epsilon^{(f_2)}$ is the polarisation tensor for the $f_2(1270)$ meson.

k_t-factorization approach, energy-momentum tensor

In the k_t-factorization approach in Jeon et al. the matrix element squared was written as:

$$
\begin{aligned}
\overline{|\mathcal{M}_{g^*g^*\to f_2}|^2} &= \frac{1}{4}\sum_{\lambda_1,\lambda_2,\lambda_{f_2}} |\mathcal{M}_{g^*g^*\to f_2}|^2 \\
&= \frac{1}{4}\frac{1}{(N_c^2-1)^2}\sum_{a,b}\frac{q_{1t\,\mu_1}}{q_{1t}}\frac{q_{2t\,\nu_1}}{q_{2t}}V_{ab}^{\alpha_1\beta_1\mu_1\nu_1}(q_1,q_2)\,P^{(2)}_{\alpha_1\beta_1,\alpha_2\beta_2}(p)\frac{q_{1t\,\mu_2}}{q_{1t}}\frac{q_{2t\,\nu_2}}{q_{2t}}\left(V_{ab}^{\alpha_2\beta_2\mu_2\nu_2}(q_1,q_2)\right)^* \\
&= \frac{1}{4}\frac{1}{(N_c^2-1)\kappa^2}P^{(2)}_{\alpha_1\beta_1,\alpha_2\beta_2}(p)H_\perp^{\alpha_1\beta_1}(q_{1t},q_{2t})H_\perp^{\alpha_2\beta_2}(q_{1t},q_{2t})\left(\frac{x_1x_2s}{2q_{1t}q_{2t}}\right)^2, \qquad (20
\end{aligned}
$$

where $\lambda_1, \lambda_2, \lambda_{f_2}$ are the helicities of the gluons and f_2 meson, a, b are color indices, N_c is the number of colors, $V_{ab}^{\alpha\beta\mu\nu}$ is the $gg \to f_2$ vertex. (see Jeon et al.) and $\kappa \approx \mathcal{O}(0.1\,\mathrm{GeV})$ is to be fixed by experiment.
No form factor(s), no α_s.

k_t-factorization approach

The $g^* g^* \to f_2(1270)$ coupling entering in the matrix element squared can be obtained from that for $\gamma^* \gamma^* \to f_2(1270)$ coupling as:

$$\alpha_{\rm em}^2 \to \alpha_{\rm s}^2 \, \frac{1}{4 N_c (N_c^2 - 1)} \, \frac{1}{(< e_q^2 >)^2} \, . \qquad (21)$$

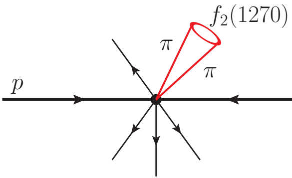
Here $(< e_q^2 >)^2 = 25/162$ for the $\frac{1}{\sqrt{2}} \left(u\bar{u} + d\bar{d} \right)$ flavour structure.

In realistic calculations the running of strong coupling constants must be included. In our numerical calculations presented below the renormalization scale is taken in the form:

$$\alpha_{\rm s}^2 \to \alpha_{\rm s}(\max\{m_T^2, \boldsymbol{q}_1^2\}) \, \alpha_{\rm s}(\max\{m_T^2, \boldsymbol{q}_2^2\}) \, . \qquad (22)$$

The Shirkov-Solovtsov prescription is used to extrapolate down to small renormalization scales. The strong coupling constant was not included by Jeon et al.

A simple $\pi\pi$ final-state rescattering model



Rysunek: General diagram for the $\pi\pi$ final-state rescattering leading to $f_2(1270)$ production in proton-proton collisions.

Both $\pi^+\pi^-$ and $\pi^0\pi^0$ rescatterings may lead to the production of the $f_2(1270)$ meson.

A simple $\pi\pi$ final-state rescattering model

The spectrum of pions will be not calculated here but instead we will use a Lévy parametrization of the inclusive π^0 cross section for $\sqrt{s} = 7$ TeV. At the ALICE energies and midrapidities we assume the following relation:

$$\frac{d\sigma^{\pi^+}}{d\mathrm{y}\, dp_t}(\mathrm{y}, p_t) = \frac{d\sigma^{\pi^-}}{d\mathrm{y}\, dp_t}(\mathrm{y}, p_t) = \frac{d\sigma^{\pi^0}}{d\mathrm{y}\, dp_t}(\mathrm{y}, p_t) \tag{23}$$

to be valid.

Our approach here is similar in spirit to color evaporation approach considered, e.g. for J/ψ.

A simple $\pi\pi$ final-state rescattering model

We write the number of produced $f_2(1270)$ per event as

$$N = \int d\mathrm{y}_1 dp_{1t} \int d\mathrm{y}_2 dp_{2t} \int \frac{d\phi_1}{2\pi} \frac{d\phi_2}{2\pi} \frac{dN^\pi}{d\mathrm{y}_1 dp_{1t}} \frac{dN^\pi}{d\mathrm{y}_2 dp_{2t}} P_{\pi\pi\to f_2} \,, \tag{24}$$

where $dN^\pi/(d\mathrm{y}dp_t)$ is number of pions per interval of rapidity and transverse momentum. Here we use the Tsallis parametrization of π^0 at $\sqrt{s} = 7$ TeV (Abelev et al.); Above $P_{\pi\pi\to f_2}$ parametrizes probability of the $\pi^+\pi^-$ and $\pi^0\pi^0$ formation of $f_2(1270)$ as well as probability of its survival in a dense hadronic system. It will be treated here as a free parameter adjusted to the $f_2(1270)$ data from the Lee thesis. The distribution $dN^\pi/(d\mathrm{y}dp_t)$ is obtained then by calculating y and p_t of the $f_2(1270)$ meson and binning in these variables. The effect of hadronic rescattering is also discussed recently by Utheim and Sjöstrand.

Numerical Results

To convert to the number of $f_2(1270)$ mesons per event (ALICE data) we use the following relation:

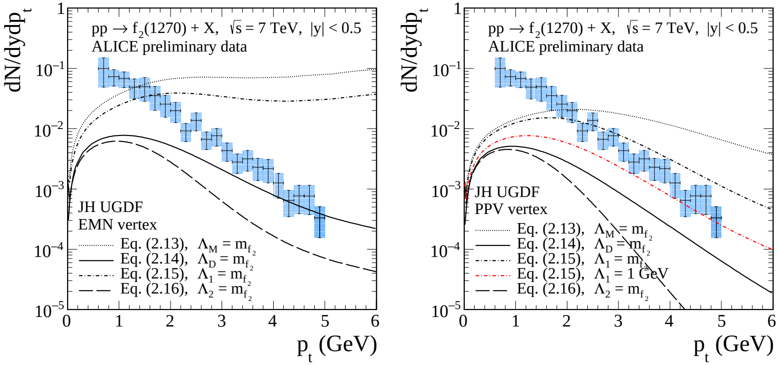
$$\frac{dN}{dp_t} = \frac{1}{\sigma_{\rm inel}} \frac{d\sigma}{dp_t} \,. \tag{25}$$

The inelastic cross section for $\sqrt{s} = 7$ TeV was measured at the LHC and is:

$$\sigma_{\rm inel} = 73.15 \pm 1.26\,({\rm syst.})\,{\rm mb}\,, \tag{26}$$
$$\sigma_{\rm inel} = 71.34 \pm 0.36\,({\rm stat.}) \pm 0.83\,({\rm syst.})\,{\rm mb}\,, \tag{27}$$

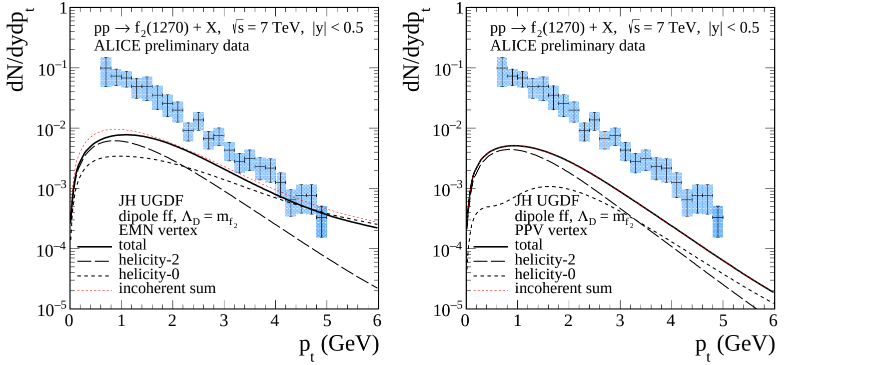
as obtained by the TOTEM (Antchev et al.) and ATLAS (Aad et al.) collaborations, respectively. We take $\sigma_{\rm inel} = 72.5$ mb.

Numerical Results



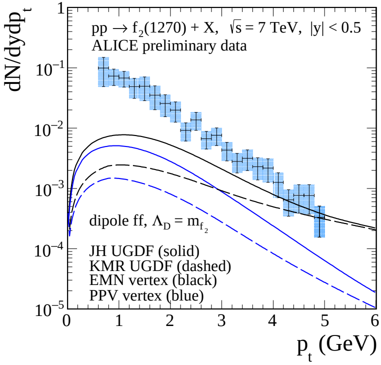
Rysunek: The $f_2(1270)$ meson transverse momentum distributions at $\sqrt{s} = 7$ TeV and $|\mathrm{y}| < 0.5$. The preliminary ALICE data from Lee thesis. The results for the EMN (left panel) and PPV (right panel) $g^* g^* \to f_2(1270)$ vertex for different $F(Q_1^2, Q_2^2)$ ff are shown. In this calculation the JH UGDF was used.

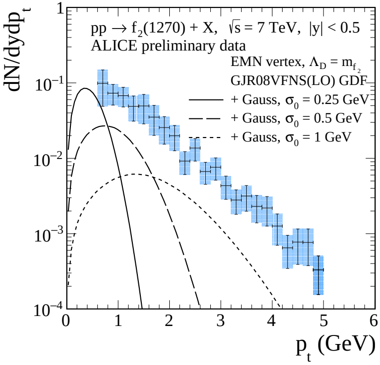
Numerical Results



Rysunek: The $f_2(1270)$ meson transverse momentum distributions at $\sqrt{s} = 7$ TeV and $|\mathrm{y}| < 0.5$ together with the preliminary ALICE data. Shown are the results calculated in the two approaches, EMN (left panel) and PPV (right panel) vertices, and the helicity-0 and -2 components separately and their coherent sum (total). Here we used dipole form factor parametrization with $\Lambda_D = m_{f_2}$. The dotted line corresponds to the contribution for the

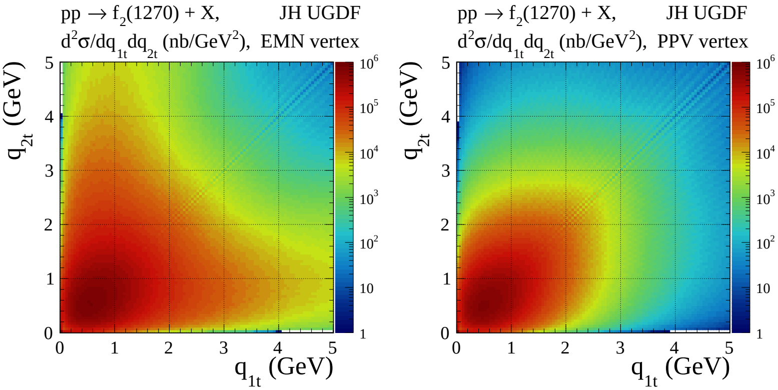
Numerical Results





Rysunek: The $f_2(1270)$ meson transverse momentum distributions at $\sqrt{s} = 7$ TeV and $|y| < 0.5$ together with the preliminary ALICE data from the Lee thesis. In the left panel two different UGDFs, JH (solid lines) and KMR (dashed lines), are shown. In the right panels the dependence on the Gaussian smearing parameter σ_0 for GJR08VFNS(LO) GDF. Here the EMN vertex and the dipole form factor with $\Lambda_D = m_{f_2}$ were used.

Numerical Results



Rysunek: Two-dimensional distributions in gluon transverse momenta for the JH UGDF and for two $g^*g^*f_2(1270)$ vertex prescription: EMN (left panel) and PPV (right panel). Here we used the dipole form factor with $\Lambda_D = m_{f_2}$.

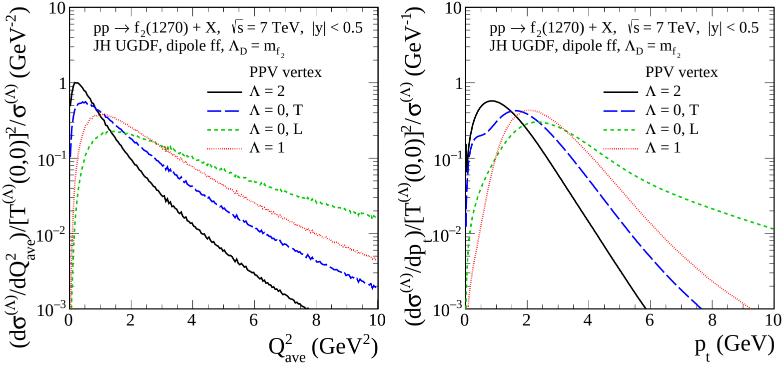
Numerical Results

We have checked that

$$\frac{d^2\sigma_{\mathrm{EMN}}}{dq_{1t}dq_{2t}}\left(\frac{d^2\sigma_{\mathrm{PPV}}}{dq_{1t}dq_{2t}}\right)^{-1}\to 1\,,\quad \mathrm{for}\;\; q_{1t}\to 0\;\;\mathrm{and}\;\; q_{2t}\to 0\,, \tag{28}$$

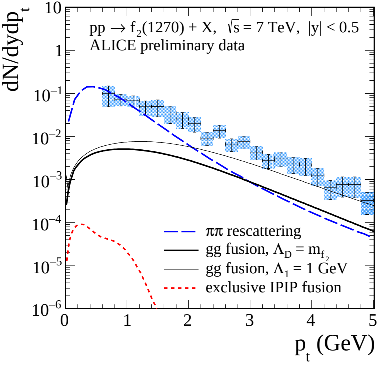
i.e. the two vertices are equivalent for both on-shell photons.

Numerical Results



Rysunek: Normalized distributions in averaged virtuality $Q^2_{\rm ave} = (Q_1^2 + Q_2^2)/2$ (left panel) and in the $f_2(1270)$ meson transverse momentum (right panel). Results for different $\Lambda = 0, 1, 2$ terms in the $g^* g^* f_2$ vertex using the same form of $F^{(\Lambda)}(Q_1^2, Q_2^2)$ with $\Lambda_D = m_{f_2}$ are shown. JH UGDF was used.

Numerical Results



Rysunek: Results for the $\pi\pi$ rescattering mechanism (long-dashed line), for the gg-fusion mechanism (solid lines), and for the $\mathbb{PP}$ fusion mechanism (dotted line) together with the preliminary ALICE data. We show maximal allowed contribution from the $\pi\pi$ rescattering. The results for gg-fusion contributions were calculated for JH UGDF and for the PPV vertex [only helicity-2 and helicity (0, T) terms] and for two form factor functions (top

Comment on exclusive $pp \to ppf_2(1270)$ process

We present the Born result (without absorptive corrections important only when restricting to purely exclusive processes) for the $pp \to ppf_2(1270)$ process proceeding via the pomeron-pomeron fusion mechanism calculated in the tensor-pomeron approach.
In the calculation we take the $\mathbb{P} - \mathbb{P} - f_2(1270)$ coupling parameters from Lebiedowicz-Nachtmann-Szczurek 2018.

Conclusions

- We have performed calculation of the gluon-gluon fusion contribution to inclusive $f_2(1270)$ production.
- k_t-factorization approach with the KMR and JH UGDFs has been applied.
- the $g^* g^* f_2(1270)$ couplings has been obtained from the $\gamma^* \gamma^* f_2(1270)$ couplings
- Both MNE and PPV set of vertices have been used.
  Helecity 0 and 2 only
  They are equivalent for on-shell photons (gluons).
  The equivalence relation has been found.
- The coupling constants were found from:
  the $\gamma\gamma \to f_2(1270) \to \pi\pi$ reaction.
- Form factors are unknown. They were parametrized, and the corresponding parameters adjusted to the $pp \to f_2(1270)$ preliminary ALICE data (Lee thesis)

Conclusions

- FF not included in earlier calculations of Jeon which would be in conflict with the ALICE data.
- Only transverse momentum distributions for $p_t > 3$ GeV could be explained as due to gluon-gluon fusion.
  Very difficult to explain low p_t part.
- A toy model for $\pi\pi$ rescattering was discussed.
  The model can explain low-p_t data by adjusting one parameter and cannot explain larger-p_t data.
- $pp \to ppf_2(1270)$ was included but its contribution is very small.
- Form factors were parametrized here but should be calculated in future with realistic $q\bar{q}$ wave functions.