Epiphany2017

Some new aspects of quarkonia production at the LHC

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Introduction

- J/ψ the lightest quarkonium.
  Relatively large cross section.
- J/ψ a good probe of quark-gluon plasma.
- Long-standing problems in microscopic description of J/ψ distributions.
  Calculated cross sections much smaller than experimental ones.
- Color octet model was a "solution"
  But it was (is) rather fitted to the data.
- Higher-order collinear or k_t-factorization non-relativistic pQCD lead to larger cross sections.
- There is less and less room for color octet contributions.
- Do we need at all color-octet contributions ?
  Not clear in my opinion.

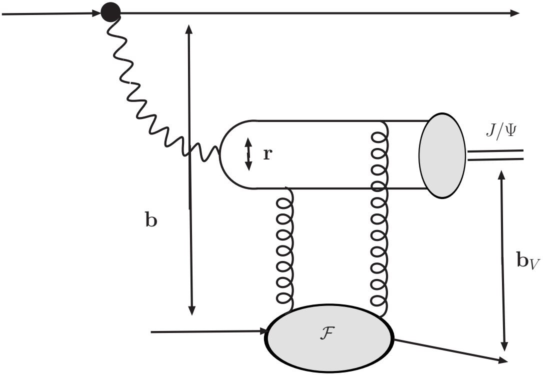
Contents

1. Exclusive $pp \to ppJ/\psi$.
2. Semi-exclusive production of J/ψ.
3. Inclusive forward production of J/ψ.
4. Double J/ψ production.

Literature

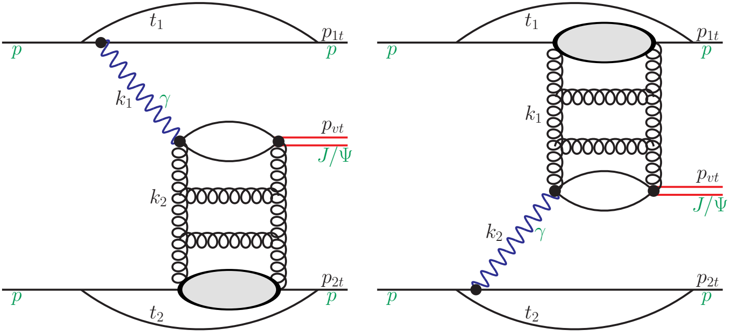
The presented work is based on our recent analyses:
A. Cisek, W. Schäfer and A. Szczurek, “Exclusive photoproduction of charmonia in $\gamma p \to Vp$ and $pp \to pVp$ reactions within k_t-factorization approach”,
JHEP **1504** (2015) 159. Phys. Rev. **D93** (2016) 074014.
A. Cisek, W. Schäfer and A. S., "Semiexclusive production of J/ψ mesons in proton-proton collisions", arXiv:1611.08210.
A. Cisek and A. S., a paper in preparation
A. Cisek, W. Schäfer and A.S., a paper in preparation

$pp \to ppJ/\psi$



A. Cisek, W. Schäfer and A. Szczurek, JHEP **1504** (2015) 159.

$pp \to ppJ/\psi$



The interference term vanishes for rapidity distributions in Born approximation
see W. Schäfer and A. Szczurek, Phys. Rev. **D76** (2007) 094014.

$\gamma p \to J/\psi p$

Imaginary part of the forward $\gamma p \to J/\psi p$ amplitude

$$\Im m\, \mathcal{M}_T(W, \Delta^2 = 0, Q^2 = 0) = W^2 \frac{c_V \sqrt{4\pi\alpha_{em}}}{4\pi^2}\, 2 \int_0^1 \frac{dz}{z(1-z)} \int_0^\infty \pi dk^2 \psi_V(z,$$

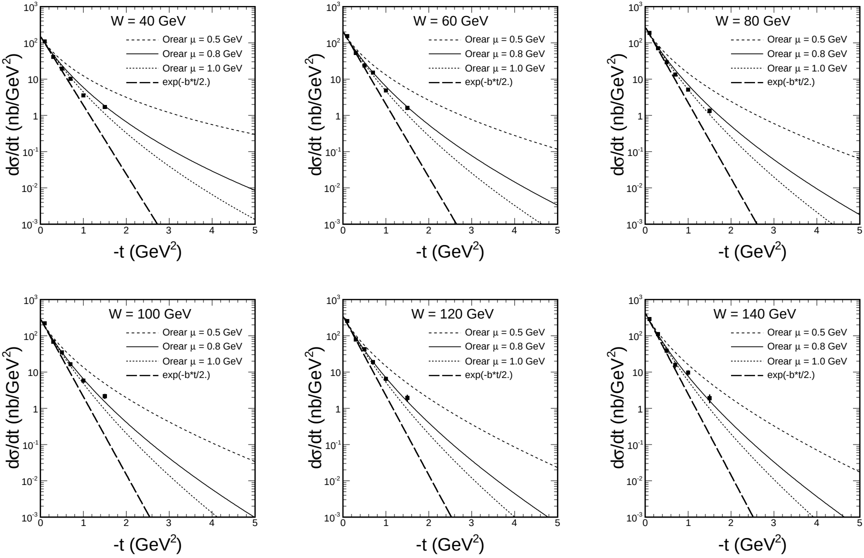
$$\int_0^\infty \frac{\pi d\kappa^2}{\kappa^4} \alpha_S(q^2) \mathcal{F}(x_{\text{eff}}, \kappa^2) \Big(A_0(z, k^2)\, W_0(k^2, \kappa^2) + A_1(z, k^2)\, W_1(k^2, \kappa^2)$$

dependence on the meson wave function and UGDF
No wave functions in collinear calculations (Jones, Martin, Ryskin)

The full amplitude, at finite momentum transfer parametrized:

$$\mathcal{M}(W, \Delta^2) = (i + \rho)\, \Im m \mathcal{M}(W, \Delta^2 = 0, Q^2 = 0)\, \exp(-B(W)\Delta^2/2)\,, \quad ($$

$\gamma p \to J/\psi p$



Deviations from exponential t dependence

$pp \to ppJ/\psi$

In the Born approximation:

$$\begin{aligned} & \mathcal{M}^{\lambda_1\lambda_2\to\lambda_1'\lambda_2'\lambda_V}_{h_1h_2\to h_1h_2V}(s,s_1,s_2,t_1,t_2) = \mathcal{M}_{\gamma\mathbf{P}} + \mathcal{M}_{\mathbf{P}\gamma} \\ & = \langle p_1',\lambda_1'|J_\mu|p_1,\lambda_1\rangle \epsilon_\mu^*(q_1,\lambda_V)\frac{\sqrt{4\pi\alpha_{em}}}{t_1}\mathcal{M}^{\lambda_{\gamma^*}\lambda_2\to\lambda_V\lambda_2}_{\gamma^*h_2\to Vh_2}(s_2,t_2,Q_1^2) \\ & +\langle p_2',\lambda_2'|J_\mu|p_2,\lambda_2\rangle \epsilon_\mu^*(q_2,\lambda_V)\frac{\sqrt{4\pi\alpha_{em}}}{t_2}\mathcal{M}^{\lambda_{\gamma^*}\lambda_1\to\lambda_V\lambda_1}_{\gamma^*h_1\to Vh_1}(s_1,t_1,Q_2^2)\,. \end{aligned} \tag{3}$$

$pp \to ppJ/\psi$

Then, the amplitude of Eq. (3) for the emission of a photon of transverse polarization λ_V, and transverse momentum $\boldsymbol{q}_1 = -\boldsymbol{p}_1$ can be written as:

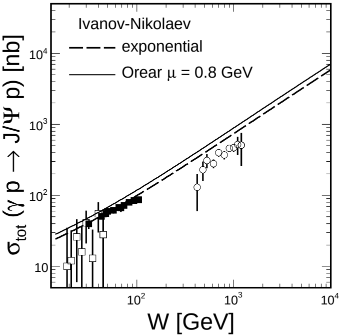
$$\langle p_1', \lambda_1' | J_\mu | p_1, \lambda_1 \rangle \epsilon^*_\mu(q_1, \lambda_V)$$

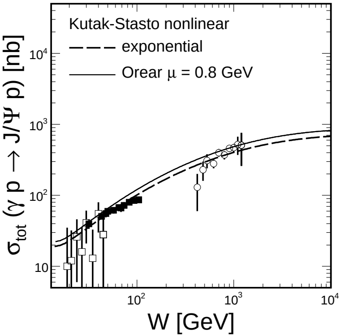
$$= \frac{(\boldsymbol{e}^{*(\lambda_V)}\boldsymbol{q}_1)}{\sqrt{1-z_1}} \frac{2}{z_1} \chi^\dagger_{\lambda'} \Big\{ F_1(Q_1^2) - \frac{i\kappa_p F_2(Q_1^2)}{2m_p} (\boldsymbol{\sigma}_1 \cdot [\boldsymbol{q}_1, \boldsymbol{n}]) \Big\} \chi_\lambda \, . \qquad (4)$$

F_1 - Dirac em ff

F_2 - Pauli em ff (new)

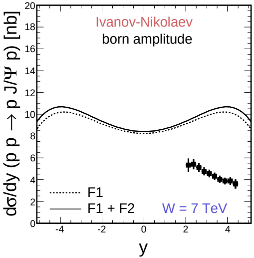
$pp \rightarrow ppJ/\psi$

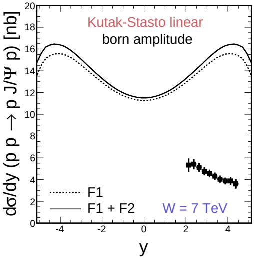




HERA data at W $\sim$ 100-200 GeV
LHCb quasi-data at W $\sim$ 1 TeV

$pp \to ppJ/\psi$


Ivanov-Nikolaev
born amplitude
F1
F1 + F2
W = 7 TeV
dσ/dy (p p → p J/Ψ p) [nb]
y
0
2
4
6
8
10
12
14
16
18
20
-4
-2
0
2
4


Kutak-Stasto linear
born amplitude
F1
F1 + F2
W = 7 TeV
dσ/dy (p p → p J/Ψ p) [nb]
y
0
2
4
6
8
10
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20
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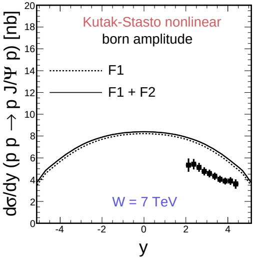
4


Kutak-Stasto nonlinear
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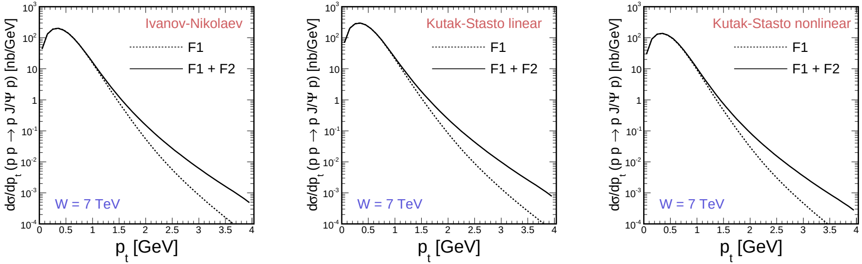
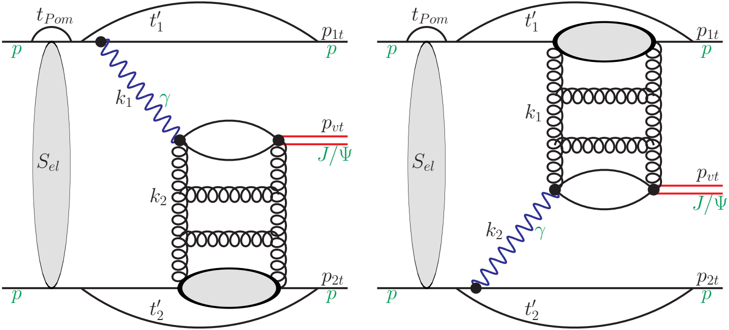
dσ/dy (p p → p J/Ψ p) [nb]
y
0
2
4
6
8
10
12
14
16
18
20
-4
-2
0
2
4

$pp \to ppJ/\psi$


dσ/dp_t (p p → p J/Ψ p) [nb/GeV]
p_t [GeV]
Ivanov-Nikolaev
Kutak-Stasto linear
Kutak-Stasto nonlinear
F1
F1 + F2
W = 7 TeV
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
0
0.5
1
1.5
2
2.5
3
3.5
4

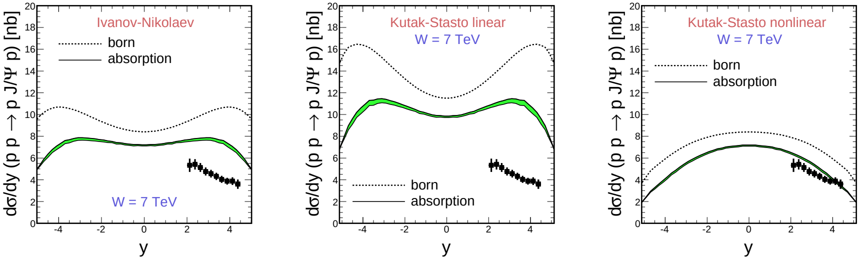
$pp \to ppJ/\psi$



Survival factor depends on the phase space point !

$pp \to ppJ/\psi$

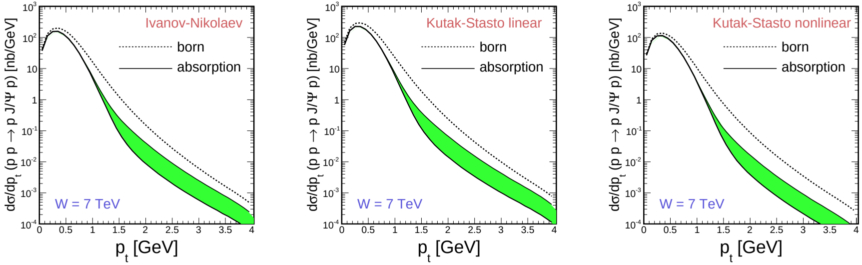
with absorption



similar for ψ'

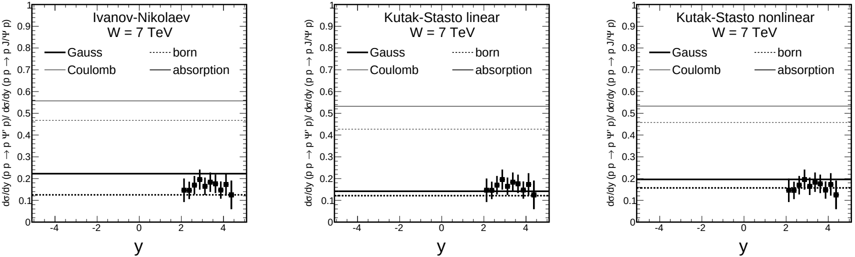
$pp \to ppJ/\psi$

with absorption



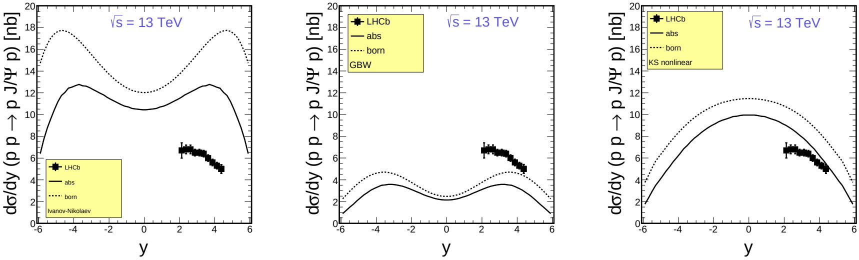
similar for ψ'

ψ' to J/ψ ratio



Gauss WF much better than Coulomb WF

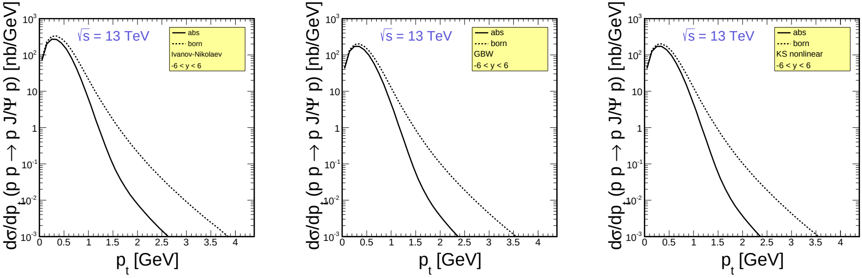
Exclusive J/ψ, Run 2



new, not yet published

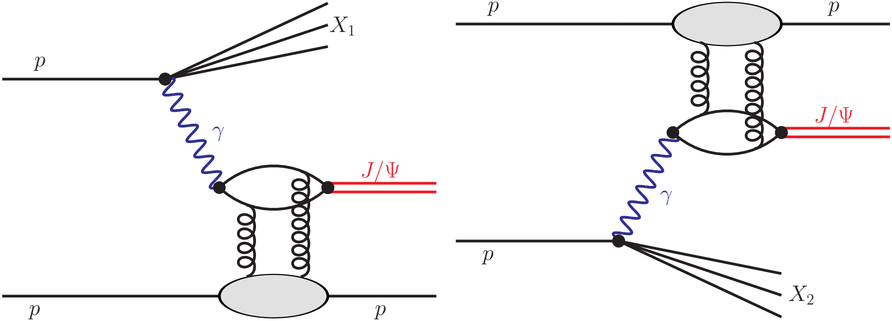
Exclusive J/ψ, Run 2

our predictions



new, not yet published

Semiexclusive production, electromagnetic excitation



One-side excitation only

A. Cisek, W. Schäfer and A. S., arXiv:1611.08210

Electromagnetic excitation

The cross section for such processes can be written as:

$$\frac{d\sigma(pp \to XVp; s)}{dy d^2\boldsymbol{p} dM_X^2} = \int \frac{d^2\boldsymbol{q}}{\pi \boldsymbol{q}^2} \mathcal{F}^{(\mathrm{inel})}_{\gamma/p}(z_+, \boldsymbol{q}^2, M_X^2) \frac{1}{\pi} \frac{d\sigma^{\gamma^* p \to Vp}}{dt}(z_+ s, t = -(\boldsymbol{q} - \boldsymbol{p})^2$$

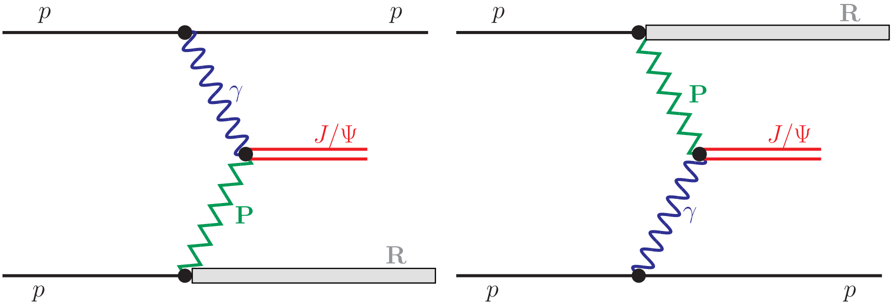
where $z_\pm = e^{\pm y} \sqrt{(\boldsymbol{p}^2 + m_V^2)/s}$.

$$\mathcal{F}^{(\mathrm{inel})}_{\gamma/p}(z, \boldsymbol{q}^2, M_X^2) = \frac{\alpha_{\mathrm{em}}}{\pi}(1 - z)\theta(M_X^2 - M_{\mathrm{thr}}^2) \frac{F_2(x_{Bj}, Q^2)}{M_X^2 + Q^2 - m_p^2} \Big[\frac{\boldsymbol{q}^2}{\boldsymbol{q}^2 + z(M_X^2 - m_p^2)}$$

where

$$Q^2 = \frac{1}{1 - z}\Big[\boldsymbol{q}^2 + z(M_X^2 - m_p^2) + z^2 m_p^2\Big], x_{Bj} = \frac{Q^2}{Q^2 + M_X^2 - m_p^2}. \qquad (7)$$

Semiexclusive production, resonance diffractive excitation



One-side excitation only

Diffractive resonance contribution

We consider Jenkovszky et al. dual Regge model.

The contribution of three positive-parity baryon resonances on the nucleon trajectory are taken into account:

1. N(1680), $J = \frac{5}{2}$
2. N(2220), $J = \frac{9}{2}$
3. N(2700), $J = \frac{13}{2}$

Their contribution is accounted for by

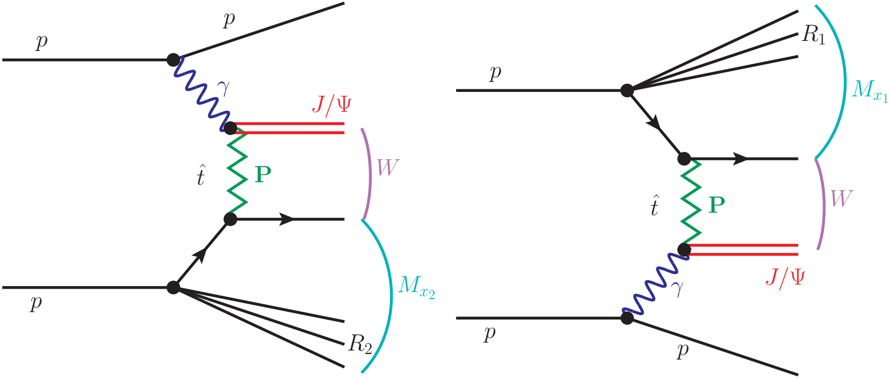
$$\Im m A(M_X^2, t) = \sum_{n=1,3} [f(t)]^{2(n+1)} \cdot \frac{\Im m\, \alpha(M_X^2)}{(J_n - \Re e\, \alpha(M_X^2))^2 + (\Im m\, \alpha(M_X^2))^2}. \tag{8}$$

Here J_n is the spin of the nth resonance, and the explicit form of the complex Regge trajectory $\alpha(M_X^2)$ as well as the form factor $f(t)$ are from Jenkovszky et al.

We can now compute the contribution from diffractive excitation of small masses from:

$$\frac{d\sigma(pp \to XVp; s)}{dy\, d^2\mathbf{p}\, dM_X^2} = \int \frac{d^2\mathbf{q}}{\pi \mathbf{q}^2} \mathcal{F}^{(\mathrm{el})}_{\gamma/p}(z_+, \mathbf{q}^2) \frac{1}{\pi} \frac{d\sigma(\gamma p \to VX)}{dt\, dM_X^2}(z_+ s) + (z_+ \leftrightarrow z_-),$$

Semiexclusive production, partonic diffractive excitation



One-side excitation only

$\mathbb{P}$ means here two-gluon exchange

Diffractive partonic excitation

We neglect transverse momenta of the photon and intial quark/antiquark. In this approximation:

$$\frac{d\sigma^{diff,partonic}_{pp\to Vj}}{dy_V dy_j d^2p_t} = \frac{1}{16\pi^2\hat{s}^2} x_1 q_{eff}(x_1,\mu_F^2) x_2 \gamma_{el}(x_2) \overline{|\mathcal{M}_{q\gamma\to Vq}|^2} + \frac{1}{16\pi^2\hat{s}^2} x_1 \gamma_{el}(x_1) x_2 q_{eff}(x_2,\mu_F^2) \overline{|\mathcal{M}_{q\gamma\to Vq}|^2} \,. \quad (10)$$

The effective “quark” distribution reads as

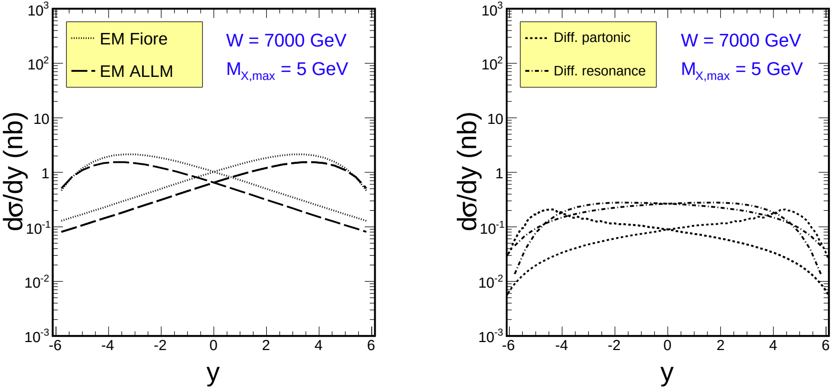
$$q_{eff}(x,\mu_F^2) = \frac{81}{16} g(x,\mu_F^2) + \Sigma_f \left[q_f(x,\mu_F^2) + \bar{q}_f(x,\mu_F^2) \right] \,. \quad (11)$$

We take $\mu_F^2 = m_V^2 + |t|$ for the factorization scale. The matrix element for the partonic subprocess is related to the corresponding t-dependence as

$$\frac{d\sigma_{\gamma q\to Vq}}{dt} = \frac{1}{16\pi\hat{s}^2} \overline{|\mathcal{M}_{\gamma q\to Vq}|^2} \,. \quad (12)$$

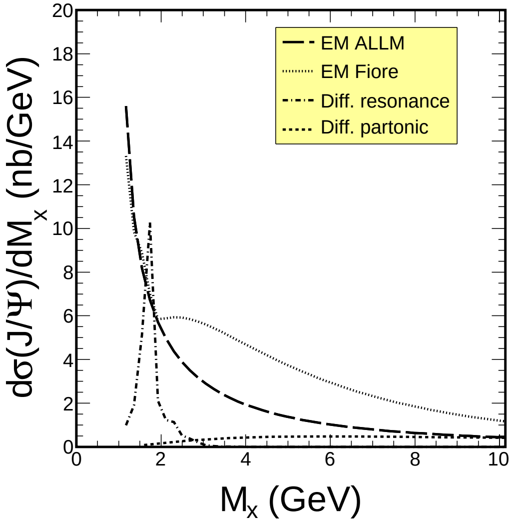
In the following we shall use a simple formula for two-gluon exchange (Ivanov et al.) where

EM vs diffractive excitation



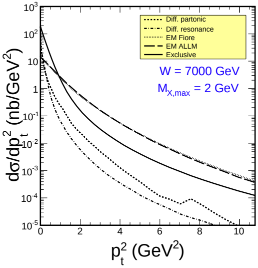
EM excitation contribution bigger than diffractive excitation contribution

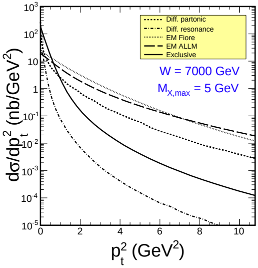
Missing mass distribution

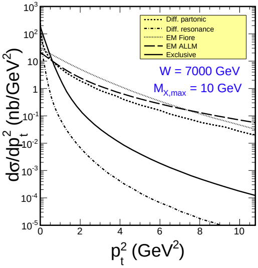


full phase space

Transverse momentum distribution for full phase space

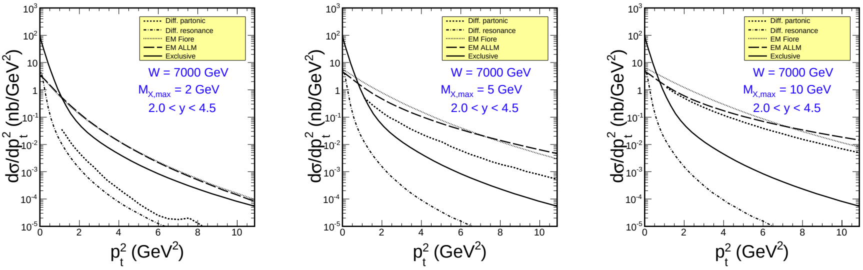






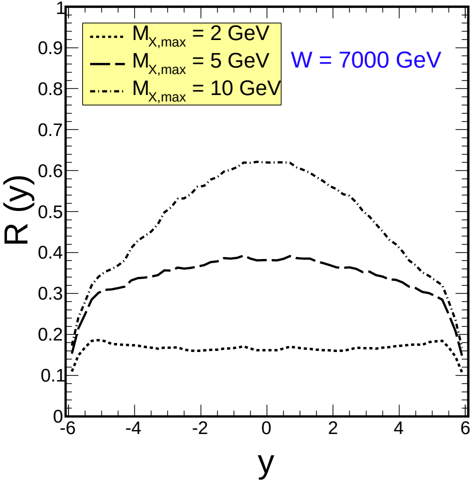
full phase space

Transverse momentum distribution for LHCb



LHCb rapidity acceptance

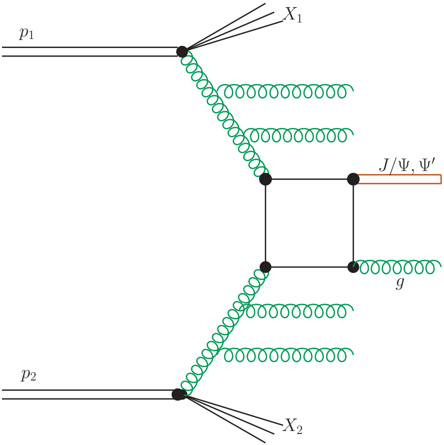
Semi-exclusive to exclusive ratio

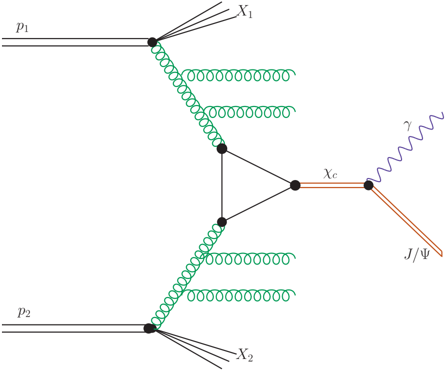


All dissociation processes

The ratio strongly depends on the range of missing masses

Inclusive J/ψ production





direct and feed down

Inclusive J/ψ (and Ψ') production

$$\frac{d\sigma(pp \to J/\psi g X)}{dy_{J/\psi} dy_g d^2p_{J/\psi,t} d^2p_{g,t}} = \frac{1}{16\pi^2 \hat{s}^2} \int \frac{d^2q_{1t}}{\pi} \frac{d^2q_{2t}}{\pi} \overline{|\mathcal{M}^{off-shell}_{g^*g^* \to J/\psi g}|^2}$$
$$\times \ \delta^2\left(\vec{q}_{1t} + \vec{q}_{2t} - \vec{p}_{H,t} - \vec{p}_{g,t}\right) \mathcal{F}_g(x_1, q_{1t}^2, \mu_F^2) \mathcal{F}_g(x_2, q_{2t}^2, \mu_F^2) \ . \quad (14)$$

The corresponding matrix element squared for the $gg \to J/\psi g$ is

$$|\mathcal{M}_{gg \to J/\psi g}|^2 \propto \alpha_s^3 |R(0)|^2 \ . \quad (15)$$

We use Baranov matrix elements

Inclusive χ_c production

In the k_t-factorization approach the leading-order cross section for the χ_c meson production can be written as:

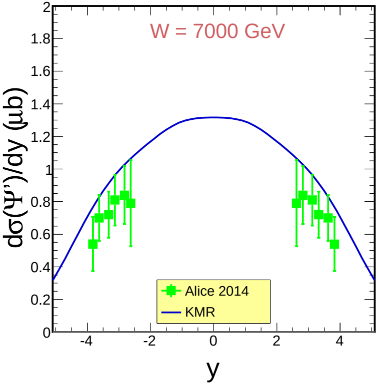
$$\sigma_{pp\to\chi_c} = \int dy d^2p_t d^2q_t \frac{1}{sx_1x_2}\frac{1}{m^2_{t,\chi_c}}\overline{|\mathcal{M}_{g^*g^*\to\chi_c}|^2} \mathcal{F}_g(x_1,q^2_{1t},\mu^2_F)\mathcal{F}_g(x_2,q^2_{2t},\mu^2_F)/4\ , \tag{16}$$

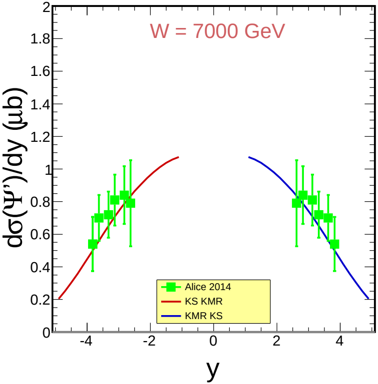
which can also be used to calculate rapidity and transverse momentum distributions of the χ_c mesons.
The matrix element squared for the $gg\to\chi_c$ subprocess is

$$|\mathcal{M}_{gg\to\chi_c}|^2 \propto \alpha_s^2|R'(0)|^2\ . \tag{17}$$

$R'(0)$ is treated as a free parameter to get correctly relative contribution of J/ψ from χ_c (was measured).
We used the matrix element taken from the Kniehl, Vasin and Saleev paper.

Ψ' production

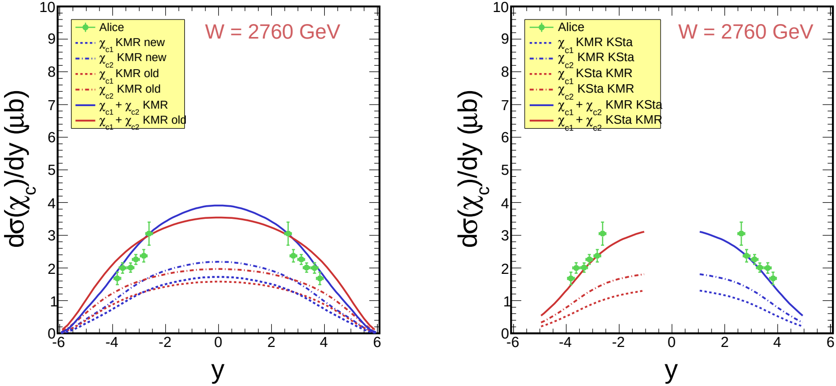




$Br(\Psi' \to J/\psi + X) = 0.574$ (PDG) - large!!!

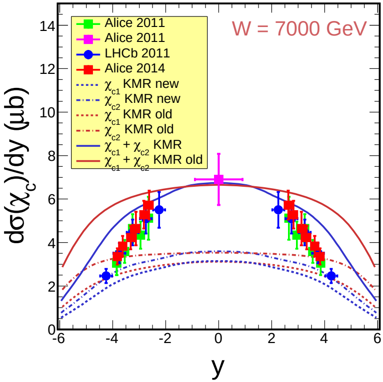
$|R_{\Psi'}(0)|^2 \approx 5/8 |R_{J/\psi}(0)|^2$ (2S versus 1S, different radial excitations)

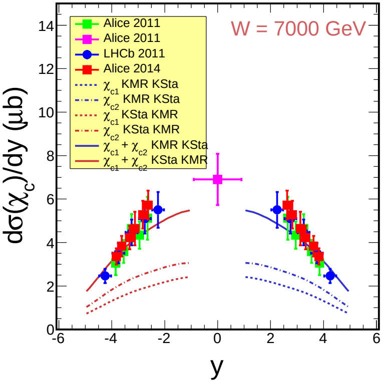
χ_c contribution to inclusive J/ψ



Arbitrary choice of $R'(0)$
Both KMR and nonlinear KS acceptable

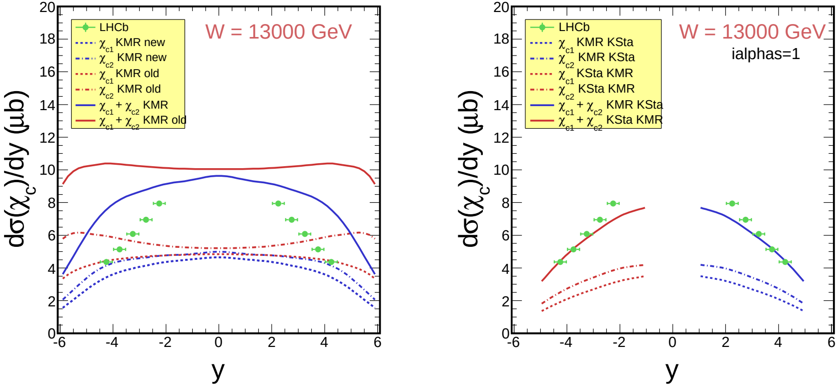
χ_c contribution to inclusive J/ψ





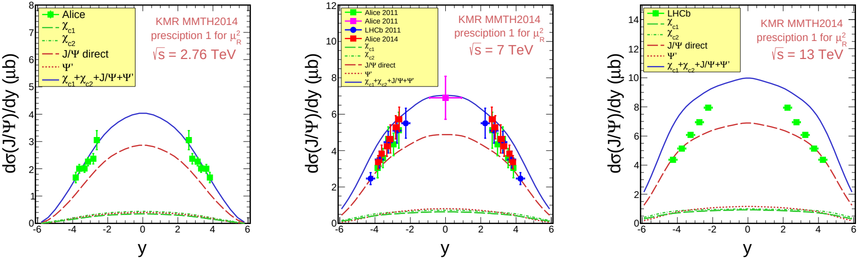
Arbitrary choice of $R'(0)$
Only nonlinear KS acceptable

χ_c contribution to inclusive J/ψ



Arbitrary choice of $R'(0)$
Only nonlinear KS acceptable

Energy dependence of J/ψ production



direct + $\chi_c \to J/\psi + \gamma$ + $\psi' \to J/\Psi + X$

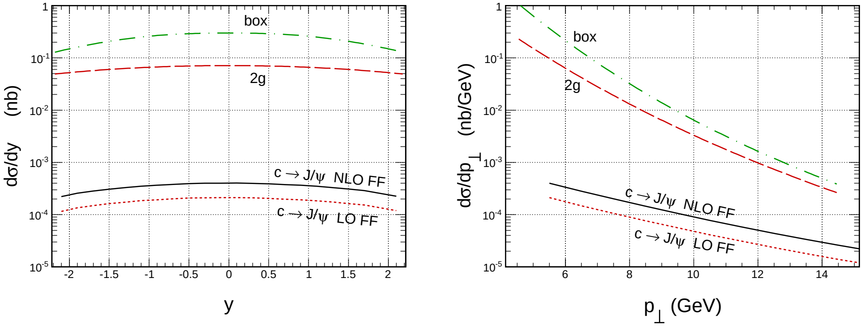
KMR UGDF (closely related to collinear GDF)

Certain choice of renormalization scales ?

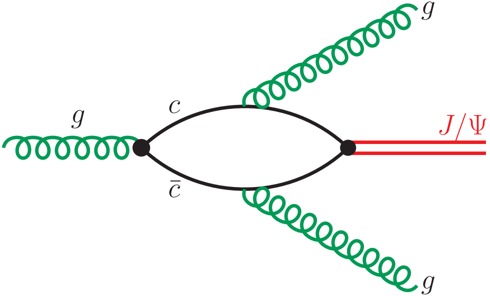
Sign of the onset of saturation ?

Missing mechanisms ?

$c \to J/\psi$ fragmentation



gluon singlet fragmentation



status nascendi

gluon singlet fragmentation

We consider decay of a virtual (time-like) gluon:
$g^*(k_1) \to J/\psi(p_\psi) + g(k_2) + g(k_3)$

$$dD(g^* \to \psi gg) = \frac{1}{(2\pi)^6}\frac{1}{32m_g^6}|\mathcal{M}(g^* \to \psi gg)|^2 dm_g^2 d\Omega_\psi d\phi ds_2 ds_3 \ , \tag{18}$$

where Ω_ψ and ϕ - orientation of the decay frame.
We define:

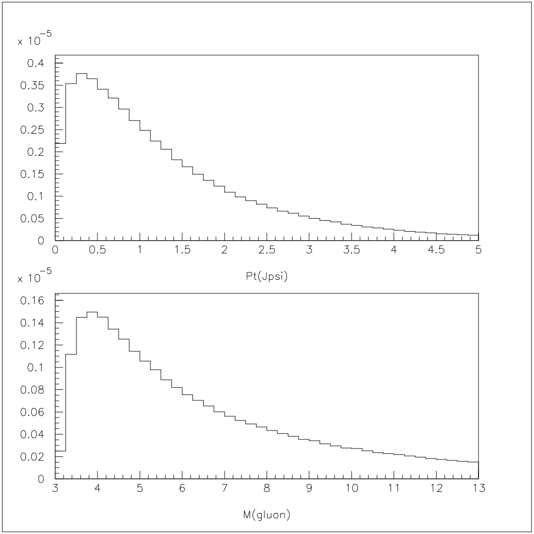
$$z = \frac{E_\psi + p_{\psi,z}}{E_1 + k_{1,z}} \tag{19}$$

Then conventional fragmentation function:

$$D(z) = \int D(g^* \to \psi gg)\delta(z - p_\psi^+/k_1^+) dm_g^2 d\Omega_\psi d\phi ds_2 ds_3 \ . \tag{20}$$

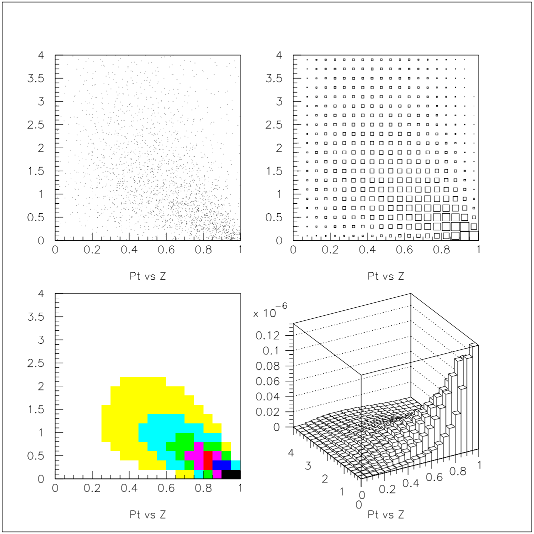
Decay matrix element is calculated.

$g^* \to J/\psi gg$ fragmentation functions



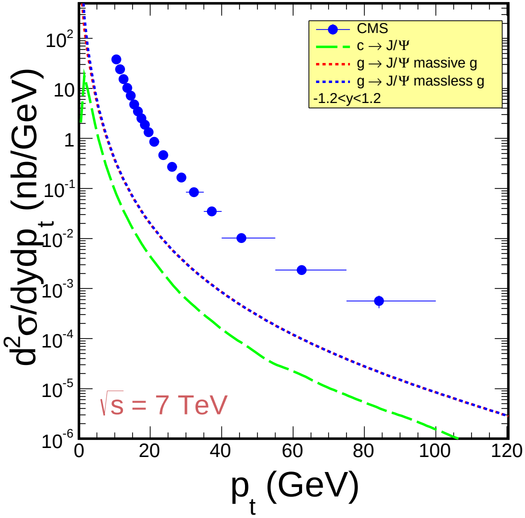
Sergey Baranov

$g^* \rightarrow J/\psi gg$ fragmentation functions



Sergey Baranov

fragmentation contributions against experimental data



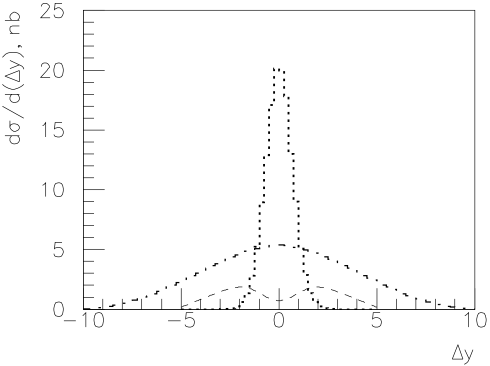
only leading gluon included (include parton showers)

$pp \to J/\psi J/\psi$

New data become available recently:

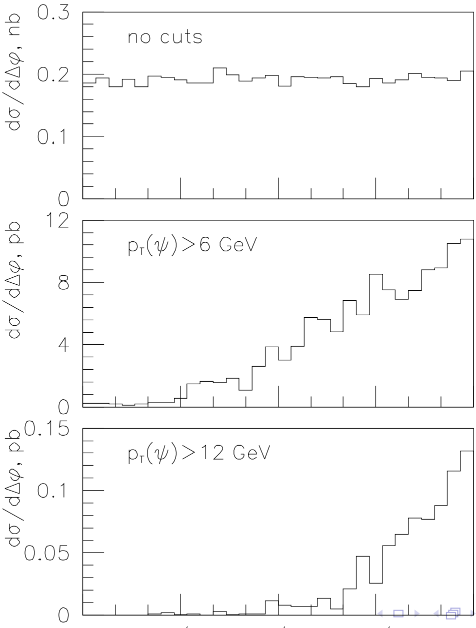
- Tevatron D0 data for $\sqrt{s}$ = 1.96 TeV (small σ_{eff} obtained)
- LHCb data ($\sqrt{s}$ = 7 TeV)
- CMS data for $\sqrt{s}$ = 8 TeV (running cuts, difficult to interprete)
- preliminary ATLAS data for $\sqrt{s}$ = 8 TeV (will be dicussed here)

$pp \to J/\psi J/\psi$, LHCb

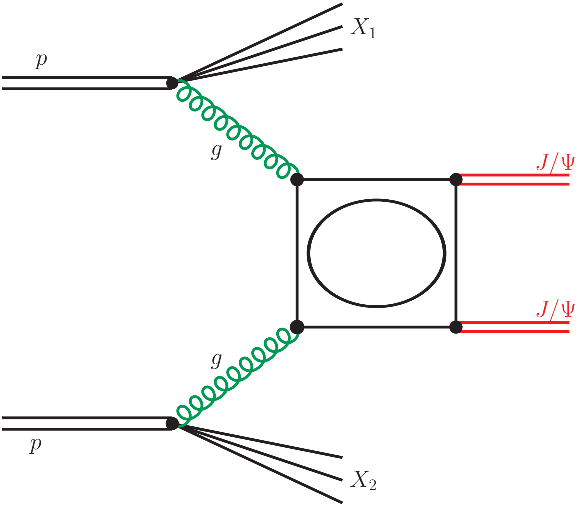


S.P. Baranov, A.M. Snigirev, N.P. Zotov, A. Szczurek and W. Schäfer, "Interparticle correlations in the production of J/ψ pairs in proton-proton collisions", Phys. Rev. **D87** (2013) 034035.

$pp \to J/\psi J/\psi$, LHCb

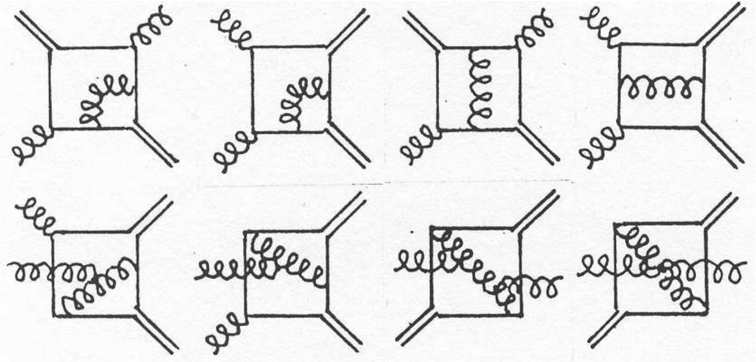


$pp \to J/\psi J/\psi$, box



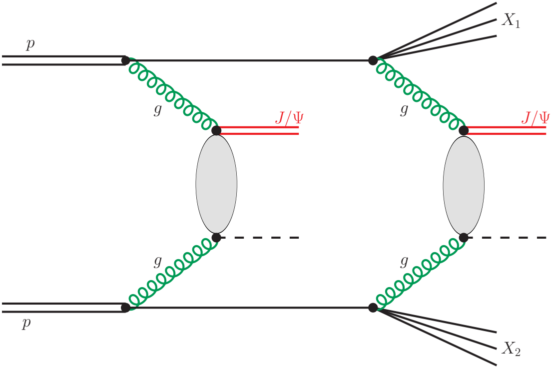
20 diagrams, box ($O(\alpha_s^4)$), $\sigma \propto |R(0)|^4$.

$pp \to J/\psi J/\psi$, box



only some are shown

$pp \to J/\psi J/\psi$, double parton scattering



DPS ($O(\alpha_s^6)$)
But enhanced by higher powers of gluon distributions $g_1^2 g_2^2$ at high energy.

$pp \to J/\psi J/\psi$, box contributions

In k_t-factorization approach:

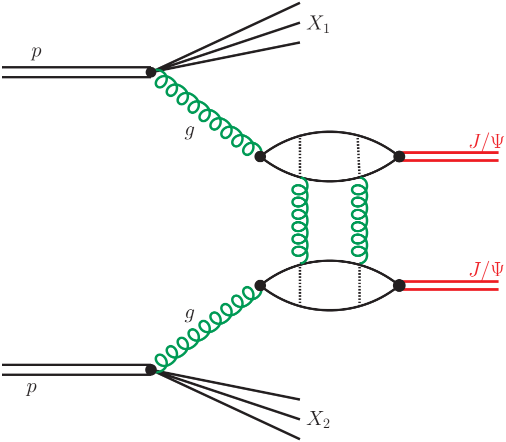
$$\frac{d\sigma(pp \to J/\psi J/\psi X)}{dy_{V_1} dy_{V_2} d^2p_{V_1,t} d^2p_{V_2,t}} = \frac{1}{16\pi^2 \hat{s}^2} \int \frac{d^2q_{1t}}{\pi} \frac{d^2q_{2t}}{\pi} \overline{|\mathcal{M}^{off-shell}_{g^*g^* \to J/\psi J/\psi}|^2}$$
$$\times \; \delta^2\left(\vec{q}_{1t} + \vec{q}_{2t} - \vec{p}_{V_1,t} - \vec{p}_{V_2,t}\right) \mathcal{F}_g(x_1, q_{1t}^2, \mu_F^2) \mathcal{F}_g(x_2, q_{2t}^2, \mu_F^2) \; . \quad (21)$$

The corresponding matrix elements squared for the $gg \to J/\psi J/\psi$ (box) is

$$|\mathcal{M}_{gg \to J/\psi J/\psi}|^2 \propto \alpha_s^4 |R(0)|^4 \; . \quad (22)$$

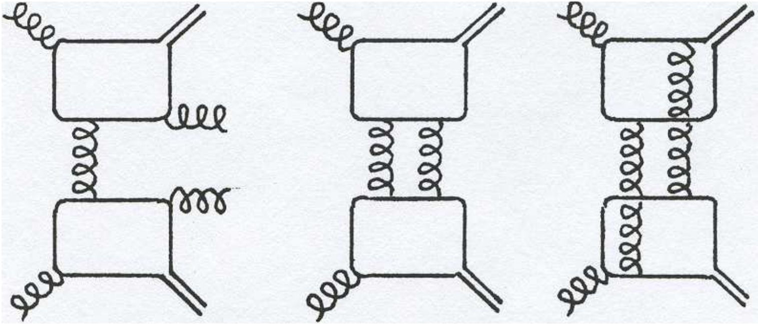
They were calculated e.g. by our collaborator S. Baranov.

$pp \to J/\psi J/\psi$, 2g exchange (NNLO)



16 diagrams, box ($O(\alpha_s^6)$) (high-order)
from $\gamma\gamma \to J/\psi J/\psi$ to $gg \to J/\psi J/\psi$ first included in:
S.P. Baranov, A.M. Snigirev, N.P. Zotov, A. Szczurek and W. Schäfer, “Interparticle correlations in the production of J/ψ pairs in proton-proton collisions”, Phys. Rev. **D87** (2013) 034035

$pp \to J/\psi J/\psi$, 2g exchange (NNLO)



and many more ...

$pp \to J/\psi J/\psi$, box contributions

Here I will show only results of collinear approach:

$$\frac{d\sigma(pp \to J/\psi J/\psi g)}{dy_{V_1} dy_{V_2} d^2p_t} = \frac{1}{16\pi^2 \hat{s}^2} \overline{|\mathcal{M}^{on-shell}_{gg \to J/\psi J/\psi}|^2} \times \; g(x_1,\mu_F^2) g(x_2,\mu_F^2) \; . \tag{23}$$

In our calculations we will use MSTW08 gluon distributions.

2g exchange mechanism

In high-energy approximation the elementary 2g-exchange process amplitude

$$\mathcal{M} \propto \hat{s} \int d^2\kappa \frac{\Phi_1^{nr}(\kappa_1)\Phi_2^{nr}(\kappa_2)}{(\kappa_1^2 + m_g^2)(\kappa_2^2 + m_g^2)} \; . \tag{24}$$

where nonrelativistic $g \to J/\psi$ impact factors:
$\Phi_k^{nr} \propto \sqrt{\Gamma_{V\to e^+e^-}}\alpha_s$ (k=1,2).
We take $m_g = 0$ (possible enhancement, but not in this corner of PS)
$\Phi_{\gamma\to V}^{nr}$ were calculated by Ginzburg,Panfil,Serbo 1987.
It was generalized to $g \to J/\psi$ transitions.

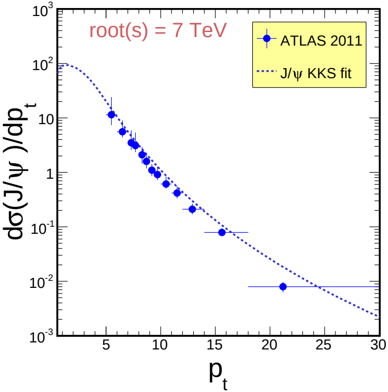
O(α_s^6) contribution !!!
(so far calculations upto O(α_s^5 in NLO) (Lansberg, Shao 2015)

experiment driven DPS

$$\frac{d\sigma(pp \to J/\psi g)}{dy_{J/\psi}dy_g d^2p_t} = \frac{1}{16\pi^2\hat{s}^2}\overline{|\mathcal{M}^{eff}_{gg\to J/\psi g}|^2} \times \quad g(x_1,\mu_F^2)g(x_2,\mu_F^2)\ . \quad (25)$$

Auxiliary final state "gluon" (could be massive).

We take parametrization by Kom-Kulesza-Stirling 2011 with MSTW08 PDF.



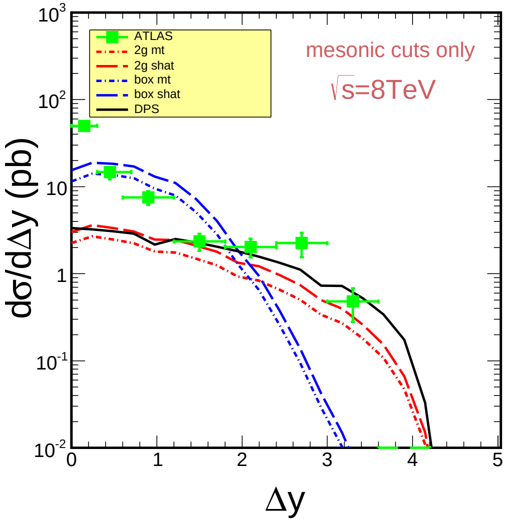
experiment driven DPS

single parton scattering → double parton scattering
We assume factorized Ansatz.

$$\frac{d\sigma}{dy_1 d^2p_{1t} dy_2 d^2p_{2t}} == \frac{1}{2\sigma_{eff}} \cdot \frac{d\sigma}{dy_1 d^2p_{1t}} \cdot \frac{d\sigma}{dy_2 d^2p_{2t}} \tag{26}$$

single J/ψ distributions were parametrized.
σ_{eff} in principle a free parameter responsible for the overlap of partonic densities of colliding protons.
σ_{eff} = 15 mb is world average for different reactions.
Much smaller value was obtained for double quarkonia production???

First results, mesonic cuts only



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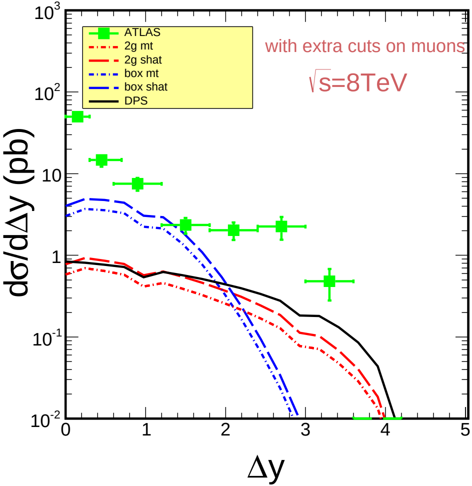
data include cuts on muons, this calculation not!

First results, with muon cuts



simultaneous decay of both J/ψ in Monte Carlo approach

-2.1 $>$ y_1, y_2 $>$ 2.1, p_t $>$ 8.5 GeV

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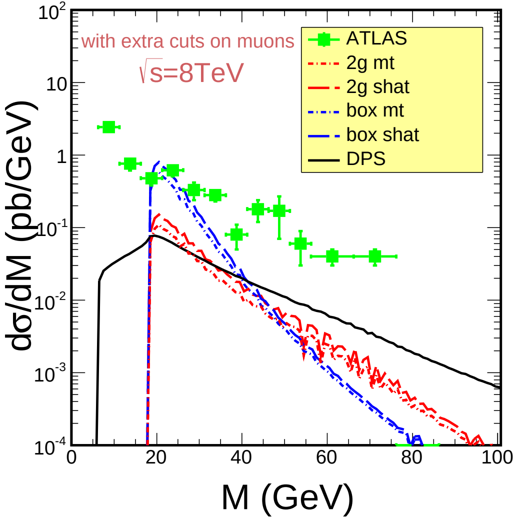
First results, with muon cuts



$p_{t,\mu} > 2.5$ GeV

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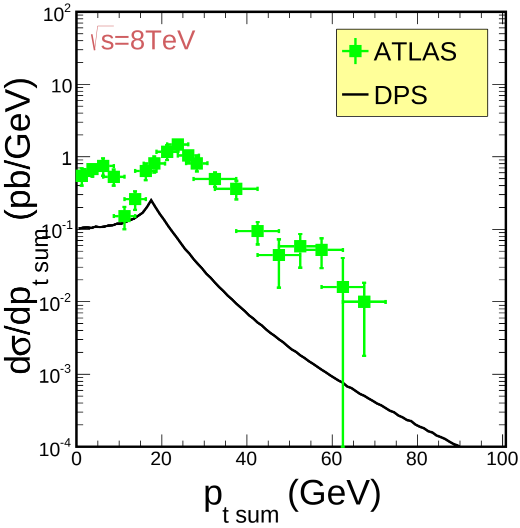
First results, with muon cuts



only DPS contribution

Conclusion, $pp \to ppJ/\psi$

There is some model dependent indication of nonlinear effects

Open problems:

- We see a signature of the onset of saturation.
- The present experiments are not exclusive.
- So far proton dissociation "extracted" in a model dependent way assuming some functional form in p_t.
- We have now better knowledge about diffractive dissociation (HERA).
- Compared to HERA there is also photon dissociation
  The contribution of electromagnetic dissociation bigger than that for diffractive dissociations.
- Interference effects due to the two diagrams were predicted. It would be nice to see modulation in ϕ_{pp} due to interference effects between the two contributing diagrams.
- CMS+TOTEM and ATLAS+ALFA could measure purely exclusive reaction and study dependences on many more variables.

Conclusion, inclusive production of J/ψ

- Several mechanisms were considered:
  - direct production ($J/\psi + g$)
  - $\chi_c \to J/\psi + \gamma$
  - $\Psi' \to J/\psi + X$
  - fragmentation ($c \to J/\psi$, $g \to J/\psi$)
- There seems to be a signiture of saturation at large energies (13 TeV) and large rapidities.
  The χ_c component is very sensitive to small x relevant for LHCb data. For comparison at low energies (2.76 GeV) our approach agrees with the data. More detailed studies are necessary to draw definite conclusions.
- Not clear how much room left for color octet contributions.
- 10 % contribution of fragmentation of gluons at large transverse momenta.

Conclusions, double J/ψ production

- We have tried several mechanisms of double quarkonium production.
- Boxes and two-gluon exchange in collinear approach.
  go to k_t-factorization (enhancement?).
- Double parton scattering calculated based on experimental data for single J/ψ production.
- Clear signature of double parton scattering mechanism.
- $\sigma_{eff} \sim 5$ mb found from experimental analyses may be too small due to two-gluon exchange contribution included in our calculation.
  The two-gluon exchange mechanism has some characteristics similar as DPS.
- There seems to be a room for other mechanisms.
  We have a list of processes to be included.
  More work clearly required.

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Thank You