
Quarkonia As Tools 2020 , Centre Paul Langevin, Aussois

Pythia and J/ψ with jets

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Quarkonia As Tools 2020
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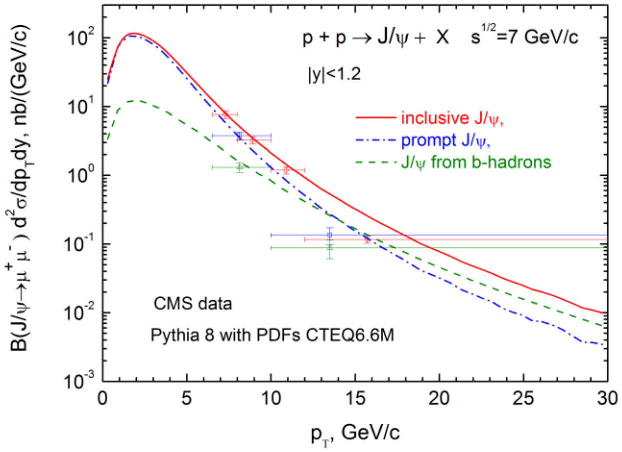
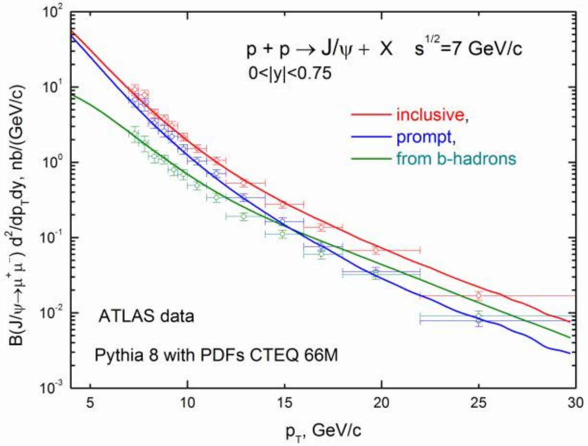
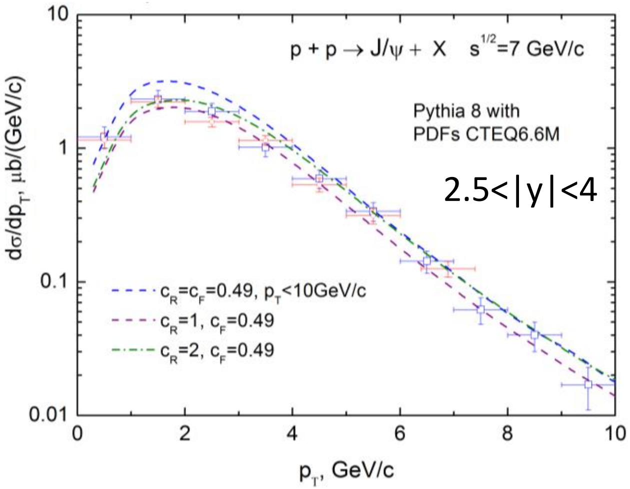
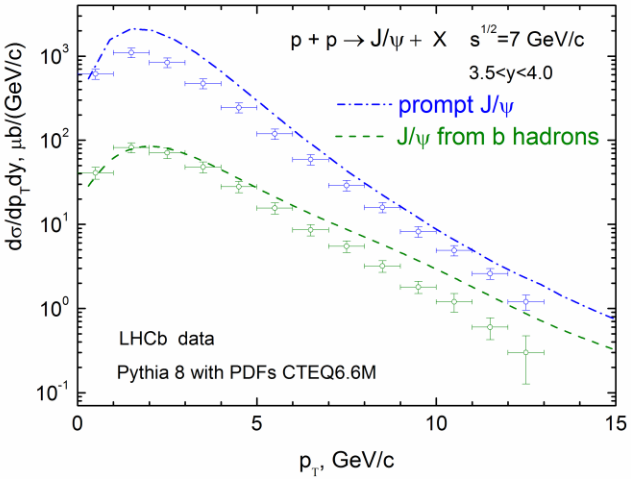
Cross sections of J/ψ production in pp collisions









Data: red circles – ALICE, blue squares – LHCB

The simulation are carried out with the help of **PYTHIA 8**

J/ψ production in junction with jets

Calculated cross section should not depend on choice
of the factorization and renormalization scales.

The aims are to calculate observables in production of J/ψ in association with jet

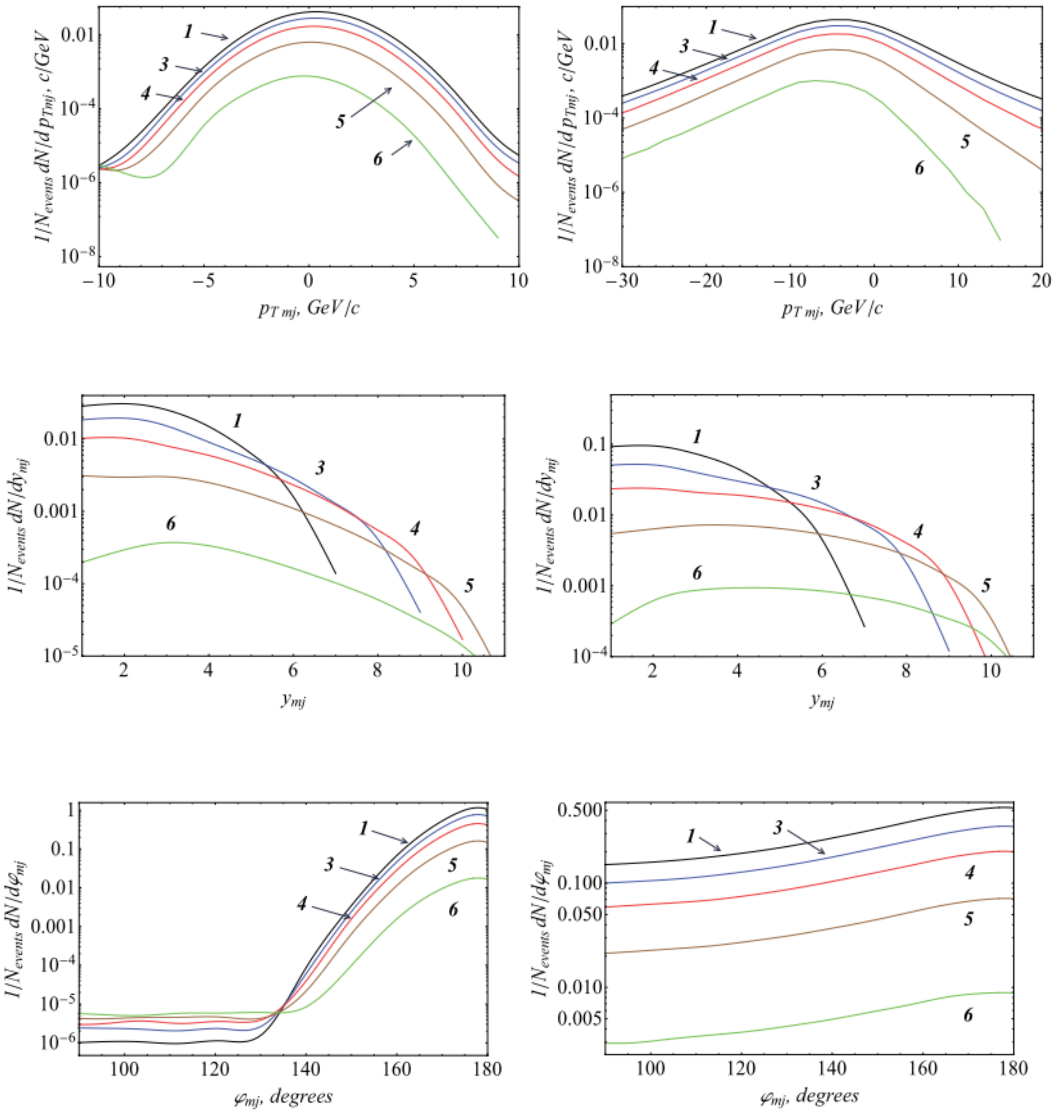
$$p + p \to J/\psi(1S) + jet + X,$$

to analyze mechanisms of the reactions, in particular MPI, time- ands pace-like parton showers under various kinematic conditions of the experiments at the LHC, and

to discuss how scale dependence could be reduced.

Correlations in J/ψ+jet production $s^{1/2}$ = 8 TeV

without ISR, FSR, MPI   with ISR, FSR, MPI



The difference of J/ψ and jet momenta is

$$p_{T\ mj} = p_{T\ J/\psi} - p_{T\ jet}\ .$$

Rapidity of J/ψ takes on values $y_{J/\psi} \in (n-1, n)$

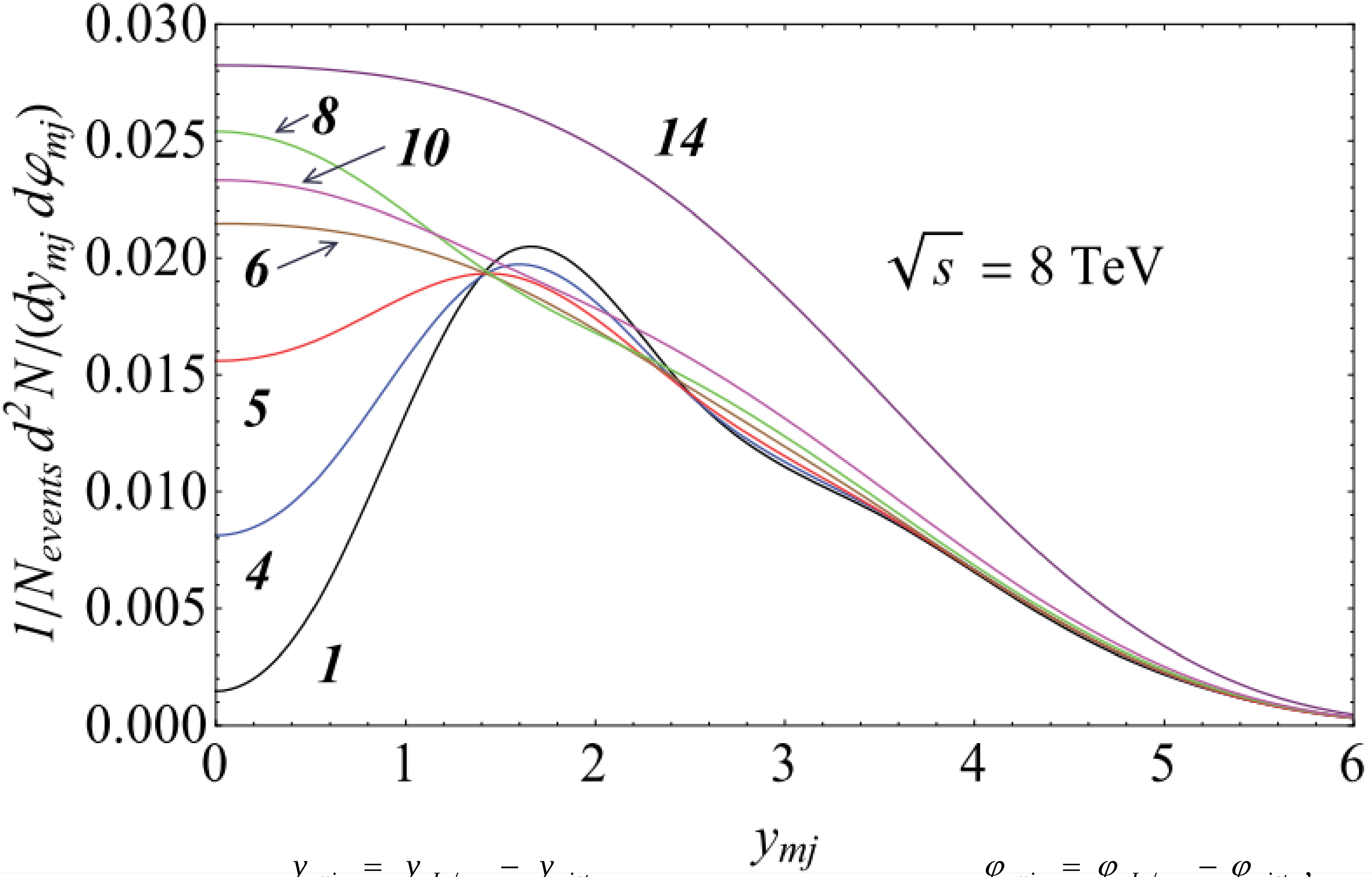
n=1 corresponds to the central area,
n=6 – to very forward region

$$y_{mj} = y_{J/\psi} - y_{jet}$$

No qualitative changes in the distributions in various J/ψ rapidity intervals are observed.

$$\varphi_{mj} = \varphi_{J/\psi} - \varphi_{jet}\ ,$$

Correlations in J/ψ+jet production



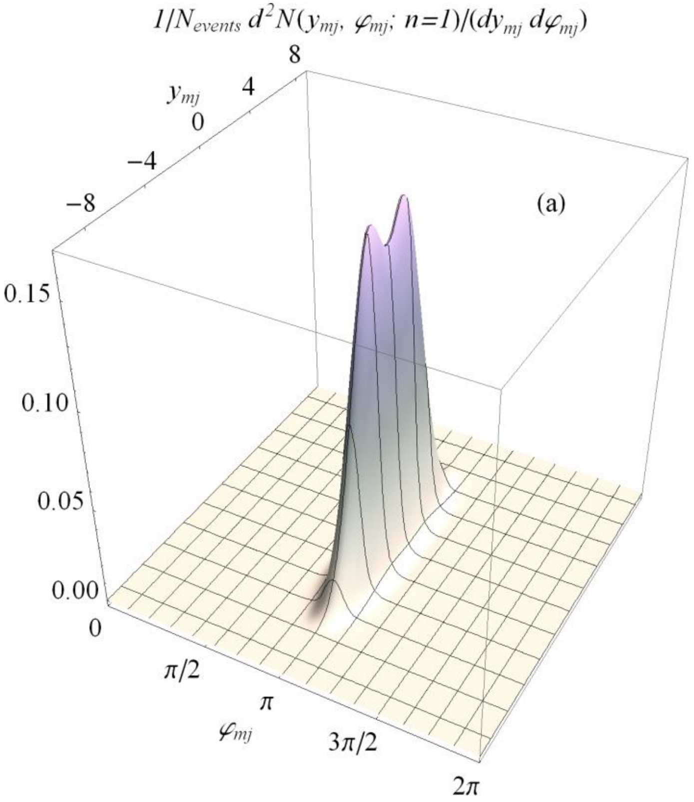
$y_{mj} = y_{J/\psi} - y_{jet}$ $\varphi_{mj} = \varphi_{J/\psi} - \varphi_{jet}$,

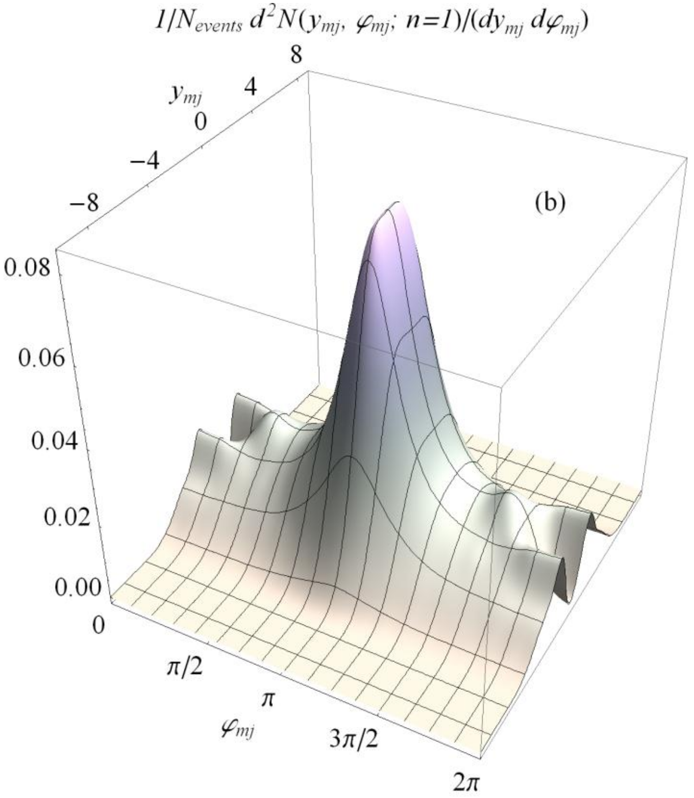
φ_{mj} is in $(\varphi_{n-1}, \varphi_n)$, where $\varphi_n = \pi n / 20$.

For $\varphi_{mj} < \varphi_6$ and $2\pi - \varphi_6 < \varphi_{mj} < 2\pi + \varphi_6$ the curves have a minima at $y_{mj} = 0$ and maxima at $y_{mj} \sim \pm(1.5...1.6)$.

The distributions are modified qualitatively.

J/ψ production in junction with jets

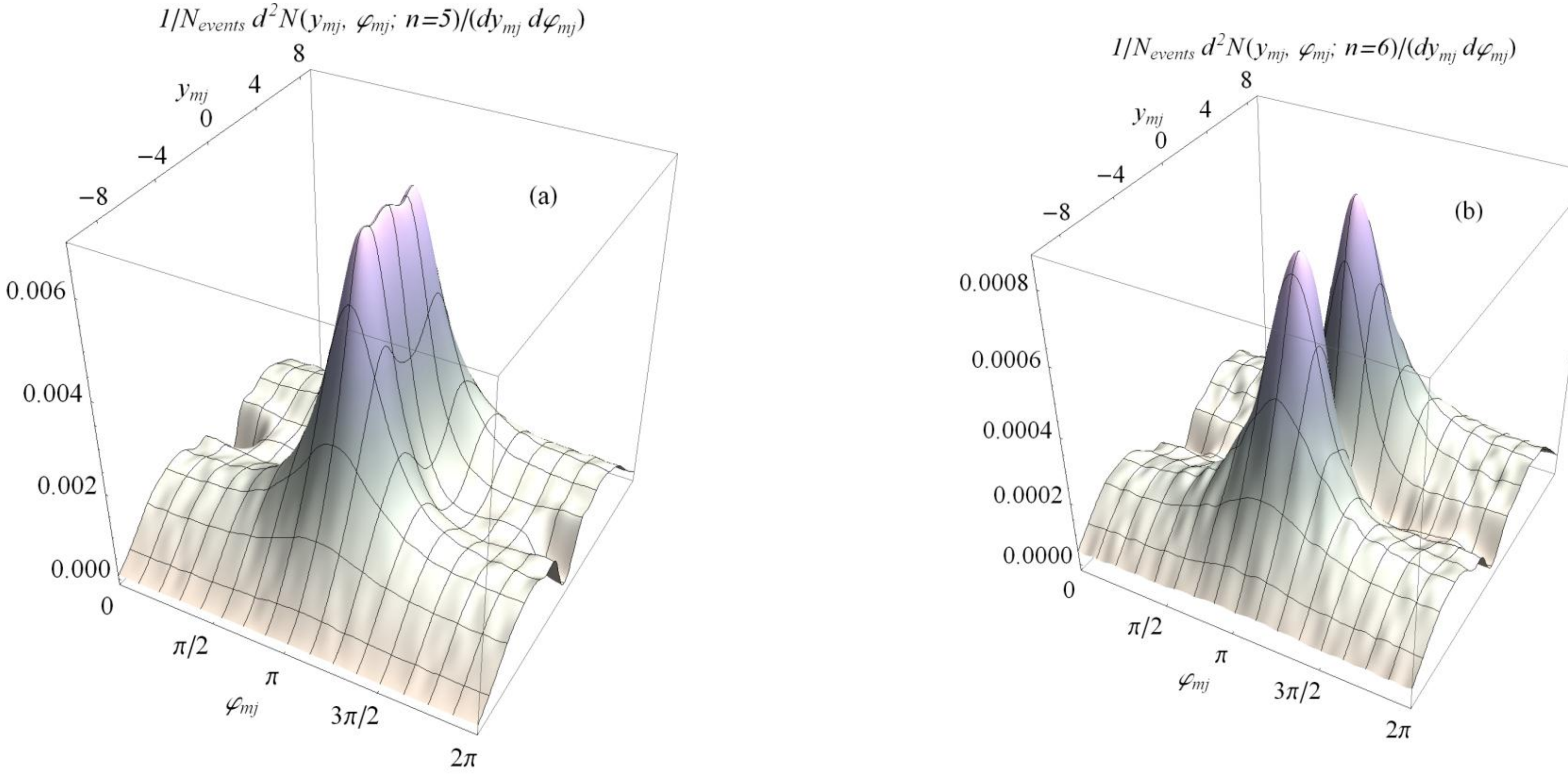




$s^{1/2}$ = 8 GeV. $y_{J/\psi}$ in interval (0,1)

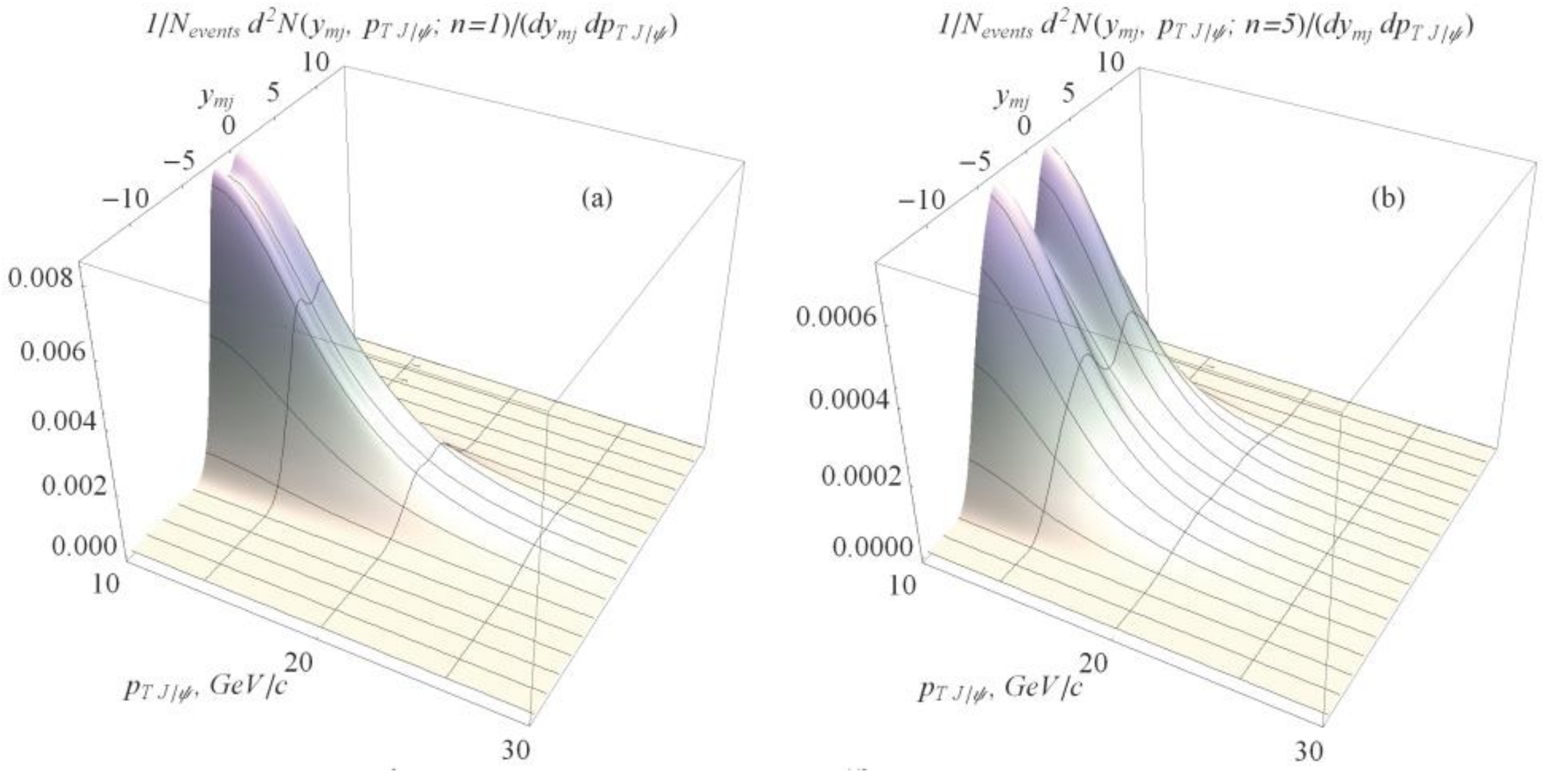
Left - without MPI, ISR, and FSR, right — with inclusion of these processes.

J/ψ production in junction with jets



$y_{J/\psi}$ in interval (4,5)

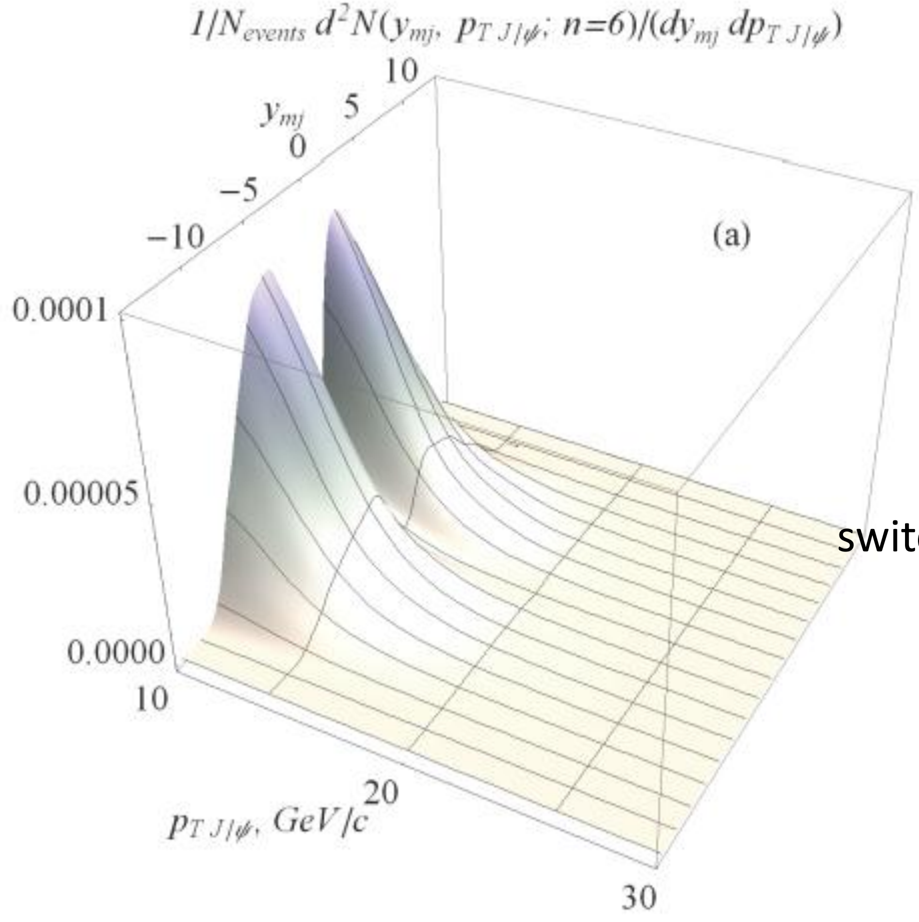
$y_{J/\psi}$ in interval (5,6).



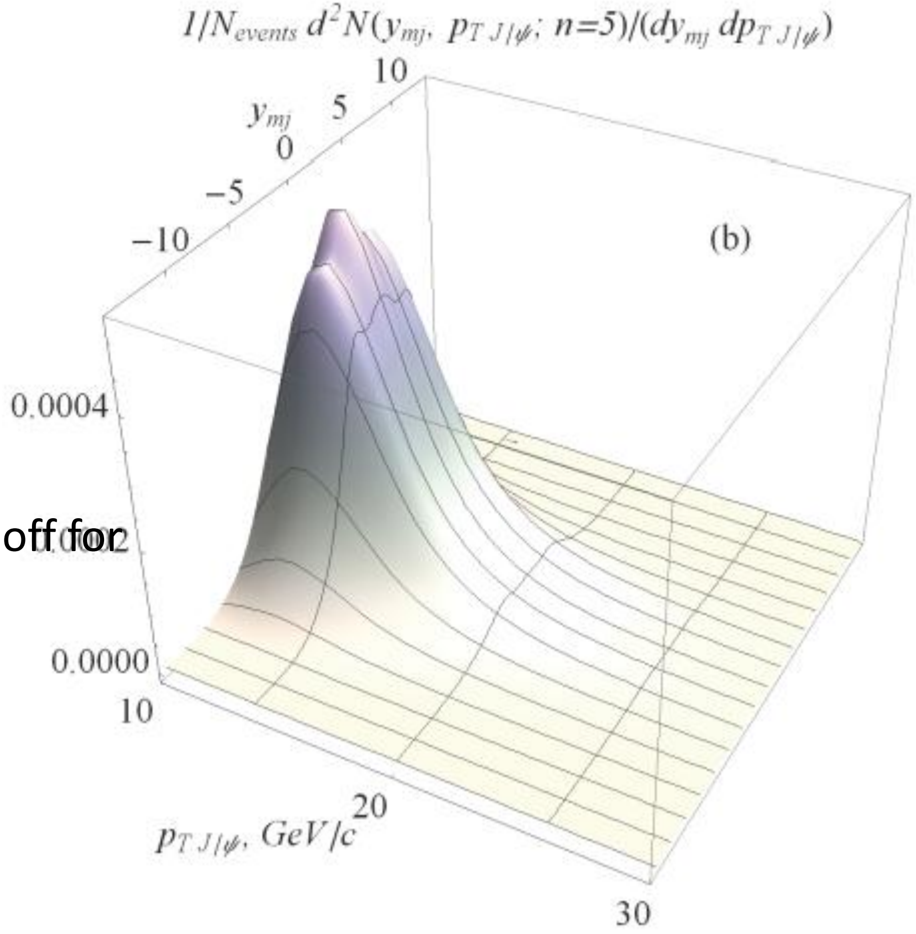
$y_{J/\psi}$ in interval (0,1)

$y_{J/\psi}$ in (4,5)

MPI, ISR, and FSR are included



switched off for



With MPI, ISR, and FSR for $y_{J/\psi}$ in (5,6)

MPI, ISR, and FSR are switched off for $y_{J/\psi}$ in (4,5)

The correlation observables have been computed with **Pythia 8** simulation at LO.
The partonic events are showered and MPI are included.
Is there any hope to reduce the scale uncertainties for ratio of observables ?

Influence of hard processes with two and three jets is being analyzed
with the help of **HELAC-Onia** with special attention to consistent treatment
of partonic processes and showers.

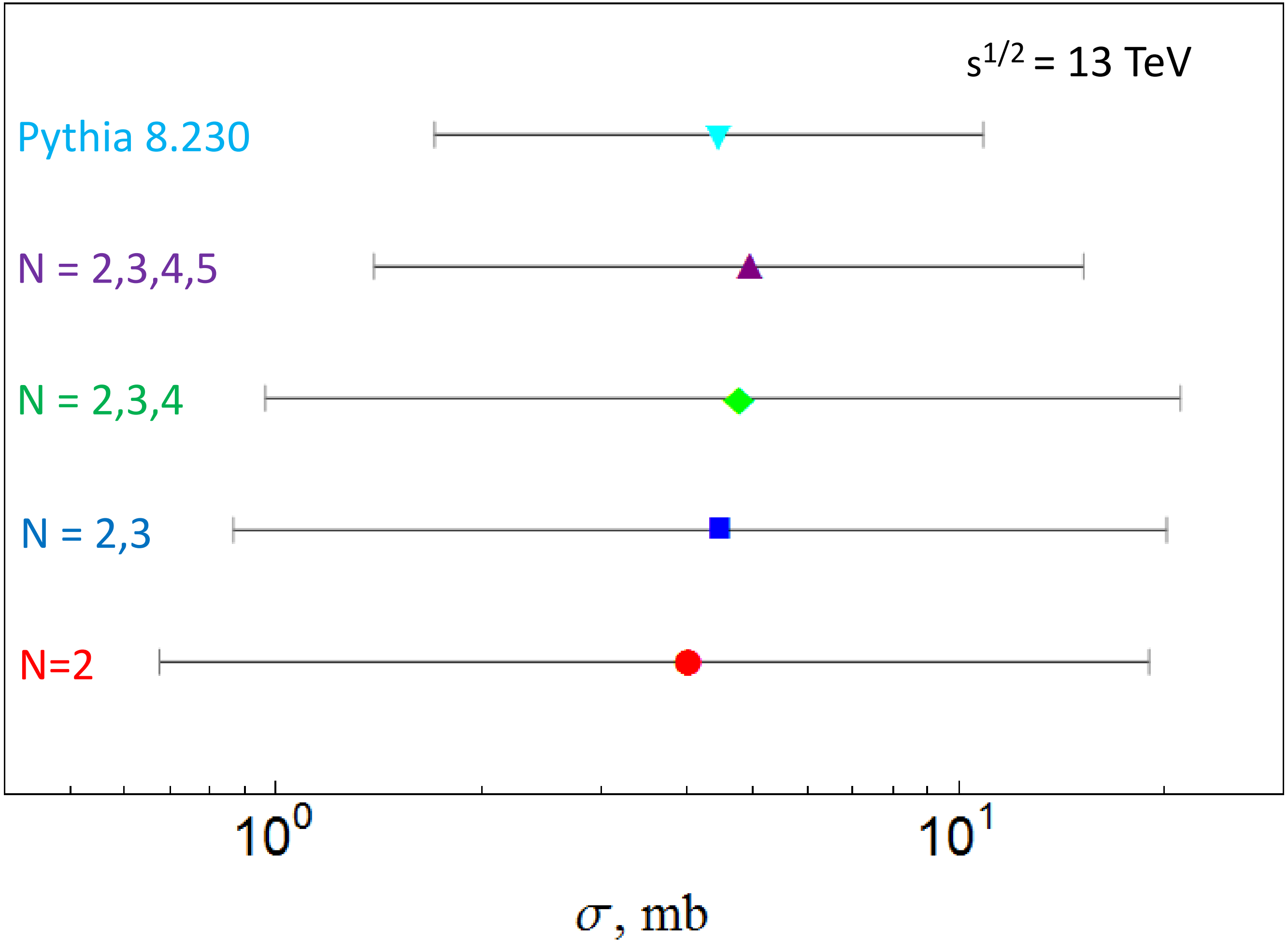
Some features of cross section variations can be inferred from
underlying production of charm anti-charm quark production at the tree level.
The corresponding calculations have been carried out with **MadGraph**.

Production of $c\bar{c}$ pairs in junction with jets

▲, ♦, ■, ● **MadGraph5_aMC@NLO**
2.6.4 - 2.6.7 **at the tree level**

$N = 5$: $c\bar{c}$ + 3*jet*, 2($c\bar{c}$) + *jet*
$N = 4$: $c\bar{c}$ + 2*jet*, 2($c\bar{c}$)
$N = 3$: $c\bar{c}$ + *jet*
$N = 2$: $c\bar{c}$

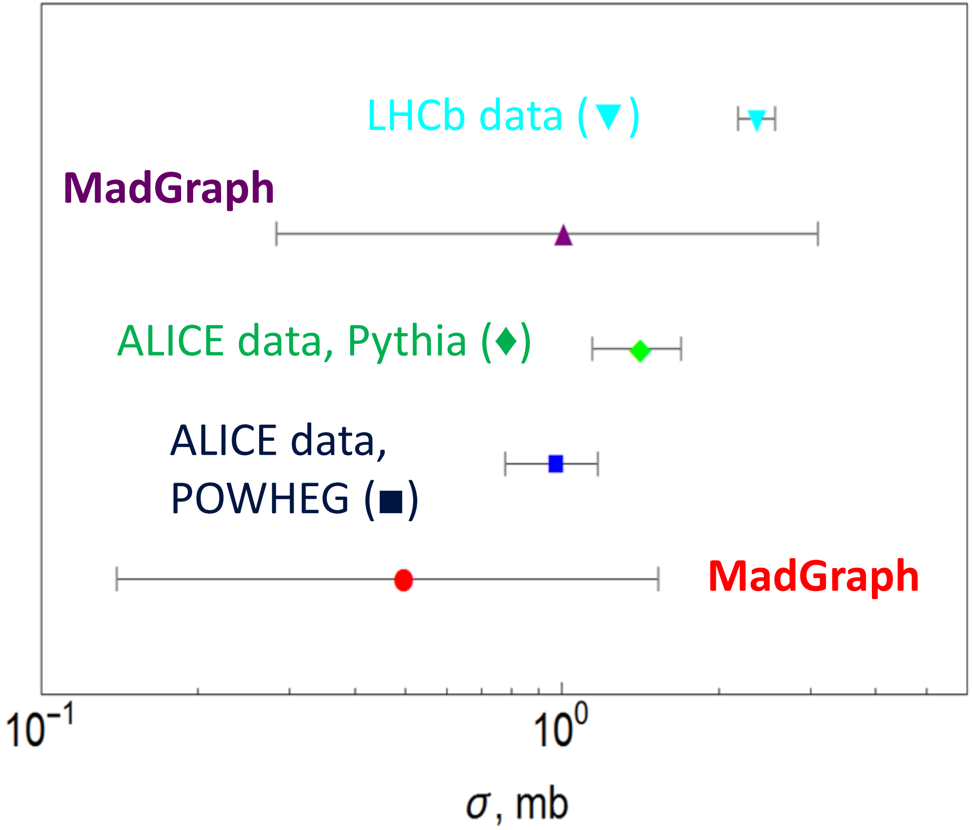
Processes with three, four, and five partons in the final states does not affect the cross sections (CSs) essentially in comparison with the uncertainties of the CSs due to variation of the renormalization and factorization scales for scale factors from ½ up to 2 that change independently.



Production of $c\bar{c}$ pairs and jets

$s^{1/2}$ = 13 TeV

MadGraph 2.6.7 (▲, ●) in the tree approximation,
$c\bar{c}$, $c\bar{c} + jet$, $c\bar{c} + 2jet$, $2(c\bar{c})$, $c\bar{c} + 3jet$, $2(c\bar{c}) + jet$
final states of partonic processes with N≤5 particles.
Minimal value of jet transverse momenta
$p_{T\,jet\,min}$ = 10 GeV/c



Results of MadGraph5_aMC@NLO in junction with Pythia 8 are in agreement with the ALICE and LHCb data within the band of uncertainties due to renormalization and factorization scale variations.

Changes in the computed cross sections under scale variations turn out to be much larger than experimental uncertainties.

LHCb data [JHEP **1603,** 159 (2016), Erratum: **1609**, 013 (2016), **1705**, 074 (2017)]

ALICE data [Phys. Lett. B. **788**, 505 (2018)].

Discussion and outlook

The correlation observables in J/ψ–jet production at LO are strongly sensitive to initial– and final–state radiation of gluons, as well as to multiparton interactions.
The observables vary substantially when J/ψ rapidity passes from central into forward region.

Influence of processes beyond leading order can be decreased by increase of minimal jet momenta.

A way out to reduce scale dependence is to treat the processes in full complexity, as far as it is possible, in particular with **inclussion of the loop** contributions. Recent advances
[J.-P. Lansberg, H.-S. Shao, N. Yamanaka Y.-J. Zhang. Eur.Phys.J. C79 (2019) 1006]
[P. Artoisenet, E. JHEP 1901 (2019) 227]
Scale dependence will weaken for **electroweak (EW) production**, e.g.
of the mesons together with vector bosons [J.-P. Lansberg arXiv:1903.09185].

MadGraph5_aMC@NLO : $\delta_{scale}(c\bar{c}W^+)$ = +31% -22%.
$\delta_{scale}(c\bar{c})$ = +245% -71.8%.

Polarization observables both for processes due to strong and EW interactions will be less affected by scale variations than the cross sections.

The author would like to express gratitude
to the Organizers for the opportunity to attend
the Workshop and to present results of the researches.

Mechanisms of J/ψ production

Color singlet model (a=1)

$$gg \rightarrow Q\overline{Q}[{}^{2S+1}L_J(a)]\, g \quad \text{with} \quad {}^{2S+1}L_J = {}^3S_1,\ {}^3P_{0,1,2},$$

$$qg \rightarrow Q\overline{Q}[{}^{2S+1}L_J(a)]\, q \quad \text{and}$$

$$q\overline{q} \rightarrow Q\overline{Q}[{}^{2S+1}L_J(a)]\, g \quad \text{with} \quad {}^{2S+1}L_J = {}^3P_J,\ \text{where} \quad J = 0, 1, \text{and} \quad 2.$$

Color octet model (a=8)

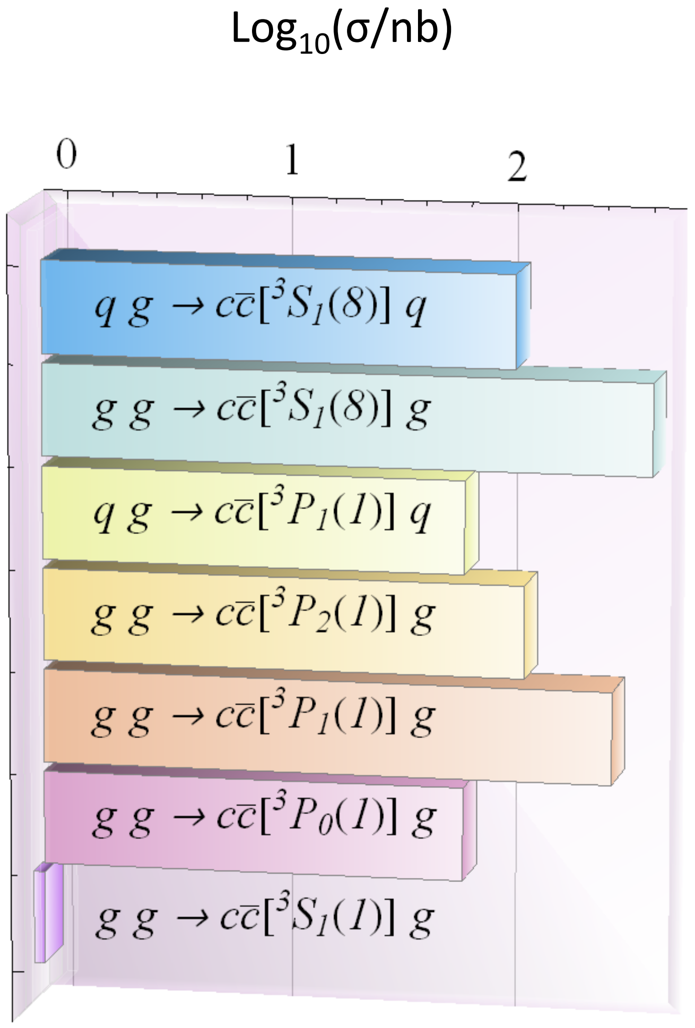
$$gg \rightarrow Q\overline{Q}[{}^{2S+1}L_J(a)]\, g,$$

$$qg \rightarrow Q\overline{Q}[{}^{2S+1}L_J(a)]\, q, \quad \text{and}$$

$$q\overline{q} \rightarrow Q\overline{Q}[{}^{2S+1}L_J(a)]\, g \quad \text{with} \quad {}^{2S+1}L_J = {}^3S_1,\ {}^1S_0,\ \text{and} \quad {}^3P_0,$$

Created heavy-quark pairs $Q\overline{Q}$, where $Q = c$,
then evolve into the quarkonium state

$$c\overline{c}[{}^{2S+1}L_J(1)] \rightarrow \gamma + J/\psi, \qquad c\overline{c}[{}^{2S+1}L_J(8)] \rightarrow g + J/\psi.$$



$$p + p \to J/\psi + X,$$
$$p + p \to J/\psi + jet + X;$$

$s^{1/2}$ = 8 TeV

Calculations with Pythia 8