Quarkonia As Tools 2020, Centre Paul Langevin, Aussois
Pythia and J/ψ with jets

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Cross sections of $J/\psi$ production in pp collisions

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

Data: red circles – ALICE, blue squares – LHCb
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

\[ p + p \rightarrow J/\psi \ (1S) + \text{jet} + X, \]

to analyze mechanisms of the reactions, in particular MPI, time- and 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 $J/\psi+\text{jet}$ production $s^{1/2} = 8\ \text{TeV}$

The difference of $J/\psi$ and jet momenta is

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

Rapidity of $J/\psi$ 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 $J/\psi$ rapidity intervals are observed.

$$\varphi_{mj} = \varphi_{J/\psi} - \varphi_{\ jet},$$
Correlations in $J/\psi$+jet production

The distributions are modified qualitatively.

$\sqrt{s} = 8$ TeV

$\varphi_{mj}$ 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.
$J/\psi$ 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

\( y_{J/ψ} \) in interval (4,5)

\( y_{J/ψ} \) in interval (5,6).
MPI, ISR, and FSR are included

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

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

$1/N_{\text{events}} \frac{d^2N(y_{mJ}, p_{TJ/\psi}; n=1)}{(dy_{mJ} dp_{TJ/\psi})}$

$1/N_{\text{events}} \frac{d^2N(y_{mJ}, p_{TJ/\psi}; n=5)}{(dy_{mJ} dp_{TJ/\psi})}$
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

$\Delta, \diamondsuit, \blacksquare, \bullet$ MadGraph5_aMC@NLO
2.6.4 - 2.6.7 at the tree level

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

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

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 $\frac{1}{2}$ up to 2 that change independently.
Production of $c\bar{c}$ pairs and jets

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


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 inclusion of the loop contributions. Recent advances


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

Polarization observables both for processes due to strong and EW interactions will be less affected by scale variations than the cross sections.
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Color singlet model (a=1)

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

\[ qg \rightarrow Q\overline{Q} \left[ ^{2S+1}L_J (a) \right] q \] and

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

Color octet model (a=8)

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

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

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

Created heavy-quark pairs \( q\overline{q} \). where \( q = c \),
then evolve into the quarkonium state

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

\[ p + p \rightarrow J/\psi + X \, , \]

\[ p + p \rightarrow J/\psi + jet + X \, ; \]

Calculations with Pythia 8