Non-prompt $J/\psi+\mu$ and $J/\psi+J/\psi$ production at LHC with k_T-factorization

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A.V. Lipatov, S.P. Baranov, H. Jung, M.A. Malyshev, Eur. Phys. J. **C78**, 2 (2018);
S.P. Baranov, A.V. Lipatov, M.A. Malyshev, Eur. Phys. J. **C78**, 820 (2018).

Outline

1. Motivation
2. Theoretical framework
3. Numerical results
4. Conclusion

Motivation

As the collision energy at the LHC increases, one can obtain precision data for a number of processes having rather small cross sections. Among such processes are the associated non-prompt $J/\psi+\mu$ and $J/\psi+J/\psi$ production, for the first time measured by ATLAS and LHCb [ATLAS Coll., JHEP 11, 62 (2017); LHCb Coll., JHEP 11, 30 (2017)].

Such processes provide a good test for pQCD calculations for heavy flavors production, especially at small opening angles between the heavy hadrons.

In the present work, we analyze recent ATLAS and LHCb data in the k_T-factorization approach.

Motivation

The goal of the present work is:

- to test applicability of the k_T-factorization approach to a new process
- to test different parametrizations of TMD parton distribution functions.
- Investigate possible effects from double parton scattering (DPS) and parton showers

Theoretical framework

Cross section of non-prompt *J/ψ* production in the k_T-factorization approach:

$$d\sigma(pp \to J/\psi + X) = d\sigma(g^* g^* \to b\bar{b}) \otimes$$

$$\otimes f_g(x_1, k_{T1}^2, \mu_{\rm fact}^2) f_g(x_2, k_{T2}^2, \mu_{\rm fact}^2) \otimes$$

$$\otimes D_{b \to J/\psi}(z, \mu_{\rm fragm})$$

The framework: TMDs

1) CCFM unintegrated distributions

[F. Hautmann, H. Jung, 2014]. Numerical solutions of Catani-Ciafaloni-Fiorani-Marchesini evolution equation.

JH2013: The starting distribution is chosen to satisfy data on proton structure functions $F_2(x,\mu^2)$ only (set 1) or both $F_2(x,\mu^2)$ and $F_2^c(x,\mu^2)$ (set 2).

2) KMR prescription at LO and NLO (MRW)

[M. Kimber *et al.*, 2001, 2003]. A procedure to introduce $\mathbf{k}_T$ at the last step of DGLAP evolution. The collinear input: MSTW2008 (at LO or NLO).

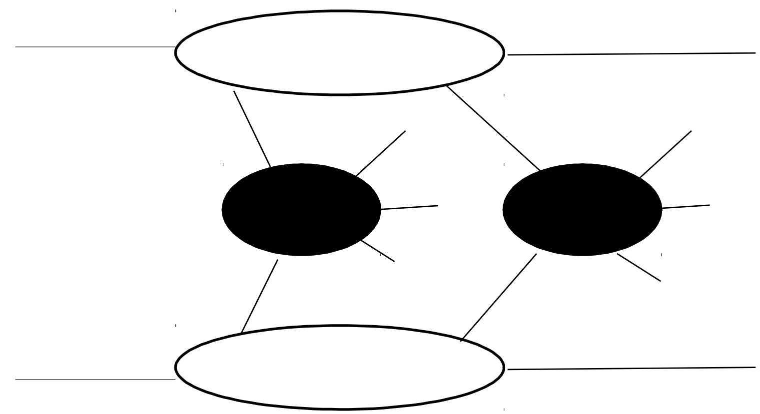
The framework: Fragmentation functions

[P. Bolzoni, B. Kniel, G. Kramer, 1999, 2013]. Fragmentation from a *b*-hadron to *J/ψ* meson in the framework of NRQCD.

$$D_{b\to J/\psi}(x,\mu_{\rm fragm}) = \int_x^1 \frac{dz}{z} D_{b\to B}(x/z,\mu_{\rm fragm}) \frac{1}{\Gamma_B}\frac{d\Gamma}{dz}(z,P_B)$$

Double parton scattering (DPS) contributions

Two parton interactions in one proton-proton collision



$$\sigma_{\rm DPS}^{\rm AB} = \frac{\sigma_{\rm SPS}^{A}\sigma_{\rm SPS}^{B}}{\sigma_{\rm eff}}$$

The formula should be corrected in case of forward production to take into account the limited phase space. We apply then a factor $F=(1-x_1-x_2)^2$. The factor reduces the cross section by 15-20%. [V. Korotkikh, A. Snigirev, 2004, and others]

Parameters

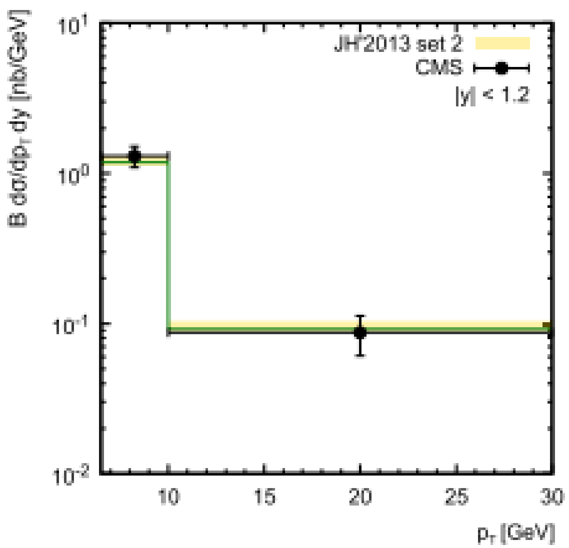
- Theoretical uncertainties are connected with the choice of the factorization and renormalization scales. We took $\mu_R^2 = \mu_F^2 = \xi(m_b^2+(\mathbf{p}_{T1}^2+\mathbf{p}_{T2}^2)/2)$. For JH2013 TMDs we took $\mu_F^2 = \xi(s+\mathbf{Q}_T^2)$, where s and $\mathbf{Q}_T^2$ are the energy of scattering subprocess and transverse momentum of the incoming off-shell gluon pair, respectively. We varied the scale parameter ξ between 1/2 and 2 about the default value $\xi = 1$.

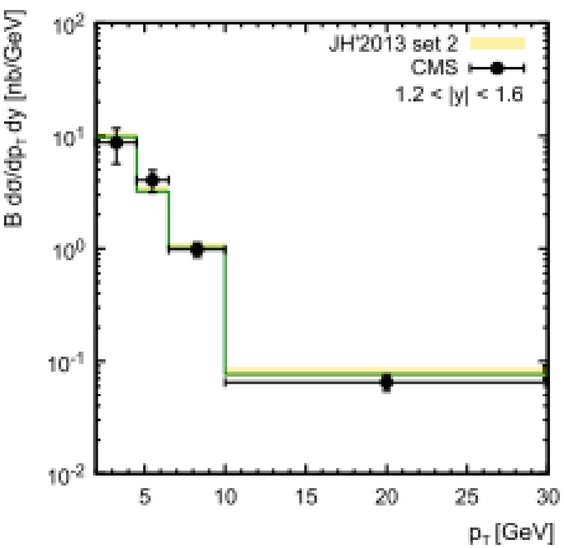
- We set m_b=4.75 GeV, $B(b\to J/\Psi+X)=0,68\%$, $B(J/\Psi\to\mu^-\mu^+)=5,96\%$, $B(b\to\mu)=9,8\%$, $B(b\to c\to\mu)=8,02\%$. In DPS calculations we took $\sigma_{\rm eff}$=15 mb.

- We take into account the feed-down contributions and take $B(b\to\Psi(2S)+X)=0,18\%$, $B(b\to\chi_{c0}+X)=0,015\%$, $B(b\to\chi_{c1}+X)=0,21\%$, $B(b\to\chi_{c2}+X)=0,026\%$, $B(\Psi(2S)\to J/\Psi+\gamma)=61\%$, $B(\chi_{c0}\to J/\Psi+\gamma)=1,27\%$, $B(\chi_{c1}\to J/\Psi+\gamma)=33,9\%$, $B(\chi_{c2}\to J/\Psi+\gamma)=19,2\%$.

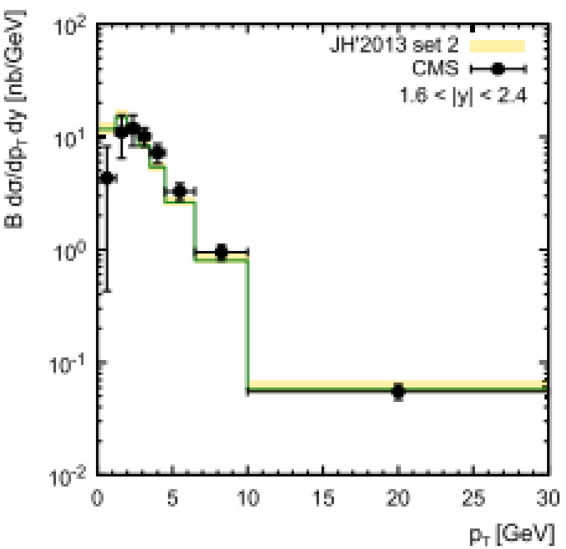
- We use 2-loop formula for the strong coupling constant $\alpha_s(\mu^2)$ with $n_f = 4$ active quark flavors at $\Lambda_{QCD} = 226$ MeV.

Numerical results: inclusive non-prompt J/ψ





$\sqrt{S}$=7 TeV



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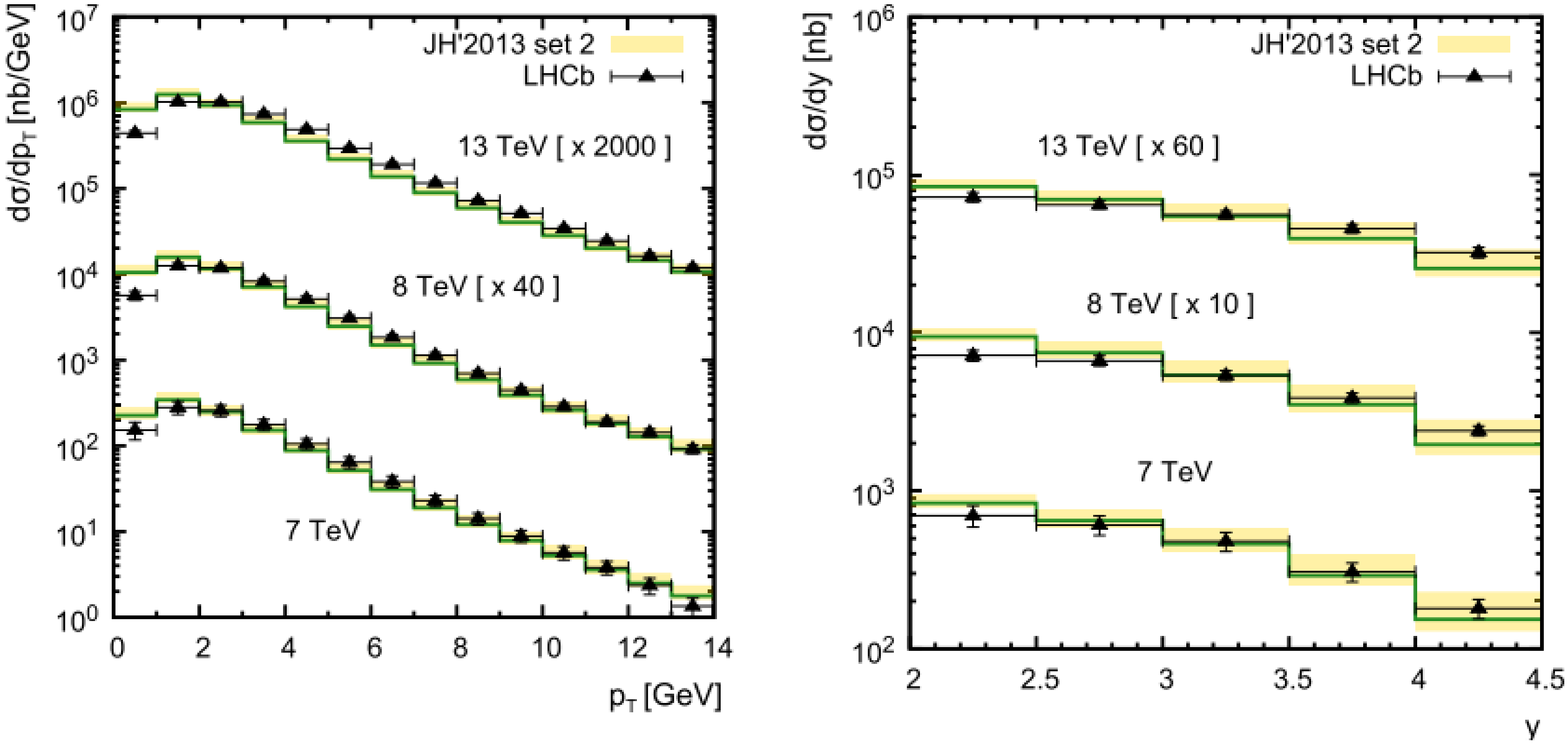
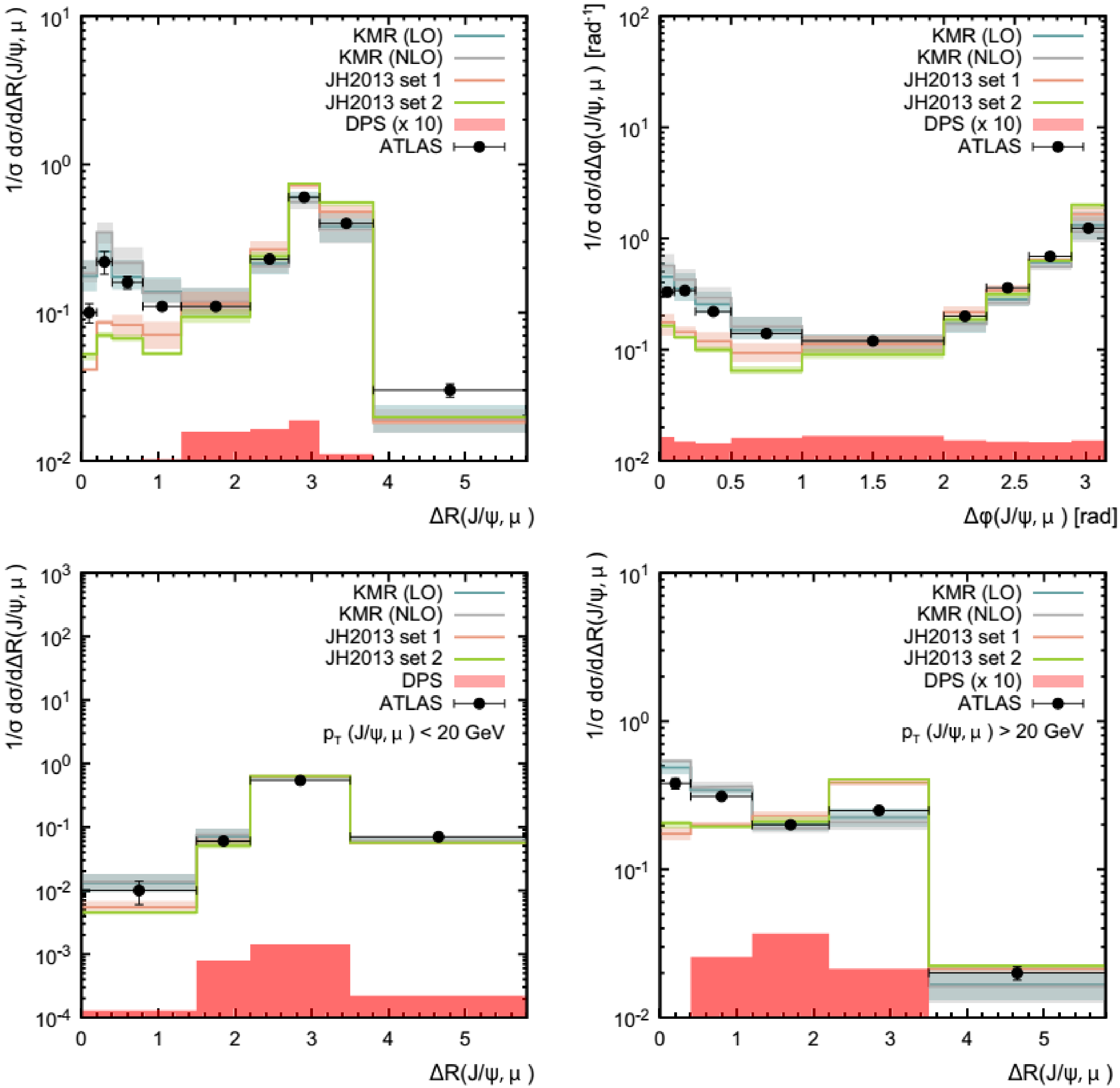
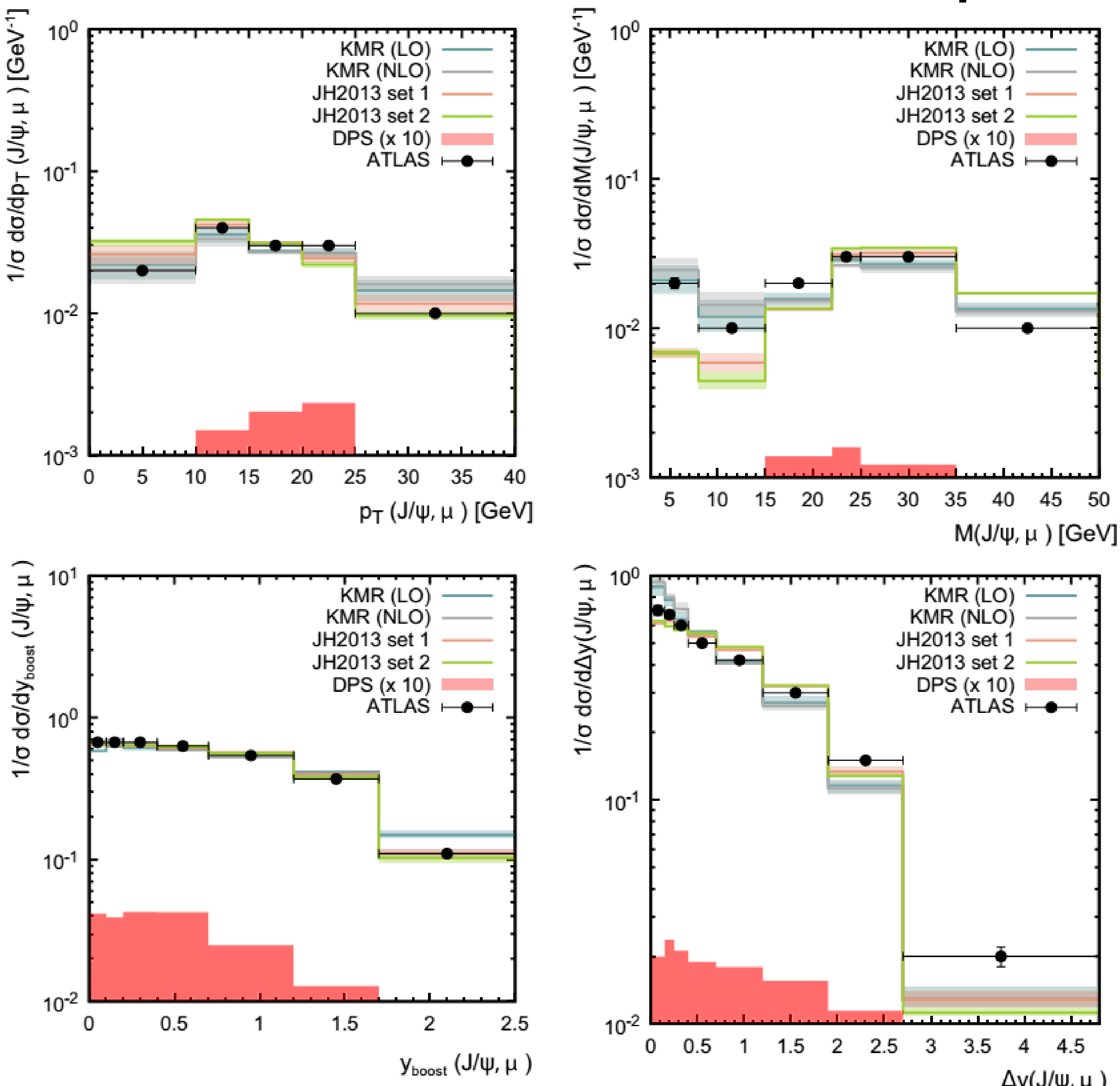


Numerical results: non-prompt $J/\psi+\mu$

$\sqrt{S}=8$ TeV



Numerical results: non-prompt $J/\psi+\mu$



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Numerical results: non-prompt $J/\psi+\mu$

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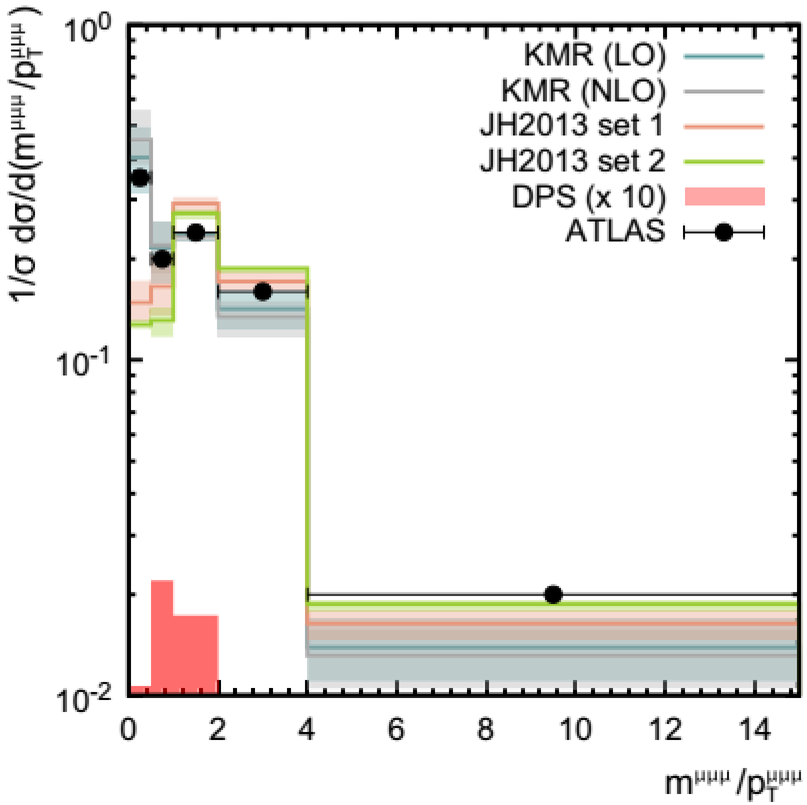
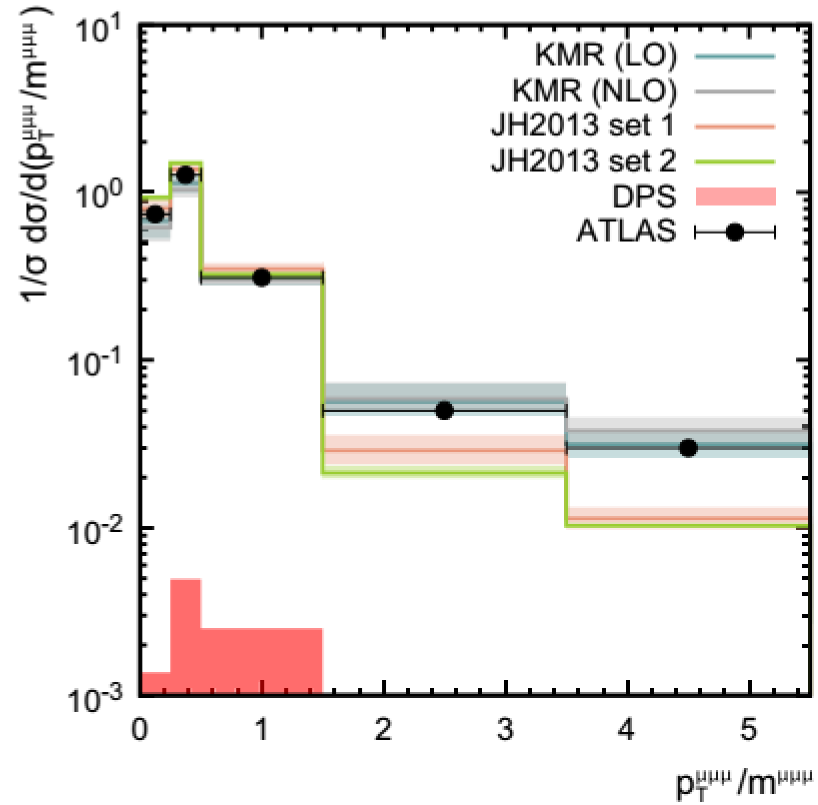
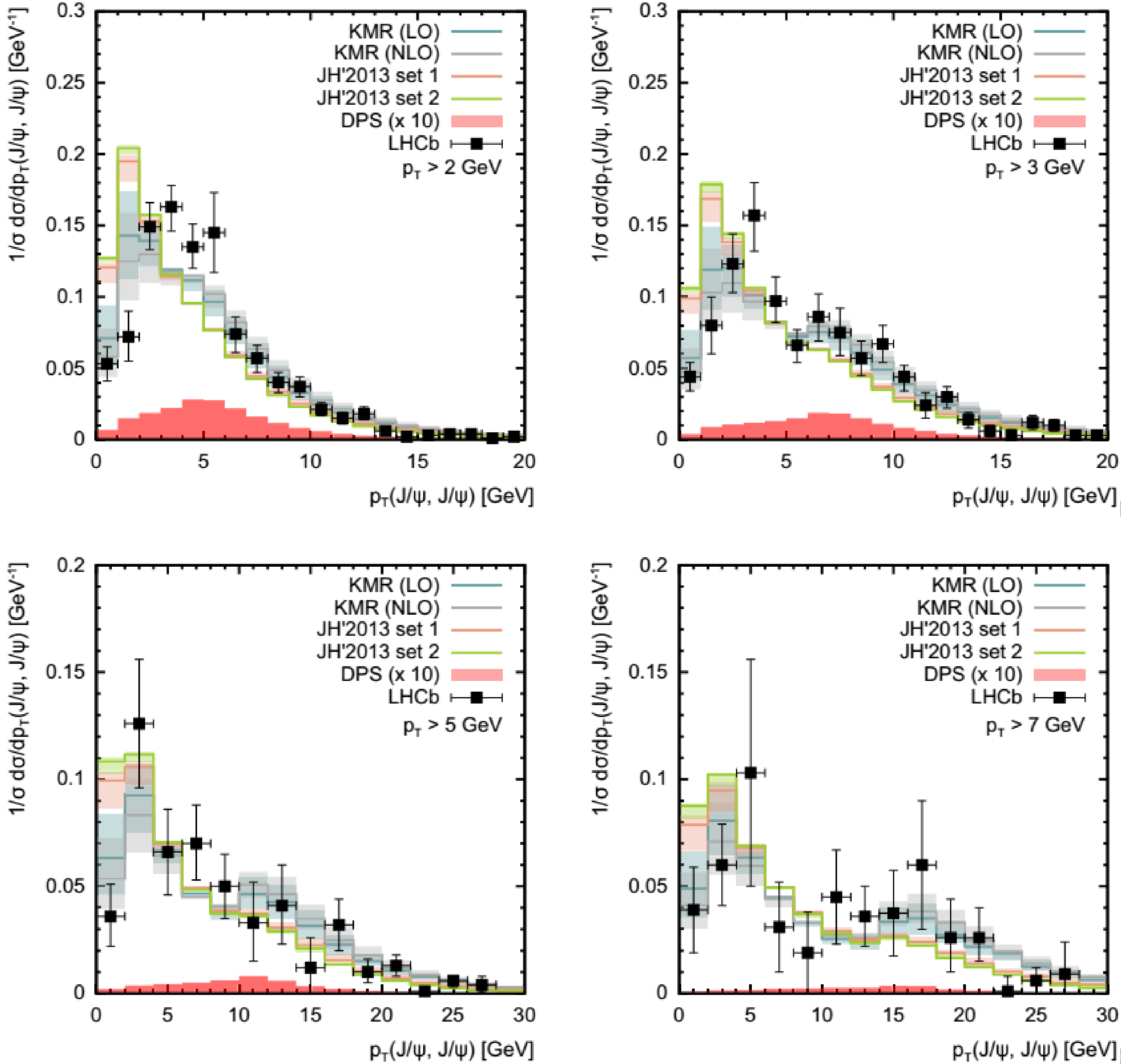


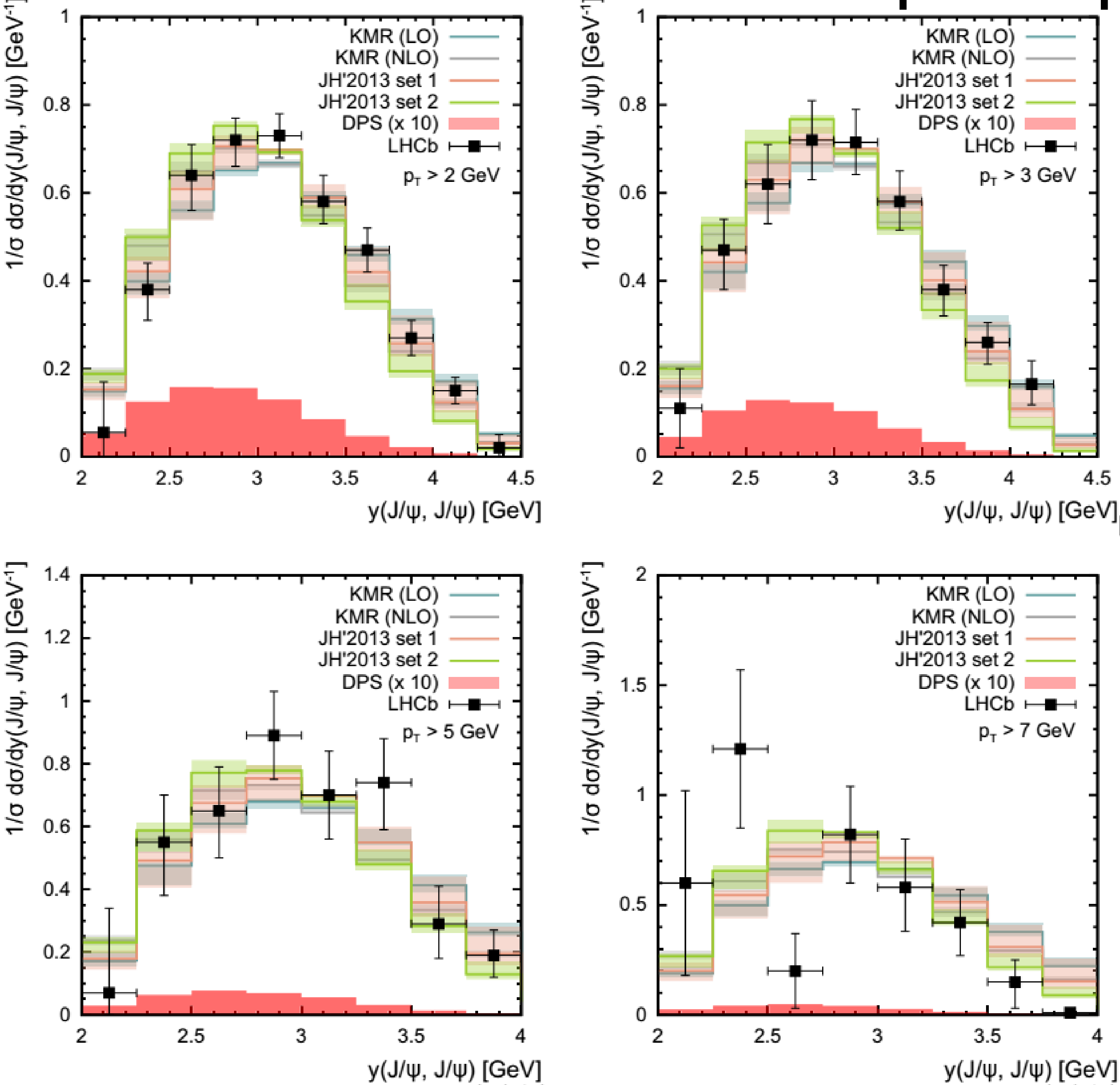


Numerical results: non-prompt $J/\psi+J/\psi$



√S=8 TeV

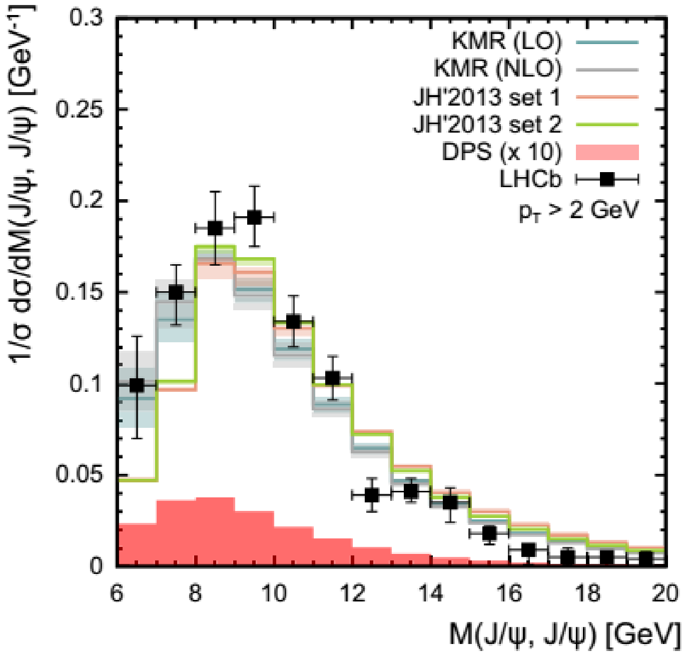
Numerical results: non-prompt $J/\psi+J/\psi$

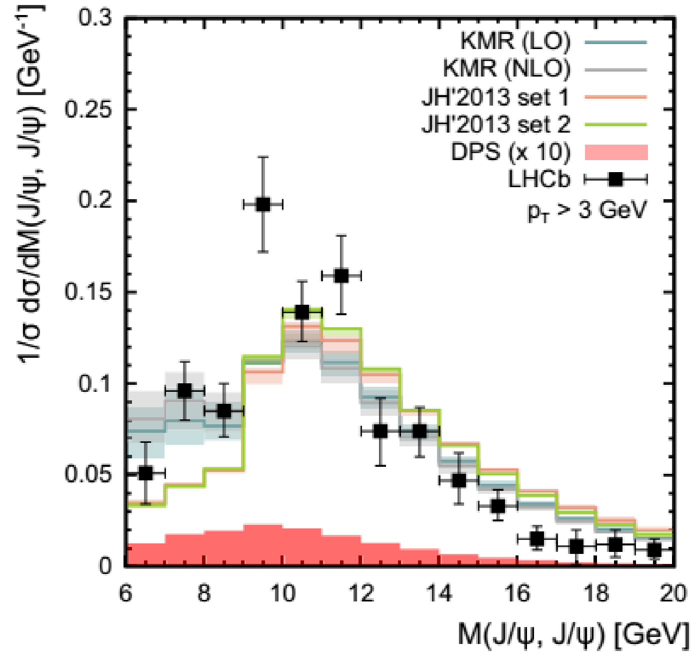


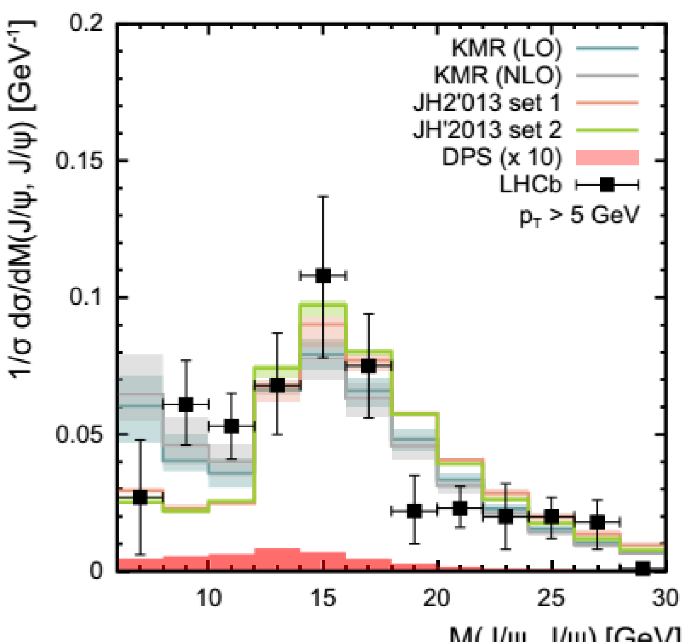
√S=8 TeV

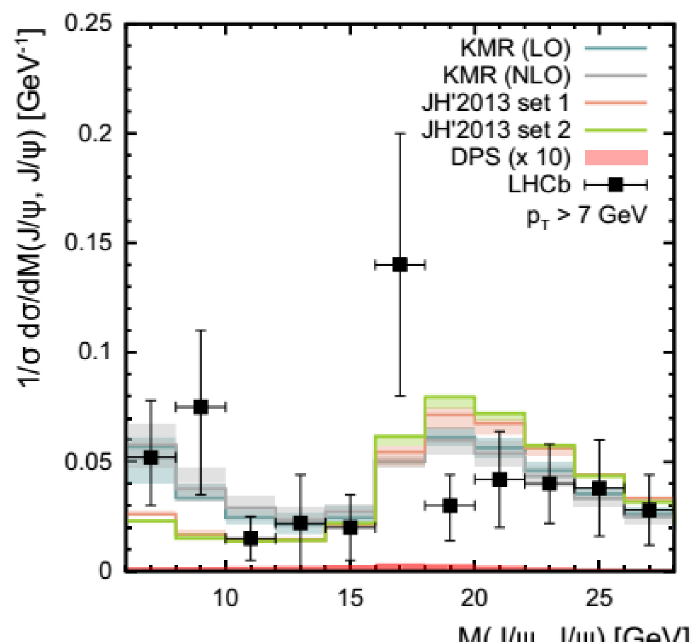
Numerical results: non-prompt $J/\psi + J/\psi$

√S=8 TeV

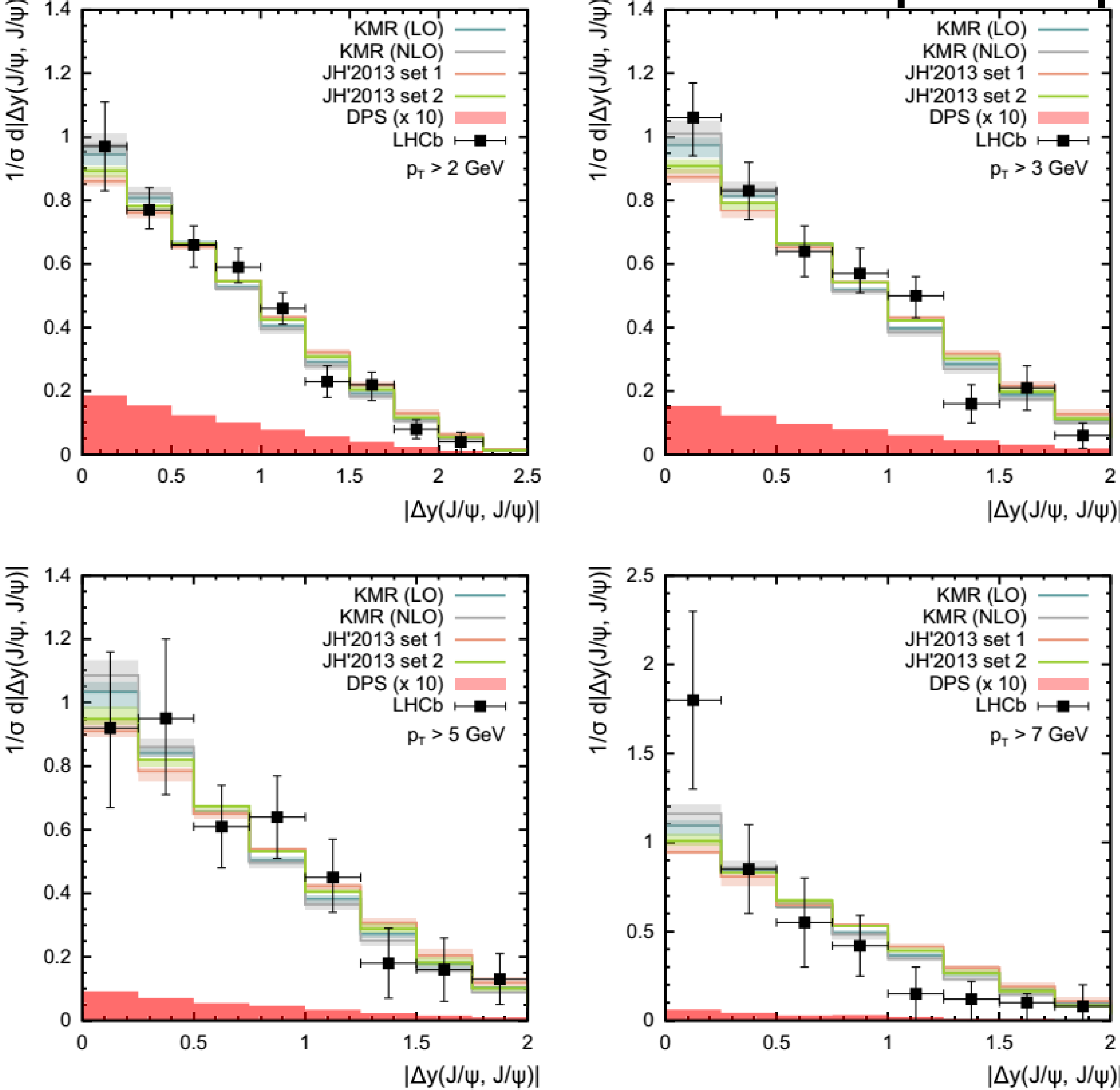






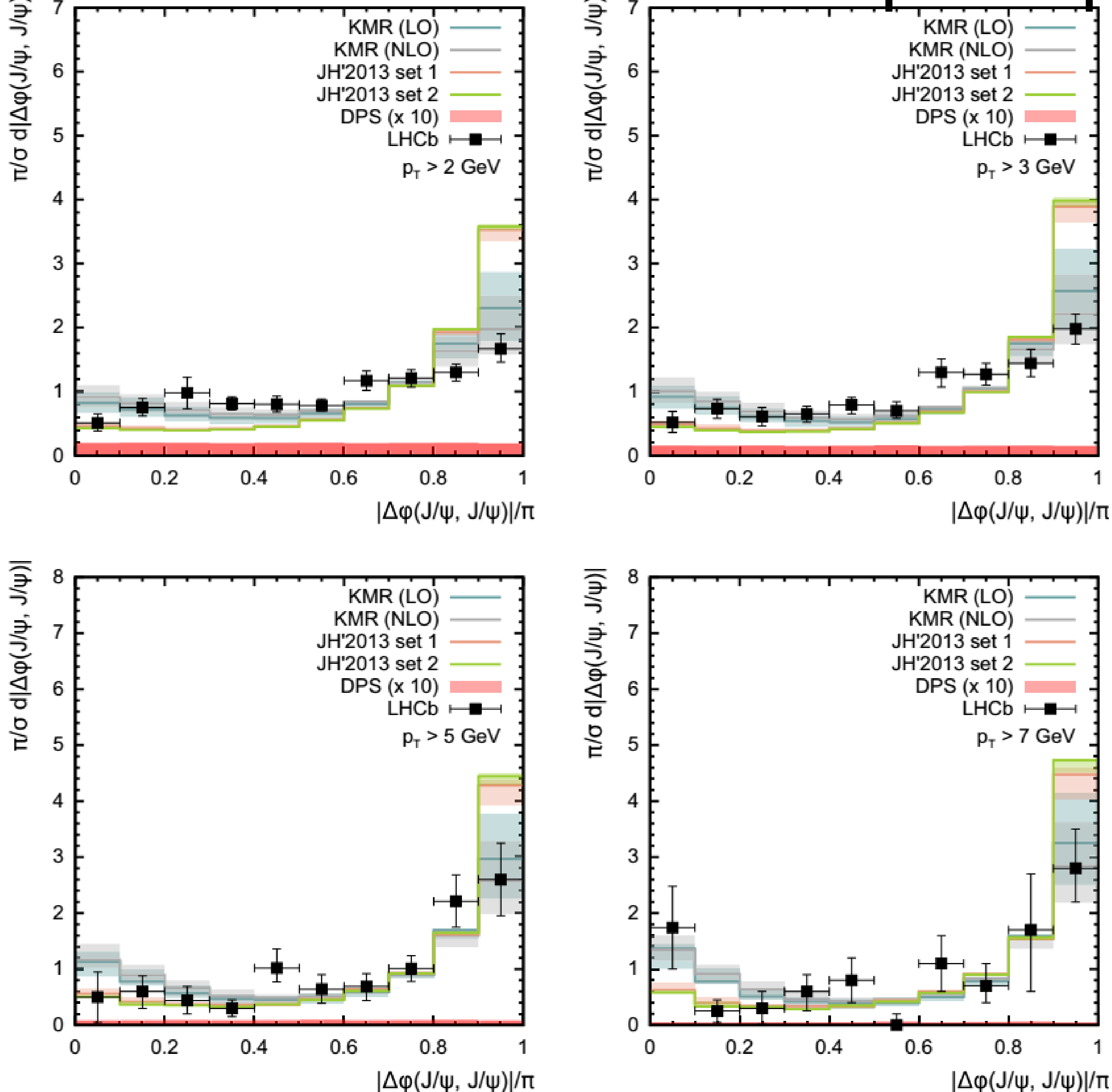


Numerical results: non-prompt $J/\psi + J/\psi$



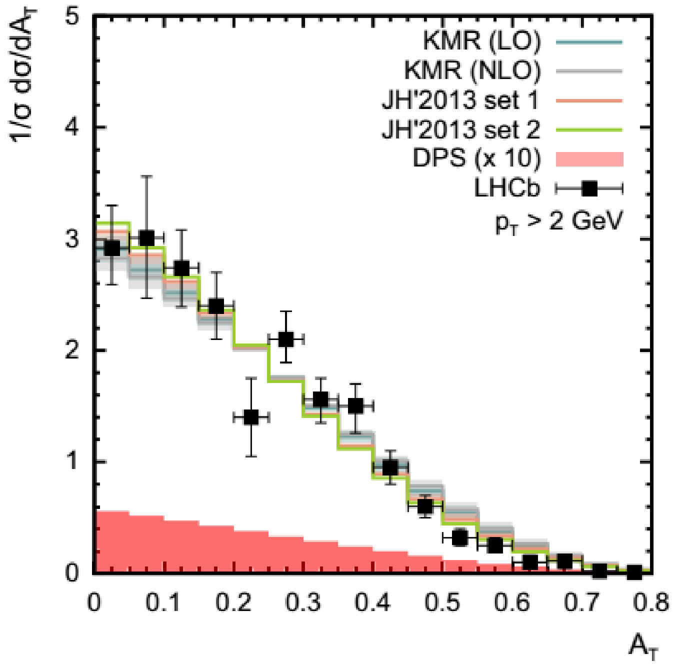
$\sqrt{S}$=8 TeV

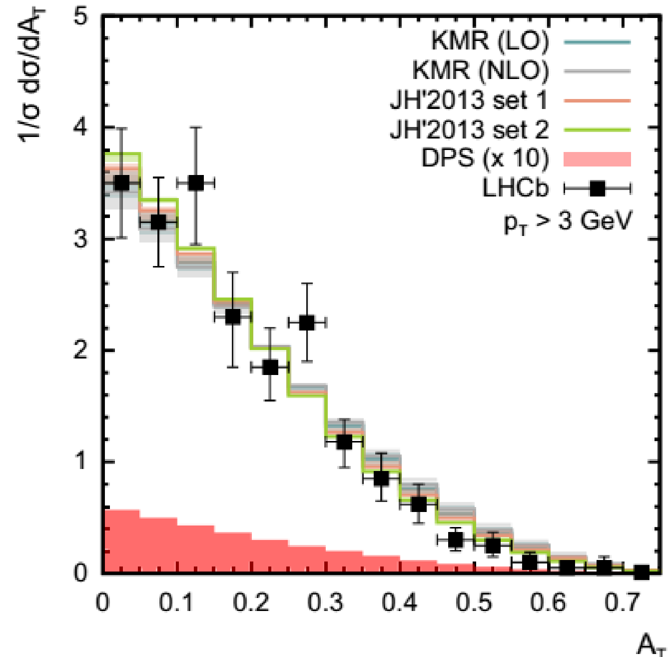
Numerical results: non-prompt $J/\psi + J/\psi$



√S=8 TeV

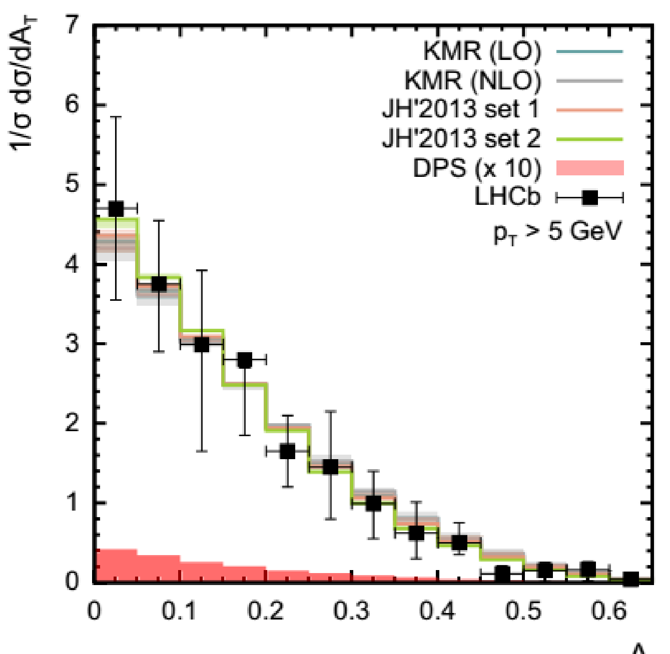
Numerical results: non-prompt $J/\psi + J/\psi$

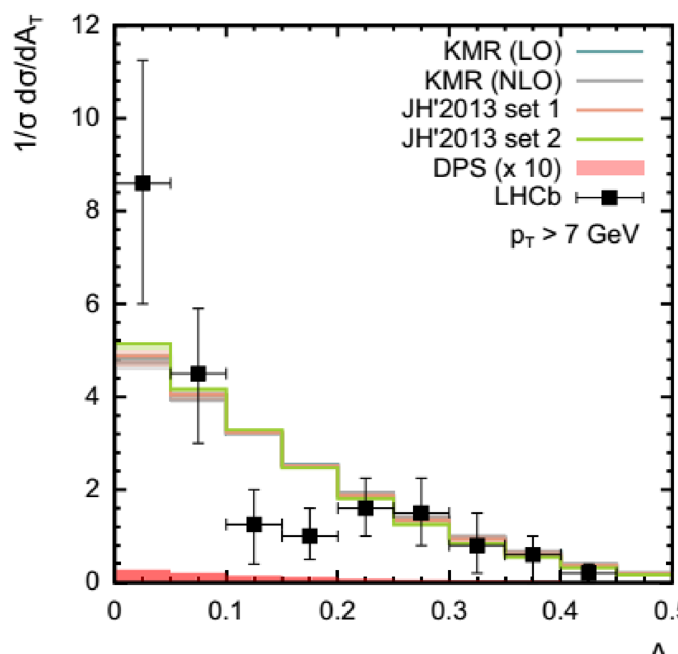




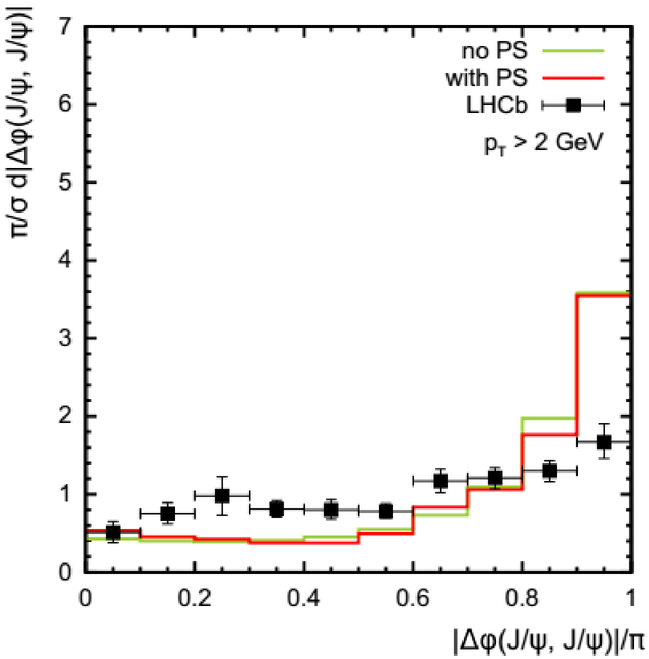
√S=8 TeV

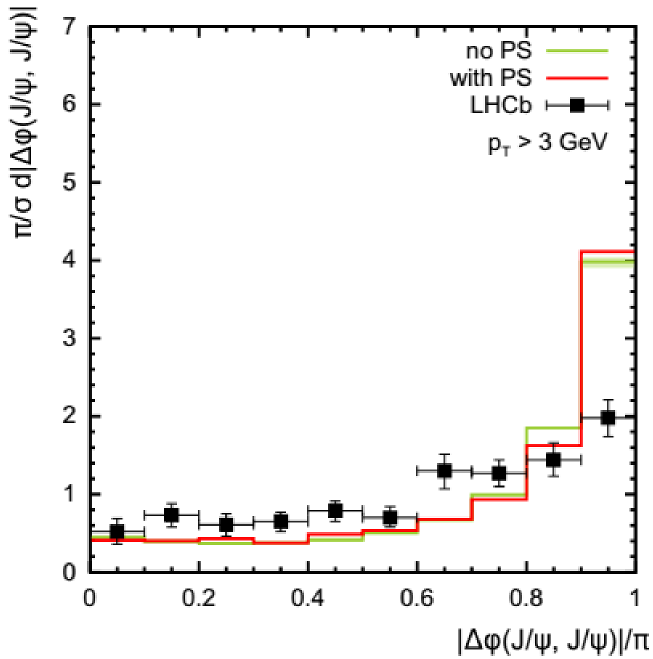
$$\mathcal{A}_T = \left| \frac{p_T^{J/\psi_1} - p_T^{J/\psi_2}}{p_T^{J/\psi_1} + p_T^{J/\psi_2}} \right|$$



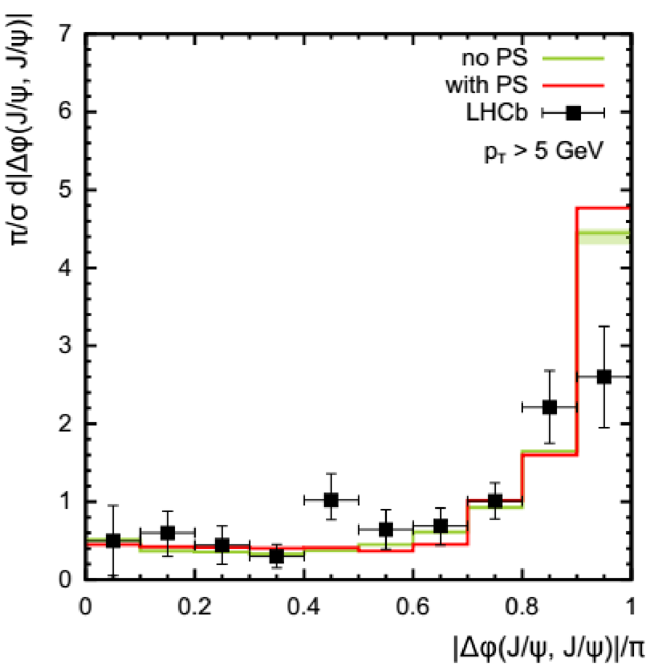


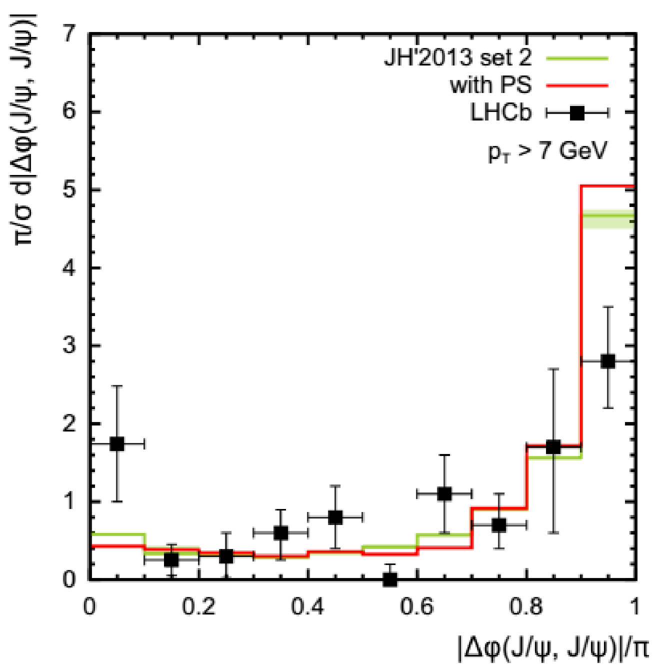
Numerical results: Parton showers



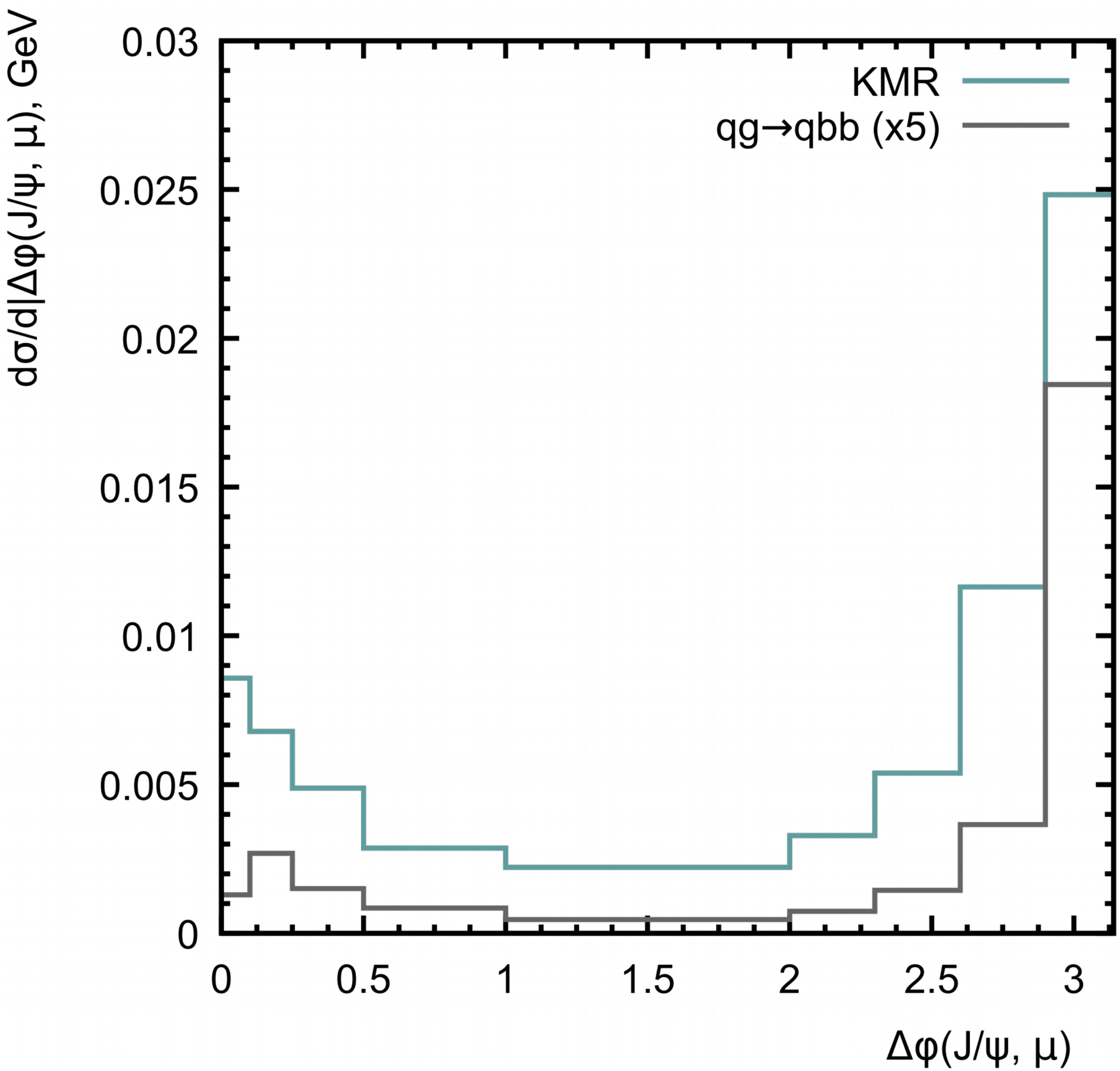


√S=8 TeV





Numerical results: Higher orders



Conclusion

Associated non-prompt $J/\psi+J/\psi$, $J/\psi+\mu$ production at LHC ($\sqrt{s}$=8 TeV) has been considered.

- The processes are sensitive to the choice of TMDs.

- KMR TMDs are more preferable for description of the data in the studied kinematical region, as can be seen from angular distributions.

- Reasonably good description of ATLAS and LHCb data is obtained.

- DPS contributions appear to be negligible in the studied kinematic region.

- Parton showers do not change the results significantly

Back up

Definitions

$$\Delta R(J/\psi_1, J/\psi_2) = \sqrt{(\eta_{J/\psi_1} - \eta_{J/\psi_2})^2 + (\phi_{J/\psi_1} - \phi_{J/\psi_2})^2}$$

$$\mathcal{A}_T = \left|\frac{p_T^{J/\psi_1} - p_T^{J/\psi_2}}{p_T^{J/\psi_1} + p_T^{J/\psi_2}}\right|$$

Off-shell gluon polarization sum

$$\epsilon_\mu \epsilon_\nu^* = \frac{k_T^\mu k_T^\nu}{\mathbf{k}_T^2}$$