Associative production of Υ and open charm hadrons at LHCb

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Introduction

A lot of new data on multiple heavy quark production have been obtained by experiments at LHC.

- B_c (seems pQCD underestimates the cross section values);
- $B_c(2S)$ [Aad et al.(2014)];
- double open charm (the cross section values in accordance with DPS, p_T distributions contradict DPS)[Aaij et al.(2012b)];
- $J/\psi + c$ (the cross section values in accordance with DPS, p_T distributions contradict DPS)[Aaij et al.(2012b)];
- double J/ψ (SPS +CS?)[Aaij et al.(2012a)].

In some cases the obtained cross section values are unexpectedly large and can not be explained within single parton scattering approach (SPS).

Briefly about double parton scattering (DPS)

Within the simplest variant of DPS correlations in longitudinal partonic momenta in the initial hadron are neglected (but we should be careful: $x_1 + x_2 \leq 1$):

$$D(x_1, x_2) \sim D(x_1) \cdot D(x_2)$$

.
This leads to the formula

$$\sigma^{\mathrm{DPS}}_{A_1 A_2} = \frac{1}{m} \frac{\sigma^{\mathrm{SPS}}_{A_1} \sigma^{\mathrm{SPS}}_{A_2}}{\sigma_{eff}},$$

where $\sigma^{\mathrm{SPS}}_{A_1}$ and $\sigma^{\mathrm{SPS}}_{A_2}$ are the cross section values of the processes A_1 and A_2 within SPS, $m = 1$ for different A_1 and A_2, $m = 1/2$ for identical A_1 and A_2, and σ_{eff} is the parameter of DPS model obtained from the experimental data [Abe et al.(1997), Abazov et al.(2010)].

Surprisingly successful in predicting of the cross section values for the kinematical condition of the LHCb experiment!

However the problems still remain: DPS fails in describing of some differential distributions (see for example J/ψ-distribution on p_T, [Aaij et al.(2012b)]).

Why $\Upsilon + c$ could be interesting?

- Simple for estimation within pQCD (6 LO diagrams v.s. 31 for double J/ψ production in gluonic interaction).
- Can be researched at LHC.
- Very interesting to compare with the researched processes of double $J/\psi + c$ and double open charm production.

For $J/\psi + c$ and double open charm production two pairs of heavy quarks are produced in different partonic interactions. Can this four quark transform into hadrons mutually?
For $\Upsilon + c$ production process there is no such effect. This is why one could suppose that DPS will work better.

Gluon fusion within SPS

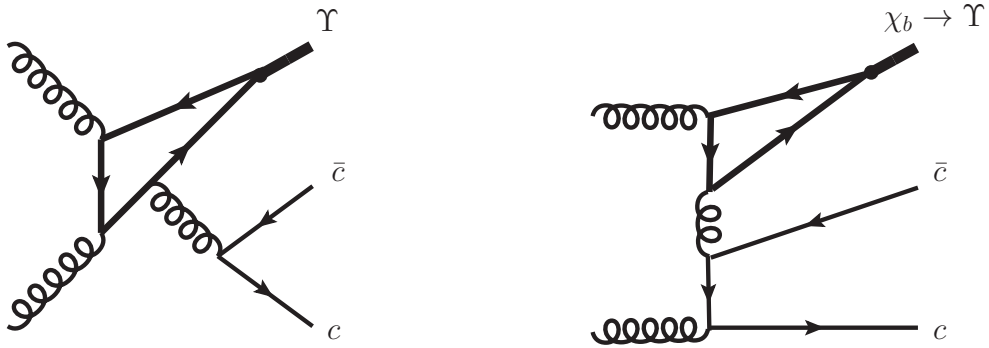


Figure : The examples of LO diagrams for the $\Upsilon + c$ production process.

By analogy with investigated in details production of P-states of B_c:

$$\frac{\sigma(gg \to \chi_b + c)}{\sigma(gg \to \Upsilon_{\text{direct}} + c)} \sim 10\% \div 20\%$$

Taking into account that $Br(\chi_{b0} \to \Upsilon) \approx 1.8\%$, $Br(\chi_{b1} \to \Upsilon) \approx 34\%$ and $Br(\chi_{b2} \to \Upsilon) \approx 19\%$:

$$\frac{\sigma(gg \to \chi_b + c\bar{c},\ \chi_b \to \Upsilon)}{\sigma(gg \to \Upsilon + c\bar{c})} \lesssim 6\%$$

Interaction with the charm quark from the sea within SPS

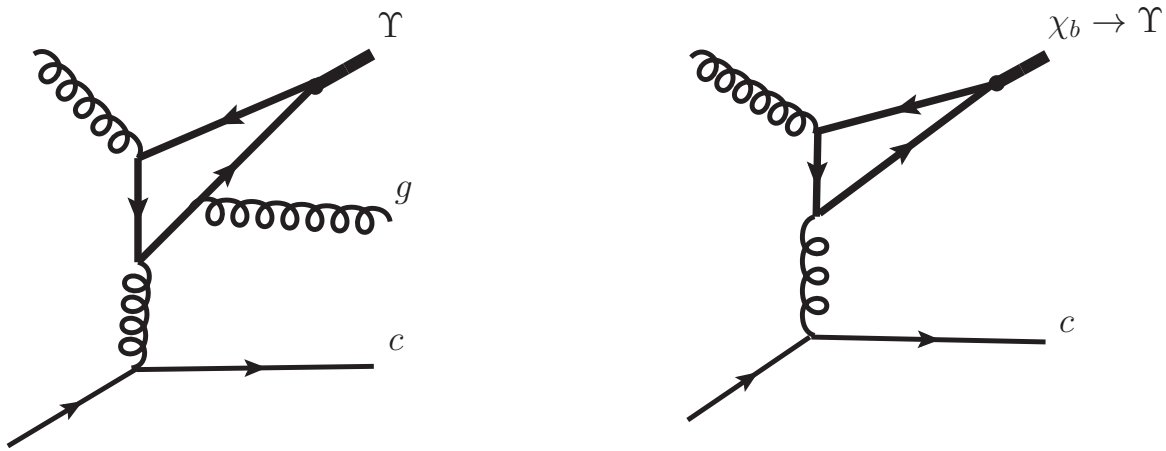


Figure : The examples of LO diagrams for the $\Upsilon + c$ production process.

It was first shown in [Baranov(1997)], that the interaction with heavy sea quark can essentially contribute to the multiple heavy quark production.
But for this process it can be neglected:

- $gc \to \Upsilon_{\text{direct}} gc$ is suppressed by additional order of α_s.
- $\sigma(gc \to \chi_b(\to \Upsilon) + c) \sim \sigma(gg \to \chi_b(\to \Upsilon) + c)$

SPS vs DPS

All SPS+LO QCD contribution (LHCb):

$$\frac{\sigma^{\Upsilon+c}_{\rm SPS}}{\sigma^{\Upsilon}_{\rm LHCb}} \sim 0.2 \div 0.6\%.$$

Alternative way to estimate SPS (gluon splitting):

According to LEP data the probability $P^{g\to c\bar{c}}_{\rm LEP}$ to produce an additional $c\bar{c}$-pair in the heavy quark production in e^+e^--annihilation via gluon splitting about 2.4% [Akers et al.(1995a), Akers et al.(1995b)].
Thus it could be supposed that gluon associated with Υ will produce c-quark in 2% of events.

$$\frac{\sigma^{\Upsilon+c}_{\rm SPS}}{\sigma^{\Upsilon}_{\rm LHCb}} \approx P^{g\to c\bar{c}}_{\rm LEP} \cdot k \sim 2\%$$

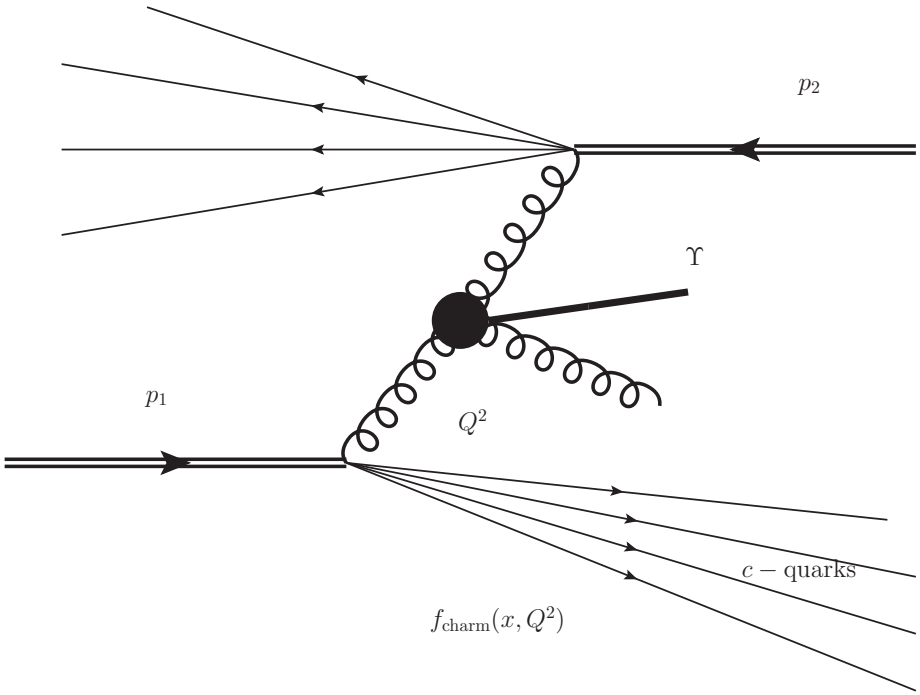
$$k = \frac{[\sigma^{\rm LO}(gg \to \Upsilon_{\rm direct} + c\bar{c})]_{\text{LHCb cuts on charm}}}{[\sigma^{\rm LO}(gg \to \Upsilon_{\rm direct} + c\bar{c})]_{\text{without cuts on charm}}} \approx 0.7$$

DPS:

$$\frac{\sigma^{\Upsilon+c}_{\rm DPS}}{\sigma_{\Upsilon}} = \frac{\sigma^{c}_{\rm LHCb}}{\sigma_{\rm eff}} \sim 10\%.$$

Problem: There is no possibility to estimate uncertainties accurately.

Accounting of c-quarks from PDF at the Υ production scale



$$n_{\text{charm}} \sim \int_{x_{\text{min}}}^{x_{\text{max}}} f_{\text{charm}}(x, Q)\, \mathrm{d}x$$

$$x \simeq \frac{E_T}{\sqrt{s}} \exp(y)$$

$$\text{LHCb} : 2 < y < 4.5$$

$$\langle E_T \rangle \sim 2.5 \text{ GeV}$$

$$Q_\Upsilon \sim 10 \text{ GeV}$$

$$\frac{\sigma_{\Upsilon+c}}{\sigma_\Upsilon} \sim \int_{0.0026}^{0.032} f_{\text{charm}}(x, 10 \text{ GeV})\, \mathrm{d}x \sim 50\%.$$

Problems: There is no possibility to estimate uncertainties accurately. The additional hypothesis about c-quark k_T is needed.

Conclusions

$\sigma(\Upsilon + c)/\sigma(\Upsilon)$:

- SPS+LO: $0.2\% \div 2\%$
- DPS: $\sim 10\%$
- There is no hope that NLO could remove the gap between SPS and DPS predictions.
- If SPS: more accurate estimations are needed.
- If DPS: the distributions for Υ and for the open charm should be close to the distributions for single production of Υ and open charm.
- We expect, that data will be describe by DPS.

Thank you for your attention.

Georges Aad et al.

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