Production properties of the Doubly Charmed Baryons at the large Feynman-X

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June 17, 2014

Abstract. This paper focuses on disagreement between theoretical predictions and the SELEX results of the production properties of Doubly Charmed Baryons. The role of the intrinsic charm mechanism in the SELEX kinematic region is researched. The production ratio of the $\Xi_{cc}^+$ baryon in the SELEX kinematic region is presented. The recent experimental results are reviewed.

PACS. XX.XX.XX No PACS code given

1 Introduction

In early 2000’s the SELEX collaboration published the first observation of 15.9 signal over 6.1 ± 0.5 background events of the doubly charmed baryons in the charged decay mode $\Xi_{cc}^+ \rightarrow \Lambda_{cc}^+ K^- \pi^+$ from $\Lambda_{cc}^+ \rightarrow pK^- \pi^+$ (1630 events) sample [1]. Three years later the SELEX collaboration reported an observation of 5.62 signal over 1.38 ± 0.13 background events of $\Xi_{cc}^+ \rightarrow pD^+ K^- \pi^+$ decay mode from 1450 $D^+ \rightarrow K^- \pi^+ \pi^+$ decays to complement the previously reported decay [2]. The mass and lifetime also have been measured by SELEX (see Table 1). Unfortunately, the SELEX collaboration did not provide production cross-section of the $\Xi_{cc}^+$ in the order of magnitude accuracy and compared to that of $\Lambda_{cc}^+$ baryon and $D^+$ meson in kinematic region $x_F > 0.4$ [3]:

$$R_{\Lambda_{cc}^+} = \frac{\sigma(\Xi_{cc}^+)}{\sigma(\Lambda_{cc}^+)} \cdot \frac{Br(\Xi_{cc}^+ \rightarrow \Lambda_{cc}^+ K^- \pi^+)}{Br(\Xi_{cc}^+ \rightarrow pD^+ K^-)} \approx 0.01$$

using known fragmentation ratio $f(c \rightarrow \Lambda_{cc}^+) = 0.071 \pm 0.003$ (exp.) ± 0.018 (br.) [4] and assuming $Br(\Xi_{cc}^+ \rightarrow \Lambda_{cc}^+ K^- \pi^+) \approx 0.5 \pm 1.3 \%$ [5], one can obtain the ratio of the production cross-section:

$$\frac{\sigma(\Xi_{cc}^+)}{\sigma(\Lambda_{cc}^+)} = R_{\Lambda_{cc}^+} \cdot \frac{Br(\Xi_{cc}^+ \rightarrow \Lambda_{cc}^+ K^- \pi^+)}{Br(\Xi_{cc}^+ \rightarrow pD^+ K^-)} \approx 1.4 \times 10^{-2}.$$ 

Similar result can be obtained from:

$$R_{D^+} = \frac{\sigma(\Xi_{cc}^+)}{\sigma(D^+)} \cdot \frac{Br(\Xi_{cc}^+ \rightarrow pD^+ K^-)}{Br(\Xi_{cc}^+ \rightarrow \Lambda_{cc}^+ K^- \pi^+)} \approx 0.004$$

using fragmentation ratio $f(c \rightarrow D^+) = 0.217 \pm 0.014$ (stat.) $+0.013 \pm 0.005$ (syst.) $+0.014$ (br.) [6] and measured ratio $Br(\Xi_{cc}^+ \rightarrow \Lambda_{cc}^+ K^- \pi^+)/(Br(\Xi_{cc}^+ \rightarrow pD^+ K^-) = 0.36 \pm 0.21$ [2], one can obtain:

$$\frac{\sigma(\Xi_{cc}^+)}{\sigma(\Lambda_{cc}^+)} = R_{\Lambda_{cc}^+} \cdot \frac{Br(\Xi_{cc}^+ \rightarrow \Lambda_{cc}^+ K^- \pi^+)}{Br(\Xi_{cc}^+ \rightarrow pD^+ K^-)} \approx 4.6 \times 10^{-2}.$$ 

So the approximated ratio of the production cross-section is $\frac{\sigma(\Xi_{cc}^+)}{\sigma(\Lambda_{cc}^+)} \sim 10^{-2}$. Comparing this result with theoretically predicted $\sigma(\Xi_{cc}^+)/(\sigma(\Lambda_{cc}^+)) \sim 10^{-6} - 10^{-5}$ [7,8] production ratio for fixed-target experiments with $\pi$ or proton beam and $P_{beam} \sim 600 - 800$ GeV, we see that measured ratio is at least $10^3$ times larger than theoretical prediction. This is a huge gap between theory and experiment. In paper [9] it has been shown that the kinematic dependencies change the ratio dramatically and obtained a new prediction for the ratio $\sigma(\Xi_{cc}^+)/\sigma(\Lambda_{cc}^+) \sim 10^{-3} - 10^{-2}$ which is compared with the SELEX data. The calculation was done in the perturbative approach, however some other researches [10,11] of the production properties of the doubly charmed baryons and some earlier papers [12,13,14] on the charm production at large Feynman-X point to us importance of the intrinsic charm mechanism. In this paper we research the role of the intrinsic charm mechanism in the production of the doubly charmed baryons in the SELEX kinematic region.

2 The ratio of production cross-section of $\Xi_{cc}^+$ baryon to double-charm at SELEX

The SELEX experiment is a fixed-target experiment used the Fermilab charged hyperon beam at 600 GeV/c to produce charm particles in a set of thin foil of Cu or in a diamond and operated in the $x_F > 0.3$ kinematic region. The negative beam composition was about 50% $\Sigma^-$, 50% $\pi^-$. The positive beam was 90% protons.
2.1 The production cross-section of $\Xi_{cc}^+$

2.1.1 The Perturbative approach

The partonic level $\Xi_{cc}^+$ production cross-section as a set of parametric functions was given in Ref. [8] in following view:

$$\hat{\sigma}_{gg} = 213 \cdot \left( 1 - \frac{4 \cdot m_c}{\sqrt{s}} \right)^{1.9} \left( \frac{4 \cdot m_c}{\sqrt{s}} \right)^{1.35} \text{pb}, \quad (1)$$

$$\hat{\sigma}_{qq} = 206 \cdot \left( 1 - \frac{4 \cdot m_c}{\sqrt{s}} \right)^{1.8} \left( \frac{4 \cdot m_c}{\sqrt{s}} \right)^{2.9} \text{pb}. \quad (2)$$

The numerical coefficients depend on the model parameters, so coefficients above given for $\hat{\sigma} \sim \alpha_s |R(0)|^2/m_c^2$, where $\alpha_s = 0.2$, $R(0) = 0.601 \text{ GeV}^2/\text{pb}$ and $m_c = 1.7 \text{ GeV}$. These formulae work for the SELEX energies, but cannot be used for LHC energies (see details in Ref. [8]). Combining Eqs. (1, 2) and using CTEQ6L [13] parametrization for parton distribution functions, we may expect $\Xi_{cc}^+$ production cross-section in the kinematic region $x_F > 0.4$ [3] to be

$$\sigma_{pQCD}^{x_F > 0.4}(\Xi_{cc}^+) \approx 2 \pm 3 \text{ pb}.$$  

2.1.2 The Intrinsic charm approach

The probability distribution for quark states in the proton can be written as [13]:

$$P|p\rangle \approx P|wdc\rangle + P|udc\rangle + P|udc\rangle + \ldots$$

There are two main approaches to have $\Xi_{cc}^+$ in the final state in the proton-proton scattering. Charm-gluon scattering $\hat{\sigma}(cg \to \Xi_{cc}^+)$ and fragmentation double charm into doubly charmed baryon $\hat{\sigma}(cc \to \Xi_{cc}^+)$. As it was shown in Ref. [10] $\sigma_{gg} \approx \Xi_{cc}^+$ : $\sigma(gc \to \Xi_{cc}^+) : \sigma(cc \to \Xi_{cc}^+)$ $\approx 1 : (25 \div 93) : 10^{-4}$. So we can see that $\hat{\sigma}(cc \to \Xi_{cc}^+)$ gives too small contribution into the final result.

The production cross-section can be written as follows:

$$\sigma_{IC}(\Xi_{cc}^+) = \int dx_1 dx_2 f_{gc}(x_1, \mu)f_{cc}(x_2, \mu)\hat{\sigma}(x_1, x_2),$$

where $f_{gc}(x, \mu)$ is gluon [15] or intrinsic charm [16] distribution functions, $x$ is the ratio of the parton momentum to the momentum of the hadron and $\mu$ is the energy scale of the interaction. Explicit view of $\hat{\sigma}(gc \to \Xi_{cc}^+)$ can be found in [11]. Doing calculations in the SELEX kinematical region find:

$$\sigma_{IC}^{x_F > 0.4}(\Xi_{cc}^+) \approx 10 \times \sigma_{pQCD}^{x_F > 0.4}(\Xi_{cc}^+).$$

Let us remind the reader that in the full kinematic region for the SELEX energies (see Ref. [10]) $\sigma_{IC}(\Xi_{cc}^+) \approx (25 \div 93) \times \sigma_{pQCD}(\Xi_{cc}^+)$.  

2.2 A pair of charm quarks production

As it was already shown in [3] in the SELEX kinematic region the production cross-section of a pair of charm quarks is suppressed by factor $10^{-4} - 10^{-3}$. This result can be easily obtained with Monte Carlo tools such as described in Refs. [17,18]. Upper limit on the intrinsic charm production cross-section at $\sqrt{s} = 20 - 40 \text{ GeV}$ can be calculated with following approximation [12,19]:

$$\sigma_{IC}(cc) \approx 0.01 \times \sigma_{pQCD}(cc) \approx 10^4 \text{ pb},$$

that is at least order more than the perturbative approach predicts.

Finally, using calculated $\Xi_{cc}^+$ and charm production cross-sections we will obtain a new ratio of the production the doubly charmed baryon and charm at the SELEX experiment:

$$\frac{\sigma(\Xi_{cc}^+)}{\sigma(cc)} \approx 10^{-3}.$$

Keeping in mind that the charm production cross-section is obtained in an optimistic approximation this ratio should be interpreted as the lower limit. So this ratio is compared with the experimentally measured by the SELEX.

3 Short review of recent results from Belle and LHCb

The Belle experiment [20] presented the upper limit on the $\sigma(e^+e^- \to \Xi_{cc}^+X)$ is $82 - 500 \text{ fb}$ for the decay mode with the $A^+_L$ at $\sqrt{s} = 10.58 \text{ GeV}$ using 980 $\text{ fb}^{-1}$. The most realistic calculations [7,21] predict $\sigma(\Xi_{cc}^+) \approx 35 \pm 10 \text{ fb}$ what turns out to be at least twice as less as the given limit.

Another recent result from the LHCb experiment [22] provides the upper limits at 95% C.L. on the ratio $\sigma(\Xi_{cc}^+)$. $Br(\Xi_{cc}^+ \to A^+_L K^- \pi^+)$/$\sigma(A^+_L)$ to be $1.5 \times 10^{-2}$ and $3.9 \times 10^{-4}$ for lifetimes 100 fs and 400 fs respectively, for an integrated luminosity of 0.65 $\text{ fb}^{-1}$. It is compared with result from Ref. [10,11,23] $\sim 10^{-4} - 10^{-3}$. However, the LHCb did not reach the lifetime measured by the SELEX experiment yet.

As we can see from above recent results review the other experiments also do not seem to manifest discrepancy between the theory and the experimental data in the
properties measured (e.g. small lifetime of the $\Xi^+_{cc}$ is important for interpreting of the LHCb data) by the SELEX experiment.

4 Summary

In our paper we researched the role of intrinsic charm mechanism in the production properties of doubly charmed baryons in the SELEX kinematic region. The intrinsic charm mechanism plays leading role in the production of $\Xi^+_{cc}$. Comparing theoretical prediction of the doubly charmed baryon production cross-section and production cross-section of a pair of charmed quarks in the SELEX kinematic region we found no significant discrepancy between the theory and the SELEX data. The latest experimental data also is in consistency with theoretical predictions and the properties measured (lifetime of the $\Xi^+_{cc}$) by the SELEX experiment.

The authors would like to thank Prof. Stanley Brodsky for pointing out the importance of the intrinsic charm mechanism and Dr. Alexander Rakitin for his friendly support and proofreading the manuscript.

References

1. M. Mattson et al. (SELEX Collaboration), Phys. Rev. Lett. 89, 112001 (2002), [ArXiv:hep-ex/0208014]
2. A. Ocherashvili et al. (SELEX Collaboration), Phys. Lett. B628, 12-24 (2005), [ArXiv:hep-ex/0406033]
3. M. Mattson, Ph.D. thesis, Carnegie Mellon University, 2002.
4. B. Aubert et al. (BaBar Collaboration), Phys. Rev. D75, 012003 (2007), [ArXiv:hep-ex/0609004]
5. J. Beringer et al., Phys. Rev. D86, 010001 (2012).
6. S. Chekanov et al. (ZEUS Collaboration), Eur. Phys. J. C44, 351-366 (2005), [ArXiv:hep-ex/0508019]
7. V. Kiselev and A. Likhoded, Phys. Ups. 45, 455 (2002), [ArXiv:hep-ph/0103169]
8. A. Berezhnoy et al., Phys. Rev. D57, 4385 (1998), [ArXiv:hep-ph/9710339]
9. S. Koshkarev, arXiv:1403.0264
10. C.-H. Chang et al., J.Phys.G34,845 (2007), [ArXiv:hep-ph/0610205]
11. C.-H. Chang et al., Phys. Rev. D73, 094022 (2006), [ArXiv:hep-ph/0601032]
12. R. Vogt, S. Brodsky and P. Hoyer, Nucl. Phys. B360, 67 (1991).
13. S. Brodsky et al., Phys. Lett. 93B, 451-455 (1980).
14. R. Vogt and S. Brodsky, Phys. Lett. B349, 569-575 (1995), [ArXiv:hep-ph/9503206]
15. J. Pumplin et al., JHEP 07, 012 (2002), [ArXiv:hep-ph/0201195]
16. J. Pumplin, Phys. Rev. D73, 114015 (2006), [ArXiv:hep-ph/0508184]
17. A. Belyaev, N. Christensen, A. Pukhov, arXiv:1207.6082
18. J. Alwall et al.,arXiv:1405.0301
19. G. Ingelman, M. Tunnun, Z. Phys. C73, 505-515 (1997), [ArXiv:hep-ph/9604289]
20. Y. Kato et al. (Belle Collaboration), Phys. Rev. D89, 052003 (2014), [arXiv:1312.1026]
21. V. Kiselev, A. Likhoded, M. Shevlyagin, Phys. Lett. B332, 411-414 (1994), [ArXiv:hep-ph/9408407]
22. R. Aaij et al. (LHCb Collaboration), JHEP 12, 090 (2013), [arXiv:1310.2538]
23. D. Günter and V. Saleev, Phys. Atom Nucl. 65, 299-304 (2002), [ArXiv:hep-ph/0104173]