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Study of inclusive di-hadron and production rates of hyperon and charmed baryons in e^+e^- colliders

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The inclusive cross sections for di-hadrons of charged pions and kaons ($e^+e^- \to hhX$), hyperons and charmed baryons in e^+e^- annihilation are reported. For di-hadrons of charged pions and kaons, the cross sections are obtained as a function of the total fractional energy and invariant mass for any di-hadron combination in the same hemisphere and di-hadron fragmentation functions are probed. For hyperons and charmed baryons, the direct production cross sections after subtracting the feeddown contributions from heavy particles are compared for the first time. We also report the first observation of transverse Λ polarization in e^+e^- colliders. The analyses are based on a data set recorded by the Belle detector from e^+e^- collisions produced by the KEKB collider

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1. Introduction

Electron-positron annihilation is a very clean process to study the fragmentation of high-energetic partons into final state hadrons as no hadrons exist in the initial state. The fragmentation functions can only be obtained experimentally since they are nonperturbative objects and cannot even be calculated on the Lattice. Once those fragmentation functions are extracted, they are universal and can be used in other processes such as semi-inclusive DIS or hadron production in hadron collisions where they help to disentagle the nucleon structure. In particular, the participating flavors can be resolved and spin dependent distribution functions can be extracted. Various fragmentation related measurements were extracted from the Belle experiment such as single light hadron cross sections [1], asymmetries of transverse spin dependent fragmentation functions [2, 3] as motivated by theory [4, 5, 6, 7]. These measurements have been already used in various global fits [8, 9, 10, 11, 12, 13, 14, 15] and then were applied to obtain the quark, gluon helicities [16] and transversity [17, 18, 19, 20, 21, 22] from SIDIS and RHIC data. The Belle experiment was operating at the KEKB collider using a 3.5 GeV positron beam colliding with an 8 GeV electron beam. The majority of the data was taken at a center of mass energy of 10.58 GeV in order to produce B mesons from the $\Upsilon(4S)$ resonance where about 75% of the hadronic cross section is produced via continuum production of quark anti-quarks pairs of light and charmed flavors. For comparison a smaller dataset was taken at 10.52 GeV where the Υ resonance cannot contribute. The Belle detector consists of a typical collider detector taking into account the nonzero boost of the center-of-mass system in the laboratory frame.

2. Baryon production

Cross sections differential in the fractional momentum x_p as well as the total production rates were extracted for various hyperons as well as charmed baryons [23]. While the hyperons qualitatively follow the distribution of other light hadrons by rapidly falling off toward higher fractional momenta, the charmed baryons behave differently. They are peaking at relatively high values of around 0.6 to 0.7 with the higher mass particles peaking at higher values. In this behavior they are also consistent with other charmed hadrons where the charm quark keeps a large fraction of its energy when fragmenting into a charmed hadron. In contrast, for light hadrons the quarks found in any particular hadron do not necessarily be the same as the fragmenting parton and therefore much lower fractional momenta are more common. In addition, also the polarizing fragmentation of a Λ was measured to be nonzero [24]. This polarizing fragmentation function is of substantial theoretical interest as it is the fragmentation counterpart to the Sivers distribution function. This measurement suggests, that different parton flavors fragmenting into a Λ produce different polarization. When correlating the polarization of the Λ with a detected pion or kaon in the opposing hemisphere, on sees the polarizations even have different signs particularly at low fractional energies of the Λ where strange quark fragmentation is not the dominating contribution. At higher fractional energies, strange quark fragmentation becomes more relevant and the polarizations show the same sign for both pion charge combintations.

3. Di-hadron production

Belle has also measured di-hadron fragmentation functions as a function of the fractional energies of the two hadrons [25]. The measurements can be separated into those where the two hadrons appear in the same hemisphere as given by the thrust axis, or in opposite hemispheres. In the same hemisphere both hadrons can be considered to be originating from the same parton as their fractional energy sum does not exceed unity. Two hadrons in opposite hemispheres can be considered as originating from different partons as their energy sum reaches up to two. In the latter case one can use the different charge and hadron type combinations to gain access to the flavor information in fragmentation which is normally inaccessible in single hadron framentation in e^+e^- annihilation due to the sum over all kinematically available quark and antiquark flavors. For the same-hemisphere di-hadrons also the cross sections as a function of invariant mass and combined fractional energy is of interest as it provides the unpolarized baseline for the previously measured chiral-odd interference fragmentation function. The combination of these two fragmentation functions is very relevant to accessing the quark transversity distribution in SIDIS [19, 20] and at RHIC [22]. Belle has measured the di-hadron cross sections for all 6 charge and hadron type combinations (for pions and kaons) [26]. The invariant mass behavior of opposite sign hadrons shows the typical di-hadron resonances such as ρ, K^*, Φ as well as various weakly decaying ones such as K_S^0 and D^0 if one choses not to remove weak decays. The same sign hadron pairs generally show smooth distributions as now resonating peaks are expected although in all charge combinations smaller bumps are visible. These are related to hadrons coming from different steps in the decay chain of heavier, particularly charmed resonances. The pion pair cross sections as a function of invariant mass and fractional energy z are displayed in Fig. 1.

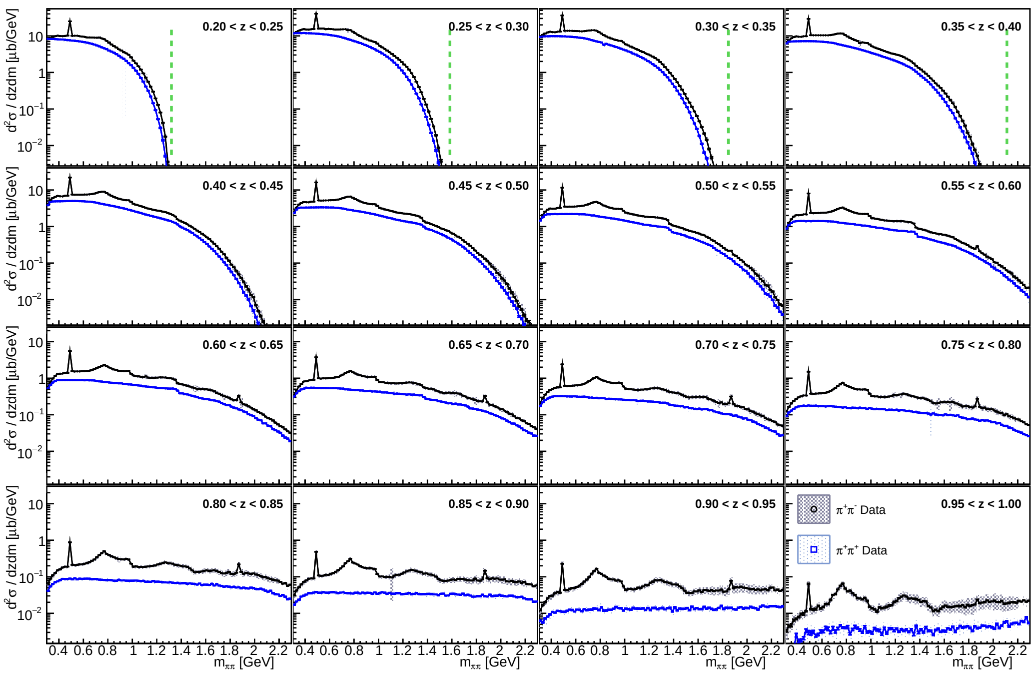

Figure 1: Opposite sign (black circles) and same sign (blue squares) dipion cross sections as a function of invariant mass in bins of z.

4. Outlook

Apart from the discussed measurements, various other are currently ongoing. Of the highest interest for the theoretical community are the transverse momentum dependent fragmentation functions which can be accessed in electron-positron annihilation in different ways. One way selects only a single hadron in the final state and calculates the transverse momentum of this hadron with respect to the thrust axis. Another possibility is to study the relative transverse momentum between two hadrons in opposite hemispheres where a convolution over the transverse momentum of two fragmentation functions is present. Both of these types of analysis are currently ongoing and are expected to be finalized soon while various other fragmentation related studies continue.

References

[1] M. Leitgab *et al.* [Belle Collaboration], Phys. Rev. Lett. **111**, 062002 (2013)

[2] R. Seidl *et al.* (Belle Collaboration), Phys. Rev. Lett. **96**, 232002 (2006) R. Seidl *et al.* (Belle Collaboration), Phys. Rev. D **78**, 032011 (2008); Erratum-ibid. D **86**, 039905 (2012)

[3] A. Vossen *et al.* (Belle Collaboration), Phys. Rev. Lett. **107**, 072004 (2011)

[4] J. C. Collins, Nucl. Phys. **B396**, 161 (1993)

[5] J. C. Collins, S. F. Heppelmann and G. A. Ladinsky, Nucl. Phys. **B420**, 565 (1994)

[6] M. Radici, R. Jakob and A. Bianconi, Phys. Rev. D **65**, 074031 (2002)

[7] D. Boer *et al.*, Phys. Rev. D **67**, 094003 (2003), D. Boer, Nucl. Phys. **B806**, 23 (2009)

[8] D. de Florian *et al.*Phys. Rev. D **91**, 014035 (2015).

[9] D. de Florian *et al.*Phys. Rev. D **95**, 094019 (2017).

[10] N. Sato *et al.* Phys. Rev. D **94**, no. 11, 114004 (2016).

[11] V. Bertone *et al.* [NNPDF Collaboration], Eur. Phys. J. C **78**, no. 8, 651 (2018).

[12] M. Anselmino, *et al.*, Phys. Rev. D **75**, 054032 (2007)

[13] Z. B. Kang, A. Prokudin, P. Sun and F. Yuan, Phys. Rev. D **93**, 014009 (2016)

[14] M. Anselmino, *et al.*, Phys. Rev. D **93**, 034025 (2016)

[15] A. Bacchetta, A. Courtoy and M. Radici, Phys. Rev. Lett. **107**, 012001 (2011) M. Radici, A. Courtoy, A. Bacchetta and M. Guagnelli, JHEP **1505**, 123 (2015)

[16] A. Adare *et al.* [PHENIX Collaboration], Phys. Rev. D **93**, no. 1, 011501 (2016).

[17] A. Airapetian *et al.* (HERMES Collaboration), Phys. Rev. Lett. **94**, 012002 (2005)

[18] C. Adolph *et al.* (COMPASS Collaboration), Phys. Lett. B **717**, 376 (2012)

[19] A. Airapetian *et al.* (HERMES Collaboration), JHEP **0806**, 017 (2008)

[20] C. Adolph *et al.* (COMPASS Collaboration), Phys. Lett. B **736**, 124 (2014)

[21] J. K. Adkins *et al.* (STAR Collaboration), Int. J. Mod. Phys. Conf. Ser. **40**, 1660040 (2016).

[22] L. Adamczyk *et al.* (STAR Collaboration), Phys. Rev. Lett. **115**, 242501 (2015)

[23] M. Niiyama *et al.* [Belle Collaboration], Phys. Rev. D **97**, no. 7, 072005 (2018)

[24] Y. Guan *et al.* [Belle Collaboration], arXiv:1808.05000 [hep-ex].

[25] R. Seidl *et al.* [Belle Collaboration], Phys. Rev. D **92**, no. 9, 092007 (2015)

[26] R. Seidl *et al.* [Belle Collaboration], Phys. Rev. D **96**, no. 3, 032005 (2017)