

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

## Probing transversity by measuring $\Lambda$ polarisation in SIDIS

### This is the author's manuscript

*Original Citation:*

*Availability:*

This version is available <http://hdl.handle.net/2318/1893015> since 2023-02-17T10:19:14Z

*Published version:*

DOI:10.1016/j.physletb.2021.136834

*Terms of use:*

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

# Probing transversity by measuring $\Lambda$ polarisation in SIDIS

The COMPASS Collaboration

G. D. Alexeev<sup>g</sup>, M. G. Alexeev<sup>z,aa</sup>, A. Amoroso<sup>z,aa</sup>, V. Andrieux<sup>i,ab</sup>, V. Anosov<sup>g</sup>, K. Augsten<sup>g,r</sup>, W. Augustyniak<sup>ac</sup>, C. D. R. Azevedo<sup>a</sup>, B. Badełek<sup>ad</sup>, F. Balestra<sup>z,aa</sup>, M. Ball<sup>c</sup>, J. Barth<sup>c</sup>, R. Beck<sup>c</sup>, Y. Bedfer<sup>t</sup>, J. Berenguer Antequera<sup>z,aa</sup>, J. Bernhard<sup>l,i</sup>, M. Bodlak<sup>q</sup>, F. Bradamante<sup>y</sup>, A. Bressan<sup>x,y</sup>, V. E. Burtsev<sup>w</sup>, W.-C. Chang<sup>u</sup>, C. Chatterjee<sup>x,y</sup>, M. Chiosso<sup>z,aa</sup>, A. G. Chumakov<sup>w</sup>, S.-U. Chung<sup>o,1,2</sup>, A. Cicuttin<sup>y,3</sup>, P. M. M. Correia<sup>a</sup>, M. L. Crespo<sup>y,3</sup>, D. D'Agostino<sup>x,y</sup>, S. Dalla Torre<sup>y</sup>, S. S. Dasgupta<sup>f</sup>, S. Dasgupta<sup>y</sup>, I. Denisenko<sup>g</sup>, O. Yu. Denisov<sup>aa</sup>, S. V. Donskov<sup>s</sup>, N. Doshita<sup>af</sup>, Ch. Dreisbach<sup>o</sup>, W. Dünnweber<sup>4</sup>, R. R. Dusaev<sup>w</sup>, A. Efremov<sup>g,12</sup>, C. Elia<sup>x,y</sup>, D. Eremeev<sup>s</sup>, P. D. Eversheim<sup>c</sup>, P. Faccioli<sup>k</sup>, M. Faessler<sup>4</sup>, A. Ferrero<sup>t</sup>, M. Finger<sup>q</sup>, M. Finger jr.<sup>q</sup>, H. Fischer<sup>h</sup>, K. J. Flöthner<sup>c</sup>, C. Franco<sup>k</sup>, J. M. Friedrich<sup>o</sup>, V. Frolov<sup>g,i</sup>, L.G. Garcia Ordóñez<sup>y,3</sup>, F. Gautheron<sup>b,ab</sup>, O. P. Gavrichtchouk<sup>g</sup>, S. Gerassimov<sup>n,o</sup>, J. Giarrà<sup>l</sup>, D. Giordano<sup>z,aa</sup>, I. Gnesi<sup>z,aa</sup>, M. Gorzellik<sup>h,6</sup>, A. Grasso<sup>z,aa</sup>, A. Gridin<sup>g</sup>, M. Grosse Perdekamp<sup>ab</sup>, B. Grube<sup>o</sup>, A. Guskov<sup>g</sup>, D. von Harrach<sup>l</sup>, R. Heitz<sup>ab</sup>, M. Hoffmann<sup>c</sup>, N. Horikawa<sup>p,7</sup>, N. d'Hose<sup>t</sup>, C.-Y. Hsieh<sup>u,8</sup>, S. Huber<sup>o</sup>, S. Ishimoto<sup>af,9</sup>, A. Ivanov<sup>g</sup>, T. Iwata<sup>af</sup>, M. Jandek<sup>r</sup>, V. Jary<sup>f</sup>, R. Joosten<sup>c,\*</sup>, E. Kabuβ<sup>l</sup>, D.-H. Kang<sup>1</sup>, F. Kaspar<sup>o</sup>, A. Kerbizi<sup>x,y</sup>, B. Ketzer<sup>c</sup>, G. V. Khaustov<sup>s</sup>, Yu. A. Khokhlov<sup>s,11</sup>, Yu. Kisselev<sup>g,12</sup>, F. Klein<sup>d</sup>, J. H. Koivuniemi<sup>b,ab</sup>, V. N. Kolosov<sup>s</sup>, K. Kondo Horikawa<sup>af</sup>, I. Konorov<sup>n,o</sup>, V. F. Konstantinov<sup>s</sup>, A. M. Kotzinian<sup>aa,13</sup>, O. M. Kouznetsov<sup>g</sup>, A. Koval<sup>ac</sup>, Z. Kral<sup>q</sup>, F. Krinner<sup>o</sup>, Y. Kulinich<sup>ab</sup>, F. Kunne<sup>l</sup>, K. Kurek<sup>ac</sup>, R. P. Kurjata<sup>ae</sup>, A. Kveton<sup>q</sup>, K. Lavickova<sup>r</sup>, S. Levorato<sup>i,y</sup>, Y.-S. Lian<sup>u,14</sup>, J. Lichtenstadt<sup>v</sup>, P.-J. Lin<sup>t,15</sup>, R. Longo<sup>ab</sup>, V. E. Lyubovitskij<sup>w,16</sup>, A. Maggiora<sup>aa</sup>, A. Magnon<sup>f</sup>, N. Makins<sup>ab</sup>, N. Makke<sup>y,3</sup>, G. K. Mallot<sup>i,h</sup>, A. Maltsev<sup>g</sup>, S. A. Mamon<sup>w</sup>, B. Marianski<sup>ac,12</sup>, A. Martin<sup>x,y</sup>, J. Marzec<sup>ae</sup>, J. Matoušek<sup>q,y</sup>

\*Corresponding authors

Email addresses: rainer.joosten@cern.ch (R. Joosten), andrea.moretti@cern.ch (A. Moretti), bakur.parsamyan@cern.ch

(B. Parsamyan), fulvio.tessarotto@cern.ch (F. Tessarotto)

<sup>1</sup> Also at Dept. of Physics, Pusan National University, Busan 609-735, Republic of Korea

<sup>2</sup> Also at Physics Dept., Brookhaven National Laboratory, Upton, NY 11973, USA

<sup>3</sup> Also at Abdus Salam ICTP, 34151 Trieste, Italy

<sup>4</sup> Supported by the DFG cluster of excellence 'Origin and Structure of the Universe' ([www.universe-cluster.de](http://www.universe-cluster.de)) (Germany)

<sup>5</sup> Supported by CERN-RFBR Grant 12-02-91500

<sup>6</sup> Supported by the DFG Research Training Group Programmes 1102 and 2044 (Germany)

<sup>7</sup> Also at Chubu University, Kasugai, Aichi 487-8501, Japan

<sup>8</sup> Also at Dept. of Physics, National Central University, 300 Jhongda Road, Jhongli 32001, Taiwan

<sup>9</sup> Also at KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

<sup>10</sup> Present address: Universität Bonn, Physikalisches Institut, 53115 Bonn, Germany

<sup>11</sup> Also at Moscow Institute of Physics and Technology, Moscow Region, 141700, Russia

<sup>12</sup> Deceased

<sup>13</sup> Also at Yerevan Physics Institute, Alikhanian Br. Street, Yerevan, Armenia, 0036

<sup>14</sup> Also at Dept. of Physics, National Kaohsiung Normal University, Kaohsiung County 824, Taiwan

<sup>15</sup> Supported by ANR, France with P2IO LabEx (ANR-10-LABX-0038) in the framework "Investissements d'Avenir" (ANR-11-IDEX-0003-01)

<sup>16</sup> Also at Institut für Theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany

<sup>17</sup> Present address: Brookhaven National Laboratory, Brookhaven, USA

<sup>18</sup> Also at University of Eastern Piedmont, 15100 Alessandria, Italy

<sup>19</sup> Present address: RWTH Aachen University, III. Physikalisches Institut, 52056 Aachen, Germany

<sup>20</sup> Present address: Universität Hamburg, 20146 Hamburg, Germany

<sup>21</sup> Supported by BMBF - Bundesministerium für Bildung und Forschung (Germany)

<sup>22</sup> Supported by FP7, HadronPhysics3, Grant 283286 (European Union)

<sup>23</sup> Supported by MEYS, Grant LM20150581 (Czech Republic)

<sup>24</sup> Supported by B. Sen fund (India)

<sup>25</sup> Supported by FCT, Grants CERN/FIS-PAR/0007/2017 and CERN/FIS-PAR/0022/2019 (Portugal)

<sup>26</sup> Supported by MEXT and JSPS, Grants 18002006, 20540299, 18540281 and 26247032, the Daiko and Yamada Foundations (Japan)

<sup>27</sup> Supported by the Ministry of Science and Technology (Taiwan)

<sup>28</sup> Supported by the Israel Academy of Sciences and Humanities (Israel)

<sup>29</sup> Supported by the Russian Federation program "Nauka" (Contract No. 0.1764.GZB.2017) (Russia)

<sup>30</sup> Supported by the National Science Foundation, Grant no. PHY-1506416 (USA)

<sup>31</sup> Supported by NCN, Grant 2017/26/M/ST2/00498 (Poland)

T. Matsuda<sup>m</sup>, G. Mattson<sup>ab</sup>, G. V. Meshcheryakov<sup>g</sup>, F. Metzger<sup>c</sup>, M. Meyer<sup>ab,t</sup>, W. Meyer<sup>b</sup>, Yu. V. Mikhailov<sup>s</sup>, M. Mikhayenko<sup>c,i</sup>, E. Mitrofanov<sup>g</sup>, Y. Miyachi<sup>af</sup>, A. Moretti<sup>x,y,\*</sup>, A. Nagaytsev<sup>g</sup>, C. Naim<sup>t</sup>, T.S. Negrini<sup>c</sup>, D. Neyret<sup>t</sup>, J. Nový<sup>r</sup>, W.-D. Nowak<sup>l</sup>, G. Nukazuka<sup>af</sup>, A. S. Nunes<sup>k,17</sup>, A. G. Olshevsky<sup>g</sup>, M. Ostrick<sup>l</sup>, D. Panziera<sup>aa,18</sup>, B. Parsamyan<sup>aa,g,\*</sup>, S. Paul<sup>o</sup>, H. Pekolet<sup>c</sup>, J.-C. Peng<sup>ab</sup>, M. Pešek<sup>q</sup>, D. V. Peshekhonov<sup>g</sup>, M. Pešková<sup>q</sup>, N. Pierre<sup>lt</sup>, S. Platchkov<sup>t</sup>, J. Pochodzalla<sup>l</sup>, V. A. Polyakov<sup>s</sup>, J. Pretz<sup>d,19</sup>, M. Quaresima<sup>u,k</sup>, C. Quintans<sup>k</sup>, G. Reicherz<sup>b</sup>, C. Riedl<sup>ab</sup>, T. Rudnicki<sup>ad</sup>, D. I. Ryabchikov<sup>s,o</sup>, A. Rychter<sup>ae</sup>, A. Rymbekova<sup>g</sup>, V. D. Samoylenko<sup>s</sup>, A. Sandacz<sup>ac</sup>, S. Sarkar<sup>f</sup>, I. A. Savin<sup>g</sup>, G. Sbrizzai<sup>x,y</sup>, P. Schiavon<sup>x,y</sup>, H. Schmieden<sup>d</sup>, A. Selyunin<sup>g</sup>, K. Sharko<sup>w</sup>, L. Sinha<sup>f</sup>, M. Slunicka<sup>g,q</sup>, J. Smolik<sup>g</sup>, F. Sozzi<sup>y</sup>, A. Srnka<sup>e</sup>, D. Steffen<sup>i,o</sup>, M. Stolarski<sup>k</sup>, O. Subri<sup>ir</sup>, M. Sulc<sup>j</sup>, H. Suzuki<sup>af,7</sup>, P. Sznajder<sup>ac</sup>, S. Tessaro<sup>y</sup>, F. Tessarotto<sup>i,y,\*</sup>, A. Thiel<sup>c</sup>, J. Tomsa<sup>q</sup>, F. Tosello<sup>aa</sup>, A. Townsend<sup>ab</sup>, V. Tskhay<sup>n</sup>, S. Uhl<sup>o</sup>, B. I. Vasilishin<sup>w</sup>, A. Vauth<sup>d,i,20</sup>, B. M. Veit<sup>li</sup>, J. Veloso<sup>a</sup>, B. Ventura<sup>t</sup>, A. Vidon<sup>t</sup>, M. Virius<sup>r</sup>, M. Wagner<sup>c</sup>, S. Wallner<sup>o</sup>, K. Zaremba<sup>ae</sup>, P. Zavada<sup>g</sup>, M. Zavertyaev<sup>n</sup>, M. Zemko<sup>i,q</sup>, E. Zemlyanichkina<sup>g</sup>, Y. Zhao<sup>y</sup>, M. Ziembicki<sup>ae</sup>

<sup>a</sup>University of Aveiro, I3N, Dept. of Physics, 3810-193 Aveiro, Portugal

<sup>b</sup>Universität Bochum, Institut für Experimentalphysik, 44780 Bochum, Germany<sup>21,22</sup>

<sup>c</sup>Universität Bonn, Helmholtz-Institut für Strahlen- und Kernphysik, 53115 Bonn, Germany<sup>21</sup>

<sup>d</sup>Universität Bonn, Physikalisches Institut, 53115 Bonn, Germany<sup>21</sup>

<sup>e</sup>Institute of Scientific Instruments of the CAS, 61264 Brno, Czech Republic<sup>23</sup>

<sup>f</sup>Matrivani Institute of Experimental Research & Education, Calcutta-700 030, India<sup>24</sup>

<sup>g</sup>Joint Institute for Nuclear Research, 141980 Dubna, Moscow region, Russia<sup>5</sup>

<sup>h</sup>Universität Freiburg, Physikalisches Institut, 79104 Freiburg, Germany<sup>21,22</sup>

<sup>i</sup>CERN, 1211 Geneva 23, Switzerland

<sup>j</sup>Technical University in Liberec, 46117 Liberec, Czech Republic<sup>23</sup>

<sup>k</sup>LIP, 1649-003 Lisbon, Portugal<sup>25</sup>

<sup>l</sup>Universität Mainz, Institut für Kernphysik, 55099 Mainz, Germany<sup>21</sup>

<sup>m</sup>University of Miyazaki, Miyazaki 889-2192, Japan<sup>26</sup>

<sup>n</sup>Lebedev Physical Institute, 119991 Moscow, Russia

<sup>o</sup>Technische Universität München, Physik Dept., 85748 Garching, Germany<sup>21,4</sup>

<sup>p</sup>Nagoya University, 464 Nagoya, Japan<sup>26</sup>

<sup>q</sup>Charles University, Faculty of Mathematics and Physics, 12116 Prague, Czech Republic<sup>23</sup>

<sup>r</sup>Czech Technical University in Prague, 16636 Prague, Czech Republic<sup>23</sup>

<sup>s</sup>State Scientific Center Institute for High Energy Physics of National Research Center 'Kurchatov Institute', 142281 Protvino, Russia

<sup>t</sup>IRFU, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France<sup>22</sup>

<sup>u</sup>Academia Sinica, Institute of Physics, Taipei 11529, Taiwan<sup>27</sup>

<sup>v</sup>Tel Aviv University, School of Physics and Astronomy, 69978 Tel Aviv, Israel<sup>28</sup>

<sup>w</sup>Tomsk Polytechnic University, 634050 Tomsk, Russia<sup>29</sup>

<sup>x</sup>University of Trieste, Dept. of Physics, 34127 Trieste, Italy

<sup>y</sup>Trieste Section of INFN, 34127 Trieste, Italy

<sup>z</sup>University of Turin, Dept. of Physics, 10125 Turin, Italy

<sup>aa</sup>Torino Section of INFN, 10125 Turin, Italy

<sup>ab</sup>University of Illinois at Urbana-Champaign, Dept. of Physics, Urbana, IL 61801-3080, USA<sup>30</sup>

<sup>ac</sup>National Centre for Nuclear Research, 02-093 Warsaw, Poland<sup>31</sup>

<sup>ad</sup>University of Warsaw, Faculty of Physics, 02-093 Warsaw, Poland<sup>31</sup>

<sup>ae</sup>Warsaw University of Technology, Institute of Radioelectronics, 00-665 Warsaw, Poland<sup>31</sup>

<sup>af</sup>Yamagata University, Yamagata 992-8510, Japan<sup>26</sup>

---

## Abstract

Based on the observation of sizeable target-transverse-spin asymmetries in single-hadron and hadron-pair production in Semi-Inclusive measurements of Deep Inelastic Scattering (SIDIS), the chiral-odd transversity quark distribution functions  $h_1^q$  are nowadays well established. Several possible channels to access these functions were originally proposed. One candidate is the measurement of the polarisation of  $\Lambda$  hyperons produced in SIDIS off transversely polarised nucleons, where the transverse polarisation of the struck quark might be transferred to the final-state hyperon. In this article, we present the COMPASS results on the transversity-induced polarisation of  $\Lambda$  and  $\bar{\Lambda}$  hyperons produced in SIDIS off transversely polarised protons. Within the experimental uncertainties, no significant deviation from zero was observed. The results are discussed in the context of different models taking into account previous experimental results on  $h_1^u$  and  $h_1^d$ .

**Keywords:** Quantum chromodynamics, deep-inelastic scattering, lambda polarisation, transversity, COMPASS

---

## 1. Introduction

The chiral-odd transversity quark distribution functions  $h_1^q(x)$ , hereafter referred to as transversity, were introduced as independent Parton Distribution Functions (PDFs) of the nucleon several decades ago [1–4]. Here, the superscript  $q$  denotes the quark flavour and  $x$  is the Bjorken variable. Several experimental approaches were proposed to access transversity in Semi-Inclusive measurements of Deep Inelastic Scattering (SIDIS) off transversely polarised nucleons.

Two of these approaches, the measurements of Collins asymmetries [5–8] and of azimuthal asymmetries of hadron pairs produced on transversely polarised protons [9–11], provided convincing evidence that transversity is indeed accessible experimentally. For  $u$ - and  $d$ -quarks, transversity was found to be different from zero at large  $x$ , where  $h_1^u(x)$  and  $h_1^d(x)$  are almost of the same size but opposite in sign, while  $h_1^{\bar{u}}$  and  $h_1^{\bar{d}}$  were found compatible with zero [12–16]. However, the uncertainties for the  $d(\bar{d})$ -quark are about a factor of 3(2) larger than the uncertainties for the  $u(\bar{u})$ -quark, due to the unbalance of the existing proton and deuteron data.

A third approach, independent from the previous two, is the SIDIS measurement of the polarisation of baryons produced in the process  $\ell p^\uparrow \rightarrow \ell B^\uparrow X$ , where  $\ell$  denotes a lepton,  $p^\uparrow$  a transversely polarised target proton and  $B$  a baryon [2, 17–19]. In the one-photon-exchange approximation, the hard interaction is  $\gamma^* q^\uparrow \rightarrow q'^\uparrow$ . When the virtual photon  $\gamma^*$  interacts with a transversely polarised quark  $q$ , the struck quark  $q'$  has a certain probability to transfer a fraction of the initial transverse polarisation to the final-state baryon. Thus a measurement of the polarisation of the final-state baryon along the spin direction of the outgoing quark allows access to transversity [20, 21].

Among all baryons,  $\Lambda(\bar{\Lambda})$  hyperons are most suited to polarimetry studies due to their self-analysing weak decay into charged hadrons,  $\Lambda \rightarrow p\pi^-$  ( $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ ), which occurs with a branching ratio  $BR = 63.9\%$ . The polarisation  $P_{\Lambda(\bar{\Lambda})}$  is accessible through the modulation of the angular distribution of the decay protons (antiprotons) [22]:

$$\frac{dN_{p(\bar{p})}}{d\cos\theta} \propto 1 + \alpha_{\Lambda(\bar{\Lambda})} P_{\Lambda(\bar{\Lambda})} \cos\theta, \quad (1)$$

where  $\theta$  is the proton (antiproton) emission angle with respect to the polarisation axis of the fragmenting quark in the  $\Lambda(\bar{\Lambda})$  rest frame and  $\alpha_{\Lambda(\bar{\Lambda})}$  is the weak decay constant. For the analysis presented in this paper, we use the most recent values of  $\alpha_{\Lambda(\bar{\Lambda})}$  [23], i.e.,  $\alpha_\Lambda = 0.750 \pm 0.009$  and  $\alpha_{\bar{\Lambda}} = -0.758 \pm 0.010$ .

As polarisation axis to access transversity we use the same that was used in QED calculations [24] for  $\gamma^*$  absorption. Accordingly, the components of the quark spins in initial ( $S_T$ ) and final ( $S'_T$ ) state in the  $\gamma^*$ -nucleon system are connected by

$$S'_{T,x} = -D_{NN} S_{T,x} \quad \text{and} \quad S'_{T,y} = D_{NN} S_{T,y}, \quad (2)$$

where as  $z$ -axis the virtual-photon direction is taken and as  $y$ -axis the normal to the lepton scattering ( $xz$ ) plane (see Fig. 1). The virtual-photon depolarisation factor  $D_{NN}(y) = 2(1-y)/(1-y)^2$  depends on  $y$ , the fraction of the initial lepton energy

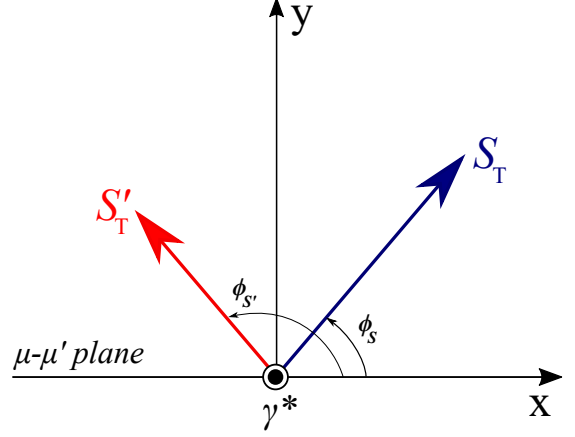


Figure 1: Definition of the reference axes: The initial ( $S_T$ ) and final ( $S'_T$ ) transverse quark spin-polarisation vectors are shown with respect to the  $\mu - \mu'$  scattering plane.

carried by the virtual photon in the target rest frame. The polarisation direction  $S'_T$  of the fragmenting quark is obtained as the reflection of the initial quark polarisation  $S_T$  with respect to the  $y$ -axis.

In the collinear approximation, where the intrinsic transverse momentum of the struck quark is assumed to be negligible, and in the current fragmentation region the leading-order expression for the transversity-induced  $\Lambda(\bar{\Lambda})$  polarisation integrated over the hadron transverse momentum  $p_T$  reads [20]:

$$P_{\Lambda(\bar{\Lambda})}(x, z, Q^2) = \frac{d\sigma^{\ell p^\uparrow \rightarrow \ell' \Lambda(\bar{\Lambda})^\uparrow X} - d\sigma^{\ell p^\uparrow \rightarrow \ell' \Lambda(\bar{\Lambda})^\downarrow X}}{d\sigma^{\ell p^\uparrow \rightarrow \ell' \Lambda(\bar{\Lambda})^\uparrow X} + d\sigma^{\ell p^\uparrow \rightarrow \ell' \Lambda(\bar{\Lambda})^\downarrow X}} = f P_T D_{NN}(y) \frac{\sum_q e_q^2 h_1^q(x, Q^2) H_{1,q}^{\Lambda(\bar{\Lambda})}(z, Q^2)}{\sum_q e_q^2 f_1^q(x, Q^2) D_{1,q}^{\Lambda(\bar{\Lambda})}(z, Q^2)}. \quad (3)$$

Here,  $Q^2$  is the photon virtuality and  $z$  the fraction of the virtual photon energy carried by the  $\Lambda(\bar{\Lambda})$  hyperon in the target rest frame;  $P_T$  is the target polarisation and  $f$  the target dilution factor representing the fraction of nucleons effectively polarised in the target. The sums in Eq.(3) run over all quark and antiquark flavours. The transversity distribution functions  $h_1^q(x, Q^2)$  appear coupled to the chiral-odd fragmentation functions  $H_{1,q}^{\Lambda(\bar{\Lambda})}(z, Q^2)$  that describe the spin transfer from the struck quark to the  $\Lambda(\bar{\Lambda})$  hyperon:

$$H_{1,q}^{\Lambda(\bar{\Lambda})}(z, Q^2) = D_{1,q^\uparrow}^{\Lambda(\bar{\Lambda})^\uparrow}(z, Q^2) - D_{1,q^\uparrow}^{\Lambda(\bar{\Lambda})^\downarrow}(z, Q^2). \quad (4)$$

The up and down arrows indicate the polarisation directions for the  $\Lambda(\bar{\Lambda})$  along the  $S'_T$  axis. The polarisation-independent fragmentation functions  $D_{1,q}^{\Lambda(\bar{\Lambda})}(z, Q^2)$  are given by

$$D_{1,q}^{\Lambda(\bar{\Lambda})}(z, Q^2) = D_{1,q^\uparrow}^{\Lambda(\bar{\Lambda})^\uparrow}(z, Q^2) + D_{1,q^\uparrow}^{\Lambda(\bar{\Lambda})^\downarrow}(z, Q^2). \quad (5)$$

Evidently, this approach gives access to transversity only if at least a part of the quark spin is transferred to the final state

74 hadron, i.e. if  $H_{1,q}^{\Lambda(\bar{\Lambda})}(z, Q^2) \neq 0$ . Alternatively, once transversity is known,  $P_{\Lambda(\bar{\Lambda})}$  can be used to shed light on the size of the  
 75 transverse-spin-dependent quark fragmentation function.  
 76

77 The expression in Eq. 3 is valid at twist-2. In this work, we  
 78 do not take into account higher-order terms [25], among which  
 79 there is the one related to the spontaneous polarization [26].  
 80 As they are not oriented along the  $S_T'$  axis, their contribution is  
 81 anyway expected to average to zero. Analogously, working -as  
 82 said- in the collinear approximation, we refrain from consider-  
 83 ing possible  $k_T$ -related terms [27] dependent on the azimuthal  
 84 angle  $\phi$  of the  $\Lambda(\bar{\Lambda})$  hyperon and on  $\phi_S^1$ .

85 In general,  $P_{\Lambda(\bar{\Lambda})}$  is not directly accessible from experimen-  
 86 tal data, as the detector acceptance distorts the angular distribu-  
 87 tions. Therefore, the measured angular distributions become

$$\frac{dN_{p(\bar{p})}}{d\cos\theta} \propto (1 + \alpha_{\Lambda(\bar{\Lambda})} P_{\Lambda(\bar{\Lambda})} \cos\theta) \cdot A(\theta), \quad (6)$$

88 where  $A(\theta)$  is the detector acceptance depending on  $\theta$ , which  
 89 generally would have to be studied via detailed Monte Carlo  
 90 simulations. However, in the COMPASS experiment [28] the  
 91 specific target setup offers the unique opportunity to measure  
 92 the transversity-induced polarisation avoiding acceptance cor-  
 93 rections (see Sec. 3).

94 The analysis presented here was performed using the data  
 95 collected by COMPASS in 2007 and 2010 with a 160 GeV/c  
 96 longitudinally polarised muon beam from the CERN SPS and  
 97 a transversely polarised NH<sub>3</sub> target with proton polarisation  
 98  $\langle P_T \rangle = 0.80$  and dilution factor  $\langle f \rangle = 0.15$ . In an earlier  
 99 analysis, the  $\Lambda(\bar{\Lambda})$  polarisation from the 2002-2004 data with  
 100 a transversely polarised deuteron target [29] was found to be  
 101 compatible with zero, as expected from the cancellation of  $u$   
 102 and  $d$  quark transversity (see Sec. 4.3). This measurement,  
 103 however, suffered from limitations in statistical power and in  
 104 spectrometer acceptance and from the lack of particle identi-  
 105 fication for a part of the data set. In this respect, the upcom-  
 106 ing 2021/2022 run using a transversely polarised deuteron tar-  
 107 get [30] will be of great importance in drawing more definite  
 108 conclusions.

## 109 2. Data selection and available statistics

110 In the data analysis, events are selected if they have at least  
 111 one primary vertex, defined as the intersection point of a beam  
 112 track, the scattered muon track, and other possible outgoing  
 113 tracks. The primary vertex is required to be inside a target cell.  
 114 The target consists of three cylindrical cells with 4 cm diameter,  
 115 a central one of 60 cm and two outer ones of 30 cm length, each  
 116 separated by 5 cm. Consecutive cells are polarised in opposite  
 117 directions, so that data with both spin directions are recorded at  
 118 the same time [7]. The extrapolated beam track is required to  
 119 traverse all three target cells to ensure equal muon flux through

120 the full target. Events originating from deep inelastic scattering  
 121 are selected by requiring  $Q^2 > 1 \text{ (GeV/c)}^2$ . For the invariant  
 122 mass of the final state produced in the interaction of virtual-  
 123 photon and nucleon,  $W > 5 \text{ GeV/c}^2$  is required to avoid the  
 124 region of exclusive resonance production. Furthermore the con-  
 125 straints  $0.003 < x < 0.7$  and  $0.1 < y < 0.9$  are applied. Here,  
 126 the upper limit in  $x$  avoids a region of low statistics, and in  $y$  the  
 127 limits avoid large radiative corrections and contamination from  
 128 final-state pion decay (upper limit) and warrant a good determi-  
 129 nation of  $y$  (lower limit).

130 The  $\Lambda$  and  $\bar{\Lambda}$  reconstruction is based on the detection of their  
 131 decay products that originate from a decay vertex ( $V^0$ ) down-  
 132 stream of the production vertex, which is not connected to the  
 133 latter by charged tracks. Due to the long  $\Lambda$  lifetime,  $\tau = (2.632 \pm$   
 134  $0.020) \cdot 10^{-10} \text{ s}$ , both vertices can be well separated. Exactly  
 135 two oppositely charged hadrons with momentum larger than 1  
 136 GeV/c are required to originate from the decay vertex; the re-  
 137 constructed momentum vector for such a hadron pair is required  
 138 to be aligned with the vector linking the production and the de-  
 139 cay vertices within a collinearity angle  $\theta_{\text{coll}} \leq 7 \text{ mrad}$ . In order  
 140 to suppress background from photon conversion  $\gamma \rightarrow e^+e^-$ ,  
 141 the transverse momentum  $p_{\perp}$  of each hadron, calculated with  
 142 respect to the line-of-flight of the hadron pair in its rest frame,  
 143 has to be larger than 23 MeV/c.

144 Particle identification is performed using the RICH detec-  
 145 tor. In order to limit the ambiguity between  $\Lambda(\bar{\Lambda})$  hyperons and  
 146  $K_s^0$  mesons decaying into  $\pi^+\pi^-$ , it is necessary to ensure that  
 147 the positive (negative) daughter particle is a proton (antipro-  
 148 ton). However, a direct identification would drastically reduce  
 149 the available statistics due to the high Cherenkov threshold for  
 150 protons of about 20 GeV/c for the radiator gas used (C<sub>4</sub>F<sub>10</sub>).  
 151 Therefore, assuming one charged track as negative (positive)  
 152 pion, the corresponding positive (negative) track is considered  
 153 to be a proton (anti-proton) unless it is identified as positive  
 154 (negative) electron, pion or kaon. The particle identification  
 155 procedure is the same as it was used in previous analyses [31].  
 156 It is based on the calculation of the maximum likelihood  $\mathcal{L}$  for  
 157 four mass hypotheses ( $e, K, \pi, p$ ) and for the background, given  
 158 the number of collected Cherenkov photons. In order to at-  
 159 tribute a mass hypothesis  $M$  to a particle,  $\mathcal{L}_M$  is requested to  
 160 be the highest and its ratio to the background hypothesis to be  
 161 larger than an optimised threshold. This approach is applied  
 162 to particles with momentum up to 50 GeV/c, a value at which  
 163 pion/kaon separation becomes difficult. Beyond this limit, the  
 164 highest likelihood is required not to be the one associated to the  
 165 pion or kaon mass hypothesis.

166  
 167 The Armenteros-Podolanski plot [32, 33] obtained after all  
 168 aforementioned selection steps is shown in Fig. 2. The remain-  
 169 ing  $K_s^0$  contribution to the selected sample is visible as the sym-  
 170 metric arc, while a selection of the left and right halves of the  
 171 figure allows to separate  $\bar{\Lambda}$  (on the left) from  $\Lambda$  hyperons (on the  
 172 right), based on the sign of the longitudinal momentum asym-  
 173 metry  $(p_{\parallel}^+ - p_{\parallel}^-)/(p_{\parallel}^+ + p_{\parallel}^-)$ . Here,  $p_{\parallel}^+$  ( $p_{\parallel}^-$ ) indicates the lon-  
 174 gitudinal momentum of the positive (negative) decay particle in

<sup>1</sup>Their contribution would not be negligible only in case of non-flat accep-  
 tance in  $\cos\phi$  and  $\cos 2\phi_S$ . It has been checked that, for the data considered  
 in this analysis, the acceptance in  $\cos\phi$  is sufficiently flat, while compatible  
 results can be found for positive and negative values of  $\cos 2\phi_S$ .

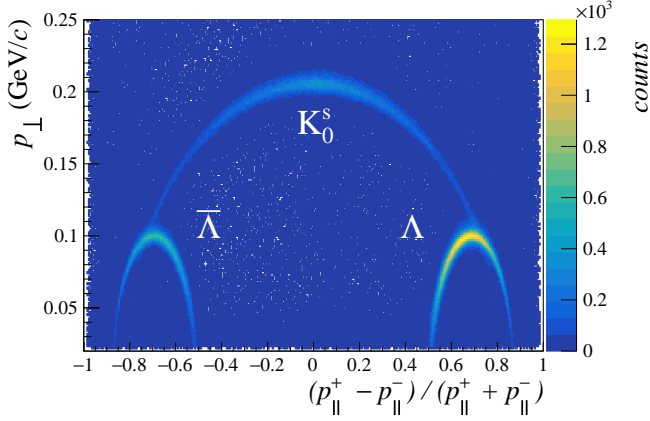


Figure 2: Armenteros-Podolanski plot.

175 the hyperon rest frame with respect to the  $\Lambda(\bar{\Lambda})$  line of flight.  
 176 In Fig. 3 the  $\Lambda$  and  $\bar{\Lambda}$  invariant mass spectra corresponding to  
 177 these selections are shown. Here, only the  $K_s^0$  in the crossing  
 178 regions of the  $K_s^0$  and  $\Lambda(\bar{\Lambda})$  arcs contribute to the background.  
 179 These invariant mass spectra are fitted with a superposition of a  
 180 Gaussian function and a constant term using the PDG value for  
 181 the  $\Lambda$  mass [34]. The background is evaluated with the sideband  
 182 method considering two equally wide intervals on the left and  
 183 on the right of the mass peak. Finally, hyperons are selected  
 184 within a  $\pm 3\sigma$  range from the peak, where  $\sigma = 2.45 \text{ MeV}/c^2$   
 185 is obtained using all data shown in Fig. 3. Depending on the  
 186 chosen kinematic bin, the signal-over-background ratio ranges  
 187 from 5.7 to 54.9. The total statistics after background subtraction  
 188 are given in Tab. 1.

189

190 A significant fraction of  $\Lambda$  and  $\bar{\Lambda}$  particles originates from  
 191 the decay of heavier hyperons. Using the event generator LEPTO  
 192 based on the Lund string model [35], tuned to reproduce the  
 193 experimental distributions, 63% of the  $\Lambda$  and 68% of the  $\bar{\Lambda}$  hy-  
 194 perons produced in the COMPASS kinematic regime are esti-  
 195 mated to originate from direct string fragmentation [36]. These  
 196 numbers get about 50% smaller when obtained with PHYTIA  
 197 [37, 38] or LEPTO with default tuning. The fractions of pri-  
 198 mary  $\Lambda$  and  $\bar{\Lambda}$  hyperons, as obtained from the PYTHIA gen-  
 199 erator with default setting and excluding the feed-down contribu-  
 200 tion from weak decays, are given in Tab. 4 as a function of  $x$ ,  
 201  $z$  and  $p_T$  in the current fragmentation region. We have checked  
 202 that the kinematic dependence of the fraction of directly pro-  
 203 duced  $\Lambda$  and  $\bar{\Lambda}$  on  $x$ ,  $z$  and  $p_T$  is very small. In this analysis, the  
 204  $\Lambda$  and  $\bar{\Lambda}$  hyperons coming from indirect production cannot be  
 205 separated from those coming from direct production. Given all  
 206 these uncertainties, their contribution is not taken into account  
 207 as a systematic uncertainty, although it could dilute a possible  
 208 polarisation signal.

209

Table 1: Available statistics for  $\Lambda$  and  $\bar{\Lambda}$  hyperons, after background subtraction, for years 2007 and 2010 and for their sum.

year	$\Lambda$	$\bar{\Lambda}$
2007	$95\,125 \pm 315$	$44\,911 \pm 227$
2010	$201\,421 \pm 466$	$99\,552 \pm 336$
total	$296\,546 \pm 562$	$144\,463 \pm 405$

### 210 3. Extraction method and results for $\Lambda(\bar{\Lambda})$ polarisation

211 For this analysis, as for all target spin asymmetries mea-  
 212 sured at COMPASS, systematic effects are minimised due to  
 213 the unique target configuration described at the beginning of the  
 214 previous section and to the fact that the data taking is divided  
 215 into periods, each consisting of two subperiods in which data  
 216 are taken with reversed polarisation orientation in each target  
 217 cell.

218 As the transversity-induced  $\Lambda(\bar{\Lambda})$  polarisation is to be mea-  
 219 sured along the spin direction of the fragmenting quark, this  
 220 reference axis has to be determined on an event-by-event ba-  
 221 sis. The initial-quark spin is assumed to be aligned with the  
 222 nucleon spin and is thus vertical in the laboratory frame. Its

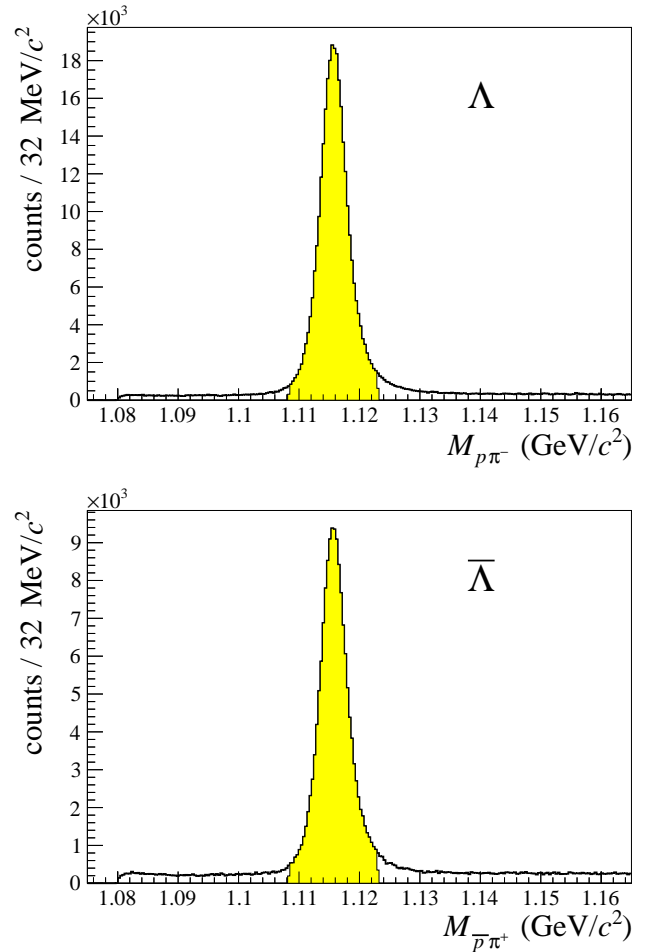


Figure 3: Invariant mass spectra of  $\Lambda$  (top) and  $\bar{\Lambda}$  (bottom) after all selection steps.

223 transverse component is rotated by an azimuthal angle  $\phi_S$  in  
 224 the  $\gamma^*$ -nucleon system (Fig. 1). As described above, the spin  
 225 direction of the quark after the interaction with the virtual photon  
 226 is obtained by reflecting it with respect to the normal to the  
 227 lepton scattering plane [21, 24, 39],  $\phi_{S'} = \pi - \phi_S$ . In the  
 228 present analysis we determine the  $\Lambda(\bar{\Lambda})$  polarisation along this  
 229 direction.

230 The number of  $\Lambda(\bar{\Lambda})$  hyperons emitting a proton (antiproton)  
 231 in a given  $\cos\theta$  range from a given target cell with a given  
 232 direction of the target polarisation can be expressed as

$$\begin{aligned} \mathcal{N}_{\Lambda(\bar{\Lambda}),i}^{\{l\}}(\cos\theta) &= \Phi_i^{\{l\}} \rho_i^{\{l\}} \bar{\sigma}_{\Lambda(\bar{\Lambda})} \\ &\times (1 \pm \alpha_{\Lambda(\bar{\Lambda})} P_{\Lambda(\bar{\Lambda})} \cos(\theta + (i-1)\pi)) \\ &\times A_i^{\{l\}}(\cos\theta). \end{aligned} \quad (7)$$

233 Here,  $i = 1, 2$  indicates the central or outer cells, respectively,  
 234  $\Phi_i^{\{l\}}$  denotes the muon flux,  $\rho_i^{\{l\}}$  the number of nucleons per  
 235 unit area, and  $\bar{\sigma}_{\Lambda(\bar{\Lambda})}$  is the cross section for the production of  
 236  $\Lambda(\bar{\Lambda})$  hyperons. The acceptance term  $A_i^{\{l\}}(\cos\theta)$  includes both  
 237 geometrical acceptance, which is slightly different for each of  
 238 the three target cells, and spectrometer efficiency. Primed quantities  
 239 refer to data taken in subperiods after target polarisation  
 240 reversal. After background subtraction, the four equations of  
 241 Eq.(7) are combined to form a double ratio

$$\varepsilon_{\Lambda(\bar{\Lambda})}(\cos\theta) = \frac{\mathcal{N}_{\Lambda(\bar{\Lambda}),1}(\cos\theta)\mathcal{N}'_{\Lambda(\bar{\Lambda}),2}(\cos\theta)}{\mathcal{N}'_{\Lambda(\bar{\Lambda}),1}(\cos\theta)\mathcal{N}_{\Lambda(\bar{\Lambda}),2}(\cos\theta)}. \quad (8)$$

242 As described in Refs. [40, 41], the acceptances cancel in this  
 243 expression as long as in each  $\cos\theta$  bin the acceptance ratios  
 244 for the target cells after polarisation reversal are equal to those  
 245 before, which is a reasonable assumption for the given setup.  
 246 As described above, equal muon flux in all three target cells is  
 247 maintained by the event selection, so that also the flux cancels  
 248 in Eq.(8). For small values of the  $\Lambda(\bar{\Lambda})$  polarisation it then  
 249 becomes:

$$\varepsilon_{\Lambda(\bar{\Lambda})}(\cos\theta) \approx 1 + 4\alpha_{\Lambda(\bar{\Lambda})} P_{\Lambda(\bar{\Lambda})} \cos\theta. \quad (9)$$

250 In each kinematic bin in  $x$ ,  $z$  or  $p_T$ , the data sample is divided  
 251 into eight  $\cos\theta$  bins. This set of eight  $\varepsilon_j$  values is then  
 252 fitted with the linear function  $f = p_0(1 + p_1 \cos\theta)$ , so that  
 253  $P_{\Lambda(\bar{\Lambda})}$  is obtained as  $P_{\Lambda(\bar{\Lambda})} = p_1/(4\alpha_{\Lambda(\bar{\Lambda})})$ .

254 The transversity-induced polarisation is measured in the full  
 255 phase-space and in the following regions:

- 257 –  $z \geq 0.2$  and Feynman variable  $x_F > 0$ , our selection of  
 258 the current fragmentation region;
- 259 –  $z < 0.2$  or  $x_F < 0$ , complementary to the current frag-  
 260 mentation region;
- 261 – high  $x$ :  $x \geq 0.032$ ;
- 262 – low  $x$ :  $x < 0.032$ ;
- 263 – high  $p_T$ :  $p_T \geq 0.5 \text{ GeV}/c$ ;

– low  $p_T$ :  $p_T < 0.5 \text{ GeV}/c$ .

265 In each of these regions, the data is scrutinised for possible  
 266 systematic biases. The two main sources of systematic uncer-  
 267 tainties are period compatibility and false  $\Lambda(\bar{\Lambda})$  polarisations.  
 268 The former are evaluated by comparing the results from the  
 269 various periods of data taking, while the latter are evaluated  
 270 by reshuffling the double ratio from Eq.(8) as  $\frac{\mathcal{N}_{\Lambda(\bar{\Lambda}),1}\mathcal{N}_{\Lambda(\bar{\Lambda}),2}}{\mathcal{N}'_{\Lambda(\bar{\Lambda}),1}\mathcal{N}'_{\Lambda(\bar{\Lambda}),2}}$ ,  
 271 so that transversity-induced  $\Lambda(\bar{\Lambda})$  polarisations cancel. Effects  
 272 of residual acceptance variations are proven to be negligible by  
 273 evaluating the  $K_s^0$  polarisation that is found to be compatible  
 274 with zero as expected. In addition,  $P_{\Lambda(\bar{\Lambda})}$  is measured assum-  
 275 ing the central cell split into two halves, thus creating two data  
 276 samples by combining each half with one of the outer cells.  
 277 Again, effects of acceptance variation are found to be negligi-  
 278 ble. A scale uncertainty of about 7.5% contributes to the overall  
 279 systematics due to the uncertainty on the weak decay constant  
 280  $\alpha$  (2%) and on the dilution and polarisation factors  $f$  and  $P_T$   
 281 (5% overall). In general,  $\sigma_{\text{syst}} < 0.85 \sigma_{\text{stat}}$ .

282 In Fig. 4, the results from the full phase-space and for the  
 283 current fragmentation region are presented in terms of the spin  
 284 transfer

$$S_{\Lambda(\bar{\Lambda})} = \frac{P_{\Lambda(\bar{\Lambda})}}{fP_T D_{\text{NN}}(y)}, \quad (10)$$

285 by definition ranging from -1 to 1. The corresponding numeri-  
 286 cal values are given in the Appendix. The full set of data for all  
 287 selections can be found on HEPData [42].

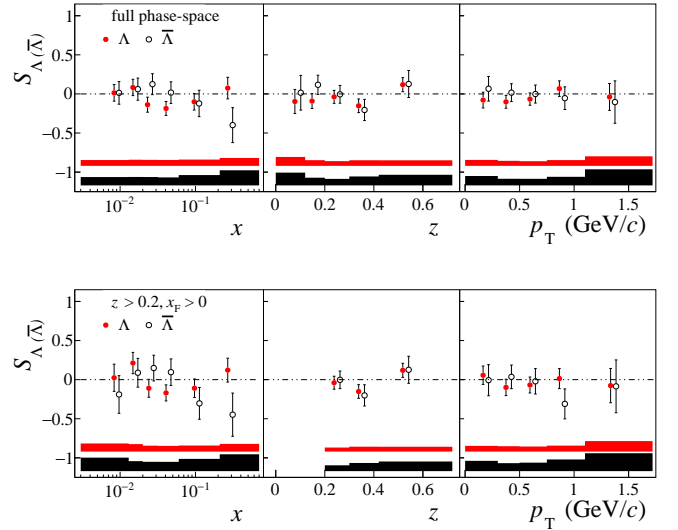


Figure 4: Spin transfer  $S_{\Lambda(\bar{\Lambda})}$  for the full phase-space (top) and for the current fragmentation region (bottom), as a function of  $x$ ,  $z$  and  $p_T$ . The bands show the systematic uncertainties, while the error bars represent statistical uncertainties. The values in  $x$ ,  $z$  and  $p_T$  are staggered for clarity.

#### 289 4. Interpretation of the results and predictions for future 290 measurements

291 The polarisations shown in Fig. 4 are compatible with zero  
292 within the experimental uncertainties in all studied kinematic  
293 regions, which is in agreement with a recent measurement of  
294 the transverse spin transfer  $D_{TT}$  in polarized Drell Yan [43].  
295 From this result, applying different hypotheses, some conclu-  
296 sions will be drawn below on the size of the fragmentation func-  
297 tion  $H_{1,u}^\Lambda(z, Q^2)$  as well as on the strange quark transversity  
298 distribution  $h_1^s(x, Q^2)$ .

300 Following Eq.(3) and Eq.(10), in the current fragmentation  
301 region the spin transfer  $S_{\Lambda(\bar{\Lambda})}$  reads

$$302 S_{\Lambda(\bar{\Lambda})} = \frac{\sum_q e_q^2 h_1^q H_{1,q}^{\Lambda(\bar{\Lambda})}}{\sum_q e_q^2 f_1^q D_{1,q}^{\Lambda(\bar{\Lambda})}}, \quad (11)$$

303 where the dependences on  $x$ ,  $z$  and  $Q^2$  are omitted for simplic-  
304 ity.

##### 305 4.1. Interpretation of the measured $\bar{\Lambda}$ polarisation

306 Considering the case of  $\bar{\Lambda}$  hyperons, the favoured fragmen-  
307 tation functions  $H_{1,\bar{u}}^\Lambda$ ,  $H_{1,\bar{d}}^\Lambda$  and  $H_{1,\bar{s}}^\Lambda$  only appear in combina-  
308 tion with the sea-quarks  $\bar{u}$ ,  $\bar{d}$  and  $\bar{s}$ . As  $h_1^{\bar{s}} \approx 0$  can be  
309 assumed in analogy to  $h_1^{\bar{u}}$  and  $h_1^{\bar{d}}$ , transversity is coupled only  
310 to unfavoured fragmentation functions. Here  $H_{1,u}^\Lambda$  and  $H_{1,d}^\Lambda$   
311 dominate, as the  $s$ -quark contribution  $h_1^s H_{1,s}^\Lambda$  can be neglected  
312 because also  $h_1^s$  is expected to be small. This yields

$$313 \sum_q e_q^2 h_1^q H_{1,q}^\Lambda \propto 4h_1^u H_{1,u}^\Lambda + h_1^d H_{1,d}^\Lambda. \quad (12)$$

314 The compatibility with zero of the measured polarisation for  
315  $\bar{\Lambda}$  hyperons is in agreement with expectations based on calcula-  
316 tions for the ratios of favoured to unfavoured fragmentation  
317 functions (see, e.g., Ref. [44]). In these calculations, the un-  
318 favoured fragmentation functions are suppressed by a factor of  
319 about 4 to 5 in the current fragmentation region at  $z$  about 0.2  
and rapidly decrease further for increasing  $z$ .

##### 320 4.2. Interpretation of the measured $\Lambda$ polarisation

321 Considering the case of  $\Lambda$  hyperons, one of the options sug-  
322 gested in e.g. Ref. [44] is to retain only the favoured combina-  
323 tions ( $H_{1,u}^\Lambda$ ,  $H_{1,d}^\Lambda$ ,  $H_{1,s}^\Lambda$ ,  $D_{1,u}^\Lambda$ ,  $D_{1,d}^\Lambda$ ,  $D_{1,s}^\Lambda$ ) in both numerator  
324 and denominator, resulting in:

$$325 S_\Lambda = \frac{4h_1^u H_{1,u}^\Lambda + h_1^d H_{1,d}^\Lambda + h_1^s H_{1,s}^\Lambda}{4f_1^u D_{1,u}^\Lambda + f_1^d D_{1,d}^\Lambda + f_1^s D_{1,s}^\Lambda}. \quad (13)$$

326 Isospin symmetry requires  $D_{1,d}^\Lambda = D_{1,u}^\Lambda$  and  $H_{1,d}^\Lambda = H_{1,u}^\Lambda$ . For  
327 the  $s$ -quark fragmentation functions, it is often assumed that  
328  $D_{1,s}^\Lambda$  is proportional to  $D_{1,u}^\Lambda$  with the proportionality constant  
329  $r$ , which is the inverse of the strangeness suppression factor  
 $\lambda = 1/r$  [45, 46]. In Ref. [47] its value is obtained from a fit

330 of experimental baryon production data in  $e^+e^-$  annihilation to  
331 be  $\lambda_\Lambda = 1/r = 0.44$ . With these simplifications, Eq.(13) turns  
332 into

$$333 S_\Lambda = \frac{[4h_1^u + h_1^d] H_{1,u}^\Lambda + h_1^s H_{1,s}^\Lambda}{[4f_1^u + f_1^d + r f_1^s] D_{1,u}^\Lambda}. \quad (14)$$

334 The interpretation is now performed in three different sce-  
335 narios. When needed, we use the CTEQ5D PDFs [48] for  $f_1^q$ ,  
336 calculated at the  $x$  and  $Q^2$  values of the data points, while the  
337 values of the transversity functions for  $u$  and  $d$  quarks are ob-  
tained from the fit presented in Ref. [12].

338 *i) Transversity is non-zero only for valence quarks in the nu-  
339 cleon*

340 If transversity is assumed non-vanishing only for valence  
341 quarks,  $h_1^s$  can be neglected and the expression for the spin  
342 transfer to the  $\Lambda$  further simplifies to:

$$343 S_\Lambda = \frac{[4h_1^u + h_1^d] H_{1,u}^\Lambda}{[4f_1^u + f_1^d + r f_1^s] D_{1,u}^\Lambda}. \quad (15)$$

344 When  $S_\Lambda$  is now inspected only as a function of  $x$ , its de-  
345 pendence upon  $z$ , carried by the fragmentation functions, is in-  
tegrated over. In a generic  $x$  bin centered at  $x^*$  it becomes

$$346 S_\Lambda|_{x=x^*} = \frac{[4h_1^u(x^*) + h_1^d(x^*)] \int_{0.2}^{1.0} dz H_{1,u}^\Lambda(z)}{[4f_1^u(x^*) + f_1^d(x^*) + r f_1^s(x^*)] \int_{0.2}^{1.0} dz D_{1,u}^\Lambda(z)}. \quad (16)$$

347 Thus the measurement of  $S_\Lambda$  as a function of  $x$  can be used  
348 to extract, in each bin of  $x$ , the ratio  $\mathcal{R}$  of the  $z$ -integrated frag-  
mentation functions  $H_{1,u}^\Lambda$  and  $D_{1,u}^\Lambda$ :

$$349 \mathcal{R}(x^*) = \frac{\int_{0.2}^{1.0} dz H_{1,u}^\Lambda(z)}{\int_{0.2}^{1.0} dz D_{1,u}^\Lambda(z)} \Big|_{x=x^*} = \frac{4f_1^u(x^*) + f_1^d(x^*) + r f_1^s(x^*)}{4h_1^u(x^*) + h_1^d(x^*)} S_\Lambda|_{x=x^*} \quad (17)$$

350 The mean value of  $\mathcal{R}$  over the measured  $x$  range is  $\langle \mathcal{R} \rangle =$   
351  $-0.27 \pm 0.56$ ; it shows a weak dependence on  $r$  and is compat-  
ible with zero within the given statistics.

352 *ii)  $\Lambda$  polarisation is carried by the  $s$  quark only*

353 Assuming instead that the polarisation is entirely carried by  
354 the  $s$  quark, as in the SU(3) non-relativistic quark model,  $H_{1,u}^\Lambda$   
355 can be neglected. Moreover, as suggested by Ref.[49],  $H_{1,s}^\Lambda$  can  
356 be approximated with  $D_{1,s}^\Lambda$  for  $z > 0.2$ , yielding

$$357 S_\Lambda = \frac{h_1^s H_{1,s}^\Lambda}{[4f_1^u + f_1^d + r f_1^s] \frac{1}{r} D_{1,s}^\Lambda} \approx \frac{r h_1^s}{4f_1^u + f_1^d + r f_1^s}, \quad (18)$$

358 so that  $h_1^s$  can be extracted. In Fig. 5 the quantity  $xh_1^s(x)$  is  
359 given for various choices of  $r$  and compared to the fitted value  
360 and accuracy of the  $xh_1^u(x)$  distribution [12]. Again, only a  
weak dependence on  $r$  is observed. Although the data suggest

361 a negative sign of  $h_1^s(x)$ , they are not precise enough to deter-  
 362 mine accurately  $h_1^s(x)$  compared to the statistical precision of  
 363 the  $h_1^u(x)$  data.

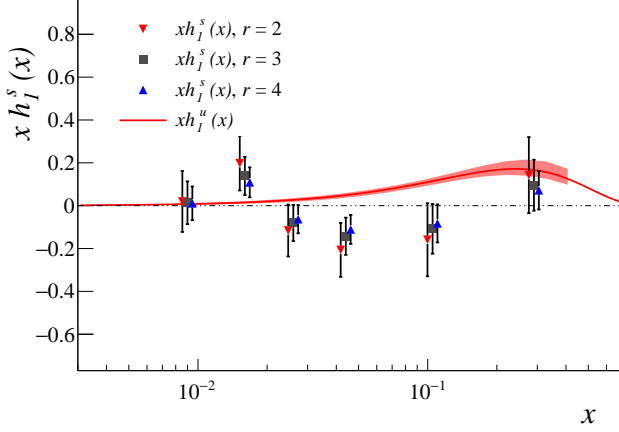


Figure 5: Extracted values of  $xh_1^s(x)$  for the three options  $r = 2, 3, 4$ . The  $u$  quark transversity curve from Ref. [12] is given for comparison. Only statistical uncertainties are shown and the  $x$  values are staggered for clarity.

364

365 *iii) Polarised- $\Lambda$  production is described by a quark-diquark frag-*  
 366 *mentation model*

367 In the context of the quark-diquark model [49, 50], the frag-  
 368 mentation of an unpolarised valence quark  $q$  into a final-state  
 369 hadron is accompanied by the emission of a diquark  $D$ , which  
 370 can be in a scalar ( $S$ ) or vector ( $V$ ) spin configuration. The  
 371 probabilities  $a_D^{(q)}(z)$  associated to these two configurations are  
 372 calculated in the model and enter the definition of the quark  
 373 fragmentation function, which depends on  $z$  and on the masses  
 374 of the fragmenting quark, the diquark and the produced hadron.  
 375 Analogously, the fragmentation of a polarised quark is described  
 376 through the probabilities  $\hat{a}_D^{(q)}(z)$ . In the case of  $\Lambda$  production,  
 377 the unpolarised fragmentation function of the  $s$  quark,  $D_{1,s}^\Lambda$ ,  
 378 is taken as reference and used to express all the other frag-  
 379 mentation functions by introducing the flavour structure ratios  
 380  $F_S^{(u/s)}(z) = a_S^{(u)}(z)/a_S^{(s)}(z)$ ,  $F_M^{(u/s)}(z) = a_V^{(u)}(z)/a_S^{(s)}(z)$   
 381 and the spin-structure ratios  $\hat{W}_D^q(z) = \hat{a}_D^{(q)}(z)/a_D^{(q)}(z)$ . The  
 382 transversity-induced polarisation can thus be written as:

$$S_\Lambda = \frac{(4h_1^u + h_1^d) \cdot \frac{1}{4} [\hat{W}_S^{(u)} F_S^{(u/s)} - \hat{W}_V^{(u)} F_M^{(u/s)}] + h_1^s \hat{W}_S^{(s)}}{(4f_1^u + f_1^d) \cdot \frac{1}{4} [F_S^{(u/s)} + 3F_M^{(u/s)}] + f_1^s} \quad (19)$$

383 where the  $x$  and  $z$  dependences are omitted for clarity. In-  
 384 formation on  $h_1^s$  can be obtained by integrating Eq.(19) over  
 385  $z$  in each  $x$  bin. The values of  $xh_1^s(x)$ , as predicted by the  
 386 quark-diquark model and based on the measured polarisation,  
 387 are shown in Fig. 6. The dependence of the final results on the

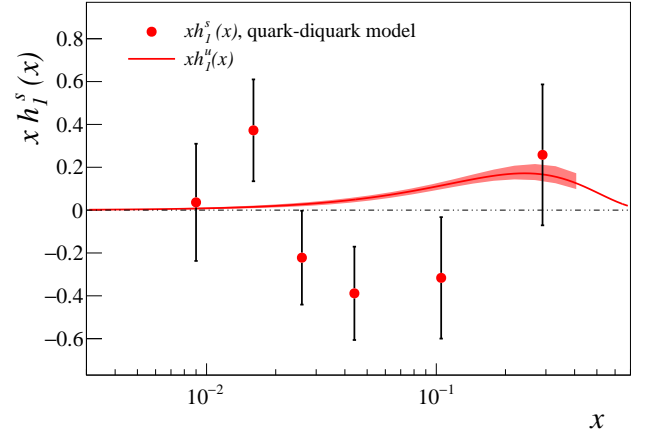


Figure 6: Extracted values of  $xh_1^s(x)$  according to a quark-diquark model [49, 50]. The  $u$  quark transversity curve from Ref. [12] is given for comparison. Only statistical uncertainties are shown.

388 mass of the diquark (containing or not the  $s$  quark) was found  
 389 negligible.

390 Again, as in scenario ii), the data suggest a negative sign of  
 391  $h_1^s(x)$ , but statistical uncertainties are even larger in this case.  
 392 Improved data will be needed to determine  $h_1^s(x)$  more accu-  
 393 rately.

#### 4.3. Projections for future data taking with transversely polarised deuterons

394  
 395 The upcoming COMPASS run aims at collecting new pre-  
 396 cision SIDIS data using a polarised deuteron (LiD) target. The  
 397 expected statistical uncertainties of the measured asymmetries  
 398 are in the order of 60% of those estimated for the proton data.  
 399 Compared to the existing deuteron data taken with the early  
 400 COMPASS setup, we expect an accuracy improvement between  
 401 a factor of two at small  $x$  and a factor of five at large  $x$  [30].  
 402 Some prospects for this measurement are described in the fol-  
 403 lowing.

404 The expression for the spin transfer, for  $\Lambda$  production on a  
 405 transversely-polarised deuteron target, reads:

$$S_\Lambda^D = \frac{5(h_1^u + h_1^d)H_{1,u}^\Lambda + 2h_1^s H_{1,s}^\Lambda}{5(f_1^u + f_1^d)D_{1,u}^\Lambda + 2f_1^s D_{1,s}^\Lambda}. \quad (20)$$

406 It is already known from earlier COMPASS data that  $h_1^d \approx$   
 407  $-h_1^u$  [51, 52]. The upcoming COMPASS run on a deuteron  
 408 target will, in addition, allow us to measure with high preci-  
 409 sion the quantity  $h_1^u + h_1^d$ . Since the fragmentation function  
 410  $H_{1,u}^\Lambda$  is expected to be smaller than the fragmentation function  
 411  $H_{1,s}^\Lambda$ , the numerator of Eq.(20) will be dominated by the prod-  
 412 uct  $h_1^s H_{1,s}^\Lambda$  if  $h_1^s$  is of significant size. Therefore, a new high  
 413 statistics measurement of the transversity-induced  $\Lambda$  polarisa-  
 414 tion on a deuteron target from the upcoming data is expected to  
 415 be very sensitive to the product  $h_1^s H_{1,s}^\Lambda$ .

418 The measurements planned to access transversity on a  $^3\text{He}$  469  
419 target, expected in the future at SOLID [53], will also be impor- 470  
420 tant in order to better constrain the transversity for the  $s$ -quark 471  
421 and, in turn, the transversely polarized fragmentation functions 472  
422  $q \rightarrow \Lambda$ . 473

## 423 5. Summary and outlook

424 Using a transversely polarised proton target and a 160 GeV/ $c$  480  
425 muon beam, the transversity-induced polarisation along the spin 481  
426 axis of the struck quark was measured by COMPASS for  $\Lambda$  and 482  
427  $\bar{\Lambda}$  hyperons. While considered to be an excellent channel to ac- 483  
428 cess transversity, the results were found to be compatible with 484  
429 zero in all studied kinematic regions. 485

430 The statistical uncertainty on the measured polarisation is still 487  
431 large, despite the fact that all COMPASS data on a transversely 488  
432 polarised proton target were used, which are the only existing 489  
433 world data suitable for this measurement. Nevertheless, some 490  
434 information could be deduced from the existing data. 491

435 Under the hypothesis that transversity is non-vanishing only for 493  
436 valence quarks, the data were used to investigate the ratio of 494  
437  $z$ -integrated polarised to unpolarised fragmentation functions. 495  
438 The results indicate a negative ratio, although compatible with 496  
439 zero due to the large uncertainties. If instead a non-relativistic 497  
440 SU(3) quark model or a quark-diquark model is considered, 498  
441 some information can be derived on the transversity distribu- 499  
442 tion for the  $s$  quark. In both cases the results tend to support a 500  
443 negative  $s$ -quark transversity  $h_1^s$  within the large uncertainties 501  
444 given. 502

445 In addition, some prospects were given for measuring precisely 503  
446 the transversity-induced polarisation of  $\Lambda$  hyperons produced 504  
447 on a transversely polarised deuteron target. Since such a mea- 505  
448 surement is anticipated to be very sensitive to  $h_1^s$ , the results ex- 506  
449 pected from the upcoming COMPASS run with a transversely 507  
450 polarised deuteron target in the years 2021 and 2022 will help 508  
451 to improve our knowledge on transversity. 509

## 452 Acknowledgements

453 We gratefully acknowledge the support of CERN manage- 510  
454 ment and staff and the skill and effort of the technicians of our 511  
455 collaborating institutions. 512

## 456 References

- 457 [1] J. P. Ralston, D. E. Soper, Production of Dimuons from High-Energy 526  
458 Polarized Proton Proton Collisions, Nucl. Phys. B 152 (1979) 109. 527  
459 doi:10.1016/0550-3213(79)90082-8. 528  
460 [2] F. Baldracchini, N. S. Craigie, V. Roberto, M. Socolovsky, A Survey of 529  
461 Polarization Asymmetries Predicted by QCD, Fortsch. Phys. 30 (1981) 530  
462 505–550. doi:10.1002/prop.19810291102. 531  
463 [3] X. Artru, M. Mekhfi, Transversely Polarized Parton Densities, their 532  
464 Evolution and their Measurement, Z. Phys. C 45 (1990) 669. 533  
465 doi:10.1007/BF01556280. 534  
466 [4] R. L. Jaffe, X.-D. Ji, Chiral odd parton distributions and 535  
467 polarized Drell-Yan, Phys. Rev. Lett. 67 (1991) 552–555. 536  
468 doi:10.1103/PhysRevLett.67.552. 537

- 469 [5] A. Airapetian, et al., Single-spin asymmetries in semi-inclusive 538  
470 deep-inelastic scattering on a transversely polarized hydrogen tar- 539  
471 get, Phys. Rev. Lett. 94 (2005) 012002. arXiv:hep-ex/0408013, 540  
472 doi:10.1103/PhysRevLett.94.012002. 541  
473 [6] A. Airapetian, et al., Effects of transversity in deep-inelastic scattering 542  
474 by polarized protons, Phys. Lett. B 693 (2010) 11–16. arXiv:1006.4221, 543  
475 doi:10.1016/j.physletb.2010.08.012. 544  
476 [7] M. G. Alekseev, et al., Measurement of the Collins and Sivers asymme- 545  
477 tries on transversely polarised protons, Phys. Lett. B 692 (2010) 240–246. 546  
478 arXiv:1005.5609, doi:10.1016/j.physletb.2010.08.001. 547  
479 [8] C. Adolph, et al., Experimental investigation of transverse spin asymme- 548  
480 tries in muon-p SIDIS processes: Collins asymmetries, Phys. Lett. B 717 549  
481 (2012) 376–382. arXiv:1205.5121, doi:10.1016/j.physletb.2012.09.055. 550  
482 [9] A. Airapetian, et al., Evidence for a Transverse Single-Spin Asymmetry in 551  
483 Leptonproduction of  $\pi^+\pi^-$  Pairs, JHEP 06 (2008) 017. arXiv:0803.2367, 552  
484 doi:10.1088/1126-6708/2008/06/017. 553  
485 [10] C. Adolph, et al., Transverse spin effects in hadron-pair production from 554  
486 semi-inclusive deep inelastic scattering, Phys. Lett. B 713 (2012) 10–16. 555  
487 arXiv:1202.6150, doi:10.1016/j.physletb.2012.05.015. 556  
488 [11] C. Adolph, et al., A high-statistics measurement of transverse spin ef- 557  
489 fects in dihadron production from muon–proton semi-inclusive deep- 558  
490 inelastic scattering, Phys. Lett. B 736 (2014) 124–131. arXiv:1401.7873, 559  
491 doi:10.1016/j.physletb.2014.06.080. 560  
492 [12] A. Martin, F. Bradamante, V. Barone, Extracting the transversity distri- 561  
493 butions from single-hadron and dihadron production, Phys. Rev. D 91 (1) 562  
494 (2015) 014034. arXiv:1412.5946, doi:10.1103/PhysRevD.91.014034. 563  
495 [13] M. Anselmino, M. Boglione, U. D’Alesio, S. Melis, F. Murgia, 564  
496 A. Prokudin, Simultaneous extraction of transversity and Collins func- 565  
497 tions from new SIDIS and  $e^+e^-$  data, Phys. Rev. D 87 (2013) 094019. 566  
498 arXiv:1303.3822, doi:10.1103/PhysRevD.87.094019. 567  
499 [14] Z.-B. Kang, A. Prokudin, P. Sun, F. Yuan, Extraction of Quark 568  
500 Transversity Distribution and Collins Fragmentation Functions with QCD 569  
501 Evolution, Phys. Rev. D 93 (1) (2016) 014009. arXiv:1505.05589, 570  
502 doi:10.1103/PhysRevD.93.014009. 571  
503 [15] H.-W. Lin, W. Melnitchouk, A. Prokudin, N. Sato, H. Shows, First Monte 572  
504 Carlo Global Analysis of Nucleon Transversity with Lattice QCD Con- 573  
505 straints, Phys. Rev. Lett. 120 (15) (2018) 152502. arXiv:1710.09858, 574  
506 doi:10.1103/PhysRevLett.120.152502. 575  
507 [16] M. Radici, A. Bacchetta, First Extraction of Transversity from a 576  
508 Global Analysis of Electron-Proton and Proton-Proton Data, 577  
509 Phys. Rev. Lett. 120 (19) (2018) 192001. arXiv:1802.05212, 578  
510 doi:10.1103/PhysRevLett.120.192001. 579  
511 [17] X. Artru, M. Mekhfi, What can we learn from unpolarized and polarized 580  
512 electroproduction of fast baryons?, Nucl. Phys. A 532 (1991) 351–358. 581  
513 doi:10.1016/0375-9474(91)90709-F. 582  
514 [18] R. L. Jaffe, Polarized  $\Lambda$ 's in the current fragmentation region, 583  
515 Phys. Rev. D 54 (11) (1996) R6581–R6585. arXiv:hep-ph/9605456, 584  
516 doi:10.1103/PhysRevD.54.R6581. 585  
517 [19] M. Anselmino, Transversity and Lambda polarization, in: Workshop on 586  
518 Future Physics at COMPASS, 2003. arXiv:hep-ph/0302008. 587  
519 [20] M. Anselmino, M. Boglione, F. Murgia, Lambda and anti-Lambda polar- 588  
520 ization in polarized DIS, Phys. Lett. B 481 (2000) 253–262. arXiv:hep- 589  
521 ph/0001307, doi:10.1016/S0370-2693(00)00455-X. 590  
522 [21] V. Barone, P. G. Ratcliffe, Transverse spin physics, Vol. River Edge, 2003. 591  
523 [22] E. D. Commins, P. H. Bucksbaum, Weak Interactions of Leptons and 592  
524 Quarks, 1983. 593  
525 [23] M. Ablikim, et al., Polarization and Entanglement in Baryon-Antibaryon 594  
526 Pair Production in Electron-Positron Annihilation, Nature Phys. 15 595  
527 (2019) 631–634. arXiv:1808.08917, doi:10.1038/s41567-019-0494-8. 596  
528 [24] A. Kotzinian, New quark distributions and semiinclusive electroproduc- 597  
529 tion on the polarized nucleons, Nucl. Phys. B 441 (1995) 234–248. 598  
530 arXiv:hep-ph/9412283, doi:10.1016/0550-3213(95)00098-D. 599  
531 [25] P. J. Mulders, R. D. Tangerman, The Complete tree level result up to 600  
532 order 1/Q for polarized deep inelastic leptonproduction, Nucl. Phys. B 601  
533 461 (1996) 197–237, [Erratum: Nucl.Phys.B 484, 538–540 (1997)]. 602  
534 arXiv:hep-ph/9510301, doi:10.1016/0550-3213(95)00632-X. 603  
535 [26] G. Bunce, et al., Lambda0 Hyperon Polarization in Inclusive Production 604  
536 by 300-GeV Protons on Beryllium., Phys. Rev. Lett. 36 (1976) 1113– 605  
537 1116. doi:10.1103/PhysRevLett.36.1113. 606  
538 [27] D. Boer, R. Jakob, P. J. Mulders, Angular dependences in electroweak 607  
539 semiinclusive leptonproduction, Nucl. Phys. B 564 (2000) 471–485. 608

- 540 arXiv:hep-ph/9907504, doi:10.1016/S0550-3213(99)00586-6. 611
- 541 [28] P. Abbon, et al., The COMPASS experiment at CERN, Nucl. 612 [51] V. Barone, F. Bradamante, A. Bressan, A. Kerbizi, A. Martin, A. Moretti,
- 542 Instrum. Meth. A 577 (2007) 455–518. arXiv:hep-ex/0703049, 613 J. Matousek, G. Sbrizzai, Transversity distributions from difference
- 543 doi:10.1016/j.nima.2007.03.026. 614 asymmetries in semi-inclusive DIS, Phys. Rev. D 99 (11) (2019) 114004.
- 544 [29] A. Ferrero, Measurement of transverse Lambda and Antilambda 615 arXiv:1902.08445, doi:10.1103/PhysRevD.99.114004.
- 545 polarization at COMPASS, AIP Conf. Proc. 915 (1) (2007) 436–440. 616 [52] M. Anselmino, A. Mukherjee, A. Vossen, Transverse spin effects in hard
- 546 doi:10.1063/1.2750815. 617 semi-inclusive collisions, Prog. Part. Nucl. Phys. 114 (2020) 103806.
- 547 [30] K. Augsten, et al., Addendum to the COMPASS-II Proposal, CERN- 618 arXiv:2001.05415, doi:10.1016/j.ppnp.2020.103806.
- 548 SPSC-2017-034, SPSC-P-340-ADD-1 (10 2017). 619 [53] J. P. Chen, H. Gao, T. K. Hemmick, Z. E. Meziani, P. A. Souder, A
- 549 [31] P. Abbon, et al., Particle identification with COMPASS RICH-1, Nucl. 620 White Paper on SoLID (Solenoidal Large Intensity Device) (9 2014).
- 550 Instrum. Meth. A 631 (2011) 26–39. doi:10.1016/j.nima.2010.11.106. 621 arXiv:1409.7741.
- 551 [32] J. Podolanski, R. Armenteros, Iii. analysis of v-events, The London, 622
- 552 Edinburgh, and Dublin Philosophical Magazine and Journal of Science 623
- 553 45 (360) (1954) 13–30. doi:10.1080/14786440108520416.
- 554 [33] R. Armenteros, K. Barker, C. Butler, A. Cachon, C. York, Lvi. the prop- 624
- 555 erties of charged v-particles, The London, Edinburgh, and Dublin Philo- 625
- 556 sophical Magazine and Journal of Science 43 (341) (1952) 597–611. 626
- 557 doi:10.1080/14786440608520216.
- 558 [34] M. Tanabashi, et al., Review of Particle Physics, Phys. Rev. D 98 (3) 627
- 559 (2018) 030001. doi:10.1103/PhysRevD.98.030001.
- 560 [35] G. Ingelman, A. Edin, J. Rathsman, LEPTO 6.5: A Monte Carlo gener- 628
- 561 ator for deep inelastic lepton - nucleon scattering, Comput. Phys. Com- 629
- 562 mun. 101 (1997) 108–134. arXiv:hep-ph/9605286, doi:10.1016/S0010- 630
- 563 4655(96)00157-9.
- 564 [36] C. Adolph, et al., Study of  $\Sigma(1385)$  and  $\Xi(1321)$  hyperon and antihy- 631
- 565 peron production in deep inelastic muon scattering, Eur. Phys. J. C 73 (10) 632
- 566 (2013) 2581. arXiv:1304.0952, doi:10.1140/epjc/s10052-013-2581-9.
- 567 [37] T. Sjöstrand, S. Mrenna, P. Z. Skands, PYTHIA 6.4 Physics and Man- 633
- 568 ual, JHEP 05 (2006) 026. arXiv:hep-ph/0603175, doi:10.1088/1126- 634
- 569 6708/2006/05/026.
- 570 [38] T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, 635
- 571 S. Mrenna, S. Prestel, C. O. Rasmussen, P. Z. Skands, An introduc- 636
- 572 tion to PYTHIA 8.2, Comput. Phys. Commun. 191 (2015) 159–177. 637
- 573 arXiv:1410.3012, doi:10.1016/j.cpc.2015.01.024.
- 574 [39] G. Baum, et al., COMPASS: A Proposal for a Common Muon and Proton 638
- 575 Apparatus for Structure and Spectroscopy, CERN-SPSLC-96-14, CERN- 639
- 576 SPSLC-P-297 (3 1996).
- 577 [40] V. Y. Alexakhin, et al., First measurement of the transverse spin 640
- 578 asymmetries of the deuteron in semi-inclusive deep inelastic scatter- 641
- 579 ing, Phys. Rev. Lett. 94 (2005) 202002. arXiv:hep-ex/0503002, 642
- 580 doi:10.1103/PhysRevLett.94.202002.
- 581 [41] E. S. Ageev, et al., A New measurement of the Collins and 643
- 582 Sivers asymmetries on a transversely polarised deuteron tar- 644
- 583 get, Nucl. Phys. B 765 (2007) 31–70. arXiv:hep-ex/0610068, 645
- 584 doi:10.1016/j.nuclphysb.2006.10.027.
- 585 [42] E. Maguire, L. Heinrich, G. Watt, HEPData: a repository for high 646
- 586 energy physics data, J. Phys. Conf. Ser. 898 (10) (2017) 102006. 647
- 587 arXiv:1704.05473, doi:10.1088/1742-6596/898/10/102006.
- 588 [43] J. Adam, et al., Transverse spin transfer to  $\Lambda$  and  $\bar{\Lambda}$  hyperons in polarized 648
- 589 proton-proton collisions at  $\sqrt{s} = 200$  GeV, Phys. Rev. D 98 (9) (2018) 649
- 590 091103. arXiv:1808.08000, doi:10.1103/PhysRevD.98.091103.
- 591 [44] B.-Q. Ma, I. Schmidt, J.-J. Yang, Ratio of anti-Lambda / Lambda in semi- 650
- 592 inclusive electroproduction, Phys. Lett. B 574 (2003) 35–40. arXiv:hep- 651
- 593 ph/0403010, doi:10.1016/j.physletb.2003.08.069.
- 594 [45] A. Rastogi, Polarized and unpolarized baryon production: SU(3) revis- 652
- 595 ited, Phys. Rev. D 59 (1999) 114012. doi:10.1103/PhysRevD.59.114012.
- 596 [46] D. Indumathi, H. S. Mani, A. Rastogi, An SU(3) model for octet baryon 653
- 597 and meson fragmentation, Phys. Rev. D 58 (1998) 094014. arXiv:hep- 654
- 598 ph/9802324, doi:10.1103/PhysRevD.58.094014.
- 599 [47] J.-J. Yang, Flavor and spin structure of quark fragmentation functions 655
- 600 in a diquark model for octet baryons, Phys. Rev. D 65 (2002) 094035. 656
- 601 doi:10.1103/PhysRevD.65.094035.
- 602 [48] A. Buckley, J. Ferrando, S. Lloyd, K. Nordström, B. Page, M. Rüfenacht, 657
- 603 M. Schönherr, G. Watt, LHAPDF6: parton density access in the 658
- 604 LHC precision era, Eur. Phys. J. C 75 (2015) 132. arXiv:1412.7420, 659
- 605 doi:10.1140/epjc/s10052-015-3318-8.
- 606 [49] J.-J. Yang,  $q \rightarrow \Lambda$  fragmentation function and nucleon transver- 660
- 607 sity distribution in a diquark model, Nucl. Phys. A 699 (2002) 562–578. 661
- 608 arXiv:hep-ph/0111382, doi:10.1016/S0375-9474(01)01281-7.
- 609 [50] R. Jakob, P. J. Mulders, J. Rodrigues, Modeling quark distribution and 662
- 610 fragmentation functions, Nucl. Phys. A 626 (1997) 937–965. arXiv:hep- 663
- 611 ph/9704335, doi:10.1016/S0375-9474(97)00588-5.

622 **Appendix**

623 Here, the spin transfer for  $\Lambda$  and  $\bar{\Lambda}$  hyperons is given for the full phase-space (Tab. 2) and for the current fragmentation region  
 624 (Tab. 3). For each bin the kinematic range is indicated, together with the mean values of  $x$ ,  $Q^2$ ,  $z$  and  $p_T$ . These and other tables  
 625 of results, for all the aforementioned kinematic regions, are available on HEPData. The fractions of primary  $\Lambda$  and  $\bar{\Lambda}$  hyperons, as  
 626 obtained from the PYTHIA generator with default setting, and excluding the feed-down contribution of weak decays, are given in  
 627 Tab. 4.

628

Table 2: Spin transfer  $S_{\Lambda(\bar{\Lambda})}$  from the full phase-space, as a function of  $x$ ,  $z$  and  $p_T$ . For each kinematic bin the mean values of  $x$ ,  $Q^2$ ,  $z$  and  $p_T$  are also given.

Full phase space						
$x$ range	$\langle x \rangle$	$\langle Q^2 \rangle$ (GeV/c) <sup>2</sup>	$\langle z \rangle$	$\langle p_T \rangle$ (GeV/c)	$S_\Lambda$	$S_{\bar{\Lambda}}$
0.003 - 0.013	0.009	1.49	0.20	0.60	0.014 ± 0.106 ± 0.074	0.014 ± 0.145 ± 0.107
0.013 - 0.020	0.016	2.06	0.25	0.59	0.083 ± 0.104 ± 0.078	0.061 ± 0.141 ± 0.108
0.020 - 0.032	0.025	2.75	0.28	0.57	-0.138 ± 0.096 ± 0.077	0.125 ± 0.134 ± 0.107
0.032 - 0.060	0.044	4.30	0.31	0.55	-0.186 ± 0.089 ± 0.076	0.017 ± 0.138 ± 0.102
0.060 - 0.210	0.104	9.54	0.32	0.52	-0.101 ± 0.105 ± 0.080	-0.122 ± 0.169 ± 0.132
0.210 - 0.700	0.290	26.5	0.34	0.53	0.074 ± 0.138 ± 0.101	-0.399 ± 0.224 ± 0.193
$z$ range	$\langle x \rangle$	$\langle Q^2 \rangle$ (GeV/c) <sup>2</sup>	$\langle z \rangle$	$\langle p_T \rangle$ (GeV/c)	$S_\Lambda$	$S_{\bar{\Lambda}}$
0.00 - 0.12	0.023	4.15	0.09	0.55	-0.097 ± 0.154 ± 0.114	0.015 ± 0.222 ± 0.163
0.12 - 0.20	0.031	4.14	0.16	0.57	-0.092 ± 0.095 ± 0.073	0.117 ± 0.123 ± 0.099
0.20 - 0.30	0.041	4.13	0.25	0.57	-0.038 ± 0.083 ± 0.060	-0.005 ± 0.113 ± 0.083
0.30 - 0.42	0.050	4.11	0.35	0.56	-0.152 ± 0.087 ± 0.072	-0.205 ± 0.136 ± 0.114
0.42 - 1.00	0.058	3.99	0.53	0.58	0.118 ± 0.090 ± 0.071	0.127 ± 0.173 ± 0.136
$p_T$ range (GeV/c)	$\langle x \rangle$	$\langle Q^2 \rangle$ (GeV/c) <sup>2</sup>	$\langle z \rangle$	$\langle p_T \rangle$ (GeV/c)	$S_\Lambda$	$S_{\bar{\Lambda}}$
0.00 - 0.30	0.045	4.33	0.27	0.19	-0.079 ± 0.101 ± 0.076	0.066 ± 0.158 ± 0.120
0.30 - 0.50	0.042	4.20	0.26	0.40	-0.101 ± 0.082 ± 0.064	0.016 ± 0.114 ± 0.085
0.50 - 0.75	0.039	4.02	0.26	0.62	-0.066 ± 0.079 ± 0.059	-0.002 ± 0.115 ± 0.084
0.75 - 1.10	0.036	3.91	0.27	0.89	0.068 ± 0.099 ± 0.074	-0.054 ± 0.145 ± 0.110
1.10 - 3.50	0.034	3.97	0.28	1.35	-0.039 ± 0.172 ± 0.122	-0.104 ± 0.271 ± 0.206

Table 3: Spin transfer  $S_{\Lambda(\bar{\Lambda})}$  from the current fragmentation region ( $z \geq 0.2, x_F > 0$ ), as a function of  $x, z$  and  $p_T$ . For each kinematic bin the mean values of  $x, Q^2, z$  and  $p_T$  are also given.

Current fragmentation region						
$x$ range	$\langle x \rangle$	$\langle Q^2 \rangle$ (GeV/c) <sup>2</sup>	$\langle z \rangle$	$\langle p_T \rangle$ (GeV/c)	$S_\Lambda$	$S_{\bar{\Lambda}}$
0.003 - 0.013	0.009	1.42	0.31	0.62	$0.024 \pm 0.174 \pm 0.104$	$-0.190 \pm 0.241 \pm 0.173$
0.013 - 0.020	0.016	1.81	0.33	0.60	$0.212 \pm 0.136 \pm 0.096$	$0.088 \pm 0.184 \pm 0.128$
0.020 - 0.032	0.026	2.31	0.35	0.57	$-0.110 \pm 0.115 \pm 0.075$	$0.148 \pm 0.164 \pm 0.119$
0.032 - 0.060	0.044	3.60	0.37	0.54	$-0.169 \pm 0.103 \pm 0.073$	$0.096 \pm 0.169 \pm 0.119$
0.060 - 0.210	0.105	8.19	0.38	0.51	$-0.110 \pm 0.118 \pm 0.077$	$-0.303 \pm 0.203 \pm 0.156$
0.210 - 0.700	0.290	23.4	0.38	0.53	$0.122 \pm 0.152 \pm 0.098$	$-0.448 \pm 0.276 \pm 0.215$
$z$ range	$\langle x \rangle$	$\langle Q^2 \rangle$ (GeV/c) <sup>2</sup>	$\langle z \rangle$	$\langle p_T \rangle$ (GeV/c)	$S_\Lambda$	$S_{\bar{\Lambda}}$
0.20 - 0.30	0.040	4.12	0.25	0.57	$-0.039 \pm 0.083 \pm 0.052$	$-0.003 \pm 0.113 \pm 0.074$
0.30 - 0.42	0.050	4.12	0.35	0.56	$-0.152 \pm 0.087 \pm 0.063$	$-0.202 \pm 0.136 \pm 0.104$
0.42 - 1.00	0.058	3.99	0.53	0.58	$0.119 \pm 0.090 \pm 0.062$	$0.126 \pm 0.173 \pm 0.123$
$p_T$ range (GeV/c)	$\langle x \rangle$	$\langle Q^2 \rangle$ (GeV/c) <sup>2</sup>	$\langle z \rangle$	$\langle p_T \rangle$ (GeV/c)	$S_\Lambda$	$S_{\bar{\Lambda}}$
0.00 - 0.30	0.052	4.24	0.35	0.19	$0.056 \pm 0.117 \pm 0.073$	$-0.007 \pm 0.199 \pm 0.131$
0.30 - 0.50	0.051	4.19	0.35	0.40	$-0.099 \pm 0.104 \pm 0.069$	$0.036 \pm 0.151 \pm 0.102$
0.50 - 0.75	0.047	4.01	0.35	0.62	$-0.068 \pm 0.102 \pm 0.065$	$-0.021 \pm 0.163 \pm 0.109$
0.75 - 1.10	0.043	3.89	0.36	0.89	$0.014 \pm 0.128 \pm 0.076$	$-0.310 \pm 0.191 \pm 0.149$
1.10 - 3.50	0.039	3.99	0.36	1.36	$-0.076 \pm 0.219 \pm 0.134$	$-0.086 \pm 0.338 \pm 0.229$

Table 4: Fraction  $f^w$  of primary  $\Lambda$  and  $\bar{\Lambda}$  hyperons according to the default PYTHIA generator, excluding the feed-down contribution of weak decays, as a function of  $x$ ,  $z$  and  $p_T$  in the current fragmentation region.

Fraction of primary $\Lambda$ and $\bar{\Lambda}$ hyperons		
$x$ range	$f_{\Lambda}^w$	$f_{\bar{\Lambda}}^w$
0.003 - 0.013	0.45	0.45
0.013 - 0.020	0.45	0.46
0.020 - 0.032	0.46	0.50
0.032 - 0.060	0.43	0.51
0.060 - 0.210	0.41	0.46
0.210 - 0.700	0.36	0.46
$z$ range	$f_{\Lambda}^w$	$f_{\bar{\Lambda}}^w$
0.20 - 0.30	0.45	0.45
0.30 - 0.42	0.44	0.49
0.42 - 1.00	0.42	0.50
$p_T$ range (GeV/ $c$ )	$f_{\Lambda}^w$	$f_{\bar{\Lambda}}^w$
0.00 - 0.30	0.40	0.43
0.30 - 0.50	0.41	0.46
0.50 - 0.75	0.44	0.50
0.75 - 1.10	0.50	0.53
1.10 - 3.50	0.53	0.62