Antihyperon potentials in nuclei via exclusive antiproton-nucleus reactions*

Alicia Sanchez Lorente[†1], *Sebastian Bleser*[1], *Marcell Steinen*[1], *and Josef Pochodzalla*[1,2]
[1]HI Mainz, D-55099 Mainz, Germany; [2]Institut für Kernphysik, D-55099 Mainz, Germany

The interaction of individual baryons or antibaryons in nuclei provides a unique opportunity to elucidate strong in-medium effects in baryonic systems. While for neutrons and protons as well as some strange baryons experimental information on their binding in nuclei exists, information on antibaryons in nuclei are rather scarce. Only for the antiproton the nuclear potential could be constrained by experimental studies. The (Schrödinger equivalent) antiproton potential at normal nuclear density turns out to be in the range of $U_{\overline{p}} \simeq -150$MeV, i.e. a factor of approximately 4 weaker than expected from naive G-parity relations [1]. Gaitanos *et al.* [2] suggested that this discrepancy can be traced back to the missing energy dependence of the proton-nucleus optical potential in conventional relativistic mean-field models. The required energy and momentum dependence could be recovered by extending the relativistic hadrodynamics Lagrangian by non-linear derivative interactions [3, 2, 4] thus also mimicking many-body forces [5]. Considering the important role played e.g. by strange baryons and antibaryons for a quantitative interpretation of high-energy heavy-ion collisions and dense hadronic systems it is clearly mandatory to test these concepts also in the strangeness sector. Of course, the question if and to what extend G-parity is violated by antihyperons in nuclei is also a challenging problem by itself.

Antihyperons annihilate quickly in nuclei and no experimental information on the nuclear potential of antihyperons exists so far. As suggested recently [6], quantitative information on the antihyperon potentials may be obtained via exclusive antihyperon-hyperon pair production close to threshold in antiproton-nucleus interactions by means of the transverse momentum asymmetry α_T which is defined in terms of the transverse momenta of the coincident particles

$$\alpha_T = \frac{p_T(\Lambda) - p_T(\overline{\Lambda})}{p_T(\Lambda) + p_T(\overline{\Lambda})}. \quad (1)$$

to the depth of the antihyperon potential. However, these schematic simulations ignored rescattering processes and refractive effects at the potential boundary. These effects may erode the two-body character of the $\overline{\Lambda}\Lambda$ production and may thus diminish or even destroy the sensitivity of α_T to the assumed antihyperon potential. In order to go beyond the schematic calculations presented in Refs. [6] and to include simultaneously rescattering, refraction and absorption effects, we performed first realistic calculations of this new observable with a microscopic transport model.

* Work supported by HI Mainz

† lorente@kph.uni-mainz.de

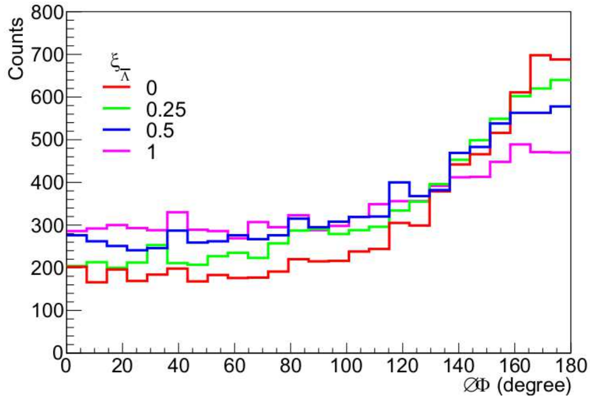

Figure 1: Coplanarity of coincident $\Lambda\overline{\Lambda}$-pairs produced exclusively in 0.85 GeV $\overline{p}$+^{20}Ne interactions. The different histograms show the GiBUU predictions for different scaling factor $\xi_{\overline{\Lambda}}$ of the $\overline{\Lambda}$-potentials.

We have studied the exclusive reaction $\overline{p}$+^{20}Ne→ $\overline{\Lambda}\Lambda$ at beam energies of 0.85 GeV and 1 GeVwithin the Giessen Boltzmann-Uehling-Uhlenbeck transport modell (GiBUU, Release 1.5) [7]. These energies correspond to antiproton momenta of 1.522 GeV/c and 1.696 GeV/c, respectively. At 0.85 GeV the excess energy with respect to the elementary reaction $\overline{p}$ +p→$\overline{\Lambda}\Lambda$ amounts to only 30.6 MeV. Therefore, the $\overline{\Sigma}\Lambda$ and $\Sigma\overline{\Lambda}$ channels are not accessible and also the production of a pion in addition to a $\Lambda\overline{\Lambda}$-pair can be neglected. In order to explore the sensitivity of the transverse momentum asymmetry on the depth of the $\overline{\Lambda}$-potential we have performed a series of calculations where only the antihyperon potentials were modified by a single scaling factor, leaving all other input parameters of the model unchanged. The calculations were performed at the High Power Computing Cluster HIMSTER located at the Helmholtz-Institute Mainz. Each GiBUU-Job comprised 1000 parallel events.

The delicate interplay between the Fermi motion of the struck nucleon, the absorption, rescattering and refraction at the nuclear surface of the produced hyperons and antihyperons is illustrated by the coplanarity of the $\overline{\Lambda}\Lambda$-pairs. Fig. 1 shows the difference between the azimuthal angle of the free $\overline{\Lambda}$ and Λ. Already for zero $\overline{\Lambda}$-potential, the coplanarity is strongly blurred. With increasing potential depth for the $\overline{\Lambda}$, the coplanarity is even less pronounced. The significant deviation from 180^o demonstrates the influence of secondary scattering prior to the emission of the $\overline{\Lambda}$ or Λ or

 DOI:10.15120/GR-2015-1-MU-HADRONS-19

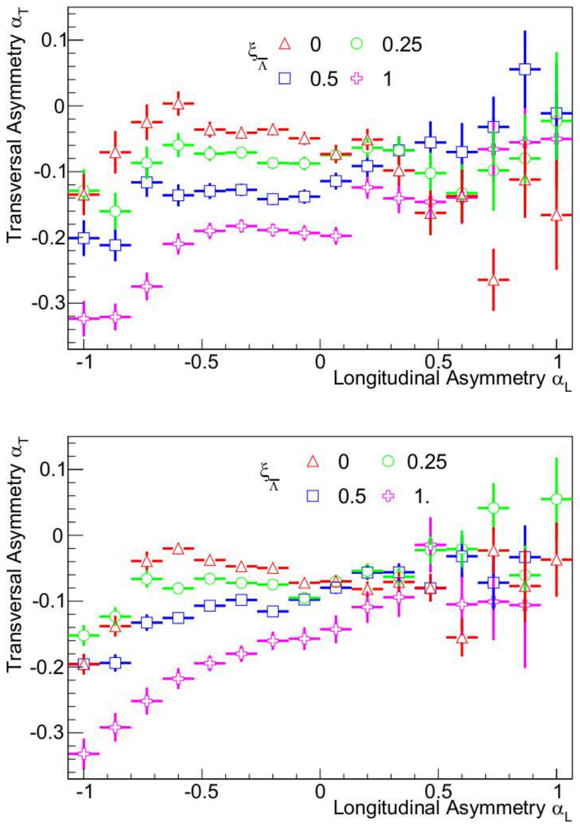

Figure 2: Average transverse momentum asymmetry as a function of the longitudinal momentum asymmetry for $\Lambda\overline{\Lambda}$-pairs produced exclusively in 0.85 GeV (top) and 1 GeV (bottom) $\overline{\mathrm{p}}^{20}$Ne interactions. The different symbols show the GiBUU predictions for different scaling factor $\xi_{\overline{\Lambda}}$ of the $\overline{\Lambda}$-potentials.

a deflection at the potential boundary.

In Fig. 2 we show the GiBUU prediction for the transverse asymmetry α_T (Eq. 1) for different scaling factors $\xi_{\overline{\Lambda}}$ of the $\overline{\Lambda}$-potential. As in Ref. [6] we plot the average α_T as a function of the longitudinal momentum asymmetry α_L which is defined for each event as

$$\alpha_L = \frac{p_L(\Lambda) - p_L(\overline{\Lambda})}{p_L(\Lambda) + p_L(\overline{\Lambda})}. \qquad (2)$$

For 0.85 GeV (top) as well as 1 GeV (bottom) antiproton energy a remarkable sensitivity of α_T on the $\overline{\Lambda}$-potential is found at negative values of α_L. Despite the concern mentioned before, secondary effects do not wipe out the dependence of α_T on the antihyperon potential. Both, the significant larger sensitivity as compared to the schematic calculation in Ref. [6] as well as the shift of the average α_T towards more negative values are linked to the substantial transverse momentum broadening for the $\overline{\Lambda}$-hyperons by secondary scattering. For positive values of α_L where the antihyperon is emitted backward with respect to the Λ-particle, the statistics in the present simulation is too low to draw quantitative conclusions. But even in this region of α_L a systematic variation of α_T with the antihyperon potential might show up with improved statistics.

The international Facility for Antiproton and Ion Research (FAIR) will provide high intensity antiproton beams with momenta between 1.5 GeV/c and 15 GeV/c. A unique feature of antiproton interactions in the energy range of PANDA is the large production cross section of hyperon-antihyperon pairs [8]. At its full luminosity the production rate of $\overline{\mathrm{Y}}$Y-pairs range from a few 100 per second for the $\overline{\Xi}\Xi$-channel, up to a few thousand per second for the $\overline{\Lambda}\Lambda$-channel in the elementary $\overline{\mathrm{p}}$p-reaction. Due to the strong absorption of antibaryons in nuclei this production rate will be lowered depending on the size of the target nucleus in antiproton-nucleus collisions. According to the GiBUU calculations presented above, for a typical medium size target nucleus like ^{20}Ne still several hundreds free $\overline{\Lambda}\Lambda$-pairs can be produced per second. For a nuclear target in this mass range and at maximum interaction rate, approximately 10 reconstructed $\overline{\Lambda}\Lambda$-pairs per second are expected [9]. Therefore, already a measurement period of about one hour will provide a statistics exceeding that of the GiBUU simulations shown above. This will be sufficient to reach a precision of about 10% for the scaling factor $\xi_{\overline{\Lambda}}$ of the antilambda potential. These numbers illustrate that even on rather pessimistic assumption about the luminosity and/or the availability of the antiproton beam during the commissioning phase of the PANDA experiment, one can reach unique and relevant information on the behavior of strange antibaryons in nuclei shortly after the delivery of the first antiproton beam at FAIR.

References

[1] A.B. Larionov, I.A: Pshenichnov, I.N. Mishustin, and W. Greiner, Phys. Rev. C **80** (2009) 021601(R).

[2] T. Gaitanos, M. Kaskulov, H. Lenske, Phys. Lett. B **703** (2011) 193.

[3] T. Gaitanos, M. Kaskulov, U. Mosel, Nucl. Phys. A **828** (2009) 9.

[4] T. Gaitanos, M. Kaskulov, Nucl. Phys. A **899** (2013) 133.

[5] R.O. Gomes, V.A. Dexheimer, S. Schramm. C.A.Z. Vasconcellos, arXiv:1411.4875 [astro-ph.SR].

[6] J. Pochodzalla, Phys. Lett. B **669** (2008) 306.

[7] O. Buss *et al.*, Phys. Rep. **512** (2012) 1.

[8] Physics Performance Report for PANDA: Strong Interaction Studies with Antiprotons, arXiv:0903.3905 [hep-ex]

[9] $\overline{\mathrm{P}}$ANDA Collaboration, Technical Progress Report (GSI Darmstadt), pp. 1-383 (2005).

DOI:10.15120/GR-2015-1-MU-HADRONS-19