Simulation study of the $\bar{p}p \to \bar{\Sigma}^0\Lambda$ reaction at $\bar{\text{P}}$ANDA at FAIR

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The $\bar{\text{P}}$ANDA* experiment is one of the pillars of the new Facility for Antiproton and Ion Research [1], currently under construction in Darmstadt, Germany. $\bar{\text{P}}$ANDA will be a fixed-target experiment which will study non-perturbative strong interaction phenomena in antiproton-proton collisions in the beam momentum range of 1.5 - 15 GeV/c. Strangeness production will be addressed through $\bar{p}p \to$ *Hyperon-Antihyperon* processes. The results of a feasibility study to measure the $\bar{p}p \to \bar{\Sigma}^0\Lambda$ reaction, at antiproton beam momenta of 1.771 GeV/c and 6 GeV/c are presented and discussed in this paper.

Keywords: Hyperon; non-perturbative QCD; PANDA experiment.

1. Introduction

To achieve a better understanding of the strong interaction mechanism, a coherent explanation of the strong coupling (α_s) over a wide range of momentum transfer (Q^2) is needed. At high Q^2, α_s is weak enabling the use of perturbative Quantum Chromodynamics (pQCD). At intermediate and low Q^2 where quarks are confined into hadrons, α_s strongly grows so that pQCD is no longer effective. The fact that different strategies must be used at certain Q^2 ranges, in the non-perturbative (confinement) domain [2], remains as one of the open topics in modern physics.

1.1. *Hyperons*

Hyperons/antihyperons ($Y/\bar{Y}$) are baryons containing at least one strange quark ($\bar{s}/s$). Strangeness production is controlled by $\text{m}_s \sim 100$ MeV which

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is close to the QCD cut-off ($\Lambda_{QCD} \sim 200$ MeV) and therefore, reactions containing hyperons test the confinement scale. Moreover, most ground state hyperons decay weakly, emitting their daughter particles in accordance with the mother hyperon spin vector. As a consequence, measuring the decay angular distributions gives access to some hyperon spin observables, which contain information on the production process.

Single-strangeness hyperon reactions of the form $\bar{p}p \to \bar{Y}Y$ were explored by the PS185 collaboration at CERN [3–6] up to $\sim$ 6 GeV/c. The results constituted a basis for the development and testing of different theoretical models for strangeness production based on: i) meson exchange (MEX) [7], ii) quark-gluon degrees of freedom (QG) [8] and iii) the combination of i) and ii) [9]. These models describe the total and differential cross-sections, however they have different degrees of freedom, mainly describe the single-strangeness sector and lack a complete spin dynamics description. These reasons motivate new experimental measurements in the single and multi-strangeness sector in a wider beam momenta range.

2. The P̄ANDA experiment

The High Energy Storage Ring (HESR) will provide luminosities of $\mathcal{L} \sim 10^{31}$ cm^{-2}s^{-1} in the starting stage (Day-One), until it achieves the desired $\mathcal{L} \sim 2{\times}10^{32}$ cm^{-2}s^{-1} at a later stage. The P̄ANDA layout includes a nearly 4π-solid angle coverage [10]. Each spectrometer consists of state-of-the-art detector systems for particle tracking and momentum reconstruction, particle identification (PID), calorimetry and muon detection. The P̄ANDA physics program includes a wide range of hyperon topics including hyperon production, spectroscopy and structure [10].

Feasibility simulation studies of exclusive event reconstruction for single and multi-strangeness channels are currently being performed for P̄ANDA, using a dedicated simulation and analysis framework with features such as ideal pattern recognition and PID. Cross section distributions based on experimental data have been used wherever available for the data generation. Model predictions are used otherwise.

3. Analysis strategy

The reaction $\bar{p}p \to \bar{\Sigma}^0\Lambda$ was studied at $p_{beam} = 1.771$ GeV/c and 6 GeV/c. These beam momenta were chosen to allow a comparison with previous measurements and other P̄ANDA simulation studies. Each sample contained ~10k events and the simulations were performed using decay models based on the experimental results from PS185[4,6]. The analysis strategy is described here and details can be found in[11].

We study $\bar{\Sigma}^0\Lambda$ where $\bar{\Sigma}^0 \to \bar{\Lambda}\gamma$ and subsequently $\bar{\Lambda} \to \bar{p}\pi^+$, whereas $\Lambda \to \pi^- p$. At both beam momenta, the event *pre-selection* consists of i) the final state particles identification, ii) a photon selection based on the reaction kinematics and iii) the combination of the $\bar{p}\pi^+/p\pi^-$ and a vertex fit of the decay tracks to obtain the $\bar{\Lambda}/\Lambda$ candidates. The only significant background source is false combinations.

In the *final selection* at p_{beam} = 1.771 GeV/c, the $\bar{\Sigma}^0$ candidates are identified and combined with pre-selected Λ candidates. Then, conservation of the initial $\bar{p}p$ system four-momentum is required for the $\bar{\Sigma}^0\Lambda$ system. At p_{beam} = 6 GeV/c, a $\bar{\Sigma}^0$ candidates selection prior to their combination with the Λ candidates is performed. Such is based on the photons energy boosted to their corresponding $\bar{\Sigma}^0$ candidate rest frame. In this case, four-momentum conservation is also imposed as the final step.

At both beam momenta, a background sample ($\bar{p}p \to$ *anything*) of 10^7 events was obtained with the DPM generator[12]. Due to the large $\bar{\Lambda}\Lambda$ channel cross-section[3] at p_{beam} = 1.771 GeV/c, the analysis strategy was also tested on an independent background sample of 10^5 $\bar{\Lambda}\Lambda$ events, generated with a decay model based on experimental data at this beam momentum. At p_{beam} = 6 GeV/c the reaction threshold for higher mass $\bar{Y}Y$ states is surpassed[3], all including a $\bar{\Lambda}\Lambda$ in the final state. To evaluate how the selection criteria works in reconstructing such channels, all events containing $\bar{\Lambda}/\Lambda$ hyperons were removed from the full DPM sample in a second background sample hereby called *DPM-filtered*. For both beam momenta, the background sources motivated additional mass window cuts, and at p_{beam} = 6 GeV/c a cut in the $\bar{\Lambda}$ decay vertex position was added.

4. Results

The final number of events, the signal to background ratio (S/B) and reconstruction efficiencies (ϵ) for signal and background samples are summarized in Table 1 for p_{beam} = 1.771 GeV/c (left) and p_{beam} = 6 GeV/c (right). If no events remain after the selection, a 90% confidence level (denoted *) is used to account for statistical fluctuations.

At p_{beam} = 1.771 GeV/c the DPM sample is fully removed while only a few $\bar{\Lambda}\Lambda$ events remain, showing that the applied criteria is successful in selecting signal events. At p_{beam} = 6 GeV/c the DPM sample was fully suppressed, while a few DPM-filtered (DPM-filt) events survived the selection. The latter highlights the importance of testing this strategy in other independent hyperon channel samples. At both p_{beam}, high S/B ratios (purity) were obtained. The latter is important given that pure samples are required for spin observables reconstruction. False combinations (Combi) are well suppressed in both beam momenta cases, but are the highest contribution to the total background. This is attributed to neutrons being wrongly identified as photons, which could be solved with an additional selection based on the photons recorded time and position [15].

Table 1. Reconstruction efficiencies for samples at p_{beam} =1.771 and 6 GeV/c.

	p_{beam} = 1.771 GeV/c			p_{beam} = 6 GeV/c		
Channel	Events	S/B	ϵ(%)	Events	S/B	ϵ(%)
$\bar{\Sigma}^0\Lambda$	526 ± 23	—	5.3 ± 0.2	614 ± 25	—	6.1 ± 0.3
Combi	38	14	0.38	111	5.5	1.1
DPM*	< 50.6	> 11	$< 5.1 \times 10^{-4}$	30	20.7	3.0×10^{-6}
$\bar{\Lambda}\Lambda$	4	120	4.0×10^{-5}	—	—	—
DPM-filt*	—	—	—	<18	>34.7	$< 3.9 \times 10^{-6}$

In Table 2, the estimated reconstruction rates for the $\bar{p}p \to \bar{\Sigma}^0\Lambda$ and other hyperon channels [a] at the *Day-One* HESR luminosity, *i.e.* $\mathcal{L} \sim 10^{31}$ cm^{-2}s^{-1} are presented. The $\bar{p}p \to \bar{\Lambda}\Lambda$ channel reconstruction is based on vertex fits, mass window selection and decay vertex position cuts. In $\bar{p}p \to \bar{\Xi}^+\Xi^-$ a Decay Chain Fitting tool was used for the full channel reconstruction. The calculated rates so show that it will be possible to start collecting large and clean exclusive hyperon samples already during the first phase of the experiment [14].

Table 2. Reconstruction rates at *Day-One* luminosity.

p_{beam} [GeV/c]	Reaction	σ [μb]	ϵ [%]	Rate [s^{-1}]
1.64	$\bar{p}p \to \bar{\Lambda}\Lambda$	64	16	10
1.77	$\bar{p}p \to \bar{\Sigma}^0\Lambda$	11	5.3	0.6
6.0	$\bar{p}p \to \bar{\Sigma}^0\Lambda$	20	6.1	1.6
4.6	$\bar{p}p \to \bar{\Xi}^+\Xi^-$	~ 1	8.2	0.1
7.0	$\bar{p}p \to \bar{\Xi}^+\Xi^-$	~ 0.3	7.9	0.03

[a] Results on $\bar{p}p \to \bar{\Lambda}\Lambda$ and $\bar{p}p \to \bar{\Xi}^+\Xi^-$ by W. Ikegami Andersson, Uppsala University [13]

5. Summary

Hyperons provide a testing tool for the strong interaction in the Q^2 region where pQCD is not applicable. At the $\bar{\text{P}}$ANDA experiment, high single and multi-strange hyperon production rates are expected from Day-one and these will increase when the full luminosity is achieved.

References

1. FAIR webpage `https://fair-center.eu/`
2. A. Deur *et al.* 2016, *Progress in Particle and Nuclear Physics* **90** 1-74.
3. T. Johansson 2003, *Proc. Int. AIP Conf. Proc. 8th Int. Conf. on Low Energy Antiproton Physics (Italy)* p 95
4. P. D. Barnes *et al.* 1996 *Phys. Rev.* C **54** 2831.
5. P. D. Barnes *et al.* 1990 *Phys. Lett.* B **246** 273.
6. H. Becker *et al.* 1978 *Nucl. Phys.* B **141** 48.
7. F. Tabakin and R. A. Eisenstein 1985, *Phys. Rev.* C **31** 1857.
8. H. R. Rubinstein and H. Snellman 1985 *Phys. Lett.* B**165** 187.
9. P. G. Ortega *et al.* 2011 *Phys. Lett.* B **696** 352.
10. Erni W. *et al.* 2009 *arXiv preprint* arXiv: 0903.3905
11. G. Pérez Andrade, 2019 , Master thesis, Uppsala University. Available from `http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-375552`
12. K. Götzen 2014, $\bar{p}p$ Cross-section estimator. Found in `https://panda.gsi.de/pbarx/index.php?&mode=1`
13. W. Ikegami-Andersson, 2020, PhD thesis Uppsala Univeristy (In preparation)
14. Jennifer Pütz *et al* 2016, *J. Phys.: Conf. Ser.* **742** 012028
15. Albrecht Gillitzer, 2018 *Private communication*