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Σ^0 reconstruction in Ag+Ag collisions at 1.58 AGeV with the HADES experiment

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Abstract. In this contribution we will discuss the production of Σ^0 baryons in Ag+Ag collisions at 1.58 AGeV beam energy measured by HADES. The experimental upgrade with an electromagnetic calorimeter enables a clear reconstruction of the Σ^0. The first sub threshold Σ^0 production in A+A collisions is compared to available p+p data as well as transport calculations and statistical hadronisation models.

1 The setup of the HADES experiment

The High Acceptance DiElectron Spectrometer HADES [1] at GSI provides capability of measuring rare probes like dileptons and strangeness as well as particle number fluctuations and collectivity [2][3][4]. The torodial magnet spectrometer satisfies the requirements of an almost full acceptance coverage in azimuth angle combined with a polar angle coverage of $16^\circ - 85^\circ$. The SIS18 provides proton beams up to 4.5 GeV, secondary pion beams as well as heavy ion beams reaching from Li to Au below 2 AGeV kinetic beam energy. In march 2019 14 billion Ag+Ag events at $\sqrt{s_{NN}} = 2.55$ GeV were recorded, with 4.5 billion events in the most central $0 - 40\,\%$ which were used for this analysis. This energy regime corresponds to moderate freeze-out temperatures of $T \approx 50{-}70$ MeV and high baryochemical potentials of $\mu_B \approx 700 - 900$ MeV. The target consists of 15 thin target silver foils of $40\,\mu$m thickness each. This segmentation avoids additional interactions of produced rare probes and additionally suppresses photon conversion. The following RICH detector covers the full forward hemisphere and was upgraded for this beamtime with multi-anode photomultipliers with enhanced electron efficiency as well as purity since the upgraded RICH is now capable of separating conversion electrons and single electrons [5]. Immediately afterwards four layers of Mini-Drift-Chambers (MDCs) provide tracking information where the torodial magnet is located after the first two layers which results in a field mainly in between layer 2 and 3 of the MDCs. A time of flight measurement is performed by the RPC for polar angles of $18^\circ - 44^\circ$ and at larger angles by the TOF system. As fundamental part of this analysis the newly installed electromagnetic calorimeter (EMC) with an energy resolution of $5.8\%/\sqrt{E[GeV]}$ was placed directly behind the RPC, with the same polar angle coverage but only 2 out of six sectors were fully equipped and utilized so far [6].

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2 Λ reconstruction

The Λ reconstruction requires the decay into a $p\pi^-$ pair, not being sensitive to the $n\pi^0$ channel. While hundreds of particles are produced in central Ag+Ag collisions, only every 10th event contains strange hadrons. The Λ decay length of $c\tau = 7.89$ cm is exploited for the selection criteria to suppress the huge amount of combinatorial background. The methodology of displaced vertices allows combinatorial background reduction up to 4 orders of magnitude. After loose pre selection criteria on the effective mass of the π^- and p, in the following a set of parameters strongly depending on each other was analyzed by the multi-variant analysis toolkit TMVA [7]. This set of parameters contains the distance of closest approach of the π^- and proton to the event vertex, the closest distance of the proton and π^-, the distance of this secondary vertex to the event vertex, the distance of the extrapolated Λ track to the event vertex, the opening angle inbetween the daughter particles as well as the effective mass of the π^-. The multi-layer perceptron was trained with Λ simulated by the transport code UrQMD [8] for the signal and background classification. The efficiency correction was performed within the acceptance in p_t–y bins up to $p_t = 1.5$ GeV/c with $\epsilon_{eff} \approx 1.5$ % around midrapidity and afterwards extrapolated to the full phase space assuming a Boltzmann distribution.
The result was extracted for each centrality class and is consistent to a HADES Λ analysis presented in [9].

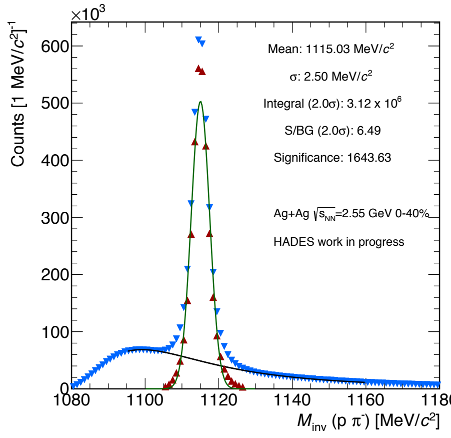

Figure 1. Raw amount of reconstructed Λ in 4.5 10^9 Ag+Ag collisions at $\sqrt{s_{NN}}$ = 2.55 GeV.

3 $\Lambda\gamma$ signal extraction

The newly installed electromagnetic calorimeter provides the opportunity of γ reconstruction without making use of photon conversion. The decay photon has a rather small energy due to the small rest mass difference of Σ^0 and Λ of $\Delta m \approx 77$ MeV and the small boost. Thus only clusters with 60 MeV$< E^{\gamma}_{rec} <$ 250 MeV are taken into account. Only clusters which are not matched to charged particles are used further. All clusters extending over more than one crystal are removed to avoid additional energy spread. Small polar angles $\theta < 17°$ are rejected due to additional material budget in this region. Due to the demanding EMC timing calibration, a cell dependent time cut is applied

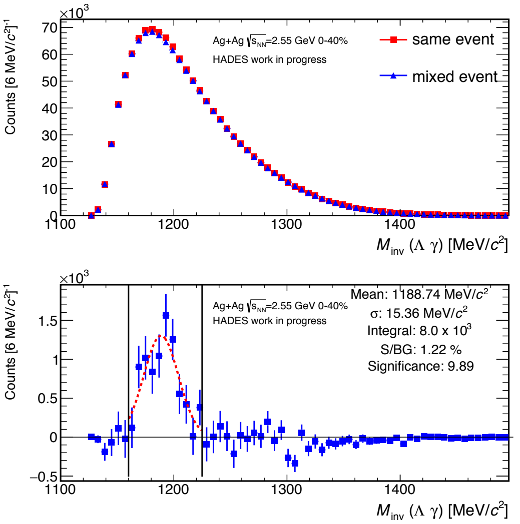

Figure 2. Invariant mass distribution of the $\Lambda\gamma$ candidates; top figure - all candidates, bottom figure - eventmix subtracted.

which rejects hadronic contamination of for example uncharged neutrons. This cell dependent time cut was extracted using high energy photons and was validated with leptons. The $\approx$ 4 MeV mass shift of the Gaussian fit is due to still imperfect EMC calibration for low energy photons. Figure 2 shows the signal in full accessible phase space.

4 $\Lambda e^{\pm}$ signal extraction

The attempt of reconstructing the $\Sigma^0 \rightarrow \Lambda e^+ e^-$ decay channel is strongly restricted by the HADES acceptance requiring $\approx$ 70 MeV energy for electrons. Similarly to the photon energy selection, only electrons with energy $E_e < 250$ MeV are taken into account including selection criteria on the effective mass and ring-track matching in the RICH. Extended simulation studies showed, that the energy distribution amongst the reconstructed conversion leptons is asymmetric. The unreconstructed electron often has an energy below 15 MeV. Thus, invariant mass spectra are calculated with only one of the two electrons. According to simulations only a few hundred counts would be expected in the available data set. Unfortunately, the statistical significance is too small here. However, this method was proven to work in the new HADES data sample with p+p collisions at $E_{kin} = 4.5$ GeV.

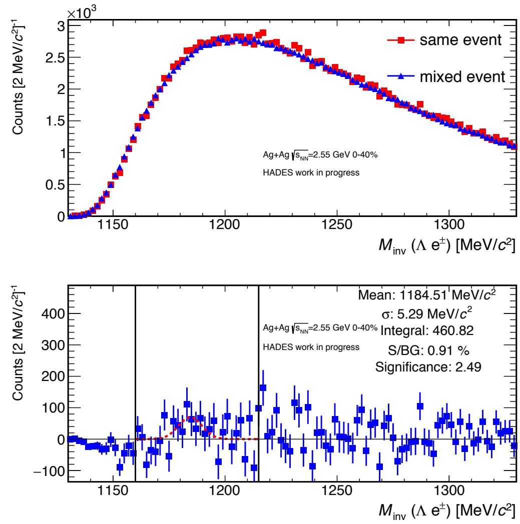

Figure 3. Invariant mass spectrum of Λe^+ or Λe^- combinations, denoted as $\Lambda e^{\pm}$.

5 Discussion of reconstructed Σ^0 yield

An efficiency correction is performed by embedding Σ^0 produced by the event generator PLUTO [10] and transported through a GEANT [11] simulation, into experimental data. An additional optimization of the photon timing cut efficiency was performed using experimental leptons since the EMC response is the same resulting in an overall efficiency $\approx 2 \cdot 10^{-4}$. Systematic errors were estimated by dividing the sample into subsets, variation of the selection criteria and sideband variations for signal extraction. A resulting multiplicity of $M(\Sigma^0) = (15.7 \pm 3.2) \cdot 10^{-3}$ per event is calculated, corresponding to a $(\Lambda + \Sigma^0)/\Sigma^0$ ratio of $R = 4.2 \pm 0.9$, accounting for the Σ^0 contribution to the measured Λ multiplicity. The statistical model Thermal FIST [12] was used for comparison of the measured Σ^0 yield to the total particle production within the 0 – 10% most central events. Within the strangeness canonical ensemble an ideal hadron gas was assumed which neglects the finite volume of the hadrons. Since a large fraction of K^- is not produced thermally, but via feed-down from ϕ decays [13], the K^- was not used for the performance of the fit, as well as the Σ^0. The fit results in a temperature of $T = (65.8 \pm 1.5)$ MeV with a baryochemical potential of $\mu_B = 762.4 \pm 8.6$ MeV with a goodness of the fit of $\chi^2/ndf = 0.71$ and $R = 10.1 \pm 0.58$ fm and $R_c = 3.38 \pm 0.34$ fm. Figure 4 shows the good agreement of the measured data to Thermal FIST, while the transport models UrQMD [8], SMASH [15] and GiBUU [16] do not convey a uniform result. Since all quantum numbers of Λ and Σ^0 are the same, the freeze out ratio of

$R_{f.o.} = \Lambda/\Sigma^0 = 3.2$ is used to estimate a freeze out temperature of $T = \Delta M/ln(R') \approx 66$ MeV which is consistent with the strangeness canonical approach as well as the grand canonical approach of all hadrons which do not contain strangeness and thus connects strangeness to the bulk properties in the statistical model description. The comparison to world data is depicted in figure 4 which is taken from [17], with the addition of our data point and the associated predictions. The result from Ag+Ag collisions is plotted at low excess energies, although the value is shifted by 85 MeV, calculated with respect to the free pp collision. The threshold energy in NN collisions for Λ production lies at 2.55 GeV thus the Σ^0 would be produced below the NN threshold: For the first time, Σ^0 production in AA collisions is measured subthreshold with respect to $\sqrt{s_{NN}}$. As the freeze-out ratio compares well to the higher energies, the ratio is obviously not influenced by the threshold.

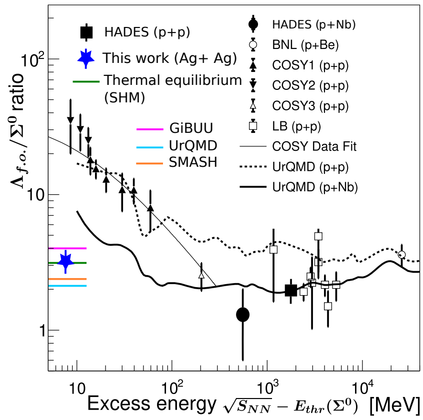

Figure 4. Comparison to existing data and transport and statistical predictions.

6 Summary

HADES presents a Σ^0 measurement in Ag+Ag collision at $\sqrt{s_{NN}} = 2.55$ GeV which is the first measurement of Σ^0 in AA collisions and subthreshold compared to p+p. The calculated Λ/Σ^0 ratio at freeze-out $R_{f.o.} = 3.2 \pm 0.7$ corresponds in a pure thermal approach to a temperature of $k_B T = 66$ MeV which is in good agreement to the properties obtained by the statistical model. This measurement explicitly shows the fundamentally different strangeness production mechanism in AA and NN collisions close to threshold.

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References

[1] G. Agakichiev et al., The European Physical Journal A **2** (2009)
[2] J. Adamczewski-Musch et al., Nature Phys. **15** 1040-1045 (2019)
[3] J. Adamczewski-Musch et al., Phys. Rev. C, **102** (2020)
[4] B. Kardan, Nuclear Physics A, **982** (2019)
[5] J. Foertsch et al. Nuc. Instruments and Methods in Physics Research Sec. A **1056** (2023)
[6] T. Galatyuk et al., KnE Energ.Phys. **3** 162-169 (2018)
[7] A. Hocker et al., TMVA - Toolkit for Multivariate Data Analysis, (2007)
[8] M. Bleicher et al., Journal of Physics G: Nuclear and Particle Physics **9** (1999)
[9] S. Spies, PhD Thesis Goethe University Frankfurt (2022)
[10] I. Froehlich, Pluto, arXiv:0708.2382 (2007)
[11] R. Brun et al., GEANT3, CERN-DD-EE-84-1 (1987)
[12] V. Vovchenko and H. Stoecker, Comp. Phys. Communications **244**, 295-310 (2019)
[13] M. Kohls et al. HADES Collaboration, Contribution to the present volume
[14] M. Becker et al. HADES Collaboration, Contribution to the present volume
[15] J. Weil et al., Phys. Rev. C **5** (2016)
[16] O. Buss et al., Phys. Rept. **512** 1-124 (2012)
[17] J. Adamczewski-Musch et al., Physics Letters B **781** (2018)