Hypernuclei at HADES

Recent results from the measurement of Hypernuclei in Ag+Ag collisions at $\sqrt{s_{NN}} = 2.55$ GeV with the HADES experiment
Nuclear collisions at few GeV

- Nucleons stopped in collision zone
- Baryon dominated fireball $N(B) \approx 10 N(\pi)$
- Large proportion of baryons clustered in light nuclei (About 50% of protons)


07.04.2022
Quark Matter Conference 2022 - Simon Spies for the HADES collaboration
Nuclear collisions at few GeV

- Strangeness production close to free NN threshold energy:
  \[ N + N \rightarrow Y + K + N: \quad \sqrt{s} = 2.55 \text{ GeV} \]
  \[ N + N \rightarrow K + \bar{K} + N + N: \quad \sqrt{s} = 2.86 \text{ GeV} \]

- Steep excitation function, sensitive to medium effects

- Strangeness exchange reactions: \( Y + \pi \rightarrow N + \bar{K} \)

- Spectral functions of mesons modified by interactions with baryons and mesons

- Decay products – leptons – decouple from the fireball
The HADES Experiment

- Fixed target experiment at SIS18 (GSI, Germany)
- Magnet spectrometer
- Low mass Mini-Drift-Chambers (MDCs)
- Time of flight walls RPC and ToF
- RICH and ECAL for $e^+e^-$ and photon identification
- Forward hodoscope for spectators detection
- Almost full azimuthal angle and polar angles between 18° and 85° covered
The HADES Experiment

- PID primarily via. momentum and velocity
- Separation of multiple charged particles via. specific energy loss
- Heavy-ion beamtimes:
  - 2012: Au(1.23A GeV)+Au $\sqrt{s_{NN}} = 2.42$ GeV
    - 7 billion events
  - 2019: Ag(1.58A GeV)+Ag $\sqrt{s_{NN}} = 2.55$ GeV
    - 14 billion events
Charged Particles

Analysis of Protons, Light Nuclei and Pions
Protons: Yield and Kinematic Distributions

➢ Large phase space coverage with small statistical and systematic errors

0-10%: Nucleons almost stopped
10-30%: Nucleons not stopped and contaminated with spectators
Weak Decays

Reconstruction and Analysis of weakly decaying Hadrons
Weak decay reconstruction

➢ Combinatorial background about factor 10,000 above signals
➢ Long lifetimes → Off-vertex-topology
➢ Evaluated by an artificial neural network

Weak decay reconstruction

- Combinatorial background about factor 10,000 above signals
- Long lifetimes $\rightarrow$ Off-vertex-topology
- Evaluated by an artificial neural network
Reconstruction and Analysis of $\Lambda$ Hyperons

- Very significant signal
- Detailed analyses of hyperon production possible
- Lifetime measurement as test-case
- Result of $(278 \pm 3 \pm 13)$ ps compatible with PDG value
Strange Yields vs. $\langle A_{\text{Part}} \rangle$

- Production below (at) free NN-threshold:
  \[ N + N \rightarrow Y + K + N: \quad \sqrt{s} = 2.55 \text{ GeV} \]
  \[ N + N \rightarrow K + \bar{K} + N + N: \quad \sqrt{s} = 2.86 \text{ GeV} \]

- Energy provided by the system

- Strange hadron yields scale similar with $\langle A_{\text{Part}} \rangle$:
  \[ \text{Mult} \sim \langle A_{\text{Part}} \rangle^\alpha \text{ with } \alpha_{\text{Au+Au}} = 1.45 \pm 0.06 \]

- Hierarchy in production thresholds not reflected

- Scaling with absolute amount of $s\bar{s}$
Strange Yields vs. $\langle A_{\text{Part}} \rangle$

- Production below (at) free NN-threshold:
  \[ N + N \rightarrow Y + K + N: \quad \sqrt{s} = 2.55 \text{ GeV} \]
  \[ N + N \rightarrow K + \bar{K} + N + N: \quad \sqrt{s} = 2.86 \text{ GeV} \]

- Energy provided by the system

- Strange hadron yields scale similar with $\langle A_{\text{Part}} \rangle$:
  \[ \text{Mult} \sim \langle A_{\text{Part}} \rangle^\alpha \text{ with } \alpha_{Au+Au} = 1.45 \pm 0.06 \]

- Hierarchy in production thresholds not reflected

- Scaling with absolute amount of $s\bar{s}$

- Ag+Ag slope equal within errors $\alpha_{Ag+Ag} = 1.46 \pm 0.03$

- Further reduction of systematic uncertainties ongoing
Hypernuclei

Reconstruction and Analysis of Hypernuclei
# Hypernuclear Properties

## The Hypertriton – $^{3}_{\Lambda}H$

- Mass of $\approx 2991$ MeV/c²
- Binding energy $B(^{3}_{\Lambda}H) \approx 0.79$ MeV/A

- Primarily four mesonic decay channels:
  - $^{3}_{\Lambda}H \rightarrow ^{3}He + \pi^{-}$ (BR $\approx 27\%$)
  - $^{3}_{\Lambda}H \rightarrow t + \pi^{0}$ (BR $\approx 13\%$)
  - $^{3}_{\Lambda}H \rightarrow d + p + \pi^{-}$ (BR $\approx 40\%$)
  - $^{3}_{\Lambda}H \rightarrow d + n + \pi^{0}$ (BR $\approx 20\%$)

- Lightest known hypernucleus

- Current World-Average Lifetime: $(211 \pm 9)$ ps

## The Hyperhydrogen $4–^{4}_{\Lambda}H$

- Mass of $\approx 3923$ MeV/c²
- Binding energy $B(^{4}_{\Lambda}H) \approx 2.63$ MeV/A
  $\rightarrow \approx 3.3 \times B(^{3}_{\Lambda}H)$

- Primarily three mesonic decay channels:
  - $^{4}_{\Lambda}H \rightarrow ^{4}He + \pi^{-}$ (BR $\approx 50\%$)
  - $^{4}_{\Lambda}H \rightarrow t + p + \pi^{-}$ (BR $\approx 33\%$)
  - $^{4}_{\Lambda}H \rightarrow t + n + \pi^{0}$ (BR $\approx 17\%$)

- Compared to the $^{3}_{\Lambda}H$ higher binding energy and BR of the two-body decay channel

- Current World-Average Lifetime: $(218 \pm 5)$ ps
$^3\Lambda$H Two-Body Decay: $^3\Lambda$H $\rightarrow^3$He + $\pi^-$

- Significant signal
- Multi-differential analysis of $^3\Lambda$H production possible
- First measurement at mid-rapidity at this energy
- Systematic studies ongoing
$^3_Λ$H Two-Body Decay: $^3_Λ$H $\rightarrow$ $^3$He + $\pi^-$

- $^3_Λ$H lifetime measurement to contribute to resolving the $^3_Λ$H lifetime puzzle
- Lifetime of $(256 \pm 22 \pm 36)$ ps compatible with free $Λ$ lifetime measured
- Further uncertainty analyses required
$^4\Lambda$H Two-Body Decay: $^4\Lambda$H $\rightarrow$ $^4$He + $\pi^-$

- Significant signal
- Multi-differential analysis of $^4\Lambda$H production possible
- First measurement at mid-rapidity at this energy
- Systematic studies ongoing

$^4\Lambda$H - 0 - 25% Centrality
$^4\Lambda H$ Two-Body Decay: $^4\Lambda H \rightarrow ^4\text{He} + \pi^-$

- $^4\Lambda H$ lifetime measurement to contribute to world data on Hypernuclei lifetimes
- Lifetime of $(222 \pm 8 \pm 13)$ ps compatible with earlier measurements measured
- Further uncertainty analyses required
Summary

➢ HADES detector upgraded with FAIR technology (ECAL, RICH, STS1,2 and fRPC)

➢ 14 billion Ag(1.58A GeV)+Ag events collected in 2019 run

➢ Very detailed analyses of bulk particles (Protons, Light Nuclei and Pions)

➢ High quality analysis of weak decays with an artificial neural network

➢ First multi-differential analysis of $^3\Lambda H$ and $^4\Lambda H$ production around mid-rapidity at SIS18 energies

➢ Contribution to $^3\Lambda H$ and $^4\Lambda H$ lifetime measurements
The HADES Collaboration
Thank you for your Attention!
Reconstruction and Analysis of $K^0_S$ Mesons

- Very significant signal
- Detailed analyses of strange meson production possible
- Lifetime measurement as test-case
- Result of $(92 \pm 1 \pm 6)$ ps compatible with PDG value