HADES at GSI, Darmstadt, Germany

Outline
- Introduction and recap QM17
- Cold matter effects
- State of the art modelling strangeness
- Reconstruction of baryonic resonances
- Summary and outlook

Sub-threshold strangeness production measured with G. Kornakov for the HADES Collaboration
Elementary and heavy-ion beams $\sqrt{s} = 2.3\text{-}2.7 \text{ GeV}$ at SIS18

- HADES explores baryon-rich matter
- Strangeness production below $\sqrt{s_{NN}}$ threshold

$100 \ p \rightarrow 10 \ \pi \rightarrow 10^{-2} \ K^{+} \rightarrow 10^{-4} \ K^{-}$

Rare probes:
$\phi \rightarrow 2\times10^{-4}/\text{Event in } K^{+}K^{-}$
$\sim 1 \ \text{event out of 5000!}$
HADES Au+Au $\sqrt{s}=2.42$ GeV

- Full azimuthal coverage, 18-85° polar angle
- Fast detector: $1.5 \times 10^6$ Au ions/s (8 kHz)
- $7 \times 10^9$ events recorded
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Off-line centrality selection:
- Hit/track multiplicity
- Forward Wall
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**High purity** hadron detectors:
- MDC: momentum ($\Delta P/P<2\%$) and dE/dx
- TOF (Diamond $T_0$, RPC and Scintillator Walls)
QM-17: Strangeness production consistent with equilibrium at SIS18

QM17 H.Schuldes et al.
QM17 M.Lorenz et al.

- $\phi$ sizeable source for $K^-$.
  Feed-down can explain lower effective temperature and rapidity spectrum of $K^-$
- Universal centrality dependence of strangeness production
- SHM describes hadron yields with global parameters: $T$, $\mu_B$, $R$, $R_C$

Strangeness in cold nuclear matter

- Secondary pion beam 1.7 GeV/C on C and W targets
- Collected events: $N_C = 10^8$ and $N_W = 1.3 \times 10^8$
- Energy: $\sqrt{s_{\pi N}} = 2$ GeV

- $K^-\pi^+$ absorption in $\pi^-W$ with respect to $\pi^-C$
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\[ \phi_W/K^- \approx \phi_C/K^- \text{ in acceptance} \]

- \( K^- \) absorption in \( \pi^- W \) with respect to \( \pi^- C \)
- \( \phi/K^- \) ratio the same for C and W

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Open question: strangeness production at low energies

- “Abundant” (multi)-strange particles demand an energy reservoir to be produced sub-threshold.

Different approaches:

- Non equilibrium: branching ratios to strange particles!
- Local forced thermalization
- Hagedorn states

Baryon resonances play a key role!
Can we directly measure resonances and their contributions to strangeness production?
A novel iterative method for estimation of the combinatorial background

The combinatorial background is generated by random rotations of measured tracks.

Rotations preserve $E$ and $P_T$ of the track and the event.
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All reconstructed pair combinations are split into signal and background iteratively.

Solution in $M-P_T-Y-\theta$
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Validation with narrow states: $\Lambda$ and $K^0_s$

No off-vertex condition.

Yield efficiency & acceptance corrected.
Validation with narrow states: $\Lambda$ and $K^0_s$

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inclusive $$\pi^+\pi^-$$

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Validation with narrow states: $\Lambda$ and $K^0_s$

No off-vertex condition.
Yield efficiency & acceptance corrected
Centrality mass and width dependence

\[ R \rightarrow \pi^+ p \]

\[ \frac{dN}{dM} \text{ [MeV/c}^2] \]

HADES
0-10% Au+Au
\( \sqrt{s} = 2.42 \text{ GeV/c}^2 \)
in acceptance

preliminary
Centrality mass and width dependence

Fit to relativistic BW with mass dependent width.

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Centrality mass and width dependence

Fit to relativistic BW with mass dependent width.

Qualitative agreement with previous results from EOS in NiCu 1.97A GeV


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Understanding of “kinematical” mass shift

Most probable $\pi^+p$ pair mass value as a function of pair $P_T$

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Understanding of “kinematical” mass shift

- Most probable $\pi^+p$ pair mass value as a function of pair $P_T$.
- UrQMD evolution with $R \rightarrow \pi^+p$ with no further re-scattering.

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- UrQMD evolution with $R \rightarrow \pi^+ p$ with further re-scattering.
- Qualitative agreement of the trend with transport models: UrQMD

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Losing strangeness is $0$ because it is a very rare probe!!!!!!!

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Inclusive spectra of $\pi^+p$

- $\text{Mult} \sim \langle A_{\text{part}} \rangle \alpha = 1.5 \pm 0.2$ in the $\Delta^{++}$ region

- Interplay between re-generation and re-scattering

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Production of charged pions from resonances: the most simple abundant mesons
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Production of charged pions from resonances: the most simple abundant mesons

![Graph showing the production of π⁻ from resonance decays](image)
Production of charged pions from resonances: the most simple abundant mesons

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Production of charged pions from resonances: the most simple abundant mesons

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0-10% centrality

HADES Acceptance

π⁻ from resonance decays

single pion

\[ M_{inv} < 1325 \text{ MeV/c}^2 \]

\[ 1325 < M_{inv} < 1825 \text{ MeV/c}^2 \]

\[ 1825 < M_{inv} < 2225 \text{ MeV/c}^2 \]

sum

preliminary

HADES Acceptance

AuAu \( \sqrt{s} = 2.42 \text{ GeV} \)

0-10% centrality
Production of charged pions from resonances: the most simple abundant mesons

❖ Assuming equally produced $\Delta^{++}$ at freeze-out: $p^{-}$ yield should be scaled by 4
❖ Pions from high-mass resonances are scaled by 4/3
Production of charged pions from resonances: the most simple abundant mesons

- Assuming equally produced $\Delta^{+0/++}$ at freeze-out: $\pi^-$ yield should be scaled by 4
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Production of charged pions from resonances: the most simple abundant mesons

- Assuming equally produced $\Delta^{3/2}/0^+/++$ at freeze-out: $\pi^-$ yield should be scaled by 4
- Pions from high-mass resonances are scaled by 4/3

- Measured charged pions in 0-10% central collisions are well reproduced from decay of baryonic resonances
Summary

- Universal centrality dependence of strangeness production
- $K^-$ and $\phi$ equally absorbed in cold nuclear matter in pion induced reactions at $\sqrt{S_{\pi N}} = 2$ GeV
- Baryon resonances are relevant for modelling strangeness production.
- A novel iterative technique allows to reconstruct signals with large combinatorial background.
- First steps toward strangeness production from measured baryonic resonances: description of single pion spectra in central collisions.
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- Understand production of resonances as a function of centrality.
- Calculate kaon spectra.
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Thank you for your attention!

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Production of charged pions from resonances: the most simple abundant mesons

- Assuming equally produced $\Delta^{-}/0^{+}/++$ at freeze-out:
  - $\pi^-$ yield should be scaled by 4
  - $\pi^+$ scaled by $4/3$
- Pions from high-mass resonances are scaled by $4/3$

- The deficit of intermediate PT $p^+$ is due to inexistence of $N \rightarrow \pi^+ p$ channel

- Measured charged pions in 0-10% central collisions from excitation of baryonic resonances

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