Deep sub threshold multi-strange hadron production: The role of heavy resonances [1]

NED workshop, Sicily, 2015

Jan Steinheimer

26.03.2015

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[1] JS and M. Bleicher, arXiv:1503.07305

Why is this interesting?

Multi-strange hadrons are of particular interest

- Strange particles have to be newly produced, in pairs.
- Because they are more massive one can study their threshold production in nuclear collisions at high densities. The production rates and properties may be sensitive to the properties of matter present in these reaction.

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- Because they are more massive one can study their threshold production in nuclear collisions at high densities. The production rates and properties may be sensitive to the properties of matter present in these reaction.
- Infer matter properties/potentials/equilibration times.
- Provides hints for novel processes.
- Explore subthreshold multi-step processes
- Explore canonical effects

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- Experimentally not well explored.
- Difficult to measure (low statistics,dileptons,multi-particle correlation)
- Theoretically not well understood

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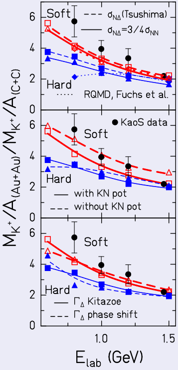
An example

Comparisons of K^+ production in different size systems has lead to the conclusion, that the EoS of nuclear matter is soft.



C. Hartnack, H. Oeschler and J. Aichelin, Phys. Rev. Lett. **96**, 012302 (2006)

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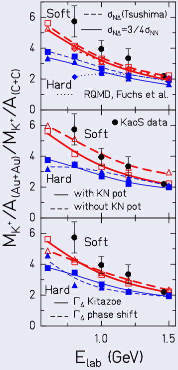

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Lots of work on strangenss

- P.Koch, B.Müller and J.Rafelski, Phys. Rept. 142, 167 (1986).
- J.Randrup and C.M.Ko, Nucl. Phys. A 343, 519 (1980)
- J.Aichelin and C.M.Ko, Phys. Rev. Lett. 55, 2661 (1985).
- W.Cassing, E.L.Bratkovskaya, U.Mosel, S.Teis and A.Sibirtsev, Nucl. Phys. A 614 , 415 (1997)
- C.Hartnack, H.Oeschler, Y.Leifels, E.L.Bratkovskaya and J.Aichelin, Phys. Rept. 510, 119(2012)
- .
- .
- .

Strangeness Production in dense (cold) matter

Subthreshold production: Two paradigms

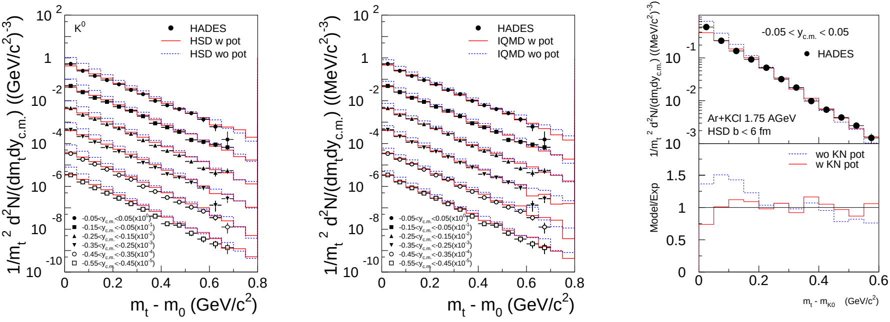
Multi-step processes

- Include a most complete spectrum of excitable resonances.
- Increases the available energy (in a dense medium) above the threshold by creation of heavy resonances.

In-medium modifications

- Decreases the needed energy by in-medium modifications

In medium production of Kaons - Example 2



- Several model calculations, including kaon potentials compared to experimental spectra.
- These comparisons suggested the importance of kaon potentials.

C. Hartnack, H. Oeschler, Y. Leifels, E. L. Bratkovskaya and J. Aichelin, Phys. Rept. **510**, 119 (2012)

Strangeness Production in UrQMD

Strange particle production goes ONLY via

- Resonance excitation:
    - N+N→ X
    - N+M→ X
    - M+M→ X

Relevant channels:

1. $NN \rightarrow N\Delta_{1232}$
2. $NN \rightarrow NN^*$
3. $NN \rightarrow N\Delta^*$
4. $NN \rightarrow \Delta_{1232}\Delta_{1232}$
5. $NN \rightarrow \Delta_{1232}N^*$
6. $NN \rightarrow \Delta_{1232}\Delta^*$
7. $NN \rightarrow R^*R^*$

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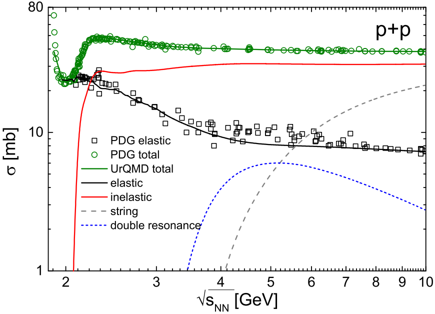

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N*(1440)	$\Delta(1232)$
N*(1520)	$\Delta(1600)$
N*(1535)	$\Delta(1620)$
N*(1650)	$\Delta(1700)$
N*(1675)	$\Delta(1900)$
N*(1680)	$\Delta(1905)$
N*(1700)	$\Delta(1910)$
N*(1710)	$\Delta(1920)$
N*(1720)	$\Delta(1930)$
N*(1900)	$\Delta(1950)$
N*(1990)	
N*(2080)	
N*(2190)	
N*(2200)	
N*(2250)	

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Not relevant at the beam energies considered here

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- Resonance excitation:
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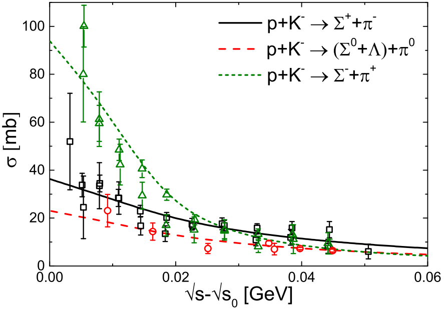
- String excitations

Maybe relevant at the beam energies considered here

Strangeness exchange reactions

In addition Strange hadrons may be created in strangeness exchange reactions.



Kaon spectra with resonances

Ratio [%]	$\Gamma_{\Lambda K}/\Gamma_{tot}$		$\Gamma_{\Sigma K}/\Gamma_{tot}$	
Resonance	I	II	I	II
N*(1650)	7	7	2	2
N*(1710)	10	10	3	3
N*(1720)	10	10	2	2
N*(1900)	2	2	0	0
N*(1990)	3	3	0	0
N*(2080)	12	0	0	0
N*(2190)	12	0	0	0
N*(2220)	12	0	0	0
N*(2250)	12	0	0	0
$\Delta(1920)$	0	0	3	3
$\Delta(1930)$	0	0	15	0
$\Delta(1950)$	0	0	12	0

'Thermal' spectra from resonances. Just T changes.

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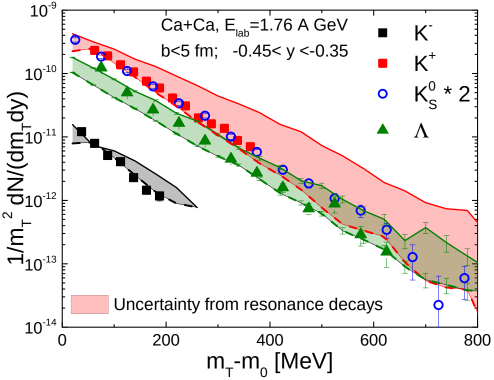
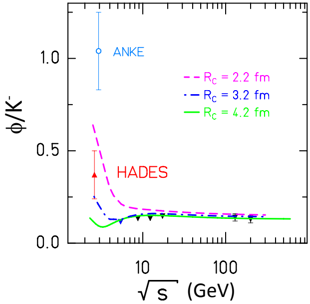
Unknown resonance branching ratios also accommodate for Kaon spectra.



'Thermal' spectra from resonances. Just T changes.

Motivation

Recent measurements on near and below threshold production.



ϕ production

HADES and FOPI reported unusually large ϕ contribution to the K^- yield.

G. Agakishiev *et al.* [HADES Collaboration], Phys. Rev. C **80**, 025209

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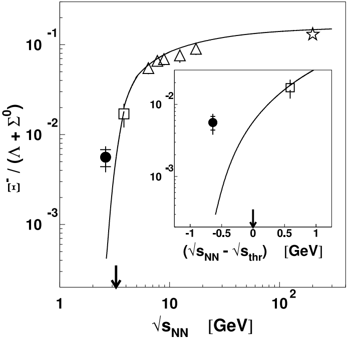

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Ξ^- yield, measured in Ar+KCl much larger than thermal model.

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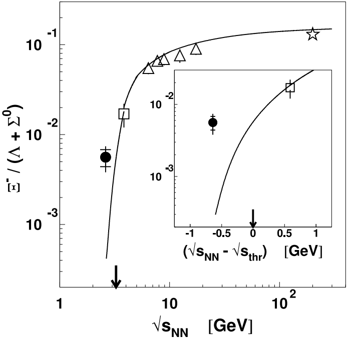

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HADES and FOPI reported unusually large ϕ contribution to the K^- yield.

Ξ production

Ξ^- yield, measured in Ar+KCl much larger than thermal model.

Both particles are not well described in microscopic transport models and thermal fits are also not convincing.

G. Agakishiev *et al.* [HADES Collaboration], Phys. Rev. Lett. **103**, 132301 (2009)

The notorious $\phi + N$ cross section

Does the ϕ have a small hadronic cross section?

- The idea that the ϕ has a small hadronic cross section is not new.
  A. Shor, Phys. Rev. Lett. **54**, 1122 (1985).
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- The ϕ would be an important probe of hadronization.
- COSY and LEPS experiments have found large nuclear absorption cross sections

ANKE	SPring-8
14-21 mb	35 mb

M. Hartmann *et al.*, Phys. Rev. C **85**, 035206 (2012)
T. Ishikawa *et al.*, Phys. Lett. B **608**, 215 (2005)

The extracted cross sections depend on model assumptions

SPring-8

Used a Glauber model for the absorption.

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SPring-8

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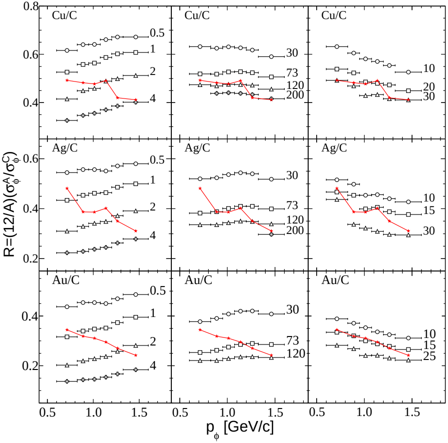
ANKE

- 1: The eikonal approximation of the Valencia group.
- 2: Paryev developed the spectral function approach for ϕ production in both the primary proton- nucleon and secondary pion nucleon channels.
- BUU transport calculation of the Rossendorf group. Accounts for baryon baryon and meson baryon ϕ production processes.



First the ϕ

Ideas on ϕ production

Modifying the thermal model

One can add an addition parameter to the thermal model to explain the ϕ.

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Catalytic ϕ production

- $\pi + Y \leftrightarrow \phi Y$: Should not contribute largely to the ϕ/K^-!
- $\overline{K} + N \leftrightarrow \phi Y$: Same?

E. E. Kolomeitsev and B. Tomasik, J. Phys. G **36**, 095104 (2009)

On the probability of sub threshold production

Sub-threshold production in UrQMD

- Fermi momenta lift the collision energy above the threshold.
- Secondary interactions accumulate energy.

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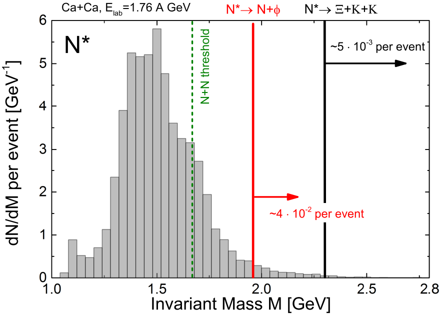

For Ar+KCl at $E_{1.76}$ A GeV:

- Is there enough energy available for ϕ (and Ξ)?

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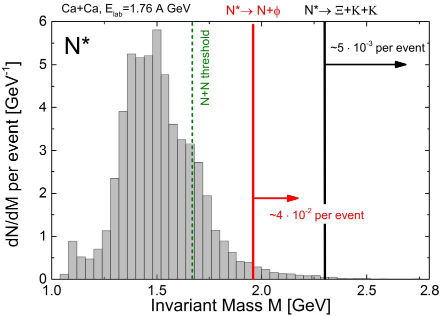


For Ar+KCl at $E_{1.76}$ A GeV:

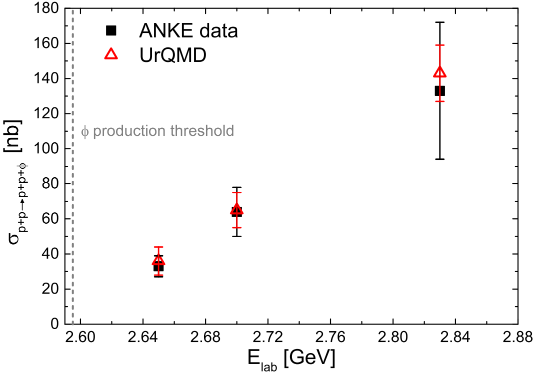
- Is there enough energy available for ϕ (and Ξ)?
- Yes but for Ξ in the "tails"

Why not introduce these decays for the less known resonances?

For our model that would be the $N^*(1990)$, $N^*(2080)$, $N^*(2190)$, $N^*(2220)$ and $N^*(2250)$.

Fixing the $N^* \to \phi + N$ decay with p+p data

We use ANKE data on the ϕ production cross section to fix the $N^* \to N + \phi$ branching fraction.



Only 1 parameter

$\Gamma_{N^* \to N\phi}/\Gamma_{tot} = 0.2\%$
Fits all 3 points!

A. Sibirtsev, J. Haidenbauer and U. G. Meissner, Eur. Phys. J. A **27**, 263 (2006) [arXiv:nucl-th/0512055].

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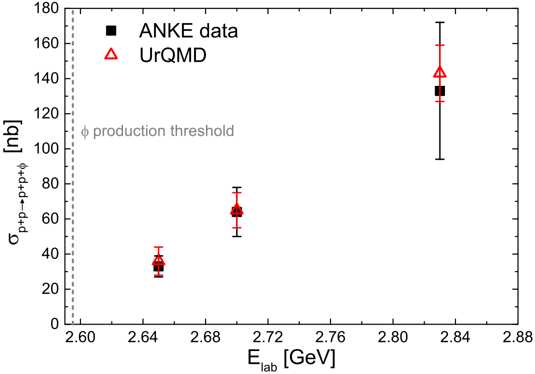

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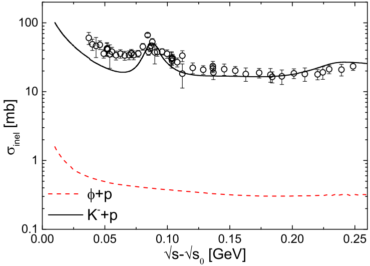
Branching fraction consistent with extracted OZI suppression (from ω/ϕ)

Y. Maeda *et al.* [ANKE Collaboration], Phys. Rev. C **77**, 015204 (2008) [arXiv:0710.1755 [nucl-ex]].

ϕ suppression in nuclear medium

Model performance

- $\phi + p$ cross section from detailed balance is very small.



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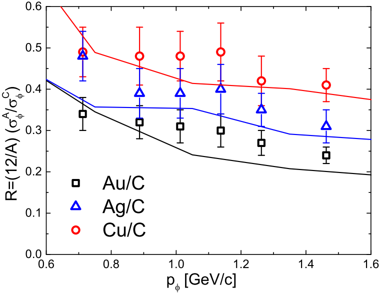

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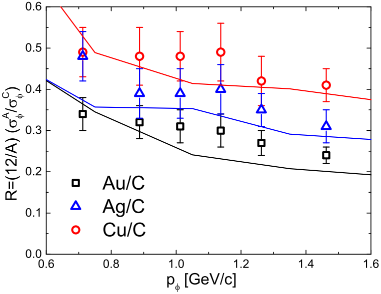

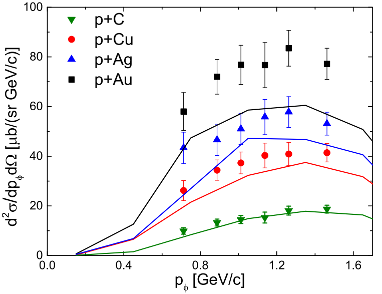

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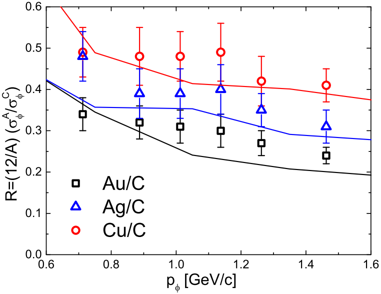
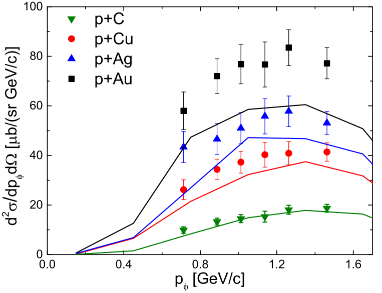
Model performance

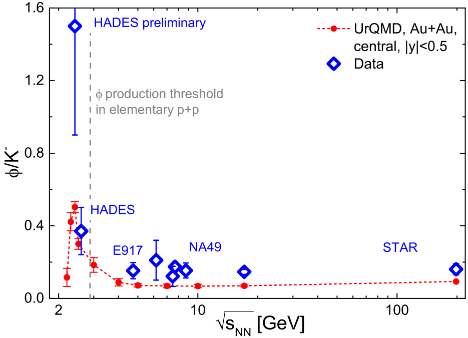
- $\phi + p$ cross section from detailed balance is very small.
- Still the transparency ratio is well reproduced. Remember: this is what lead to the 20 mb claim from ANKE.
- Even the shape of the spectra looks good.
- Not 'absorption' of the ϕ, but of the mother resonance.
- Reactions of the type:
  $N^* + N \rightarrow N'^* + N'^*$
  $N^* + N \rightarrow N'^* + N'^*$
  where the mass of $N'^* < N*$ so no ϕ can be produced.





ϕ production in nuclear collisions below the p+p threshold

When applied to nuclear collisions:



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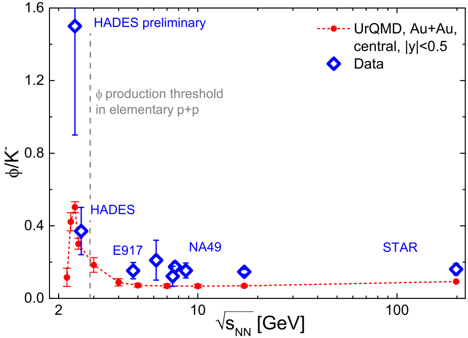

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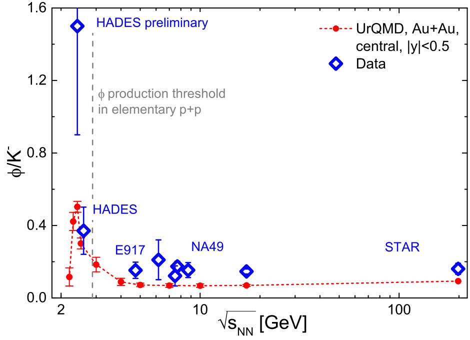

- Qualitative behavior nicely reproduced
- Predicted maximum at 1.25 A GeV
- High energies: too low due to string production
- HADES preliminary results (1.23 A GeV) still much higher

Now the Ξ

The $Y + Y \rightarrow \Xi + N$ exchange reaction

First ideas: Hyperon-hyperon reactions

- Study with the RVUU transport model.
- Using a gauged flavor SU(3)-invariant hadronic Lagrangian.

F. Li, L. W. Chen, C. M. Ko and S. H. Lee, Phys. Rev. C **85**, 064902 (2012)

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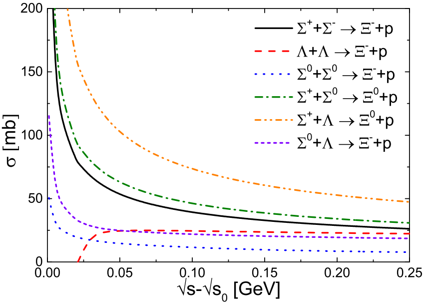

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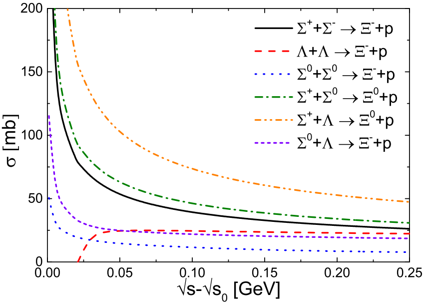

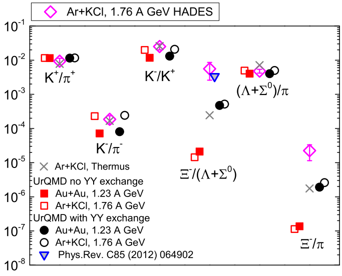

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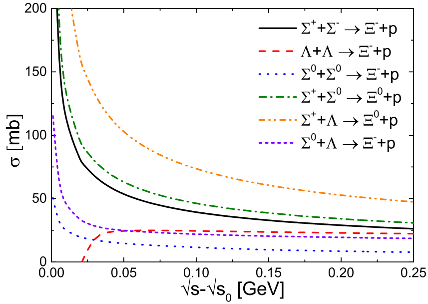
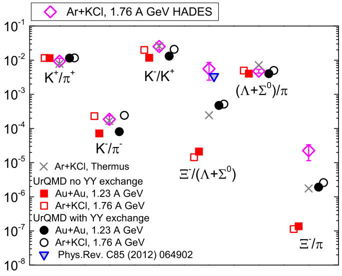
- Differences due to test-particle method, delayed Λ production and isospin dependence.





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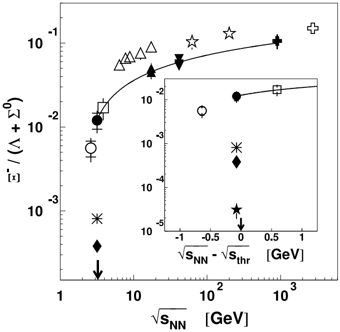
Then came the p+Nb data! G. Agakishiev *et al.*, Phys. Rev. Lett. **114** (2015) 21, 212301

- Enhanced Ξ^- production also measured in p+Nb reactions.



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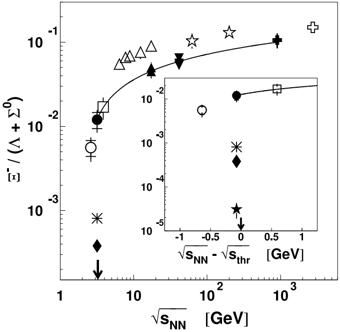

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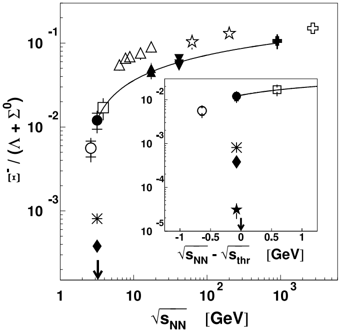
- Especially Y+Y reactions cannot account for the Ξ.
- Need single step production process.



How to fix the $N^* \rightarrow \Xi^- + K + K$ decay?

No elementary measurements near threshold.
We use p+Nb at $E_{\mathrm{lab}} = 3.5$ GeV data $\rightarrow \Gamma_{N^* \rightarrow \Xi + K + K} / \Gamma_{tot} = 10.0\%$ (for masses where this decay is energetically allowed)

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HADES data	
$\langle \Xi^- \rangle$	Ξ^- / Λ
$(2.0 \pm 0.3 \pm 0.4) \times 10^{-4}$	$(1.2 \pm 0.3 \pm 0.4) \times 10^{-2}$
UrQMD	
$\langle \Xi^- \rangle$	Ξ^- / Λ
$(1.44 \pm 0.05) \times 10^{-4}$	$(0.71 \pm 0.03) \times 10^{-2}$

Table: Ξ^- production yield and Ξ^- / Λ ratio for minimum bias $p + Nb$ collision at a beam energy of $E_{\mathrm{lab}} = 3.5$ GeV, compared with recent HADES results

Note:

G. Agakishiev *et al.*, arXiv:1501.03894 [nucl-ex].

How to fix the $N^* \to \Xi^- + K + K$ decay?

No elementary measurements near threshold.
We use p+Nb at $E_{\rm lab} = 3.5$ GeV data → $\Gamma_{N^* \to \Xi + K + K}/\Gamma_{tot} = 10.0\%$ (for masses where this decay is energetically allowed)

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Note:

- Above pole mass for all included resonances
- 0.2% of total branching fraction.

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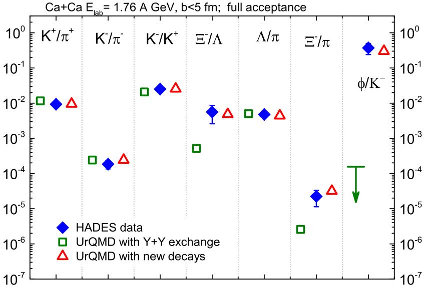
Ξ^- production in nuclear collisions below the p+p threshold



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- Consistent with the p+Nb data.
- Indication for Ξ production from non-thermal 'tails' of particle production.

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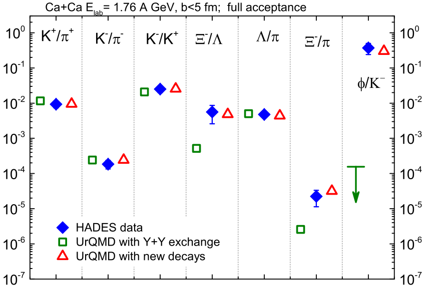
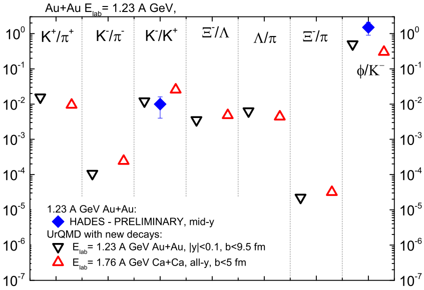


- Ξ^- yield in Ar+KCl collisions is nicely reproduced
- Consistent with the p+Nb data.
- Indication for Ξ production from non-thermal 'tails' of particle production.
- All other strange particle ratios are also in line with experiment

Predictions for Au+Au at $E_{\mathrm{lab}} = 1.23$ A GeV

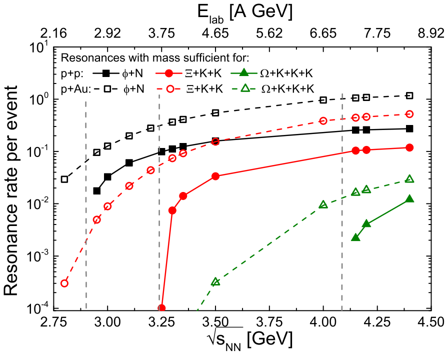


Ξ^-/Λ does not decrease much
Maybe measurable

Outlook

More interesting resonance channels?

- What happens if we include more massive N^* resonances?
- Can we extend these ideas to Ω production?



Summary

- We introduced a new mechanism of ϕ and Ξ production in elementary and nuclear collisions, through the decay of heavy resonances.
- We can nicely describe the ϕ and Ξ^- production in elementary and nuclear collisions near and below the ϕ production threshold.
- To successfully describe Ξ^- production in p+Nb and Ar+KCl reactions a small branching fraction is required.

Conclusions for SIS18 to SIS100

Consequently our study highlights the importance of resonance physics and dynamics in elementary and nuclear collisions in the energy regime of the SIS18 and future SIS100 accelerator. Rare probes, like the multi strange hadrons discussed in this paper can be very sensitive on unknown resonance states and their properties. Therefore if any conclusions on new physics are to be drawn from measuring such rare probes it is necessary to have a better understanding of the hadronic resonances and their dynamics in nuclear collisions.