Sub Threshold strange hadron production in UrQMD

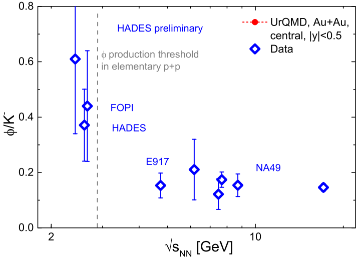
Jan Steinheimer and Marcus Bleicher

10.05.2016

FIAS Frankfurt Institute for Advanced Studies

Motivation

Recent measurements on near and below threshold production.



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

G. Agakishiev *et al.* [HADES Collaboration], Phys. Rev. C **80**, 025209 (2009)

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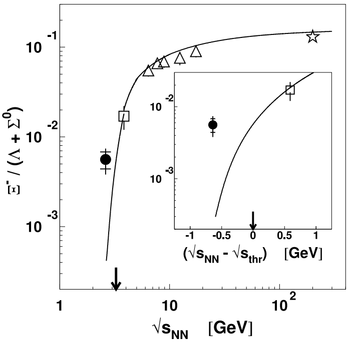

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Ξ^- yield, measured in Ar+KCl much larger than thermal model.
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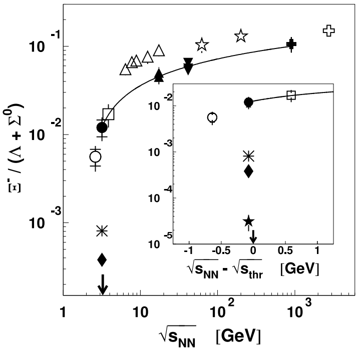

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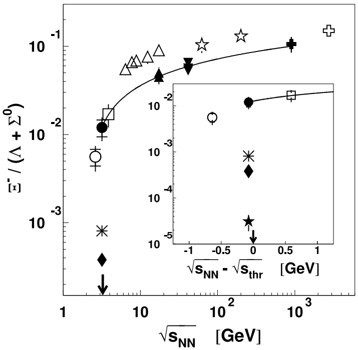

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Both particles are not well described in microscopic transport models and thermal fits are also not convincing.

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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.
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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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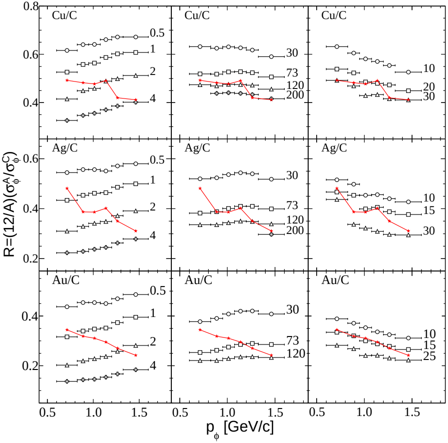
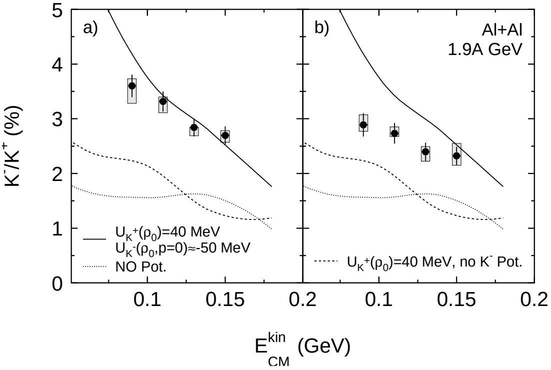
ANKE

- 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.



The Kaon-Nuclear potential



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- The K^-/K^+ ratio is used to determine the Kaon nuclear potentials.

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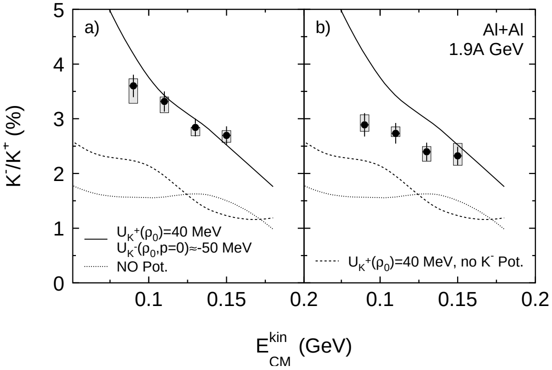

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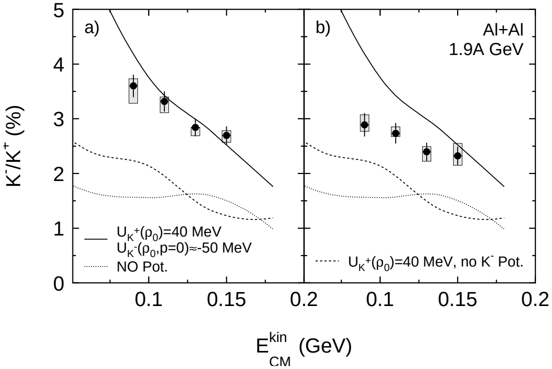

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An example

- The K^-/K^+ ratio is used to determine the Kaon nuclear potentials.
- Quantitative result relies on the baseline of non-potential case.
- ϕ contribution to the K^- found to be important.

Why is a sub threshold charm prediction interesting?

Charm at high baryon densities

- Study properties of charmed hadrons in dense nuclear matter.

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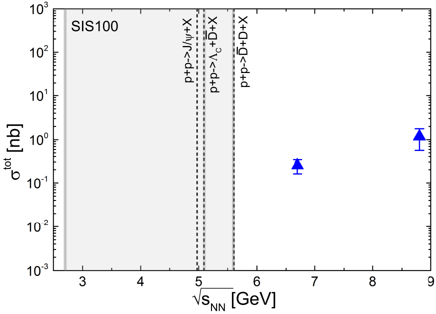
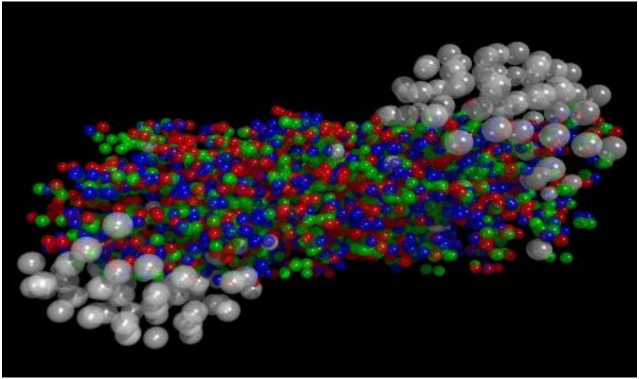


UrQMD

UrQMD is a microscopic transport model

- We will use it in cascade mode.



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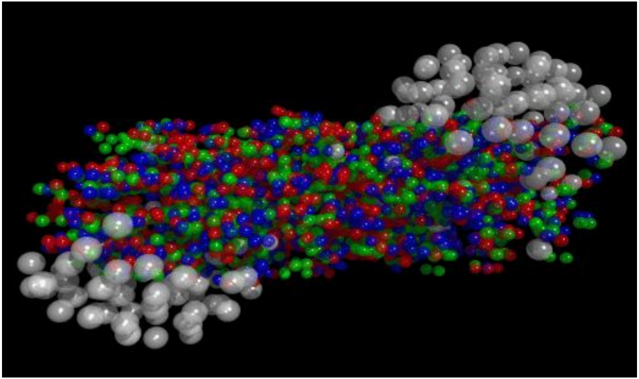

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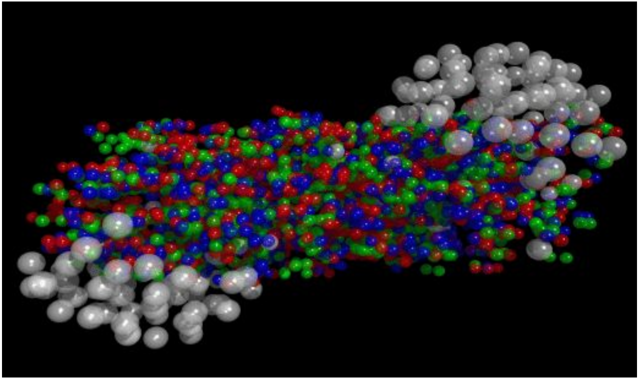
- No long range interactions like potentials.



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- Only $2 \leftrightarrow 2$, $2 \leftrightarrow 1$, $2 \rightarrow N$ and $1 \rightarrow N$ interactions allowed.
- Resonance decays according to PDG values + guesstimates.
- Detailed balance. (Violated in string excitations, annihilations and some dacays)

Strangeness Production in UrQMD

Strange particle production goes ONLY via

Resonance excitation:

- N+N$\rightarrow$ X
- N+M$\rightarrow$ X
- M+M$\rightarrow$ 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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N*(1650)	$\Delta(1232)$
N*(1710)	$\Delta(1600)$
N*(1720)	$\Delta(1620)$
N*(1875)	$\Delta(1700)$
N*(1900)	$\Delta(1900)$
N*(1990)	$\Delta(1905)$
N*(2080)	$\Delta(1910)$
N*(2190)	$\Delta(1920)$
N*(2220)	$\Delta(1930)$
N*(2250)	$\Delta(1950)$
N*(2600)	$\Delta(2440)$
N*(2700)	$\Delta(2750)$
N*(3100)	$\Delta(2950)$
N*(3500)	$\Delta(3300)$
N*(3800)	$\Delta(3500)$
N*(4200)	$\Delta(4200)$

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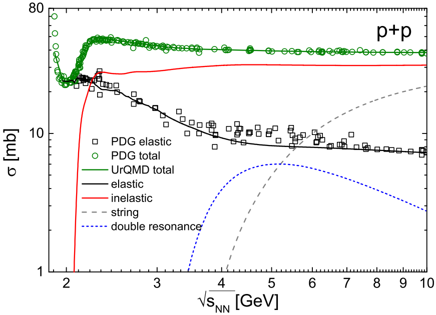


N+N Cross section

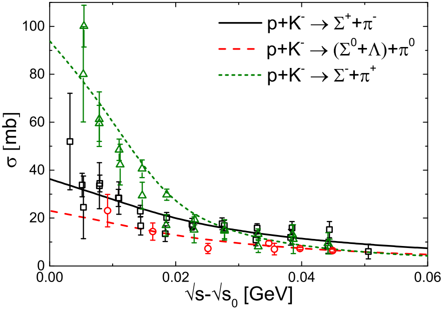
$$\sigma_{1,2\rightarrow 3,4}(\sqrt{s}) \propto (2S_3+1)(2S_4+1)\frac{\langle p_{3,4}\rangle}{\langle p_{1,2}\rangle}\left|M(m3,m4)\right|^2$$

with

$$\left|M(m3,m4)\right|^2 = \frac{A}{(m_4-m_3)^2(m_4+m_3)^2}$$

Strangeness exchange reactions

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



First the ϕ

On the probability of sub threshold production

Sub-threshold production in UrQMD

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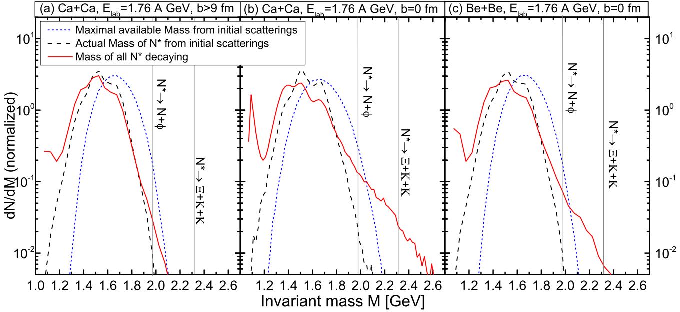

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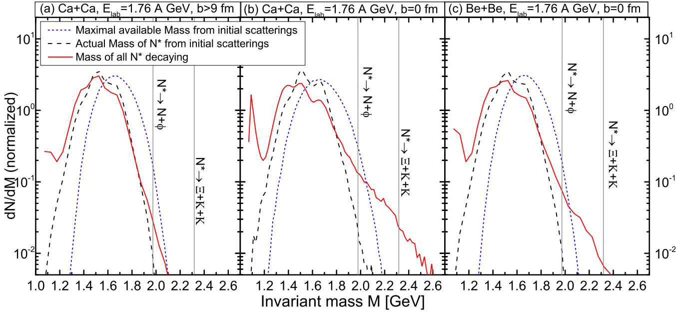
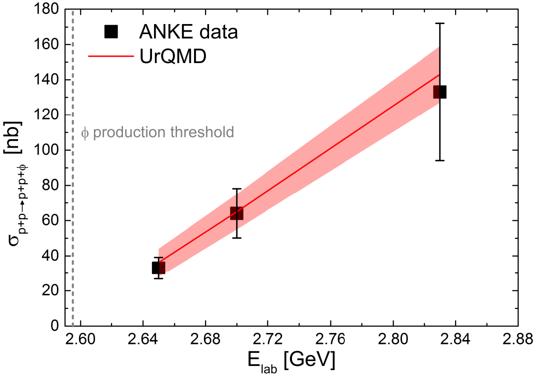


Why not introduce these decays for the less known resonances?

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

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



Only 1 parameter

$\Gamma_{N^* \rightarrow N\phi}/\Gamma_{tot} = 0.2\%$

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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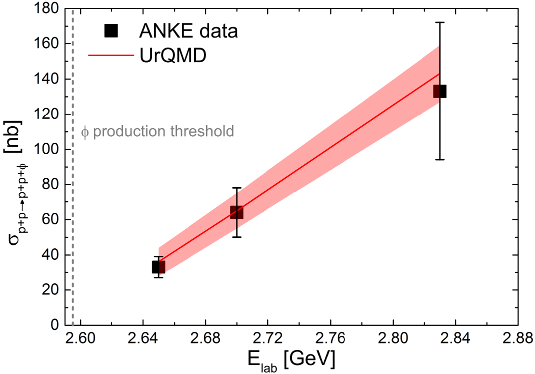

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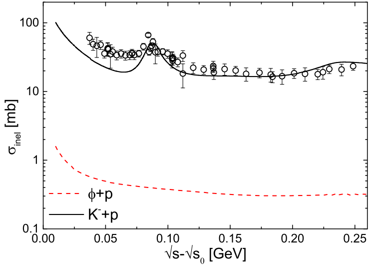
Branching fraction consistent with extracted OZI suppression (from ω/ϕ)
Y. Maeda *et al.* [ANKE Collaboration], Phys. Rev. C **77**, 015204 (2008) [arXiv:0710.1755 [nucl-ex]].

ϕ suppression in nuclear medium

Detailed balance $\rightarrow$ absorption cross section

$$\frac{d\sigma_{b\to a}}{d\Omega} = \frac{\langle p_a^2 \rangle}{\langle p_b^2 \rangle} \frac{(2S_1+1)(2S_2+1)}{(2S_3+1)(2S_4+1)} \sum_{J=J_-}^{J_+} \frac{\langle j_1 m_1 j_2 m_2 || JM \rangle^2}{\langle j_3 m_3 j_4 m_4 || JM \rangle^2} \frac{d\sigma_{a\to b}}{d\Omega}$$

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



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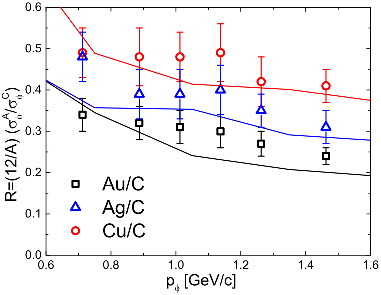

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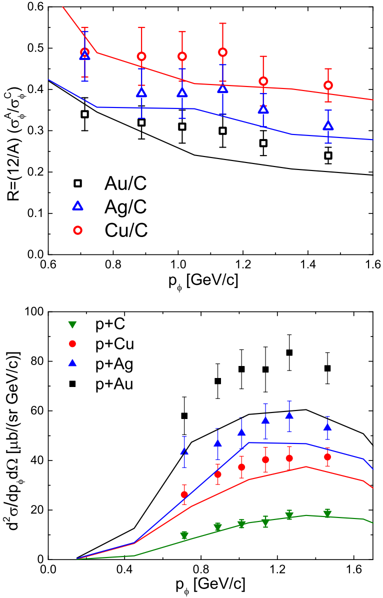

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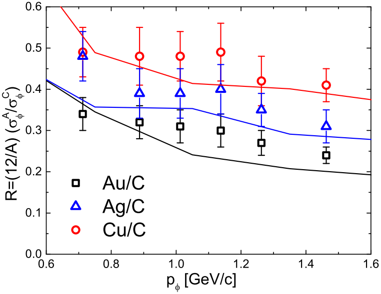

- Not 'absorption' of the ϕ, but of the mother resonance.
- Reactions of the type:
  $N^* + N \rightarrow N'^* + N'^*$
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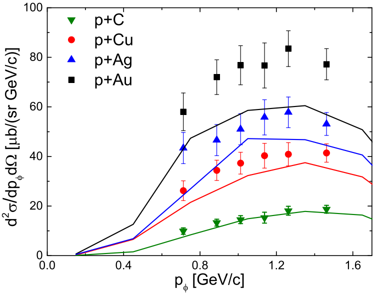
  where the mass of $N'^* < N*$ so no ϕ can be produced.



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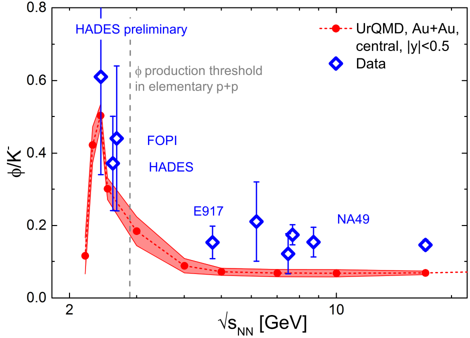

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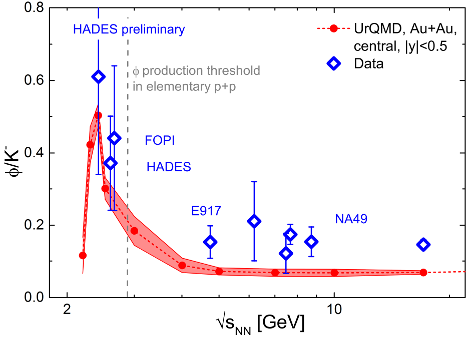

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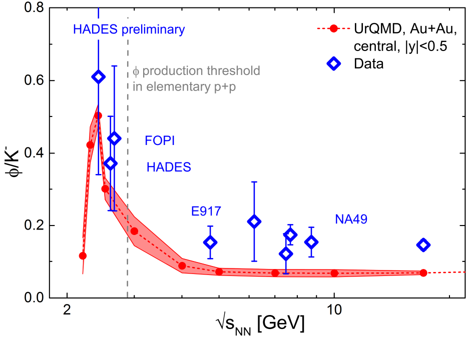
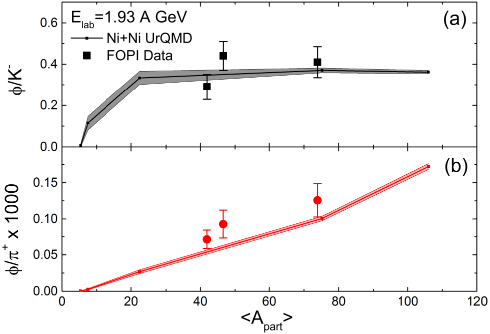


- Qualitative behavior nicely reproduced
- Predicted maximum at 1.25 A GeV
- High energies: too low due to string production
- HADES preliminary results for 1.23 A GeV, see HADES DPG talk.

ϕ production in nuclear collisions below the p+p threshold

Even centrality dependence works well:



Data from: K. Piasecki et al., arXiv:1602.04378 [nucl-ex].

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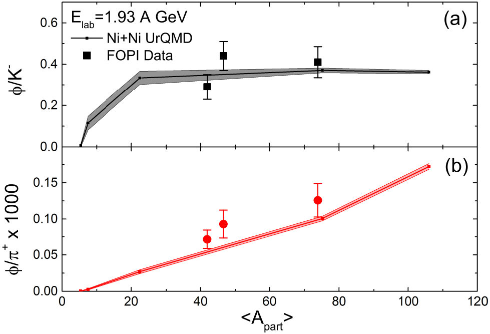

- Centrality dependence nicely reproduced.
- Good indicator for multi step production.

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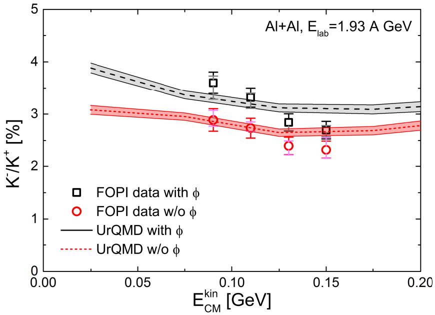

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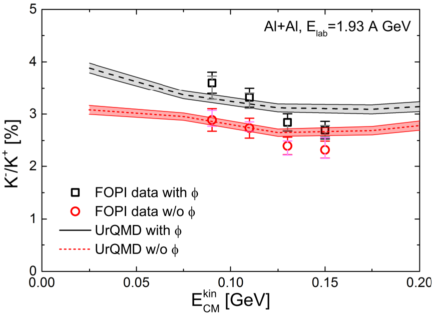

UrQMD results

- K^-/K^+ ratio as function of Kaon energy.
- With and without the ϕ the ratio is much closer to the data already as in a comparable study with K^- potential.
- Can we make robust quantitative statements?

Now the Ξ

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 $\to \Gamma_{N^* \to \Xi + K + K}/\Gamma_{tot} = 3.0\%$

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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 $E_{\rm lab} = 3.5$ GeV, compared with recent HADES results

Note:

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

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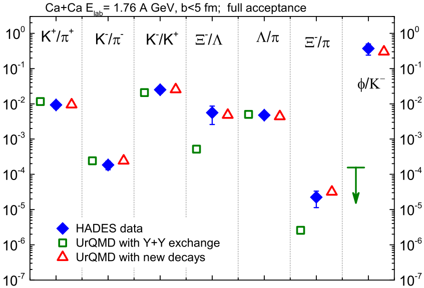
Note:

- Branching ratio seems large, however may be contributed to the limited number of heavy states in the model.

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

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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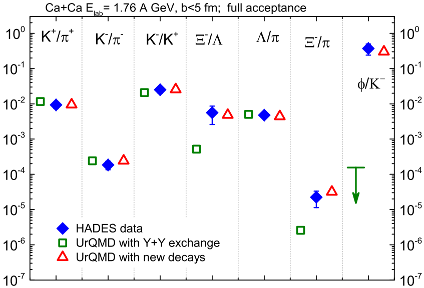
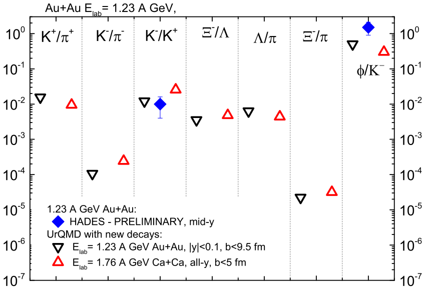


- Ξ^- yield in Ar+KCl collisions is nicely reproduced
- Consistent with the p+Nb data.
- Indication for Ξ production from non-thermal 'tails' of particle production.
- All other strange particle ratios are also in line with experiment

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

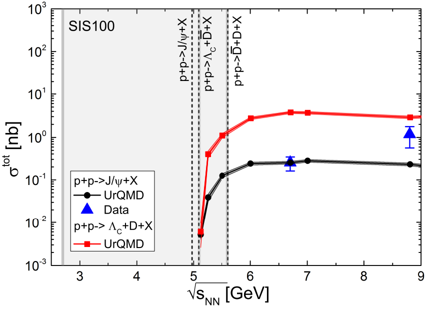


Ξ^-/Λ does not decrease much.

Can we make predictions about sub threshold charm production?

Fixing the $N^* \to J/\Psi + N$ decay with p+p data

We use data from p+p at $\sqrt{s} = 6.7$ GeV to fix the $N^* \to N + J/\Psi$ branching fraction.



Assumptions

Only 1 parameter

$$\Gamma_{N^* \to NJ\Psi}/\Gamma_{tot} = 2.5 \cdot 10^{-5}$$

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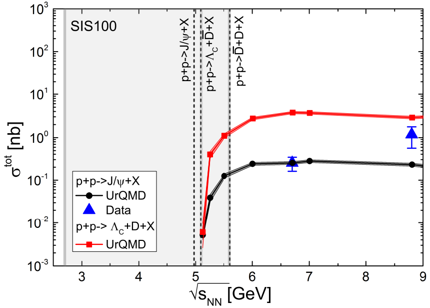

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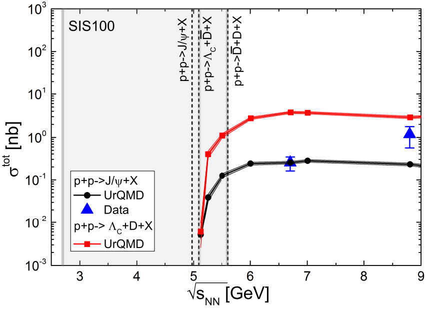

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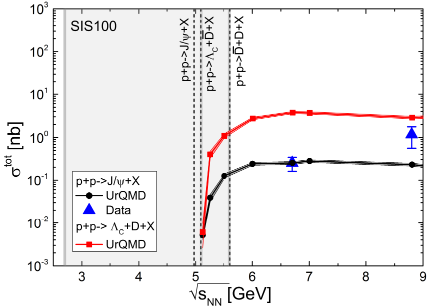

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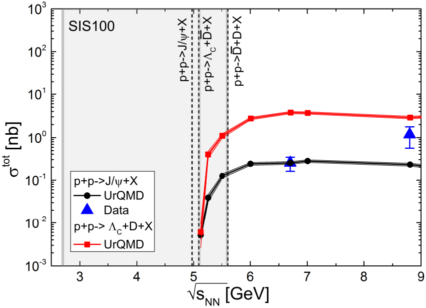

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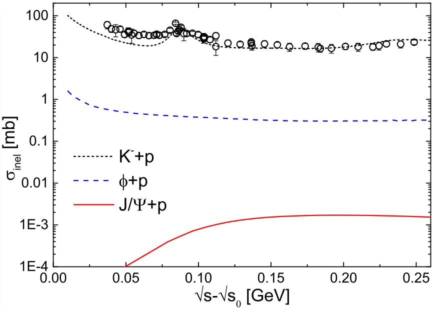
- All the contributions should even increase the expected yield.

J/Ψ suppression in nuclear medium

Detailed balance → absorption cross section

- $J/\Psi + p$ cross section from detailed balance is very small.

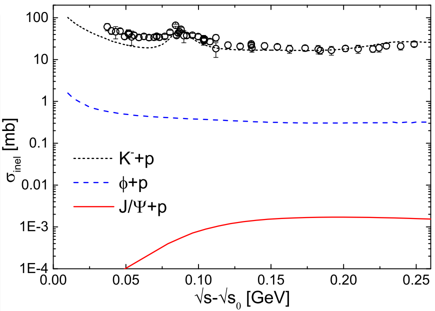


Comparable to: D. Kharzeev and H. Satz, Phys. Lett. B **334**, 155 (1994).

J/Ψ suppression in nuclear medium

Detailed balance → absorption cross section

- $J/\Psi + p$ cross section from detailed balance is very small.
- Not 'absorption' of the J/Ψ, but of the mother resonance.
- Reactions of the type:
  $N^* + N \to N'^* + N'^*$
  $N^* + N \to N'^* + N'^*$
  where the mass of $N'^* < N^*$ so no J/Ψ can be produced.



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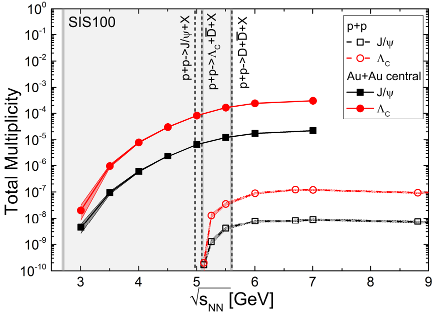
J/Ψ and open charm production in nuclear collisions below the p+p threshold

When applied to central nuclear collisions (min. bias: divide by 5):



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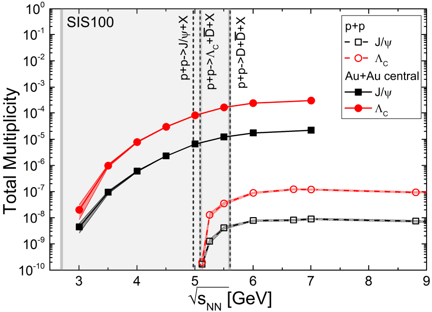

$E_{\rm lab} = 6$ A GeV

- $3 \cdot 10^{-7}$ J/Ψ per event or $3 \cdot 10^{4}$ in 10 weeks
- $4 \cdot 10^{-6}$ Λ_c per event or 121 in 10 weeks
- $\approx 6 - 8 \cdot 10^{-6}$ $\overline{D}$ per event

Measured yields are according to specifications in "'The CBM physics book"'

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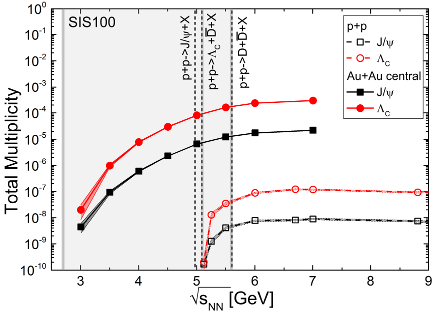


$E_{\text{lab}} = 11$ A GeV

- $1.5 \cdot 10^{-6}$ J/Ψ per event or $1.5 \cdot 10^{5}$ in 10 weeks
- $2 \cdot 10^{-5}$ Λ_c per event or 600 in 10 weeks
- $\approx 3 - 4 \cdot 10^{-5}$ $\overline{D}$ per event

Measured yields are according to specifications in "'The CBM physics book"'

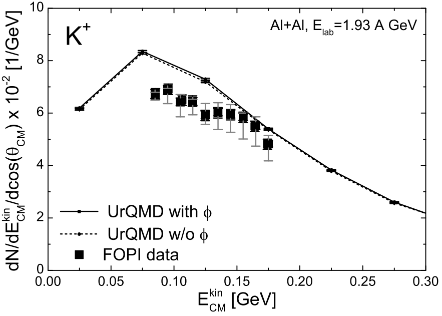
Summary

- 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+Pb and Ar+KCl reactions a large branching fraction of 10% is required.

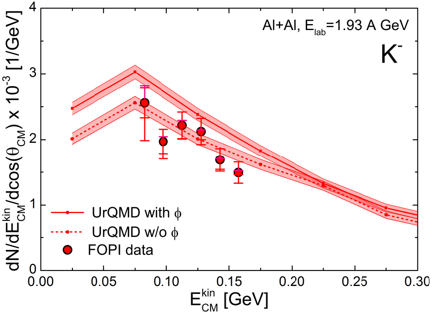
Summary

- 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+Pb and Ar+KCl reactions a large branching fraction of 10% is required.
- For the first time we made predictions for sub threshold J/Ψ, Λ_c and $\overline{D}$ production in sub threshold collisions at the SIS100.

Backup



K+
Al+Al, E_lab=1.93 A GeV
dN/dE^kin_CM/dcos(θ_CM) x 10^-2 [1/GeV]
E^kin_CM [GeV]
UrQMD with ϕ
UrQMD w/o ϕ
FOPI data
0
2
4
6
8
10
0.00
0.05
0.10
0.15
0.20
0.25
0.30



Al+Al, E_lab=1.93 A GeV
K-
dN/dE^kin_CM/dcos(θ_CM) x 10^-3 [1/GeV]
E^kin_CM [GeV]
UrQMD with ϕ
UrQMD w/o ϕ
FOPI data
0
1
2
3
4
0.00
0.05
0.10
0.15
0.20
0.25
0.30