Strange meson-baryon interaction in hot and dense medium: recent progress for a road to GSI/FAIR

Daniel Cabrera

In collaboration with: Laura Tolós, Joerg Aichelin and Elena Bratkovskaya

ITP and FIAS

SQM 2015, JINR Dubna

07.07.2015

E-mail: cabrera@fias.uni-frankfurt.de

Outline

- $\bar{K}$ and K in hot and dense medium: towards a transport description
- ϕ and Ξ production in hadronic phase
- Summary

$\bar{K}N$, KN in medium: theoretical status

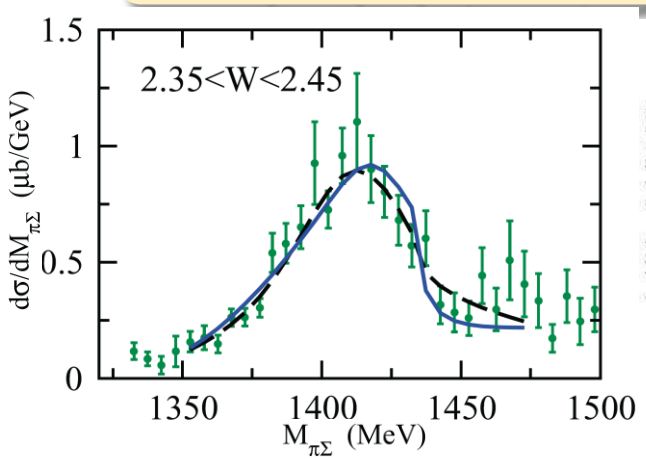
Unitarized coupled-channel approach: highlights

- $\Lambda(1405)$ is a dynam. generated MB state
- Double-pole structure!
- Moderately attractive K potential

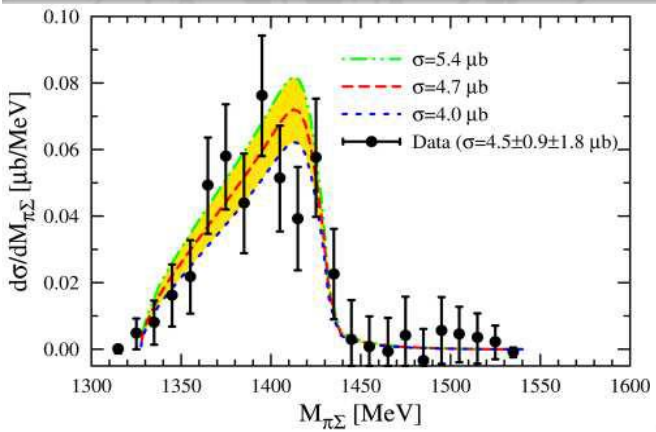
$$U_{\bar{K}}(\rho_0) \simeq [-80, -50]\ \text{MeV}$$

vs phenom. potentials: $U_{\bar{K}}(\rho_0) \simeq [-200, -100]\ \text{MeV}$

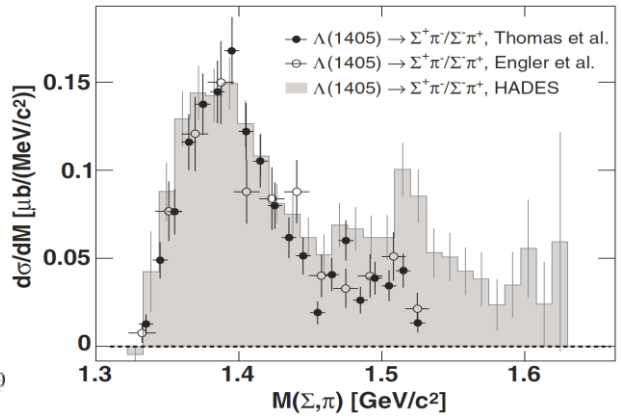
Koch; Kaiser, Waas , Weise; Lutz, Kolomeitsev, Korpa, Moller; Schaffner-Bielich; Ramos, Oset, Tolos; Oller, Meissner; Hosaka, Jido; Nieves, Ruiz-Arriola; Cassing, Bratkovskaya, Tolos, Ramos; Geng, Oset; Roca, Oset;…



Moriya et a. PRC87 (2013) 035206
Roca, Oset, PRC87 (2013) 055201



Zychor et al., PLB660 (2008) 167
Geng, Oset, EPJA34 (2007) 405

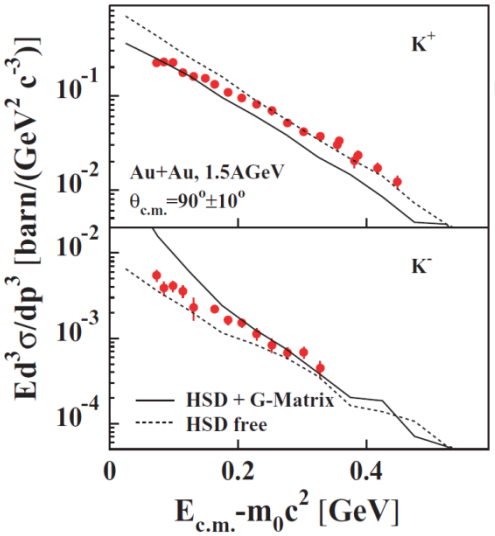


Agakishiev et al. PRC87 (2013) 025201
Siebenson, Fabbietti, PRC88 (14) 055201

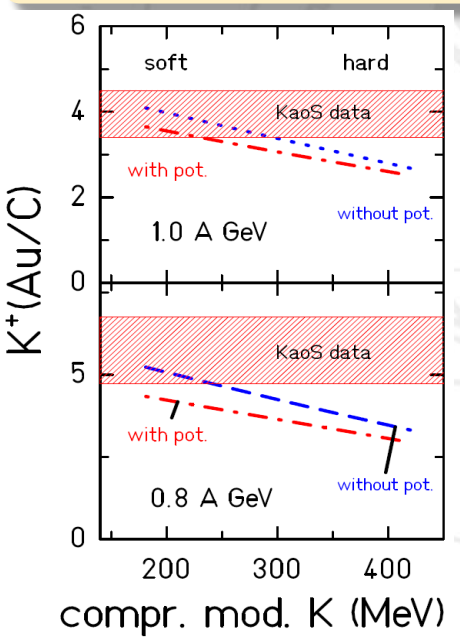
$\bar{K}N$, KN in medium: theoretical status

Lessons from exp + transport theory

- K^+ and K^- yields coupled by strangeness exchange
  $NN \leftrightarrow N\Delta \leftrightarrow K^+\Lambda N$, $\pi Y \leftrightarrow K^- N$
- Later emission of K^- vs K^+ (diff. freeze-out)
- K^+ probes the EoS at high densities (soft)



Förster et al (KaoS), PRC75, 024906 (2007)



Hartnack et al, Phys. Rep. 510 (2012) 119

(see also: Zinyuk et al. arXiv:1403.1504)

Hadronic theory + transport

- BUU/HSD with selfconsistent coupled-cannel approach Cassing, Tolos, Bratkovskaya, Ramos, NPA727 (2003) 59
- Room for improvement in hadronic models: $\bar{K}/K$ spectral functions AND cross sections

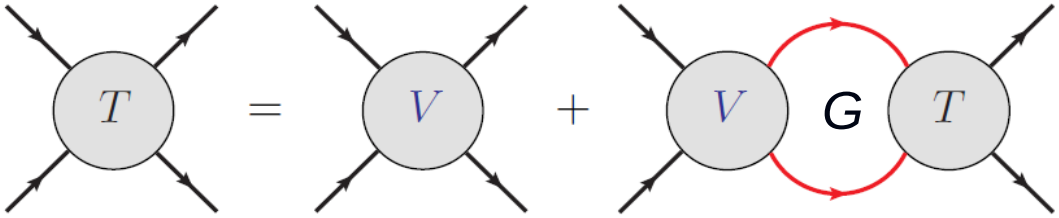
Work in progress Frankfurt-Barcelona-Nantes

Modelling $\bar{K}$ and K in hot/dense matter

Selfconsistent and **unitary coupled-channel** approach

Lutz, PLB426 (1998) 12; Ramos, Oset, NPA671 (2000) 481; Tolos et al. NPA690 (2001) 547, PRC74 (2006) 015203; Lutz, Korpa, Moller, NPA808 (2008) 124; Tolos, DC, Ramos, PRC78 (2008) 045205

Vacuum

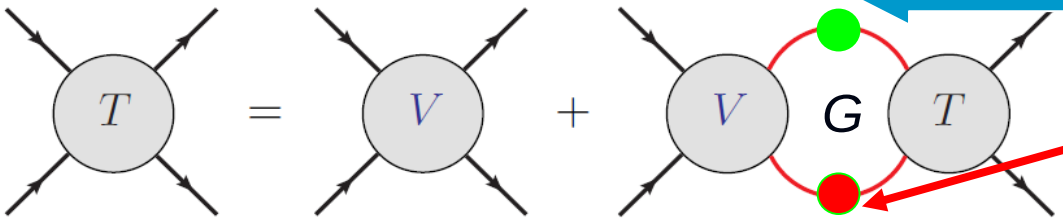


Interaction: SU(3) ChPT

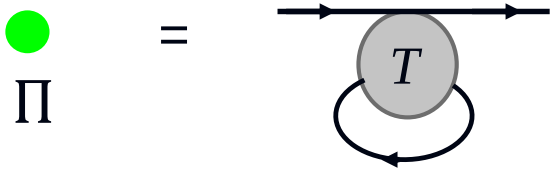
$$\mathcal{T}_{ij} = V_{ij} + V_{il}\, G_l\, \mathcal{T}_{lj}$$

Pauli blocking and potential dressing

Medium



$$\mathcal{T}_{ij}(\rho,T) = V_{ij} + V_{il}\, G_l(\rho,T)\, \mathcal{T}_{lj}(\rho,T)$$

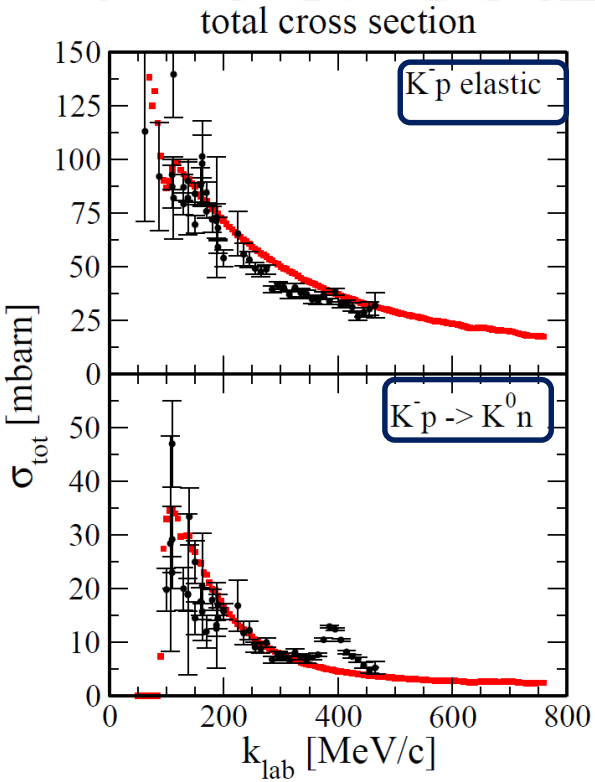


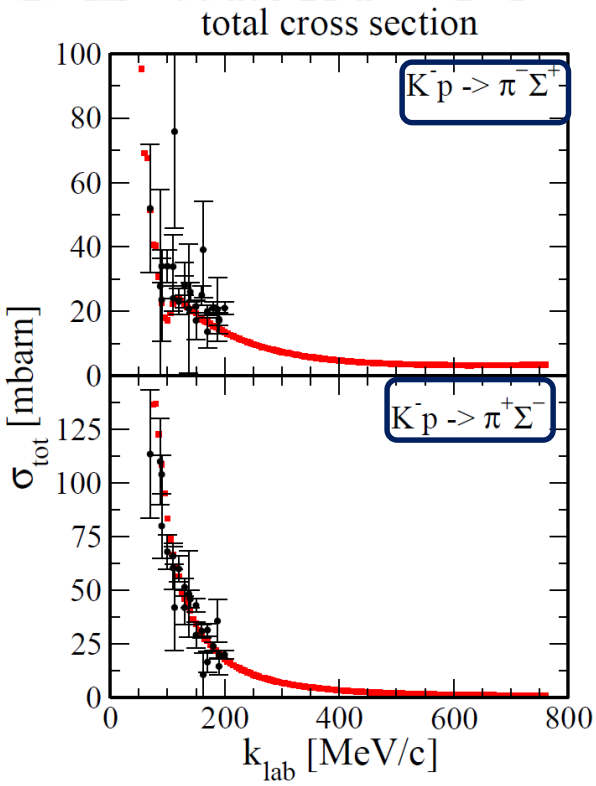
Meson selfenergy and spectral function

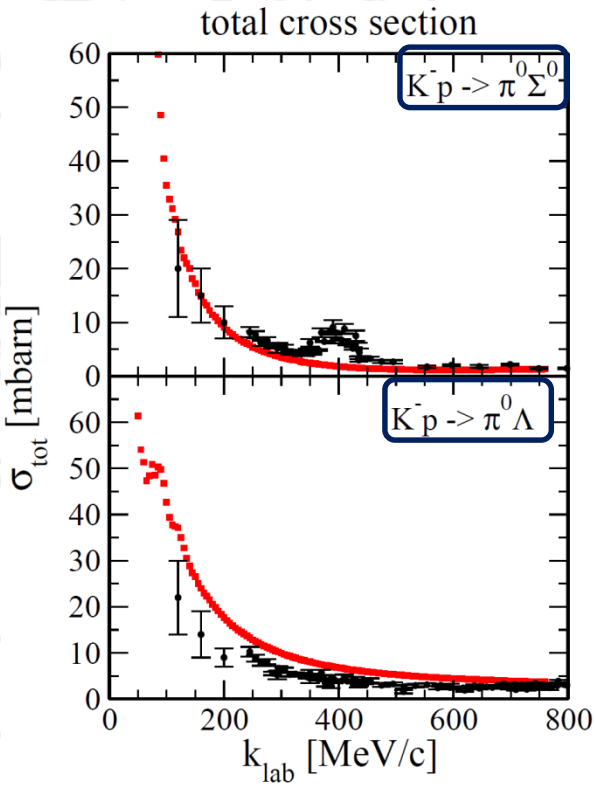
Modelling $\bar{K}$ and K in hot/dense matter

Scattering observables in vacuum

1-parameter model







…differential cross sections also OK!

Modelling $\bar{K}$ and K in hot/dense matter

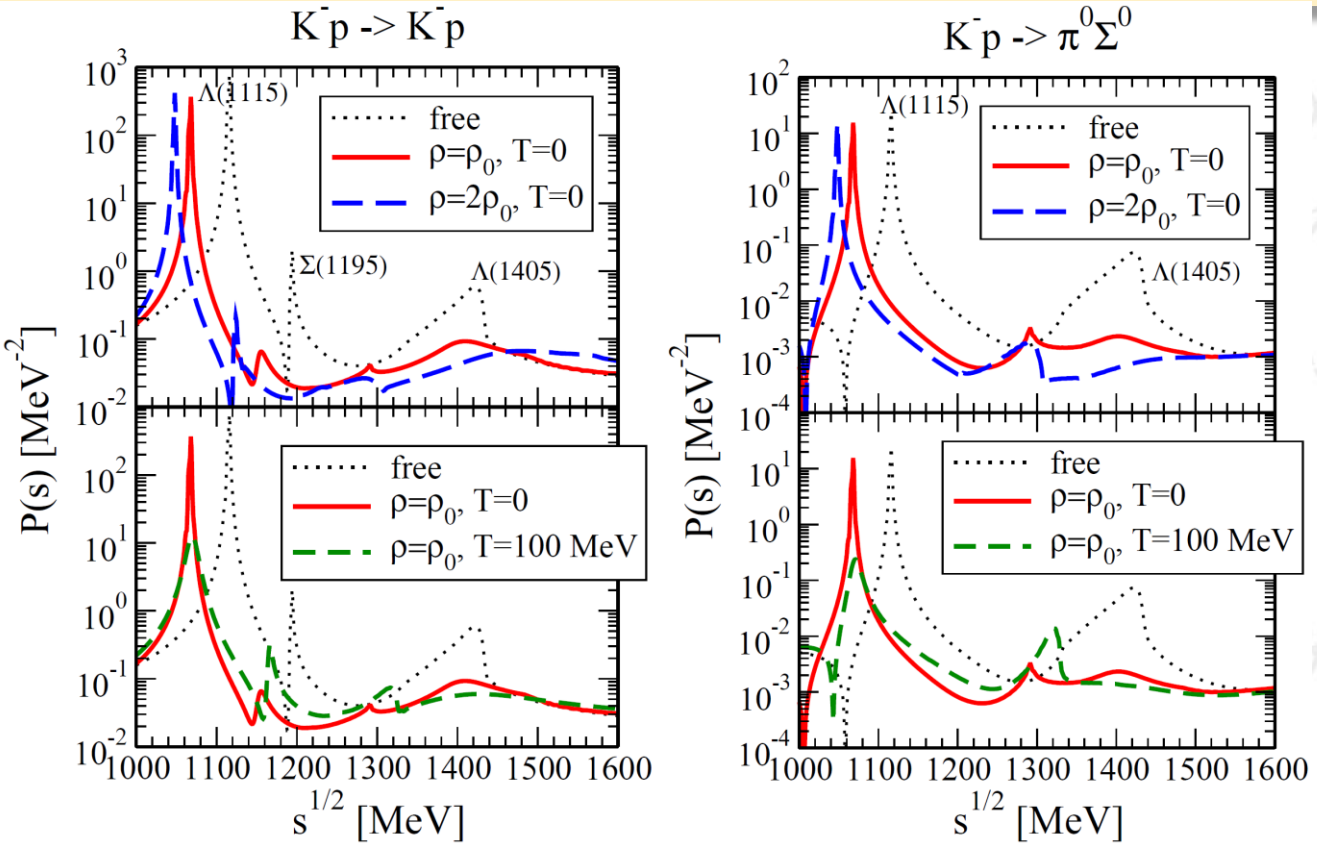
Towards a transport description of strangeness

- **Binary reactions**: cross sections / transition rates

$$K^- p \leftrightarrow K^- p,\ K^0 n,\ \pi^0\Lambda,\ \pi^{\pm}\Sigma^{\mp}, \pi^0\Sigma^0 \ +\ \eta \text{ and } \Xi \text{ channels}$$

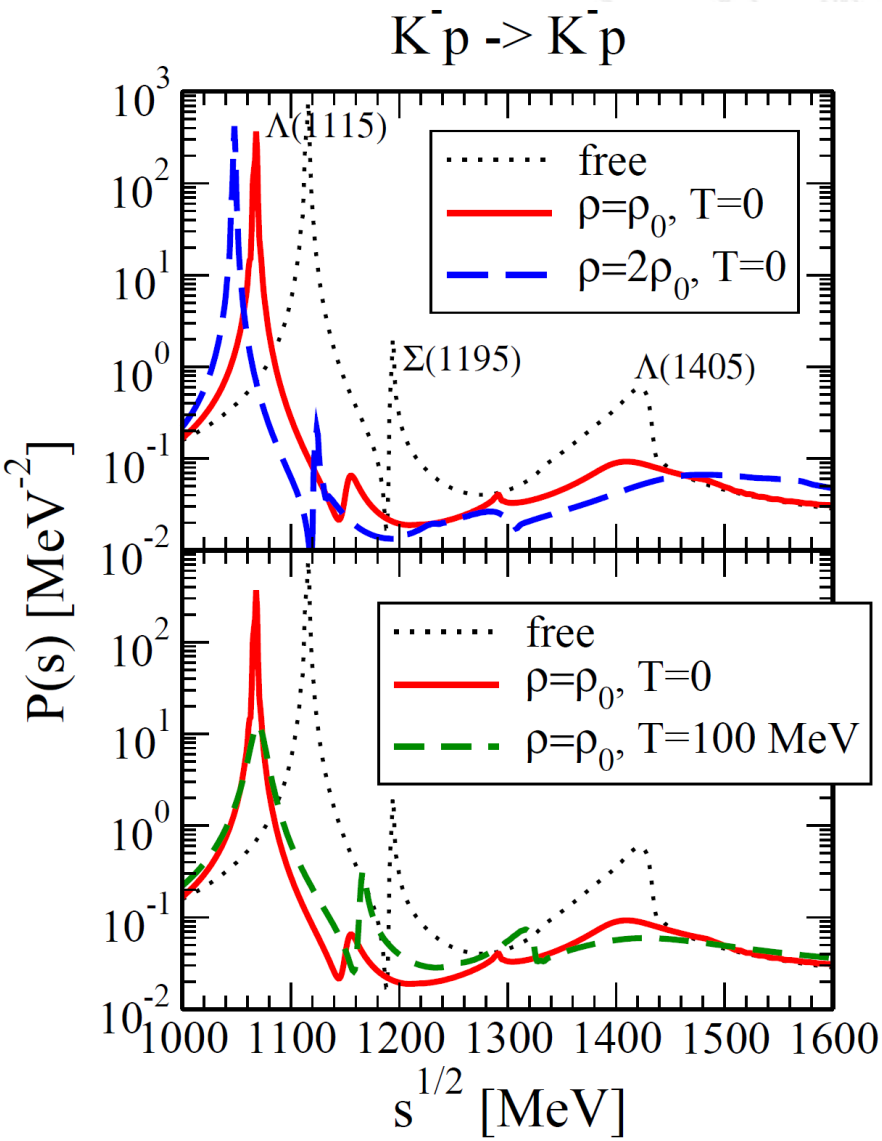
DC, Tolos, Aichelin, Bratkovskaya, PRC90 (2014) 055207; Cassing, Tolos, Bratkovskaya, Ramos, NPA727 (2003) 59

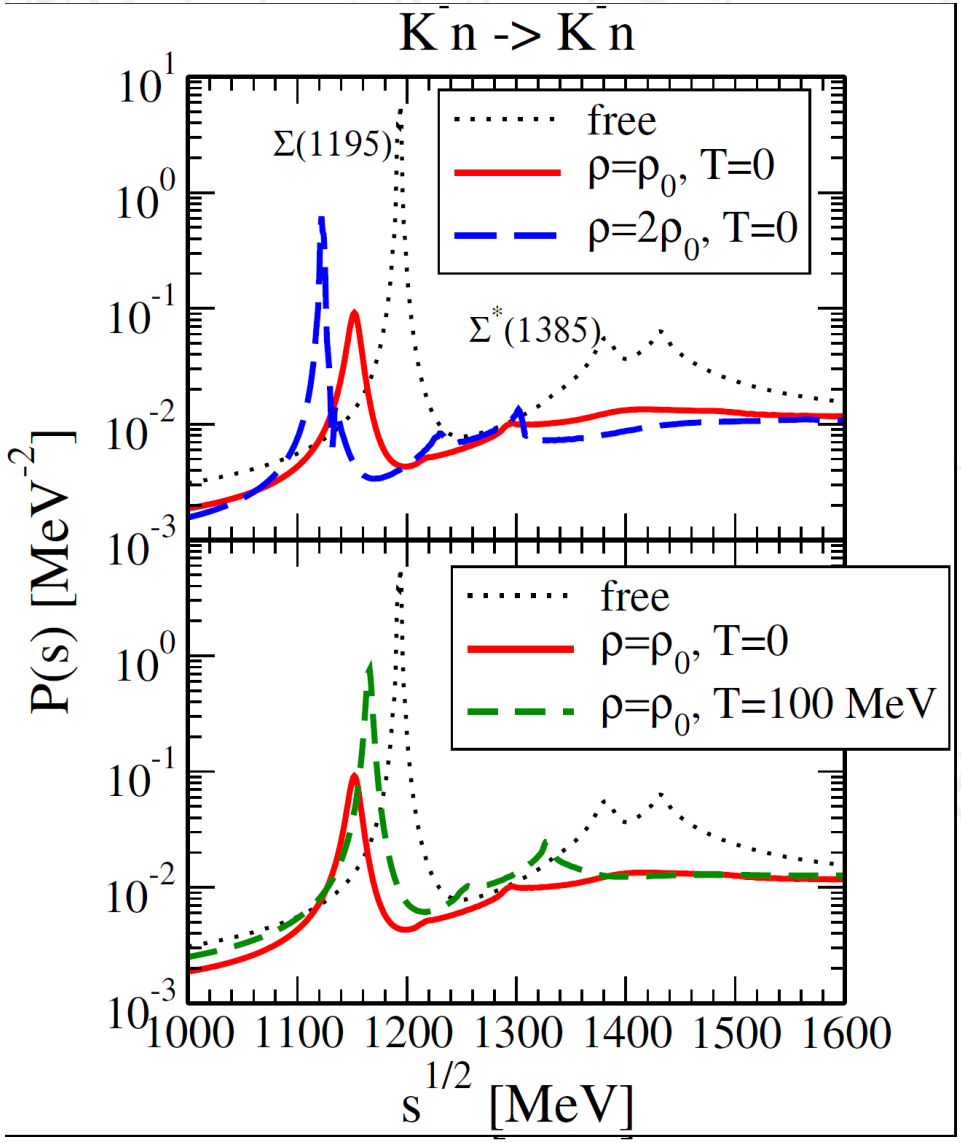
$P \propto |T|^2$



Modelling $\bar{K}$ and K in hot/dense matter

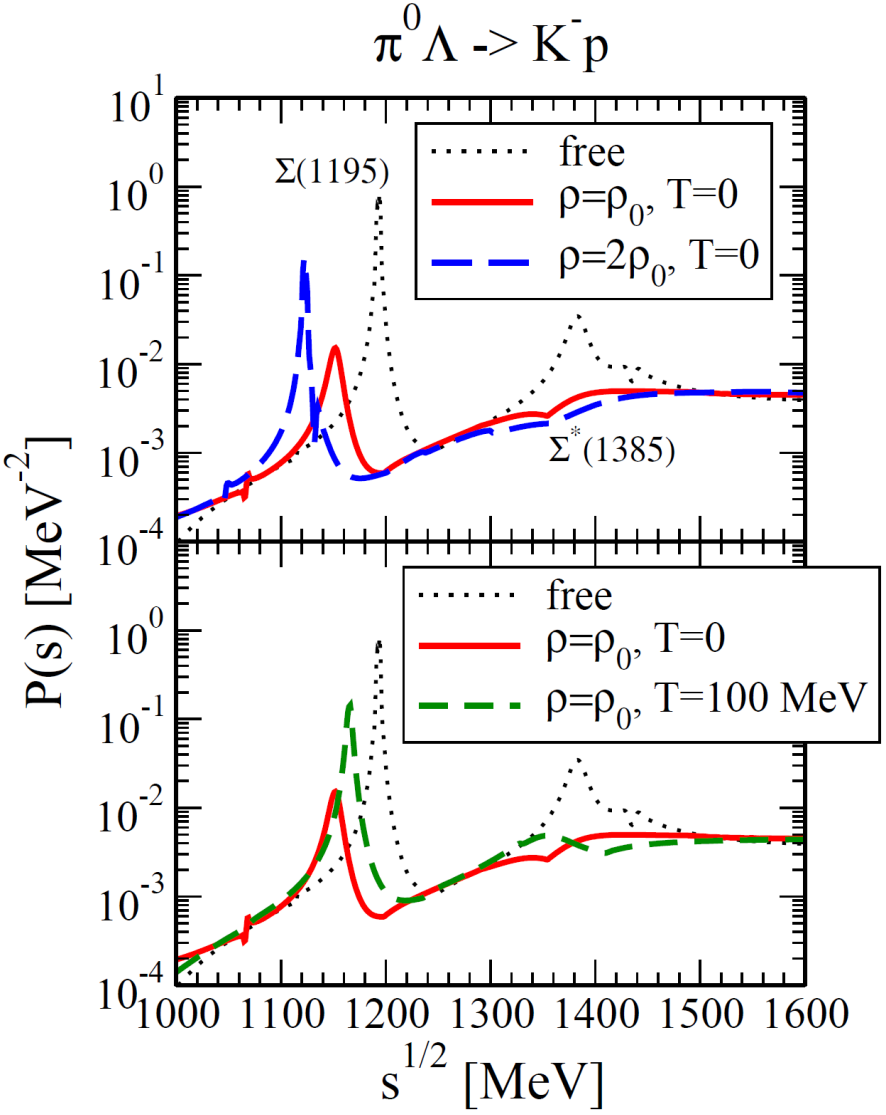
Transition rates: $K^- p$ vs $K^- n$ (isospin)

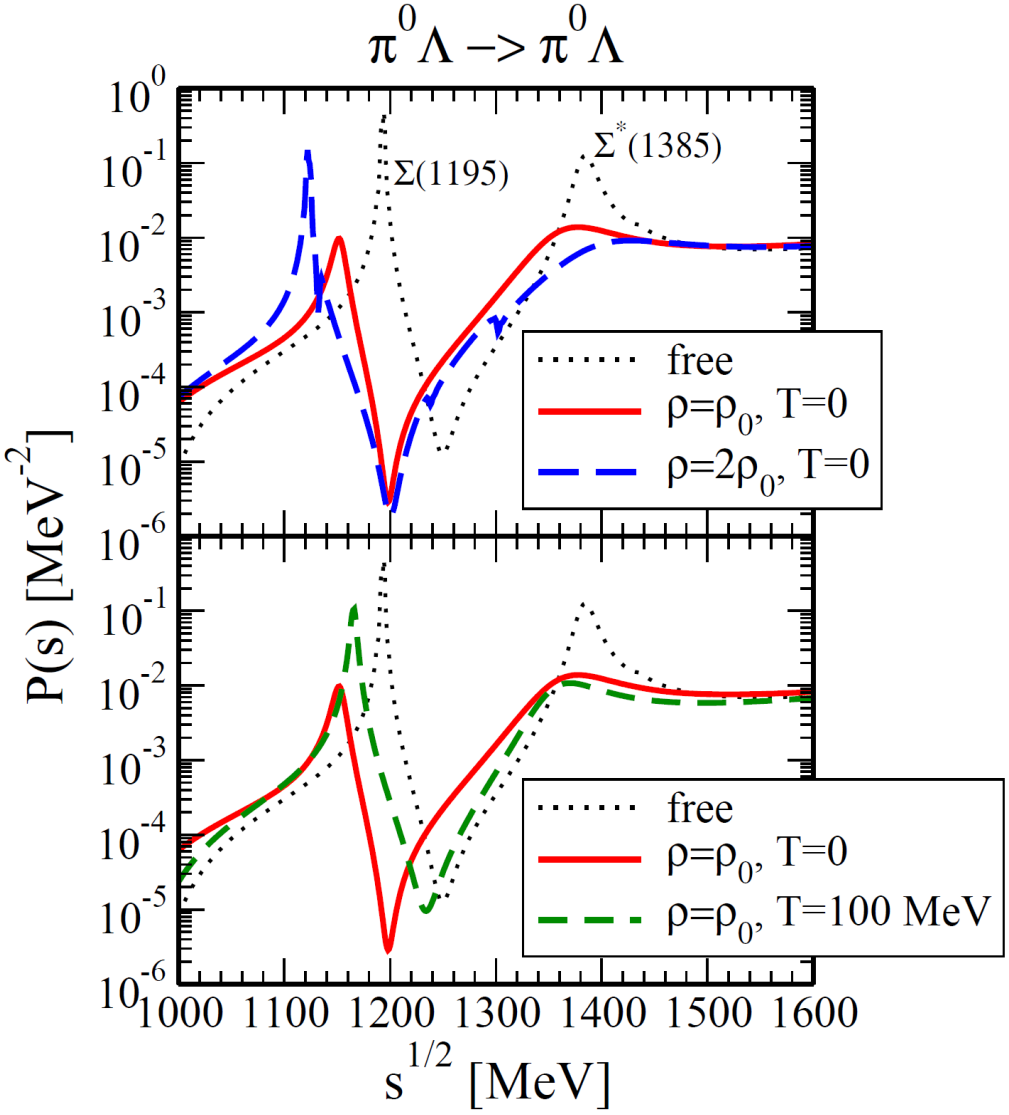




Modelling $\bar{K}$ and K in hot/dense matter

Transition rates: pure **isospin 1**





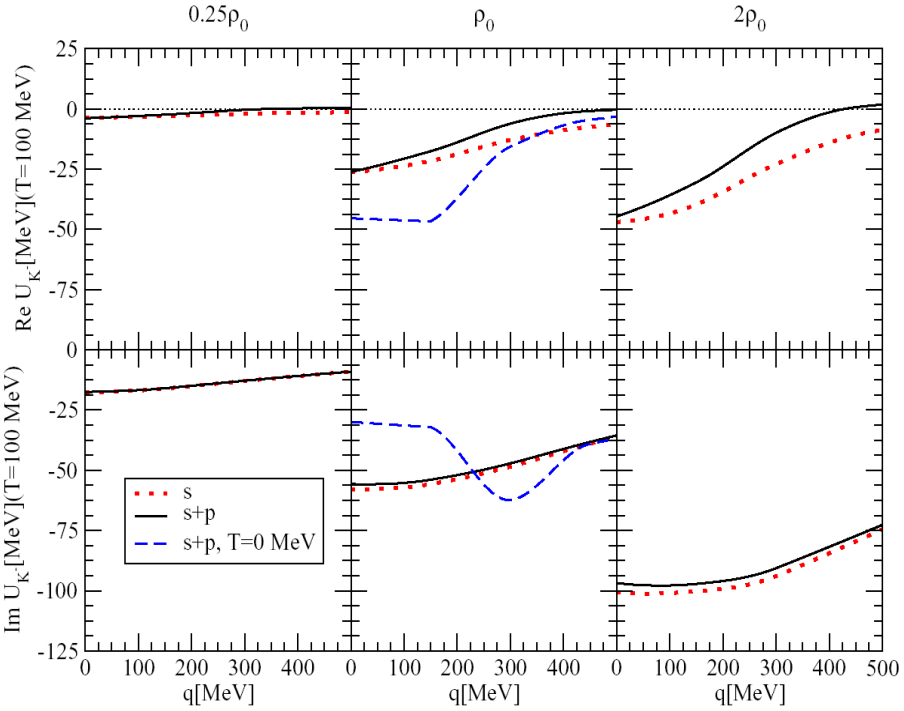
Modelling $\bar{K}$ and K in hot/dense matter

Towards a transport description of strangeness

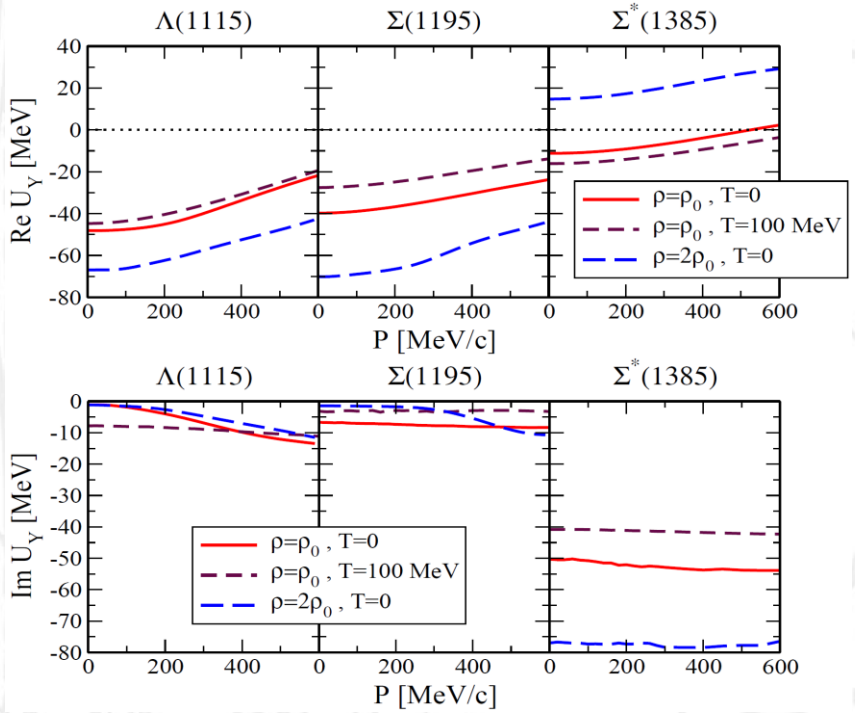
- **Propagation**: $\bar{K}$, K and Y optical potentials

DC, Tolos, Aichelin, Bratkovskaya, PRC90 (2014) 055207; Cassing, Tolos, Bratkovskaya, Ramos, NPA727 (2003) 59

$\bar{K}$ nuclear optical potential



Y nuclear optical potential



Modelling $\bar{K}$ and K in hot/dense matter

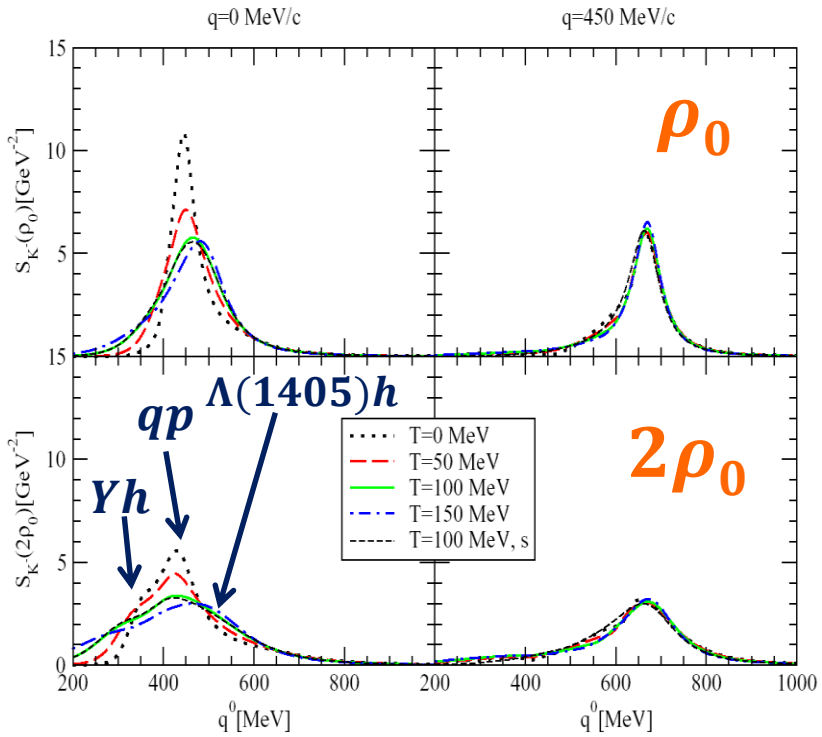
Towards a transport description of strangeness

- **Production**: $\bar{K}$, K (off-shell) Spectral functions

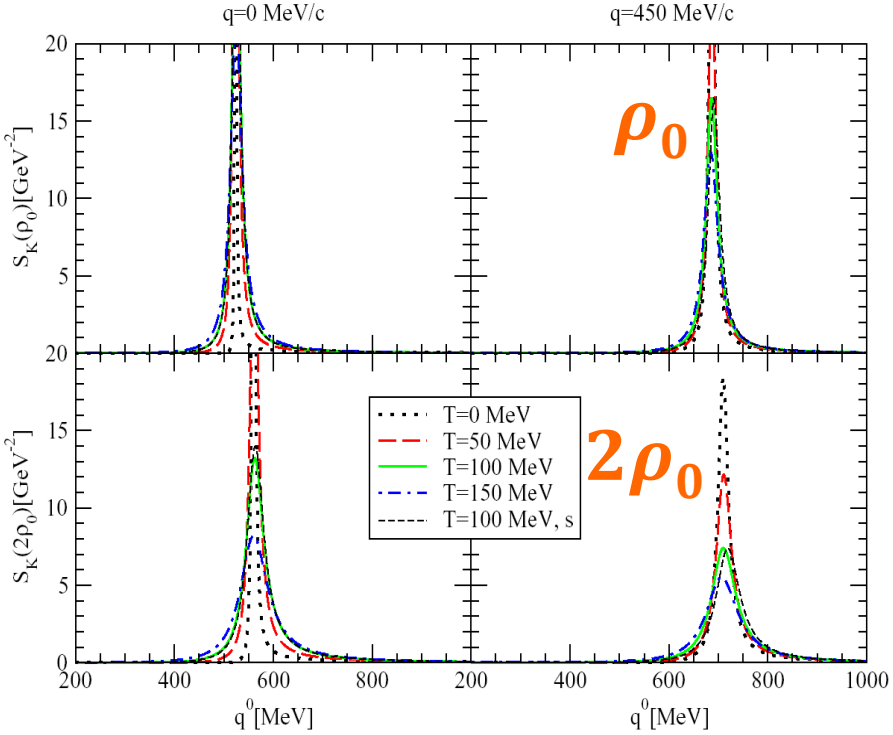
$$NN \rightarrow NNK\bar{K},\ \pi N \rightarrow NK\bar{K},\ldots$$

DC, Tolos, Aichelin, Bratkovskaya, PRC90 (2014) 055207; Cassing, Tolos, Bratkovskaya, Ramos, NPA727 (2003) 59

$\bar{K}$ spectral function



K spectral function

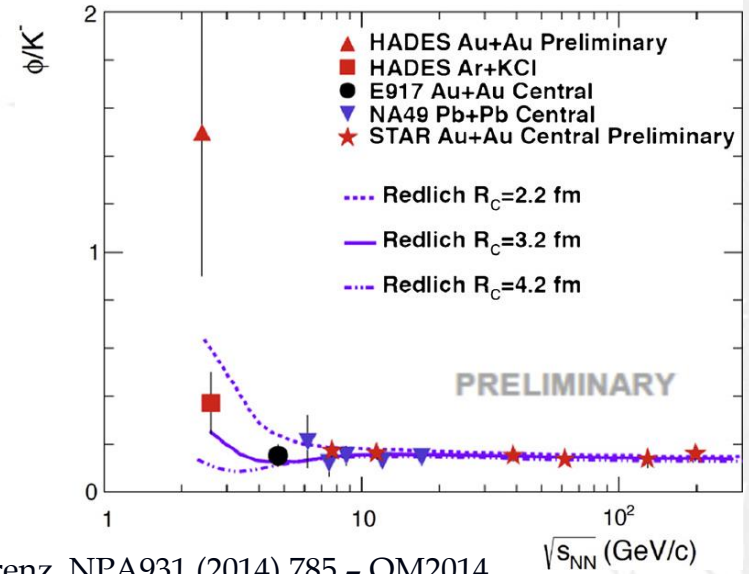


ϕ and Ξ production in hadronic phase

ϕ and Ξ production in hadronic phase

Motivation: recent HADES measurements

- (Pseudo-)rapidity spectra indicate some production mechanisms could be missing
- PHSD simulations show high sensitivity to production cross sections in hadronic phase
- Relevant for studies at NICA/Dubna, GSI/FAIR and also low beam-energy scan at RHIC

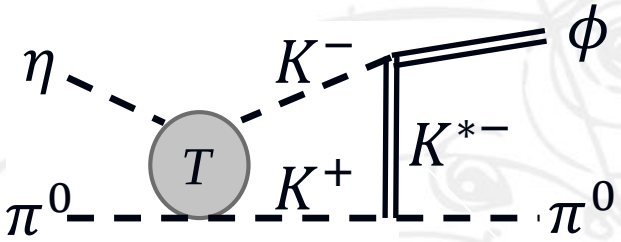


M. Lorenz, NPA931 (2014) 785 – QM2014

Idea: η-induced production reactions to exploit "hidden" strangeness of η meson

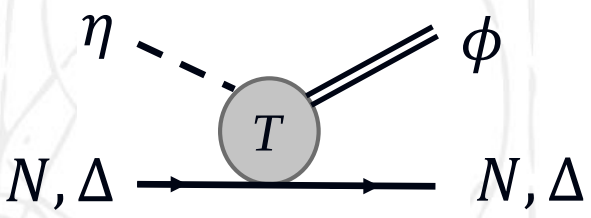
See also M. Bleicher's talk and P. Moreau's talk (S2)

ϕ and Ξ production in hadronic phase



- $\eta\pi \to \phi\pi$ requires intermediate $K\bar{K}$ state to "free" strangeness
- Amplitudes for $\eta\pi^0 \to \phi\pi^0$ vanish due to ***C*-parity**!
- Charged pions do not help: $\eta\pi^\pm \to \phi\pi^\pm$ violates ***G*-parity**!

- Meson-baryon not suppressed by symmetries
- Plenty of N and Δ in hadron medium
- Challenge: mix **pseudoscalar** and **vector** meson octets



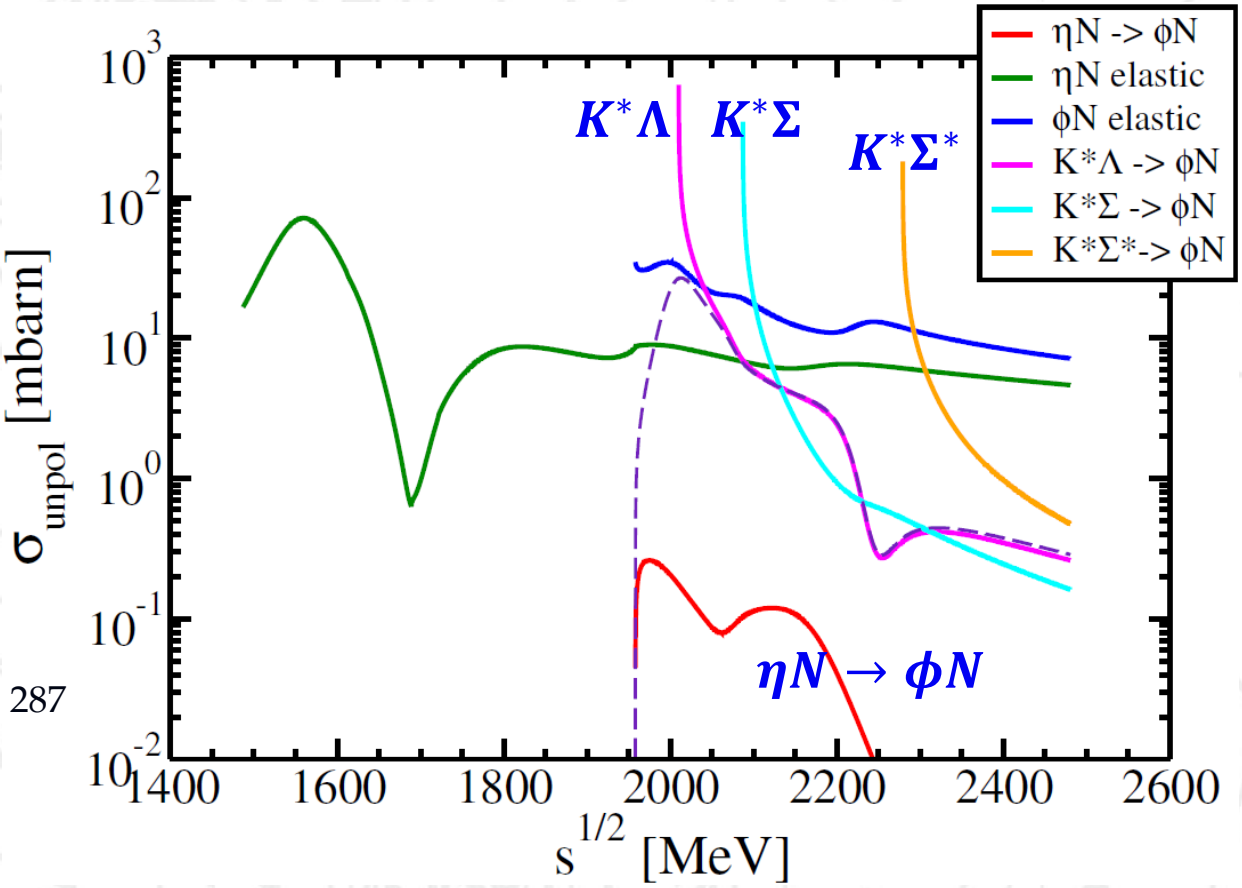
ϕ and Ξ production in hadronic phase

Results: some cross sections in $SU(6)$ spin-flavor model

Gamermann, Garcia-Recio, Nieves, Salcedo, PRD84, 056017 (2011); see also Oset, Ramos, EPJA44 (2010) 445

- Minimal extension of meson-baryon ChPT
- Mixes 0^- and 1^- meson octets with baryon octet and decuplet
- **Resonances above 2GeV! (ϕN thres.)**

See, e.g., Ramos, Oset PLB727 (2013) 287



- $\eta N \to \phi N$ turns to be small: next-to-leading in chiral expansion
- **Strangeness-exchange** important! Also for $\boldsymbol{\Xi}, \boldsymbol{\Omega}$ production (in progress)

Summary

- **Strange mesons** stand as unique probes for testing strong interactions at GSI/FAIR conditions, as long as we understand their dynamics in the *hot and dense nuclear medium.*

- **A lot of theoretical work** is required, within *realistic approaches* to interactions in the hadronic gas, in connection with experimental information.

- **Chiral self-consistent approach**: *transition probabilities, spectral functions, quasi-particle properties…* inputs for transport models: $\overline{K}N$ *and* KN, $\overline{K}^*, K^*, \phi$ properties, multi-strange hadron production.

- **Transport simulations** with the input of realistic, in-medium interactions are the key to understand the production and propagation of strangeness in HICs.

BACK-UP SLIDES

Strange vector mesons: ϕ and $\bar{K}^*$ / K^*

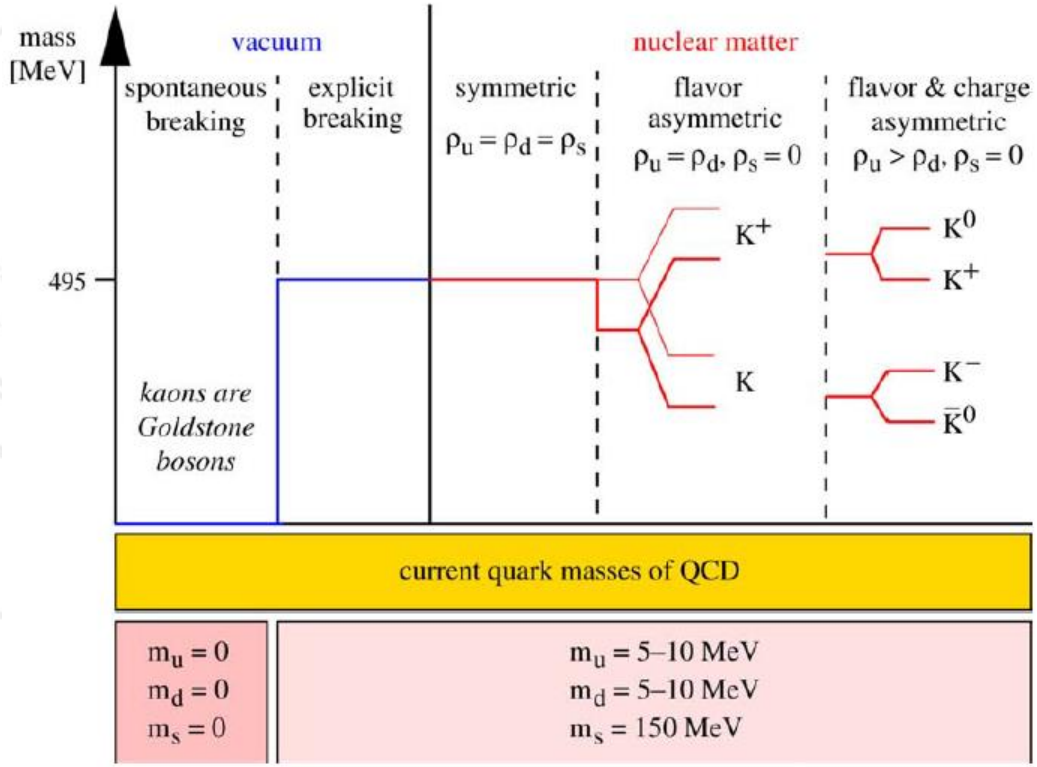
Strange vector mesons: ϕ and $\bar{K}^* / K^*$

$S = -1$: $\bar{K} = \begin{bmatrix} \bar{K}^0 \\ -\bar{K}^- \end{bmatrix} \begin{matrix} (\bar{d}s) \\ (\bar{u}s) \end{matrix}$ $S = +1$: $K = \begin{bmatrix} K^+ \\ K^0 \end{bmatrix} \begin{matrix} (u\bar{s}) \\ (d\bar{s}) \end{matrix}$ $S = 0$: $\phi = (s\bar{s})$

$\bar{K} / K$: $I(J^P) = 1/2(0^-)$

$\bar{K}^* / K^*(892)$: $I(J^P) = 1/2(1^-)$

$\phi(1020)$: $I(J^P) = 0(1^-)$



C. Fuchs, Prog. Part. Nucl. Phys. 56 (2006) 1

Strange vector mesons: ϕ and $\overline{K}^* / K^*$

Medium effects on strange vector mesons

- $\overline{K}^* / K^*$ do not couple to E.M. current (dileptons)
- Recent theoretical developments
- Experiments: hadronic resonances in HICs!

pp, pA and AA at HADES/GSI

Agakishiev et al. PRC87 (2013) 025201; PRC85 (2012) 035203

Agakishiev et al. arXiv:1404.7011

Lorenz et al. EPJ Web of Conf. 66 (2014) 09011

γ-production CLAS/Jlab and CBELSA/TAPS

Moriya et al. PRC87 (2013) 035206; Wood et al. PRL105 (2010) 112301

Nanova et al. PRC82 (2010) 035209; Kotulla et al. PRL100 (2008) 192302

AA at RHIC (STAR)

Aggarwal et al. PRC84 (2001) 034909

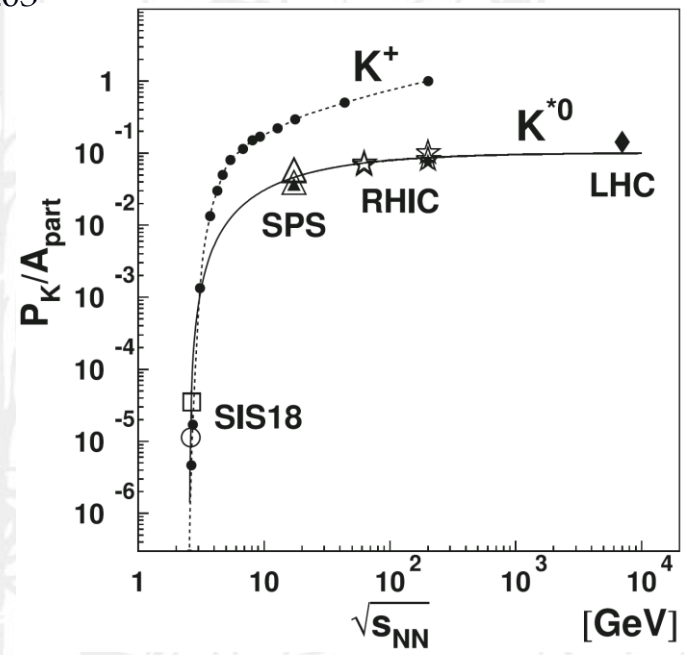
Abelev et al. PRL97 (2006) 132301

Adams et al. PRC71 (2005) 064902

Wada @ QM2012

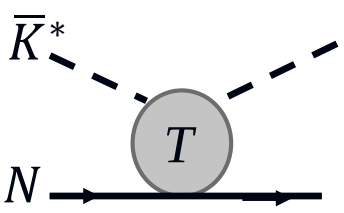
pp and AA at LHC (ALICE)

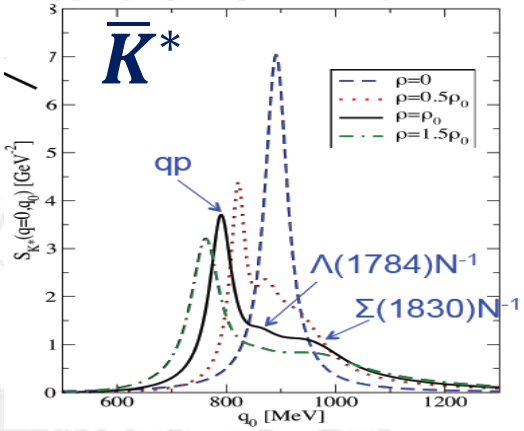
ALICE, EPJC 72 (2012) 2183; ALICE, arXiv:1404.0495



Strange vector mesons: ϕ and $\bar{K}^* / K^*$

Interactions with the medium (1): **collisional selfenergy**





Tolos et al, PRC82 (2010)

***t*-channel vector-exchange potentials** based on Hidden Local Symmetry

Bando, Kugo Ukehara, Yamawaki, Yanagida PRL 54 (1985) 1215; Bando, Kugo, Yamawaki, PR164 (1988) 217

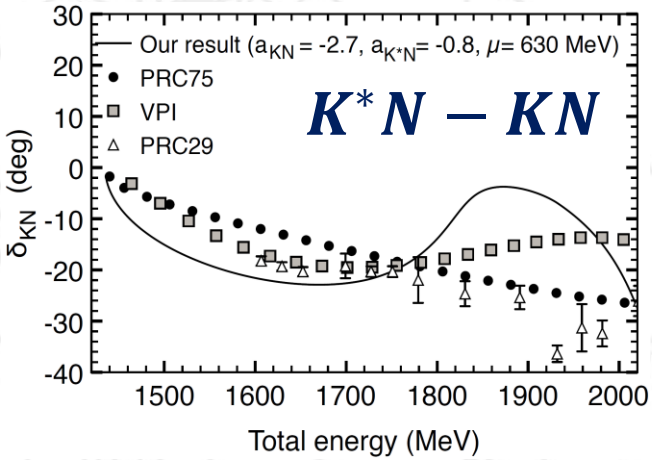
- $\bar{K}^*$: strong modifications from mixing with YN^{-1} excitations

Tolos, Molina, Oset, Ramos, PRC82 (2010)

- K^*: mild repulsive effect $\Delta M \sim 5\%$

Ilner, DC, Srisawad, Bratkovskaya, NPA927 (2014) 249; Khemchandani, Martinez et al., arXiv:1406.7203

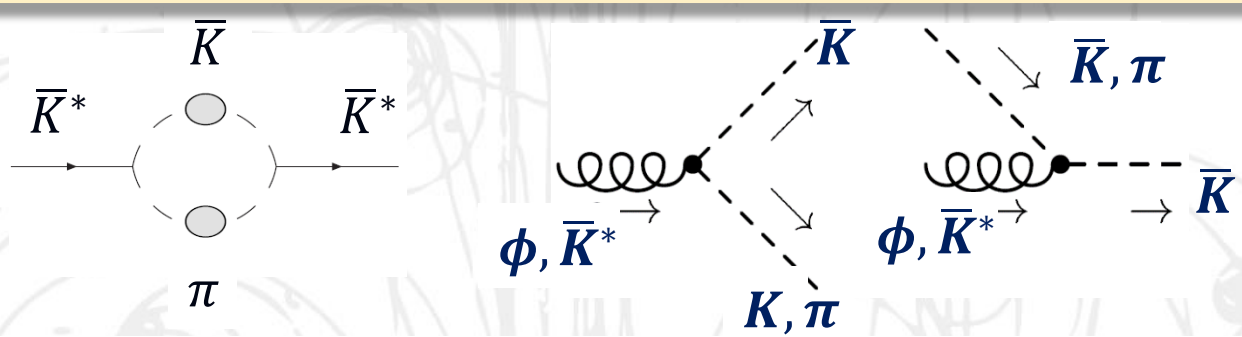
See also: Tsushima et al. PRC62 (2000)064904



Khemchandani et al., arXiv:1406.7203

Strange vector mesons: ϕ and $\bar{K}^* / K^*$

Interactions with the medium (2): **in-medium decay**



$$\mathrm{Im}\,\Pi_{\phi\bar{K}K}(P^0,\vec{0}\,;\rho,T) = \frac{4}{3}\,2\,g_\phi^2 \int \frac{\mathrm{d}^3q}{(2\pi)^3}\,q^2$$
$$\times \left\{(-\pi)\int_0^{P^0} \mathrm{d}\omega\, S_{\bar{K}}(\omega,\vec{q}\,;T)\, S_K(P^0-\omega,\vec{q}\,;T)\,[1+f(\omega)+f(P^0-\omega)]\right.$$
$$\left. +\; 2\,(-\pi)\int_0^{\infty} \mathrm{d}\omega\, S_{\bar{K}}(P^0+\omega,\vec{q}\,;T)\, S_K(\omega,\vec{q}\,;T)\,[f(\omega)-f(P^0+\omega)]\right\}$$

"Stimulated" (Bose enhanced) decay

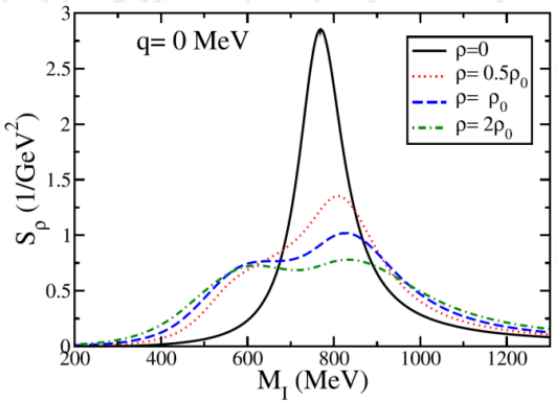
Diffusion term (low energy)

Pioneering work in hadronic many-body methods

Chanfray, Schuck,NPA 555 (1993) 329

Herrmann, Friman, Nörenberg, NPA 560 (1993) 411

Urban, Buballa, Rapp, Wambach, Nucl.Phys. A641 (1998) 433



Riek, Rapp, Lee, Oh, PLB 677 (2009) 116

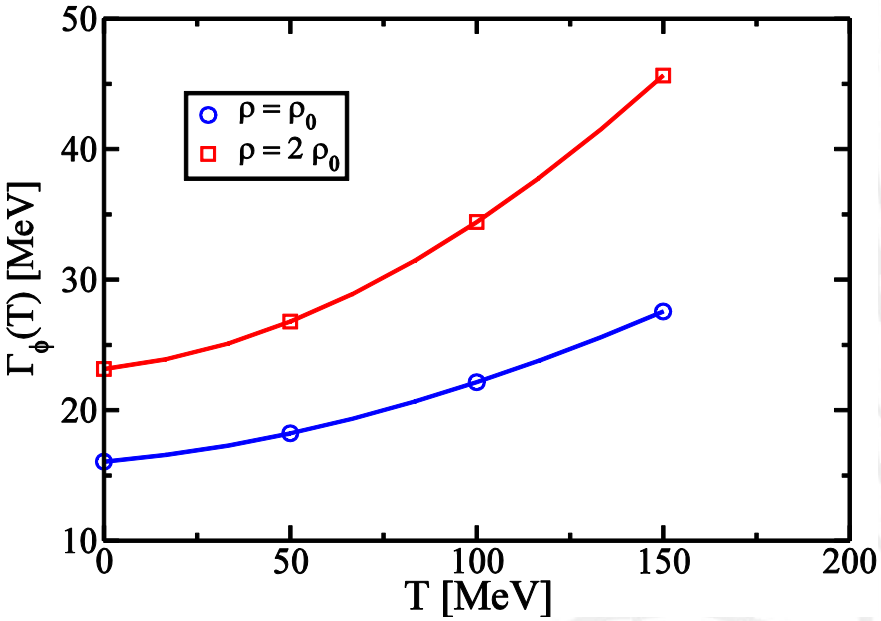
Strange vector mesons: ϕ and $\bar{K}^* / K^*$

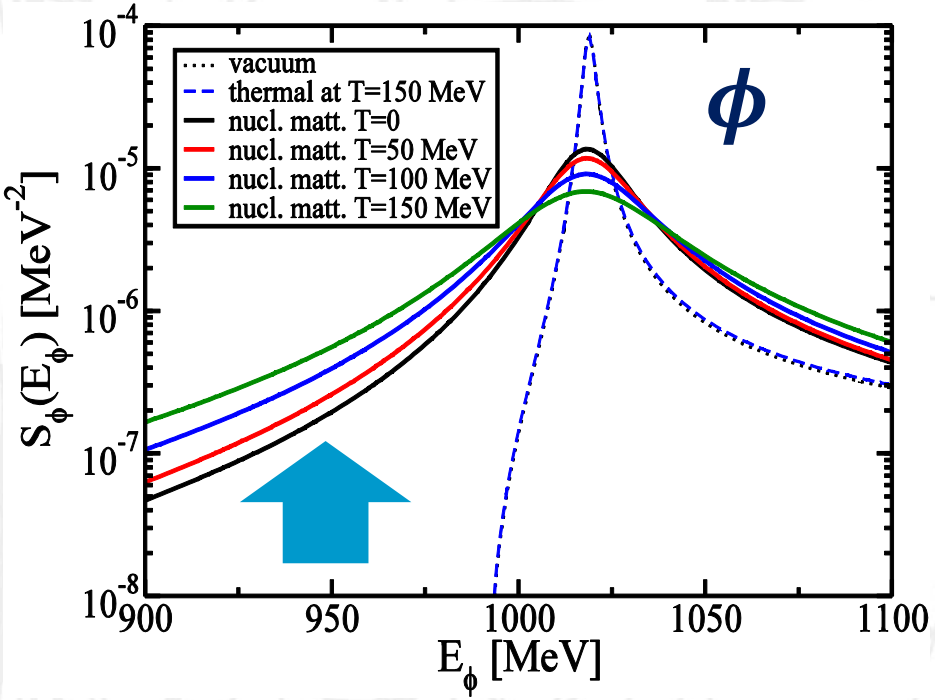
Some results at finite **nucl. density** AND **temperature**

ϕ meson

DC et al., EPJ Web Conf 97 (2015) 00008

$\Gamma_\phi(T) = -\,\mathrm{Im}\,\Pi_\phi(M_\phi,0;T) / M_\phi$





- In-medium open channels: $\phi N \to K\Lambda(1405),\ \phi N \to K\Lambda,\ K\Sigma,\ K\Sigma^*(1385)$
- Broadening + sizable population of *low-energy region* at GSI/FAIR conditions

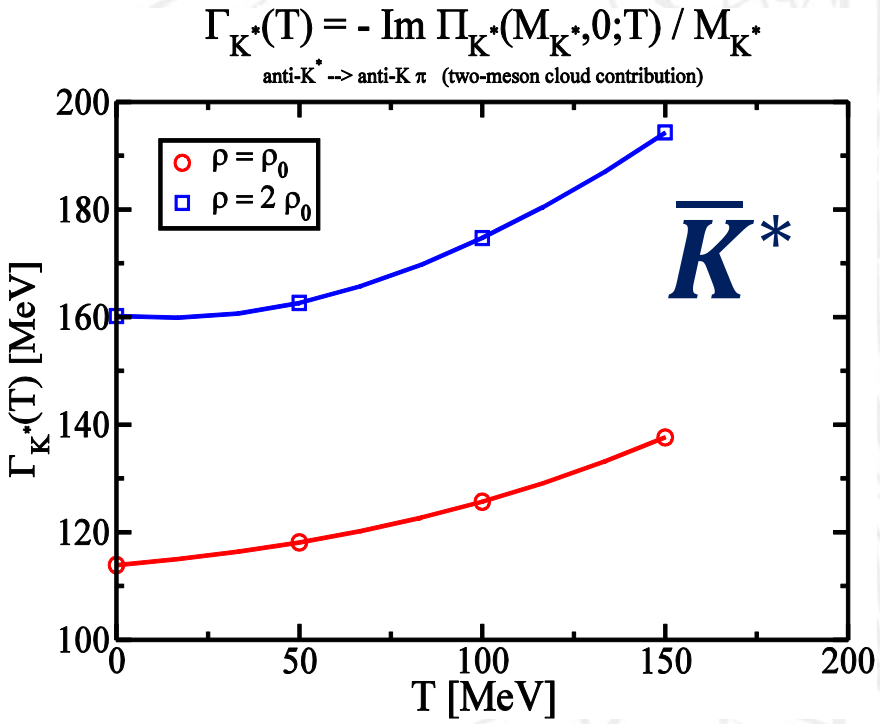
Ko et al. PRC45 (1992) 1400; Klingl, Kaiser, Weise, NPA 624 (1997) 527; Oset, Ramos, Nucl.Phys. A679 (2001) 616; DC, Vicente-Vacas, PRC67 (2003) 045203; DC, in preparation.

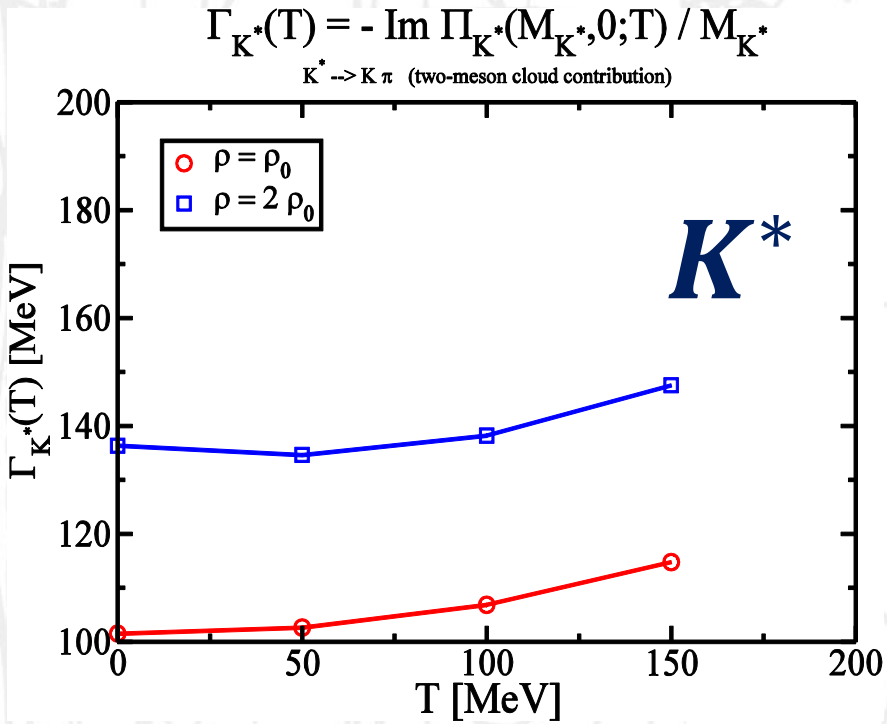
Strange vector mesons: ϕ and $\bar{K}^* / K^*$

Some results at finite **nucl. density** AND **temperature**

$\bar{K}^*$ and K^* mesons

DC et al., EPJ Web Conf 97 (2015) 00008





- Deep sub-threshold $K^*(892)^0$ in $Ar + KCl$ at 1.76 AGeV **(HADES)**
- Yield suppression also reported in $Pb + Pb$ at $\sqrt{s_{NN}} = 2.76$ TeV (**ALICE)**

Agakishiev et al., Eur. Phys. J. A49 (2013) 34; Bass et al, PPNP41 (1998) 255; Bleicher et al, JPG 25 (1999) 1859; ALICE, arXiv:1404.0495

Strange vector mesons: ϕ and $\bar{K}^* / K^*$

Some results at finite **nucl. density** AND **temperature**

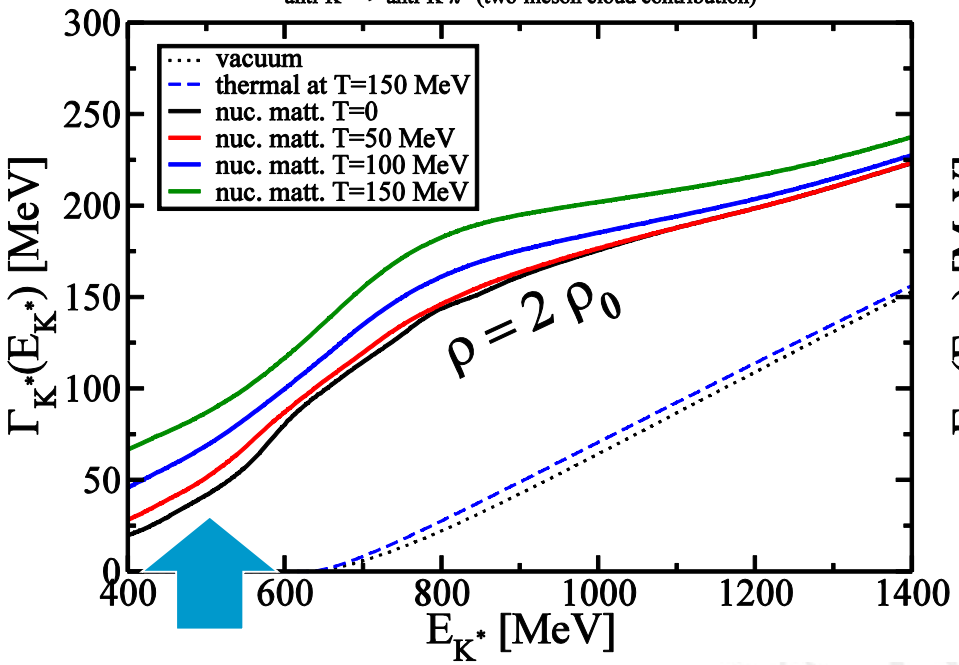
$\bar{K}^*$ and K^* mesons

DC et al., EPJ Web Conf 97 (2015) 00008

$\bar{K}^*$

$\Gamma_{K^*}(E_{K^*}) = -\,\mathrm{Im}\,\Pi_{K^*}(E_{K^*},0;T) / E_{K^*}$

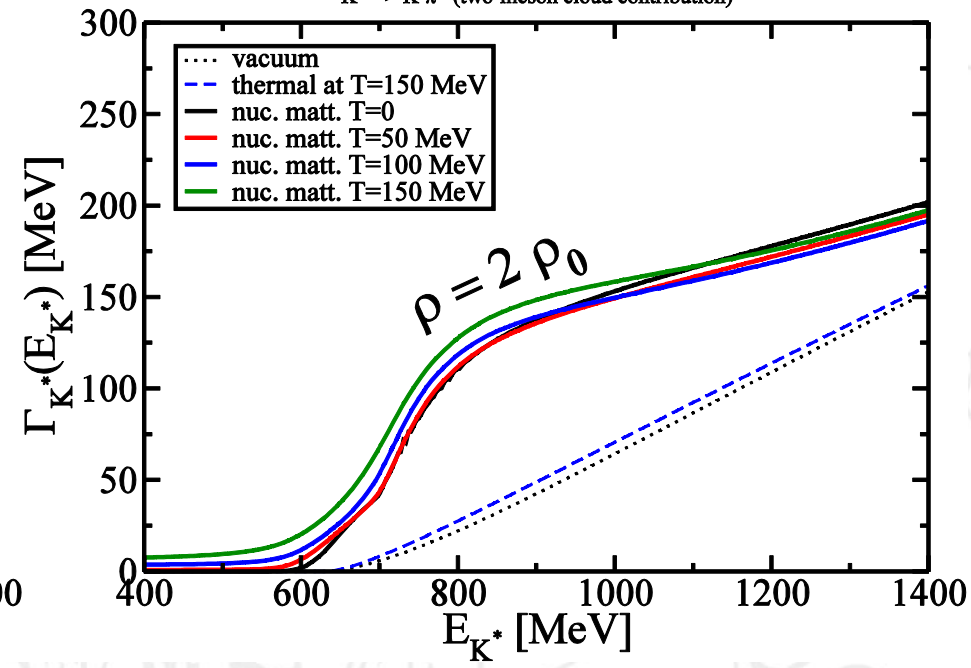
anti-K^* --> anti-K π (two-meson cloud contribution)



K^*

$\Gamma_{K^*}(E_{K^*}) = -\,\mathrm{Im}\,\Pi_{K^*}(E_{K^*},0;T) / E_{K^*}$

K^* --> K π (two-meson cloud contribution)



More on $SU(3)$ unitarized ChPT model

Modelling $\bar{K}$ and K in hot/dense matter

Dynamics: meson-baryon Chiral PerturbationTheory

Lutz, Korpa, Moller, NPA808 (2008) 124; Tolos, DC, Ramos, PRC78 (2008) 045205; DC, Tolos, Aichelin, Bratkovskaya, PRC90 (2014) 055207

Chiral $SU(3)$ Lagrangian

$$\mathcal{L}_1^{(B)} = \langle \bar{B} i\gamma^\mu \nabla_\mu B\rangle - M\langle \bar{B}B\rangle + \frac{1}{2}D\left\langle \bar{B}\gamma^\mu\gamma_5\{u_\mu, B\}\right\rangle + \frac{1}{2}F\left\langle \bar{B}\gamma^\mu\gamma_5[u_\mu, B]\right\rangle$$

S-wave potential (Weinberg-Tomozawa)

$$V_{ij}^s = -C_{ij}\frac{1}{4f^2}(2\sqrt{s} - M_{B_i} - M_{B_j})$$

P-wave potential (Λ, Σ, Σ^*)

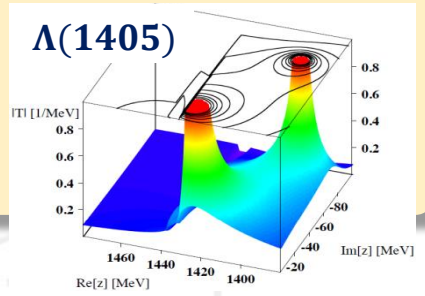
$$V_{ij}^{\Lambda} = D_i^{\Lambda} D_j^{\Lambda}\frac{1}{\sqrt{s}-\tilde{M}_{\Lambda}}(\vec{\sigma}\cdot\vec{q}_j)(\vec{\sigma}\cdot\vec{q}_i)\left(1+\frac{q_j^0}{M_j}\right)\left(1+\frac{q_i^0}{M_i}\right)$$

$$V_{ij}^{\Sigma} = D_i^{\Sigma} D_j^{\Sigma}\frac{1}{\sqrt{s}-\tilde{M}_{\Sigma}}(\vec{\sigma}\cdot\vec{q}_j)(\vec{\sigma}\cdot\vec{q}_i)\left(1+\frac{q_j^0}{M_j}\right)\left(1+\frac{q_i^0}{M_i}\right)$$

$$V_{ij}^{\Sigma^*} = D_i^{\Sigma^*} D_j^{\Sigma^*}\frac{1}{\sqrt{s}-\tilde{M}_{\Sigma^*}}(\vec{S}\cdot\vec{q}_j)(\vec{S}^\dagger\cdot\vec{q}_i)\ ,$$

Coupled-channels [full $SU(3)$ basis, isospin $I = 0,1$]

- $S = -1$: $\begin{cases} K^-p,\ \bar{K}^0n,\ \pi^0\Lambda,\ \pi^0\Sigma^0,\ \eta\Lambda,\ \eta\Sigma^0,\ \pi^+\Sigma^-,\ \pi^-\Sigma^+,\ K^+\Xi^-,\ K^0\Xi^0 \\ K^-n,\ \pi^0\Sigma^-,\ \pi^-\Sigma^0,\ \pi^-\Lambda,\ \eta\Sigma^-,\ K^0\Xi^- \end{cases}$
- $S = +1$: $K^+p;\ K^+n,\ K^0p$

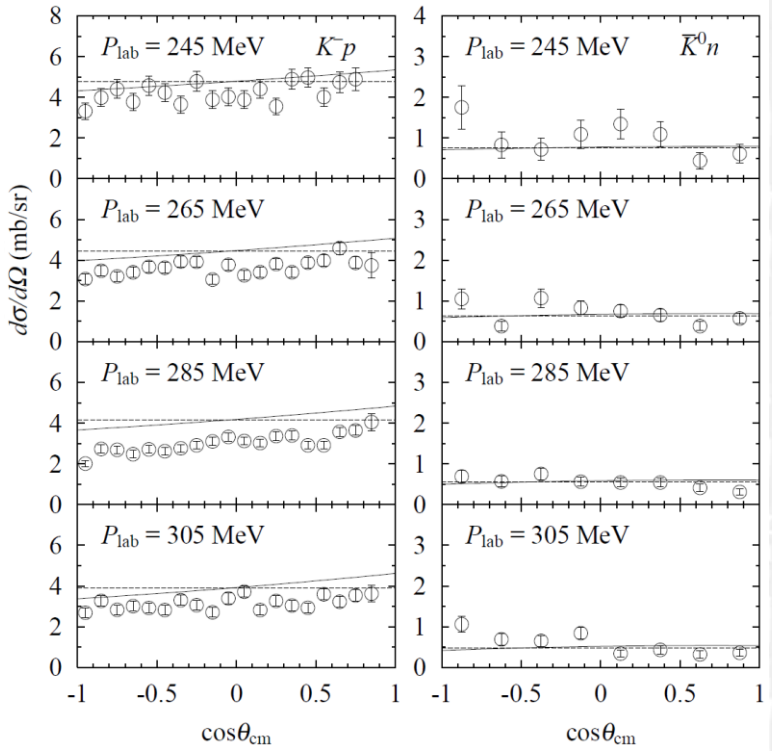


Modelling $\bar{K}$ and K in hot/dense matter

Scattering observables in vacuum

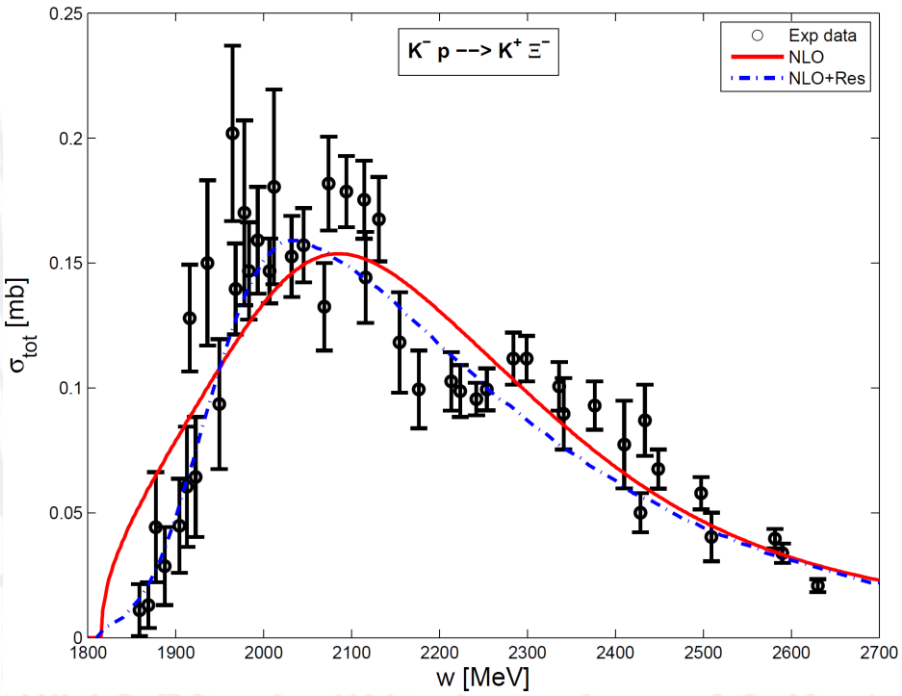
1-parameter model

Differential cross sections



D. Jido, E. Oset and A. Ramos, PRC66 (2002) 055203

$K\Xi$ channels (test of NLO)



Magas, Feijoo, Ramos, arXiv:1502.07956