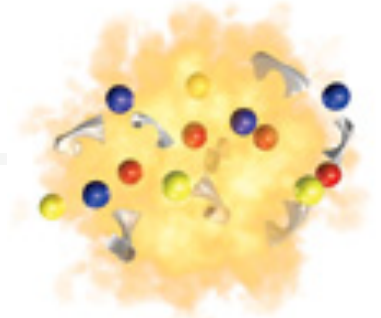
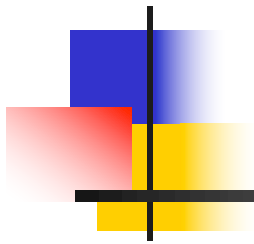


Medium modification of (strange) hadronic resonances at (SIS), RHIC and LHC energies



Institute of
Space Sciences

 **CSIC** **IEEC** 
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

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for Advanced Studies



in collaboration with

Daniel Cabrera, Kanchan Khemchandani, Alberto Martinez-Torres,
Raquel Molina, Eulogio Oset and Angels Ramos;
Elena Bratkovskaya and Joerg Aichelin

Motivation

Strangeness production in matter

is one of the major research domains in heavy-ion collisions from SIS/GSI to LHC and RHIC up to the future FAIR/NICA/BESII/J-PARC-HI

low-energy HICs:

KaoS/SIS18: K^+, K^- , ...

FOPI/SIS18: $K^+, K^-, \phi(1020)$..

HADES/SIS18: $K^+, K^*(892)^0, \phi(1020), \Xi(1321), \Omega, \dots$

Zinyuk (FOPI) '14

Foerster et al (KaoS) '07

Agakishiev et al (HADES) '13 '14

Galatyuk (HADES) '17..

high-energy HICs:

STAR/RHIC: $K^*(892)^0, \phi(1020), \Omega$..

ALICE/LHC: $K^*(892)^0, \phi(1020), \Sigma^-(1385), \Xi(1530)^0$..

Adams et al. (STAR) '05

Aggarwal et al (STAR) '11

Kumar et al (STAR) '15

Abelev (ALICE) '15

Adam (ALICE) '16

Badala (ALICE) '17..

future:

CBM/FAIR

BM@N/NICA

BESII/RHIC

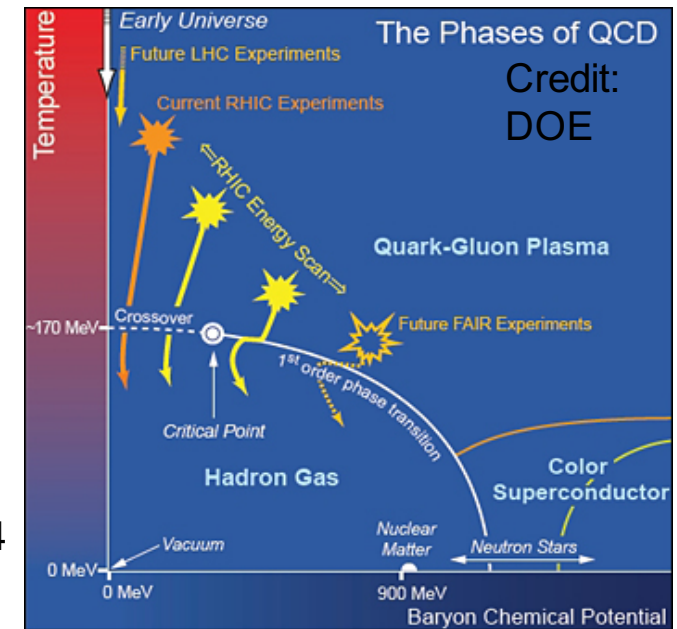
J-PARC-HI

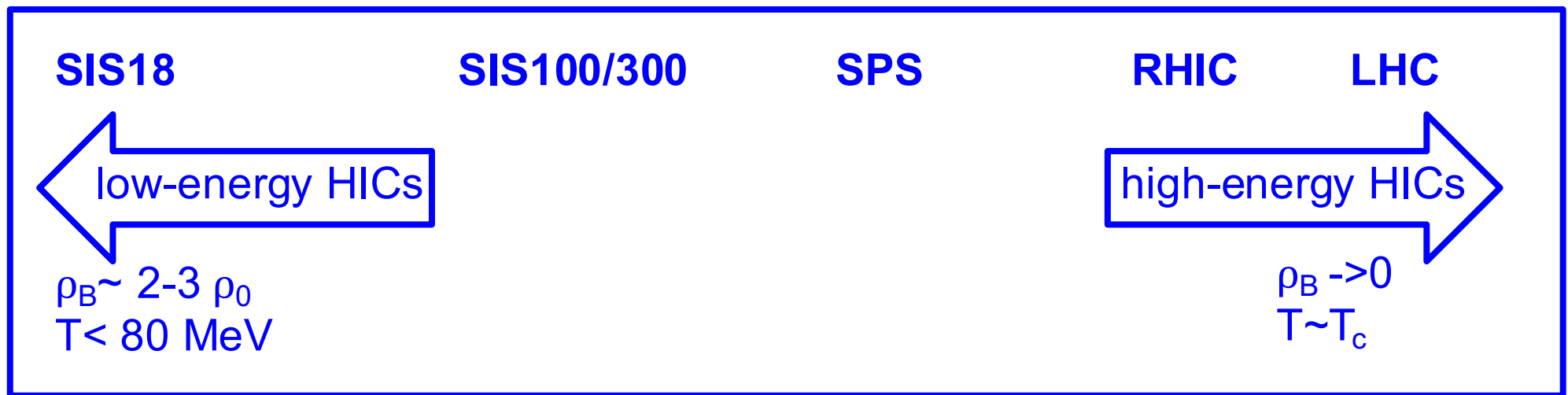
CBM (FAIR) Physics Book '11

NICA: <http://theor0.jinr.ru/twiki-cgi/view/NICA>

Aggarwal et al (BES STAR White Paper) '10

JPARC: <http://silver.j-parc.jp/sako/white-paper-v1.21.pdf-HI>





Some open questions on medium:

- What colliding energies are best suited to study QGP or/and hadronic phase?
- What are the experimental signatures of in-medium effects coming from QGP or/and hadronic phase on the final observables?
- Are in-medium effects important on the final observables?

Method:

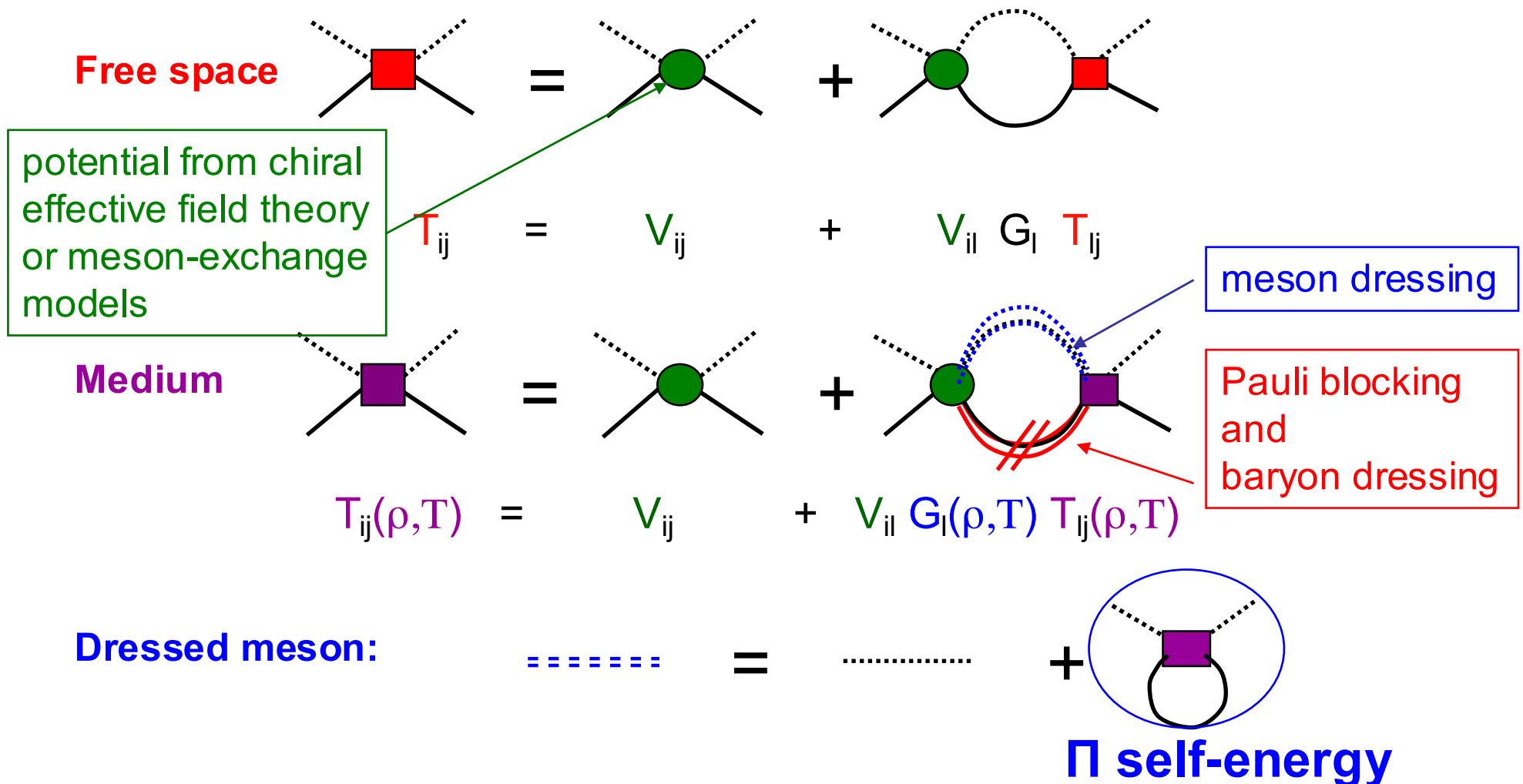
models on QGP or/and hadronic phase + transport approaches

In this talk:

medium modifications of pseudoscalar (K , \bar{K}) and vector (K^* , \bar{K}^*) mesons as well as associated strange baryon resonances in hadronic matter

Strange pseudoscalar mesons and strange baryon resonances in **hadronic** matter

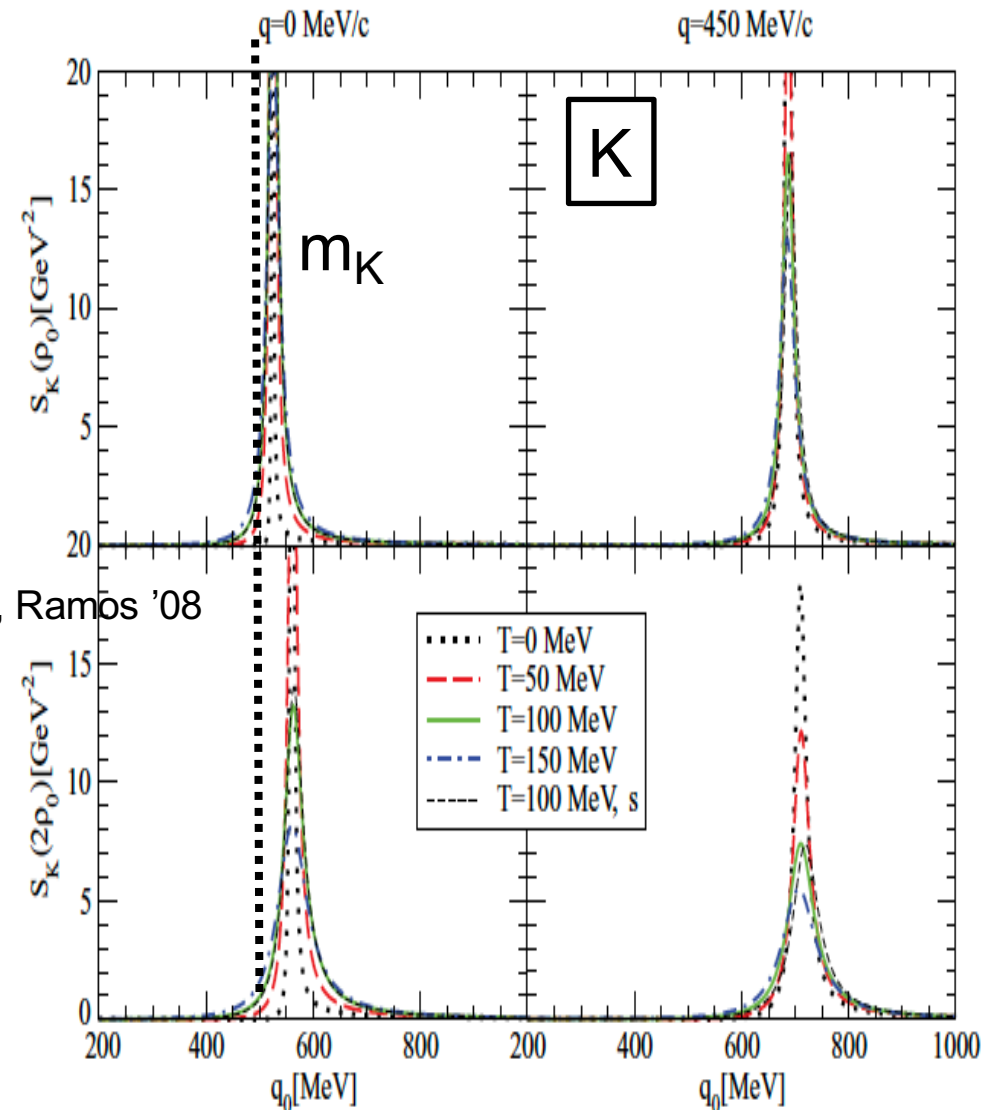
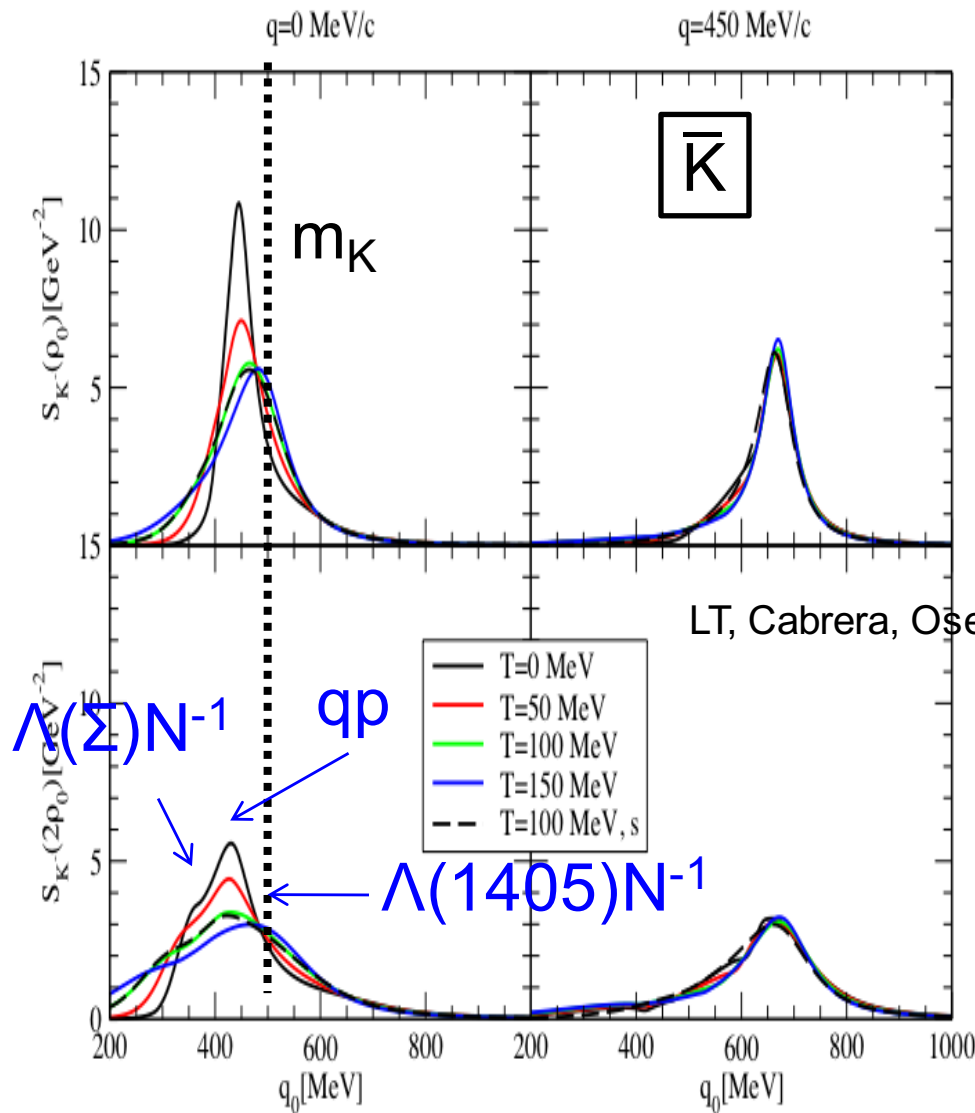
**Unitarized theory in hot dense nuclear matter:
selfconsistent coupled-channel procedure**



\bar{K} and K spectral functions in hot dense hadronic matter

$$S = -\frac{1}{\pi} \frac{\text{Im}\Pi}{[q_0^2 - \vec{q}^2 - m^2 - \text{Re}\Pi]^2 + \text{Im}\Pi^2}$$

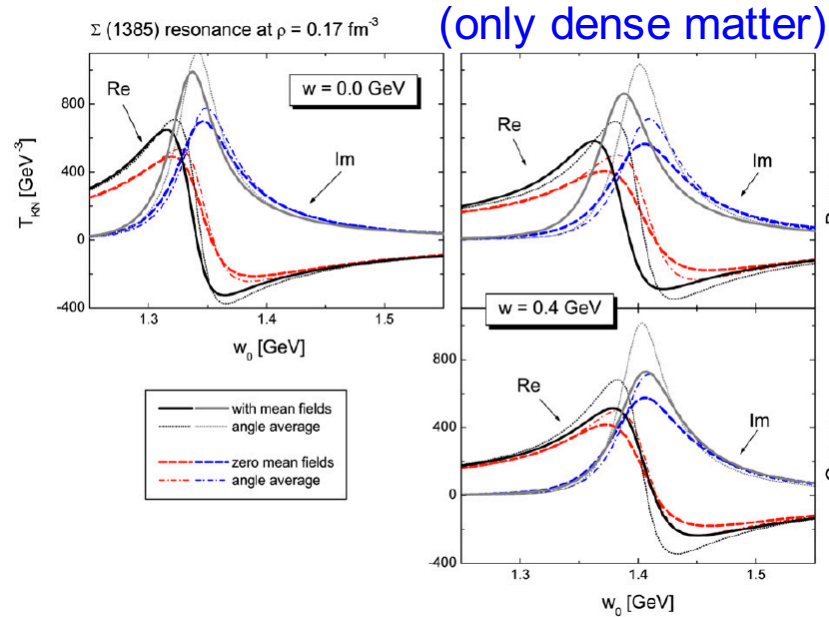
Koch '94; Waas and Weise '97;
Kaiser et al '97; Oset and Ramos'98;
Lutz '98; Schaffner-Bielich et al '00;
Ramos and Oset '00; Lutz et al '02 ;
LT et al '01 '02; Jido et al '02 '03;
Magas et al '05; LT et al '06 '08;
Lutz et al '08



Hyperons in hot dense hadronic matter

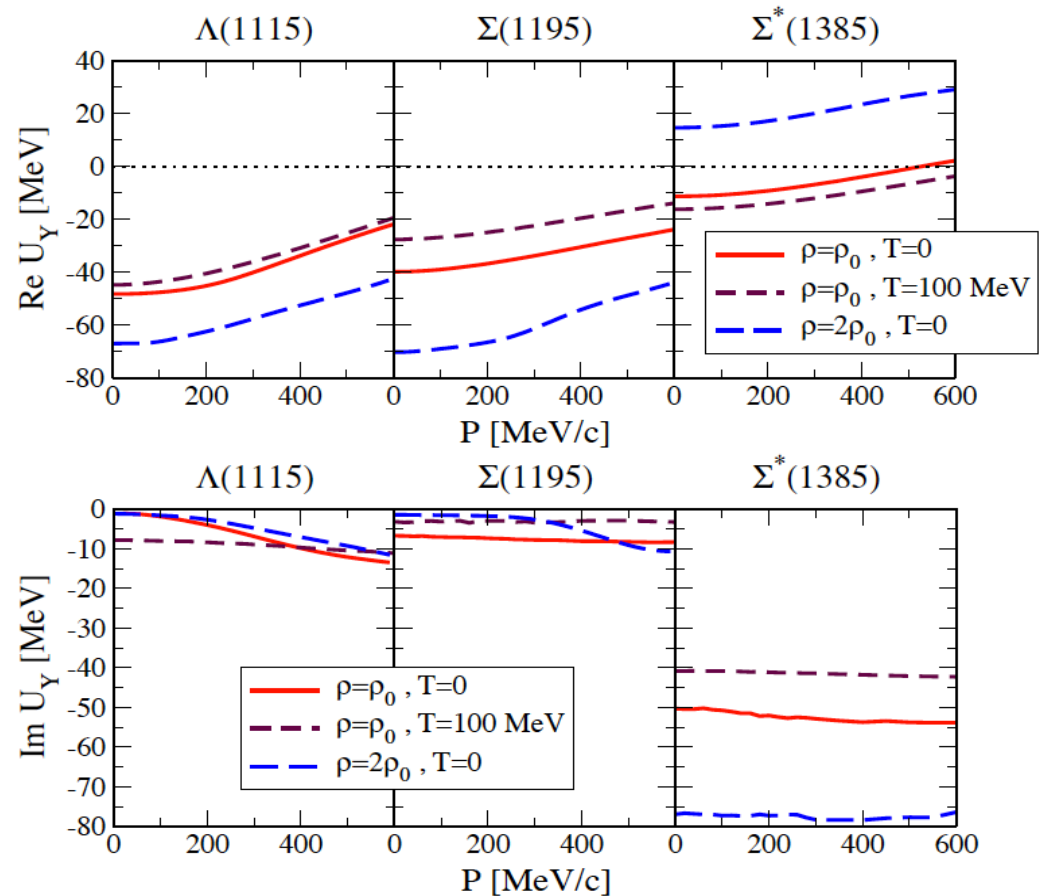
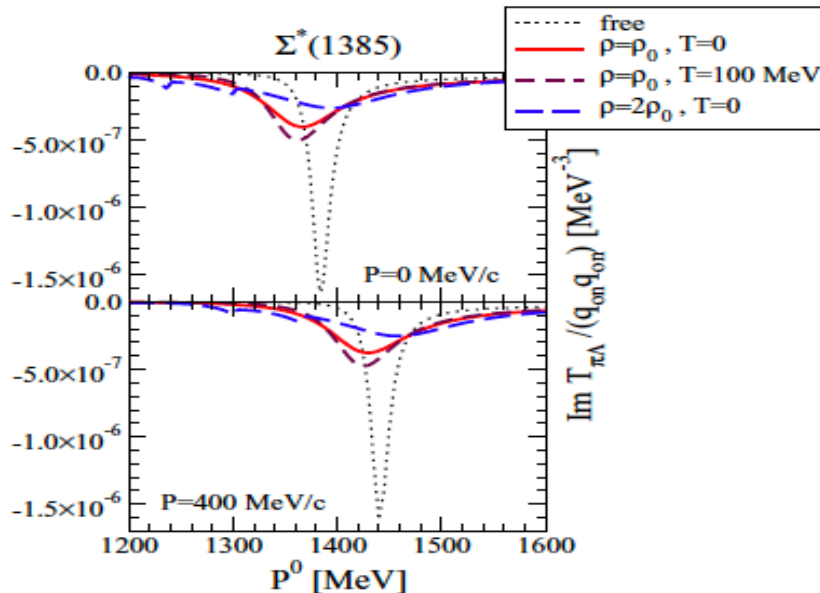
Lutz, Korpa and Mueller '08

Cabrera, LT, Aichelin, Bratkovskaya '14



Tolos, Ramos and Oset '06

Cabrera, LT, Aichelin, Bratkovskaya '14

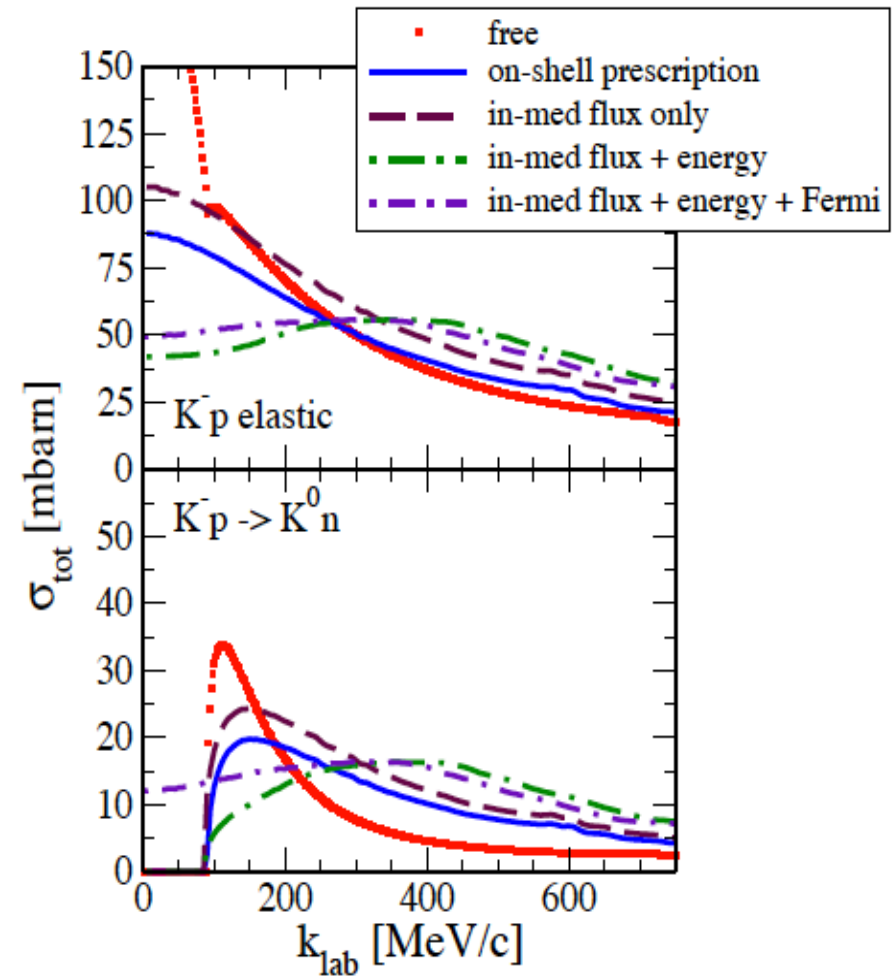
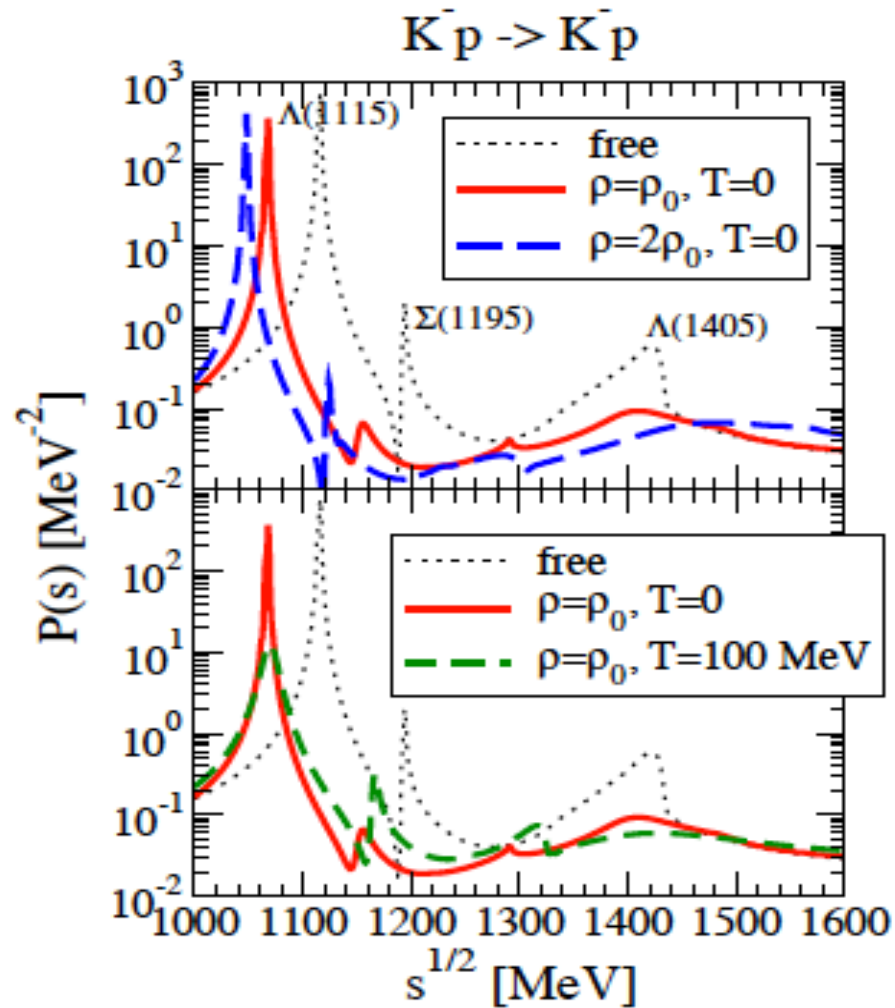


- Attractive mass shift for Λ and Σ , while Λ and Σ acquire a finite width at finite density and temperature
- Attraction at ρ_0 for Σ^* turns into repulsion at higher densities while width increases
- Smooth behavior of hyperon potentials with momentum

Transition probabilities/cross sections in hot dense hadronic matter

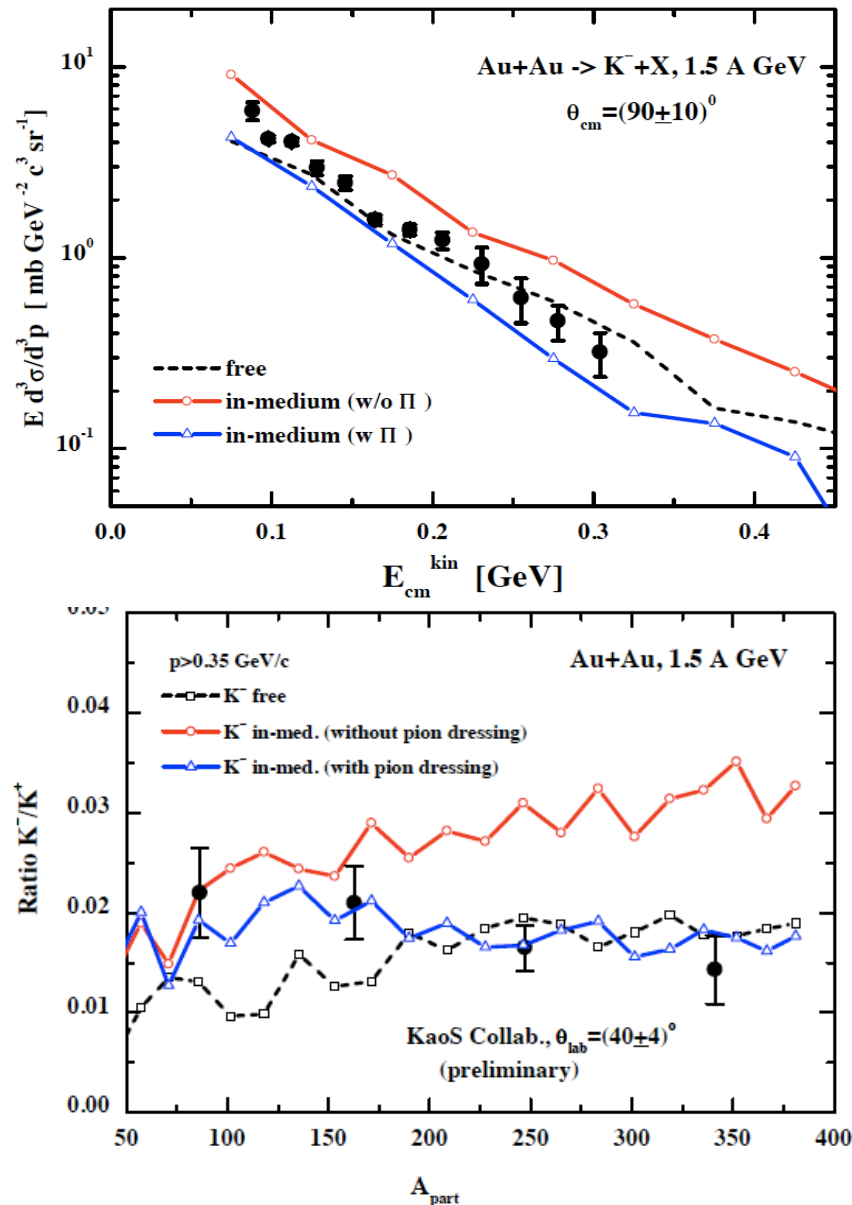
$$P = \int d\Omega |T|^2$$

$$\sigma(s) \propto \frac{M_i M_j}{s} \frac{q_j}{q_i} \int d\Omega |T|^2$$



Strangeness production in low-energy HICs

Strangeness production close to threshold in proton-nucleus and heavy-ion collisions
Hartnack, Oeschler, Leifels, Bratkovskaya and Aichelin '12



First attempts to describe
all data simultaneously with full spectral
features of strange pseudoscalar mesons
Cassing, LT, Bratkovskaya and Ramos '03

Collaboration ICE-FIAS-SUBATECH:
working on implementing the properties of
strange pseudoscalar mesons and strange
baryon resonances in hot dense hadronic
matter in an off-shell transport approach for
HICs @SIS18 (HADES) and @ SIS300
(CBM)

Comments on high-energy HICs:

- in-medium properties of strange hadrons in hot mesonic matter are required
- **how important is the hadronic phase** as compared to QGP phase?

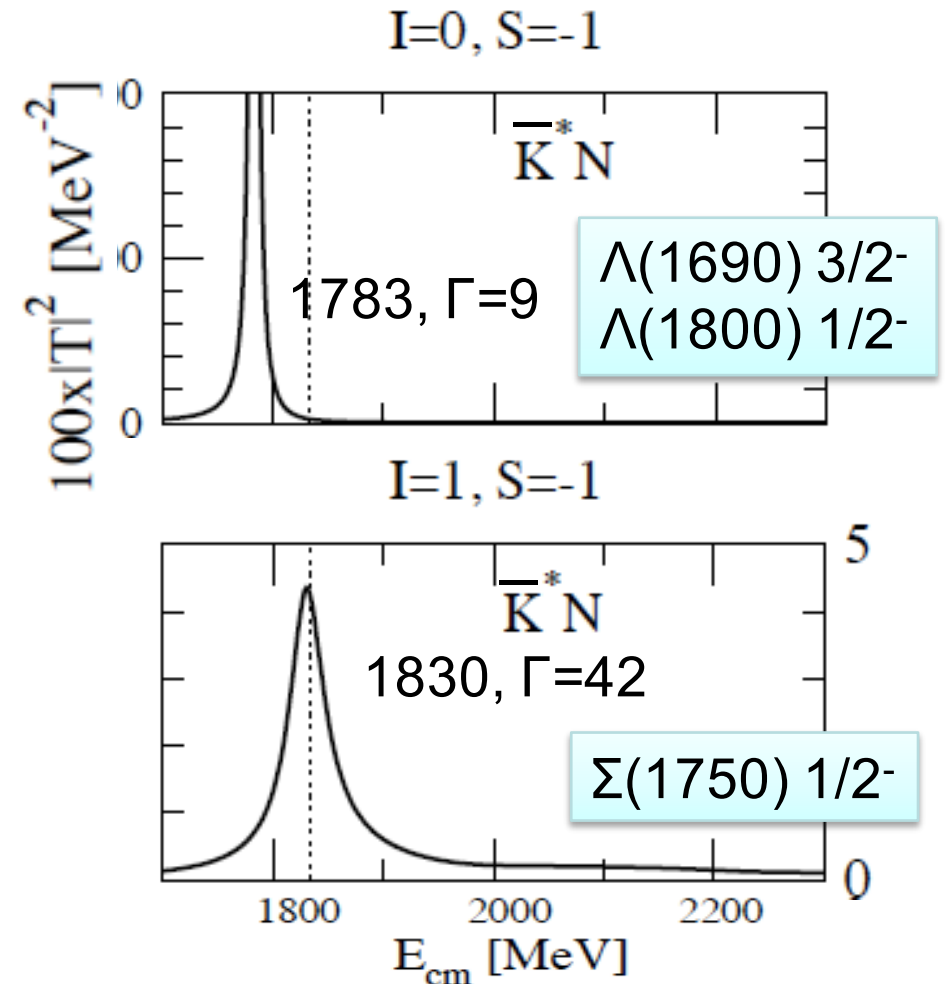
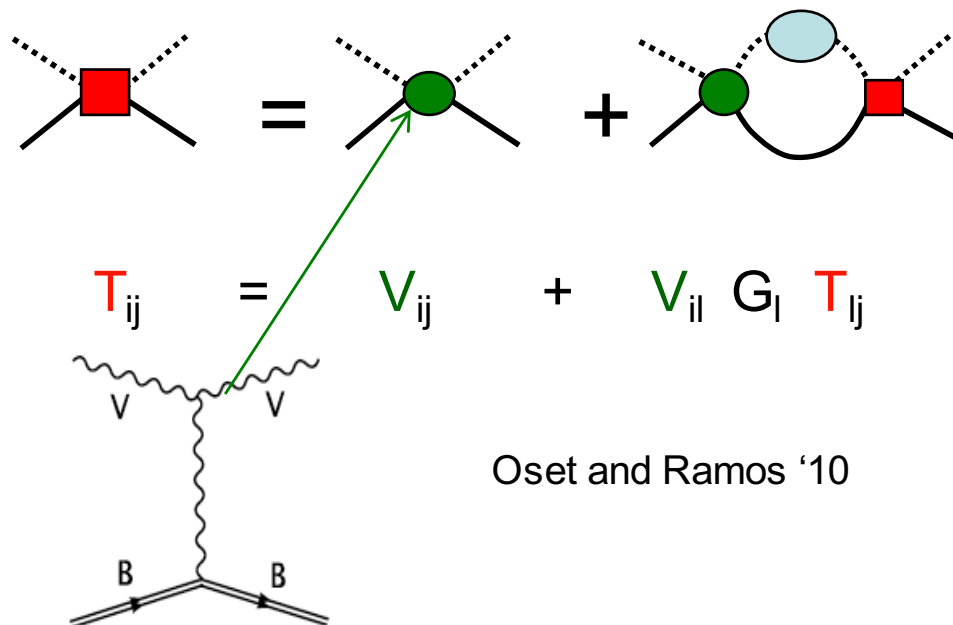
Strange vector mesons and strange baryon resonances in **hadronic** matter

\bar{K}^* in free space

within the **local hidden gauge formalism**

Bando, Kugo, Uehara, Yamawaki
and Yanagida '85 '88;
Harada and Yamawaki, '03;
Meissner '88

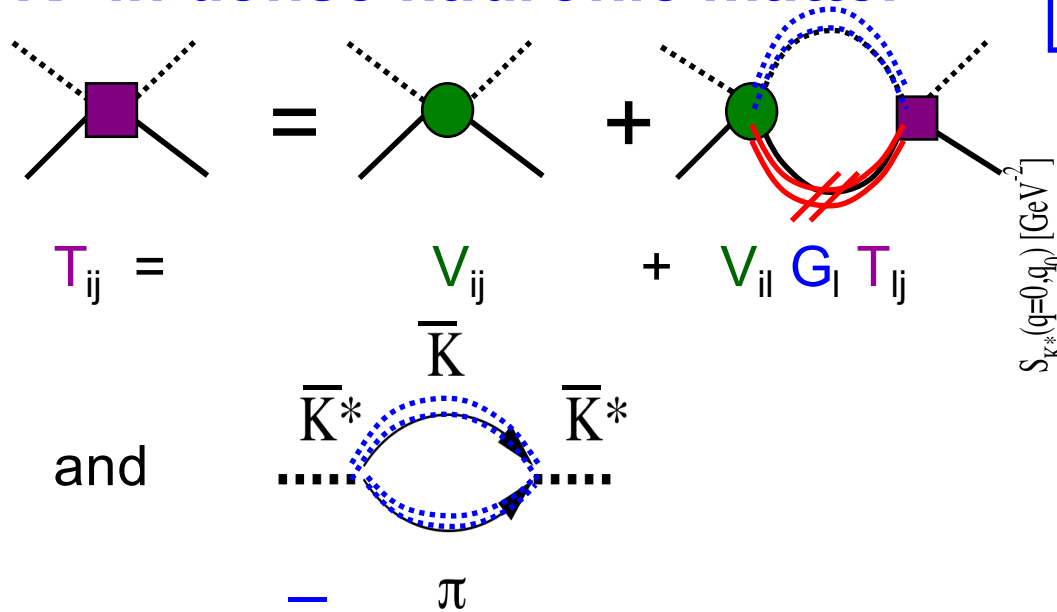
using a coupled-channel unitary
approach with VB-VB interaction



Latest works in $K^* N$ also incorporate
PB-VB couplings and beyond t-channel

Khemchandani, Kaneko, Martinez Torres,
Nagahiro, Hosaka, '11 '12; Khemchandani,
Martinez Torres, Navarra, Nielsen, LT '15

\bar{K}^* in dense hadronic matter



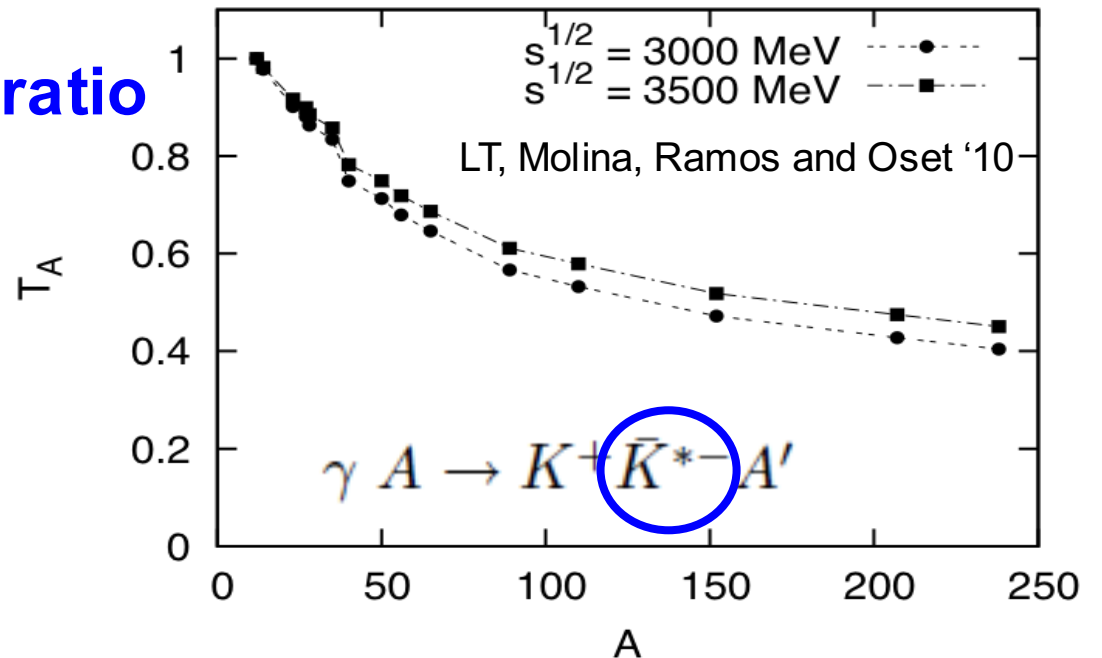
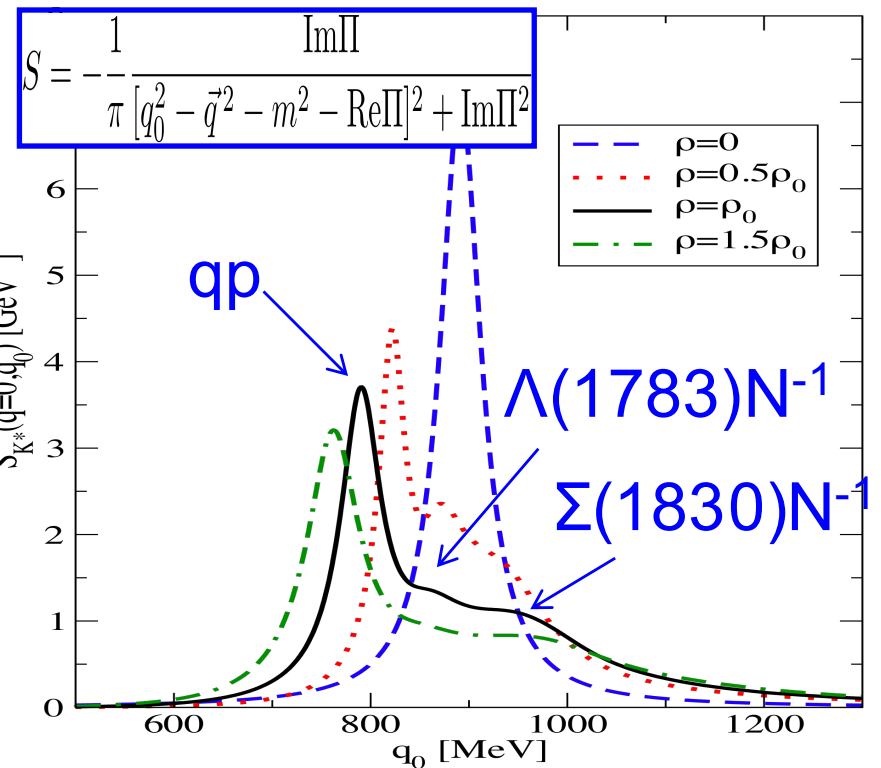
in-medium \bar{K}^* width is five times larger than in free space

Experiments: **transparency ratio**

$$\tilde{T}_A = \frac{\sigma_{\gamma A \rightarrow K^+ K^{*-} A'}}{A \sigma_{\gamma N \rightarrow K^+ K^{*-} N}}$$

$$T_A = \frac{T_A}{\tilde{T}_{12C}}$$

40-60% reduction in heavy nuclei (A=50-250) with respect to ^{12}C



K* in free space

Khemchandani, Martinez-Torres, Navarra, Nielsen and LT '15

Potential for

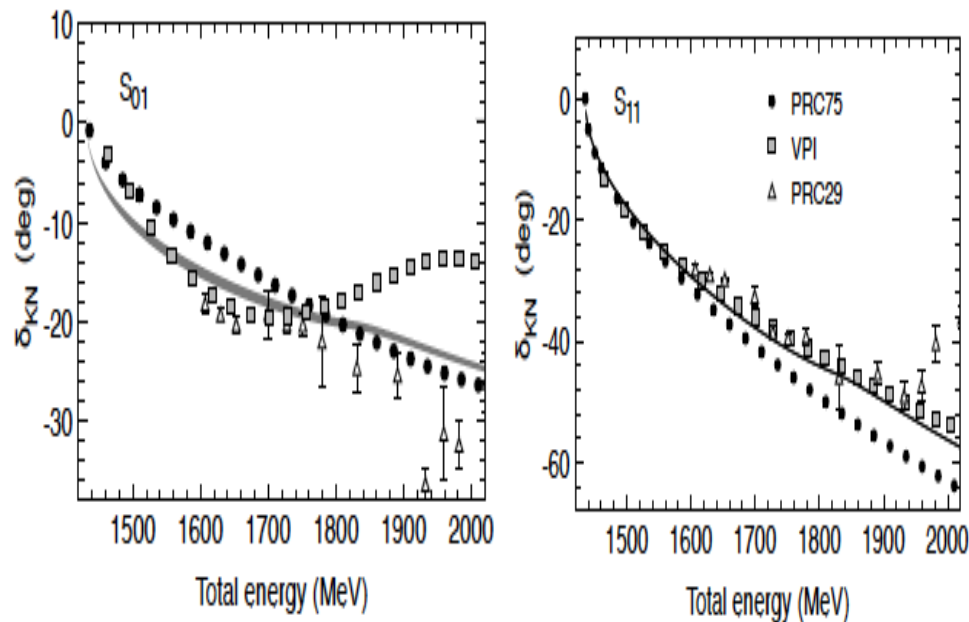
KN : LO chiral Lagrangian

K*N : s-,t-,u- channels and contact term from hidden gauge formalism

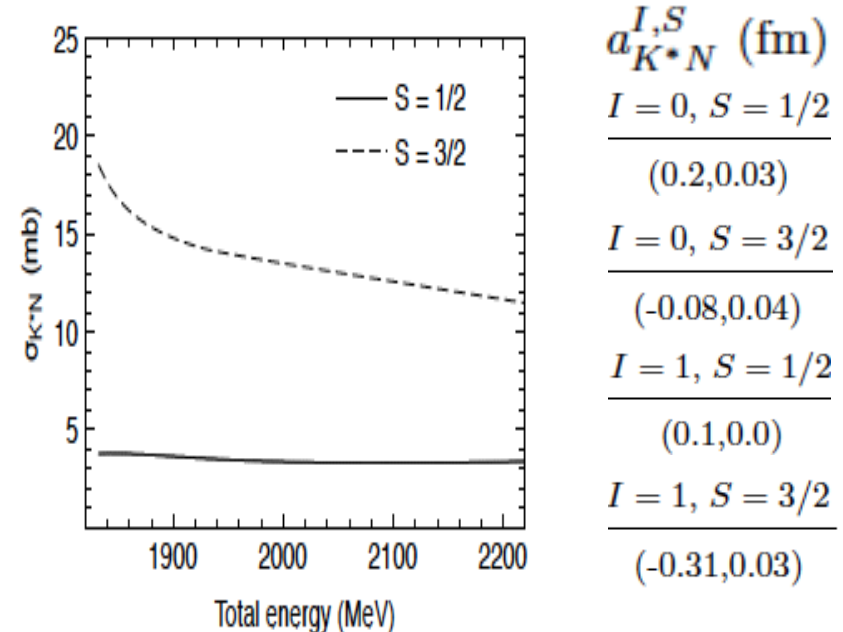
KN-K*N : extension of Kroll-Ruderman term

+ exchange of light hyperon resonances, such as $\Lambda(1405)$ and $\Lambda(1670)$

We fit subtraction constants
to KN $I=0$ and $I=1$ phase shifts



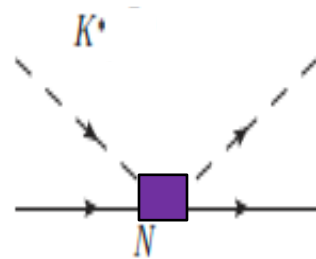
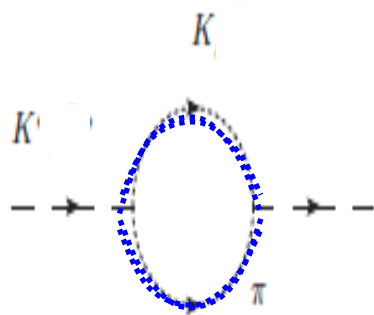
We predict KN and K*N cross sections,
and K*N scattering lengths



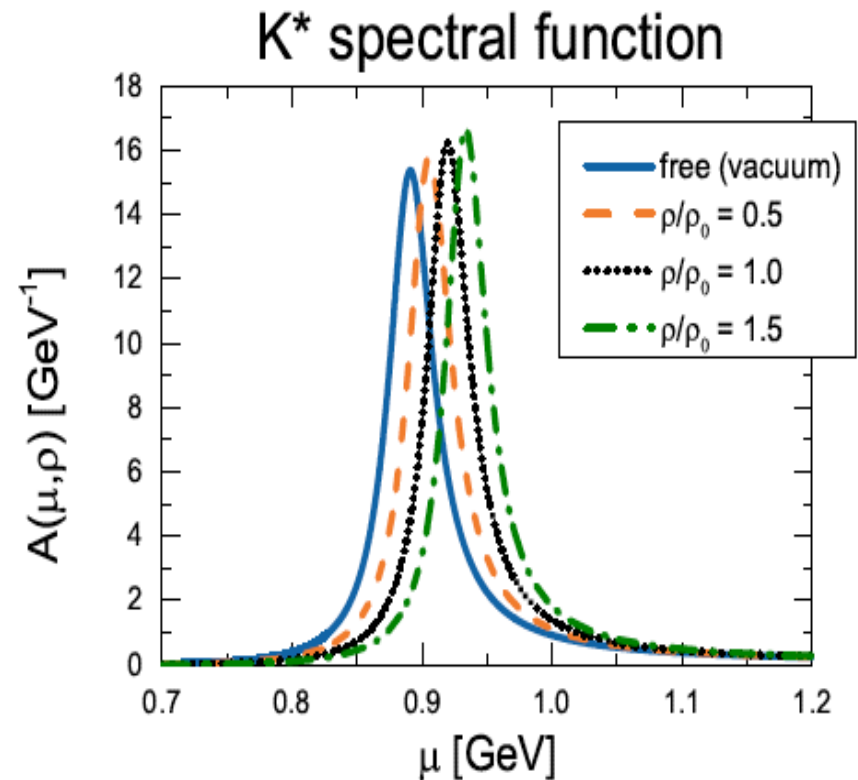
Results of special interest from K* production in p+p and p+A collisions
@ HADES, STAR and NA49

K^* in dense hadronic matter

Illner, Cabrera, Srisawad and Bratkovskaya '14



($T\rho$ approximation)



Warning: in-medium properties of K^* and \bar{K}^* only
at dense hadronic matter
(no finite temperature corrections included yet)

K^*/\bar{K}^* dynamics in low- and high-energy HiCs

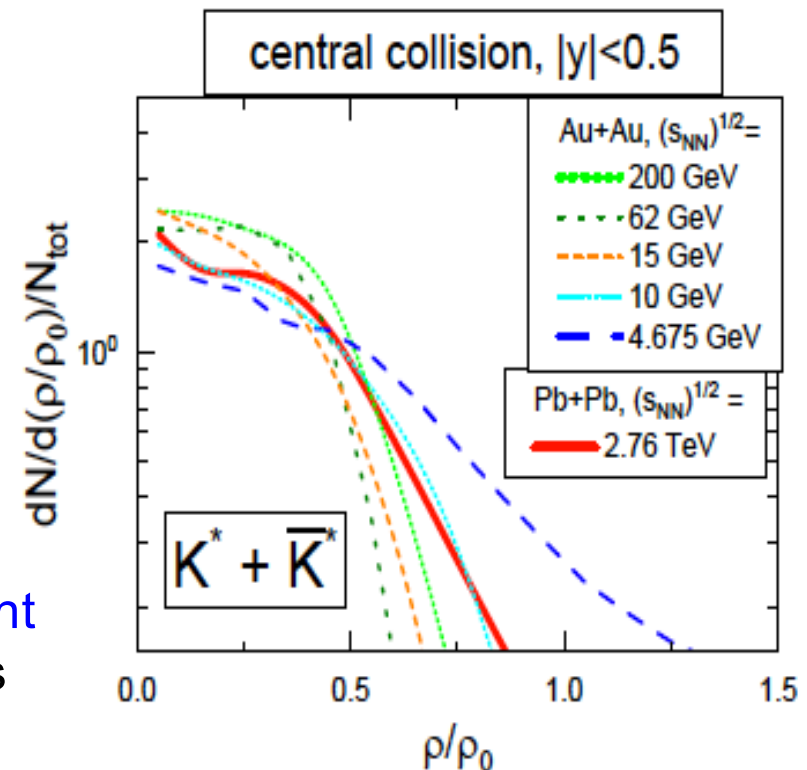
Ilner, Cabrera, Markert and Bratkovskaya '17; Ilner, Blair, Cabrera, Markert, Bratkovskaya '17

to investigate the **dynamics of K^*/\bar{K}^* in HiCs** using the PHSD transport model that implements in-medium effects on K^*/\bar{K}^* coming from their production from QGP as well as from the hadronic phase

PHSD calculations for Au+Au at $\sqrt{s_{NN}} = 200$ GeV (STAR/RHIC) and Pb+Pb $\sqrt{s_{NN}} = 2.76$ TeV (ALICE/LHC) as well as Au+Au for $\sqrt{s_{NN}} \sim 5-60$ GeV (CBM/FAIR or BM@N/NICA or low BES/RHIC) using **off-shell behavior of K^*/\bar{K}^***

Some conclusions on K^*/\bar{K}^* production:

- at **LHC/RHIC** the **main production channel** is resonant annihilation of $\pi + K$ (\bar{K}) **in the final hadronic phase**
- rather low baryon densities at LHC/RHIC, so in-medium effects do not play a role, while at **lower energies (CBM/BM@N/low BES)** the **in-medium hadronic effects** might be relevant due to longer reaction time and higher densities
- **difficulties** to extract in-medium properties **due to rescattering and absorption of decay channels**



Ilner, Blair, Cabrera,
Markert, Bratkovskaya '17

Summary

- We have presented the properties of strange pseudoscalar and vector mesons as well as strange baryon resonances in hot dense hadronic matter
- The in-medium modified properties of strange mesons and baryon resonances are being implemented in transport models to analyze experimental data from low to high-energy HICs
- Fundamental open question:
importance of the hadronic phase
(and associated in-medium effects) as compared to QGP??

Stay tuned!!

