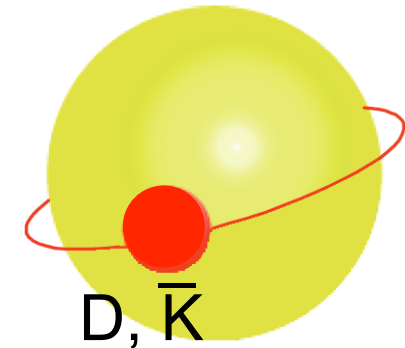
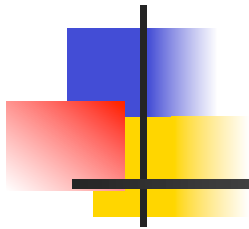


# Strange and Charmed Mesons in Nuclear Matter and Nuclei

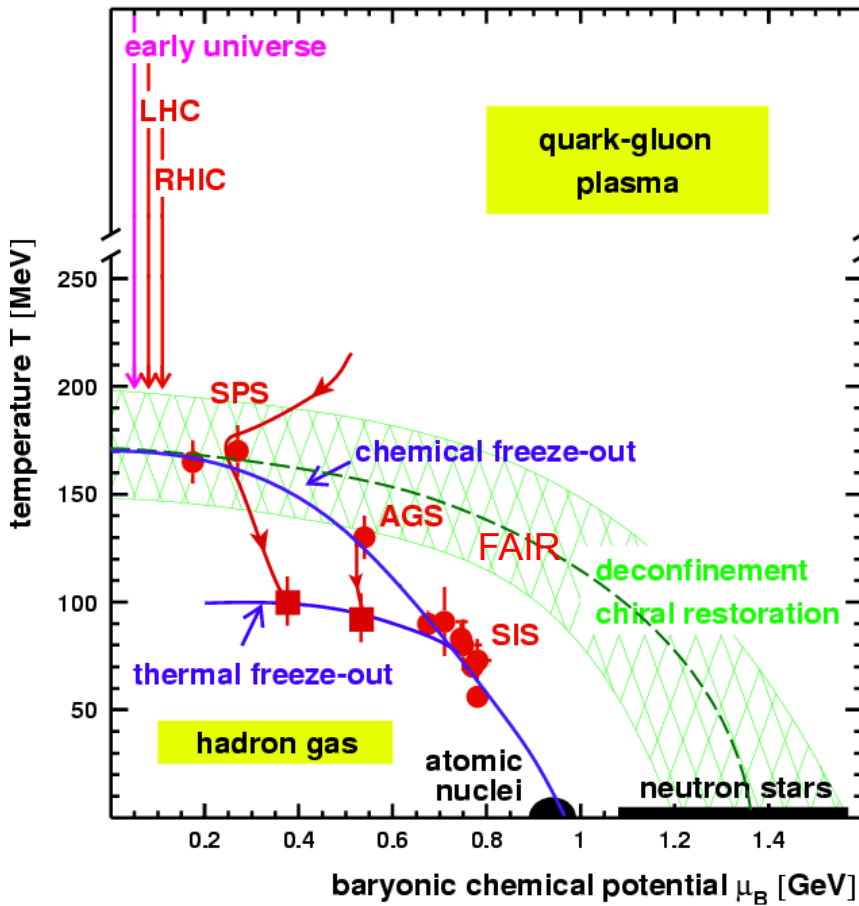


Laura Tolós

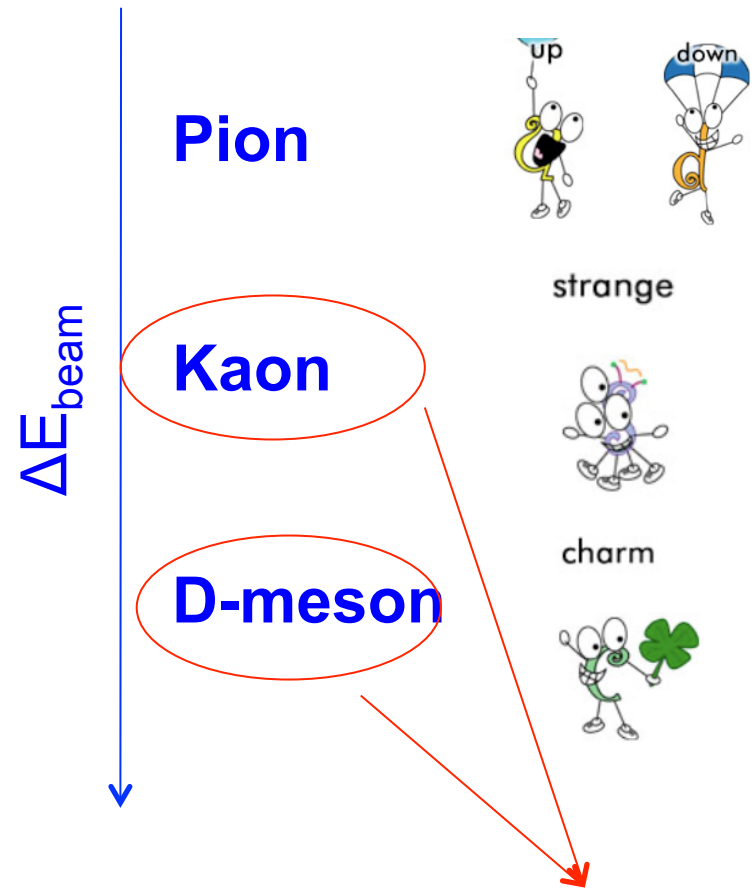
ICE, IEEC/CSIC, Barcelona  
FIAS, University of Frankfurt



# Understand matter under extreme conditions

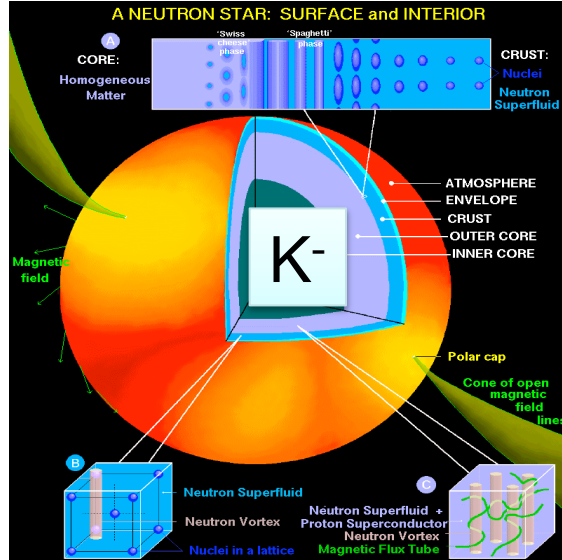
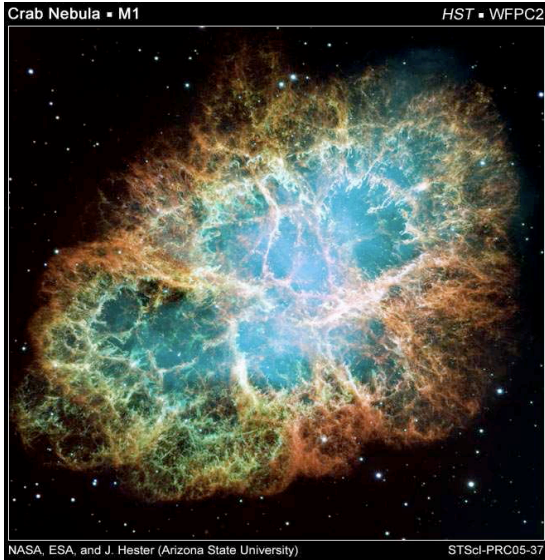


NuPECC report



in this talk !!

# Strange mesons in dense matter

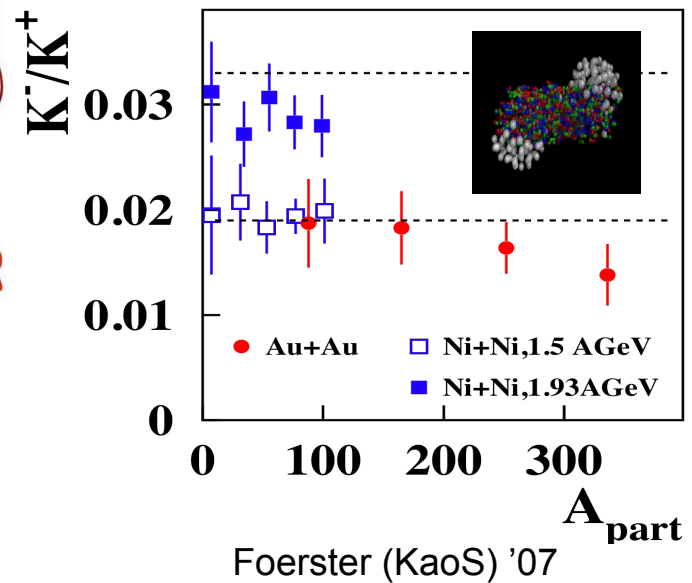
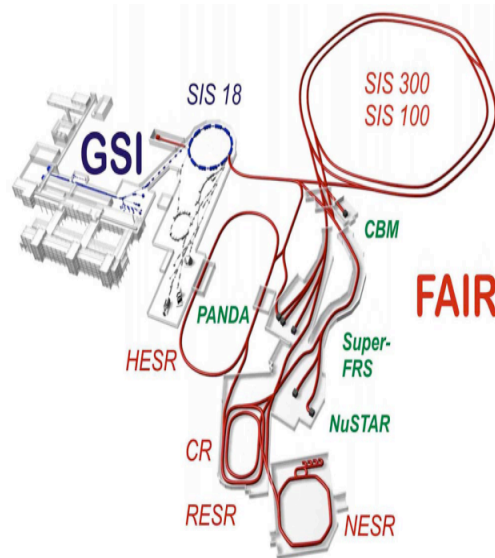


## Kaon condensation in neutron stars

Kaplan and Nelson '86 ...

## GSI/SIS data (KaoS/FOPI/HADES) and future FAIR

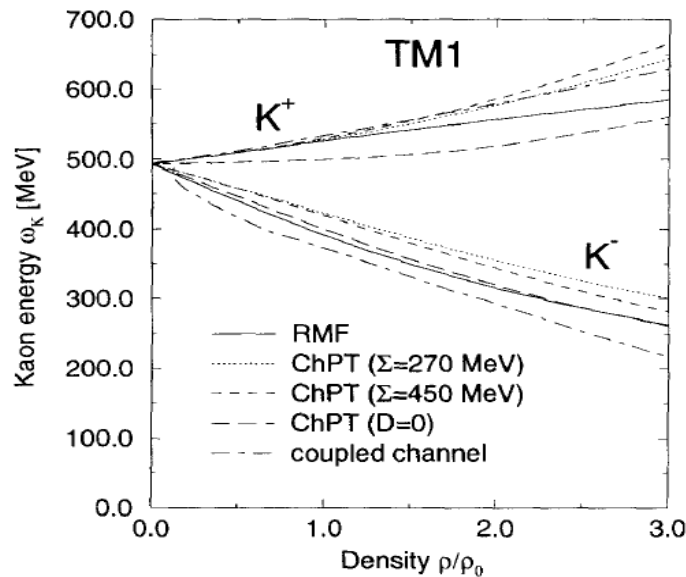
- Crochet et al (FOPI)'00
- Wisniewski et al (FOPI) '00
- Foerster et al (KaoS) '07
- Salabura '12 (HADES)
- CBM (FAIR) Physics Book '11..



# Strange pseudoscalar mesons: Kaons in matter

## Relativistic mean-field models

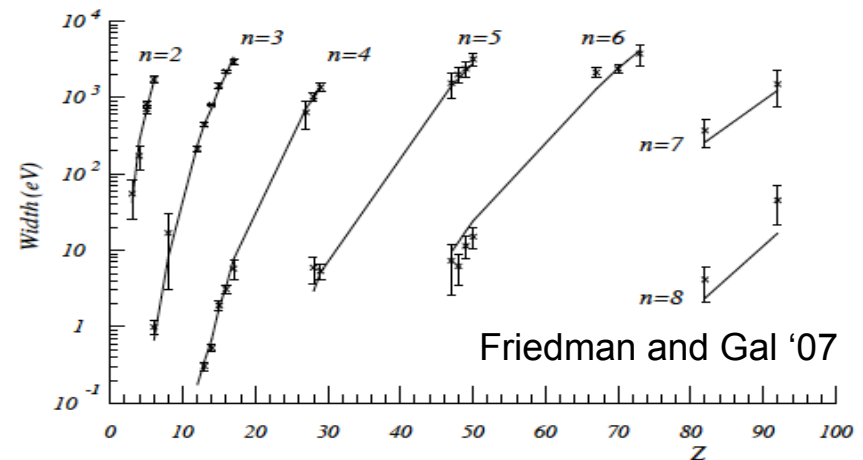
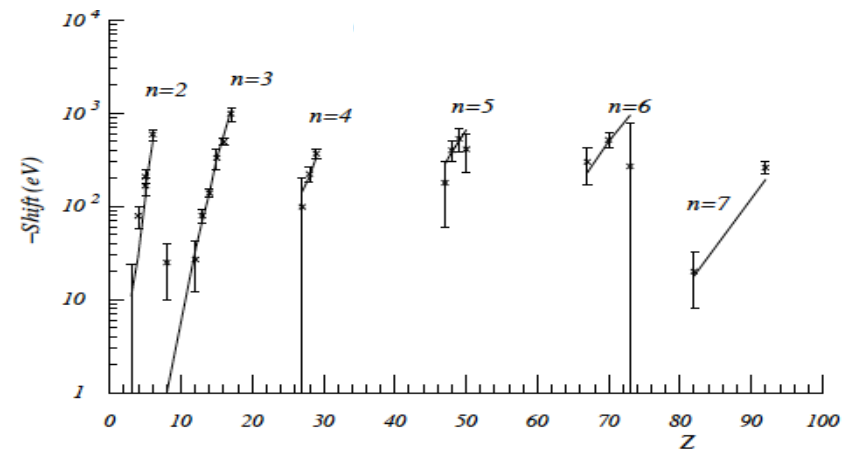
Early works on meson-exchange picture or the chiral approach for the  $\bar{K}N$  interaction on the mean-field level and fit the parameters to the  $\bar{K}N$  scattering length



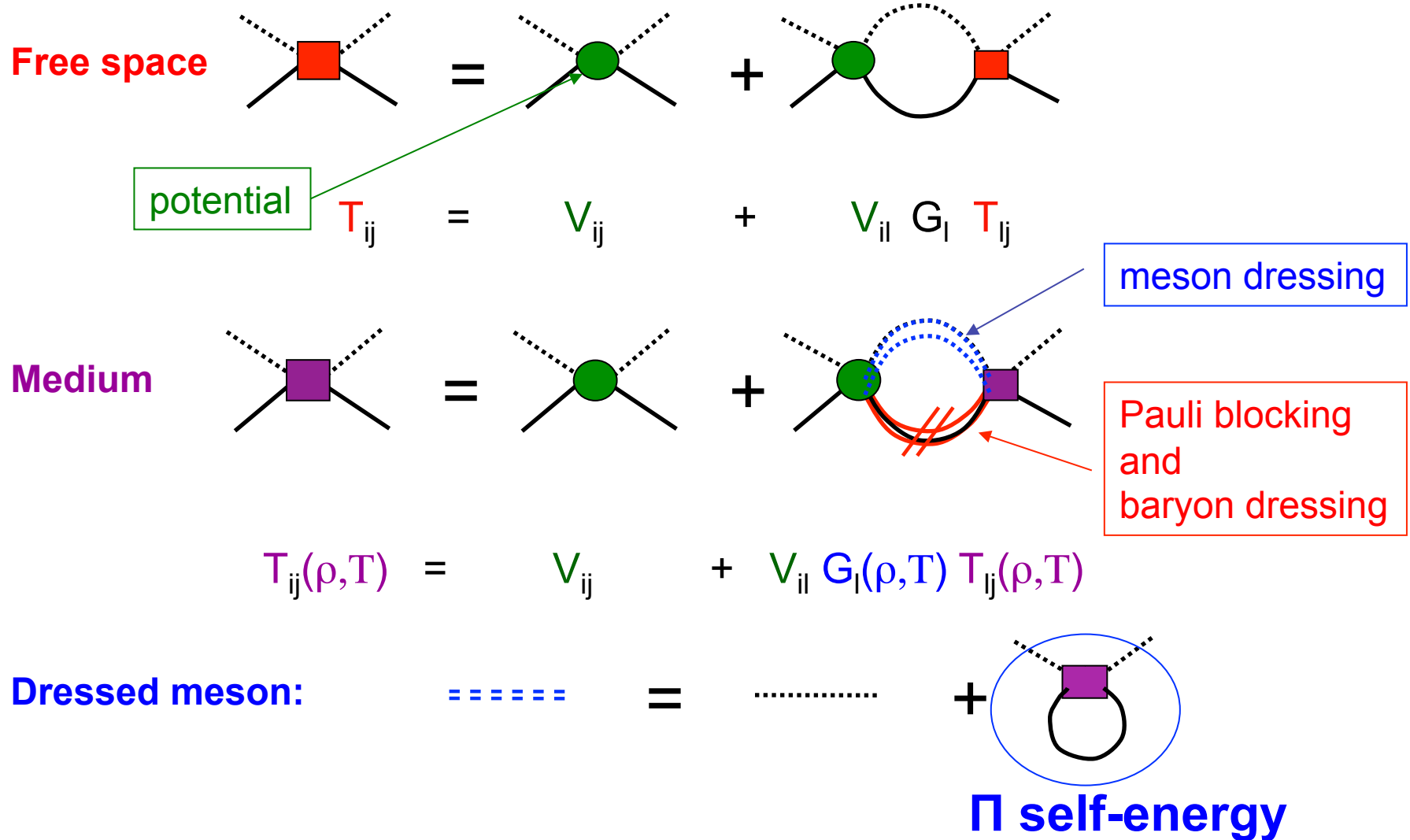
Schaffner-Bielich, Mishustin and Bondorf '97

## Phenomenological models

density dependent potentials fitted to kaonic atoms ( $\chi^2$  fit)

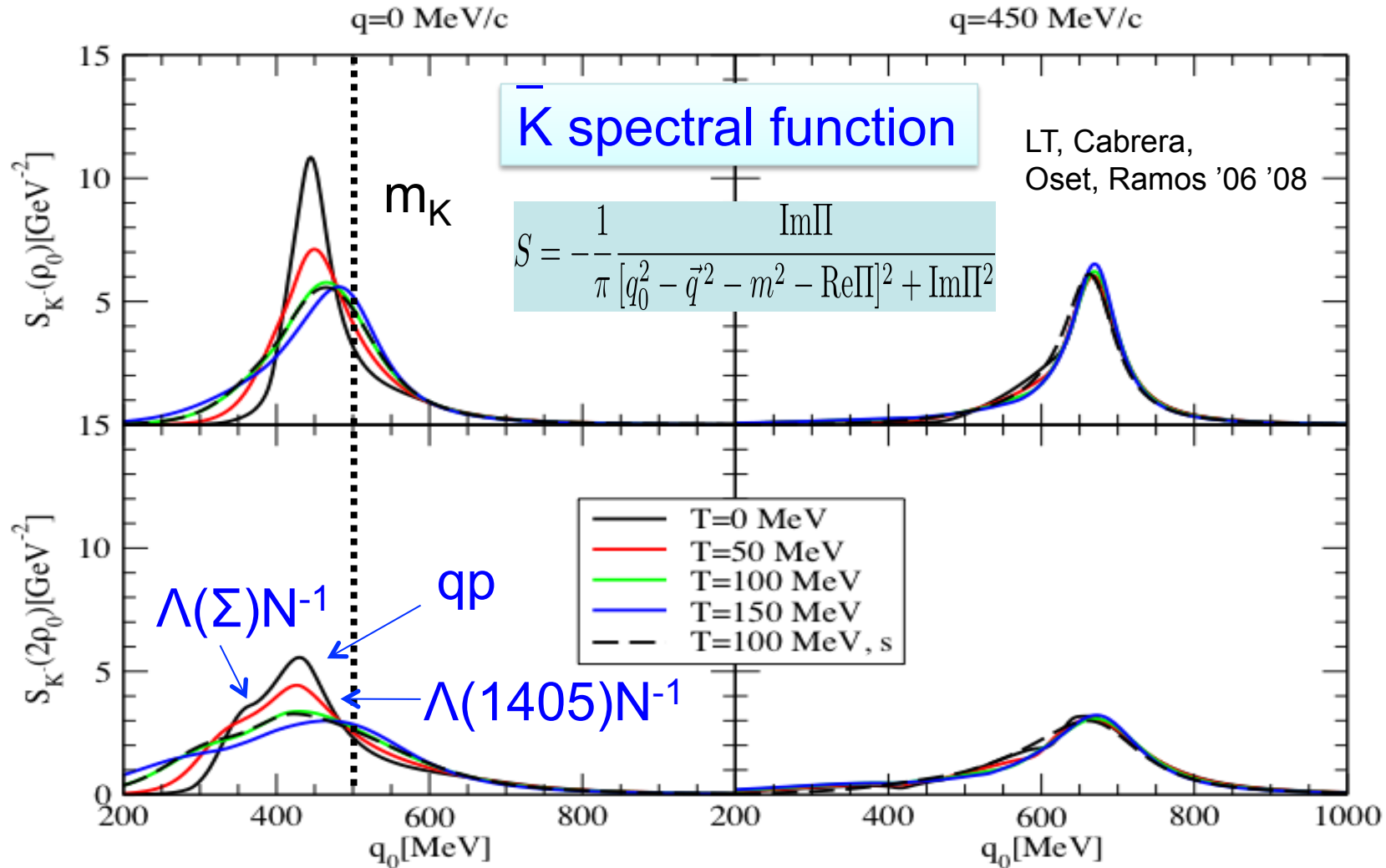


# Unitarized theory in matter: selfconsistent coupled-channel procedure



# Unitarized theory in matter: selfconsistent coupled-channel procedure

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

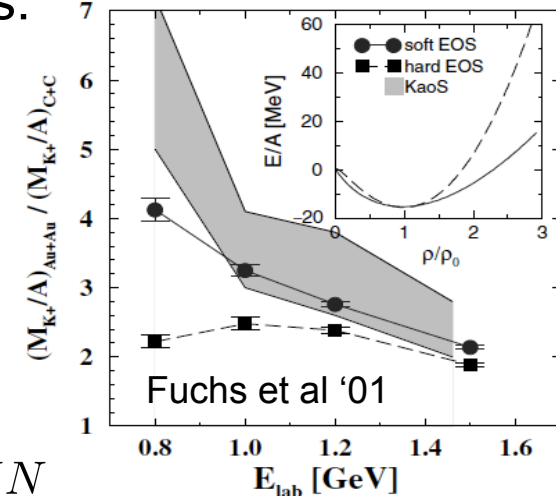


# Strangeness production at SIS/GSI (KaoS)

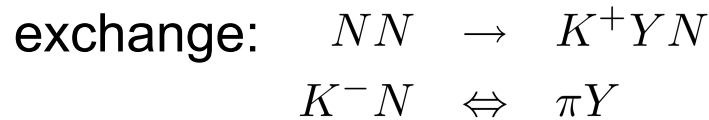
Foerster et al (KaoS) '07

From systematics of the experimental results and detailed comparison to transport model calculations:

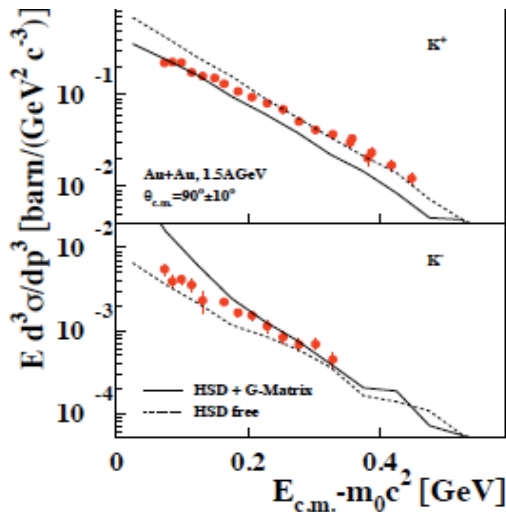
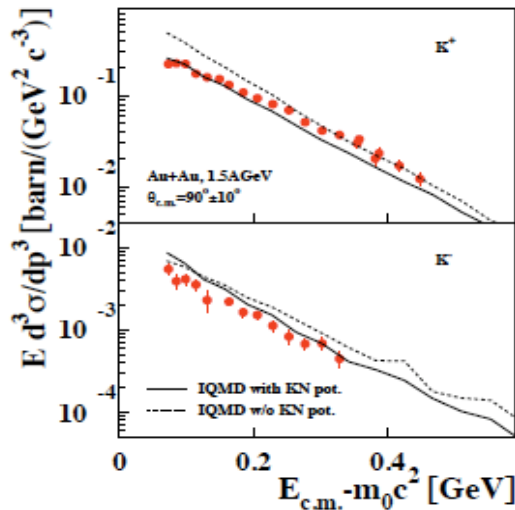
- $K^+$  probe a soft EoS



- $K^+$  and  $K^-$  yields are coupled by strangeness exchange:



- $K^+$  and  $K^-$  exhibit different freeze-out conditions
- No clear conclusion about medium modifications on  $K^-$



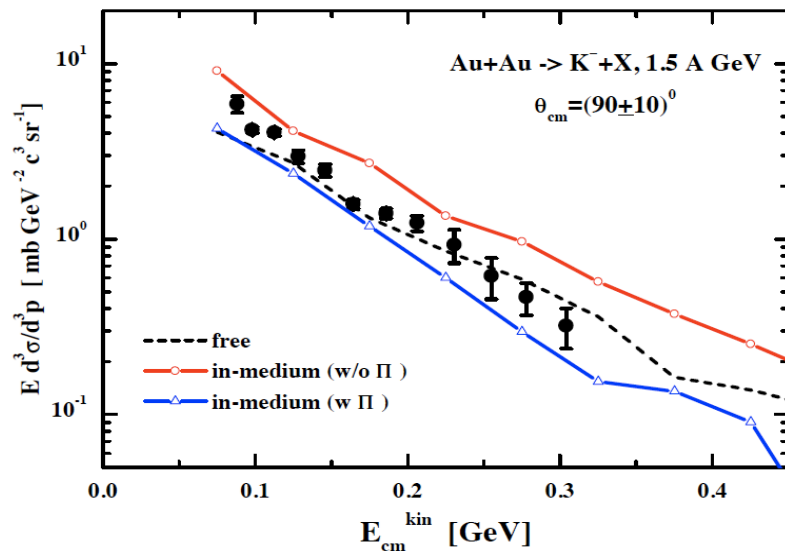
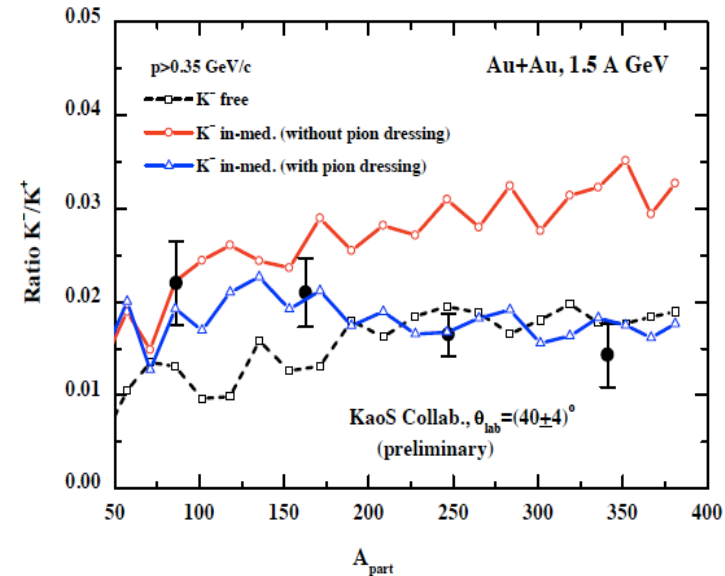
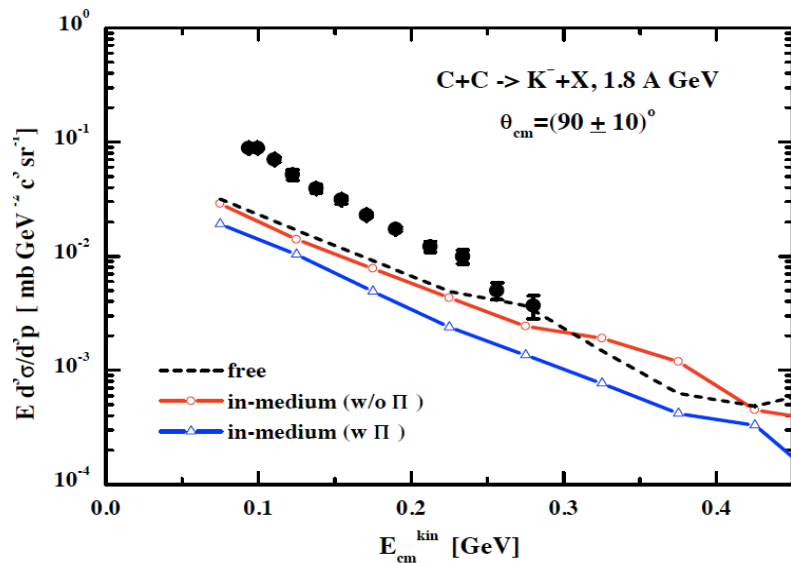
Recent report on strangeness production close to threshold in proton-nucleus and heavy-ion collisions

Hartnack, Oeschler, Leifels, Bratkovskaya, Aichelin '12

# Antikaon production in A+A at SIS within offshell model

BUU transport model with antikaons dressed following G-matrix approach with Juelich meson-exchange model

Cassing, LT, Bratkovskaya and Ramos '03



First attempts to describe all data simultaneously with full spectral features of strange mesons

**Working on constructing an off-shell transport model with a realistic many-body scheme for strange mesons in matter**

**(Aichelin, Bratkovskaya, Cabrera, LT)**



# Vector mesons with strangeness: $\bar{K}^*$ and $K^*$ in matter

- Vector mesons in nuclear matter are tied to fundamental aspects of QCD
- Lot of attention paid to  $\rho$ ,  $\omega$ ,  $\phi$  in dense matter

modification:  
width increased,  
mass shift  $\Delta m \approx 0$ ?

*$\rho$  meson: KEK325, CLAS-g7, CERES, NA60*

*$\omega$  meson: NA60, CBELSA/TAPS*

*$\phi$  meson: KEK325, LEPS*

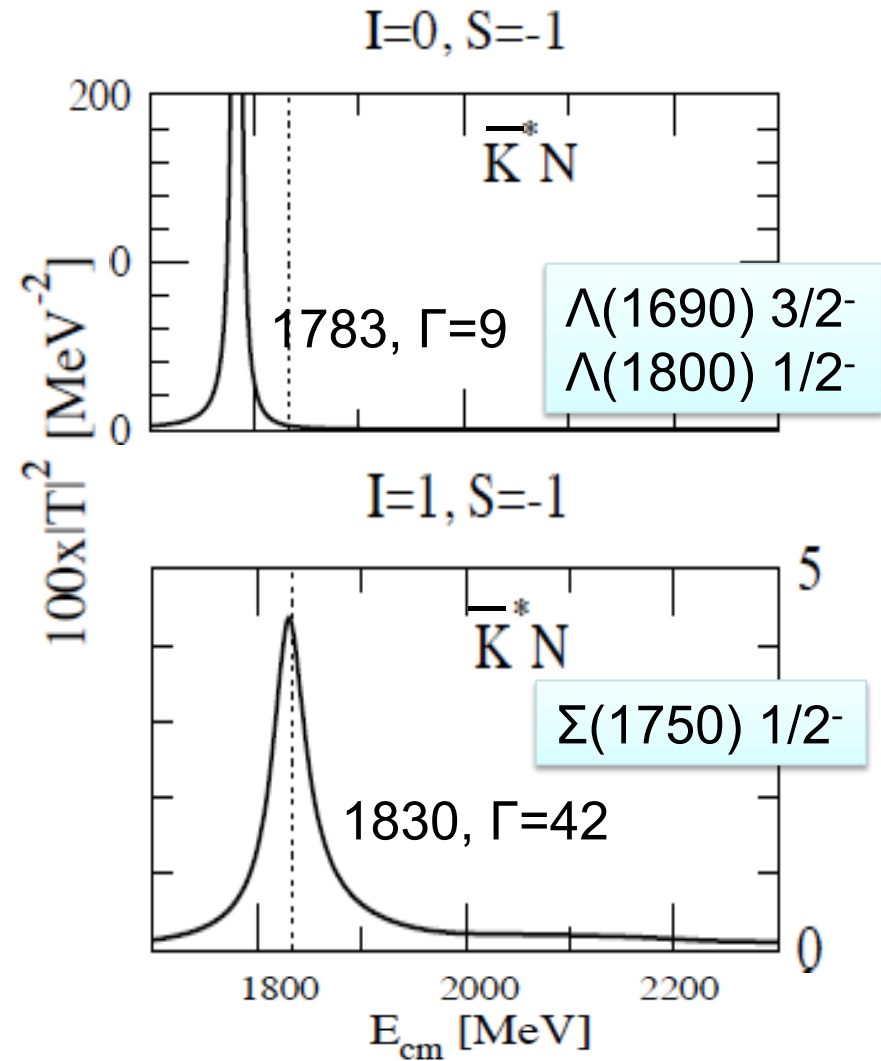
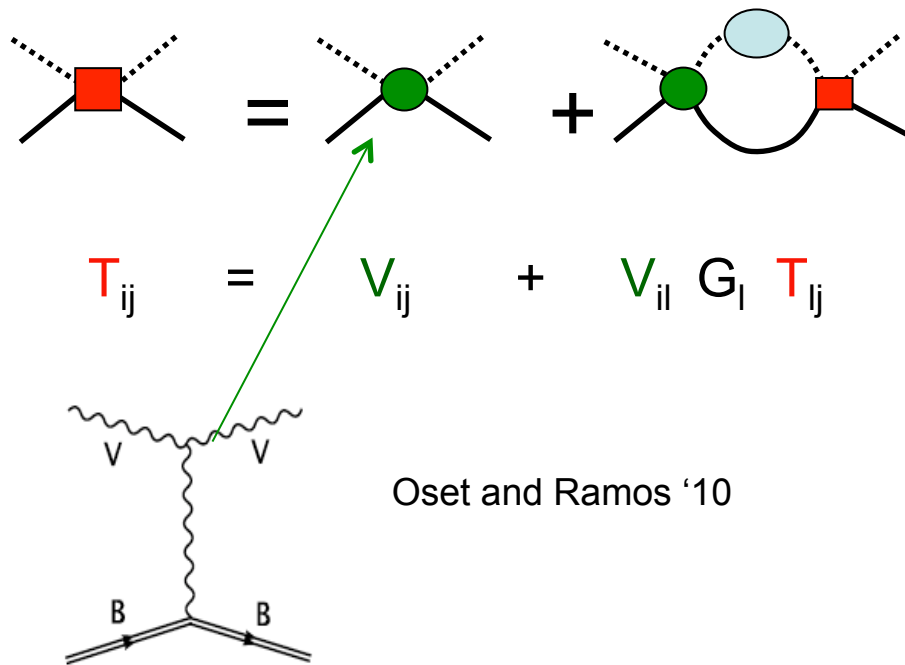
- What about strange vector mesons, such as  $\bar{K}^*/K^*$  ?

# Free space

within the local hidden gauge formalism

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

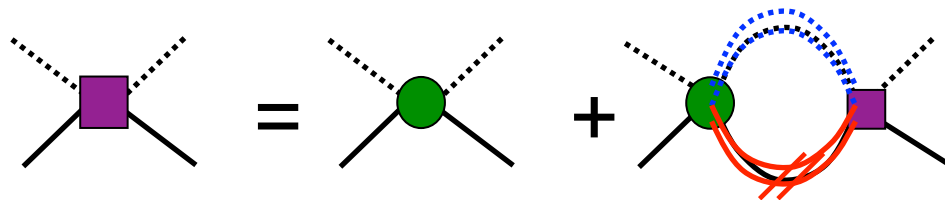
using a coupled-channel unitary  
approach with VB-VB interaction



Latest works incorporate also  
PB-VB couplings and  
beyond t-channel

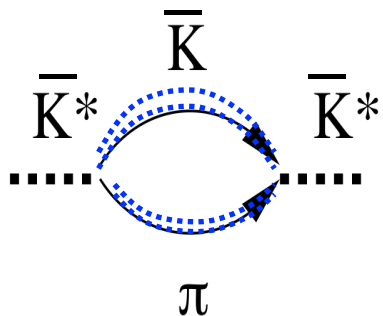
Khemchandani, Kaneko, Martinez Torres,  
Nagahiro, Hosaka, '11 '12

# Medium



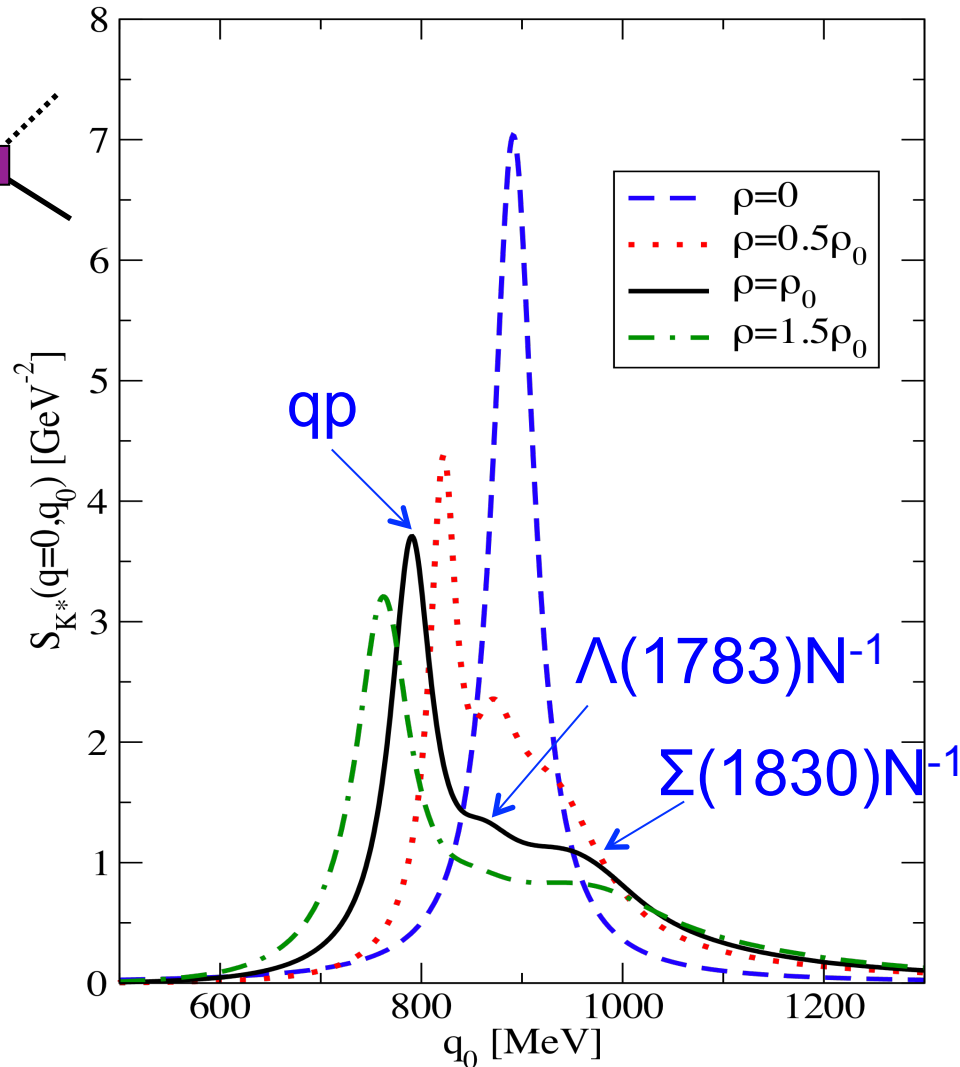
$$T_{ij} = V_{ij} + V_{il} G_l T_{lj}$$

and



$\bar{K}^*$  width becomes five times larger than in free space.

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

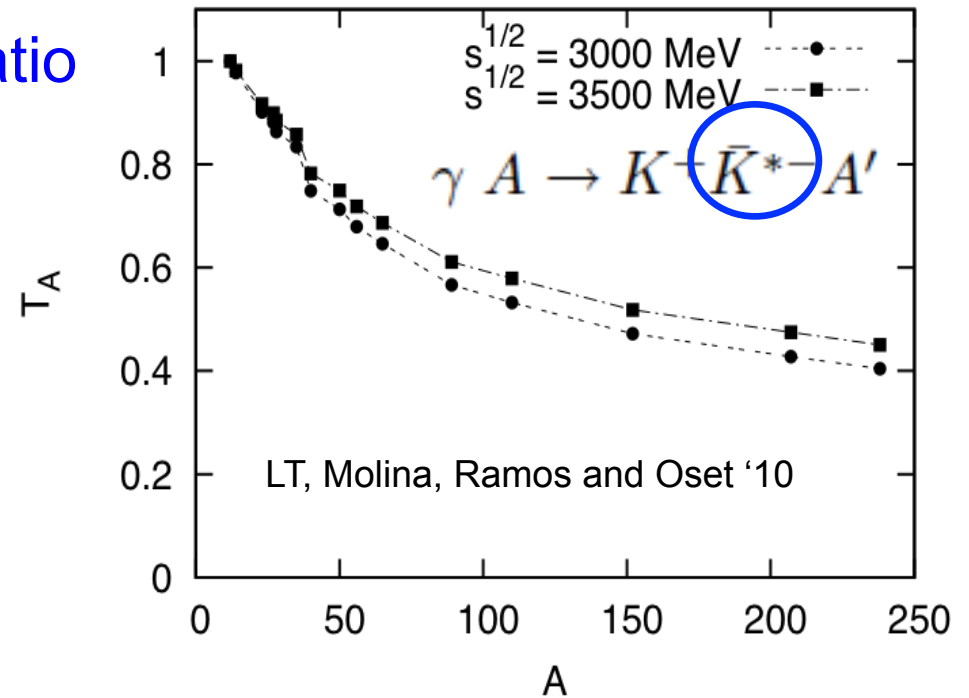


## Experiments: transparency ratio

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

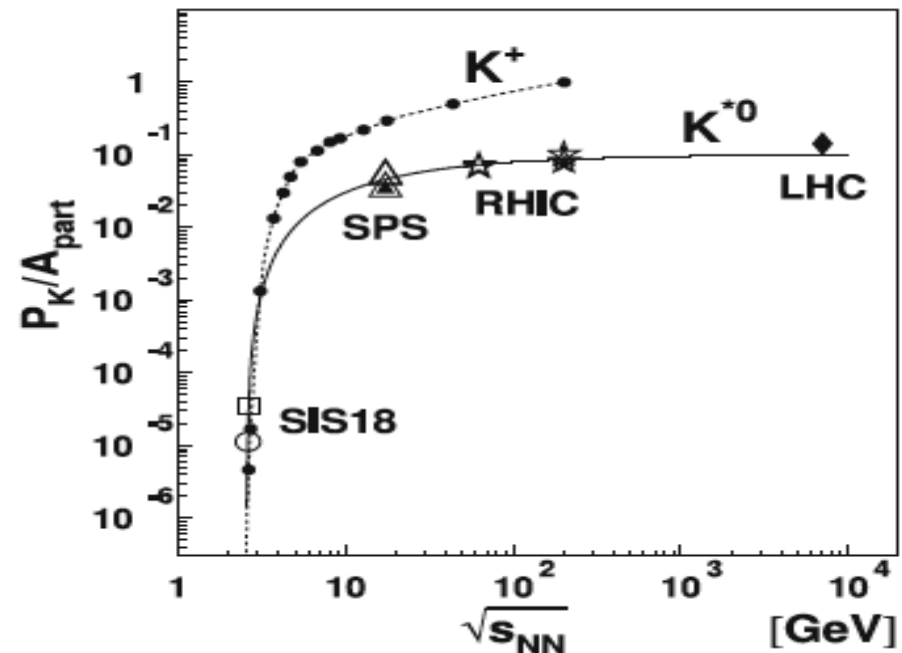
$$T_A = \frac{\tilde{T}_A}{\tilde{T}_{12C}}$$

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



## Working on the $K^{*(0,+)}$ properties in the nuclear medium at HADES

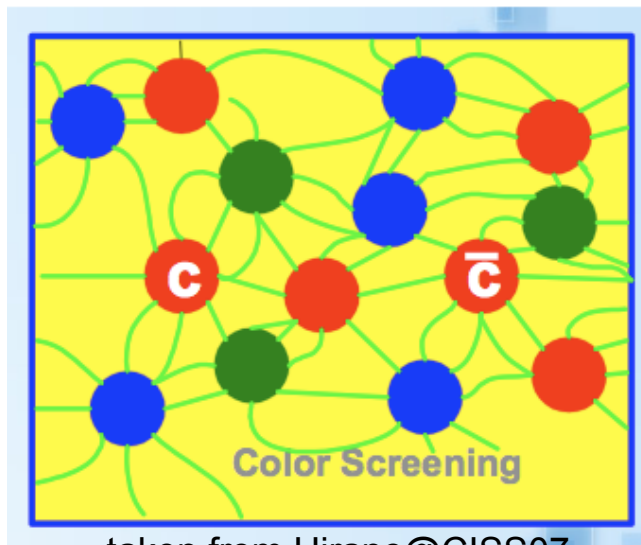
Recent results on deep subthreshold  $K^*(892)$  production in Ar+KCl at 1.76 AGeV  
 Agakishiev et al (HADES) '13



# In-medium properties of charm in the laboratory

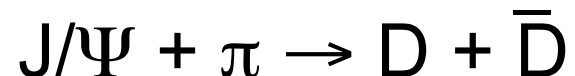
## J/ $\Psi$ suppression

Gonin et al (NA50) '96, Matsui and Satz '86



taken from Hirano@CISS07

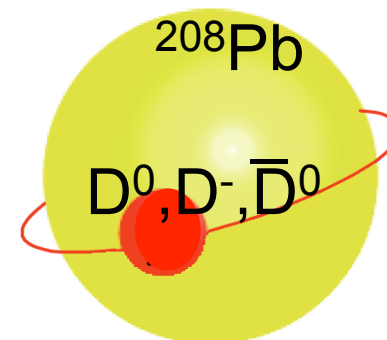
but also comover scattering



Capella, Ferreiro, Vogt, Wang, Bratkovskaya, Cassing, Andronic..

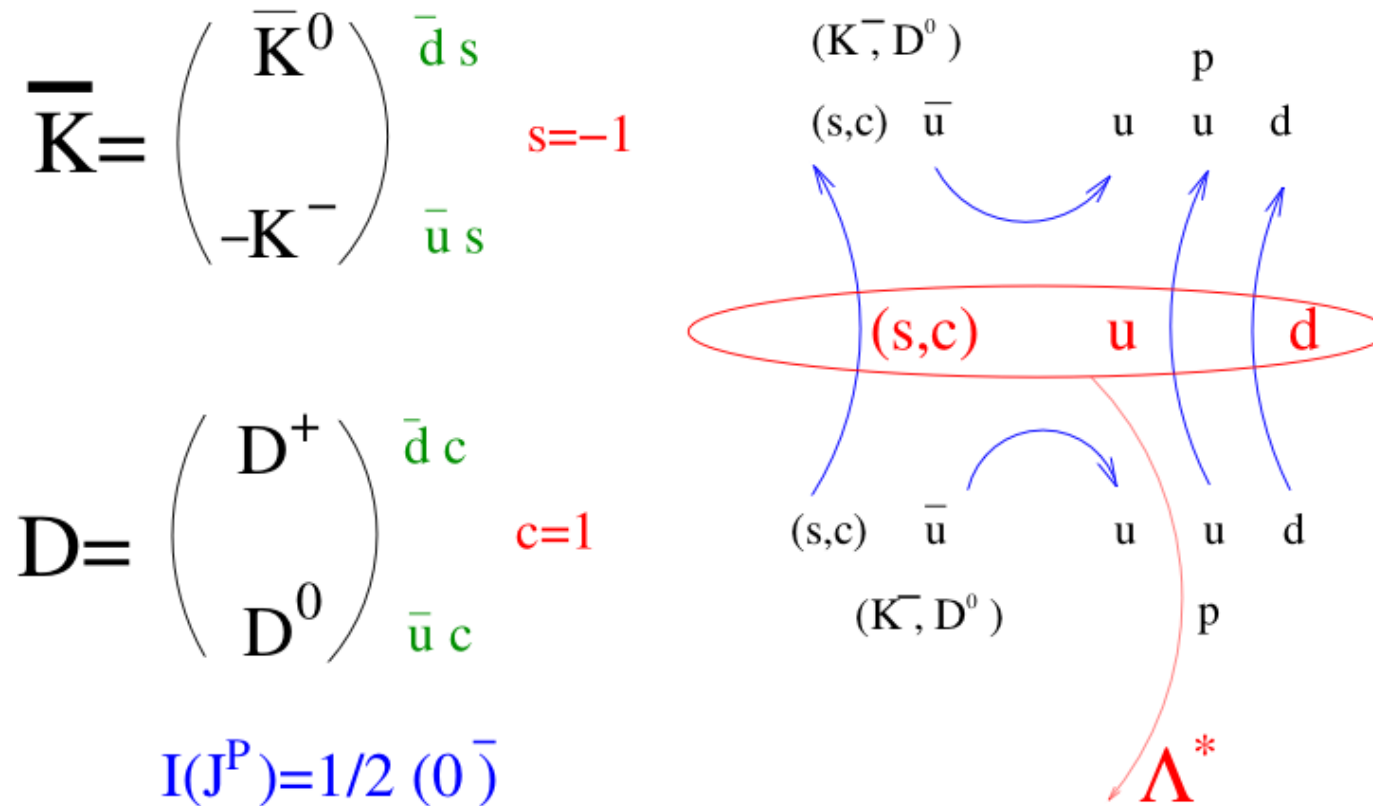
## D-mesic nuclei

Tsushima et al '99,  
Garcia-Recio et al '10  
Garcia-Recio et al '12  
Yasui et al '12..



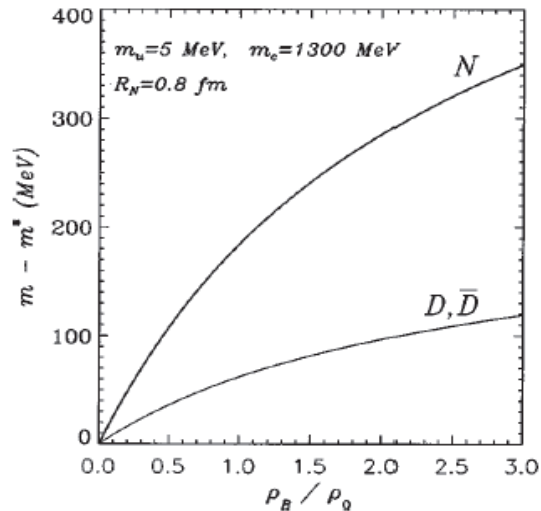
# Can we learn something from the strange sector?

$\bar{K}N$  and  $DN$  interactions show similarities. In the charm sector we also find a subthreshold  $I=0$  resonance, the  $\Lambda_c(2595)$  ( $udc$ ) with a strong resemblance to the  $\Lambda(1405)$  ( $uds$ ).



## QMC model

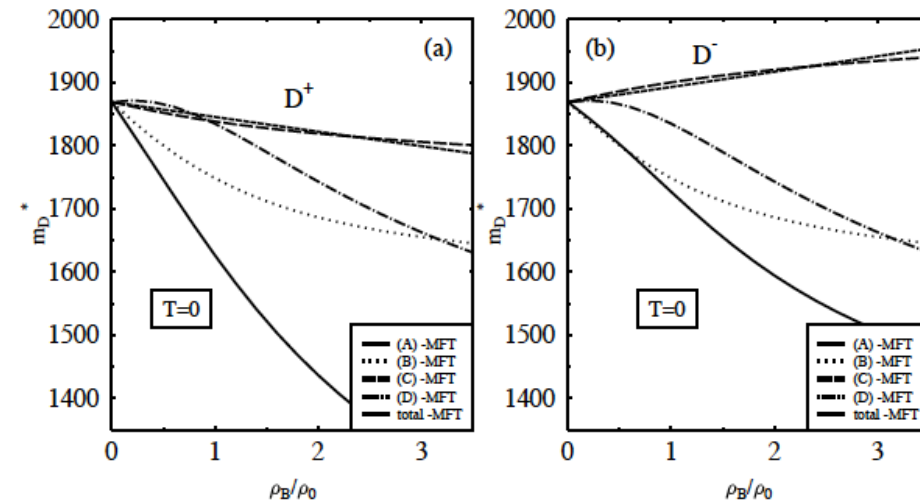
exchange of  $\omega$ ,  $\rho$ ,  $\sigma$  mesons among quarks in a meson/baryon bag



Tsushima,  
Thomas,  
Sibirtsev,  
Fountoura..

## MF/RHF model

Mishra, Kumar,...

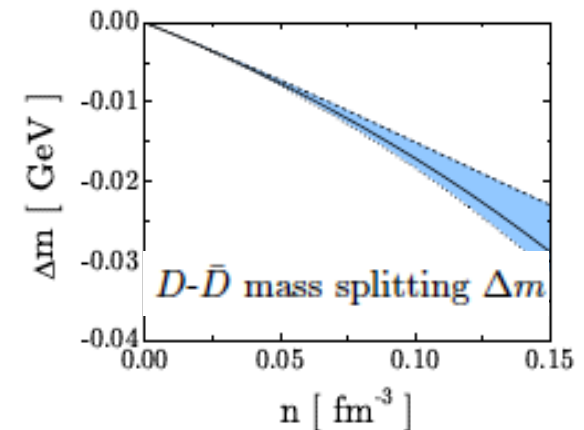


Effective lagrangian approach generalized to include charmed mesons in the mean field or relativistic Hartree-Fock approach

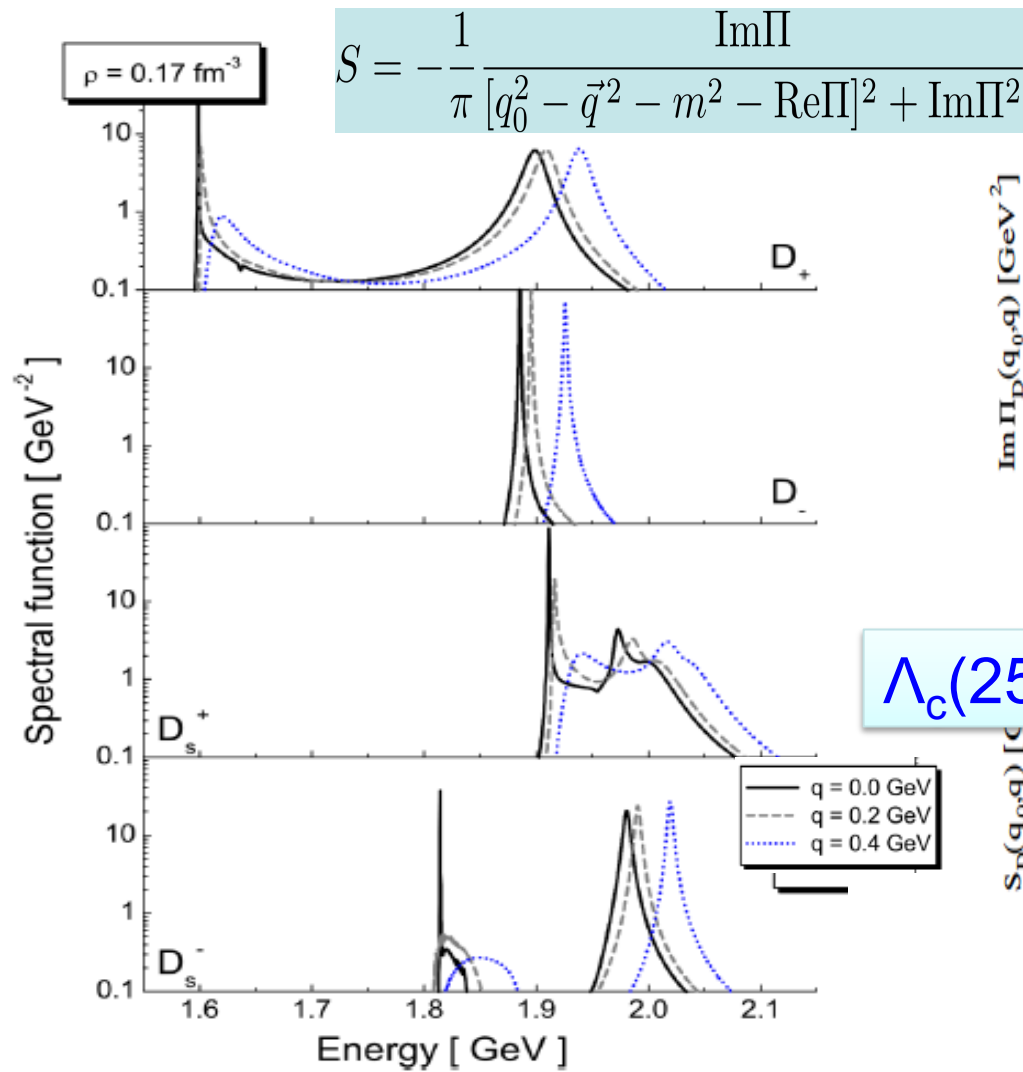
## QCD sum-rule

Hayashigaki,  
Weise, Hilger,  
Kaempfer, Leupold,  
Thomas,...

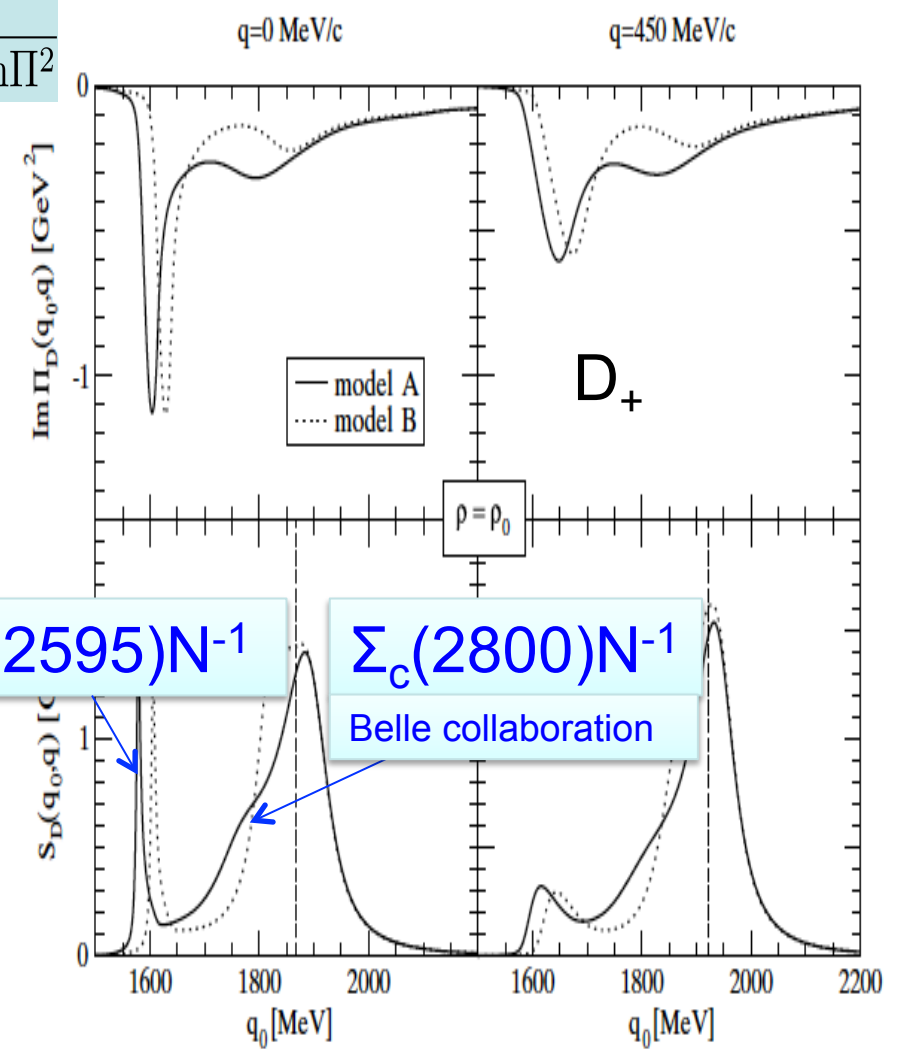
obtain the in-medium current-current correlation function for meson by applying operator product expansion and relate it to the spectral density



# Unitarized theory in matter: selfconsistent coupled-channel procedure (bare interaction saturated by t-channel vector-meson exchange)



Lutz, Korpa, Hofmann..



Ramos, Mizutani, Jimenez-Tejero, Vidana, LT,..

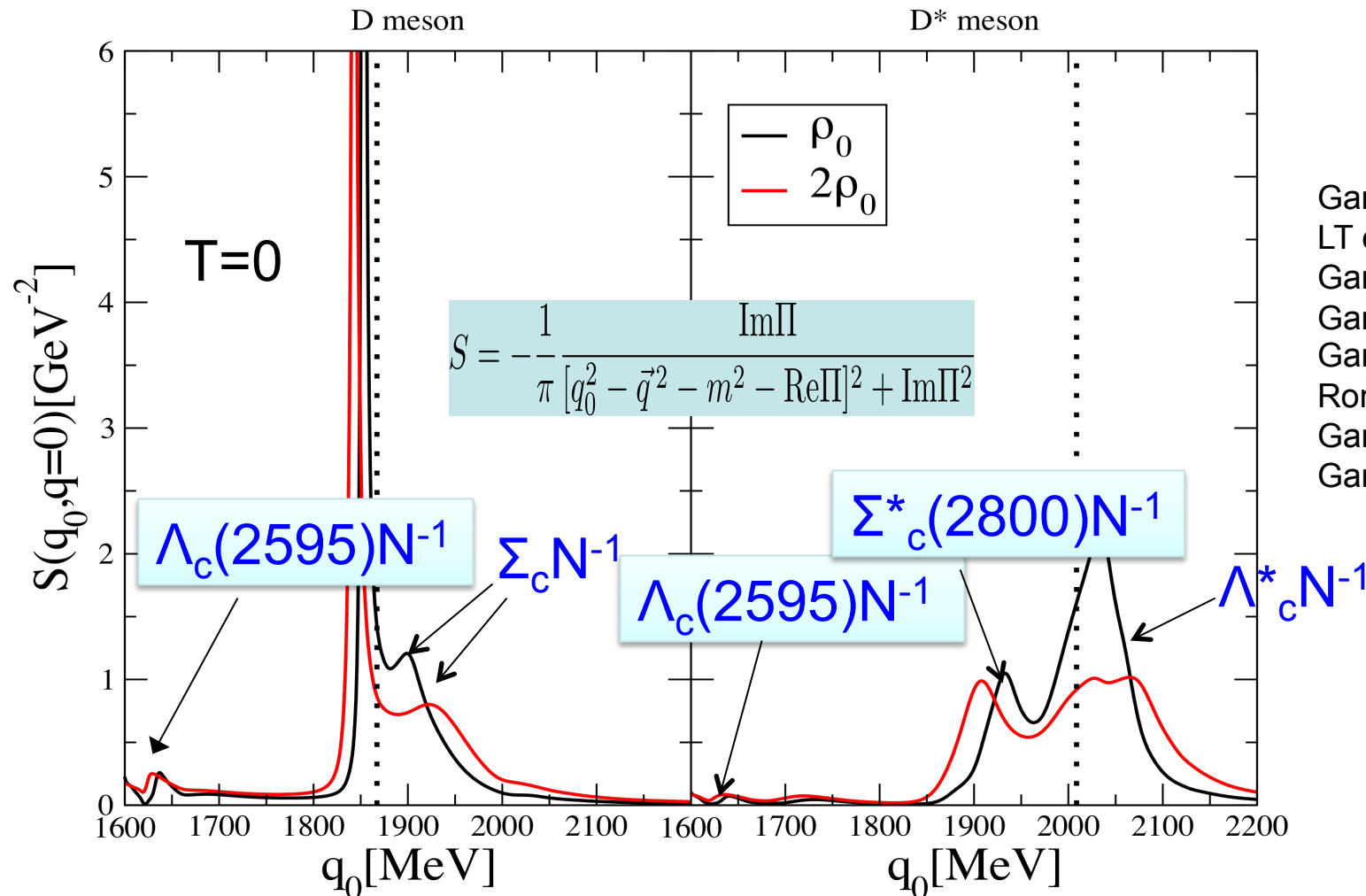


# Incorporate Heavy Quark Spin Symmetry

HQSS\*: spin interactions vanish for infinitely massive quarks

To construct a model for four flavors for **pseudoscalar and vector mesons as well as  $1/2^+$  and  $3/2^+$  baryons** that incorporates HQSS in the charm sector

\*Isgur, Wise, Manohar, Neubert

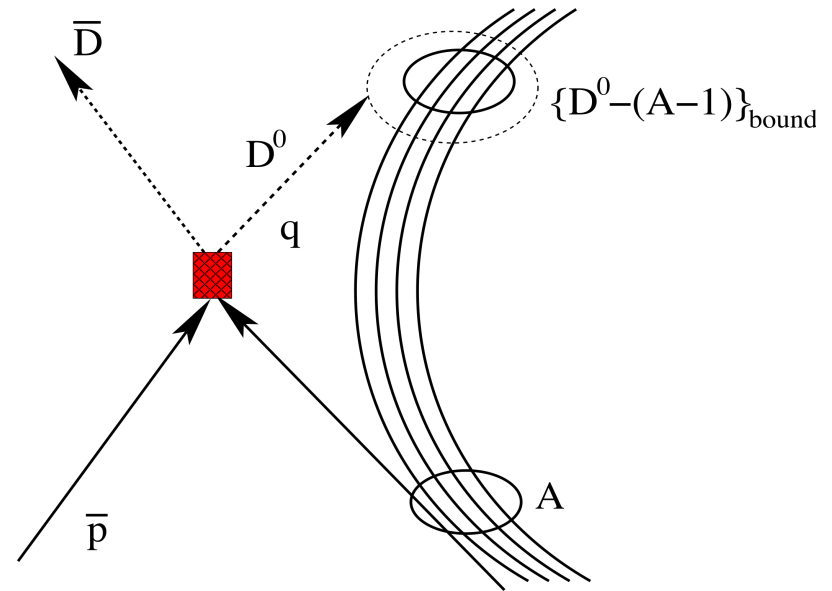
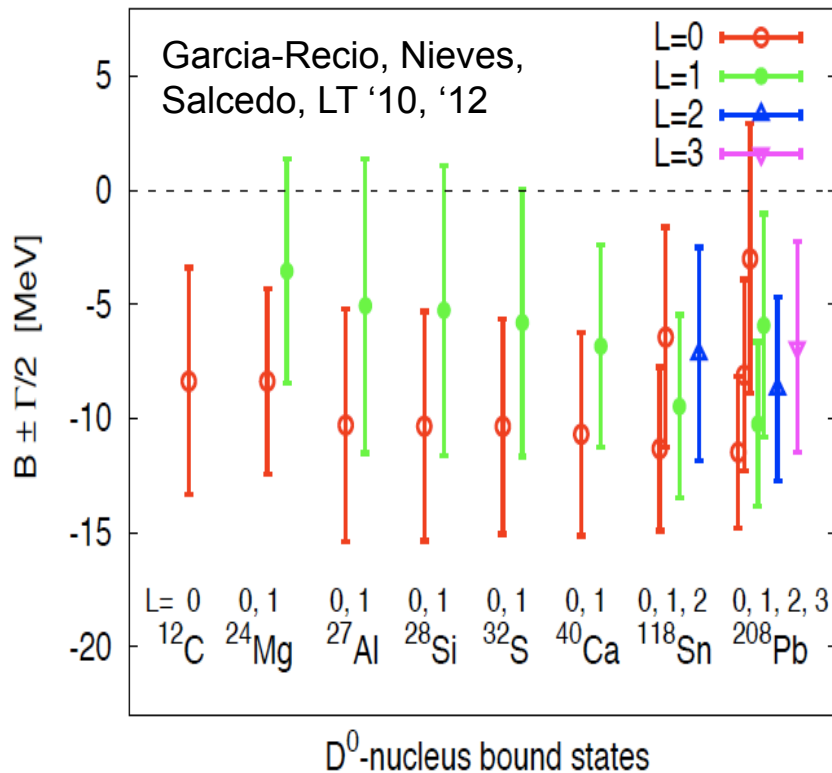


Garcia-Recio et al '09  
 LT et al. '10;  
 Gamermann et al. '10  
 Garcia-Recio et al. '10  
 Garcia-Recio et al.'12  
 Romanets et al. '12  
 Garcia-Recio et al. '13  
 Garcia-Recio et al. '13

# D mesic nuclei

Initially predicted in  $^{208}\text{Pb}$  within QMC model Tsushima et al. '99

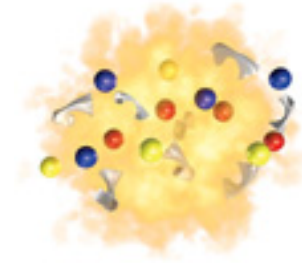
Within the self-consistent coupled-channel approach that incorporates HQSS



PANDA @FAIR?

Working on analyzing hidden charm states, eg.  $J/\psi$ ,  $\psi(3770)$ ,... in matter (at finite temperature) for PANDA/CBM @ FAIR. Signal for deconfinement?

# Present and Future



- it is an **exciting moment**
- moving from **strangeness** to **charm**
- a lot of **theoretical effort** is needed
- but in close **connection to experiments**