Charm mesons @ CBM

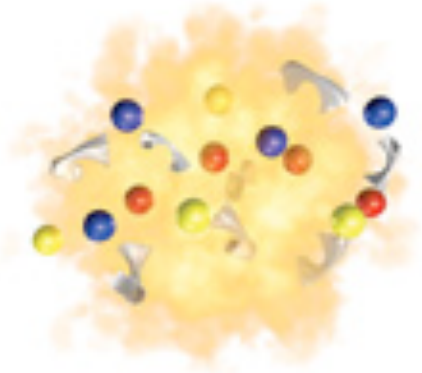
Laura Tolos

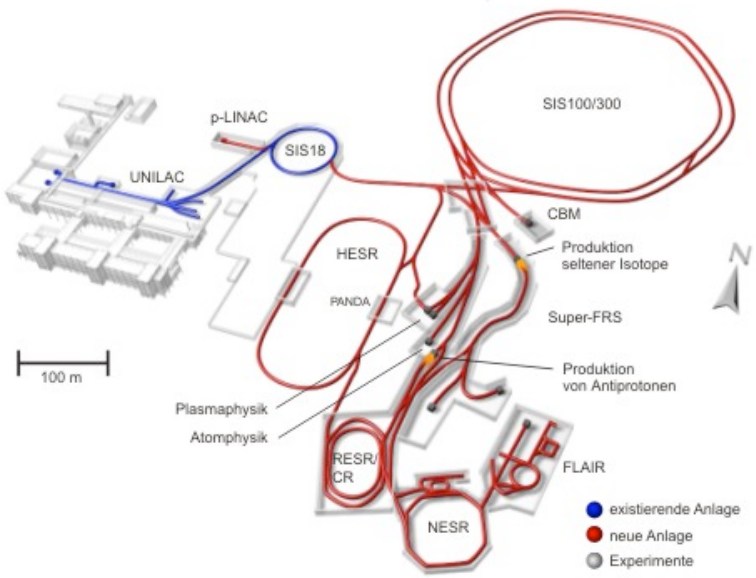
KVI

Excited QCD'09, Zakopane, February 8-14, 2009

Some challenges in hadron physics...

- Strong force and confinement
- Restoration of chiral symmetry
- Origin of hadron masses
- Exotic matter
- Phases of matter at high T and ρ



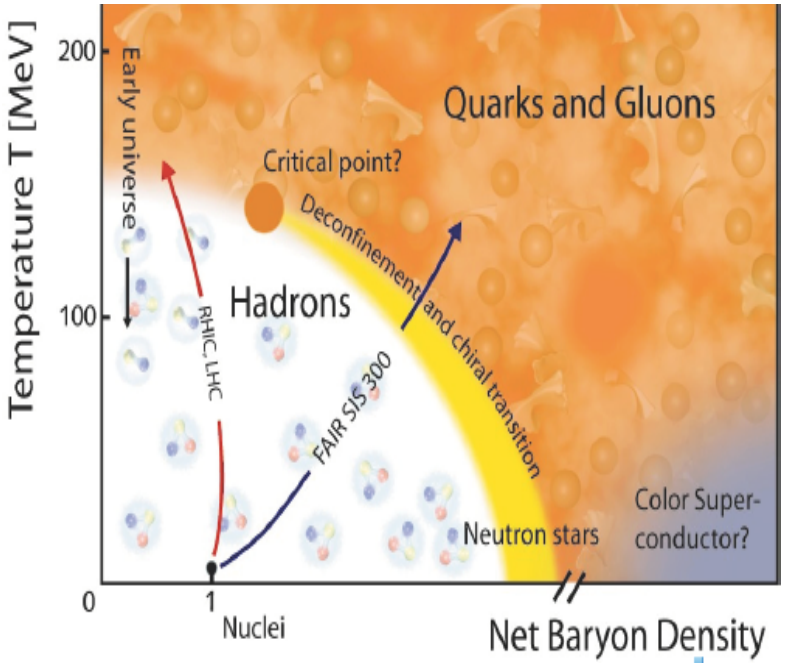


FAIR

will address the origin of those phenomena

FAIR moves from the light to the heavy sector

The **CBM** experiment will investigate highly compressed nuclear matter in nuclear collisions with a beam energy range between 10 and 40 GeV/u



In particular, **CBM** will extend the GSI program for in-medium modification of hadrons in the light quark sector, and provide first insight into charm-nucleus interaction

Charm in nuclei

To study the properties of open and hidden charm embedded in a nuclear many-body system

Some topics related to open charm (D,D_s,D^*)…

- in-medium DN interaction at finite temperature
- charm and hidden charm scalar resonances in dense matter
- coupled DN and D* N interaction using heavy-quark symmetry
- in-medium D_sN interaction at finite temperature
- influence of D_sN system on DN and D*N interaction

In-medium DN interaction at finite temperature

LT, Ramos, Mizutani, PRC 77 (2008) 015207

Experimental scenarios for open charm..

- J/Ψ suppression

  NA50 Collaboration, Gonin et al., NPA 610 (1996) 404c

  initially predicted by color screening in QGP

  Matsui and Satz, PLB 178 (1986) 416

  but also due to comover scattering

  several authors: Capella, Vogt, Wang, Bratkovskaya, Cassing, Linnyk, Andronic..

  $$J/\Psi + \pi,\ \rho \rightarrow D + \bar{D}$$

- Open-charm enhancement

  NA50 Collaboration, Abreu et al., EPJC 14 (2000) 443

  but debate because of dimuon production by NA60

  NA60 Collaboration, Shahovan, JPG 34 (2007) S1029

- D-mesic nuclei

  predicted by QMC model for D^-, $\bar{D}^0$ & D^0 in ^{208}Pb

  Tsushima et al. PRC 59 (1999) 2824

From the theoretical side..

- Predictions for the ***mass shift*** in mean-field models:

  $U_{D+}(\rho_0) \sim -60$ to -200 MeV and $U_{D-}(\rho_0) \sim 20$ to -140 MeV

  - QMC model *Tsushima et al., PRC 59 (1999) 2824, Sibirtsev et al., EPJA 6 (1999) 351*
  - QCD sum-rule model *Hayashigaki, PLB 487 (2000) 96; Weise, Hirschegg'01, 249*
    Hilger, Thomas and Kaempfer, arXiv:0809.4996
  - Chiral model *Mishra et al., PRC 69 (2004) 015202; Mishra and Mazumdar, arXiv:0810.3067*

- ***Spectral function*** in self-consistent coupled-channel approach:
  - D meson self-energy with a SU(3) potential for u-, d- and c- quarks as bare interaction *LT, Schaffner-Bielich and Mishra, PRC 70 (2004) 025203;*
    LT, Schaffner-Bielich and Stoecker, PLB 635 (2006) 85 (finite T!)
  - D and $\bar{D}$ meson self-energy with a bare interaction saturated by a t-channel vector meson exchange between SU(4) multiplets
    Lutz and Korpa, PLB 633 (2006) 43
  - D meson self-energy using modified t-->0 limit (WT) + scalar-isoscalar attractive term (Σ_{DN}) *Mizutani and Ramos, PRC 74 (2006) 065201*

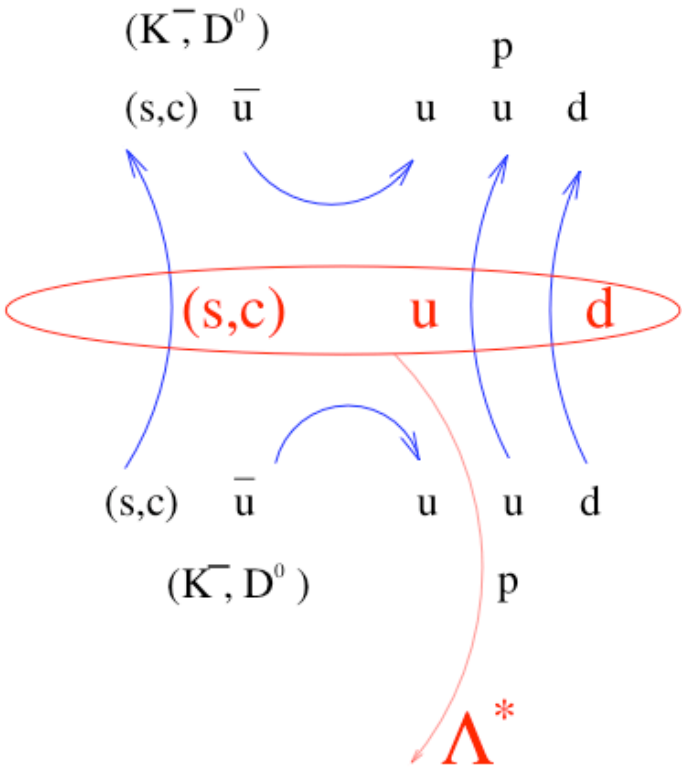
HERE: we extend the model to $\bar{D}$ mesons and implement finite T effects

DN interaction: similar features as KN interaction. In the charm sector we also find a subthreshold I=0 resonance, the $\Lambda_c(2593)$ (udc) with a strong resemblance to the $\Lambda(1405)$ (uds).

$$\overline{K}=\begin{pmatrix}\bar{K}^0 & \bar{d}\,s\\ -K^- & \bar{u}\,s\end{pmatrix} \qquad s=-1$$

$$D=\begin{pmatrix}D^+ & \bar{d}\,c\\ D^0 & \bar{u}\,c\end{pmatrix} \qquad c=1$$

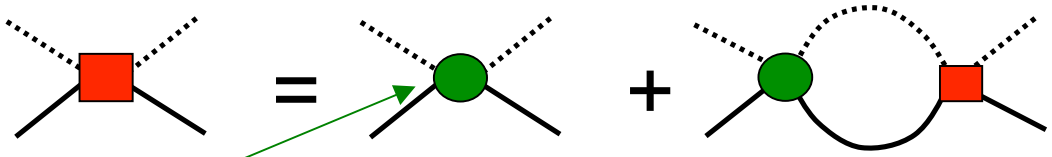
$$I(J^P)=1/2\ (0^-)$$



May the $\Lambda_c(2593)$ be also generated dynamically?
To which extend do the similarities hold?

DN interaction in hot nuclear matter:
selfconsistent coupled-channel procedure

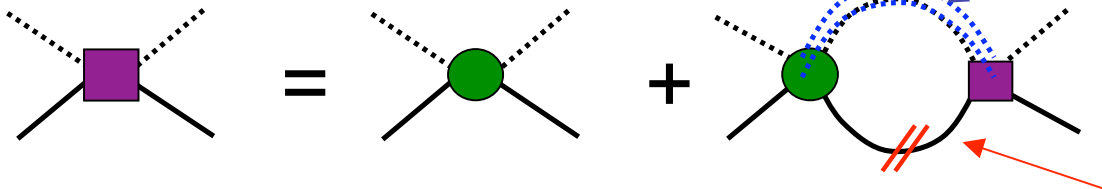
Free space



potential using broken SU(4) symmetry

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

Medium

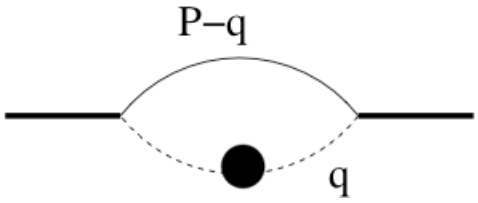


$$T_{ij}(\rho,T) = V_i + V_{il}\ G_l(\rho,T)\ T_{lj}(\rho,T)$$

Dressed D meson:

Loop function G depends on ρ and T

adjusted to reproduce $\Lambda_c(2593)$



$$G(P_0,\vec{P},T) = \int^{\Lambda} \frac{d^3q}{(2\pi)^3}\frac{M_N}{E_N(\vec{P}-\vec{q},T)}\times$$

$$\left[\int_0^\infty d\omega S(\omega,\vec{q},T)\frac{1-n(\vec{P}-\vec{q},T)}{P_0-\omega-E_N(\vec{P}-\vec{q},T)+i\varepsilon}+\int_0^\infty d\omega S(\omega,\vec{q},T)\frac{n(\vec{P}-\vec{q},T)}{P_0+\omega-E_N(\vec{P}-\vec{q},T)-i\varepsilon}\right]$$

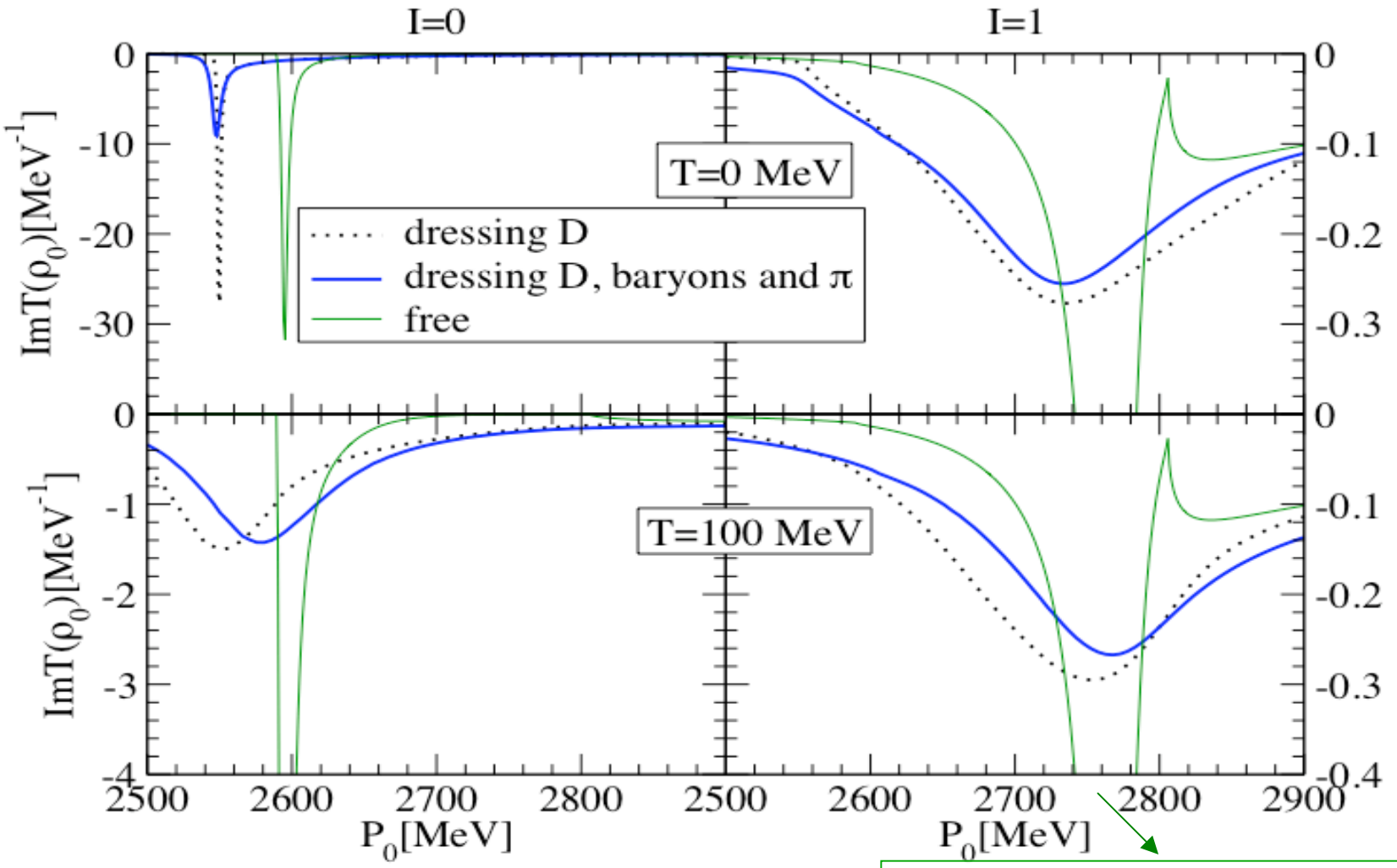
Spectral density

$$S(q_0,\vec{q},T) = -\frac{1}{\pi}\mathrm{Im}\,D(q_0,\vec{q},T) = -\frac{1}{\pi}\frac{\mathrm{Im}\,\Pi(q_0,\vec{q},T)}{\mid q_0^2-\vec{q}^{\,2}-m^2-\Pi(q_0,\vec{q},T)\mid^2}$$

Self-energy

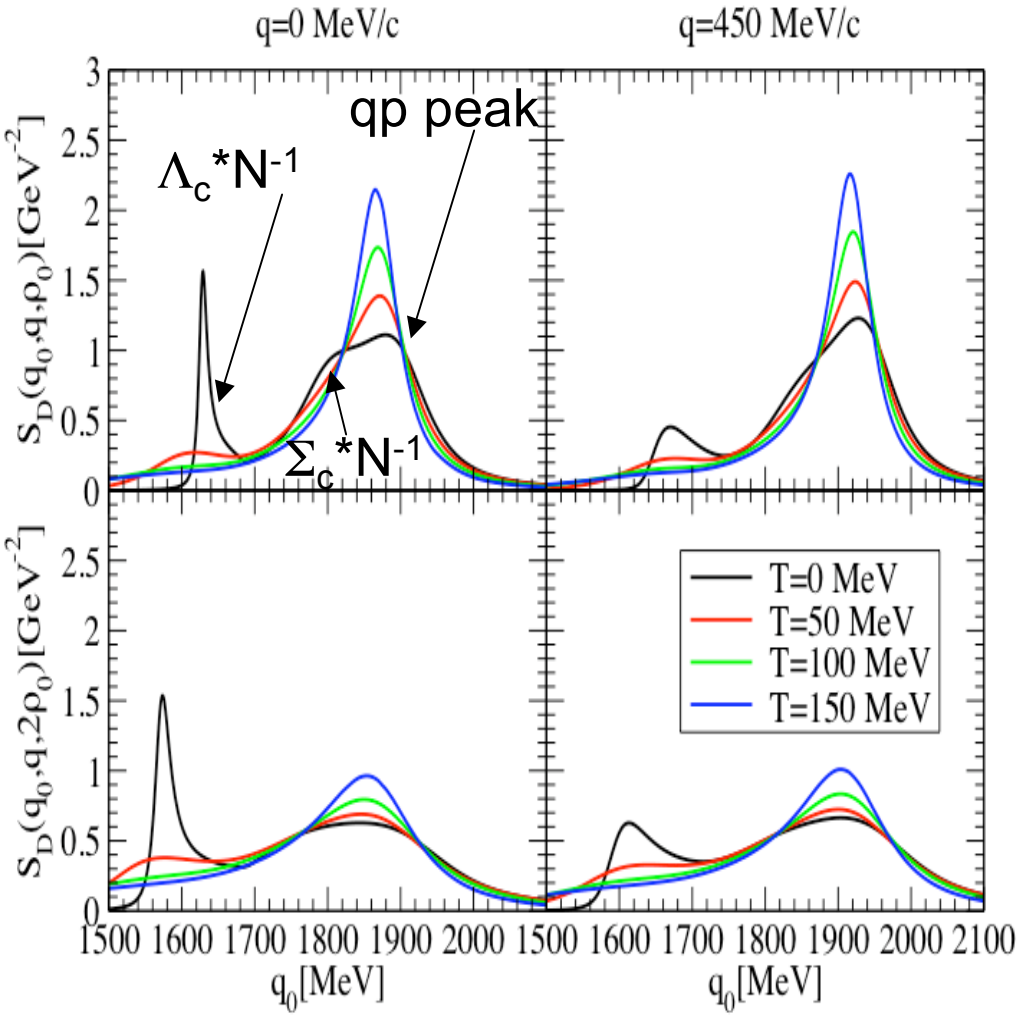
$$\Pi(q_0,\vec{q},T) = \int \frac{d^3p}{(2\pi)^3}\,n(\vec{p},T)\times\left[T^{(I=0)}(P_0,\vec{P},T)+3T^{(I=1)}(P_0,\vec{P},T)\right]$$

The model generates the I=0 $\Lambda_c(2593)$ and another resonance in I=1 around the nominal $\Sigma_c(2800)$



R. Mizuk et al. [Belle Collaboration]
PRL 94 (2005) 122002:
$\Sigma_c(2800)$, Γ~60 MeV

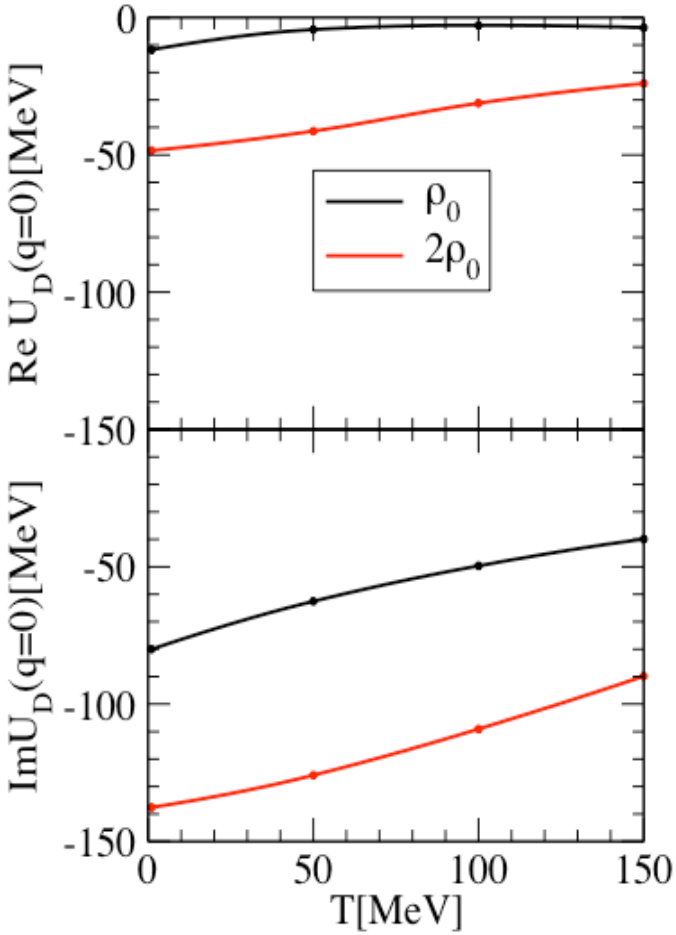
D meson



Similar trend to previous finite temperature results

LT, Schaffner-Bielich, Stoecker, PLB 635 (2006) 85

$$U_D = \frac{\Pi_D(E_{qp}(\vec{q}),\vec{q})}{2\sqrt{m_D^2+\vec{q}^{\,2}}}$$



D meson develops an important width

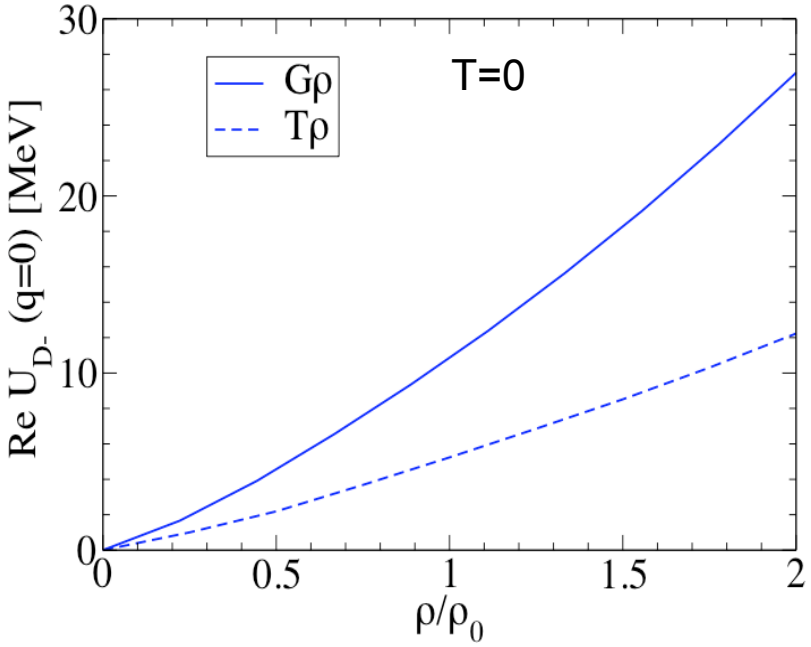
$$a_{\bar{D}N} = -\frac{1}{4\pi}\frac{M_{\bar{D}N}}{\sqrt{s}} T_{\bar{D}N\to\bar{D}N}$$

Table 1: $\bar{D}N$ scattering lengths (fm)

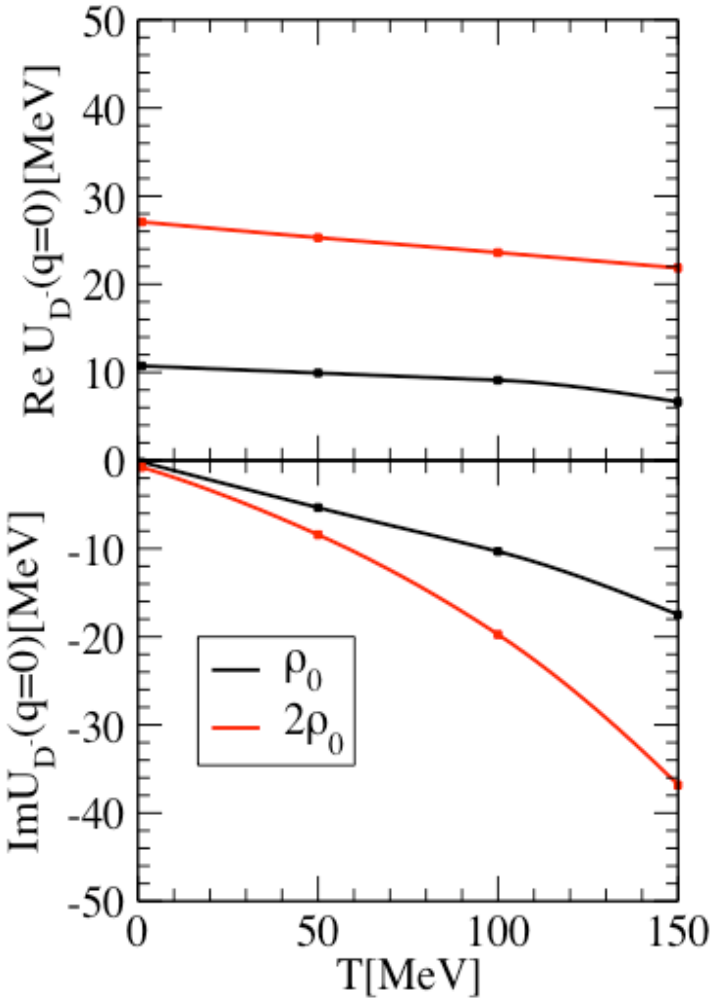
	WT+Σ	WT
$I=0$	0.607	0
(Born approx.)	0.262	0
$I=1$	-0.264	-0.289
(Born approx.)	-0.614	-0.876

close to

Lutz and Korpa, PLB 633 (2006) 43
Haidenbauer et al., EPJA 33 (2007) 107



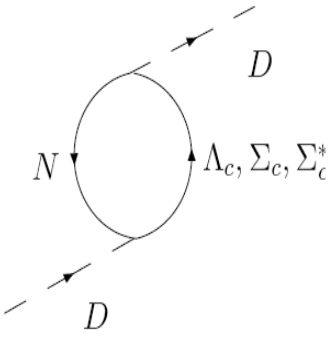
D̄ meson

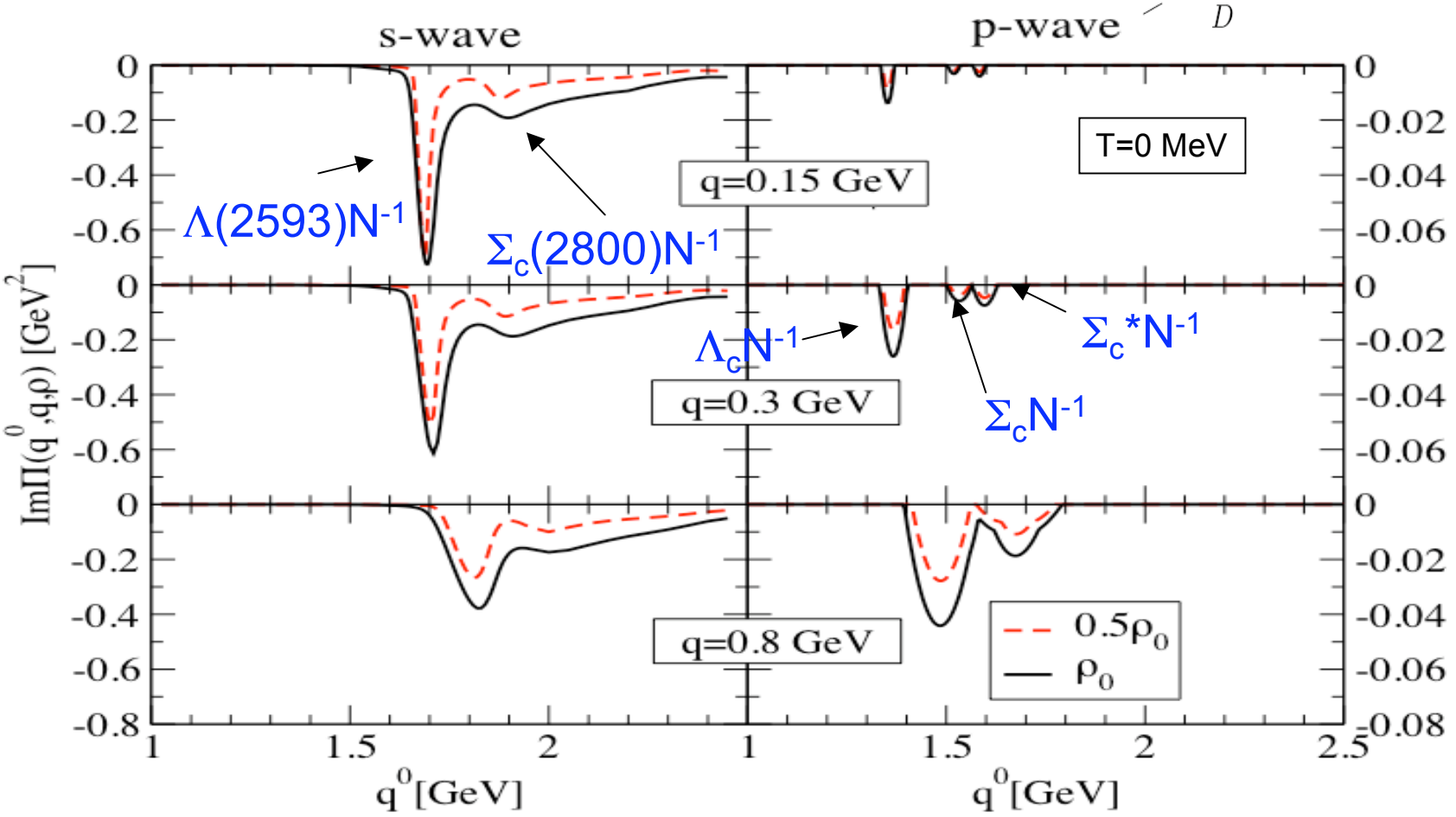


D̄ meson also shows an important width

Including p-wave self-energy..

Molina, Gamermann, Oset and LT, arXiv:0806.3711





D-meson: s-wave much more important than p-wave

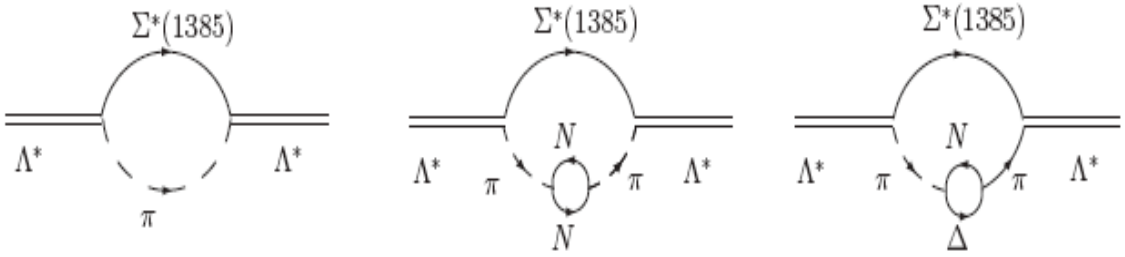
Charm scalar resonances in nuclear matter

Molina, Gamermann, Oset and LT, arXiv:0806.3711

The modification of the properties of elementary particles in nuclei give us information about the excitation mechanisms in the nucleus as well as the nature of those particles

ex. **Λ(1520)** resonance: width at nuclear matter density is five times bigger than the free one

$$\Lambda^*(1520) + p \rightarrow \Sigma^*(1385) + n$$

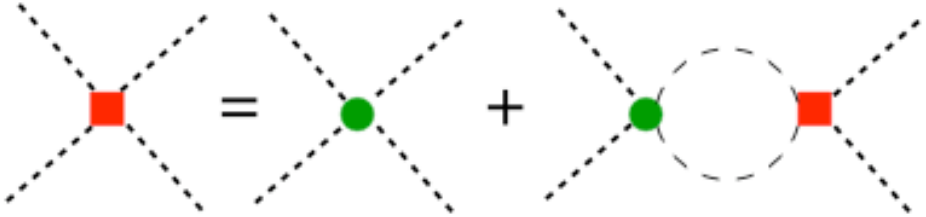


Kaskulov and Oset, PRC 73 (2006) 045213

$D_{s0}(2317)$[1], $D_0(2400)$[2] and X(3700)

[1]BaBar
[2]Belle,FOCUS

Charm and hidden charm scalar resonances are generated dynamically*



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

broken SU(4) symmetry

Close to a pole:

$$T_{ij} \approx \frac{g_i g_j}{z - z_R}$$

$D_{s0}(2317)$

Channel	$\lvert g_i \rvert$ (GeV)
DK	10.36
$D_s\eta$	6.00
$D_s\eta_c$	1.52

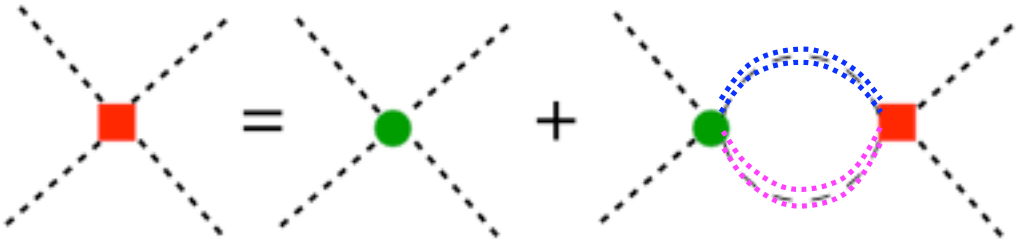
X(3700)

Channel	$\lvert g_i \rvert$ (GeV)
$\pi\pi$	0.21
$K\bar{K}$	0.03
$\eta\eta$	0.00
$D\bar{D}$	10.41
$D_s\bar{D}_s$	6.73
$\eta\eta_c$	0.29

$D_0(2400)$

Channel	$\lvert g_i \rvert$(GeV)
$D\pi$	10.87
$D\eta$	3.77
$D_s\bar{K}$	8.52
$D\eta_c$	2.14

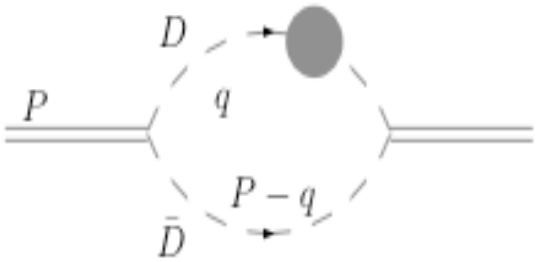
*Kolomeitsev and Lutz, PLB 582 (2004) 39; Hofmann and Lutz, NPA 733 (2004) 142; Guo, Shen, Chiang, Ping, PLB 641 (2006) 278; Gamermann, Oset, Strottman, Vicente-Vacas, PRD 76 (2007) 074016



Two meson loop in the medium

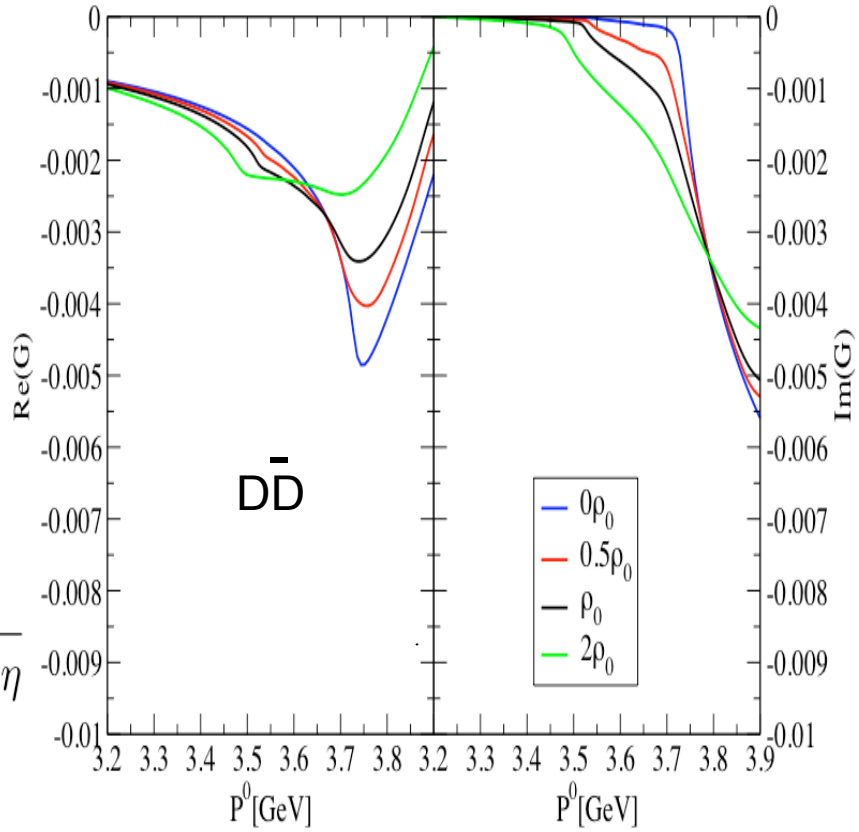
$T_{ij}(\rho) = V_{ij} + V_{il}\, G_l(\rho)\, T_{lj}(\rho)$

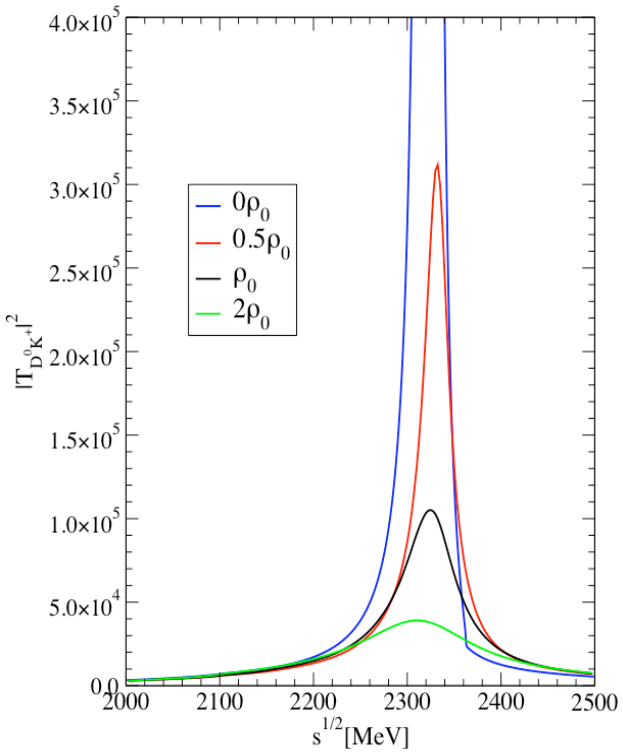
X(3700)

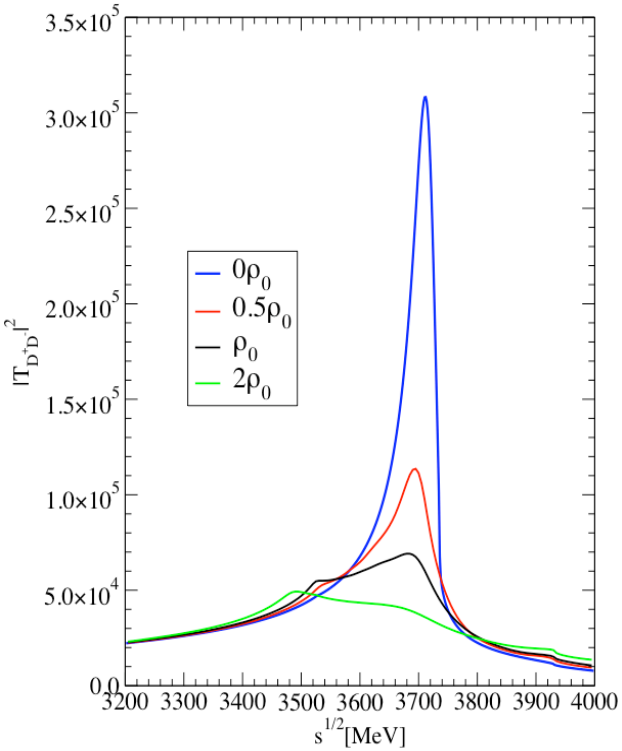


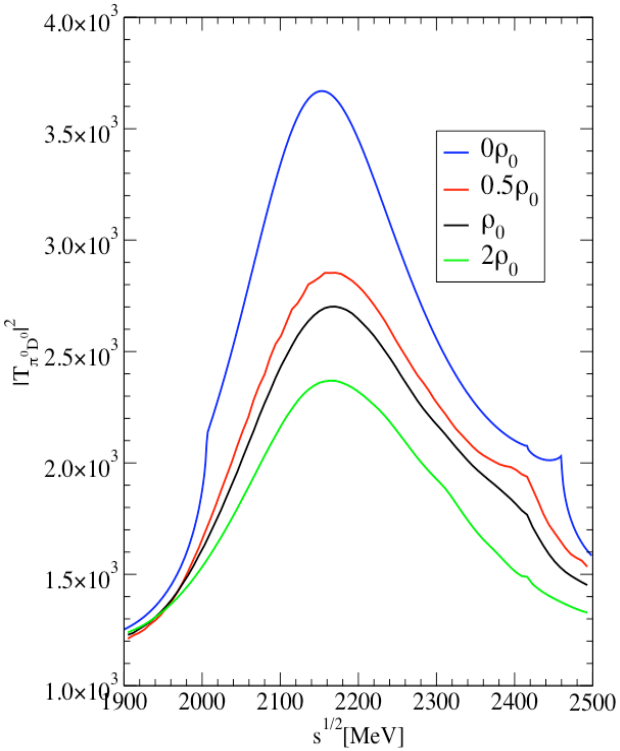
$$G(P^0, \vec{P}, \rho) = i \int \frac{d^4q}{(2\pi)^4} D_D(q,\rho) D_{\bar{D}}(P-q,\rho)$$

$$= i \int \frac{d^4q}{(2\pi)^4} \int_0^\infty d\omega \frac{S_D(\omega, \vec{q}, \rho)}{q^0 - \omega + i\eta} \frac{1}{(P^0 - q^0)^2 - \vec{q}^{\,2} - m_{\bar{D}}^2 + i\eta}$$







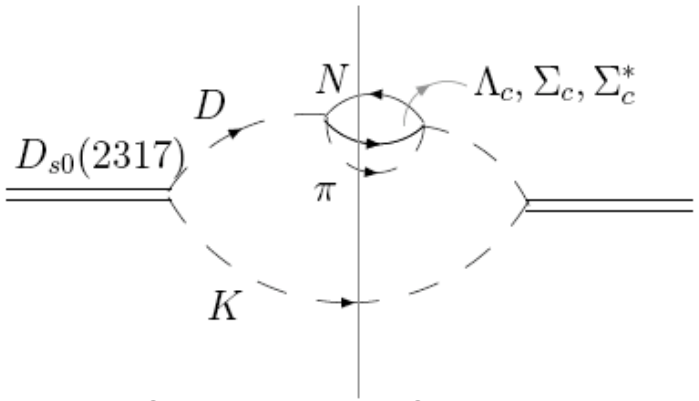


$D_{s0}(2317)$:
$D^0K^+ \rightarrow D^0K^+$

$X(3700)$:
$D^0\bar{D}^0 \rightarrow D^0\bar{D}^0$

$D_0(2400)$:
$D^0\pi^0 \rightarrow D^0\pi^0$

Experimental analysis of the resonances in nuclear medium (transparency ratio) *: test of the D meson interaction in nuclei and the nature of those charm scalar resonances

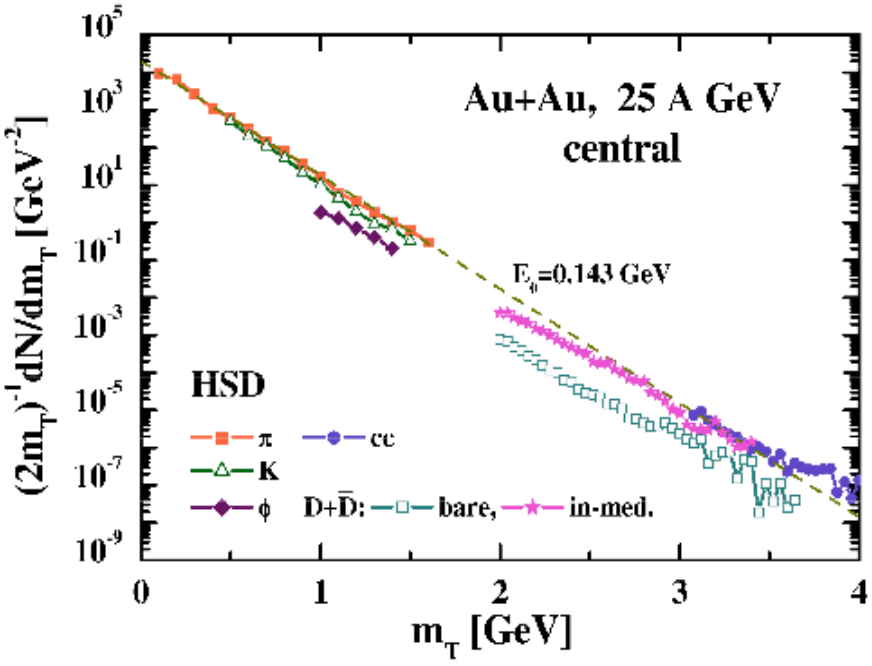


* ϕ: Cabrera, Roca, Oset, Toki and Vicente-Vacas, NPA 733 (2004) 130

Connection to heavy-ion collisions…
…transport models

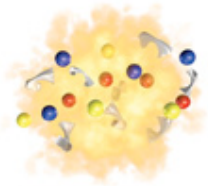
- URQMD *Bleicher, JPG 25 (1999) 1859; Bass et al., Prog. Part. Nucl. Phys. 41 (1998) 255*
- IQMD *Thomere et al., PRC 75 (2007) 064902 (dileptons)*
- NRD+eVMD model in RQMD *Santini et al., PRC 78 (2008) 034910 (dileptons); Shekhter et al., PRC 68 (2003) 014904 (dileptons)*
- HSD

Linnyk, Bratkovskaya and Cassing, Int. J. Mod. Phys. E 17 (2008) 1367 (charm)



Off-shell transport is needed!!

Present and Future



- it is an exciting moment
- new degree of freedom: charm
- a lot of theoretical effort is needed
- but in close connection to experiments