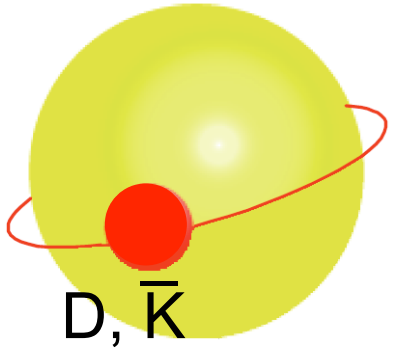
Open Charm @ FAIR: what do we need/want to know?



Laura Tolós

ICE, IEEC/CSIC, Barcelona

FIAS, University of Frankfurt

HICforFAIR Workshop: Heavy Flavor Physics with CBM, 26-28 May 2014

Open charm @ FAIR

• Open Charm spectroscopy:

- Charmonium above open charm: $\Psi, X_{cJ}, h_c, \ldots$ Interesting case: X(3872)
- Charmed exotics (multiquark states)
- Charmed hybrids

• Charm in nuclei (?):

- J/Ψ +N cross sections
- $\Psi(3770), \Psi', X_{c2}$ decay in open charm

• CPV with charm mesons

FAIR-ESAC/Pbar/Technical Progress Report

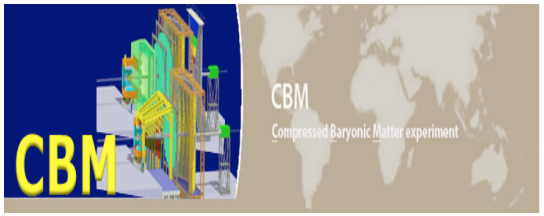
Open Charm Probes of
Hot and Dense Matter

- Charm-Quark Interactions in QGP

- Charm-Nucleon and Charm-Nucleus Interaction in Hot Dense Hadronic Matter

- Charmed Baryonic Resonances in Heavy-ion Collisions

The CBM Physics Book
Lecture Notes in Physics
Vol. 814 (2010) 1-980



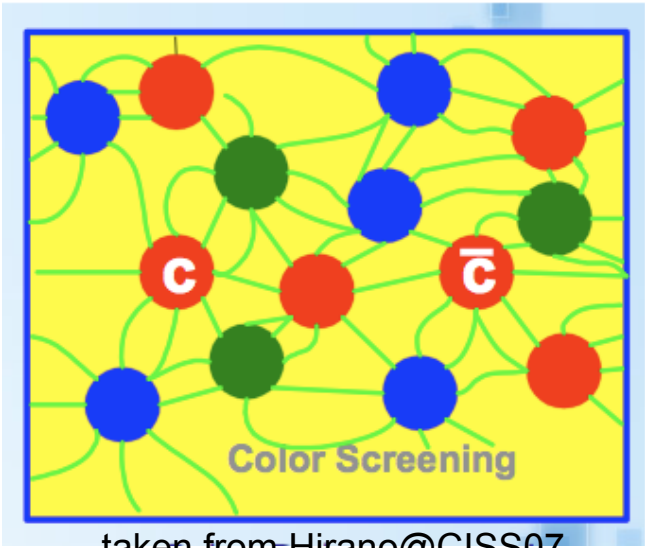
Open Charm in Hot Dense Hadronic Matter

- Open charm in dense nuclear matter: Incorporate Heavy-Quark Spin Symmetry
- D mesons in nuclei
- D meson propagation in hot dense matter

In the laboratory…

J/Ψ suppression

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



taken from Hirano@CISS07

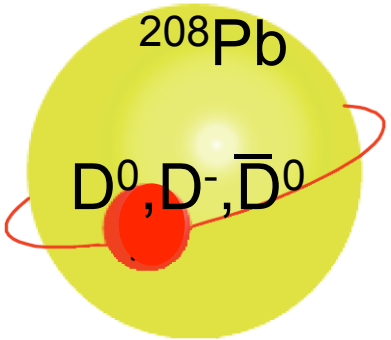
but also comover scattering

$J/\Psi + \pi <-> D + \bar{D}$

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

D-mesic nuclei

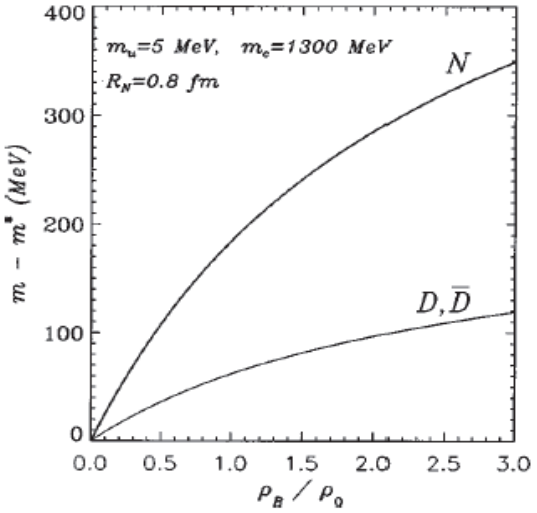
Tsushima et al ’99,
Garcia-Recio et al ’10
Garcia-Recio et al ’12
Yasui et al ’12..



From theory…

QMC model

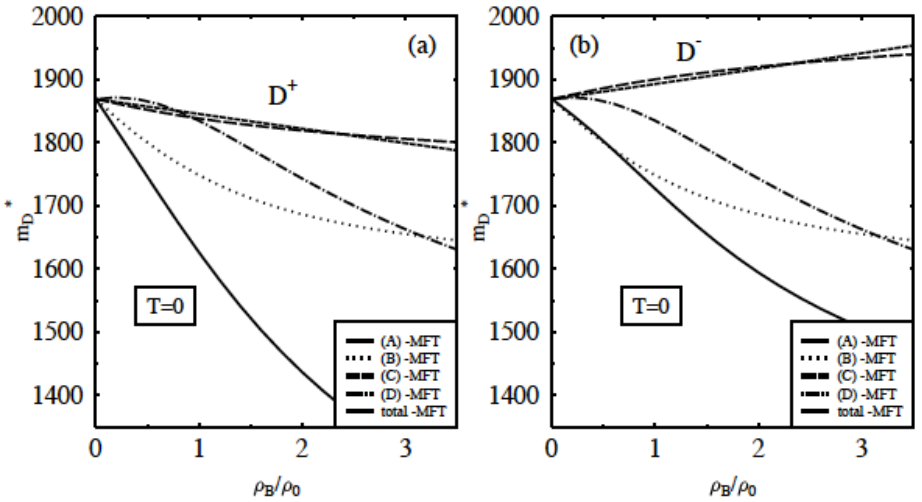
exchange of ω, ρ, σ mesons among quarks in a meson/baryon bag



Tsushima, Thomas, Sibirtsev, Fountoura..

MF/RHF model

Mishra, Kumar,..

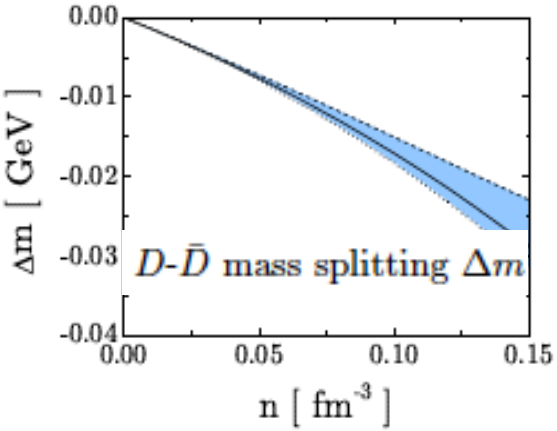


Effective lagrangian approach generalized to include charmed mesons in the mean field or relativistic Hartree-Fock approach

QCD sum-rule

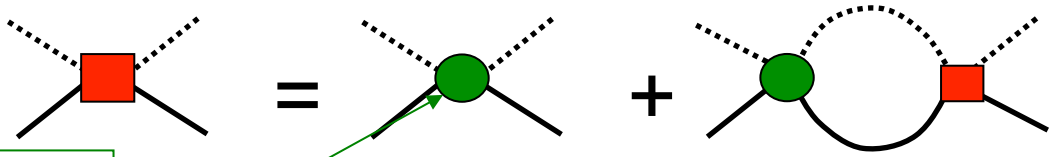
Hayashigaki, Weise, Hilger, Kaempfer, Leupold, Thomas, Nielsen, Navarra,..

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

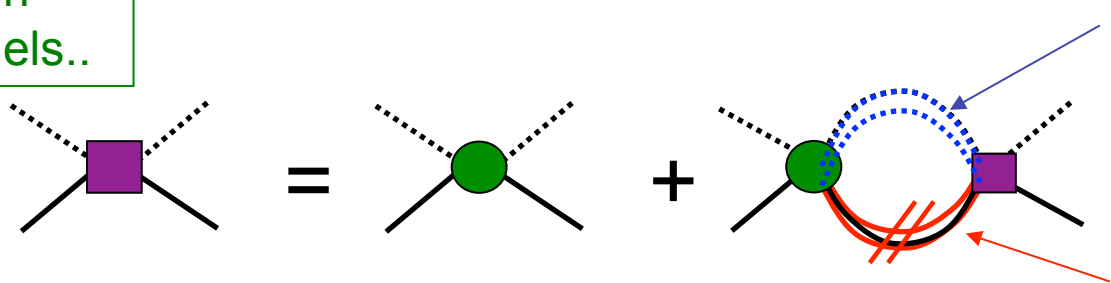
Free space



Potential from effective field theories, meson-exchange models..

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

Medium



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

Dressed meson:

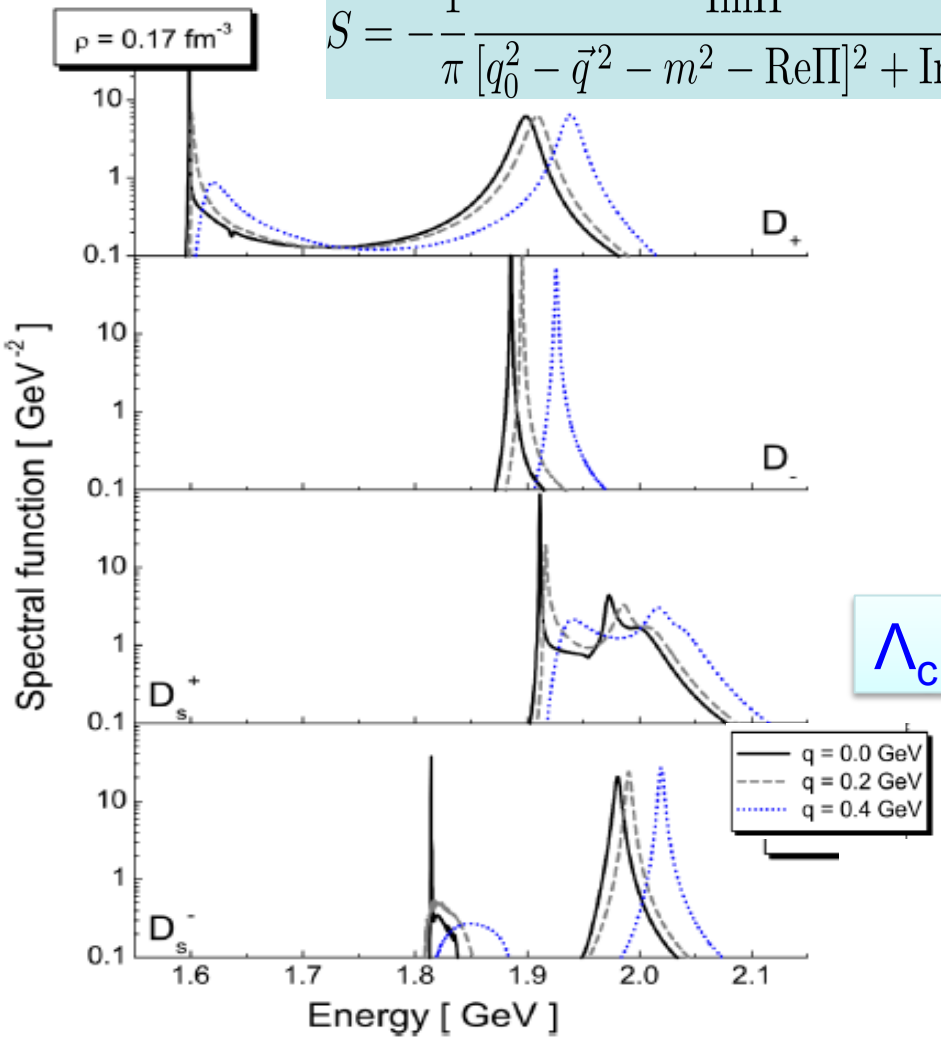
Π self-energy

Unitarized theory in matter:

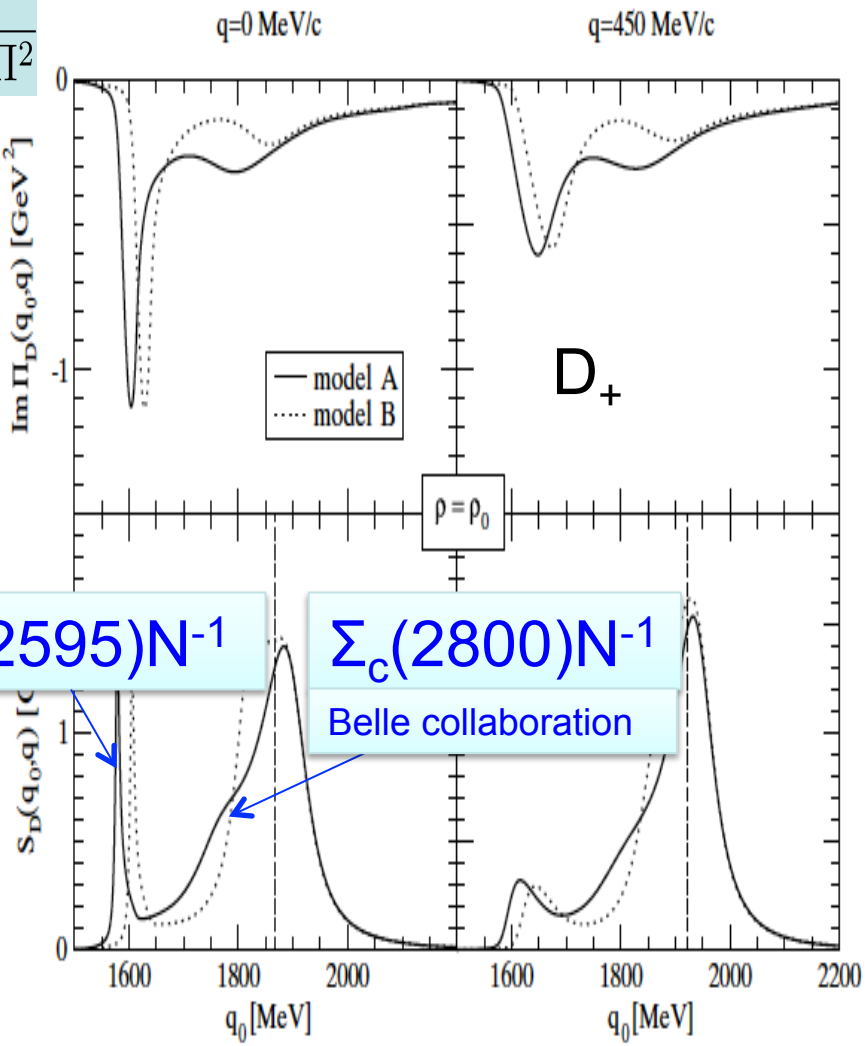
selfconsistent coupled-channel procedure

(bare interaction saturated by t-channel vector-meson exchange)

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



Lutz, Korpa, Hofmann..



$\Lambda_c(2595)N^{-1}$

$\Sigma_c(2800)N^{-1}$

Belle collaboration

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

Incorporate Heavy Quark Spin Symmetry

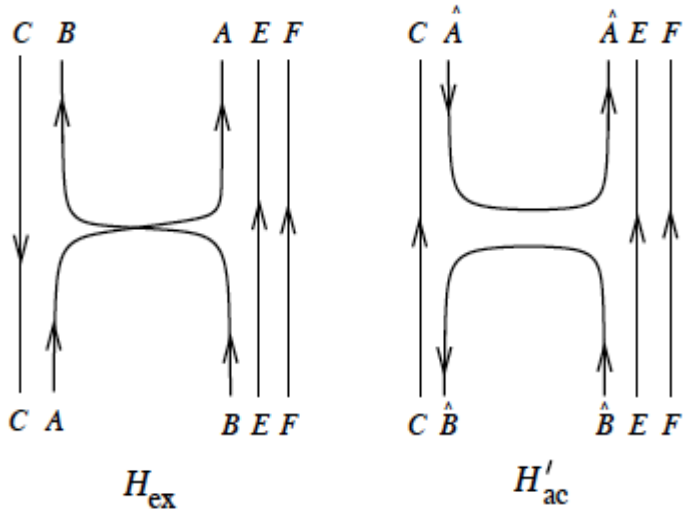
HQSS*: spin interactions vanish for infinitely massive quarks

*Isgur, Wise, Manohar, Neubert

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: extended WT interaction that fulfills SU(6)xHQSS and it is consistent with chiral symmetry in the light sector

$$V = \frac{K(s)}{4f^2} H'_{\mathrm{WT}}, \qquad H'_{\mathrm{WT}} = H_{\mathrm{ex}} + H'_{\mathrm{ac}}.$$

K(s): depends on meson-baryon energy
f: decay constant



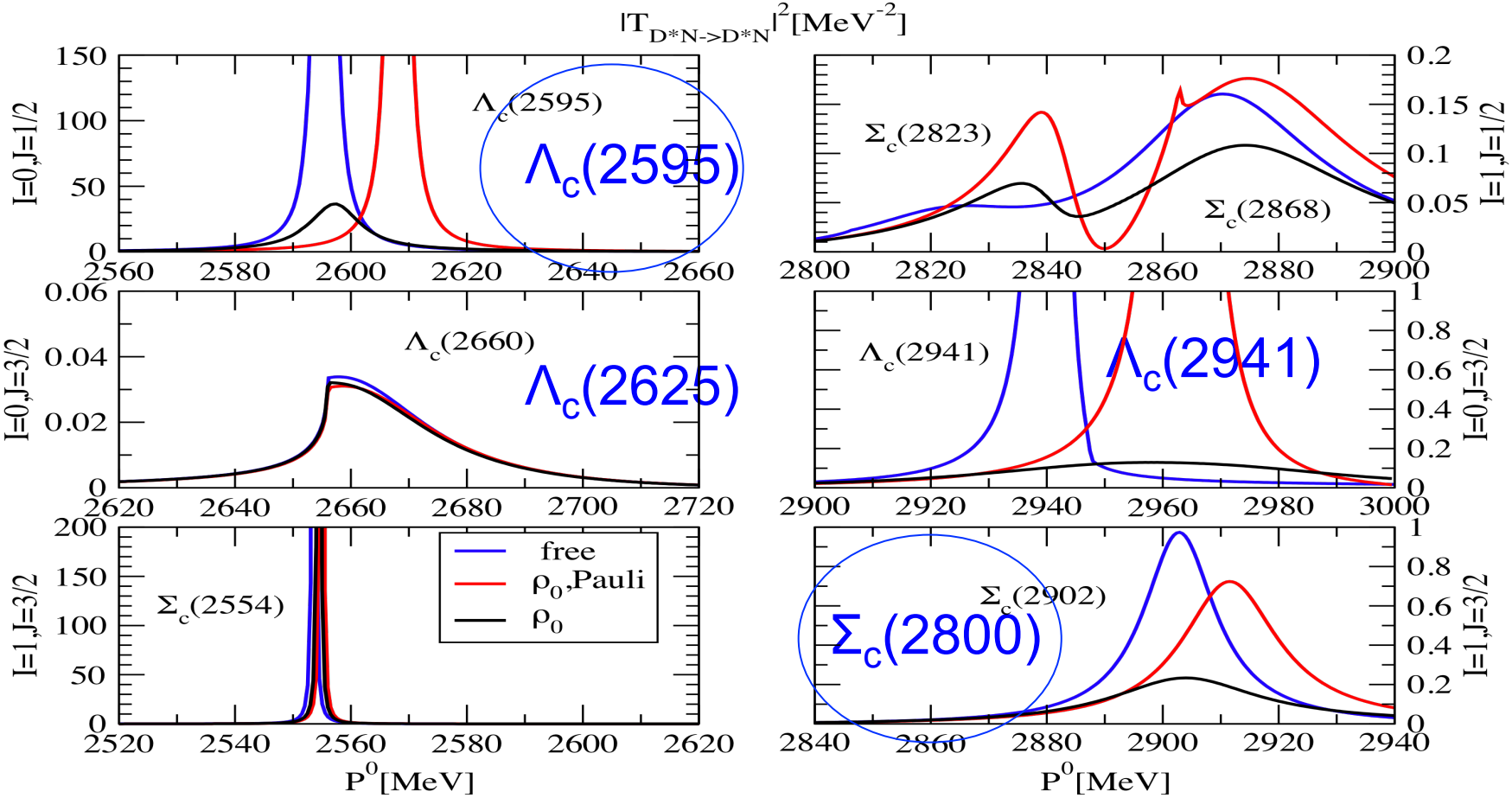
H_{ex} H'_{ac}

H_{ex}: exchange of quarks
H'_{ac}: annhilation and creation of quark-antiquark pairs, corrected with HQSS constraints (only light quarks)

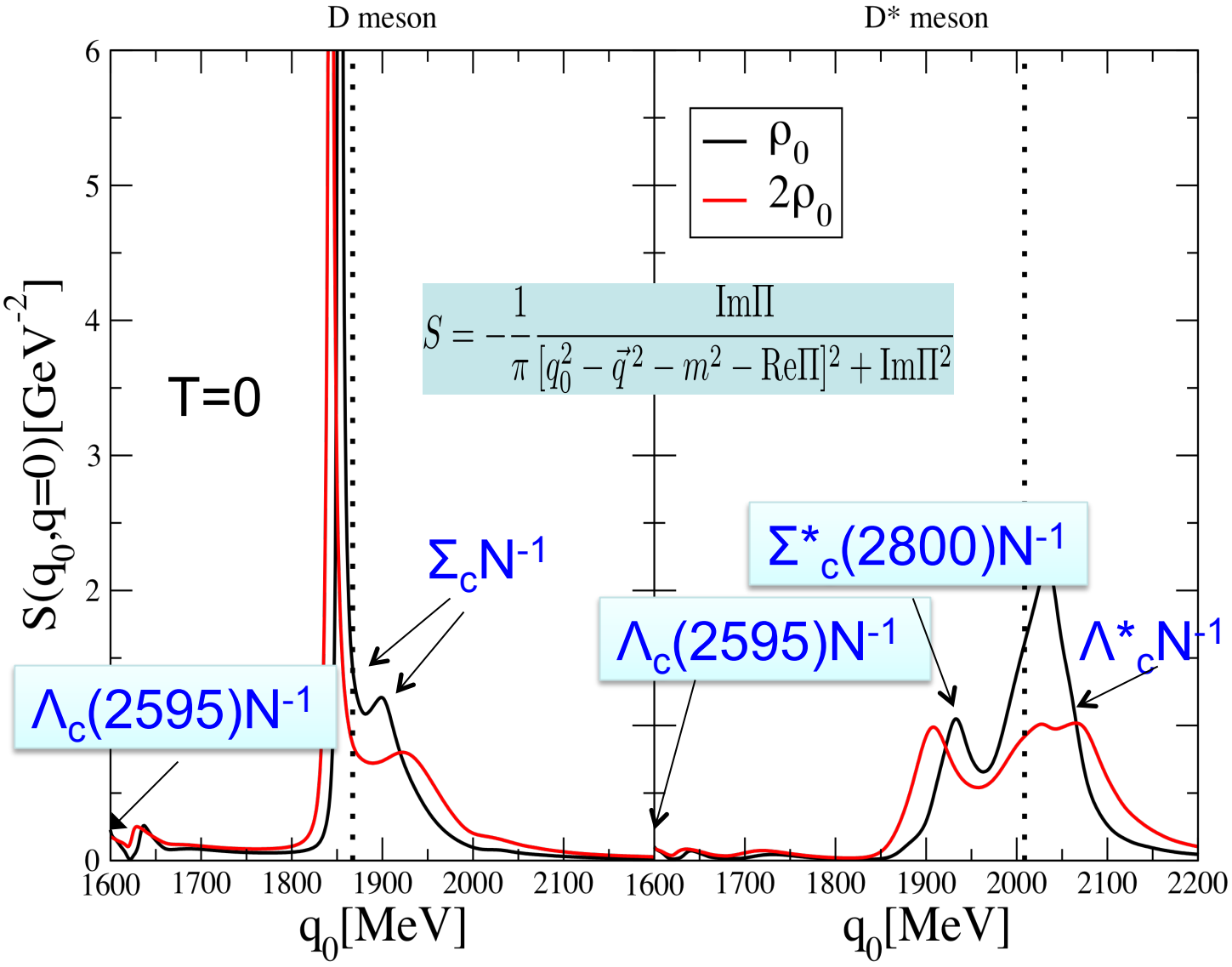
PDG

Resonance	$I(J^P)$	Status	Mass (MeV)	Γ (MeV)
$\Lambda_c(2595)$	$0(1/2^-)$	***	2595.4 ± 0.6	$3.6 + 2.0 - 1.3$
$\Lambda_c(2625)$	$0(3/2^-)$	***	2628.1 ± 0.6	<1.9
$\Lambda_c(2765)$	$?(?^?)$	*	2766.6 ± 2.4	50
or $\Sigma_c(2765)$				
$\Lambda_c(2880)$	$0(5/2^+)$	***	2881.9 ± 0.5	5.8 ± 1.9
$\Lambda_c(2940)$	$0(?^?)$	***	2939.8 ± 1.6	18 ± 8
$\Sigma_c(2800)^{++}$	$1(?^?)$	***	$2801 + 4 - 6$	$75 + 22 - 17$
$\Sigma_c(2800)^{+}$	$1(?^?)$	***	$2792 + 14 - 5$	$62 + 60 - 40$
$\Sigma_c(2800)^{0}$	$1(?^?)$	***	$2802 + 4 - 7$	$61 + 28 - 18$

Dynamically-generated baryonic resonances in nuclear matter



Unitarized theory in matter:
selfconsistent coupled-channel procedure



Simultaneous calculation of D and D* self-energies

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

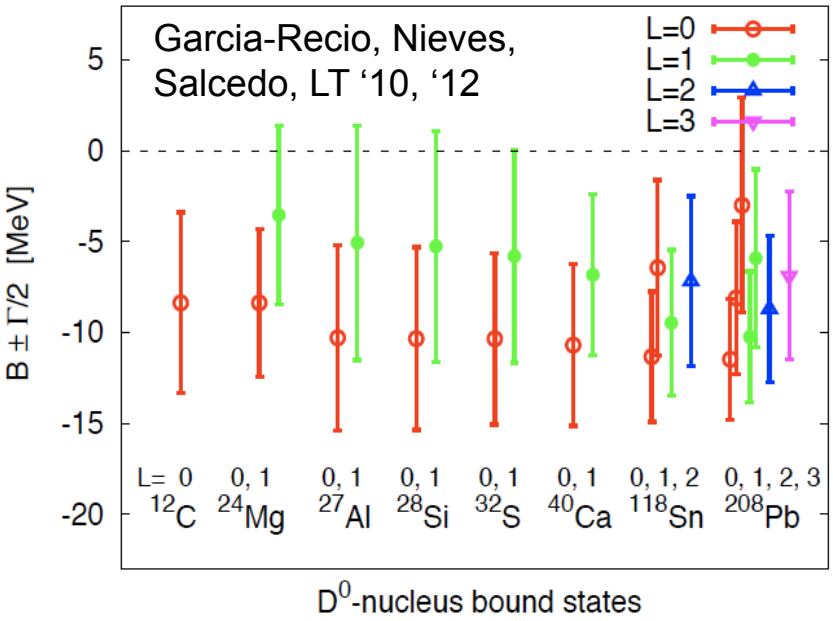
Initially predicted in ^{208}Pb within QMC model Tsushima et al. '99

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

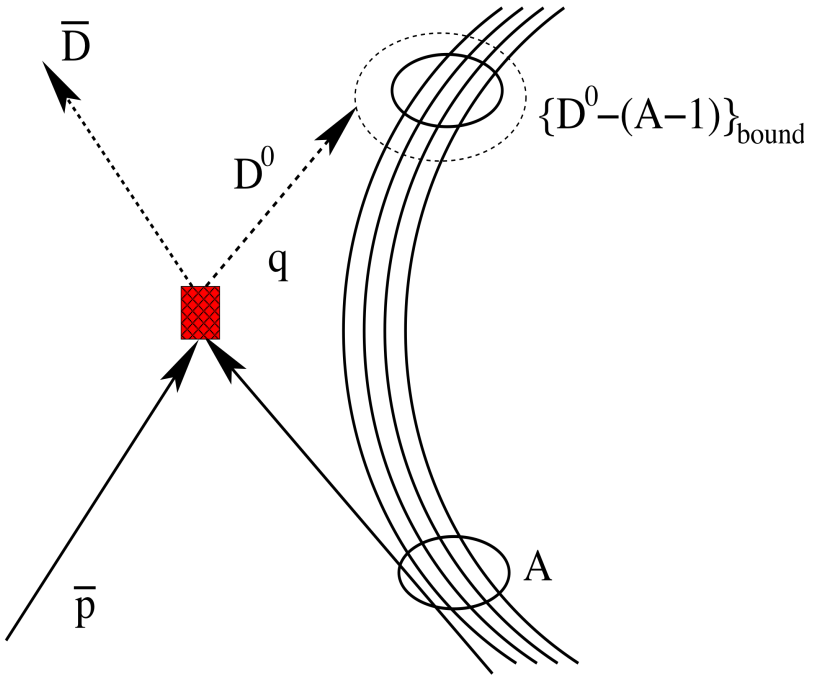
$$\left[-\frac{\nabla^2}{2m_{\rm red}} + V_{\rm coul}(r) + V_{\rm opt}(r)\right]\Psi = (-B - i\Gamma/2)\Psi$$

$$V_D(r,E) = \frac{\Pi_D(q^0 = m_D + E, \vec{q} = 0, \rho(r))}{2m_D}$$

$$E = q^0 - m_D$$



PANDA @FAIR?



pA reaction seems
more likely to trap a D^0 in nuclei

D meson propagation in hot dense matter

D-mesons: One of the cleanest probes of the early stages of the collision

Their trelaxation time is long enough to not fully thermalize, but short enough to undergo significant reinteractions which reflect on their coupling to the medium.

$$\tau_{rel}^{H} \sim \frac{M}{T}\,\tau_{rel}^{light}\ ; \qquad \frac{M}{T} \sim 6-20$$

Teaney and Moore '05

The D meson propagation can be studied using a kinetic description for the distribution function.

Given that $m_D >> m_{light}$

$$\frac{\partial f(t,\mathbf{p})}{\partial t} = \frac{\partial}{\partial p_i}\left\{F_i(\mathbf{p}) f(t,\mathbf{p}) + \frac{\partial}{\partial p_j}\left[\Gamma_{ij}(\mathbf{p}) f(t,\mathbf{p})\right]\right\},$$

drag force — diffusion coefficient

Fokker-Planck equation

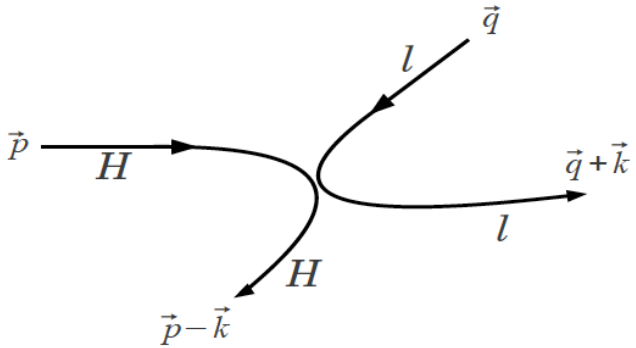
For an isotropic bath

$$F(p) = \int d\mathbf{k} w(\mathbf{p}, \mathbf{k}) \frac{k_i p^i}{p^2},$$

$$\Gamma_0(p) = \frac{1}{4} \int d\mathbf{k} w(\mathbf{p}, \mathbf{k}) \left[\mathbf{k}^2 - \frac{(k_i p^i)^2}{p^2} \right],$$

$$\Gamma_1(p) = \frac{1}{2} \int d\mathbf{k} w(\mathbf{p}, \mathbf{k}) \frac{(k_i p^i)^2}{p^2},$$

$$\omega \propto \int |T|^2 d\Omega$$



We need scattering amplitudes $|T|^2$ in matter

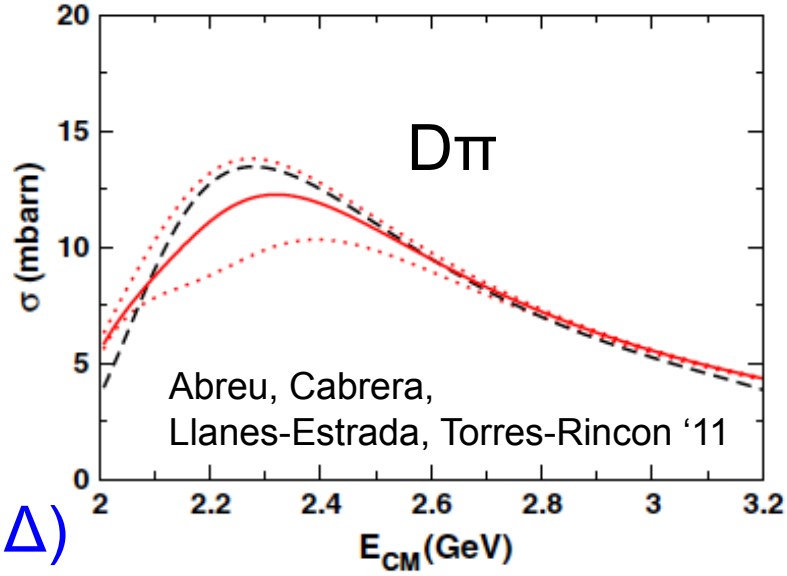
Previous works on D-meson propagation with different models for $|T|^2$

Laine ‘11; He, Fries, Rapp ‘11; Ghosh, Das, Sarkar, -eAlam ’11;
Abreu, Cabrera, Llanes-Estrada, Torres-Rincon ‘11

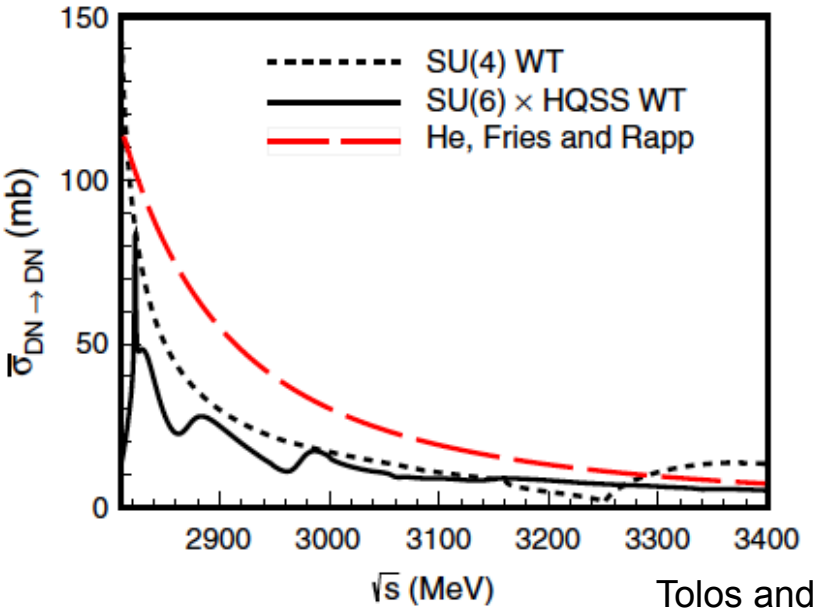
(Vacuum) cross sections for open charm with mesons and baryons

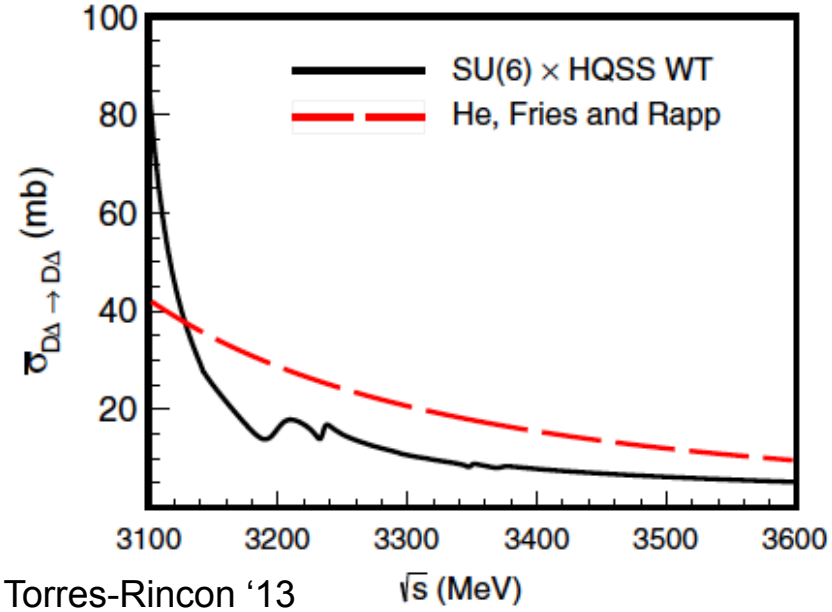
- D-mesons with light mesons (π, K, K, η)

Daniel Cabrera's talk!



- D-mesons with baryons (N, Δ)

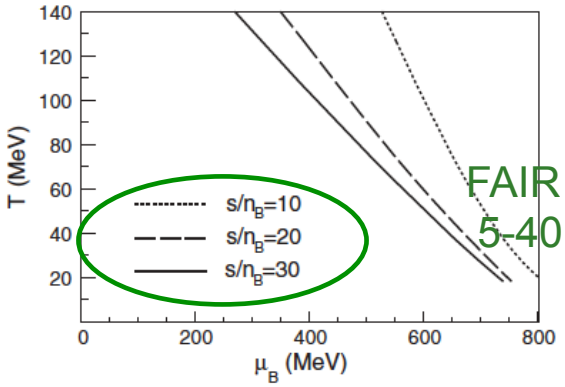




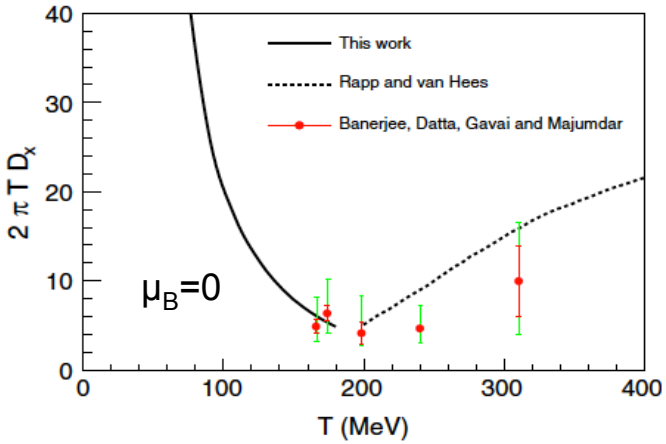
Tolos and Torres-Rincon '13

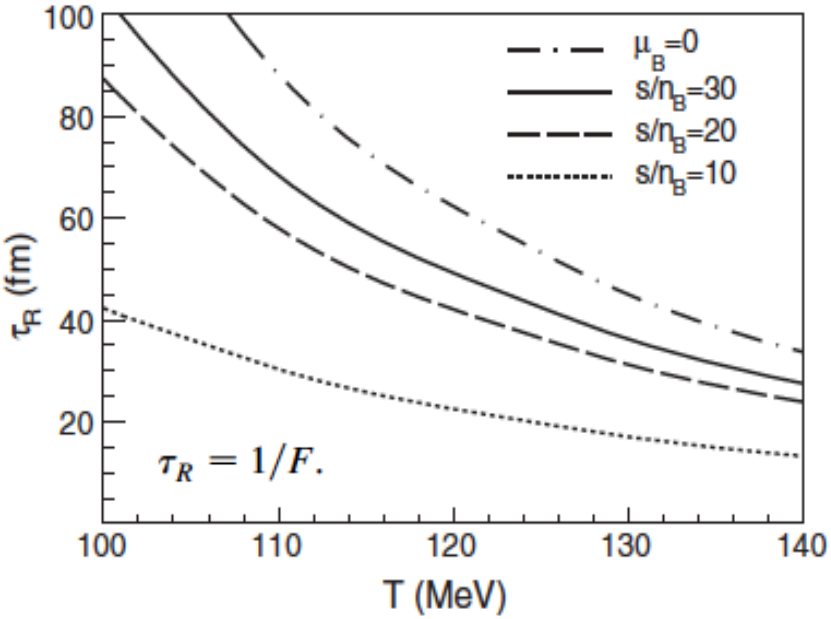
Some results for CBM/FAIR energies

Tolos and Torres-Rincon '13

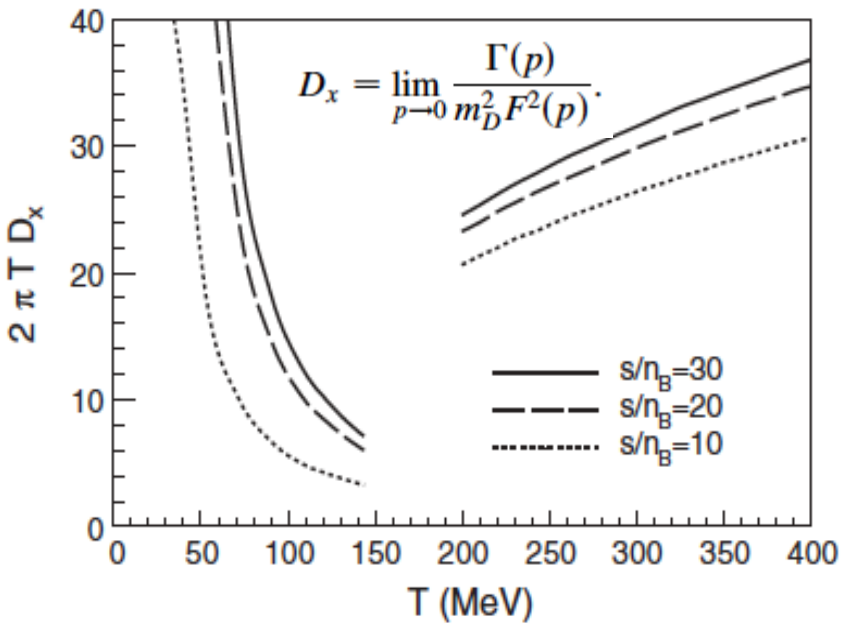


FAIR energies
5-40 AGeV



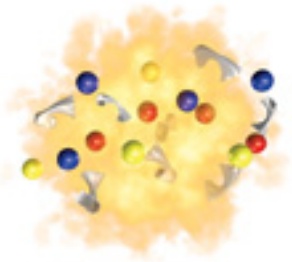


Shorter relaxation time
for lower energy beams (baryons!)



Minimum at T_c for FAIR energies??
Non continuous transition??

Present and Future @FAIR



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