Chiral Condensate & Open Charm

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CBM option: study in-medium D mesons
(analog to K+-)

Charm = probe of QCD vacuum?

Antenna?

with S. Zschocke, R. Thomas, Th. Hilger

Universal Material Constants of Vacuum

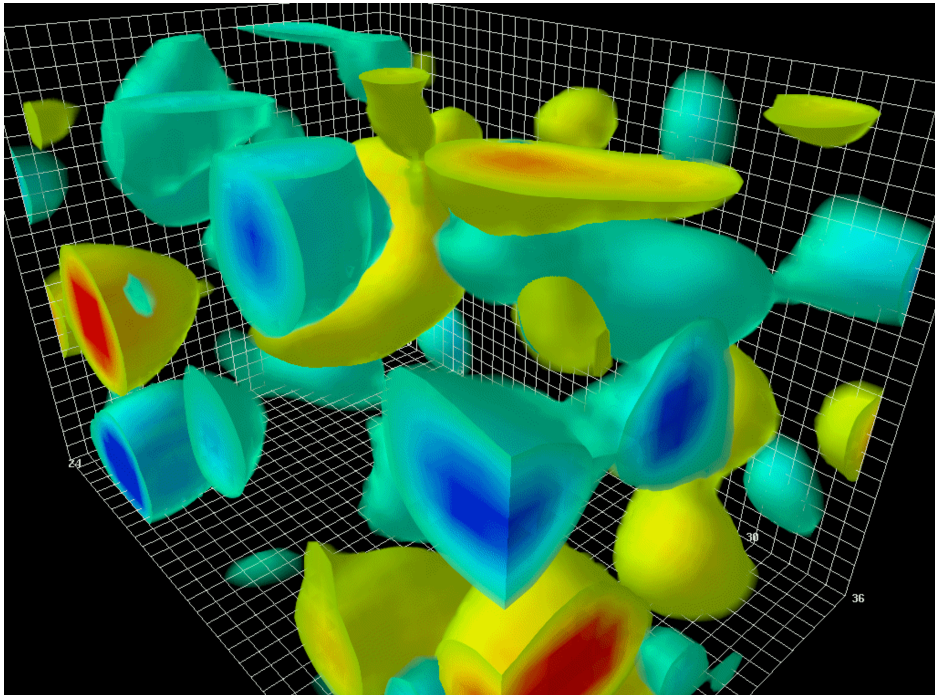
$$\langle \bar{q} q \rangle_0, \quad \langle \frac{\alpha_s}{\pi} G^2 \rangle_0, \quad \langle \bar{q} \sigma \, G q \rangle_0, \cdots$$

dil. symm. break.

χ symm. break. (spont.), o.p.

D. Leinweber's

Vacuum



monopoles, instantons, vortices, ...

Expansion not à la Taylor but à la Wilson: OPE

$$\mathcal{F}_{x\to q}\{J(x)J(0)\} = \sum_d C_d(q^2,\mu)\mathcal{O}(\mu)_d$$

Wilson coeff.

quark & gluon operators

d	operator	operator	d
3	$\bar{q}q$	$m\bar{q}q$	4
4	G^2		4
5	$\bar{q}\sigma Gq$	$m\bar{q}\sigma Gq$	6
6	$(\bar{q}\Gamma q)(\bar{q}\Gamma q)$		6
6	G^3		6

Observables:

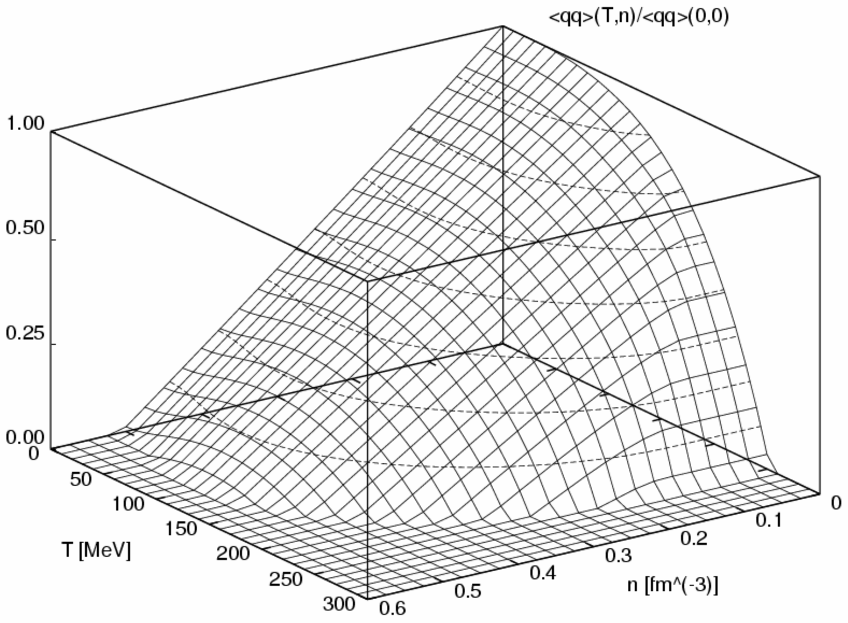
$$\langle\mathcal{F}J(x)J(0)\rangle = \sum_d \frac{\bar{C}_d\langle\mathcal{O}_d\rangle}{Q^{2d}}$$

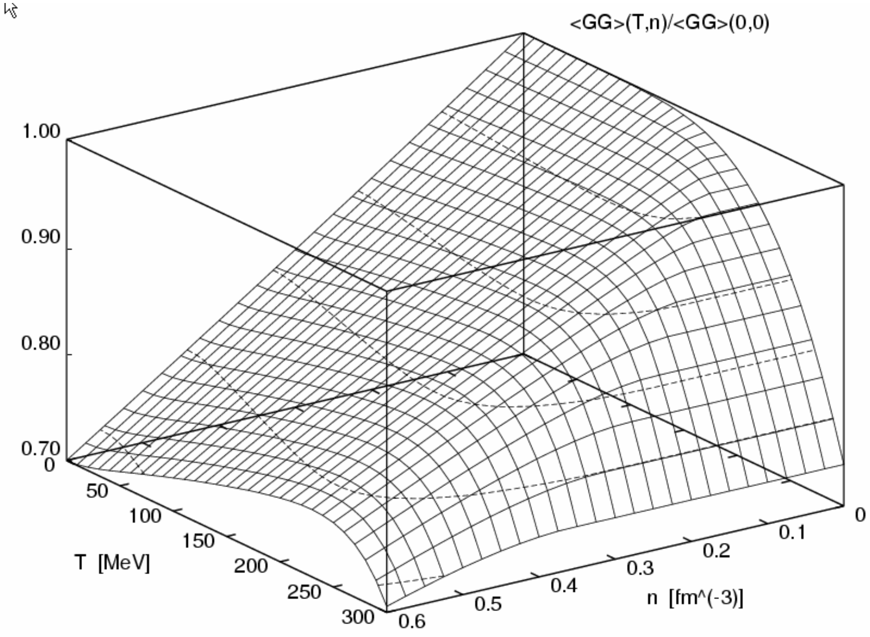
In Medium

$$\begin{aligned}\langle \mathcal{O}_d \rangle &= \langle \mathcal{O}_d \rangle_0 \\ &+ \frac{n}{2m_N} \langle N | \mathcal{O}_d | N \rangle \\ &+ \frac{T^2}{8} \langle \pi | \mathcal{O}_d | \pi \rangle + \cdots \end{aligned}$$

Dilute
Gas
Approx.

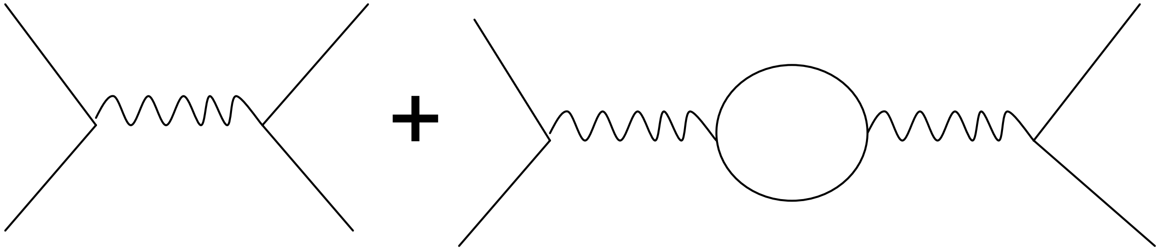
$$\langle \bar{q} q \rangle = \langle \bar{q} q \rangle_0 (1 - 0.35 \tfrac{n}{n_0}) \qquad \langle \tfrac{\alpha_s}{\pi} G^2 \rangle = \langle \tfrac{\alpha_s}{\pi} G^2 \rangle_0 (1 - 0.07 \tfrac{n}{n_0})$$





CCC: Current-Current Correlator

$$\begin{aligned} e^+e^- &\rightarrow e^+e^- \\ e^-e^- &\rightarrow e^-e^- \end{aligned}$$

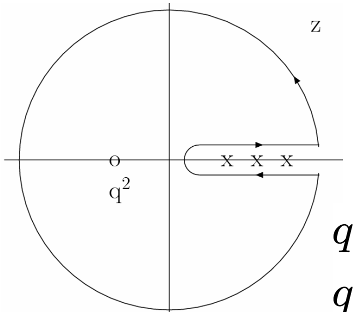


$$\Pi_{\mu\nu}(q^2) = i\int d^4q e^{iqx}\langle 0|\mathcal{T}J_\mu(x)J_\nu(0)|0\rangle$$

$q^2 > 0$: e^+e^- $J^P = 1^-$: $\rho, \omega, \phi, J/\psi, \Upsilon$

$q^2 < 0$: e^-e^- $J_\mu = \bar{q}\gamma_\mu q$

$$\Pi(q^2 < 0) = \frac{1}{\pi}\int_{th}^{\infty} ds \frac{Im\Pi(s)}{s - q^2 - i\epsilon}$$



$$Im\Pi \propto \sigma_{e^+e^- \rightarrow hadrons}$$

$q^2 < 0$: short-distance $\bar{q}q$ fluctuations

$q^2 > 0$: bound hadronic states

QCD Sum Rules à la Borel

1. qq sector: ρ, ω mesons $j^\omega_\mu = \frac{1}{2}\left(\bar{u}\gamma_\mu u + \bar{d}\gamma_\mu d\right)$

Shifman,Vainshtein,Zakharov
Hatsuda,Lee
Klingl,Weise
Leupold,Mosel

$$\Pi^\omega(0,n) - \frac{1}{\pi}\int_0^\infty ds \frac{\mathrm{Im}\Pi^\omega(s,n)}{s} e^{-s/\mathcal{M}^2}$$

$$= c_0\mathcal{M}^2 + \sum_{j=1}^\infty \frac{c_j}{(j-1)!\mathcal{M}^{2(j-1)}}$$

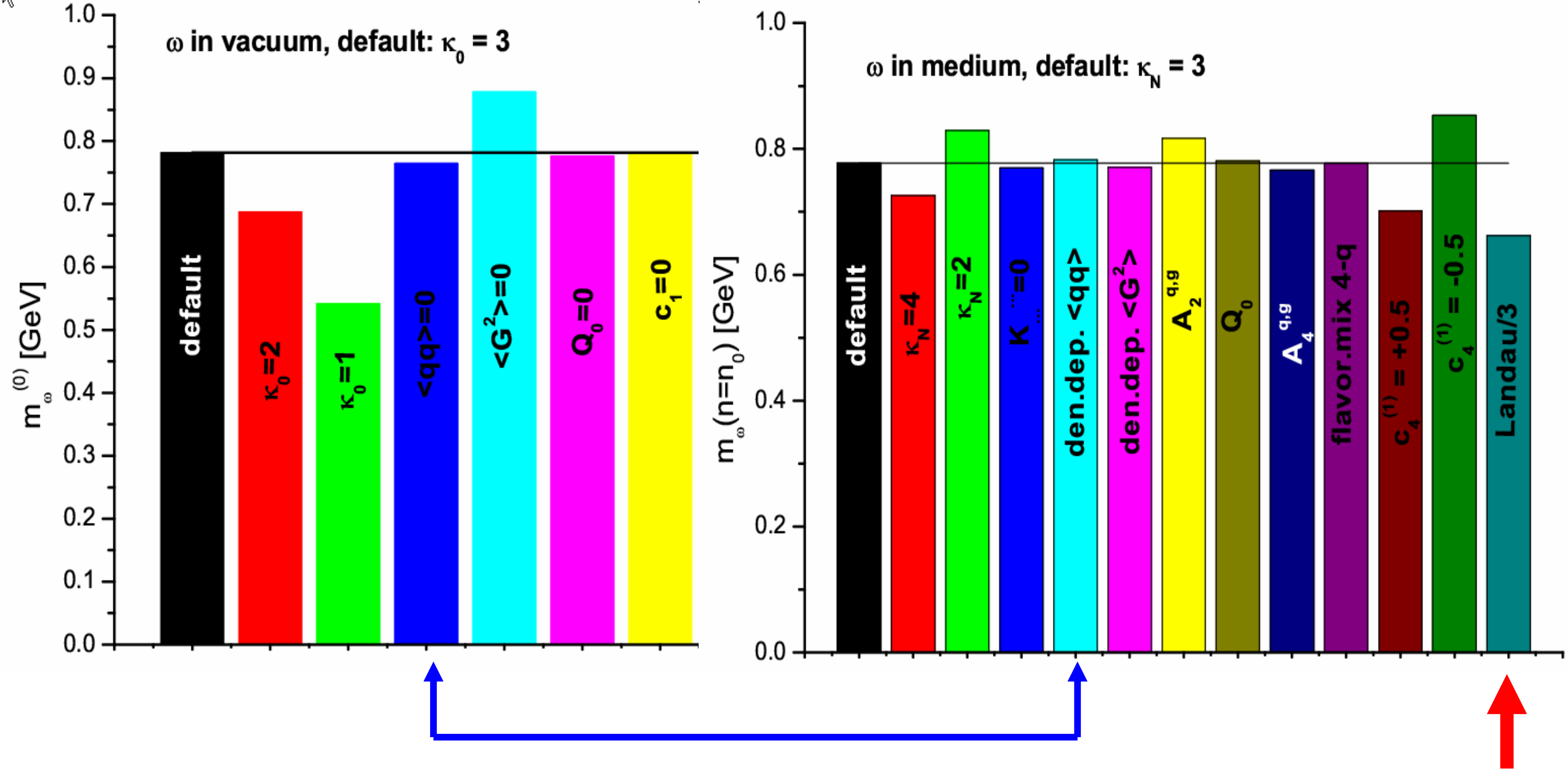
$c_2 \propto m_q\langle\bar{q}q\rangle$: negligibly small

$$\begin{aligned} c_3 &= \frac{2}{9}\langle\bar{u}\gamma^\mu\lambda_A u\bar{d}\gamma_\mu\lambda_A d\rangle \\ &+ \langle\bar{u}\gamma_5\gamma^\mu\lambda_A u\bar{d}\gamma_5\gamma_\mu\lambda_A d\rangle \\ &+ \frac{2}{9}\langle\bar{q}\gamma^\mu\lambda_A q\bar{q}\gamma_\mu\lambda_A q\rangle \\ &+ \langle\bar{q}\gamma_5\gamma^\mu\lambda_A q\bar{q}\gamma_5\gamma_\mu\lambda_A q\rangle \end{aligned}$$

4-quark condensates

(factorization fails)

$$\langle O_1 O_2\rangle \neq \langle O_1\rangle\langle O_2\rangle$$

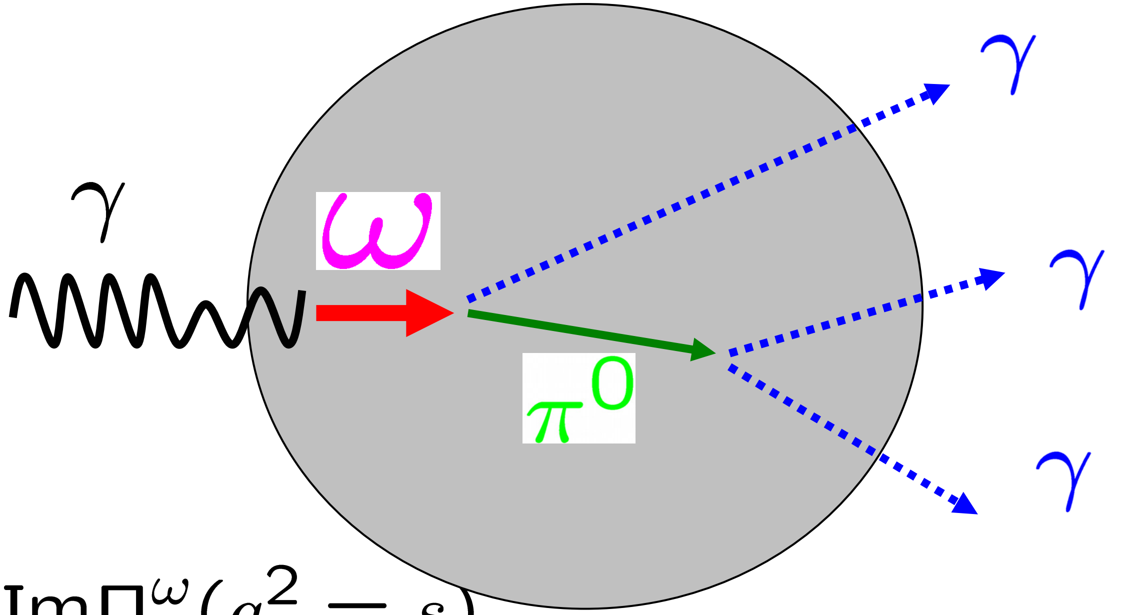


chiral condensate

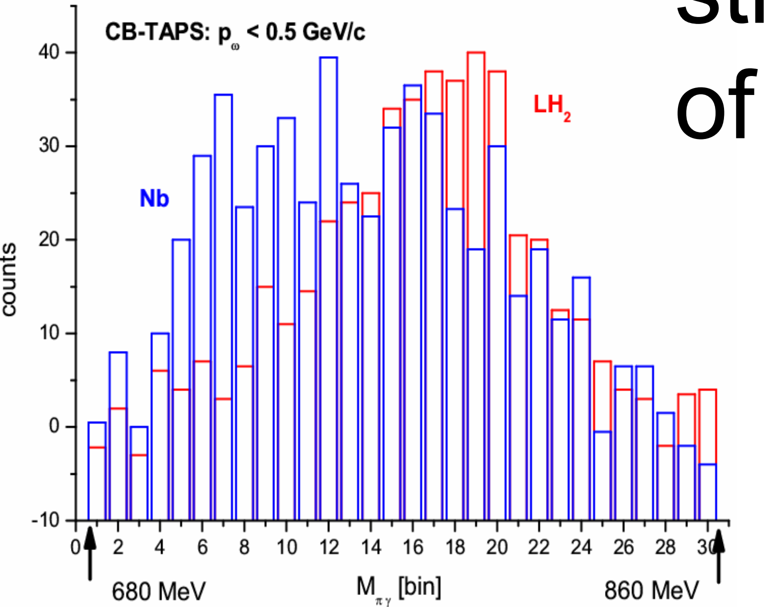
ω meson: fairly independent of $\langle \bar{q}q \rangle$

= genuine chiral condensate

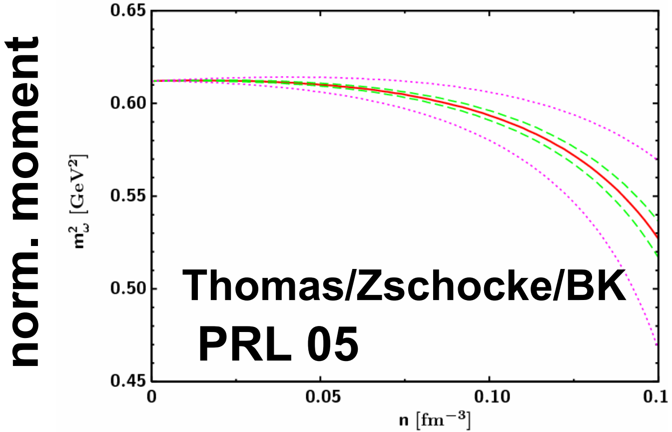
CB-TAPS:
Trnka et al. 05



$$\frac{dR_{\omega\rightarrow\pi^0\gamma}}{d^4q} = (\frac{6d}{f_\pi})^2\frac{\pi}{3q^2}(q^2 - m_\pi^2)^3\,\mathrm{Im}\Pi^\omega(q^2 = s)$$



strong density dependence of combined 4-quark conds.

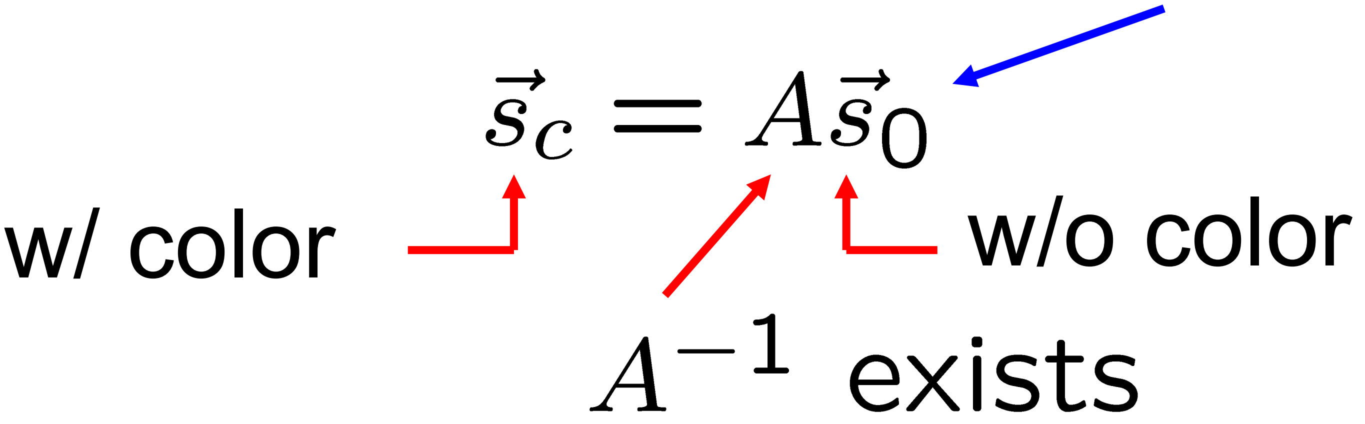


also dim-8 contributions

Book Keeping of 4-Quark Condensates

$\langle \bar{u}\Gamma u \bar{u}\Gamma u \rangle$: inv. vs. time & parity reversal

vacuum: 5, medium: 12 indep. 4-q conds.



$$\vec{s}_c = A\vec{s}_0$$

w/ color

w/o color

A^{-1} exists

nucleon: $$\vec{z} = \frac{2}{3}\underbrace{\left(1 - \frac{3}{4}A\right)}_{\text{no inverse}}\vec{s}_0$$

dim $\vec{z}_N <$ dim $\vec{z}$

relations exist between 4-q conds.
(not accurately fulfilled in models)

$\langle\bar{u}\Gamma u\bar{d}\Gamma d\rangle$: inv. vs. time & parity reversal

vacuum: 10, medium: 32 indep. 4-q conds.

$\int dq_0 q_0^3(\Pi_V - \Pi_A) \sim$ 4-q cond.

Hatsuda,Lee
Kapusta,Shuryak

chiral cond.:

$\bar{\psi}\psi$: $U(1)\times SU(2)_V$, $\bar{\psi}_R\psi_L+\bar{\psi}_L\psi_R$

ω meson

$\psi\gamma_5\gamma_\mu\vec{\lambda}_a\psi\bar{\psi}\gamma_5\gamma^\mu\lambda^a\psi+\frac{2}{9}\bar{\psi}\gamma\lambda^a\psi\bar{\psi}\gamma^\mu\lambda_a\psi$:

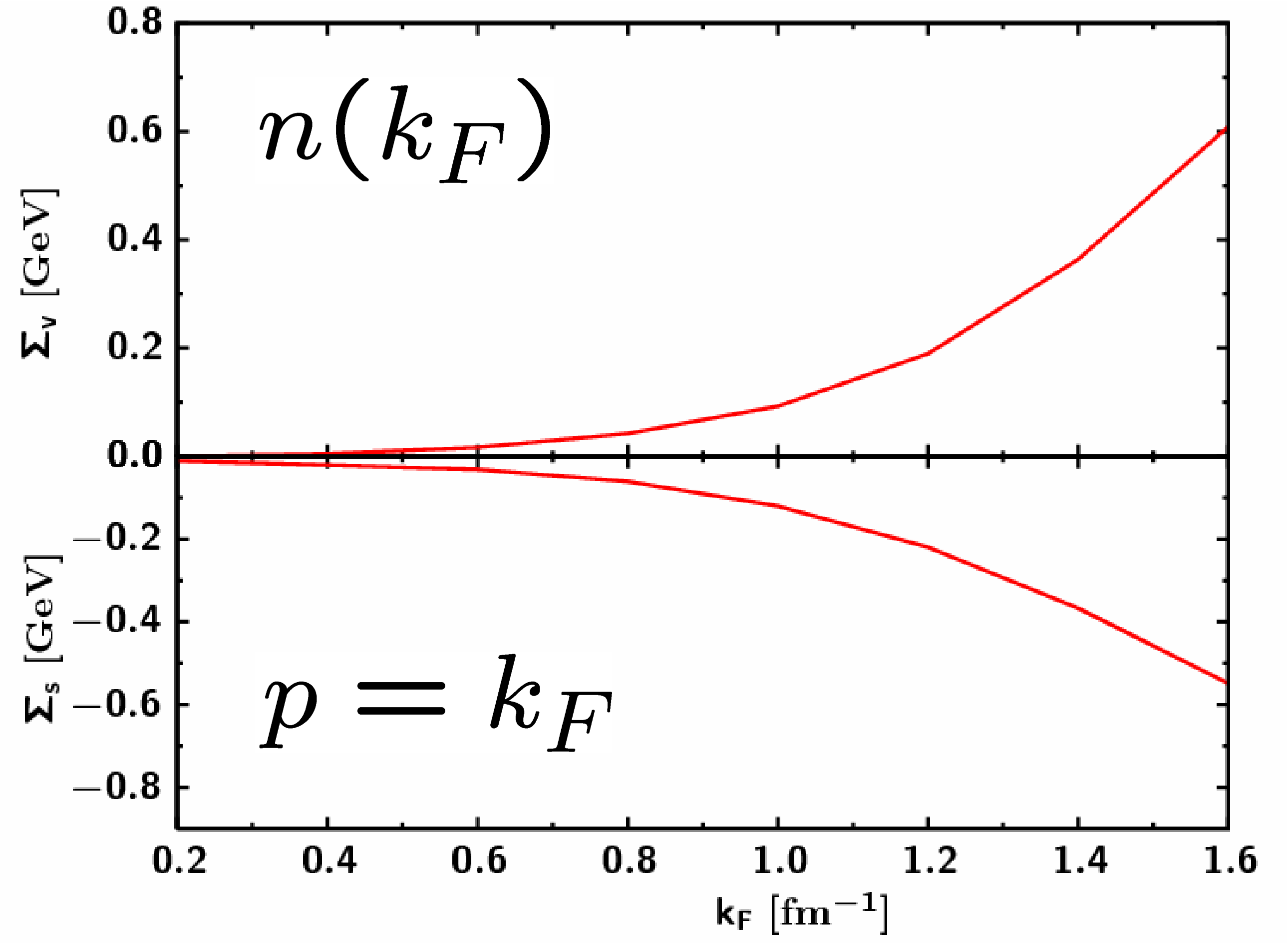
$U(1)_V\times SU(2)_V\times U(1)_A\times SU(2)_A$,

$\bar{\psi}_L\psi_R\bar{\psi}_L\psi_R+\cdots$

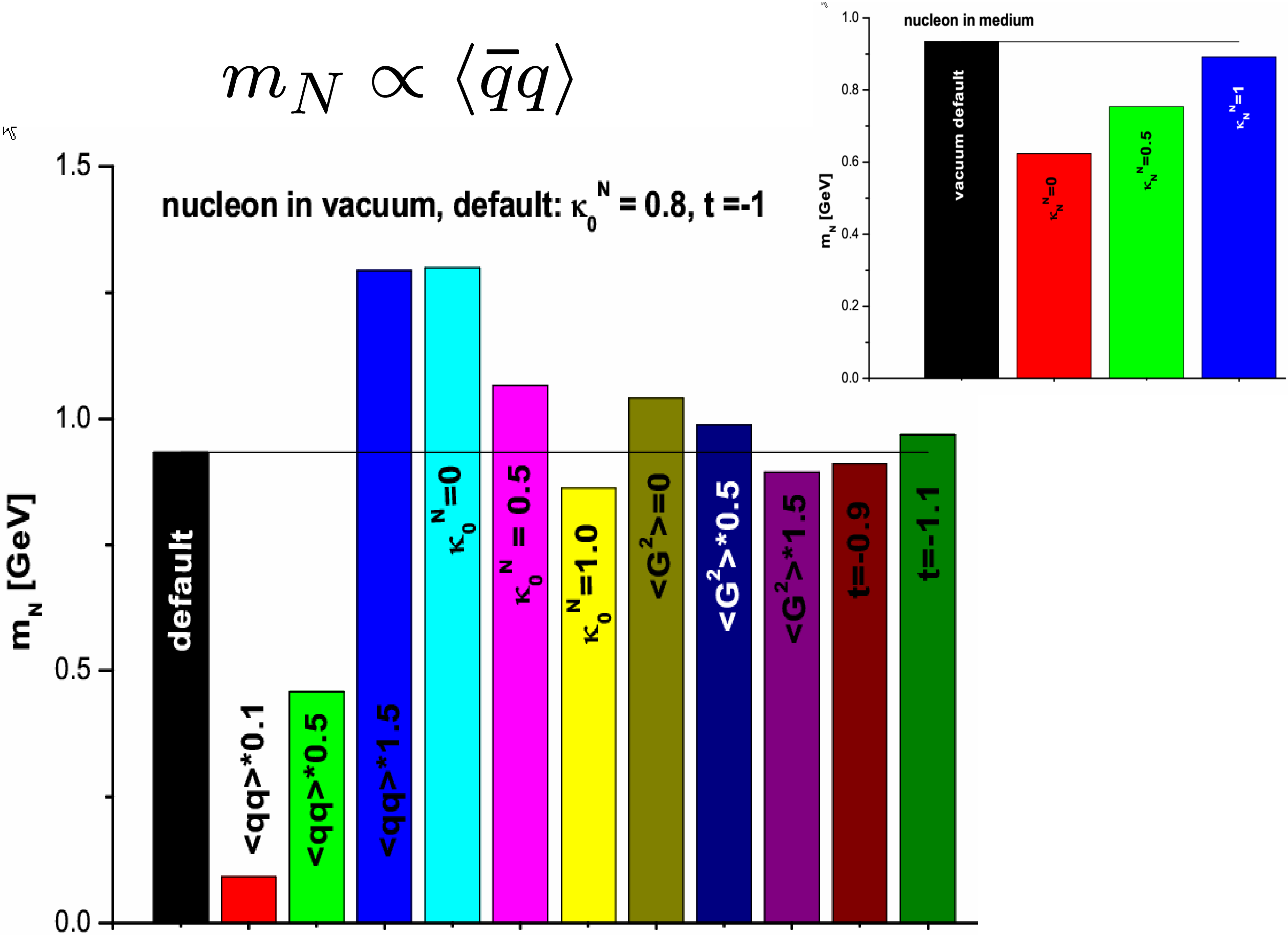
2. qqq sector: nucleon

4-q conds. for nucleon $\not\rightarrow$ 4-q conds. for V

3 indep. combinations of 4-q conds.



$$m_N \propto \langle \bar{q}q \rangle$$



3. qQ sector: D mesons

$$c_2 \propto m_Q \langle \bar q q \rangle$$

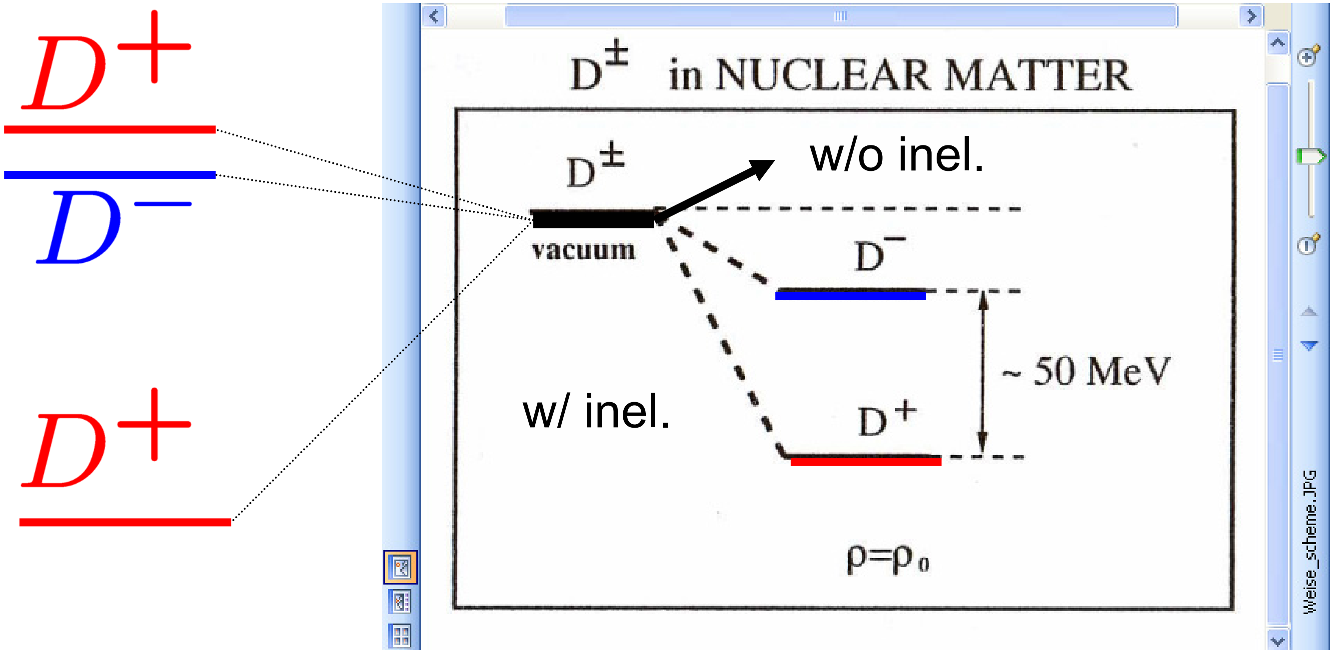
amplifier

K^+:	$u\bar s$	+ 25 MeV	K^-:	$\bar u s$	- 90 MeV
D^-:	$d\bar c$		D^+:	$\bar d c$	
$\bar D^0$	$u\bar c$		D^0:	$\bar u c$	

D in medium: Weise/Morath^{2001}, Hayashigaki^{2000}

expected pattern:

hadron scenario
Lutz, Korpa 2005:



Tolos, Schaffner-Bielich ...
Tsushima ... Sibirtsev

Problems: D^+ vs. D^-

$$\Pi(q^2, qu) \to \Pi^e(q^2) + q_0 \Pi^o(q^2)$$

$$\frac{1}{2\pi}\int_0^\infty ds e^{-s/\mathcal{M}^2} s^{e,o}(Im\Pi_{D^+}(s) \pm Im\Pi_{D^-})$$
$$+\Pi^{e,o}(0,n) = \mathcal{B}\Pi^{e,o}_{OPE}$$

History of the Factor of $\langle g_s \bar{q}\sigma G q\rangle$:

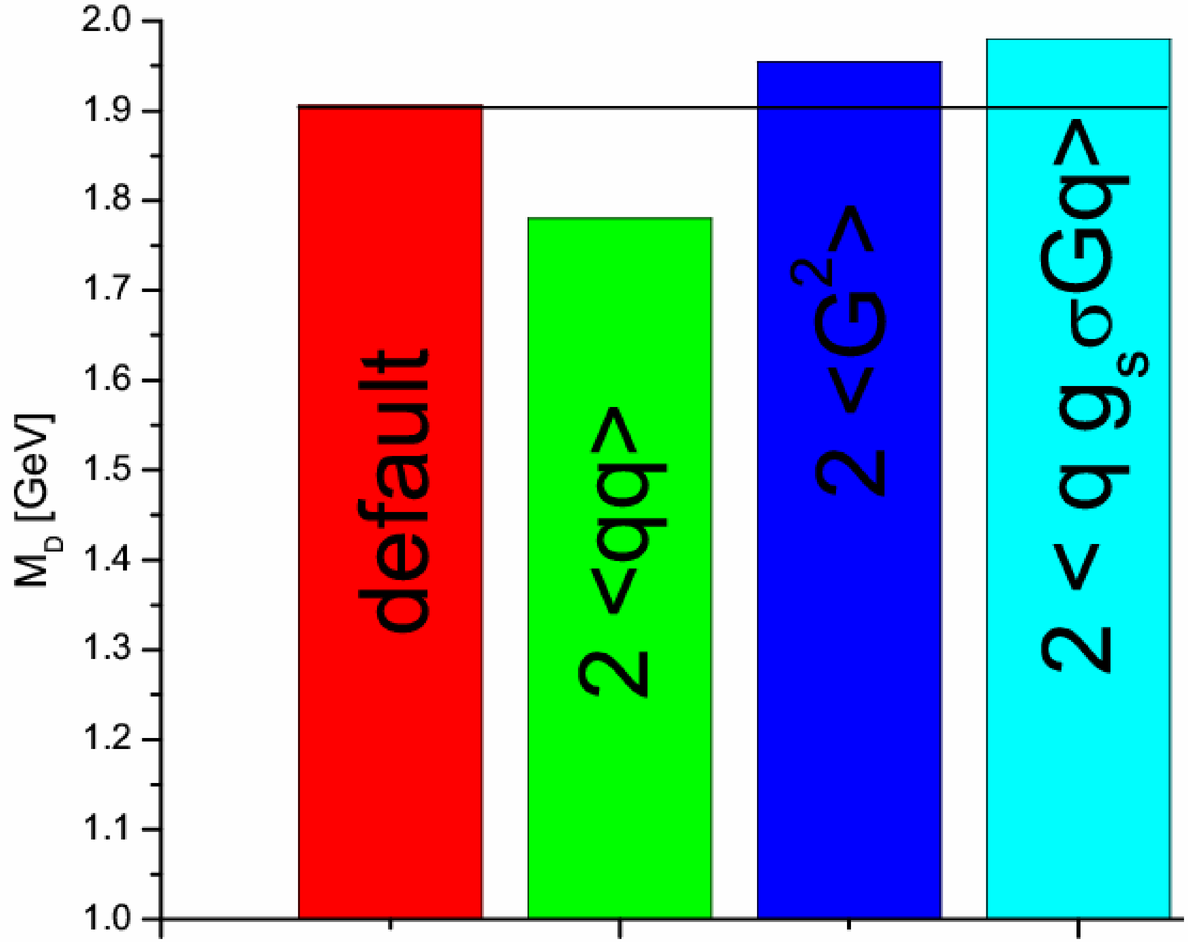
Wilson coeff. of
$\frac{\alpha_s}{\pi}\langle (uG)^2 - \frac{1}{4}G^2\rangle$

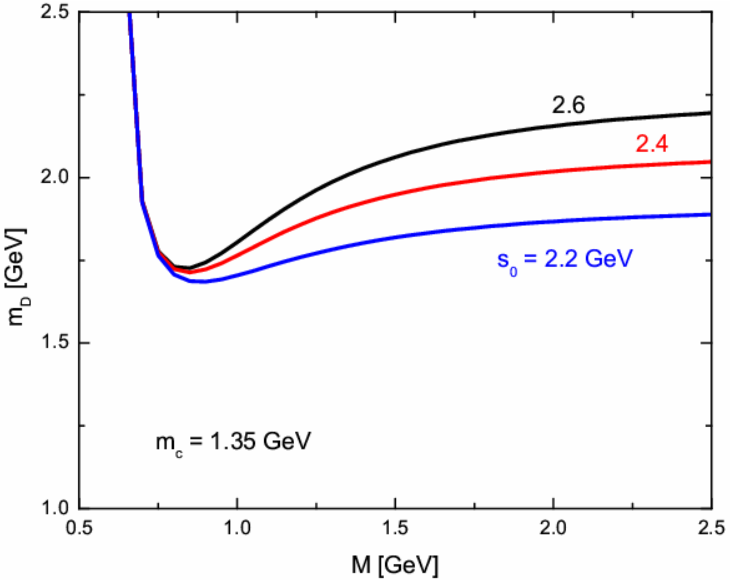
mass sing. vs. mixing

Novikov et al.	79:	+	1/4
Alier, Eletski	83:	+	1/2
Narison	88:	-	1/4
Neubert	92:	-	1/2
Jamin, Münz	93:	+	1/2
Narison	01:	-	1/2
Narison	05:	+	1/2
we	05:	+	1/2

M_D, vacuum

S_0 = 2.45 GeV





basic features (Weise,Morath 2001):

Pole + Continuum Ansatz

w/o change of continuum

$$\begin{aligned}\delta(m_{D^-} - m_{D^+}) &= F_1 \langle \bar{q}\gamma_0 q\rangle \\ &= 40 MeV \frac{n}{n_0}\end{aligned}$$

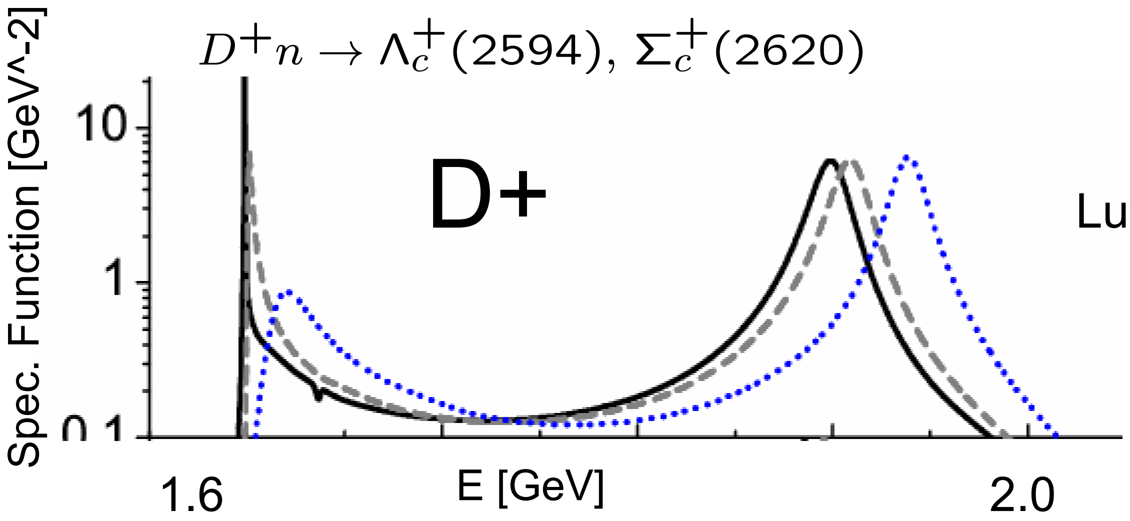
$$\begin{aligned}\delta\frac{1}{2}(m_{D^-} + m_{D^-}) &= F_2 \delta(m_c\langle \bar{q}q\rangle) \\ &= -10 MeV \frac{n}{n_0}\end{aligned}$$

	$m_{D^-} - m_{D^+}$	$D^\pm$ center
Hayashigaki	-	- 50 MeV 95% from $m_c\langle \bar{d}d\rangle$
Morath, Weise	50 MeV	dep. on inel. cont.
we		tiny ? Landau term

$$\bar{m}^2 = \frac{\int_0^{s_0} ds Im\Pi e^{-s/\mathcal{M}^2}}{\int_0^{s_0} ds Im\Pi e^{-s/\mathcal{M}^2}/s}$$

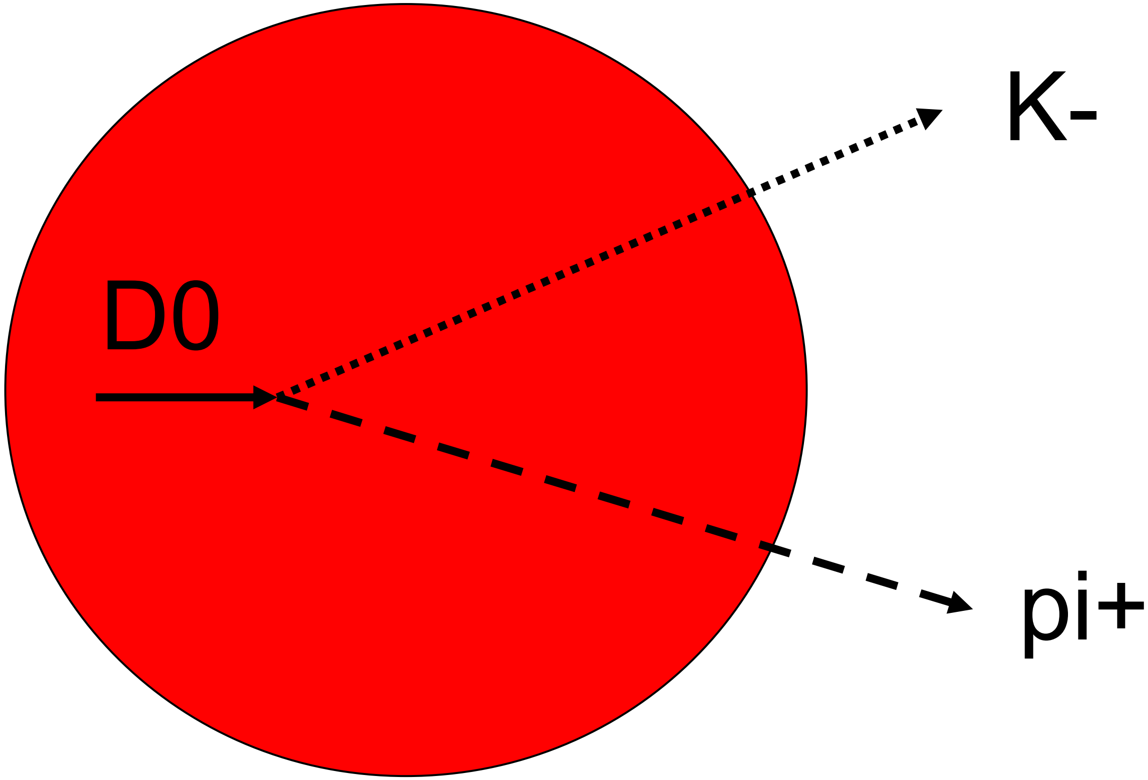
= center of gravity of $Im\Pi e^{-s/\mathcal{M}^2}/s$

pole ansatz is not appropriate:



Lutz, Korpa

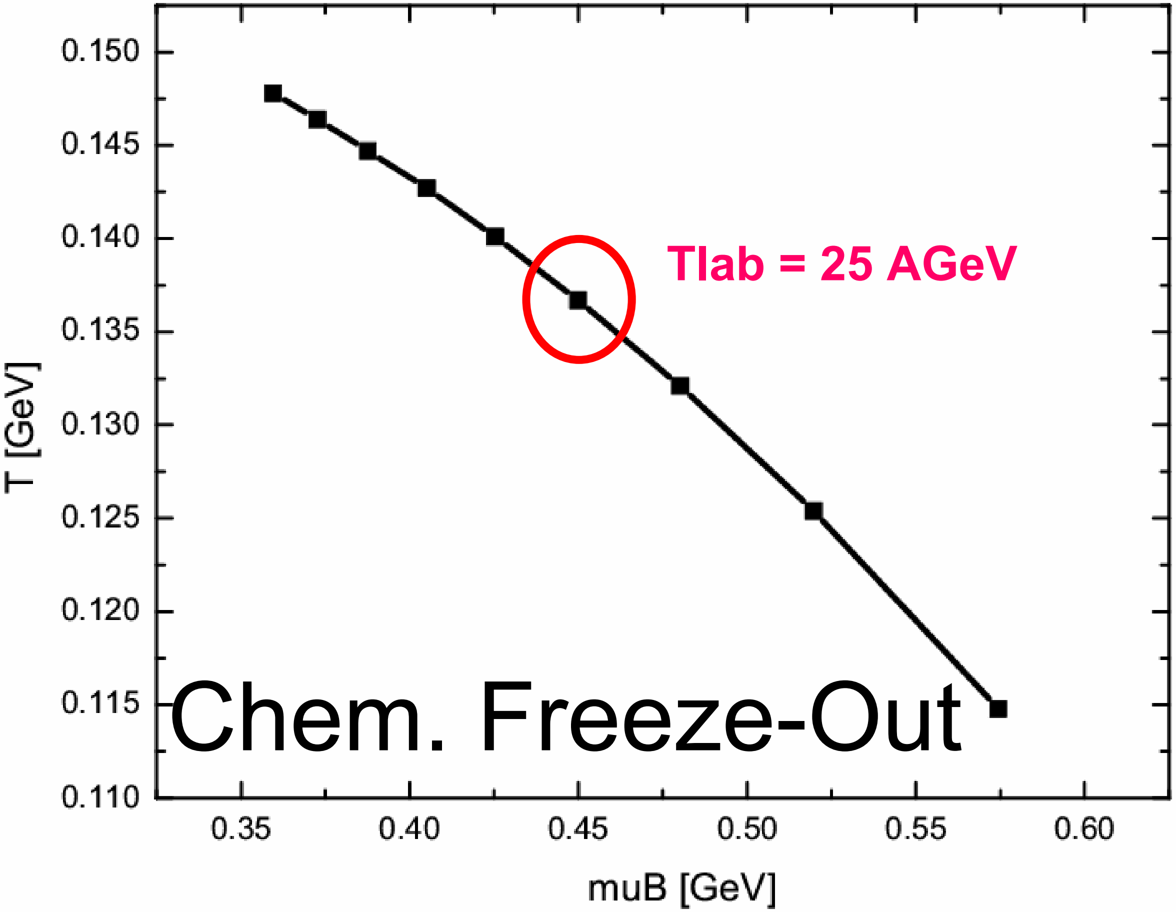
How to Measure Med.-Mod. of D Mesons?

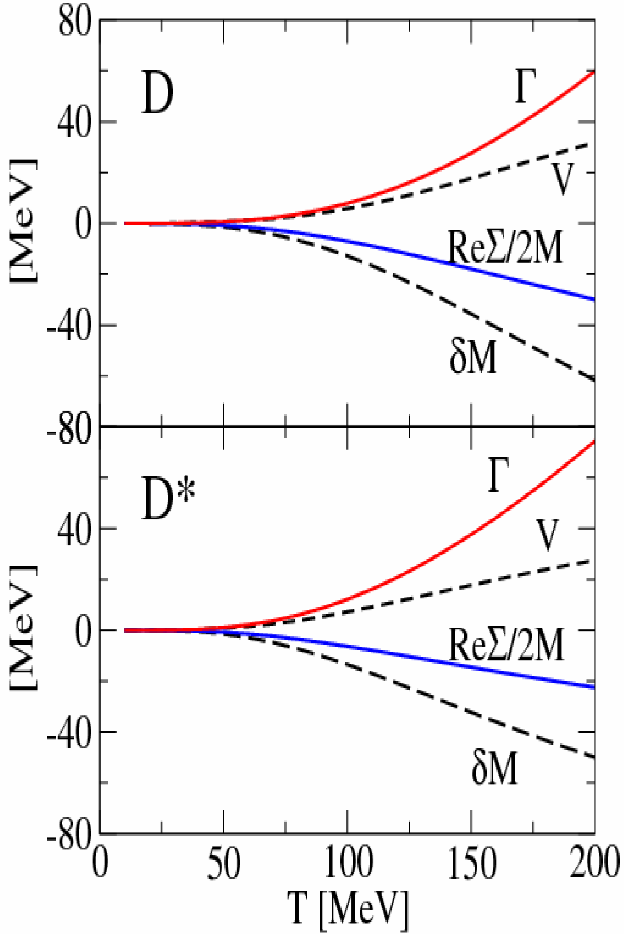


lesson from K-

$n_B - T$ Effects

Cleymans-Redlich-Wheaton param.





Fuchs et al.: T > 100 MeV → meson effects

4. QQ sector: J/ψ

Generalis/Broadhurst 84:

$$m_Q\langle\bar{Q}Q\rangle = -\frac{1}{12}\langle\frac{\alpha_s}{\pi}G^2\rangle - \frac{1}{m_Q^2}\frac{1}{1440\pi^2}\langle g_s^3 G^3\rangle + ...$$

medium resistent

Weise/Morath ... 99: tiny in-medium effects

$$\mathcal{O}(5MeV)$$

Conclusions

1. ω: CB-TAPS & Borel QSR:

   strong in-medium change of 4q cond.

   4q cond. = new order parameter?

2. N: 4q conds. vs. phenomenlogy $\Sigma_{s,v}$

3. D: sizeable effects of $m_c\langle\bar{q}q\rangle$ antenna of QCD vaccum

   QSR details need to be clarified

   quantitative predictions $=$?

Quantify change of QCD vacuum:
nB, T dependence of material constants