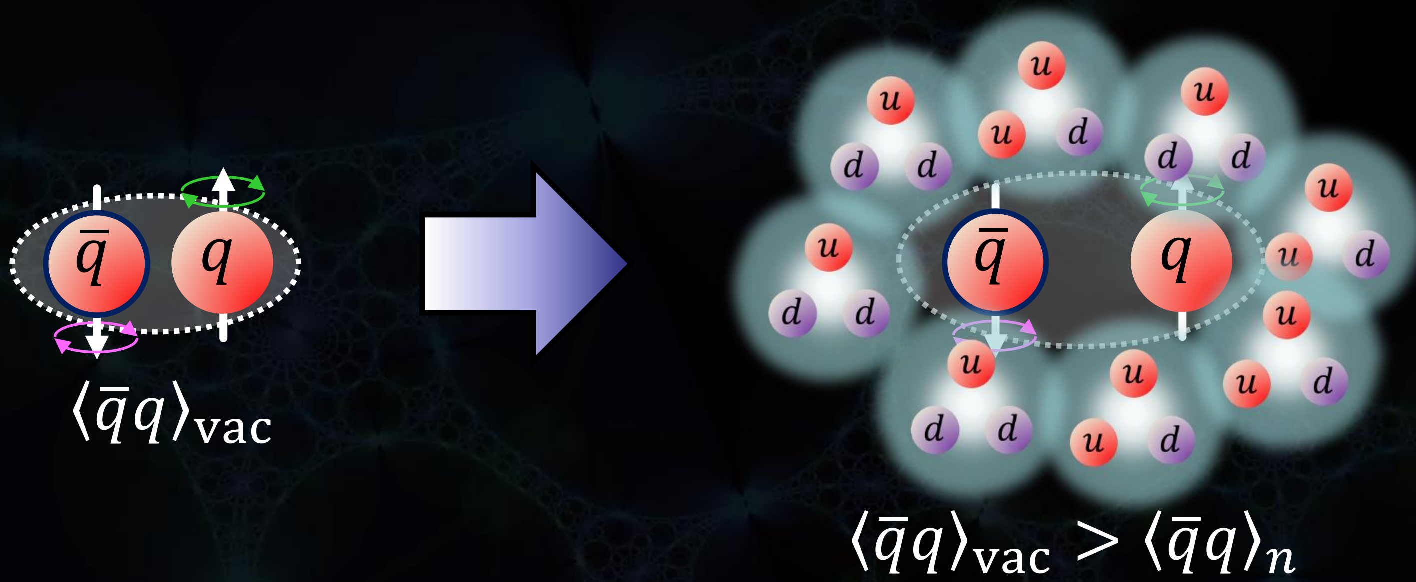
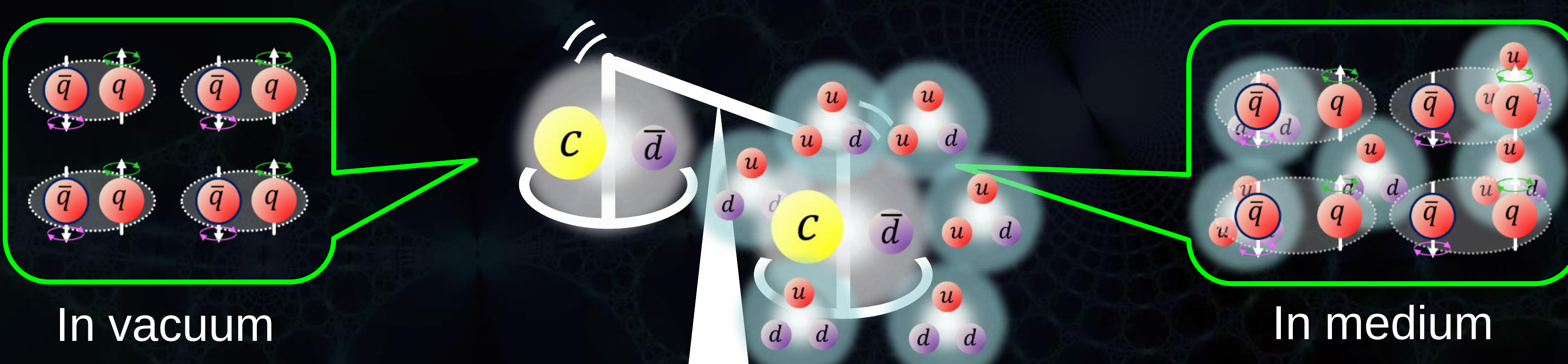


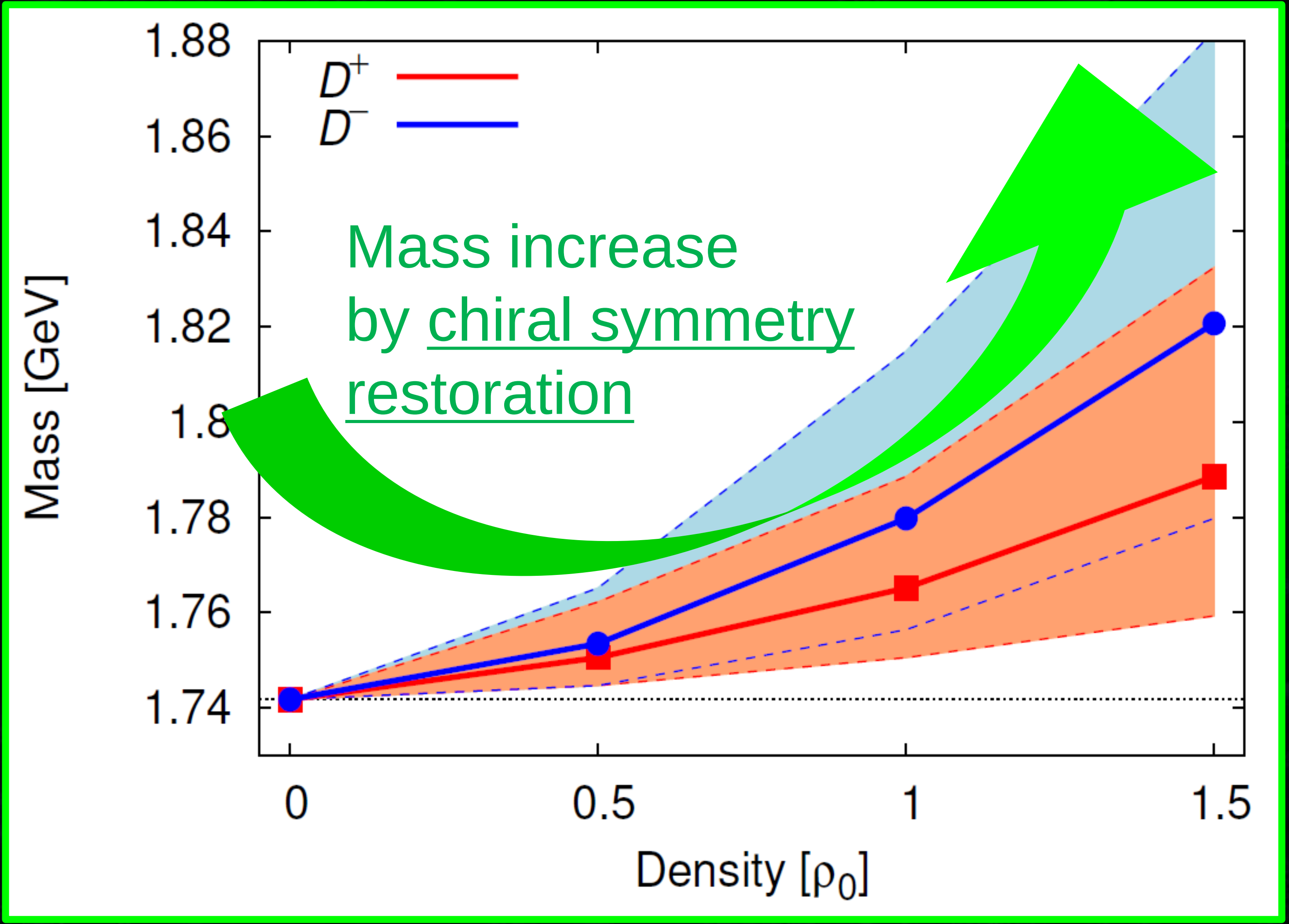
D meson and chiral symmetry breaking

Kei Suzuki (Yonsei U.)



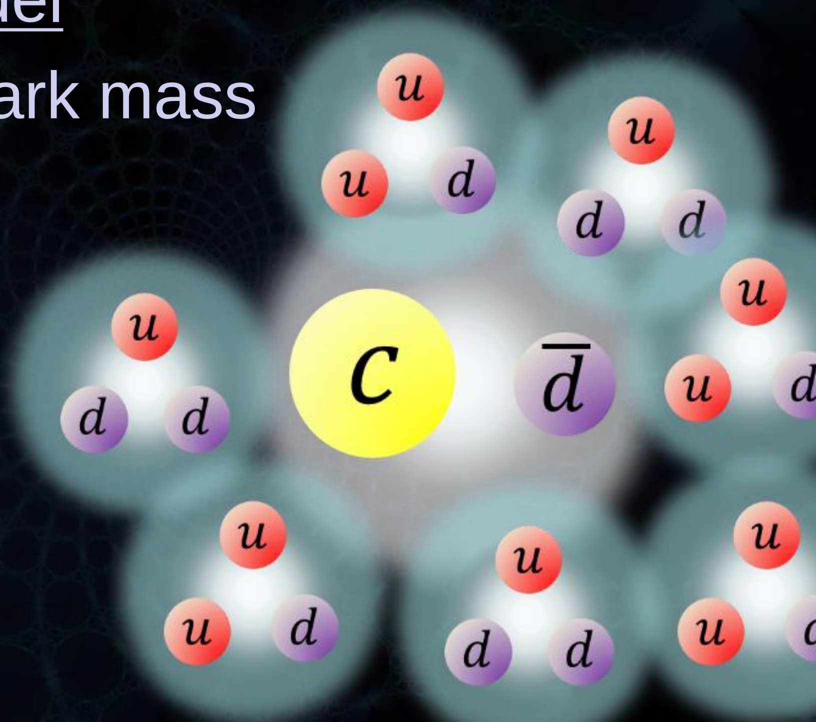
KS, P. Gubler and M. Oka, PRC93, 045209 (2016)

$D^{\pm}$ meson mass in nuclear matter from QCD sum rules



Outline

1. Why does D meson mass increase by χSR <u>in QCD sum rules</u> ?
    - $\langle \bar{q}q \rangle$ term is predominant in D meson OPE
    - Opposite sign in OPE for chiral partners
2. D meson mass in <u>Potential model</u>
    - χSR = smaller constituent quark mass
    - Application
3. Summary



1. Why does D meson mass increase in QCD sum rules?

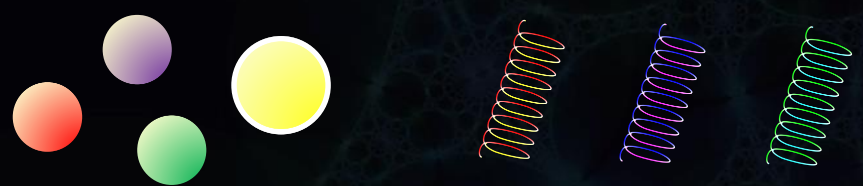
M.A. Shifman, A.I. Vainshtein, and V.I. Zakharov, Nucl. Phys. B**147**, 385 (1979); B**147**, 448 (1979)

QCD sum rule

Relation between operator product expansion (OPE) of QCD correlation function and hadron spectral function

$$\Pi_{\mathrm{OPE}}(M^2) = \int_0^\infty K(s, M^2)\, \rho(s)\, ds$$

Quark and Gluon dynamics

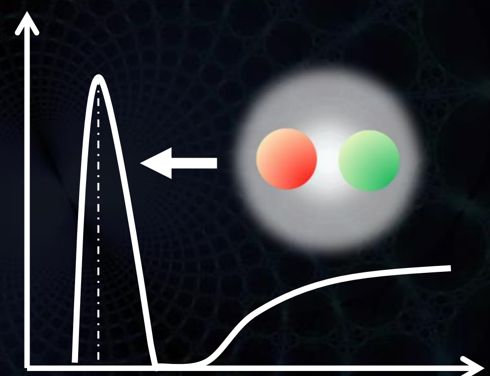


QCD vacuum condensates

$\langle \bar{q} q \rangle$ $\langle G_{\mu\nu} G^{\mu\nu} \rangle$

etc…

Hadron properties (mass, width…)



M.A. Shifman, A.I. Vainshtein, and V.I. Zakharov, Nucl. Phys. B**147**, 385 (1979); B**147**, 448 (1979)

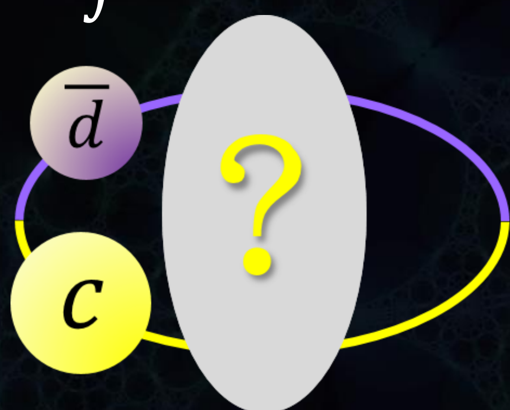
QCD sum rule

Relation between operator product expansion (OPE) of QCD correlation function and hadron spectral function

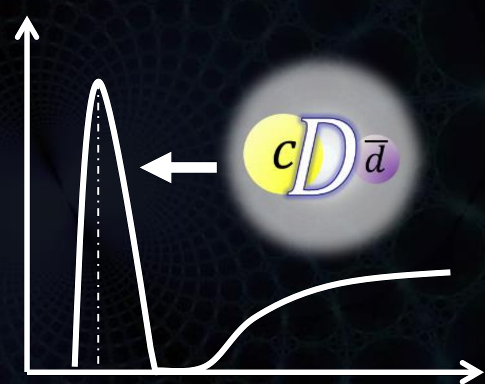
$$\Pi_{\mathrm{OPE}}(M^2) = \int_0^\infty K(s, M^2)\, \rho(s)\, ds$$

Current-current correlator

$$\Pi(q) = i \int d^4x\, e^{iq\cdot x} T[j^\dagger(x) j(0)]$$

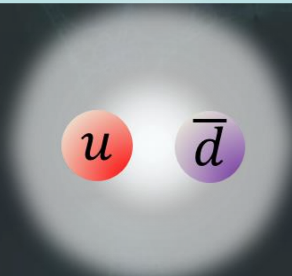
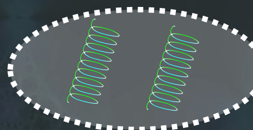
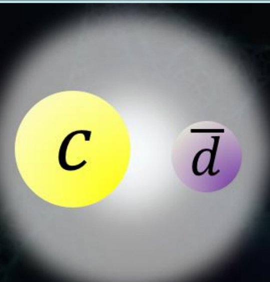
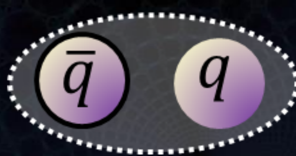
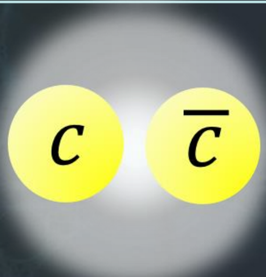
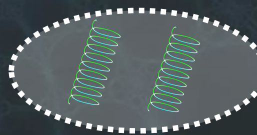


Hadron properties (mass, width…)



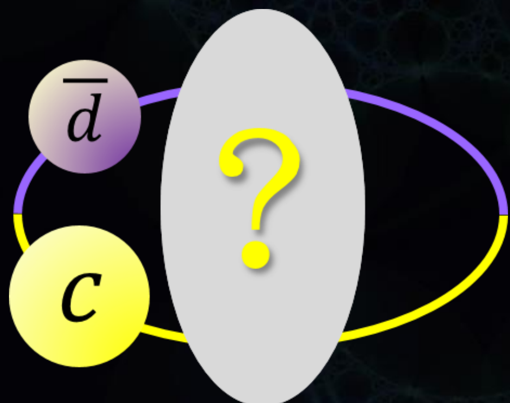
$\bar{d}$
c
?
=
Free term (LO)
+
α_s correction (NLO)
+
$\langle \bar{q}q \rangle$
Chiral condensate
+
$\langle \bar{q}gG\sigma q \rangle$
Mixed condensate
$\langle \frac{\alpha_s}{\pi} G^{\mu\nu} G_{\mu\nu} \rangle$
+
Gluon condensate
+…

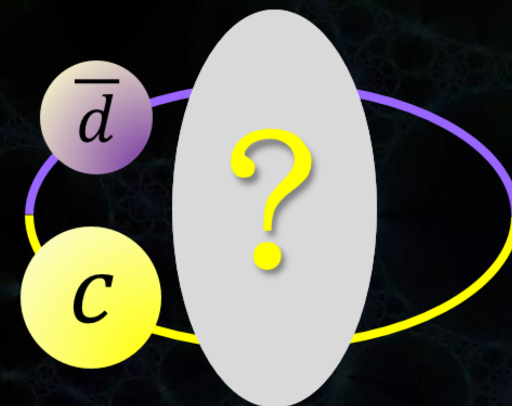
Different meson systems probe different condensates!

Meson	Dominant contributions in vacuum
Light-Light (ρ, ω meson) 	・Probe of 4-quark and gluon condensates (2-quark condensate is suppressed as $m_q\langle\bar{q}q\rangle$) $\langle\bar{q}q\bar{q}q\rangle$  
Heavy-Light (D, B meson) 	・Probe of 2-quark condensate as $m_c\langle\bar{q}q\rangle$  $\langle\bar{q}q\rangle$
Heavy-Heavy ($J/\psi, \Upsilon$) 	・Almost perturbative object (Probe of gluon condensate)  $\left\langle\frac{\alpha_s}{\pi}G^{\mu\nu}G_{\mu\nu}\right\rangle$

Chiral partners from OPE

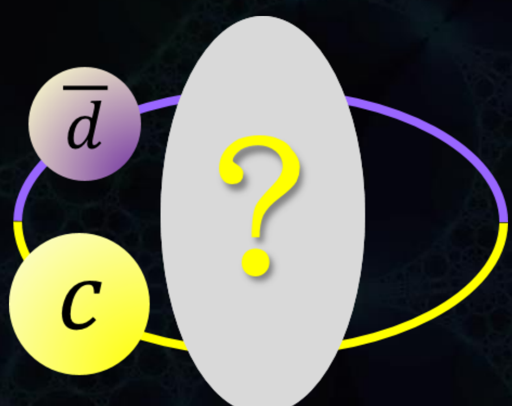
- Chiral symmetric terms ⇒ Pseudoscalar = Scalar

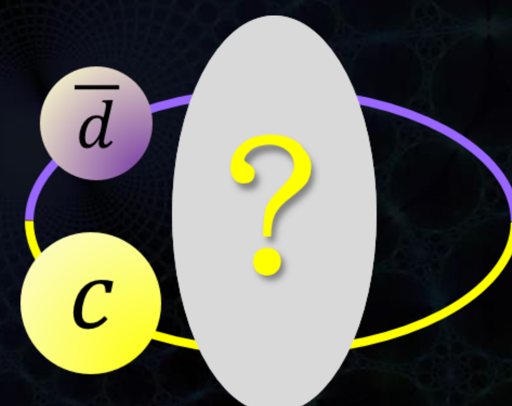
$ic\gamma_5\bar{d}$ 

$i\bar{c}\gamma_5 d$ $=$ $c\bar{d}$ 

$\bar{c}d$

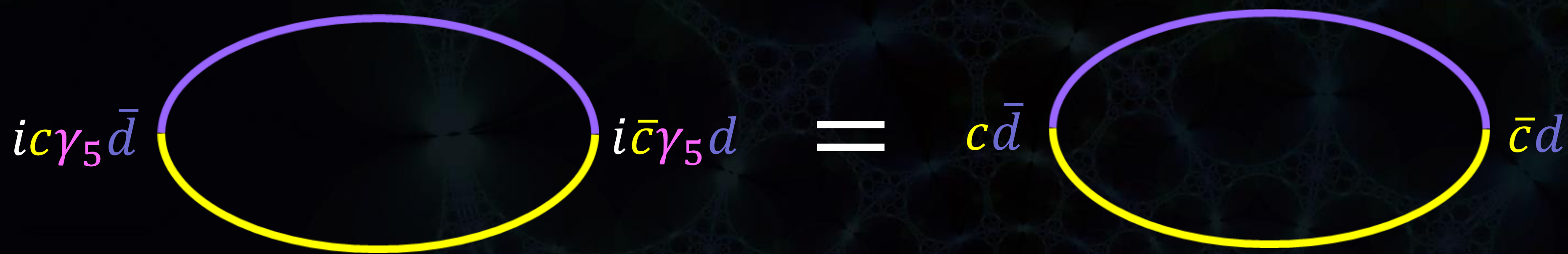
- Chiral breaking terms ⇒ Pseudoscalar ≠ Scalar

$ic\gamma_5\bar{d}$ 

$i\bar{c}\gamma_5 d$ $\neq$ $c\bar{d}$ 

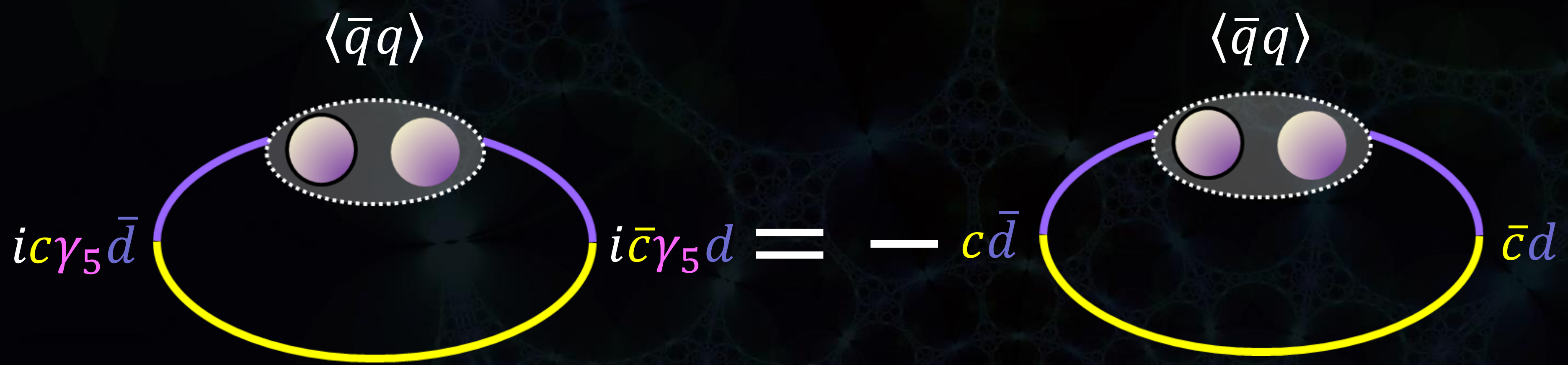
$\bar{c}d$

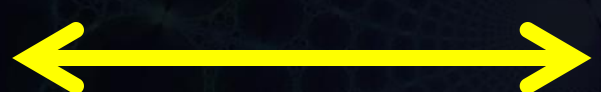
Ex. Chiral symmetric term



Same contribution
for chiral partners

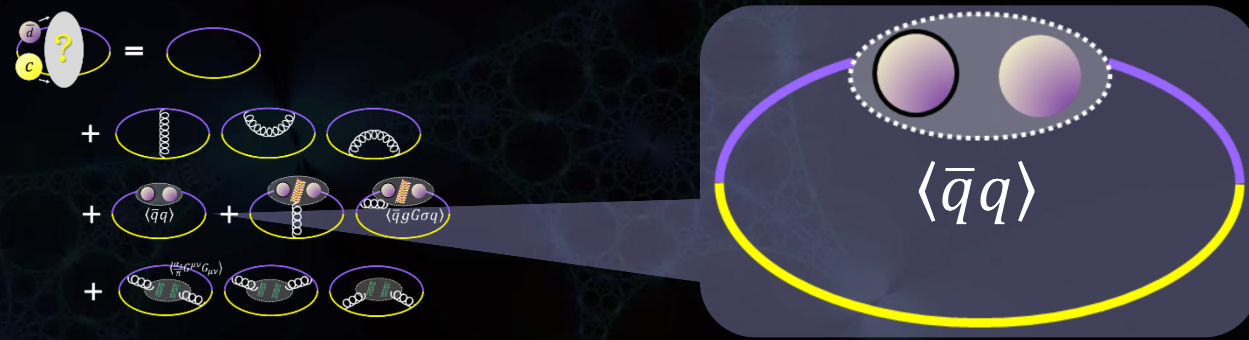
Ex. Chiral breaking term





Opposite contribution
for chiral partners

Points

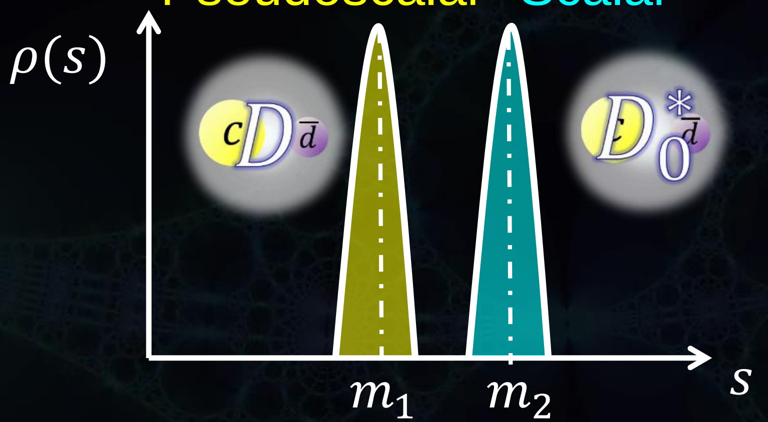


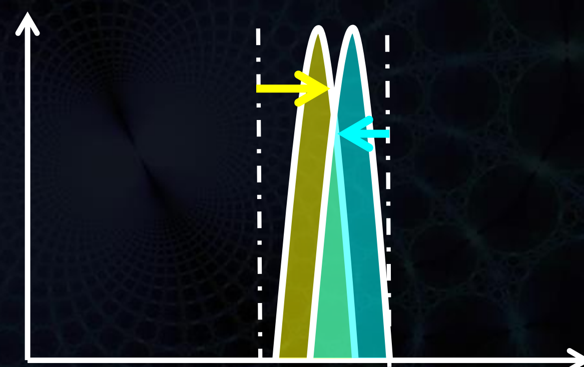
- In Heavy-Light meson OPE, $m_c\langle\bar{q}q\rangle$ diagram is predominant

(For Light-Light meson, this term is suppressed by $m_q\langle\bar{q}q\rangle$)

- This diagram has opposite sign to the chiral partner
⇒Mass shift in matter has also opposite sign

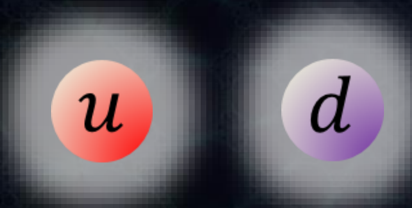
Pseudoscalar Scalar





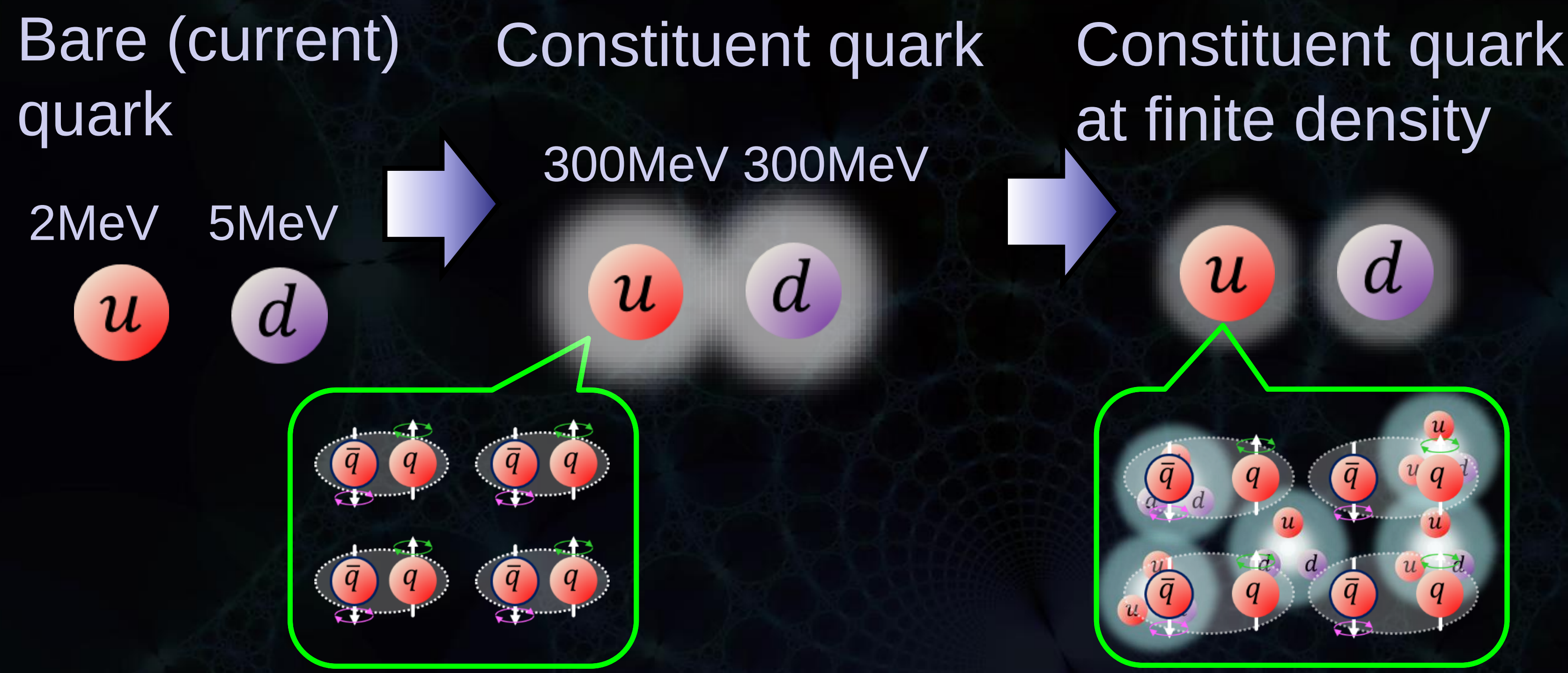
⇒D meson mass <u>increase</u> by χSR

2. D meson mass in potential model



Constituent quarks

Chiral condensate in Constituent quark model



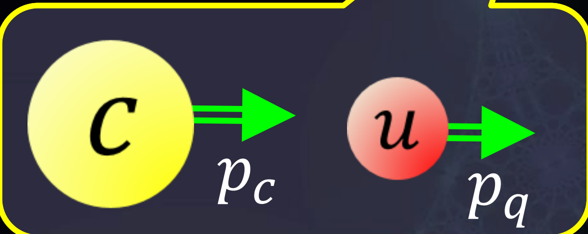
- Contributions of chiral condensate should be included in the (light) constituent quark mass
- χSR ⇒ smaller constituent quark mass?

Park, Gubler, Harada, Lee, Nonaka and Park, PRD93 054035 (2016)

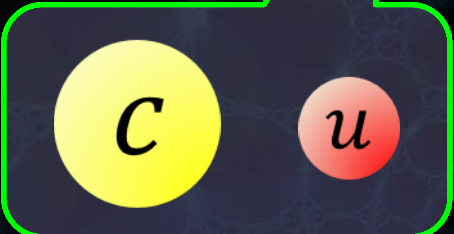
m_q dependence of quark model for heavy-light meson

$$H = \frac{p_c^2}{2m_c} + \frac{p_q^2}{2m_q} + m_c + m_q + V(r)$$

Kinetic term

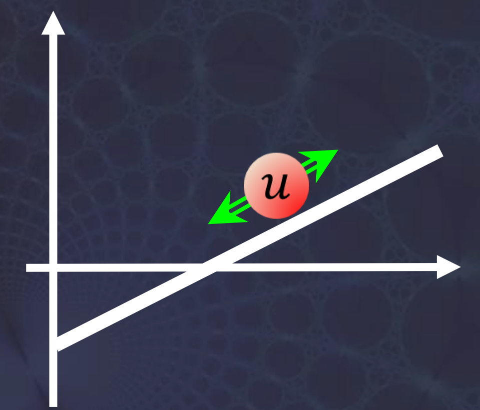


Rest mass



Potential term

$$V(r) = \sigma r + C$$



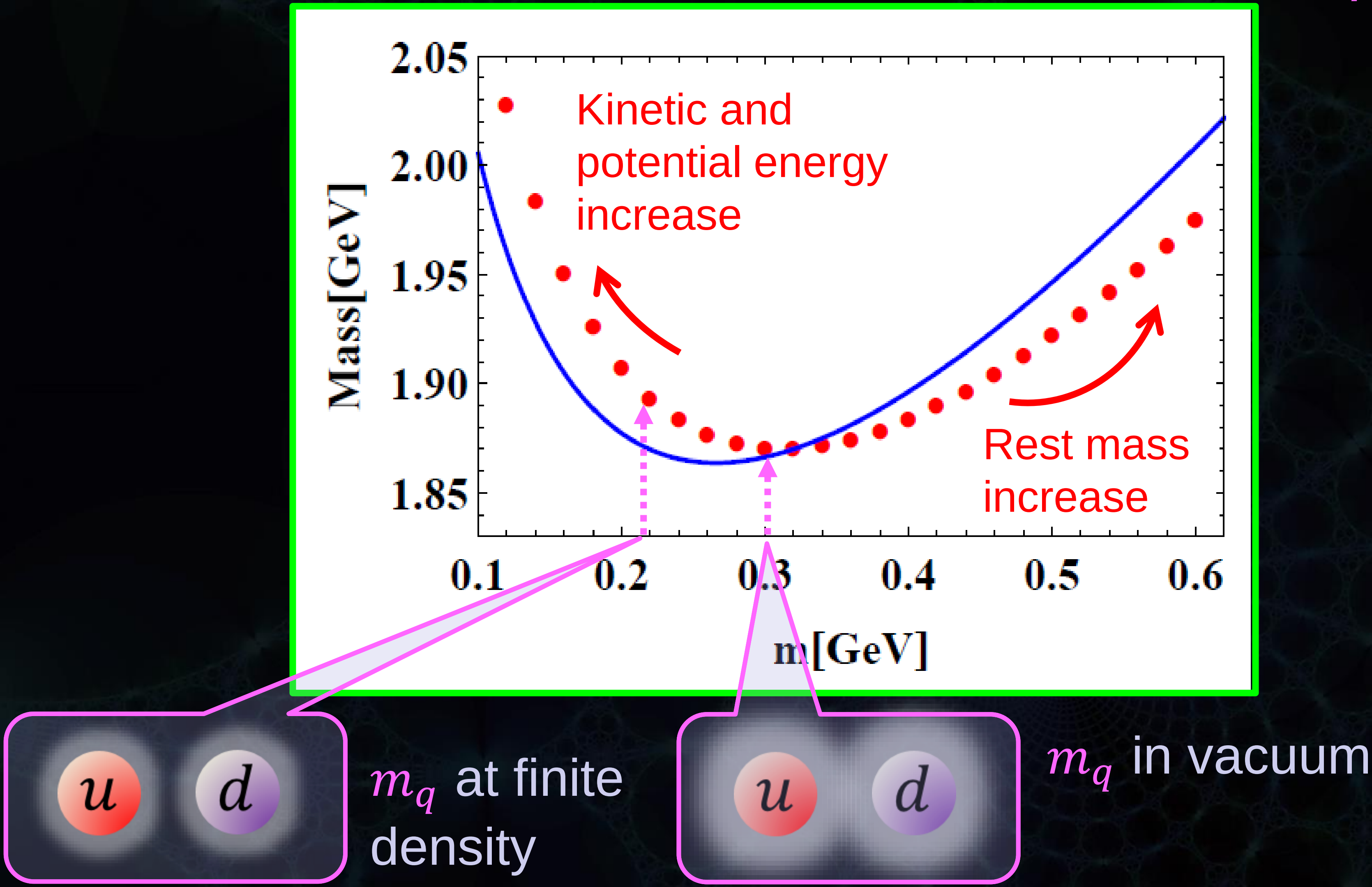
$$E = \frac{p_c^2}{2m_c} + m_c + m_q + \left(\frac{\sigma^2}{m_q}\right)^{1/3} + C$$

⇒D meson mass shift = a balance between rest mass $\sim m_q$ and kinetic and potential energies $\sim 1/m_q$

Park, Gubler, Harada, Lee, Nonaka and Park, PRD93 054035 (2016)

D meson mass shifts = rest mass + kinetic and potential energies

$$E = \frac{p_c^2}{2m_c} + m_c + m_q + \left(\frac{\sigma^2}{m_q}\right)^{1/3} + C$$



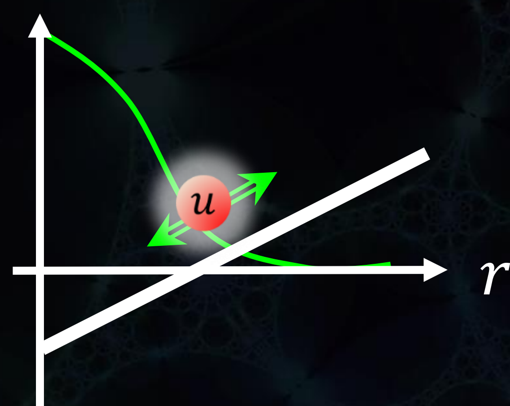
Points

In vacuum

In nuclear medium

$$V(r) = \sigma r + C$$

+



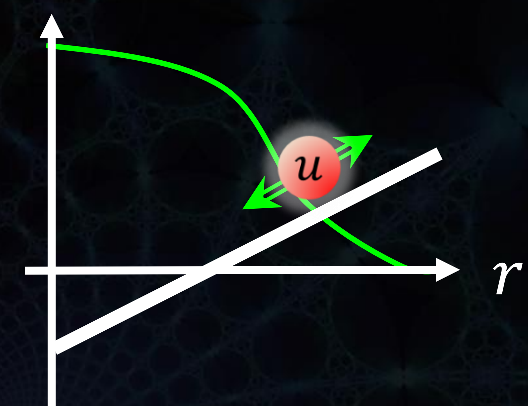
m_q~300MeV

Light quark WF overlaps with confinement potential

$$m_D = m_q + 1/m_q + \cdots$$

$$V(r) = \sigma r + C$$

+



m_q decrease↘

WF expands

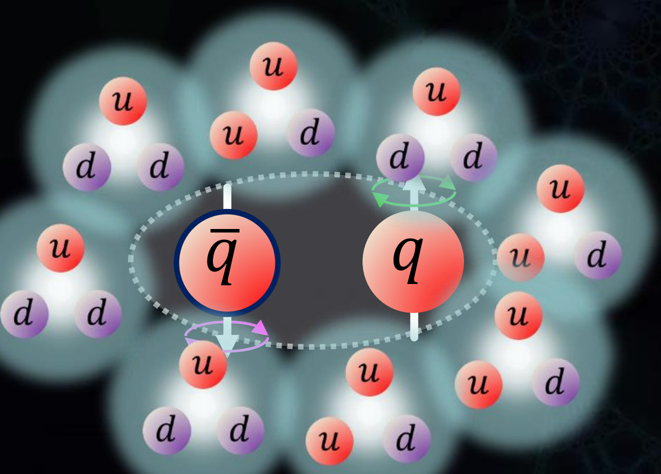
⇒potential energy increase↗

$$m_D = m_q \downarrow + 1/m_q \uparrow + \cdots$$

⇒D meson mass <u>increases</u> by χSR

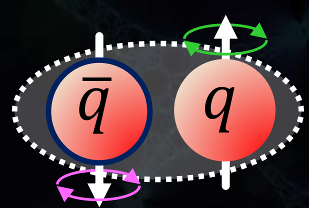
Application:
Magnetic field enhances $\langle \bar{q}q \rangle$ condensate

Nuclear matter reduces $\langle \bar{q}q \rangle$



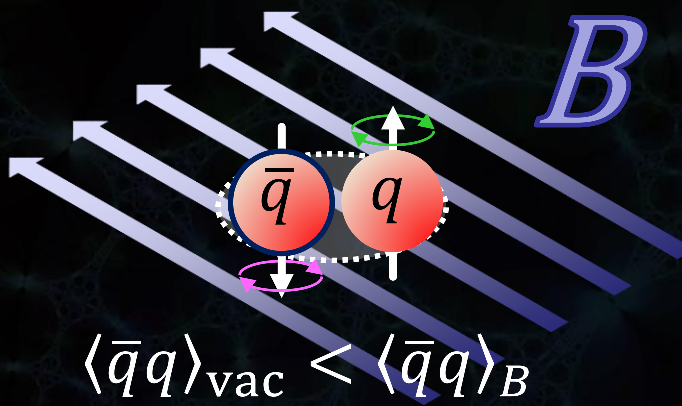
$\langle \bar{q}q \rangle_n < \langle \bar{q}q \rangle_{\mathrm{vac}}$

In vacuum



$\langle \bar{q}q \rangle_{\mathrm{vac}}$

Magnetic field enhances $\langle \bar{q}q \rangle$
(Magnetic catalysis)



$\langle \bar{q}q \rangle_{\mathrm{vac}} < \langle \bar{q}q \rangle_B$

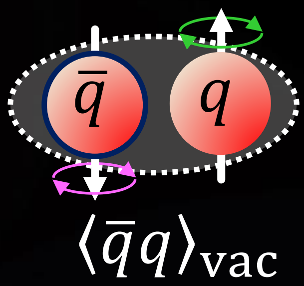
$\langle \bar{q}q \rangle$

We can tune $\langle \bar{q}q \rangle$ by external environments!

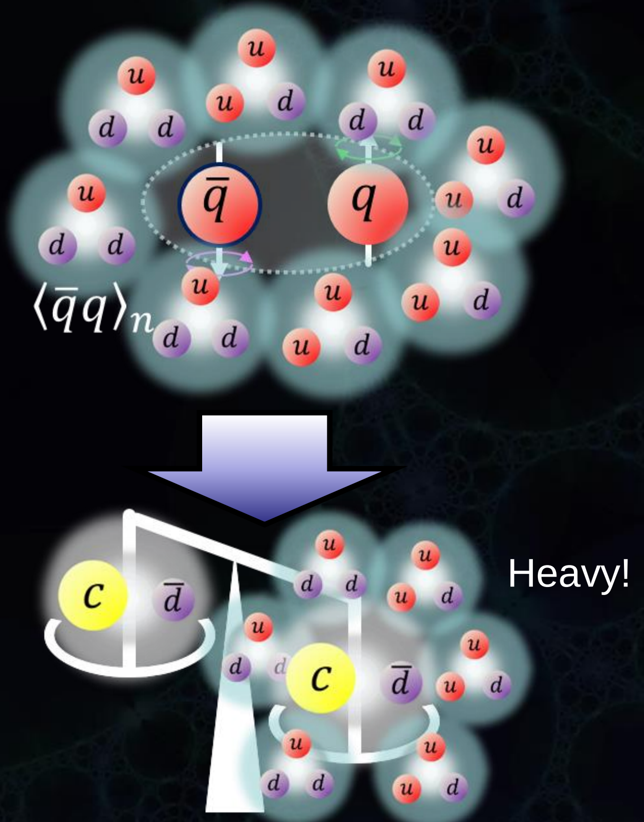
- Realistic in nuclei, neutron star, and low energy HIC at J-PARC and FAIR
- Sign problem in Lattice QCD

- Realistic (?) in relativistic HIC at RHIC and LHC
- NO sign problem in Lattice QCD

D meson mass shifts can be a probe of $\langle \bar{q}q \rangle$ tuning ?

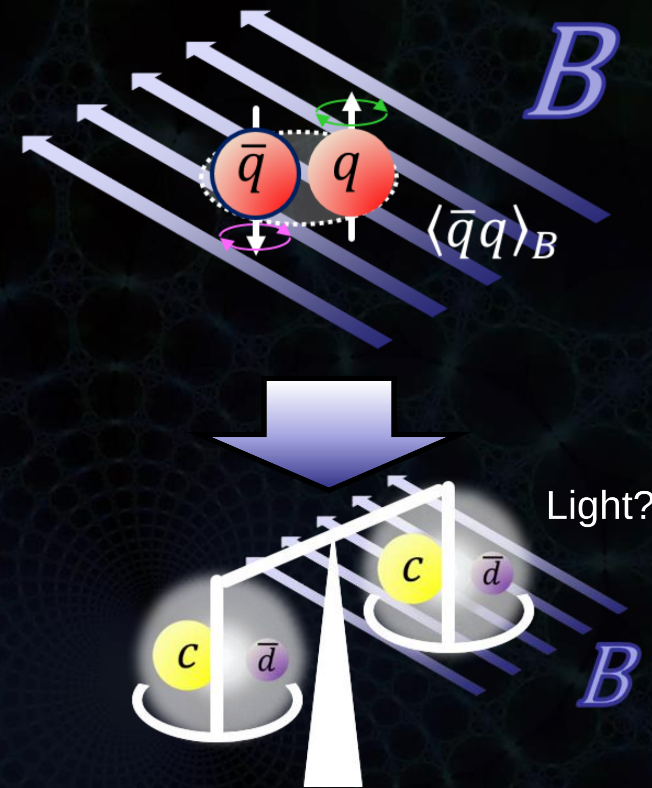


Nuclear matter reduces $\langle \bar{q}q \rangle$



QCD sum rule : KS-Gubler-Oka, PRC93, 045209 (2016)
Quark model : Park-Gubler-Harada-Lee-Nonaka-Park, PRD93 054035 (2016)

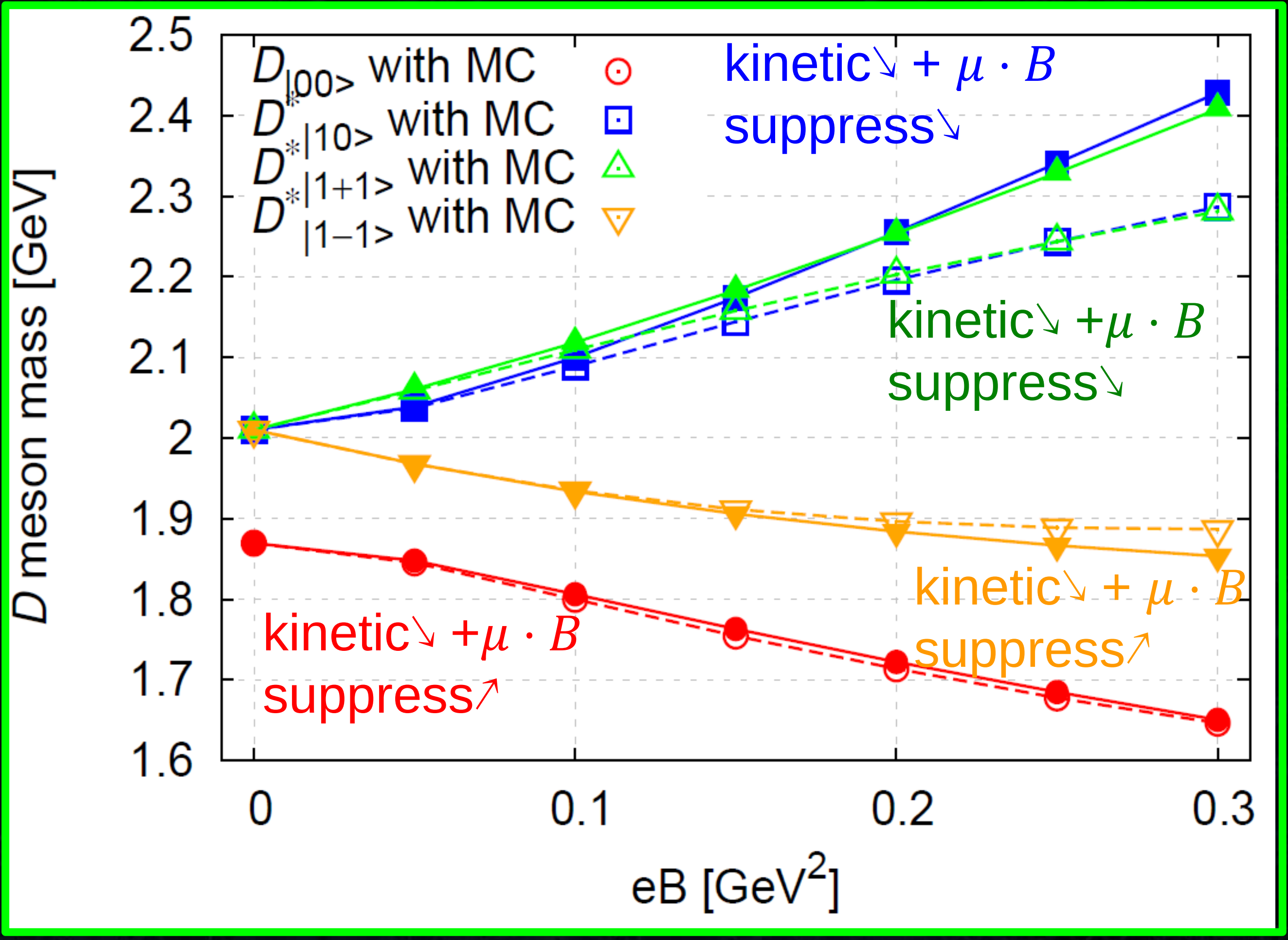
Magnetic field enhances $\langle \bar{q}q \rangle$



QCD sum rule : Gubler-Hattori-Lee-Oka-Ozaki-KS, PRD93, 054026 (2016)
Quark model : Yoshida-KS, arXiv:1607.04935

T. Yoshida and KS, arXiv:1607.04935

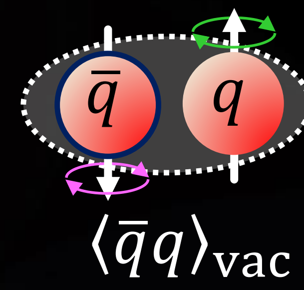
D meson mass in magnetic field can probe $\langle \bar{q}q \rangle$ enhancement? (from quark model)



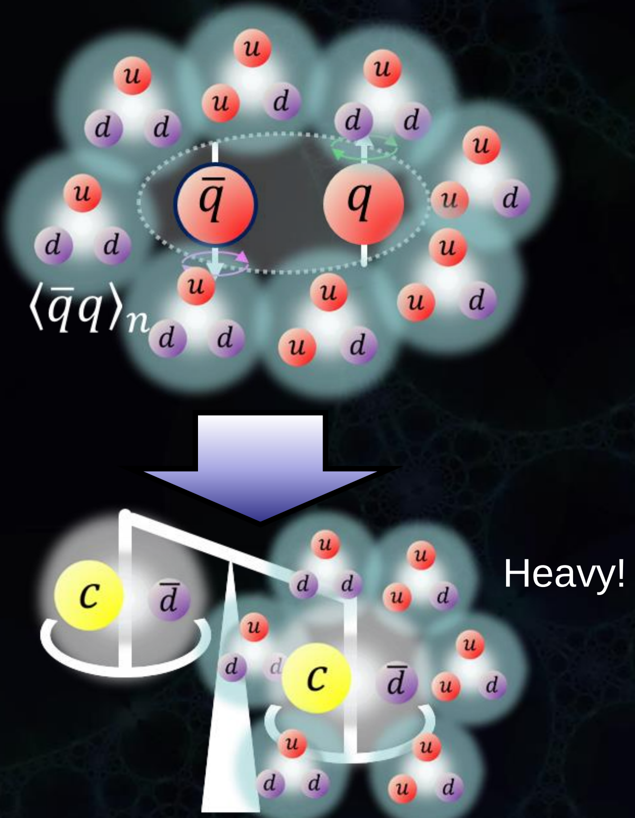
⇒ D meson : mass shift cancelation by χSB

⇒ D* mesons : mass <u>decrease</u> by χSB

D meson mass shifts can be a probe of $\langle \bar{q}q \rangle$ tuning !

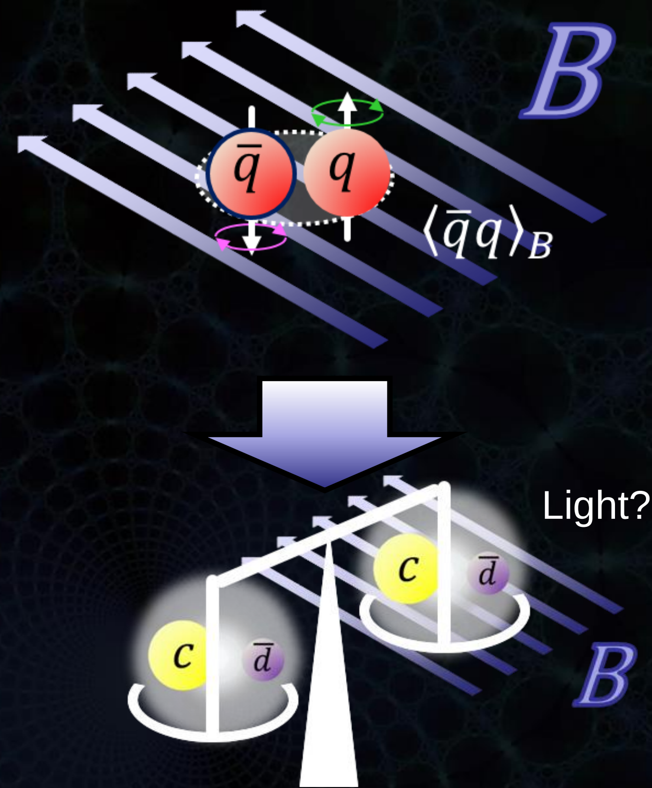


Nuclear matter reduces $\langle \bar{q}q \rangle$



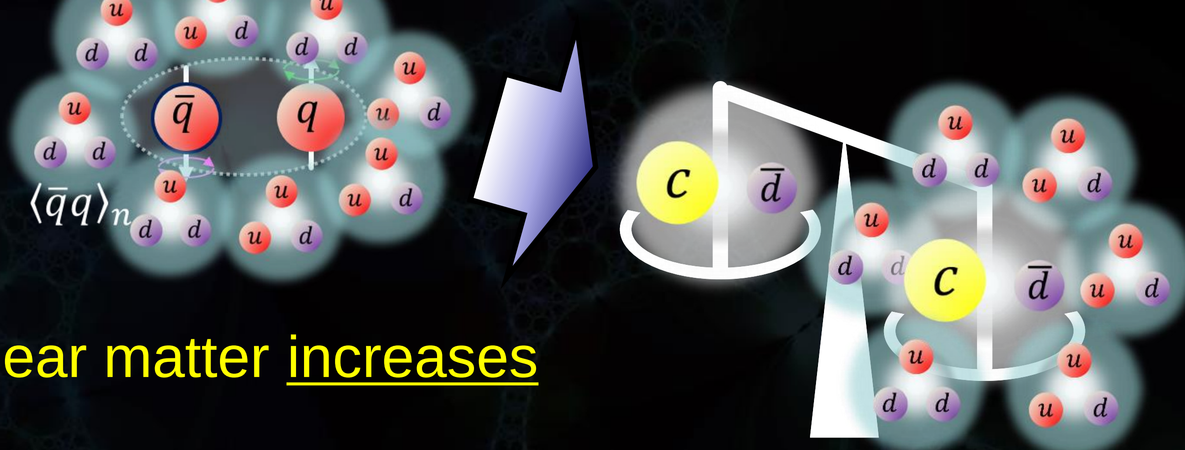
QCD sum rule : KS-Gubler-Oka, PRC93, 045209 (2016)
Quark model : Park-Gubler-Harada-Lee-Nonaka-Park, PRD93, 054035 (2016)

Magnetic field enhances $\langle \bar{q}q \rangle$

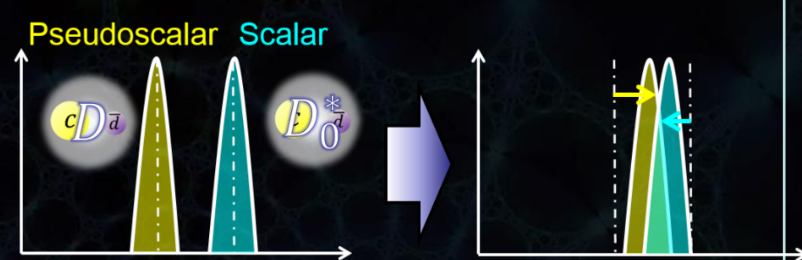
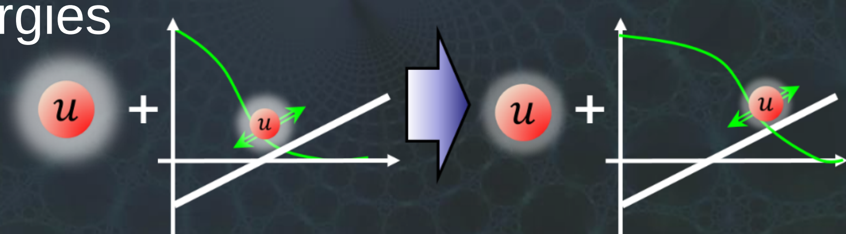


QCD sum rule : Gubler-Hattori-Lee-Oka-Ozaki-KS, PRD93, 054026 (2016)
Quark model : Yoshida-KS, arXiv:1607.04935

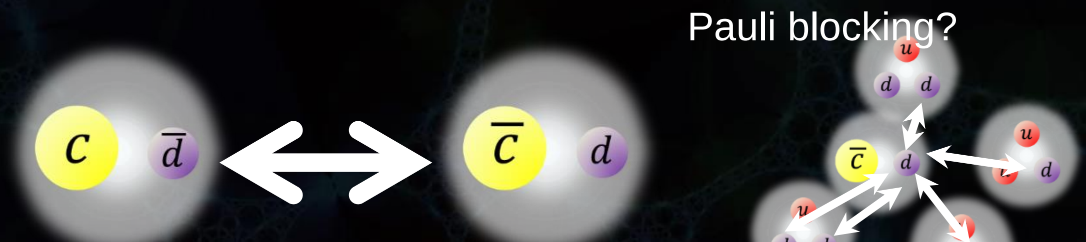
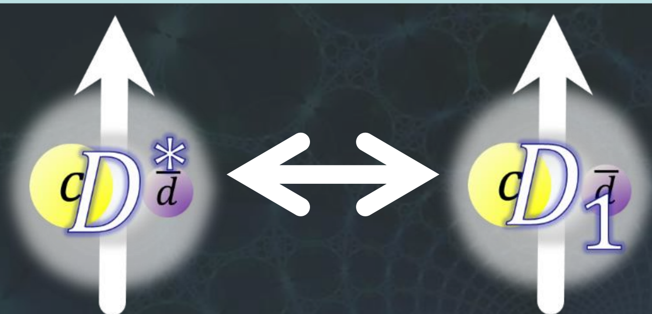
Summary



D meson mass in nuclear matter <u>increases</u>
by χSR !

QCD sum rules	▪D meson mass shift = density dependence of $m_c\langle\bar{q}q\rangle$ diagram ▪Opposite sign to the chiral partner 
Quark model	▪χSR = smaller constituent quark mass ▪D meson mass shift = rest mass + kinetic and potential energies 

Skipped topics in this talk are also interesting!

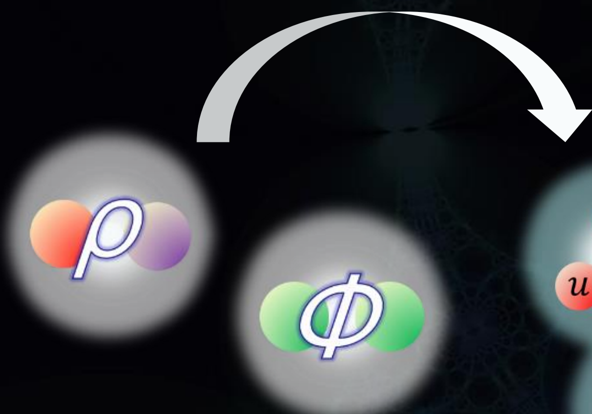
$D^+ - D^-$ splitting (Charge symmetry breaking)	 KS-Gubler-Oka, PRC93, 045209 (2016)
$D^* - D_1$ in matter (Vector-Axialvector Chiral partners)	
$K - D - B$ in matter (Other heavy-light mesons)	

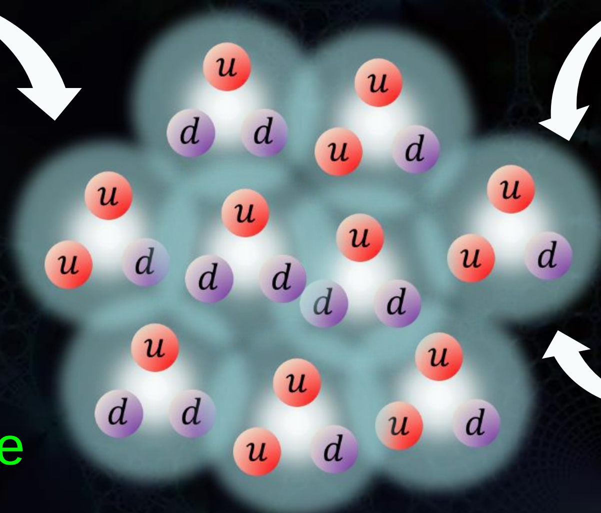
Backup

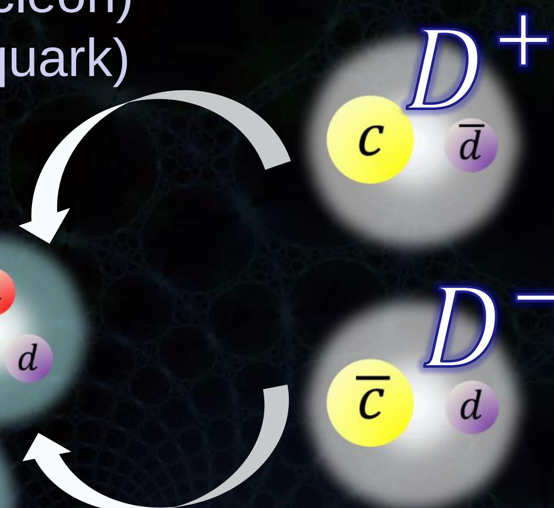
Charge Symmetry Breaking = imbalance b/w particle and anti-particle

Nuclear matter has only nucleons (NOT anti-nucleon) and quarks (NOT anti-quark)

D meson has only one light anti-quark







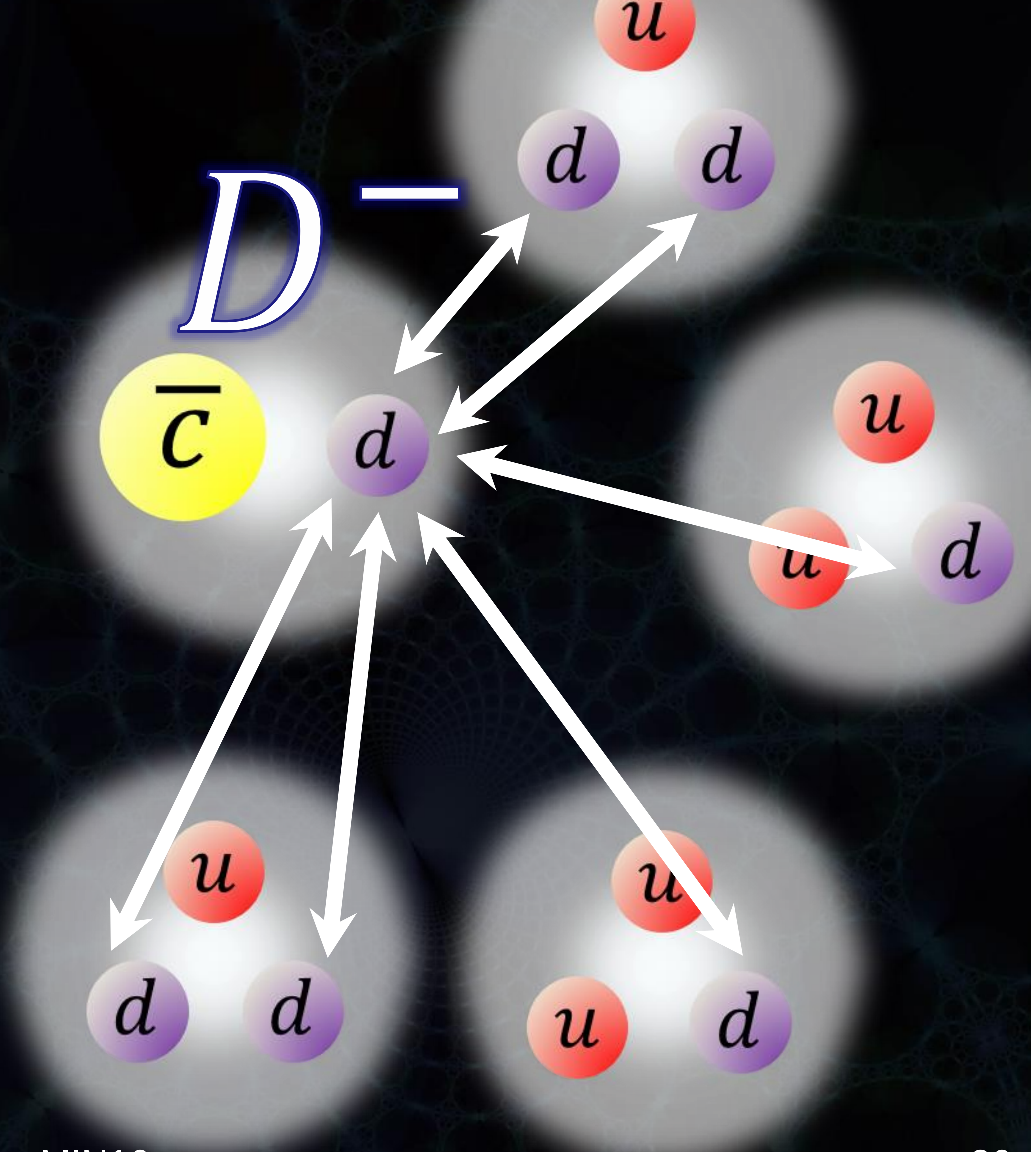
ρ and φ mesons have one quark and one anti-quark

$\bar{D}$ meson has only one light quark

⇒ρ and φ mesons in NM : NOT probe of charge symmetry breaking

⇒Heavy-light meson in NM: a probe of charge symmetry breaking

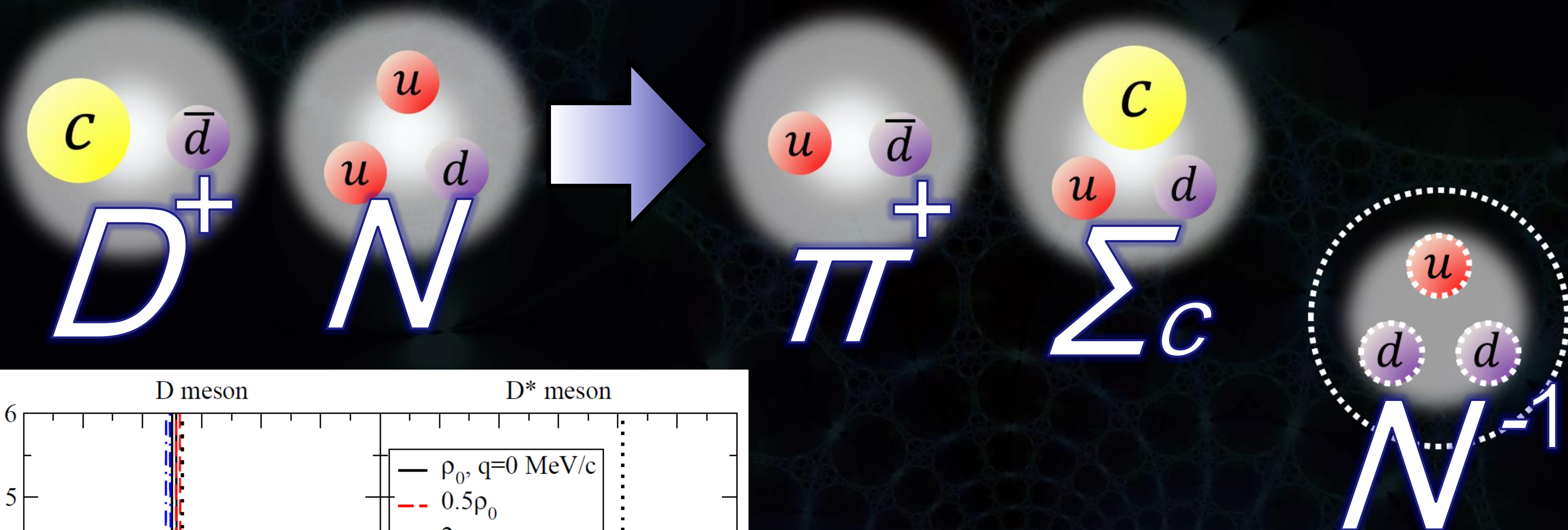
Ex. Quark Pauli blocking

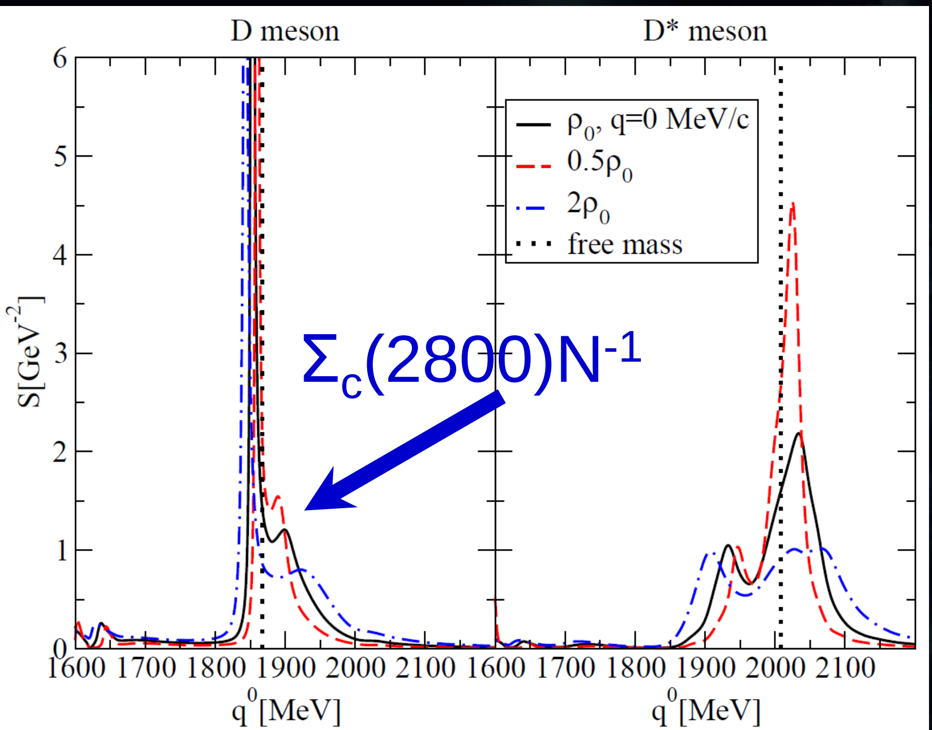


Only D⁻ feels <u>repulsive forces from Pauli effect</u>

⇒positive mass shift

Ex2. Y_c-N^{-1} excitation





Only D^+ forms <u>excitation</u> from a charmed baryon and a nucleon hole

⇒Spectral function is deformed

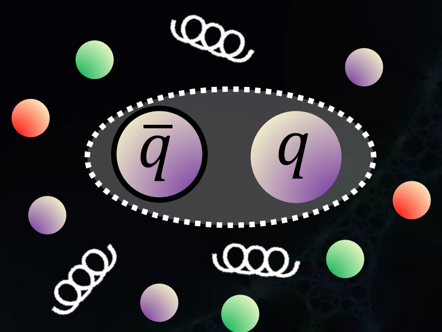
L. Tolos, C. Garcia-Recio, J. Nieves
Phys.Rev. C80 (2009) 065202

QCD sum rules in medium

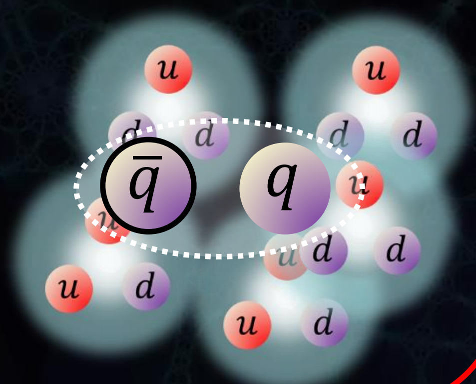
$$\Pi_{\mathrm{OPE}}(M^2) = \int_0^{\infty} K(s, M^2)\, \rho(s)\, ds$$

Medium modification of OPE INPUT

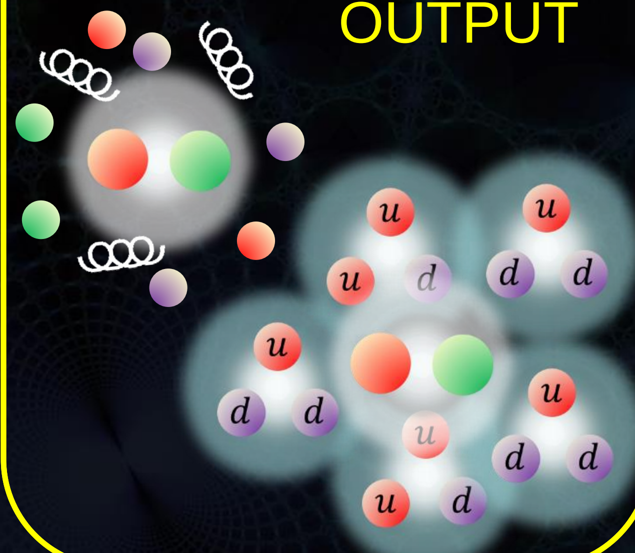
T- depend.
(ex. in hot π gas, QGP)



density depend.
(ex. in nuclear matter)

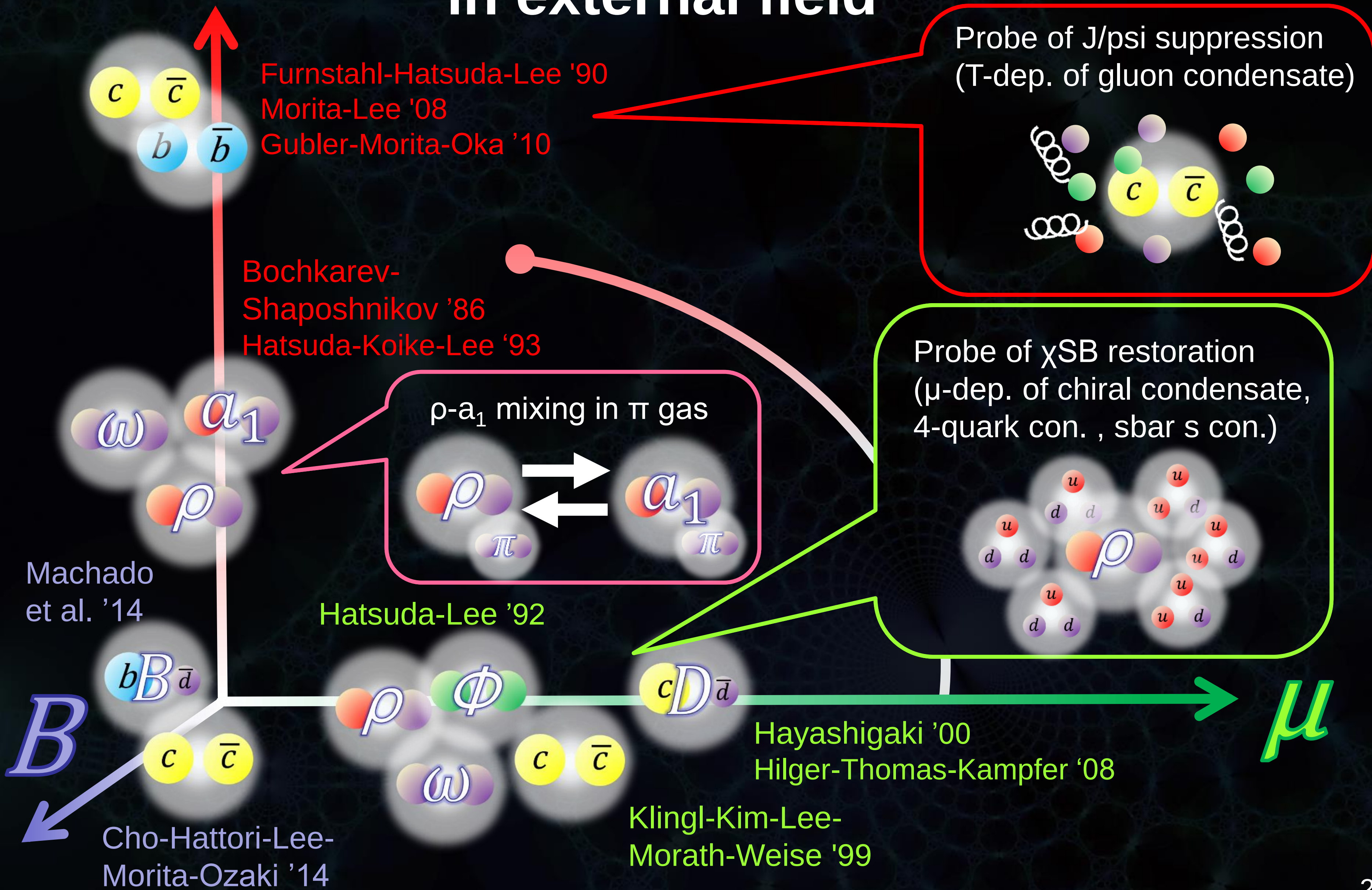


Hadron modification
OUTPUT



⇒QCD sum rule relates modification of OPE (or condensate) to modification of hadron state

Applications of QCD sum rules in external field



QCD sum rules in nuclear matter

QCD sum rule

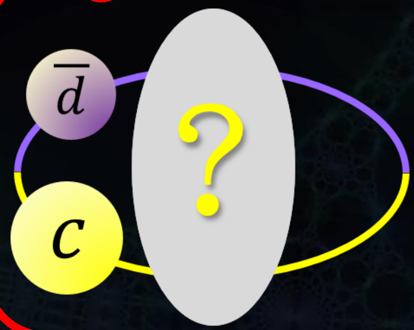
$$\Pi_{\mathrm{OPE}}(M) = \int_0^\infty K(s,M)\,\rho(t)\,ds$$

② Kernel

Weight of spectral function

- Gaussian sum rule

① OPE



- **dens.-dependence** of condensates up to dim.5

③ Output spectral function

- Maximum entropy method (MEM)

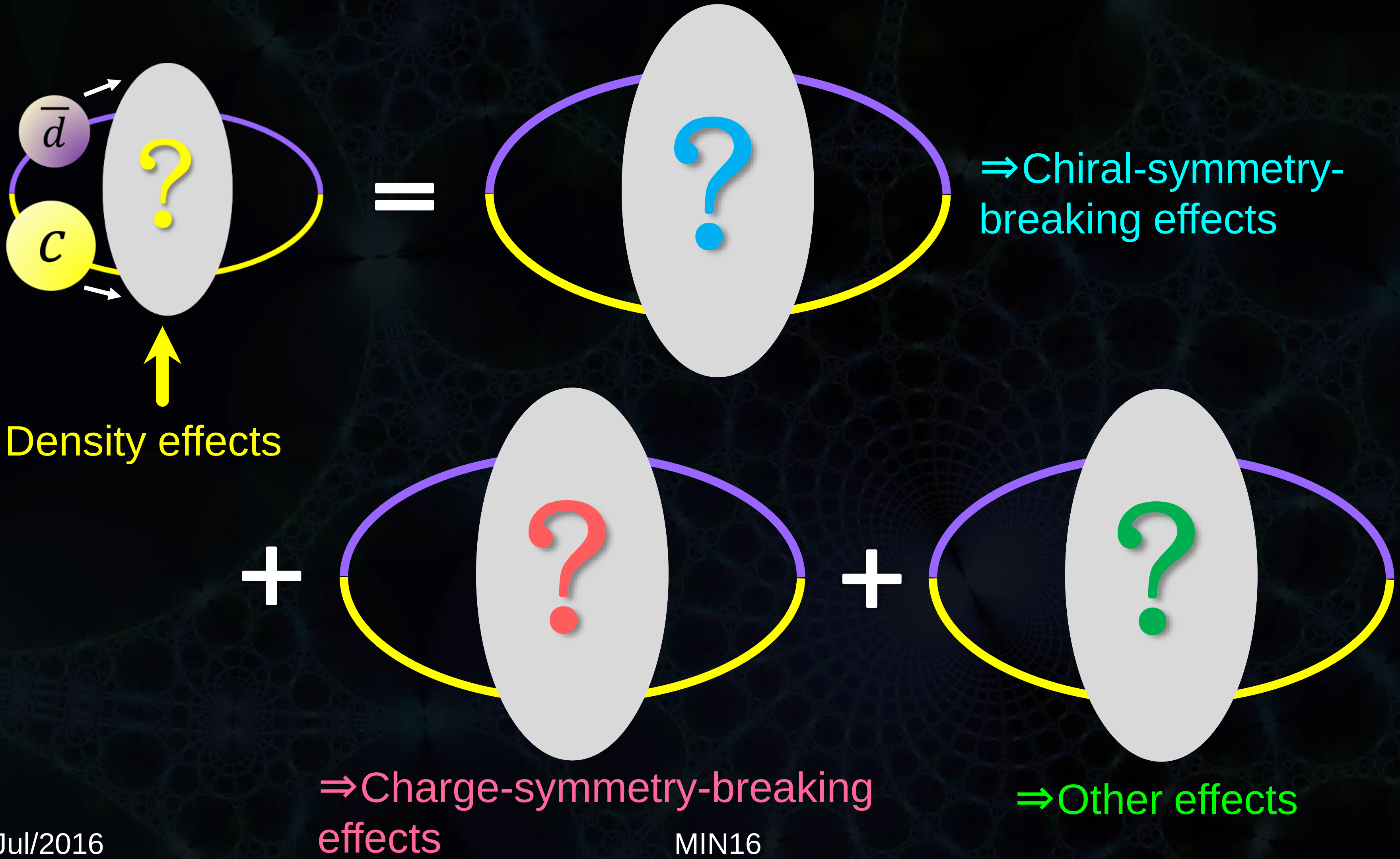
P. Gubler and M. Oka, PTP124 (2010) 995

- Charge-conjugate projection

cf.) D. Jido, N. Kodama, and M. Oka, PR**D54**, 4532 (1996)

cf.) A. Hayashigaki, PLB487 (2000) 96
T. Hilger, R. Thomas, B. Kampfer, PRC79 (2009) 025202

In QCD sum rules, we can separate all the density effects into QCD condensates



In QCD sum rules, we can separate all the density effects into QCD condensates

- Chiral-symmetry-breaking condensates

$\langle \bar{q}q \rangle_n = \langle \bar{q}q \rangle_{vac} + \frac{\sigma_N}{2m_q} n$	$\langle \bar{q}g\sigma Gq \rangle_n = \lambda^2 \langle \bar{q}q \rangle_n$
$\left[\langle \bar{q}D_0^2 q \rangle_n - \frac{1}{8} \langle \bar{q}g\sigma Gq \rangle_n \right] = -\frac{3}{4} M_N^2 e_2^q(\mu^2) n$	

- Charge-symmetry breaking condensates

$\langle q^\dagger q \rangle_n = \frac{3}{2} n$	$\langle q^\dagger g\sigma Gq \rangle_n = (0.33\mathrm{GeV}^2) n$	$\langle q^\dagger D_0^2 q \rangle_n = -\frac{1}{4} M_N^2 A_3^q(\mu^2) n + \frac{1}{12} \langle q^\dagger g\sigma q \rangle_n$

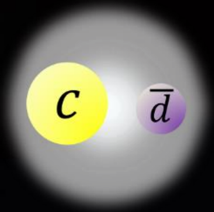
⇒Opposite signs in particle and Anti-particle

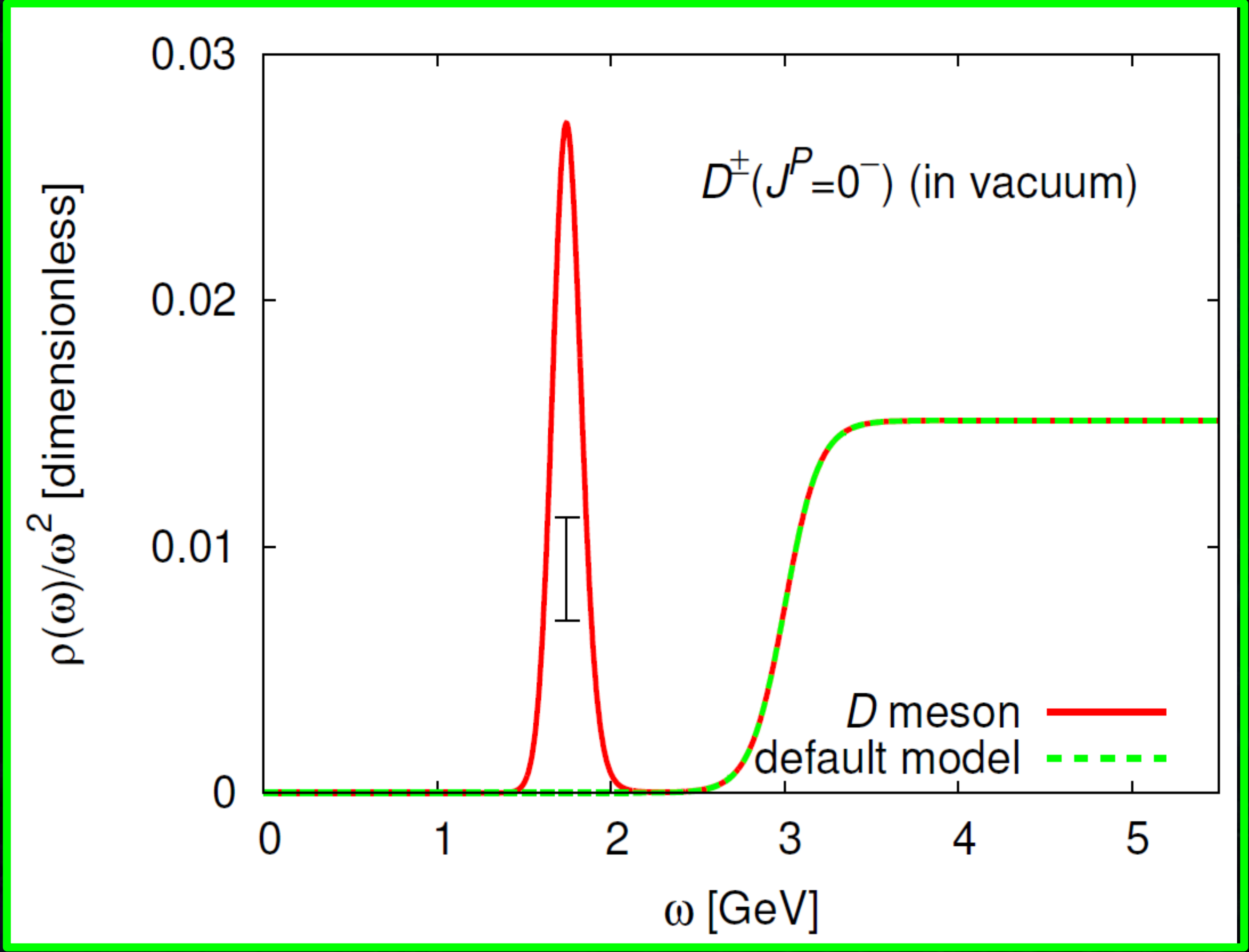
- Other condensates (gluon condensate, twist condensates…)

$\left\langle \frac{\alpha_s}{\pi} G^2 \right\rangle_n = \left\langle \frac{\alpha_s}{\pi} G^2 \right\rangle_{vac} - \frac{8M_N^0}{9} n$	$\left\langle \frac{\alpha_s}{\pi} \left(\frac{(vG)^2}{v^2} - \frac{G^2}{4} \right) \right\rangle_n$	$\langle q^\dagger i D_0 q \rangle_n = \frac{3}{8} M_N A_2^q(\mu^2) n$

KS, P. Gubler and M. Oka, PRC93, 045209 (2016)

D meson spectral function (in vacuum)

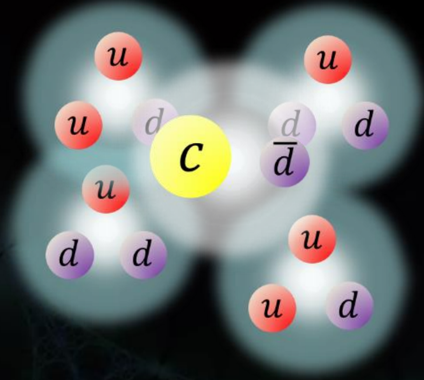




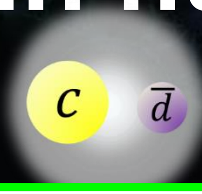
Mass : 1.75GeV Exp. : 1.87GeV

KS, P. Gubler and M. Oka, PRC93, 045209 (2016)

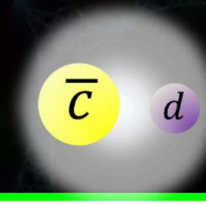
D meson spectral function (in nuclear medium)

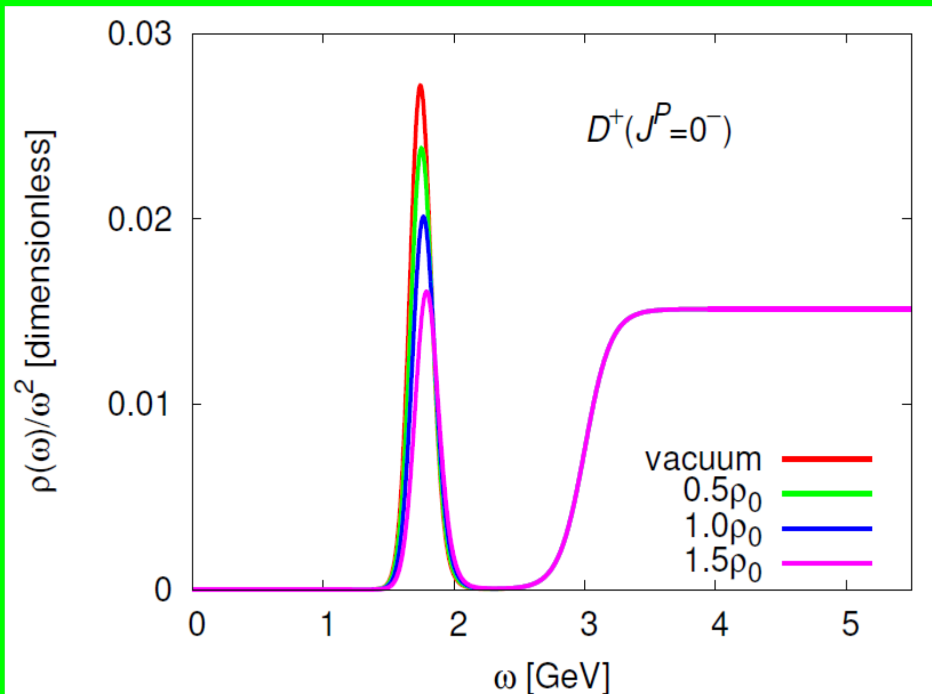


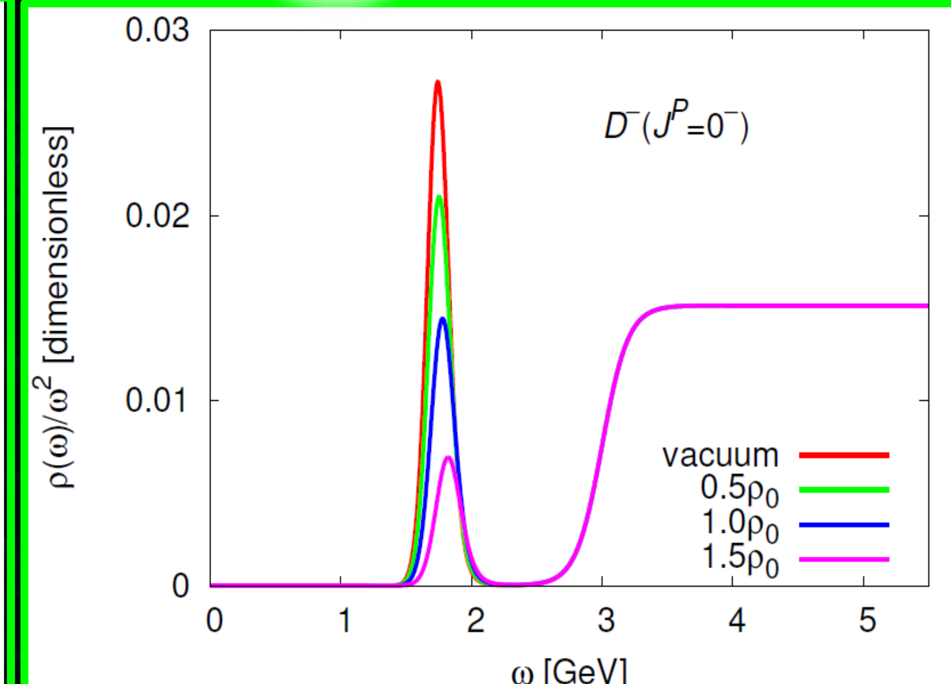
D^+



D^-

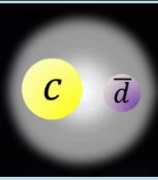
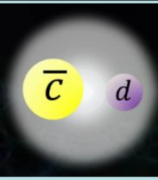
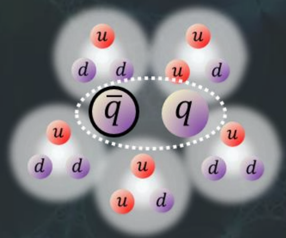
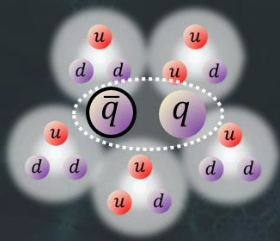
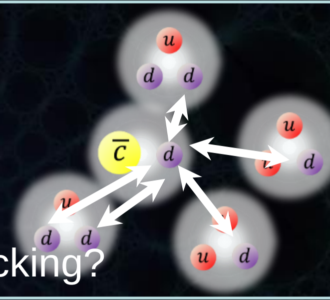






⇒Peak position in $D^{\pm}$ shifts to higher energy side with increasing density (D^+: ~25MeV D^-: ~40MeV at ρ_0)

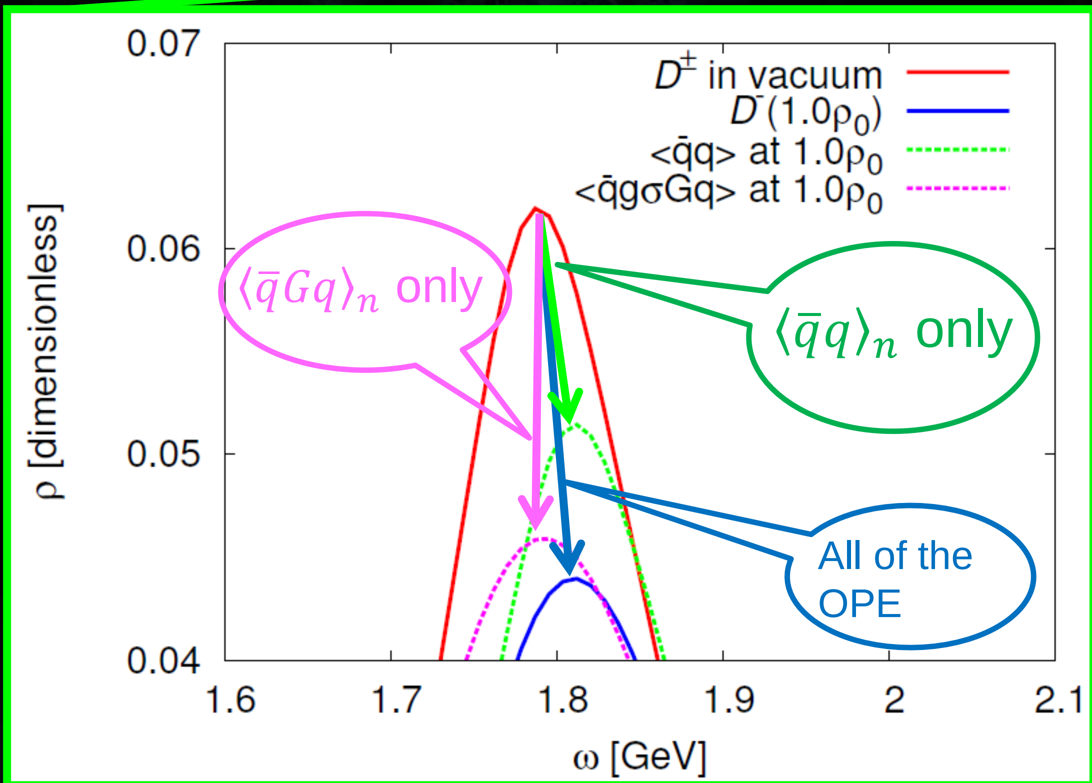
Summary of D meson in nuclear matter

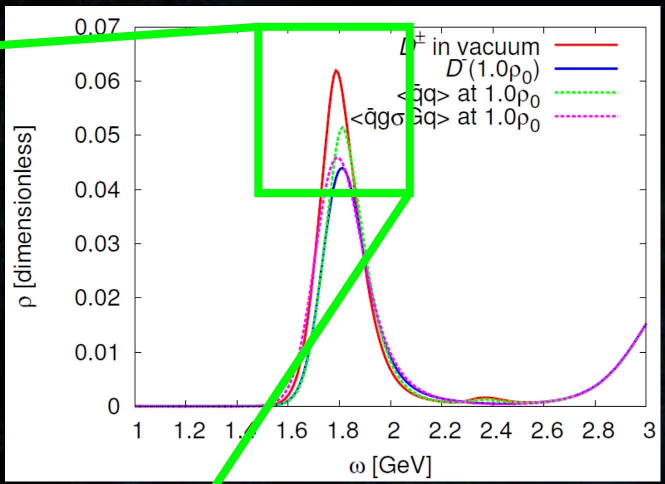
	D+ 	D- 
χSR = $\langle \bar{q}q \rangle$ reduction	Increase↑↑ 	Increase↑↑ 
CSB effect	Decrease↓	Increase↑ 
Our results	Increase↑ (~25MeV)	More increase↑↑(~40MeV)

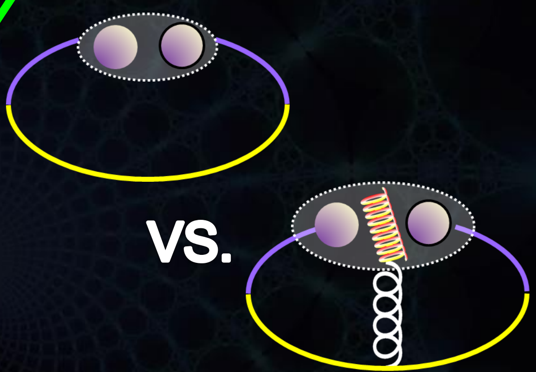
⇒D meson is a good probe of χSR and CSB

KS, P. Gubler and M. Oka, PRC93, 045209 (2016)

Contributions of vacuum condensates

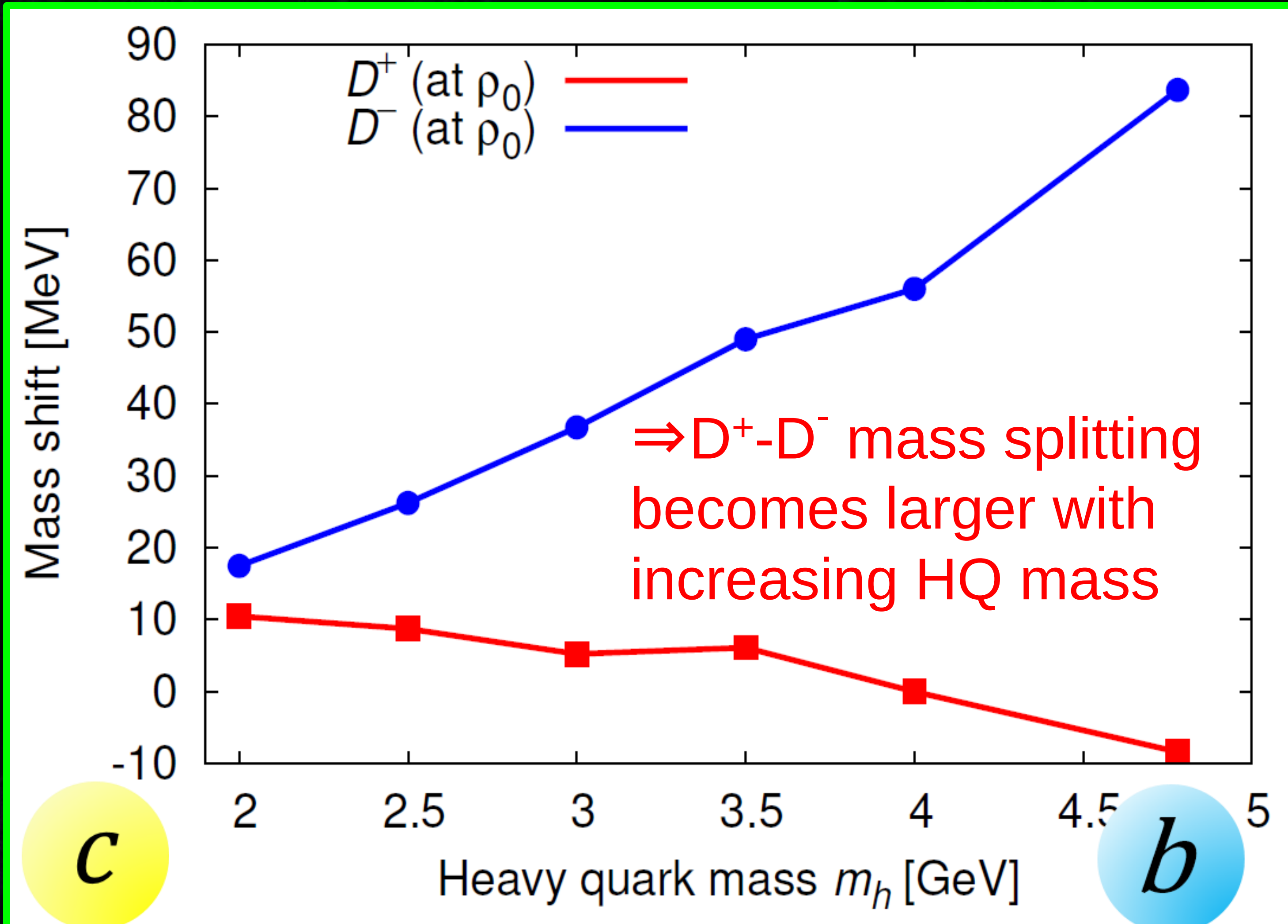




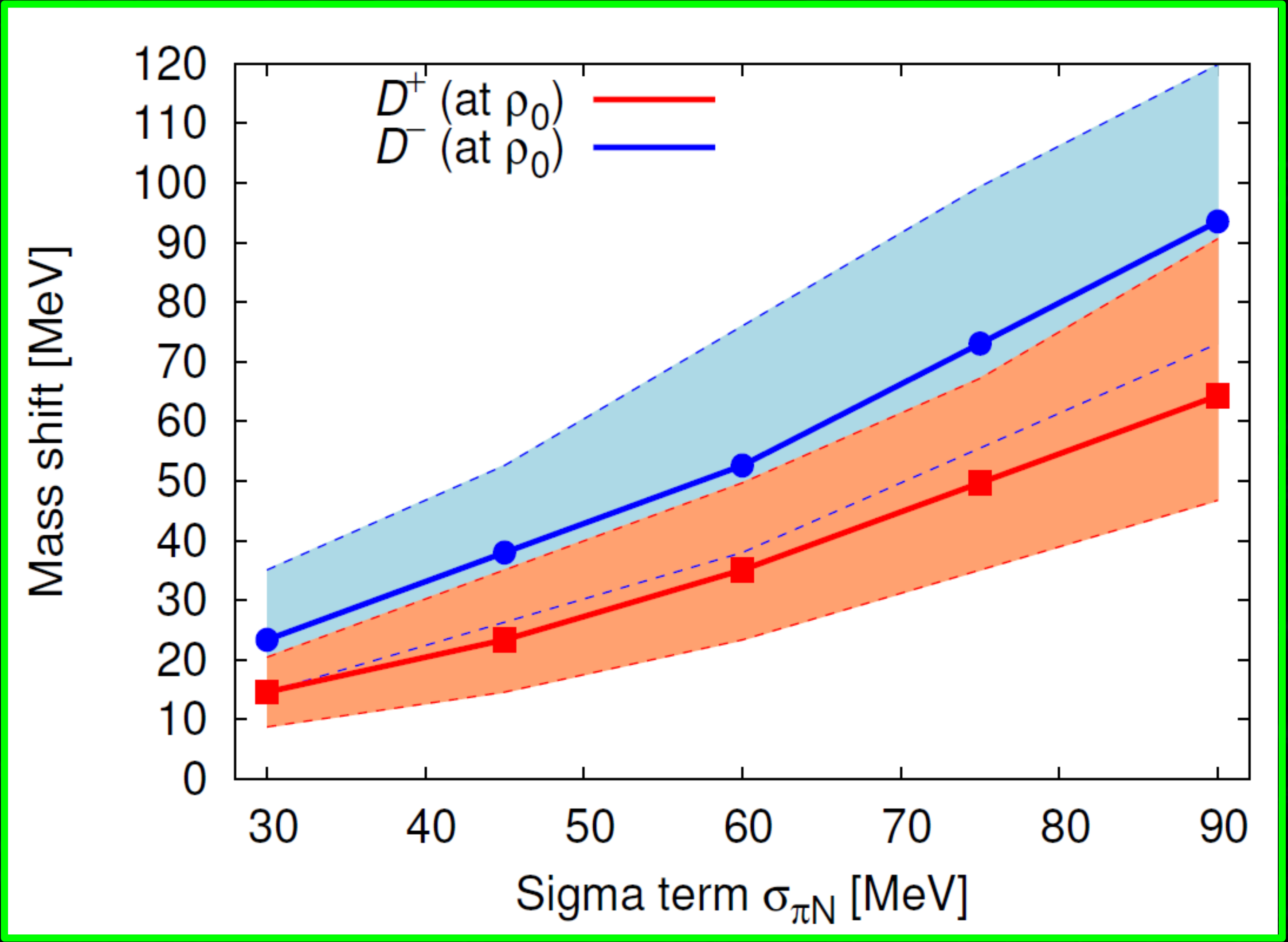


⇒Positive mass shift of D meson is caused by <u>Density dependence of chiral condensate</u>

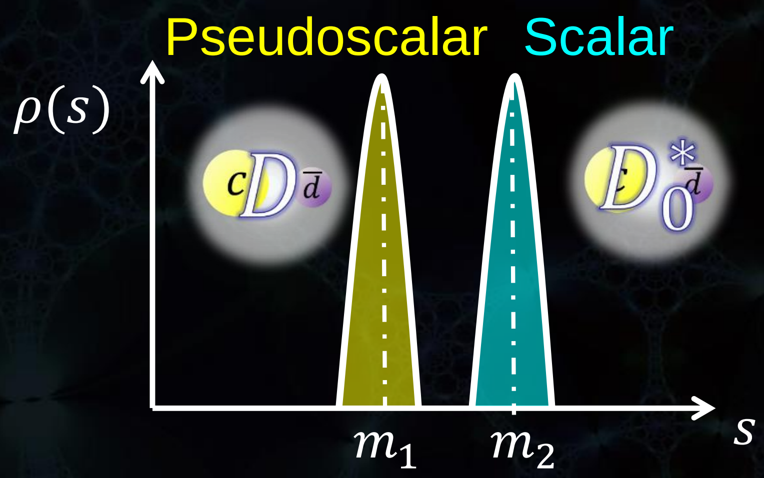
Heavy quark mass dependence



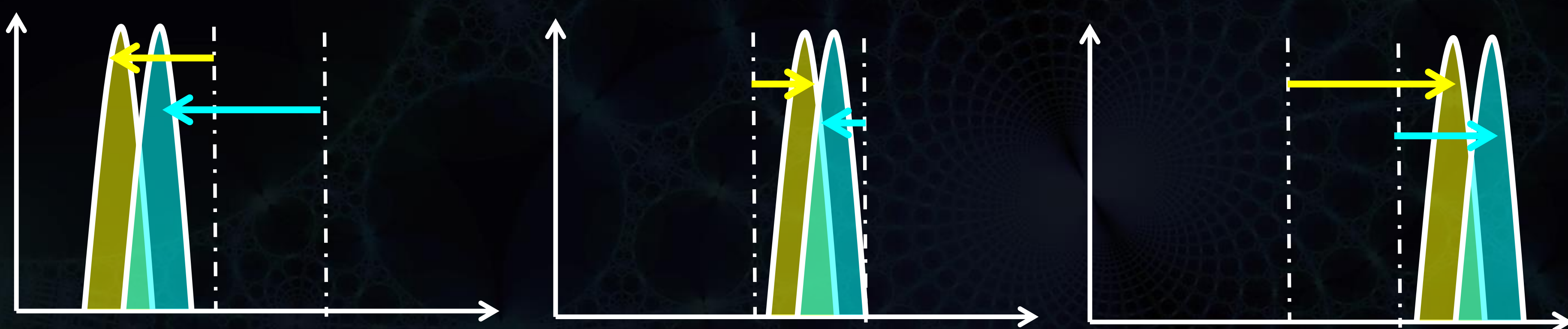
Sigma term dependence



3 scenarios of chiral partners



1. Dropping degen. 2. Approaching degen. 3. raising degen.

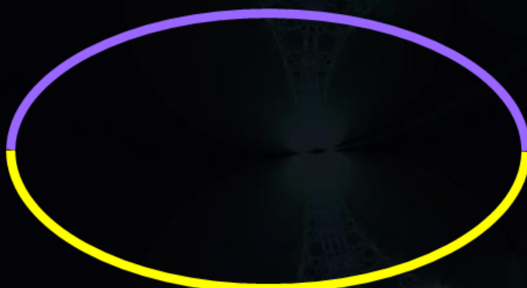


⇒Which pattern should be chosen?

Chiral symmetric term

$$\frac{k^\mu \gamma_\mu + m_l}{k^2 - m_l^2}$$

$ic\gamma_5\bar{d}$



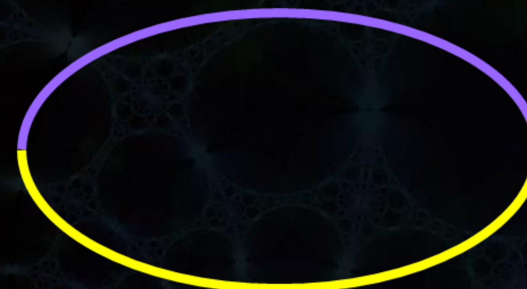
$i\bar{c}\gamma_5 d$

$$\frac{q^\nu \gamma_\nu + m_c}{q^2 - m_c^2}$$

$=$ $ic\bar{d}$

$$\gamma_\mu\gamma_5 = -\gamma_5\gamma_\mu$$
$$\gamma_5^2 = 1$$

$$\frac{k^\mu \gamma_\mu + m_l}{k^2 - m_l^2}$$



$i\bar{c}d$

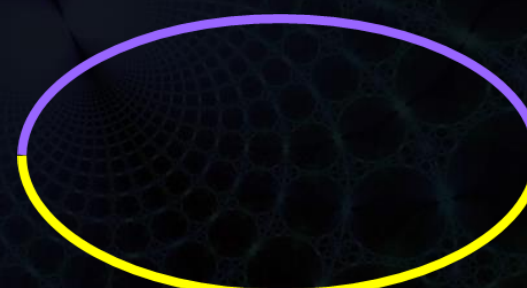
$$\frac{-q^\nu \gamma_\nu + m_c}{q^2 - m_c^2}$$

$$= \frac{4kq - m_l m_c}{(k^2 - m_l^2)(q^2 - m_c^2)} =$$

$Tr[\gamma_\mu] = 0$

$m_l \to 0$

$c\bar{d}$

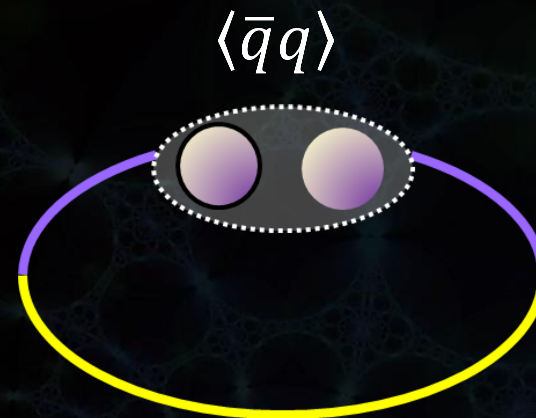


$\bar{c}d$

Chiral breaking term

$i c \gamma_5 \bar{d}$

$i \bar{c} \gamma_5 d$ $=$ $i c \bar{d}$



$i \bar{c} d$

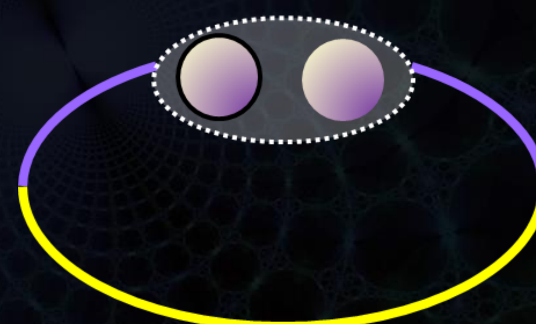
$$\frac{q^\nu \gamma_\nu + m_c}{q^2 - m_c^2}$$

$$\gamma_\mu \gamma_5 = -\gamma_5 \gamma_\mu$$
$$\gamma_5^2 = 1$$

$$\frac{-q^\nu \gamma_\nu + m_c}{q^2 - m_c^2}$$

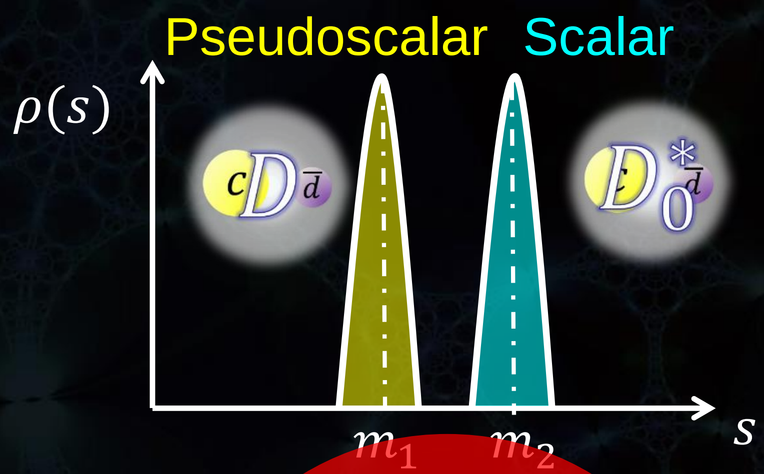
$$= \frac{-m_c \langle \bar{q} q \rangle}{q^2 - m_c^2} = - \; c\bar{d}$$

$Tr[\gamma_\mu] = 0$



$\bar{c} d$

Conclusion from OPE



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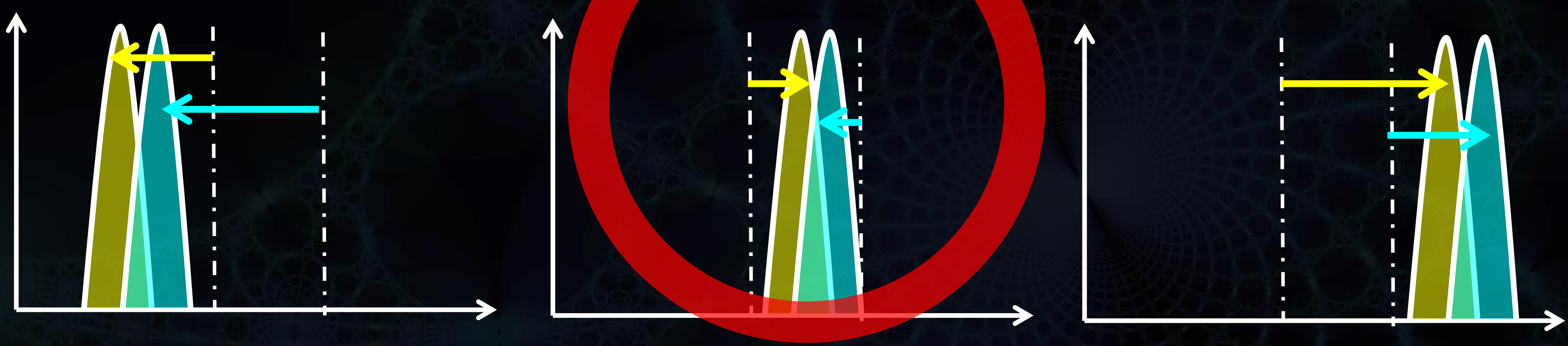


⇒Ps mass increases and S mass decreases

Many theoretical works for D meson in matter

Coupled chanel approach
- L. Tolos, J. Schaffner-Bielich, and A. Mishra, PRC70, 025203 (2004)
- M. Lutz and C. Korpa, PLB633, 43 (2006)
- T. Mizutani and A. Ramos, PRC74, 065201 (2006)
- L. Tolos, A. Ramos, and T. Mizutani, PRC77, 015207 (2008)
- L. Tolos, C. Garcia-Recio, and J. Nieves, PRC80, 065202 (2009)
- C. Jimenez-Tejero, A. Ramos, L. Tolos, and I. Vidana, PRC84, 015208 (2011)

Mean field approach
- A. Mishra, E. Bratkovskaya, J. Schaffner-Bielich, S. Schramm, and H. Stoecker, PRC69, 015202 (2004)
- A. Mishra and A. Mazumdar, PRC79, 024908 (2009)
- A. Kumar and A. Mishra, PRC81, 065204 (2010)
- A. Kumar and A. Mishra, EPJ. A47, 164 (2011)

Pion exchange model for Dbar -N
- S. Yasui and K. Sudoh, PRC87, 015202 (2013)

QMC model
- K. Tsushima, D.-H. Lu, A. W. Thomas, K. Saito, and R. Landau, PRC59, 2824 (1999)
- A. Sibirtsev, K. Tsushima, and A. W. Thomas, EPJ. A6, 351 (1999)

QCD sum rules
- P. Morath, W. Weise, and S.-H. Lee (1999)
- A. Hayashigaki, PLB487, 96 (2000)
- T. Hilger, R. Thomas, and B. Kampfer, Phys. Rev. C79,025202 (2009)
- K. Azizi, N. Er, and H. Sundu, EPJ. C74, 3021 (2014)
- W.Z. Gang (2015) arXiv:1501.05093 [hep-ph]

Many previous works for D meson in medium

Coupled chanel approach

L. Tolos, J. Schaffner-Bielich, and A. Mishra, PRC70, 025203 (2004)

M. ... 6)

T. M... 201 (2006)

L. T... C77, 01520

L. T... s, PRC80, 0

C. ... and I. Vidar

Mea...

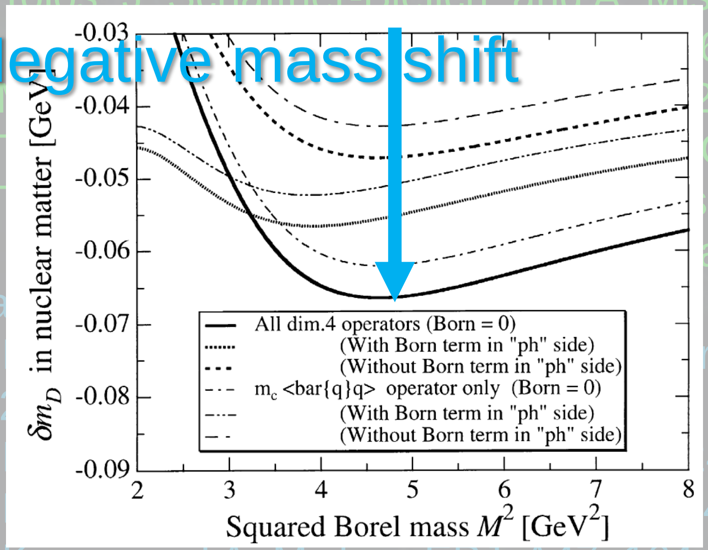
A. ... r-Bielich, S.

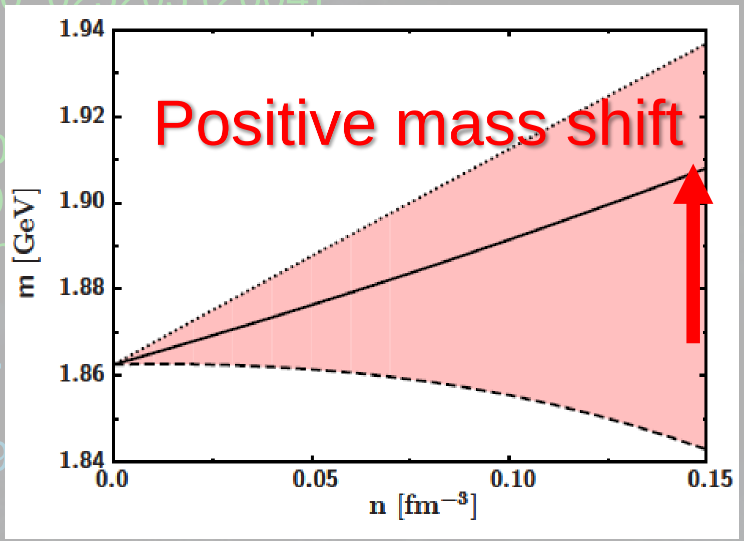
0152...

A. ... 4908 (2009

A. ... 4 (2010)

A. Kumar and A. Mishra, EPJ. A47, 164 (2011)





Pion exchange model

S. Yasui and K. Sudoh, PRC87, 015202 (2013)

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QCD sum rules

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T. Hilger, R. Thomas, and B. Kampfer, Phys. Rev. C79,025202 (2009)

K. Azizi, N. Er, and H. Sundu, EPJ. C74, 3021 (2014)

W.Z. Gang (2015) arXiv:1501.05093 [hep-ph]

What is difference between previous works? ⇒Borel window

1. Hayashigaki, PLB487, 96 (2000)
2. K. Azizi, N. Er, and H. Sundu, EPJ. C74, 3021 (2014)
3. W.Z. Gang (2015) arXiv:1501.05093 [hep-ph]

They applied relation to forward D-N scattering amplitude
As a result, they chose higher Borel window (1.7<M<2.8GeV)
⇒They obtained Negative mass shift by chiral symmetry restoration

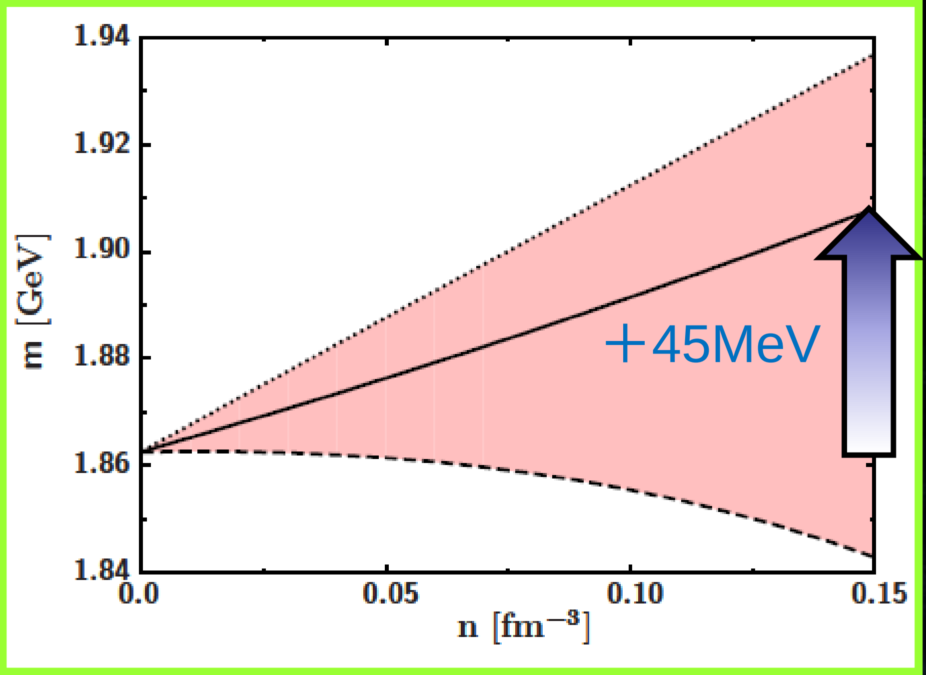
4. T. Hilger, R. Thomas, and B. Kampfer, Phys. Rev. C79,025202 (2009)
5. Our results

Hilger et al. applied Delta + step function ansatz
They chose lower Borel window (0.9<M<1.1GeV)
⇒They obtained Positive mass shift by chiral symmetry restoration

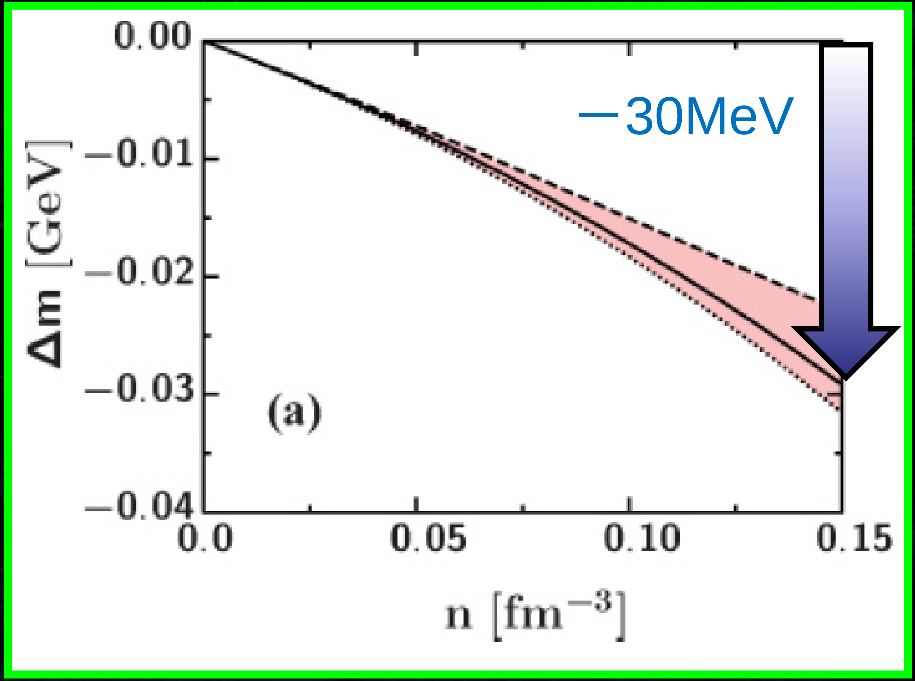
Previous works from QCD sum rules

4. T. Hilger, R. Thomas, and B. Kampfer, Phys. Rev. C79,025202 (2009)

Mass shift $(\Delta m_{D+} + \Delta m_{D-})/2$



mass splitting $(m_{D+} - m_{D-})/2$



- These results depend on phenomenological parameter

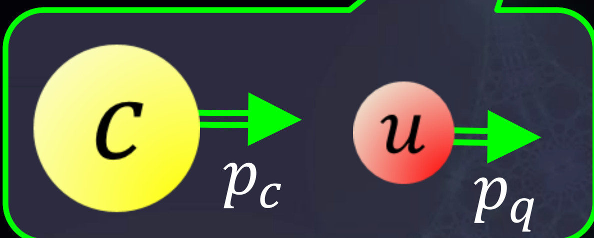
⇒We need parameter independent analysis (=MEM)

Park, Gubler, Harada, Lee, Nonaka and Park, PRD93 (2016)

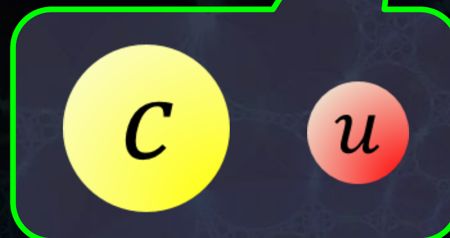
m_q dependence of quark model for heavy-light meson

$$H = \frac{p_c^2}{2m_c} + \frac{p_q^2}{2m_q} + m_c + m_q + V(r)$$

Kinetic term

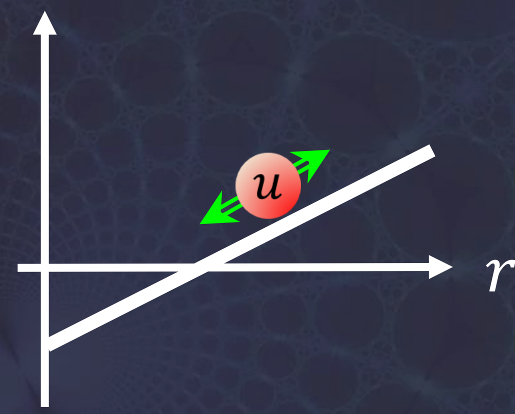


Mass term



Linear potential

$$V(r) = \sigma r + C$$



When $r \to 1/p_q$,

$$H = \frac{p_c^2}{2m_c} + \frac{p_q^2}{2m_q} + m_c + m_q + \frac{\sigma}{p_q} + C$$

Park, Gubler, Harada, Lee, Nonaka and Park, PRD93 (2016)

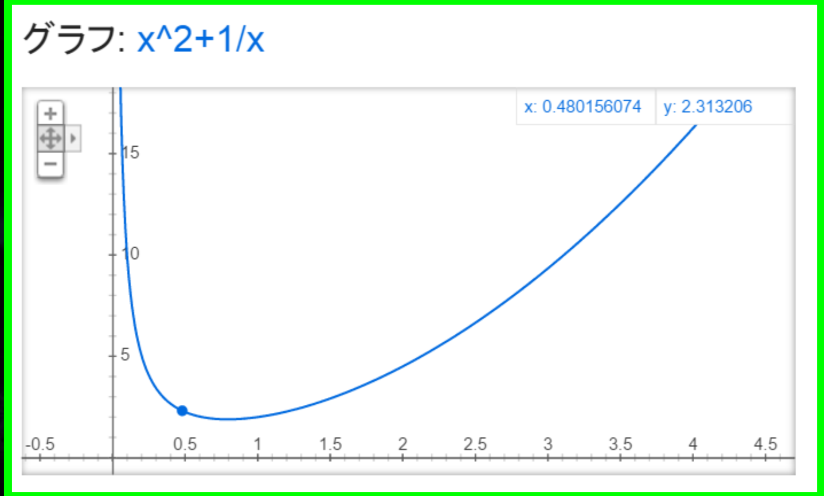
m_q dependence of quark model for heavy-light meson

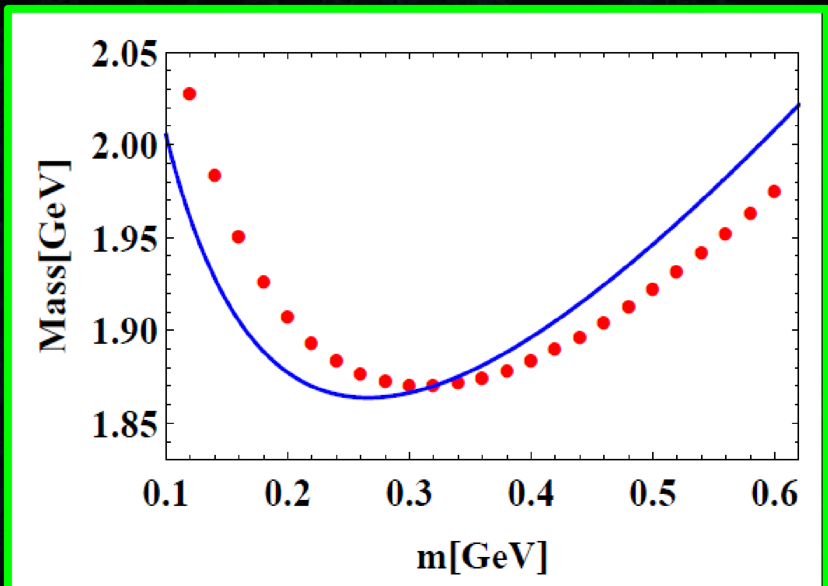
$$H = \frac{p_c^2}{2m_c} + \frac{p_q^2}{2m_q} + m_c + m_q + \frac{\sigma}{p_q} + C$$

When p_q is minimized, we remove p_q and find m_q-depend. of the energy

$$E = \frac{p_c^2}{2m_c} + m_c + m_q + \left(\frac{\sigma^2}{m_q}\right)^{1/3} + C$$

- There is a minimum of energy for a light quark mass m_q
- If m_q decreases, D meson mass increases

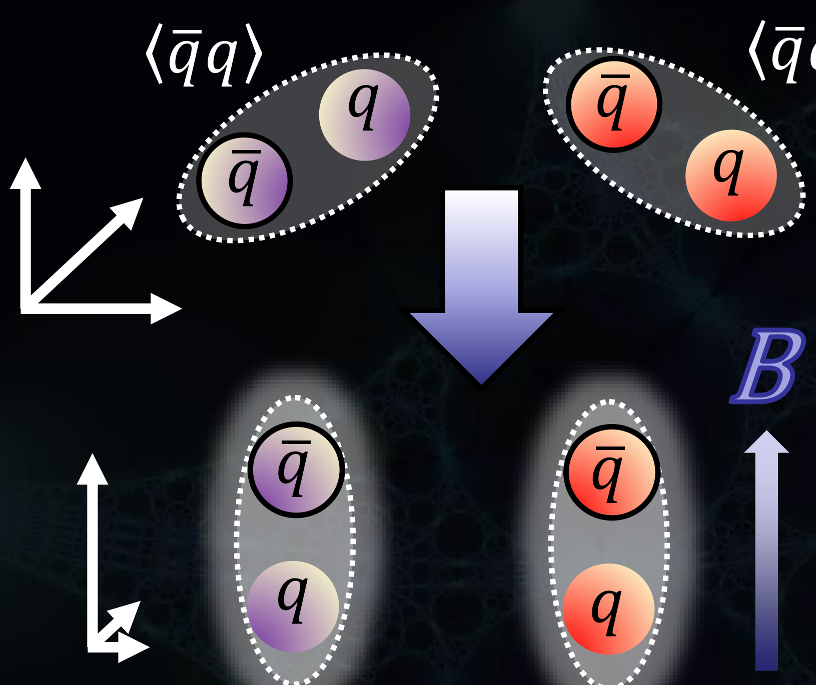


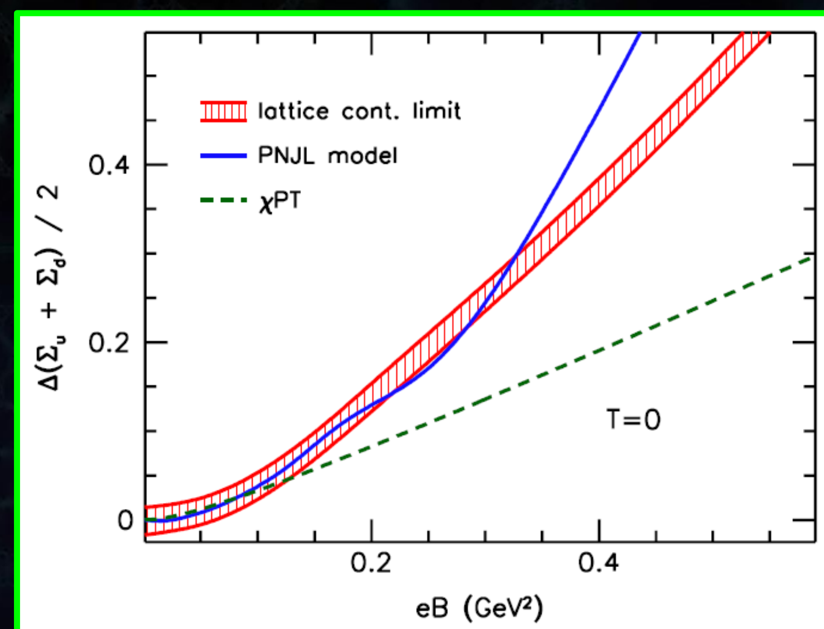


Magnetic Catalysis

- Charged particle is trapped in 1+1 dimension by magnetic field

⇒chiral condensate is enhanced





G.S. Bali et al., PRD86 (2012) 071502

Cf.) J. Alford and M. Strickland, PRD88 (2013)

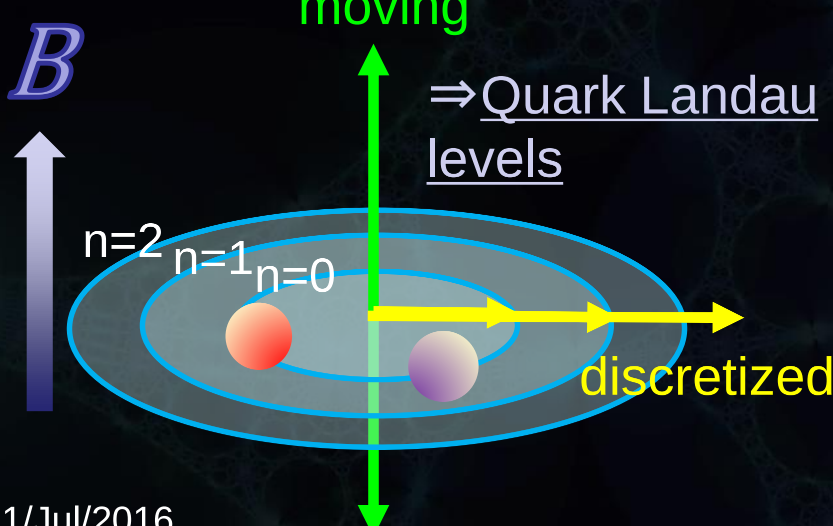
Nonrelativistic two-body Hamiltonian in B-field

$$H=\sum_{i=1,2}\frac{1}{2m_i}(\boldsymbol{p}_i-q_i\boldsymbol{A})^2-\boldsymbol{\mu}_i\cdot\boldsymbol{B}+m_i+V(r)$$

$$\boldsymbol{A}=\frac{1}{2}\boldsymbol{B}\times\boldsymbol{r}_i$$

Linear + Coulomb

(1) Modification of kinetic energy perpendicular to B



⇒Quark Landau levels

(2) Alignment of magnetic moment

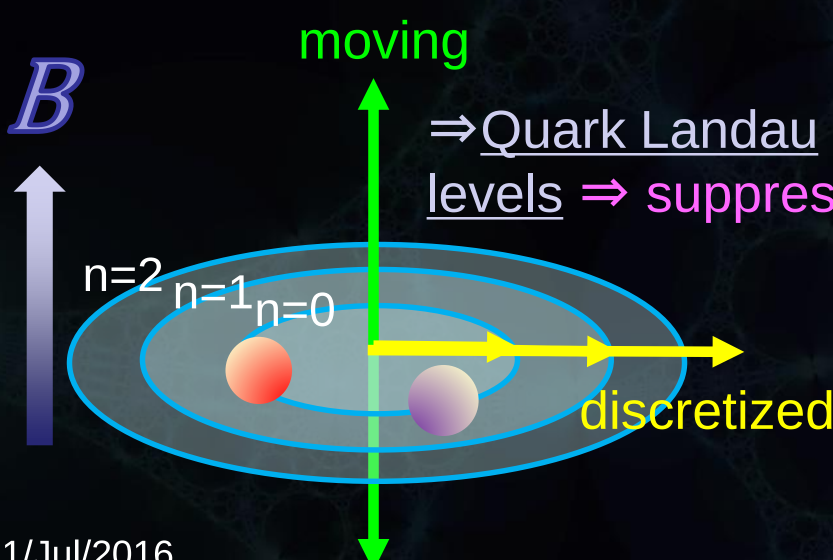
⇒Spin mixing or Zeeman splitting

m_q dependence of quark model for heavy-light meson in B-field

$$H = \sum_{i=1,2} \frac{1}{2m_i}(\boldsymbol{p}_i - q_i\boldsymbol{A})^2 - \boldsymbol{\mu}_i \cdot \boldsymbol{B} + m_i + V(r)$$

$$\boldsymbol{\mu}_i = \frac{g q_i}{2m_i} S_i$$

(1) Modification of kinetic energy perpendicular to B



⇒Quark Landau levels ⇒ suppress

(2) Alignment of magnetic moment

⇒Spin mixing or Zeeman splitting

⇒ suppress

m_q dependence of quark model for heavy-light meson in B-field

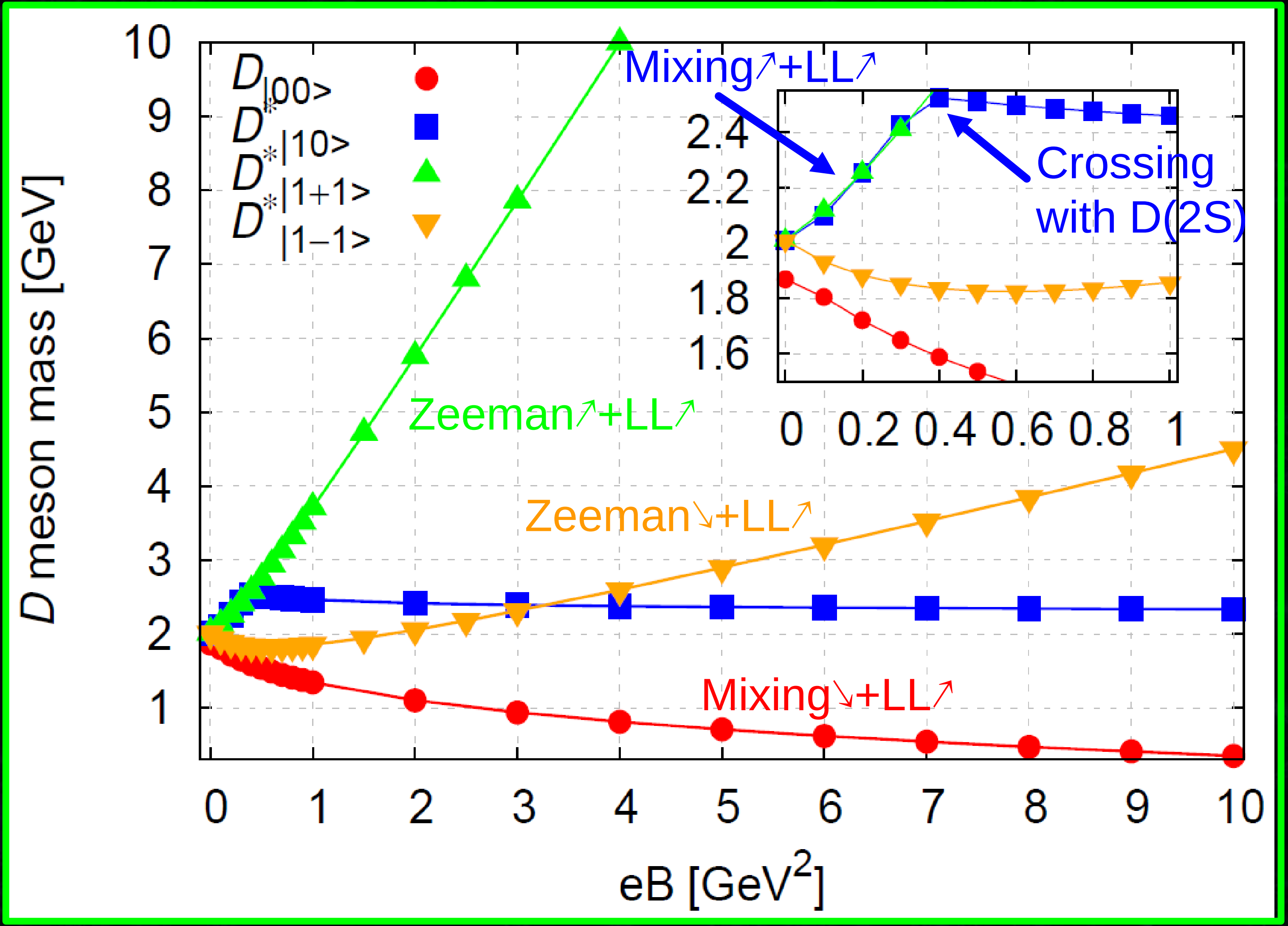
$$H = \sum_{i=1,2} \frac{1}{2m_i}(\boldsymbol{p}_i - q_i \boldsymbol{A})^2 - \boldsymbol{\mu}_i \cdot \boldsymbol{B} + m_i + V(r)$$

$$\boldsymbol{\mu}_i = \frac{g q_i}{2m_i} S_i$$

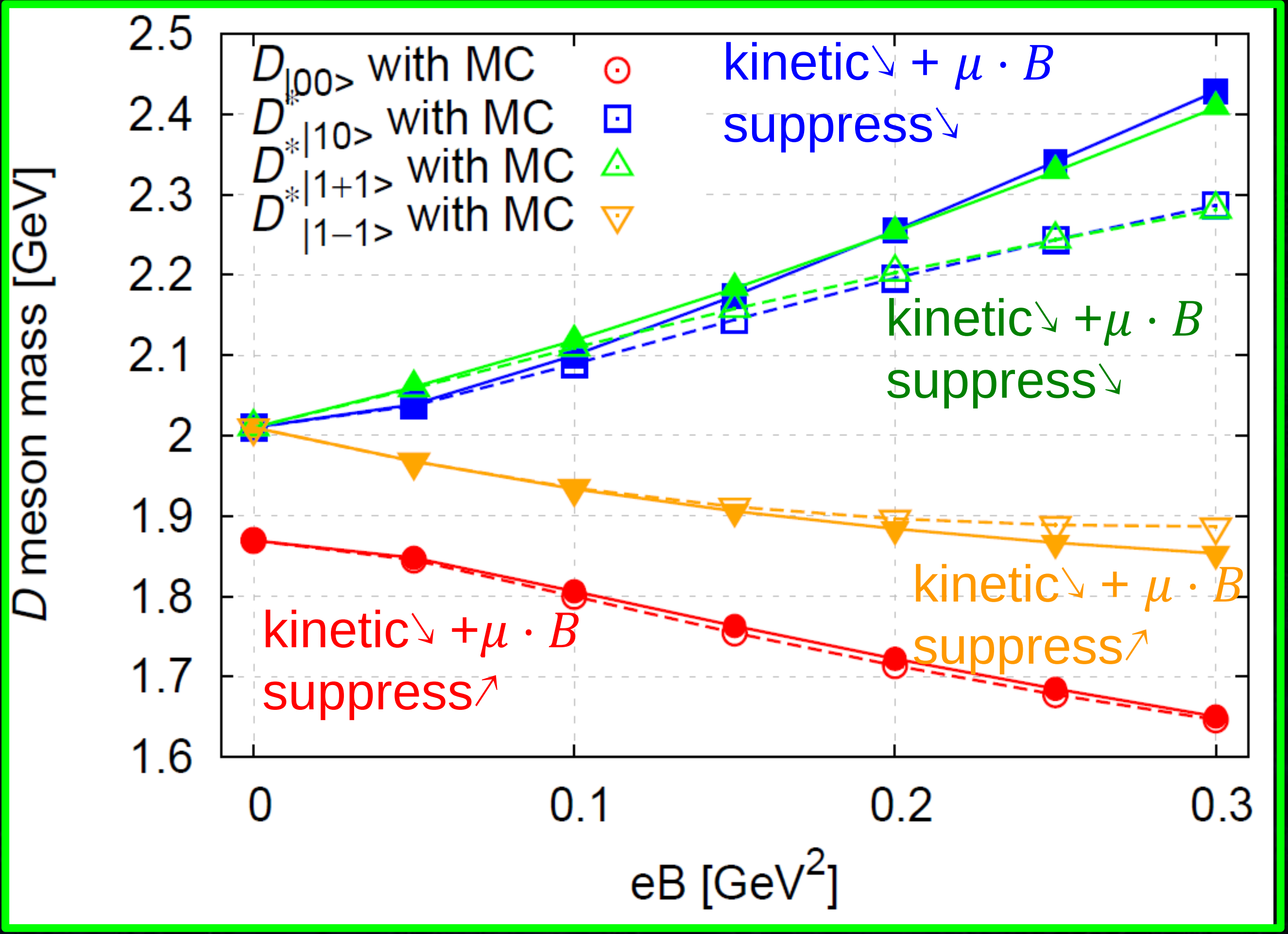
⇒D meson mass shift = rest mass increase $\sim m_q$ + kinetic and potential energy suppression $\sim 1/m_q$ + magnetic moment supression $\sim 1/m_q$

T. Yoshida and KS (in preparation)

D meson mass in magnetic field w/o MC



D meson mass in magnetic field can probe $\langle \bar{q}q \rangle$ enhancement? (from quark model)



⇒ D meson : mass shift cancelation by χSB

⇒ D* mesons : mass <u>decrease</u> by χSB