Dynamical chiral symmetry breaking and a critical mass

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  - ⋆ This talk based on L. Chang, Y.-X. Liu, M. S. Bhagwat, C. D. Roberts, and S. V. Wright Phys. Rev. C75 (2007) 015201

Outline

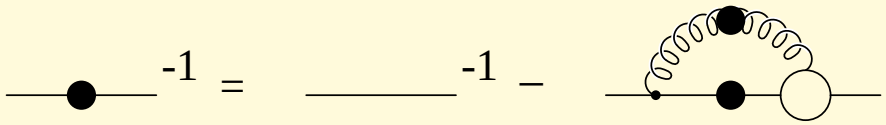
- Introduction
- An example
- Closer to QCD
- Summary

Introduction

- Dynamical chiral symmetry breaking is fundamentally important in strong interaction physics(generation of constituentlike masses, realization of Goldstone's theorem, etc)
- We report here novel aspects of the interplay between explicit and dynamical chiral symmetry breaking
- DSEs $\int D\bar{q}qG\frac{\delta}{\delta q(x)}e^{-S[\bar{q},q,G]+(\bar{\eta},q)+(\bar{q},\eta)+(J,G)}$
  - Euclidean metric, p-space,covariant
  - Truncate to minimum 2-point, 3-point
  - Insist on preserving 1-loop QCD renorm group in UV
  - Constraints for truncation: vector WTI, axial vector WTI

Introduction

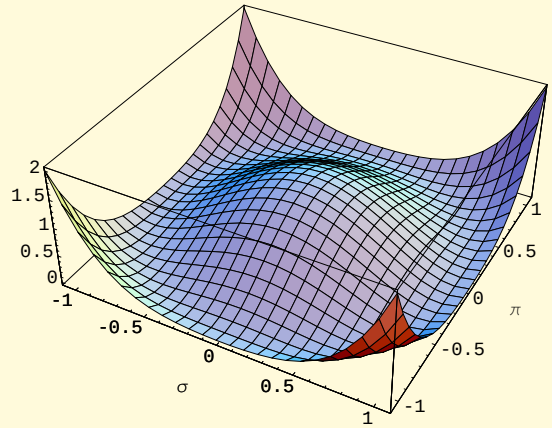
- DSE for quark propagator



  ⋆ $S(p) = \frac{Z(p^2,\zeta^2)}{i\gamma\cdot p + M(p^2)}$

  ⋆ Perturbation Theory: $M(p^2) = m_0(1 - \frac{\alpha}{\pi}\ln[\frac{p^2}{m_0^2}] + ...)$

- Dynamical chiral symmetry breaking in the chiral limit



- Question: whether the massive gap equation admits solutions other than that which is positive define, the effect of the current-quark mass on such solutions.

An example

- the model choice

$$g^2 D_{\mu\nu}(p-q) \;=\; \delta_{\mu\nu}\,\frac{1}{m_G^2}\,\theta(\tilde{\Lambda}^2 - q^2)\,, \tag{1}$$

$$\Gamma^a_\nu(q,p) \;=\; \gamma_\nu \frac{\lambda^a}{2}\,; \tag{2}$$

- the gap equation

$$G(M) := M - m^{\rm bm} - M\,\frac{1}{3\pi^2}\,\frac{1}{m_G^2}\,C(M^2,1) = 0\,; \tag{3}$$

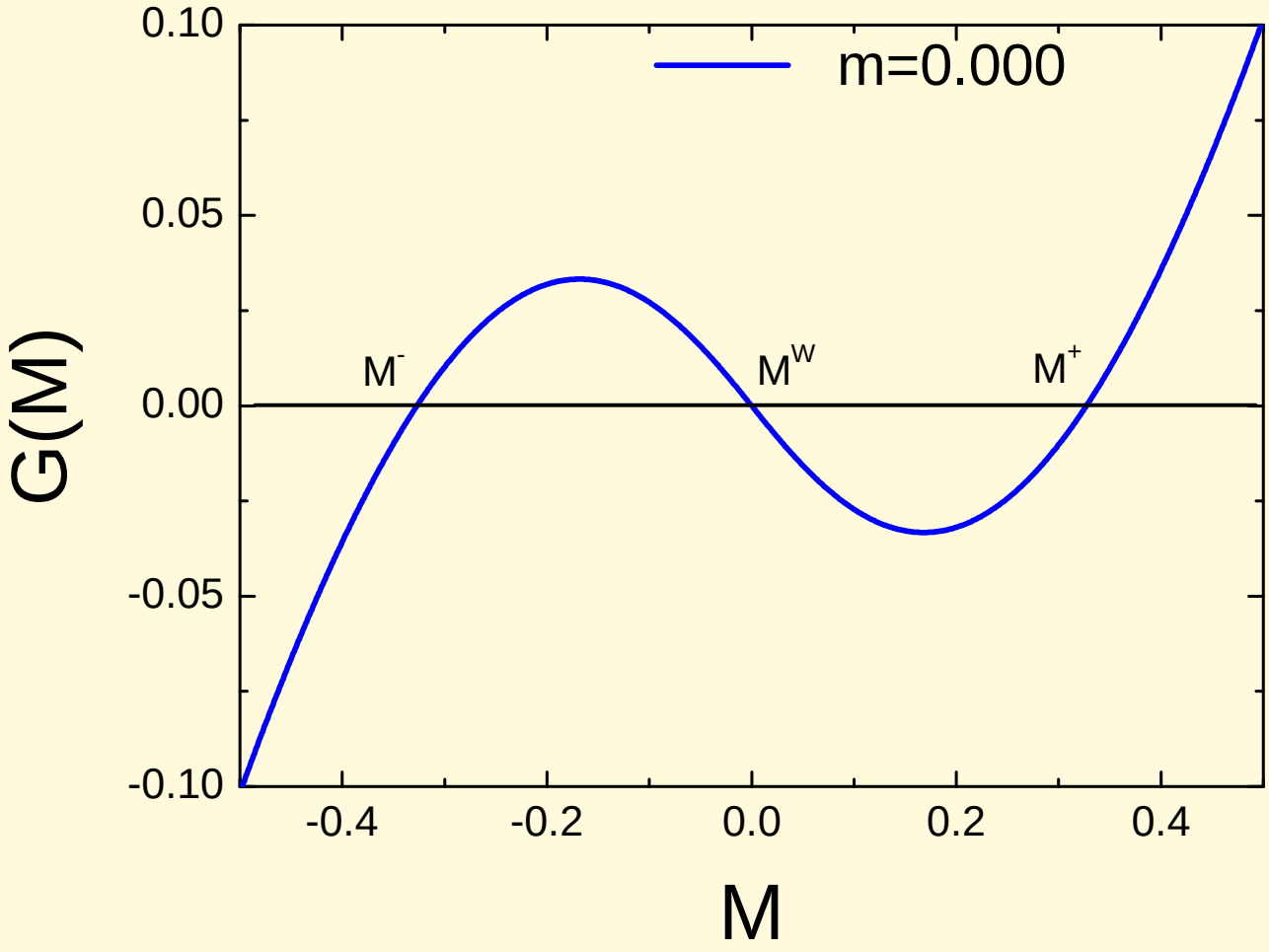
where

$$C(M^2,1) \;=\; 1 - M^2 \ln\left[1 + 1/M^2\right]\,. \tag{4}$$

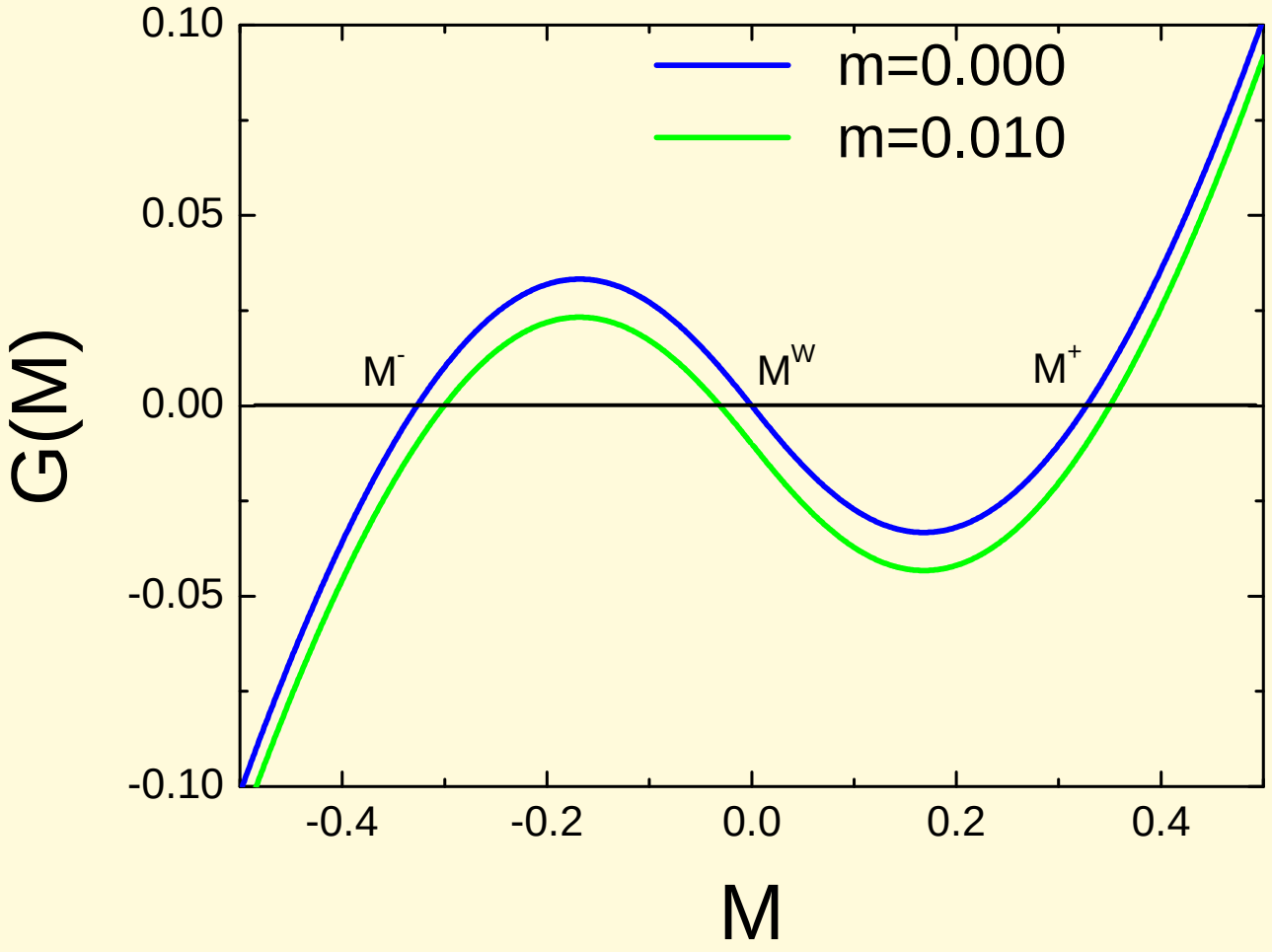
- the critical coupling

$$m_G^2 < (m_G^{cr})^2 = \frac{1}{3\pi^2}\,; \tag{5}$$

- Description of solutions



- Description of solutions



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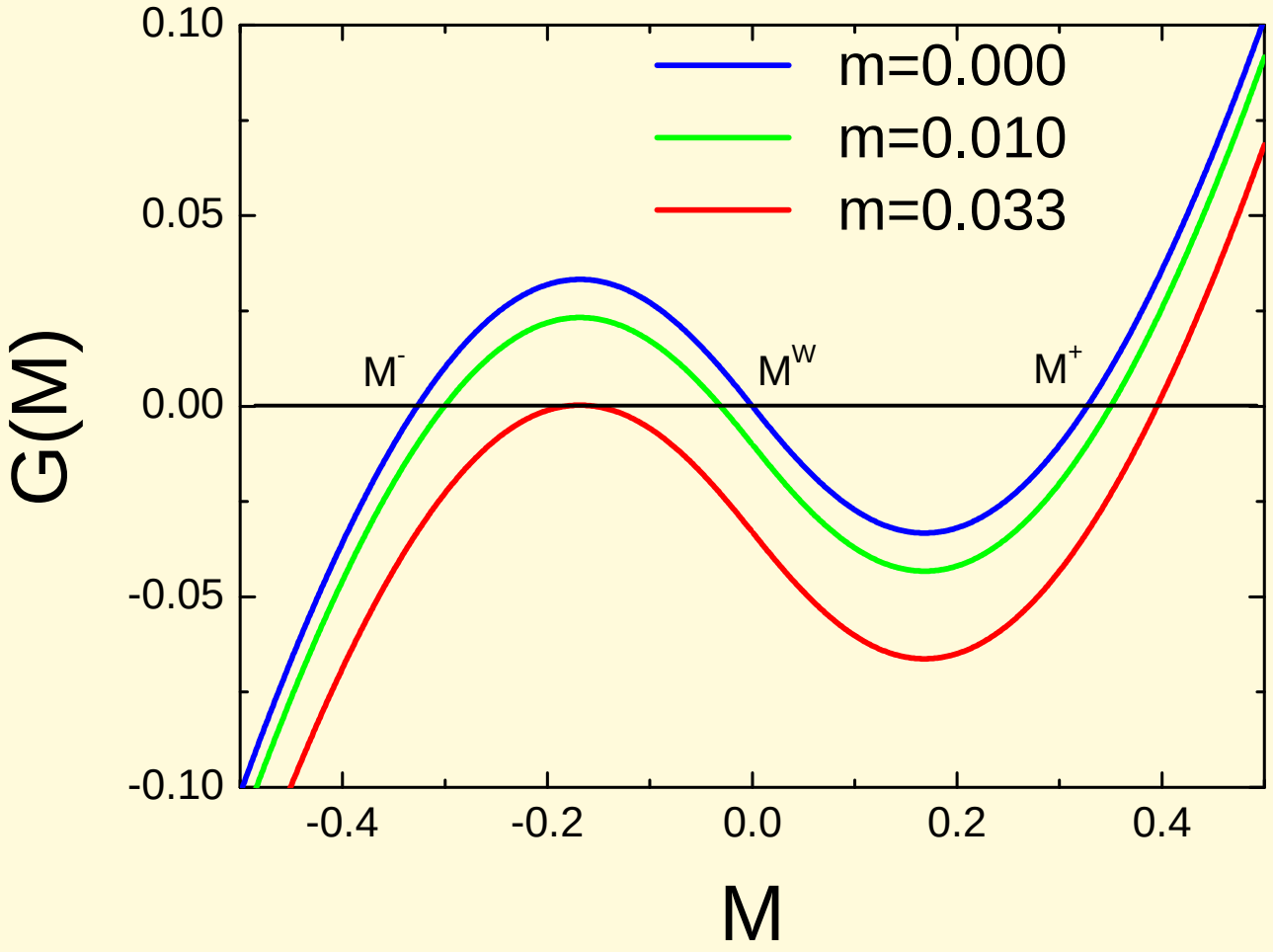
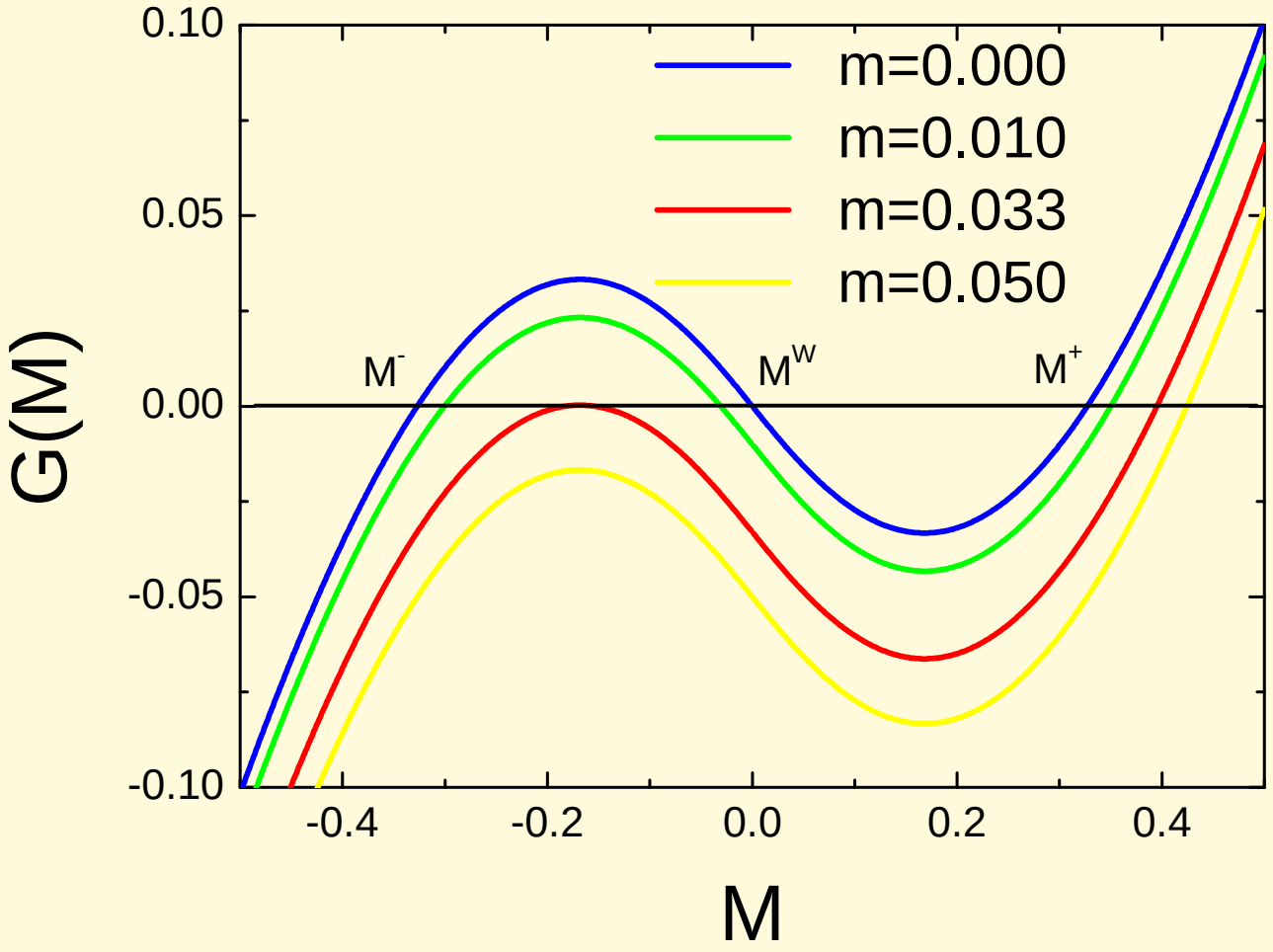


- Description of solutions



- The radius of convergence for chiral expansion

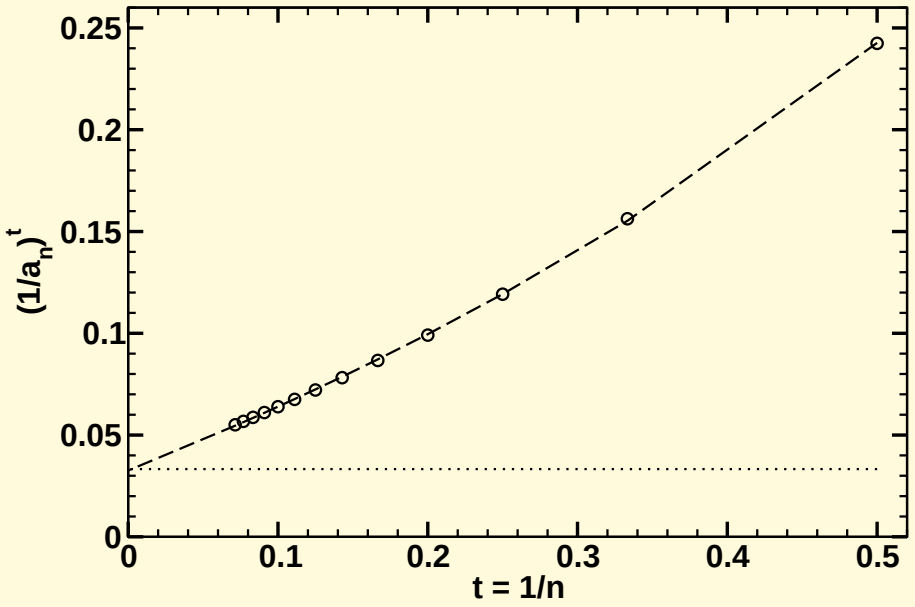
The chiral expansion

$$M_+(m^{bm}) = M_0 + \sum_{n=1}^{\infty} a_n (m^{bm})^n \tag{6}$$

is absolutely convergent, so long as $\forall n$

$$(\frac{1}{|a_n|})^{1/n} > (\frac{1}{|a_{n+1}|})^{1/(n+1)} \tag{7}$$

and the radius of convergence is $m_{rc} := \lim_{n\to\infty} (\frac{1}{|a_n|})^{1/n}$.



Closer to QCD

- the model choice

$$\frac{\mathcal{G}(t)}{t} = \frac{4\pi^2}{\omega^6} D\, t\mathrm{e}^{-t/\omega^2} + \frac{8\pi^2\,\gamma_m}{\ln\left[\tau + \left(1 + t/\Lambda^2_{\mathrm{QCD}}\right)^2\right]}\,\mathcal{F}(t)\,, \tag{8}$$

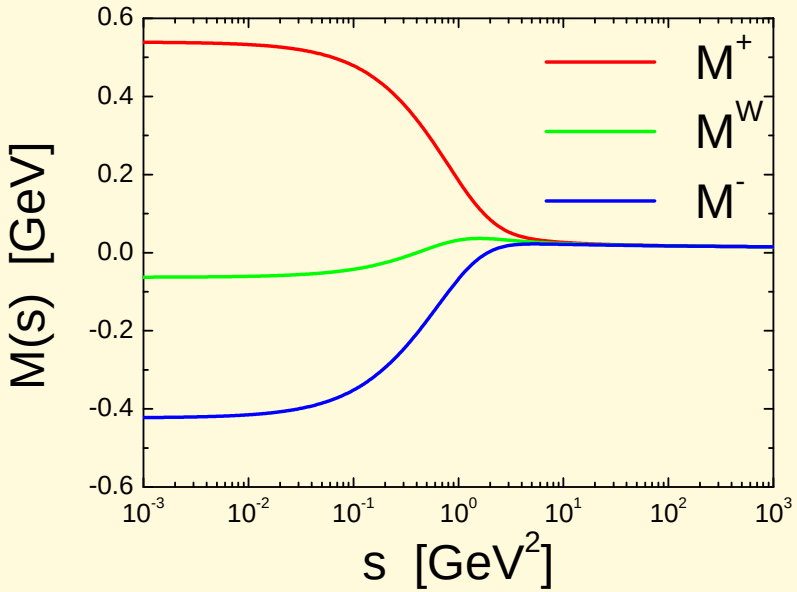
with $t = k^2$, $\mathcal{F}(t) = [1 - \exp(-t/[4m^2_{\mathcal{F}}])]/t$, $m_{\mathcal{F}} = 0.5\,\mathbf{GeV}$, $\tau = \mathrm{e}^2 - 1$, $\gamma_m = 12/25$ and $\Lambda_{\mathrm{QCD}} = \Lambda^{(4)}_{\overline{MS}} = 0.234\,\mathbf{GeV}$.

- $(\omega D) = (0.72 GeV)^3$
- one-loop version of mass function

$$M(p^2) \stackrel{p^2 \gg \Lambda^2_{\mathrm{QCD}}}{=} \frac{\hat{m}}{(\frac{1}{2}\ln p^2/\Lambda^2_{\mathrm{QCD}})^{\gamma_m}}, \tag{9}$$

where $\hat{m}$ is the renormalisation-group-invariant mass.

• Quark mass functions at $m(\zeta_{19}) = 16MeV$



⋆ three different solutions exist at this special current quark mass

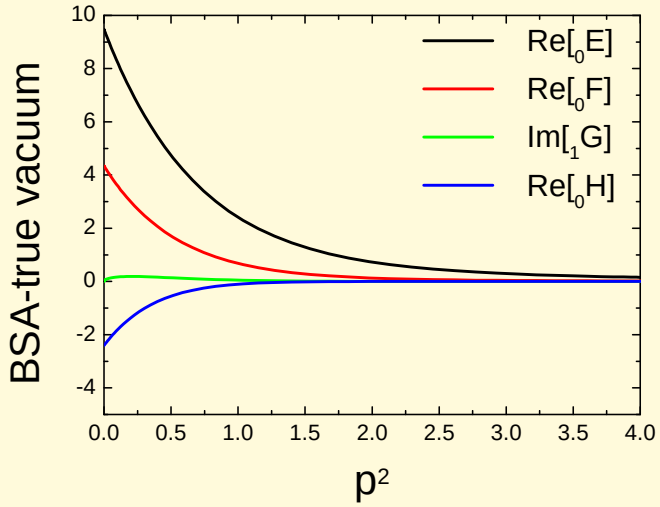
⋆ $M_+(p^2) \overset{p^2 \gg \Lambda^2_{\rm QCD}}{=} M_-(p^2) \overset{p^2 \gg \Lambda^2_{\rm QCD}}{=} M_W(p^2)$

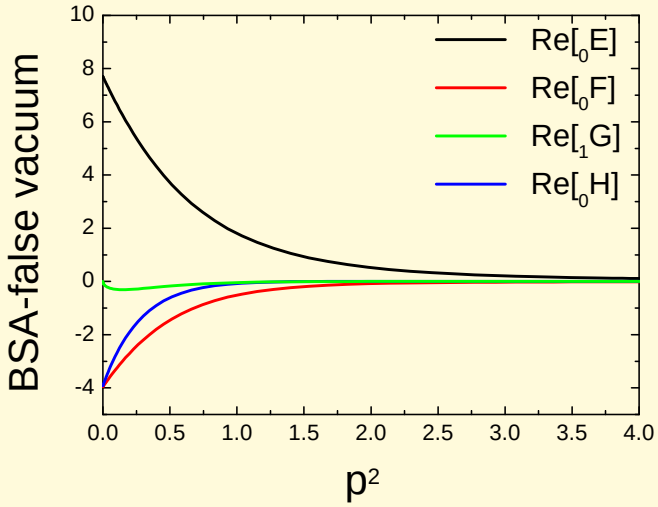
⋆ $M_W(p^2)$ is unstable under perturbation of current quark mass

- The pion properties in different vacuum

The pion Bethe-Salpeter amplitude is commonly decomposed into

$$\Gamma(q;P) = \gamma_5[iE + \gamma\cdot P F + \gamma\cdot q G + i[\gamma\cdot P, \gamma\cdot q]H]\,, \tag{10}$$

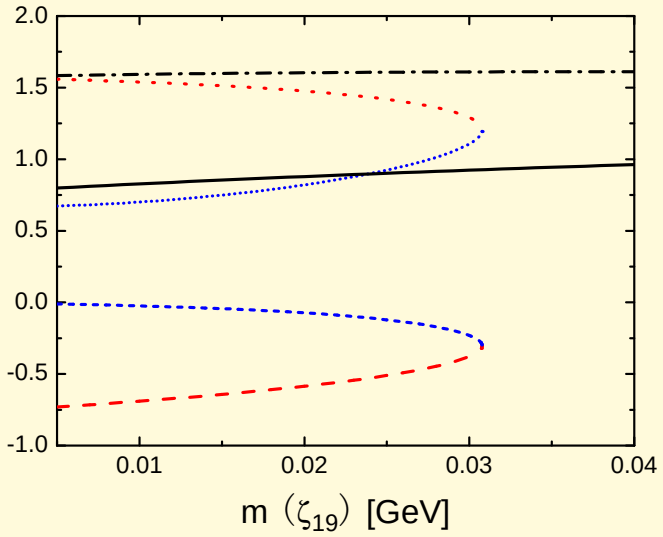


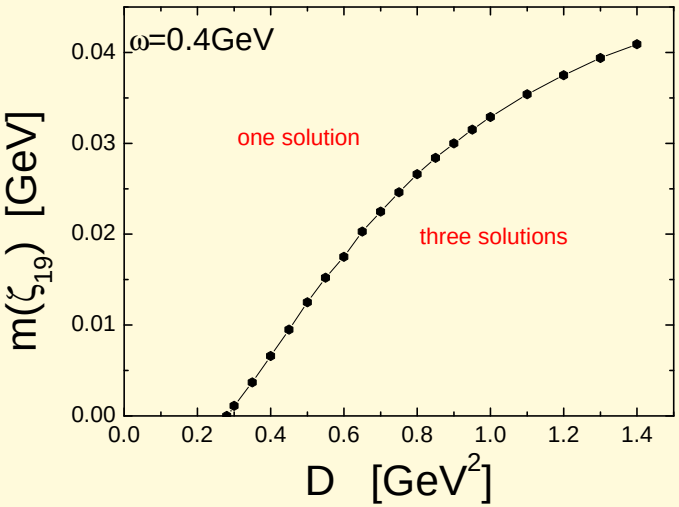


$$M_\pi^2 = 0.0852\ GeV^2$$
$$f_\pi = 0.104\ GeV$$

$$M_\pi^2 = -0.0828\ GeV^2$$
$$f_\pi = -0.079\ GeV$$

• the critical mass in M-T model

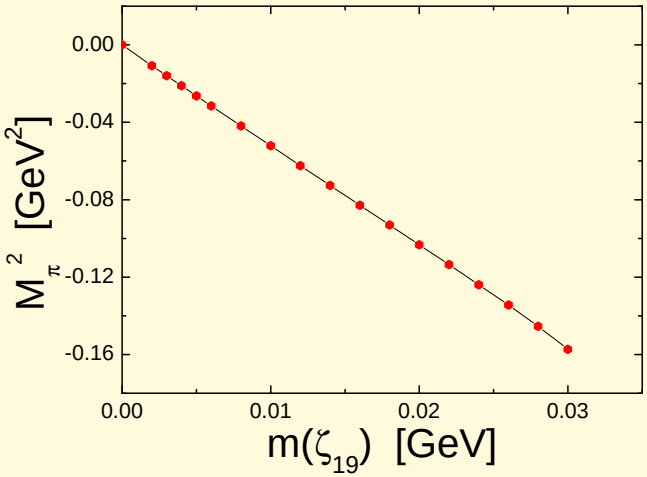


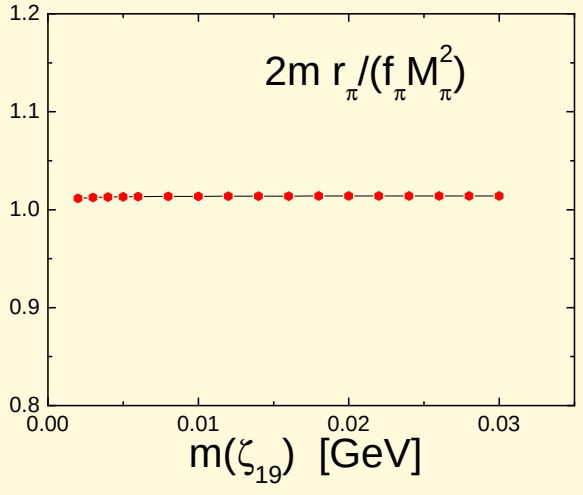


⋆ This model also exhibits a bounded domain of current-quark mass;

⋆ The critical current mass increases with increasing of coupling strength.

- Pion mass in false vacuum on the bounded domain





- Chiral quark condensate beyond the chiral limit-I

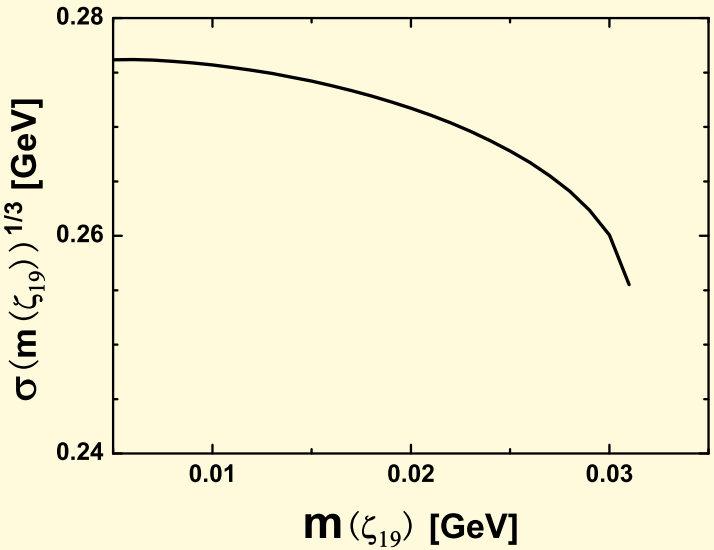
A definition:

$$\bar{\sigma}(m(\zeta)) := \lim_{\Lambda\to\infty} Z_4(\zeta^2,\Lambda^2)\, N_c\, \mathrm{tr}_{\mathrm{D}} \int_q^{\Lambda} \bar{S}^{m(\zeta)}(q,\zeta)\,, \tag{11}$$

where

$$\bar{S}^{m(\zeta)}(q,\zeta) = \frac{1}{2}\left[S_+^{m(\zeta)}(q,\zeta) - S_-^{m(\zeta)}(q,\zeta)\right], \tag{12}$$

⋆ gauge-invariant quantity, well defined, finite and unambiguous



⋆ the essentially dynamical chiral symmetry breaking decreases with increasing current quark mass

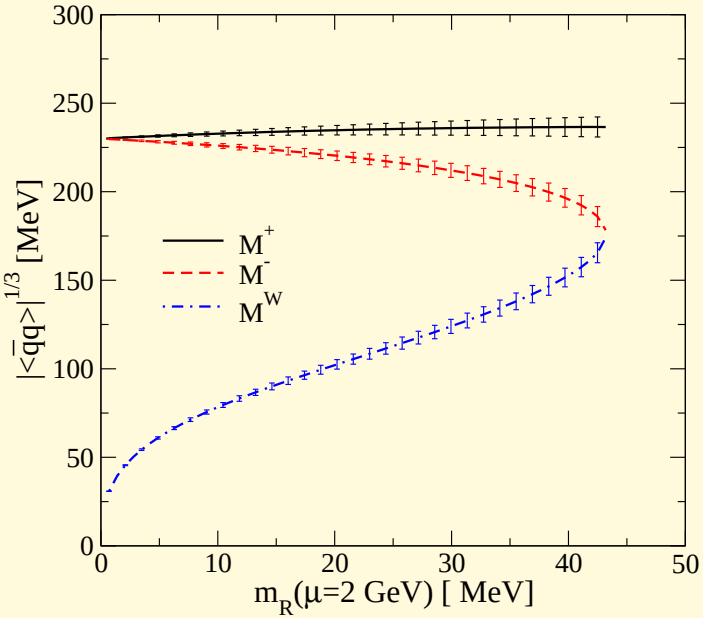
- Chiral quark condensate beyond the chiral limit-II

R. Williams, C. S. Fischer, M. R. Pennington, Phys.Lett. B645 (2007) 167-172.

Motivation: the mass function at very large momenta

$$M(p^2)_{asym} = \overline{m}\left[\log\left(p^2/\Lambda_1^2\right]\right)^{-\gamma_m} + \frac{2\pi^2}{3}\frac{\mathcal{C}}{p^2}\left[\frac{1}{2}\log\left(p^2/\Lambda_2^2\right)\right]^{\gamma_m - 1} \quad . \tag{13}$$

Extracting the Condensates



Summary

- On a bounded interval of current-quark mass realistic models of the QCD gap equation can simultaneously admit three different solutions;
- We provide evidence that the upper boundary also defines the radius of convergence for an chiral expansion;
- The pion properties in false vacuum be calculated, the mass square is non-positive and depend on current quark mass linearly;
- A definition of chiral quark condensate beyond chiral limit is elucidated.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