Weak magnetic field corrections to low energy light vector and axial mesons couplings and mixings

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Workshop on Electromagnetic Effects in Strongly Interacting Matter

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OUTLINE

1- Motivations and framework

- Dynamical derivation of hadron models/couplings from QCD
- The limiting case of the NJL model under strong B

2- Light Vector/axial mesons couplings (Yukawa and higher order)
- Wess-Zumino-Witten type couplings
  and the axial (vector) content of vector (axial) mesons

3 (Relatively) Weak magnetic fields
- Vector/axial mesons mixings and VMD at finite magnetic field
- Results for vector and axial coupling constants, form factors, averaged quadratic radii

- Final remarks

Talk based on:

F.L.B., Phys. Rev. D105, 054009 (2022)
T.H.Moreira, F.L.B., Phys. Rev. D105, 114009 (2022)
F.L.B., Journ. of Phys. G47, 115102 (2020)
F.L.B., Phys. Rev. D97, 0140022 (2018) ; D101, 039902(E) (2020)
F.L.B., Phys. Rev. D94, 074030 (2016)

Funding:

Motivations

Constituent Quark Model (CQM)

GellMann-Zweig
And many others

Most of Hadrons Spectra support or suggest the idea (original quark models/ eightfold way)

It can receive corrections:
Diquarks
Virtual n-quarks states from Fock space
etc

In these models: “dressed” (constituent) quark masses are responsible for the hadrons masses
They are assumed to be “quasiparticles” (not propagating(?))
And it works...

Quark masses (from the HIggs) are much smaller than needed to describe hadron masses

Mechanisms of mass generation :
Dynamical Chiral Symmetry Breaking
Associated to other effects

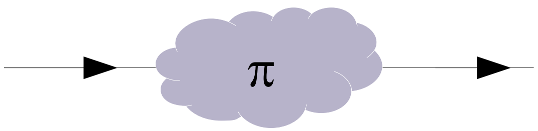
$$< \bar{q}_R q_L + \bar{q}_L q_R > \simeq -(250MeV)^3$$

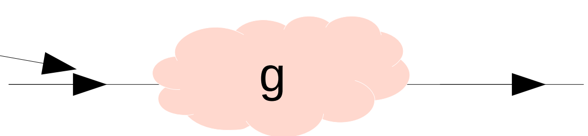
Other works/talks in this conference

<u>From constituent quarks</u>

M*u ~ 360 MeV
M*d ~ 370 MeV
M*s ~ 510 MeV

Constituent quarks:
two main possible contributions
Usually considered separatedly
Maybe “competing” contributions





$$m_{qqb} = m_{qb} + m_q + \Delta^1_{spin}$$
$$m_{qqq} = m_q + m_{q'} + m_{q''} + + \Delta^2_{spin}$$

Motivations

Strong magnetic fields

Weak with respect to a hadron energy scale M*, Mproton, Mpion

$$\frac{eB_0}{M^*} \sim 0.2 \to 10$$

$$\left(\frac{eB_0}{M^*}\right)^n, \qquad n = 1, 2$$

Non-central Relativistic Heavy Ions Collisions (r.h.i.c.)

$$eB_0 \simeq 0.5 m_\pi^2 \simeq 0.1 M^{*2} \simeq 10^{17}\,\mathrm{G},$$

Many possible effects some of them addressed in this conference

$$\frac{eB_0}{M^*} \sim 0.2 \to 10$$

Specific questions:
Usually: how masses, decay rate change with B?
<u>Here mostly: how couplings between hadrons change with B?</u>

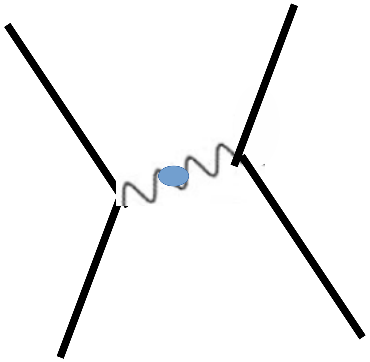
Dense-stars/ Magnetars

And

Primordial Universe

Several groups addressed hadron couplings under B
Ferrer, de la Incera, Hoffmann, Ayala, etc

The idea is to investigate
a leading term of the QCD quark-effective action
Obtained from QCD Lagrangian

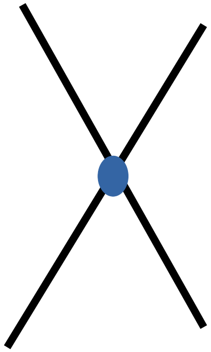


The quark-quark interaction mediated by ONE gluon exchange

WITH however an improvement due to **“non perturbative” (non Abelian) effects**

This present approach provides, to some extent,
similar results to the QCD-SDE at the rainbow ladder approach

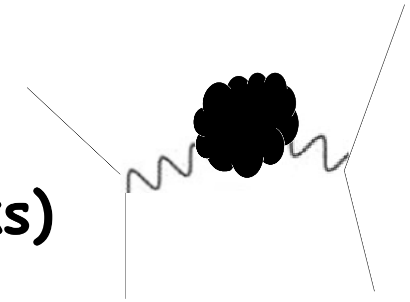
And also, to some extent, similar to the **NJL model**
- leading flavor structure independent of gluon sector



$G_{NJL} \sim 1/M_g^2$

Other effects for quark interactions and/from
Gluon dynamics and related effects: under work

QCD Effective action → quark antiquark interaction



One leading term of the QCD effective action (quarks)

$$Z = N \int \mathcal{D}[\bar{\psi},\psi] \exp i \int_x \left[\bar{\psi}(i\partial\!\!\!/ - m)\psi \; - \frac{g^2}{2} \int_y j^b_\mu(x) \tilde{R}^{\mu\nu}_{bc}(x-y) j^c_\nu(y) + \bar{\psi} J + J^* \psi \right]$$

Gluon propagator as external input

* non perturbative one → DChSB

* to some extent non Abelian dynamics accounted

Quark-gluon (running) Coupling Constant (external input)

Equal current quark mass
Flavor
SU(2) or SU(3)

In the 1980's and 1990's by considering
bosonization-type approaches **for mesons:**
Chiral Perturbation theory Has been derived from quark-antiquark interactio
by many With works in the following decades
Roberts,Praschifka,Cahill,Ebert,Reinhardt,Volkov,Holdom and others

General approach
For the flavor structure

Quark field $\longrightarrow$ Background quark + (sea+mesons) quark field

Quark-antiquark mesons and sea quarks

Dressed by gluon cloud and
Sea quarks

Becomes
a constituent quark

Auxiliary fields for all the
Dirac-flavor-color quark currents
Quark-antiquark mesons:

[color singlet ones
leading by 1/Nc]

Emergence
Of

Pion cloud

This improves usual
One loop background field method
By taking into account
Dynamical Chiral Symmetry Breaking and M*
FLB,
EPJA (2016, 2018)+PRD (2018)

The NJL-limit
is also directly
obtained

Quark sector
(very large gluon
Effective mass)

TH Moreira, FL Braghin, PRD105, 114009

Nambu-Jona-Lasinio model: ONE-LOOP BACKGROUND quark sector

Many works with **G(B)** for strong magnetic fields
Farias, Krein, Avancini, Costa, Oliveira, Endrodi, Marko,
Chao, Scoccola, Coppola, and several others
Usually **G(B)** is atributed to gluon dynamics (polarization)
So that gluon propagator and effective mass should depend on B

The difference
Between Gs and Gps
Is a symmetry
breaking prop to M*

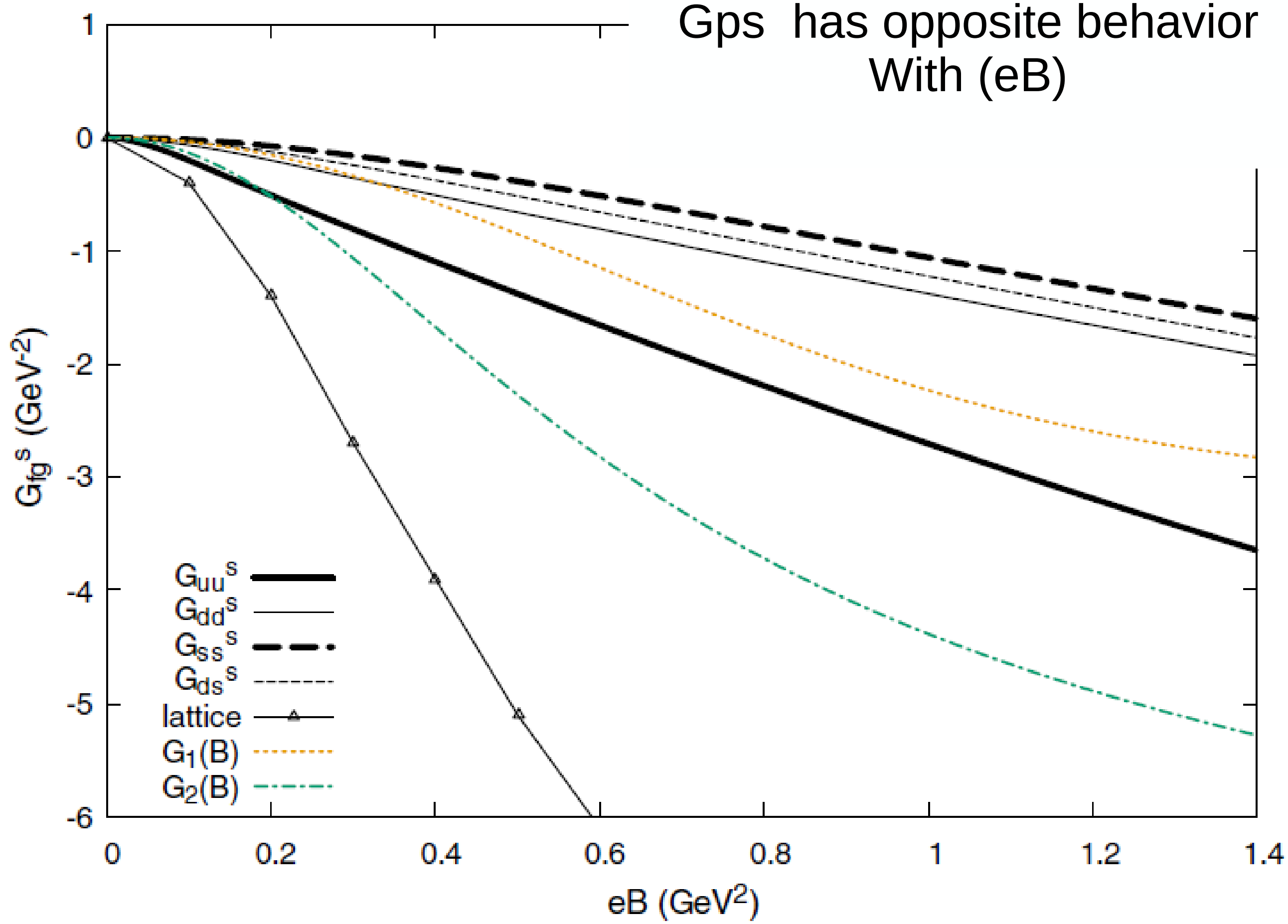
$$\mathcal{L}_{1\mathrm{loop}} = \frac{\bar{G}_s^{ij}(B)}{2}(\bar{\psi}\lambda_i\psi)(\bar{\psi}\lambda_j\psi) + \frac{\bar{G}_{ps}^{ij}(B)}{2}(\bar{\psi}i\gamma_5\lambda_i\psi)(\bar{\psi}i\gamma_5\lambda_j\psi),$$

A mechanism to generate **G(B)**
different from gluon dynamics
1-loop

Non degenerate

Guu, Gdd, Gss

Gij, including mixing

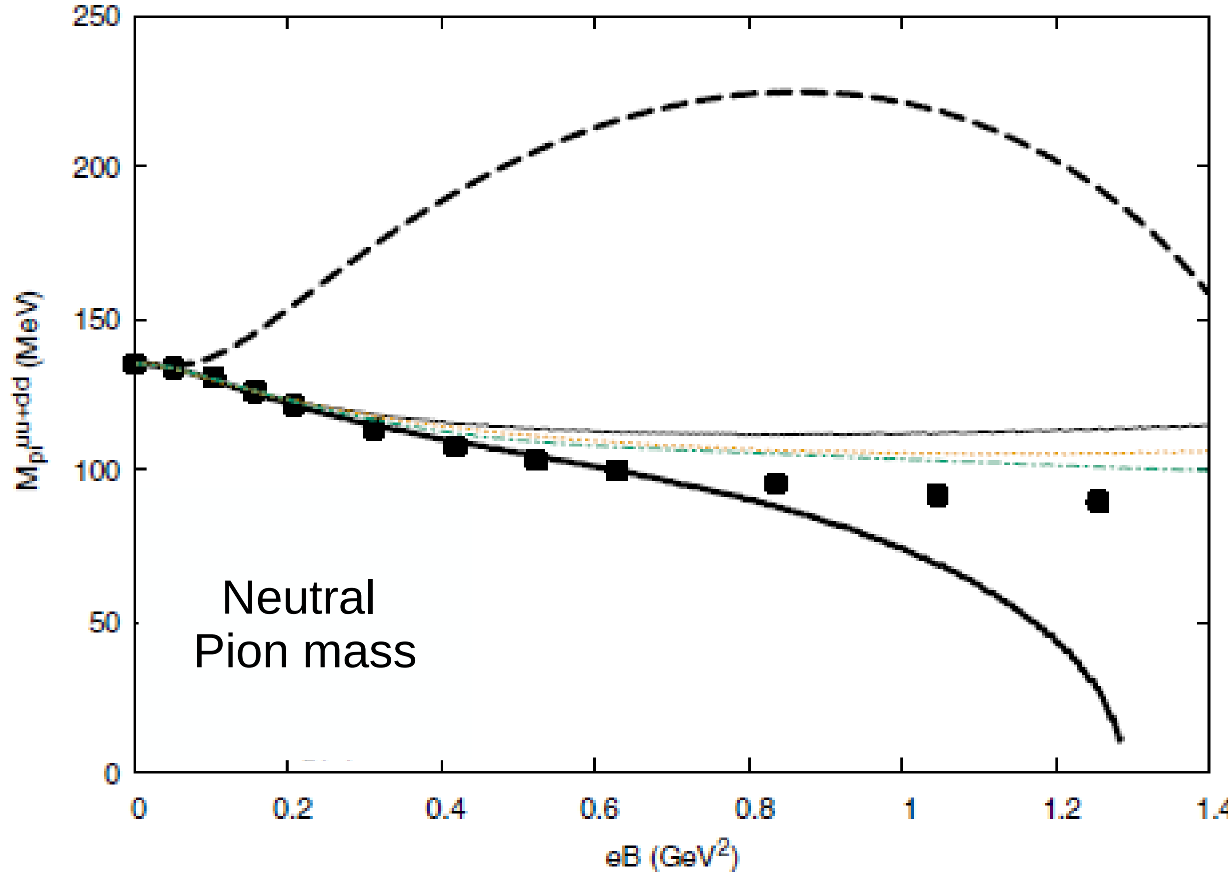


Gps has opposite behavior
With (eB)

However
when using effetive models (or any EFT)

- trying to improve the predictive power
- one may has to deal with possible double counting effects (eg. Quantum fluctuations of fundamental d.o.f OR of effective d.o.f.)

- in other words:
what is an effective model?



Other mixing effects for the NJL model:
On going

Effective action and

Large quark effective mass expansion

(large mass + derivarive expansion at leading order)

All the constituent quark
Currents with Dirac/flavor
Structures (from Fierz)
And corresponding
Component of gluon kernel

Vector and axial mesons

$$S_{eff} = -i\, Tr\, \ln \left\{ i \left[S_0^{-1}(x-y) + \Xi_v(x-y) + \Xi_s(x-y) + \sum_q a_q \Gamma_q j_q(x,y) \right] \right\},$$

Sum of (background)
Constituent quarks currents

$$S_0^{-1}(x-y) = \left(i\not{D} - M^* \right) \delta(x-y).$$

This is a NJL-like quark propagator

The effect of running quark mass+Z(q)
Maybe to be used in the future

Linear realization: Scalars + Pseudoscalars
Or
Non linear realization Goldstone boson

Scheme for complete renormalization
(Yukawa model)
A.A.Nogueira, F.L.Braghin, IJMPA
2103.05133

In some versions:
Of constituent quark model

With a pion cloud

Large Nc EFT : **benchmark of the method**

S.Weinberg, (2010)
to cope * CQM - Manohar-Georgi form
And * Large Nc- 't Hooft]

vacuum

$$\mathcal{L}_{\text{eff}} = -\frac{1}{4g^2}\text{Tr}\{F_{\mu\nu}F^{\mu\nu}\} - \frac{1}{g^2}[\bar{\psi}(D^\mu\gamma_\mu + m)\psi]$$
$$- \frac{F_\pi^2}{2}\mathcal{D}_\mu\vec{\pi}\cdot\mathcal{D}^\mu\vec{\pi} - \frac{2ig_A}{g^2}(\bar{\psi}\gamma_5\gamma^\mu\vec{t}\psi)\cdot\mathcal{D}_\mu\vec{\pi}$$
$$- c_1(\mathcal{D}_\mu\vec{\pi}\cdot\mathcal{D}^\mu\vec{\pi})^2 - c_2(\mathcal{D}_\mu\vec{\pi}\cdot\mathcal{D}_\nu\vec{\pi})$$
$$\times(\mathcal{D}^\mu\vec{\pi}\cdot\mathcal{D}^\nu\vec{\pi}).$$

Constituent gluons coupling
+ Pion vector -coupling

Leading terms
chiral perturbation theory

Although
The pseudoscalar pion coupling is also obtained

Large Nc GCM ~ Large Nc QCD – quark sector

This EFT (local pion field)
+ chiral symmetry breaking terms:

F.L.B. Eur. Phys. Journ. (2016)

Values for lec's obtained
are numerically nearly equal to
1-loop ChPT
(truncated quark propagator)

$$\mathcal{O}\left(\frac{1}{M^{*2n}}\right)$$

Vacuum and Weak B

Large Nc EFT : **benchmark of the method**

S.Weinberg, (2010)
to cope * CQM - Manohar-Georgi form
And * Large Nc- 't Hooft]

Including hadron electromagnetic couplings U(1)

$$\mathcal{L}_1 = -g_1 \,\mathrm{tr}_F \,(U + U^\dagger) + \frac{F^2}{4} g_c \,\mathrm{tr}_F \; D^\dagger U^\dagger D U$$
$$-l_5 \, e^2 \,\mathrm{tr}_F \left(Q F_{\mu\nu} U^\dagger Q F^{\mu\nu} U\right),$$

$$D_\mu U = \partial_\mu U + ie A_\mu \left[\frac{\tau_3}{2}, U\right],$$
$$(D_\mu U)^\dagger = \partial_\mu U^\dagger - ie A_\mu \left[\frac{\tau_3}{2}, U^\dagger\right],$$

$$I_{\pi-A_\mu} = +\frac{(l_3 + l_4)}{16} m_\pi^4 \,\mathrm{tr}_F \left(U^2 + {U^\dagger}^2\right)$$
$$+\frac{l_4}{8} m_\pi^2 \,\mathrm{tr}_F \left(D_\mu U^\dagger D^\mu U\right) \left(U + U^\dagger\right)$$
$$-\frac{l_1}{4} \,\mathrm{tr}_F \,(D_\mu U^\dagger D^\mu U)^2$$
$$-\frac{l_2}{4} \,\mathrm{tr}_F \,(D_\mu U^\dagger D_\nu U) \cdot (D^\mu U^\dagger D^\nu U),$$

Coupling of photon
To Quarks and to mesons states
Emerge naturally

$$L_{q-\pi-A} = \left(M_{AA} A_\mu^2 + M_{FF} F_{\mu\nu} F^{\mu\nu}\right) j_s + g_{vmd} A_\mu \, j^\mu_{i=3}$$
$$+ i g_{F-js-\pi} \, F \, F^2_{\mu\nu} \,\mathrm{tr}_F(\{Q, Z_+\}\, Q) j_s$$
$$+ i g_{F-ps-\pi} \, F \, F^2_{\mu\nu} \,\mathrm{tr}_F \left([Q, Z_-]\, [Q, \sigma_i]\right) j^i_{ps}$$
$$+ i g_{jVA} \, F \, F^{\mu\nu} \,\mathrm{tr}_F([\partial_\mu Z_+, Q]\, \sigma_i) j^i_{V,\nu}$$
$$+ i g_{jAA} \, F \, F^{\mu\nu} \,\mathrm{tr}_F([Q, \partial_\mu Z_-] \sigma_i) j^i_{A,\nu} + \mathcal{O}(A_\mu^2),$$

$$L_{D-F} = -i \frac{l_6}{2} \,\mathrm{tr}_F \left[\left(Q F_{\mu\nu} (D^\mu U)^\dagger (D^\nu U)\right)\right.$$
$$\left. + \left(Q F_{\mu\nu} (D^\mu U)(D^\nu U)^\dagger\right)\right],$$

This EFT (local pion field)
with electromagnetic couplings
+ chiral symmetry breaking terms:

F.L.B. Eur. Phys. Journ. (2018)

Veff for U(1) NJL in terms of sigma+pion
Miransky-Shovkovy - 2015

Leading vector and axial mesons couplings to Constituent quarks

PHYS. REV. D **97,** 054025 (2018)

And Erratum
(not wrong issues)

Very Long wavelength limit..

$$\mathcal{L}_{v-q} = g_{r1}\left(V_i^{\mu}(x)j_{\mu}^{V,i}(x) + (1+\delta_A)\bar{A}_i^{\mu}(x)j_{\mu}^{A,i}(x)\right) -$$

$$+ g_{v1}\left(V^{\mu}(x)j_{\mu}(x) + (1+\delta_A)\bar{A}_{\mu}(x)j_A^{\mu}(x)\right)$$

Minimal couplings
Proposed by Sakurai (1960)

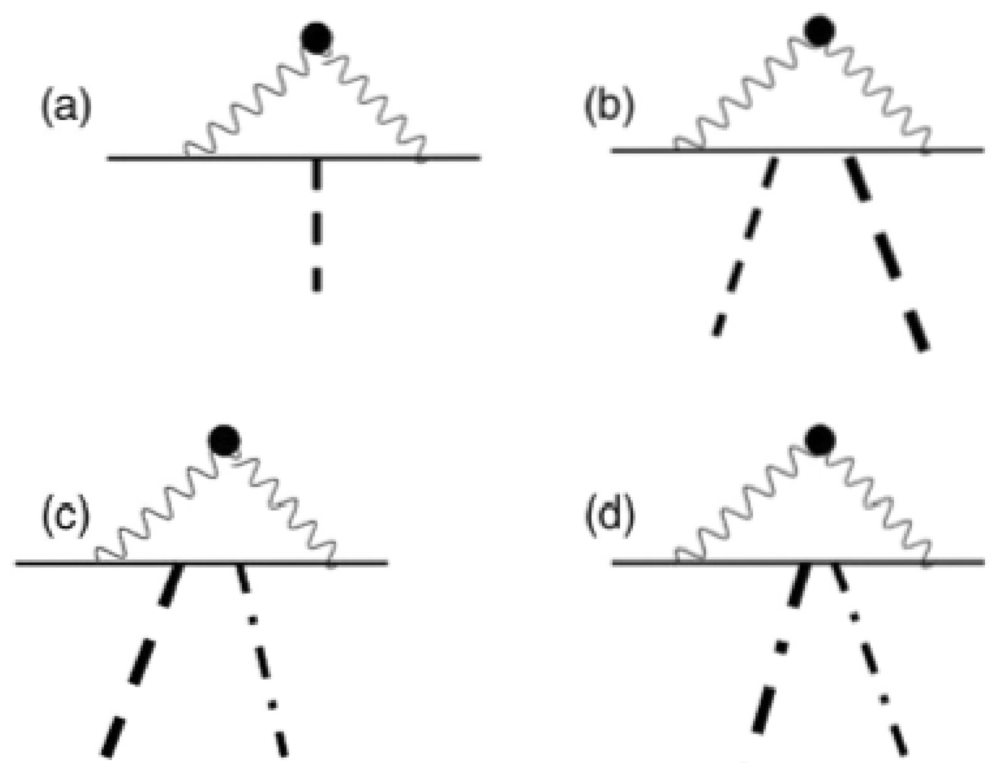
In the vacuum

$\rho(770)$

$a_1(1260)$

$\omega(782)$

$f_1(1285)$



Leading
And
Next leading
Couplings

For
Large quark M* mass

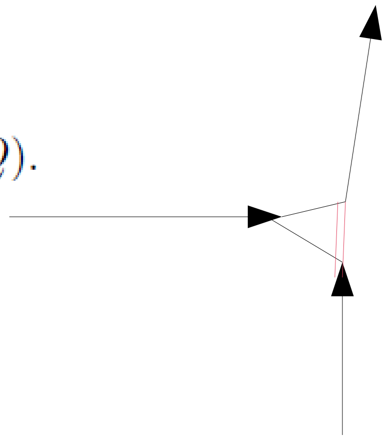
Unusual ("anomalous")

Vector mesons couplings to the axial quark current

In the vacuum

$$\mathcal{L}_{vja} = i\delta_{ij}\epsilon^{\sigma\rho\mu\nu}F^{vja}K_\sigma\mathcal{F}^i_{\rho\mu}j^{A,j}_\nu + i\epsilon^{\sigma\rho\mu\nu}F^{vja}K_\sigma\mathcal{F}_{\rho\mu}j^A_\nu,$$

$$\mathcal{F}^i_{\rho\mu}(Q) = Q_\rho V^i_\mu(Q) - Q_\mu V^i_\rho(Q), \qquad \mathcal{F}_{\rho\mu}(Q) = Q_\rho V_\mu(Q) - Q_\mu V_\rho(Q).$$



These are **Wess-Zumino-Witten terms**

$$n\Gamma = -\frac{i}{240\pi^2}\int d^4K\, d^4Q\, \epsilon_{\sigma\rho\mu\nu}F^{vja}(K,Q)K_\sigma\mathcal{F}^i_{\rho\mu}(Q)j^{A,i}_\nu(K,K+Q),$$

By comparing the anomalous vector meson coupling to jA

To the pion axial coupling (jA)

And to the axial meson coupling to jA

$$\mathcal{L}_{j_A} = \left[G_A Q_\mu \pi^i + G_{\bar{A}} \bar{A}^i_\mu + i\ F_{vja} \epsilon_{\mu\nu\rho\sigma} K^\nu Q^\rho V_i^\sigma\right] j^\mu_{A,i}$$

In the vacuum

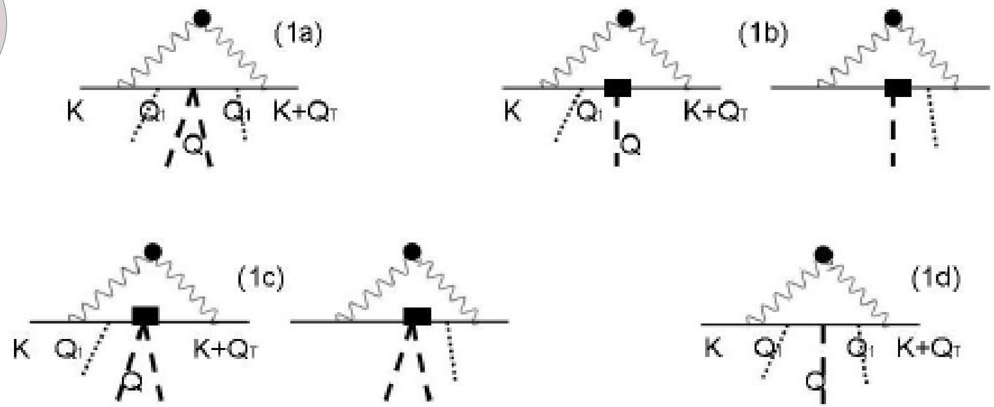
$$\frac{F_{vja}(K,Q)}{G_A(K,Q)} = \frac{1}{4M^* F}.$$

Equal
Internal Momentum dependence to the constituent quark axial form factor
(1-loop level)

$$\left.\frac{F_{\mathrm{vja}}(K,Q) \times |K||Q|}{G_V(K,Q)}\right|_{Q\sim K\sim 200\text{–}500\ \mathrm{MeV}} \sim 0.1.$$

Effect of "weak" magnetic field: eB << M*^{2}

1



... photons

- - - mesons

_____ quarks

Wiggly line = gluons

This is Possible Due to The emerging Electromagnetic couplings

The background photon field interacting with hadrons
(B as "strong-photon field")

And

2

Quark propagator

$$G(k) \;=\; S_0(k) + S_1(k)(eB_0)$$

Both lead basically/mostly to equal structures

Possibly with a Different proportionality factor

Vector / axial mesons couplings to constituent quarks

- relatively weak B -

Leading photon coupling to

axial and vector mesons

$$I_{FF} = 2 g_1 i\epsilon_{ij3}(F_{\mu\nu}\mathcal{G}_i^{\mu\nu} j_p^j + F_{\mu\nu}\mathcal{F}_i^{\mu\nu} j_s^j),$$

and scalar/pseudoscalar quark currents j

Momentum integrals

Background Photons

Correct **vector meson electric charges**
Of charged vector mesons (rho) Q = + 1, -1

And in some terms
average u-d quark electric charge

B along z-axis

$$I_{FF} \to 2 g_1^B i\epsilon_{ij3}[\mathcal{G}_i^{xy} j_p^j + \mathcal{F}_i^{xy} j_s^j],$$

Vector mesons stress tensors:

Flavor-triplet (rho) flavor-singlet (omega)

$$\mathcal{F}^i_{\rho\mu}(Q) = Q_\rho V^i_\mu(Q) - Q_\mu V^i_\rho(Q), \qquad \mathcal{F}_{\rho\mu}(Q) = Q_\rho V_\mu(Q) - Q_\mu V_\rho(Q).$$

Background photon field

$$I_{AV} = g_{qA}\left(A_\mu(x) j_3^\mu(x) + \frac{1}{3} A_\mu(x) j^\mu(x)\right) \longrightarrow$$

Vector meson dominance

$$I_{FFm} = g_1 [F_{\mu\nu}\mathcal{F}_3^{\mu\nu} j_s + F_{\mu\nu}\mathcal{F}^{\mu\nu} j_s^3 + F_{\mu\nu}\mathcal{G}_3^{\mu\nu} j_p + F_{\mu\nu}\mathcal{G}^{\mu\nu} j_p^3$$
$$+\frac{1}{3}(F_{\mu\nu}\mathcal{G}^{\mu\nu} j_p + F_{\mu\nu}\mathcal{F}^{\mu\nu} j_s + F_{\mu\nu}\mathcal{G}_i^{\mu\nu} j_p^i + F_{\mu\nu}\mathcal{F}_i^{\mu\nu} j_s^i)],$$

There are some not explicitely gauge invariant
Because it is missing writing them
The photon field as part of a covariant derivative

Constant Magnetic field along z-direction:

$$I_{FFm} \to g_1^B \left[\mathcal{F}_3^{xy} j_s + \mathcal{F}^{xy} j_s^3 + \mathcal{G}_3^{xy} j_p + \mathcal{G}^{\mu\nu} j_p^3 \right.$$
$$\left. + \frac{1}{3} \left(\mathcal{G}^{xy} j_p + \mathcal{F}^{xy} j_s + \mathcal{G}_i^{xy} j_p^i + \mathcal{F}_i^{xy} j_s^i \right) \right],$$

$$I_{VF} \to g_3^{B_1} i\epsilon_{ij3} [V_i^x j_{j,V}^y + \bar{A}_i^x j_{j,A}^y],$$

$$I_{AF} \to g_3^{B_2} i\epsilon_{ij3} [\mathcal{F}_{y\delta}^i j_{j,V}^\delta + \mathcal{G}_{y\delta}^i j_{j,A}^\delta)],$$

$$\frac{g_1^B}{g_3^{B_1}} \sim \frac{1}{M^*}, \qquad \frac{g_3^{B_2}}{g_2^B} = \frac{1}{M^*}.$$

$$L_{v-q} = g_{r1} (V_i^\mu (x) j_\mu^{V,i} (x) + \bar{A}_i^\mu (x) j_\mu^{A,i} (x))$$

$$\frac{g_3^{B_1}}{g_{r1}} \sim \frac{3}{4} \frac{eB_0}{M^{*2}}.$$

All the coupling constants (in momentum space)

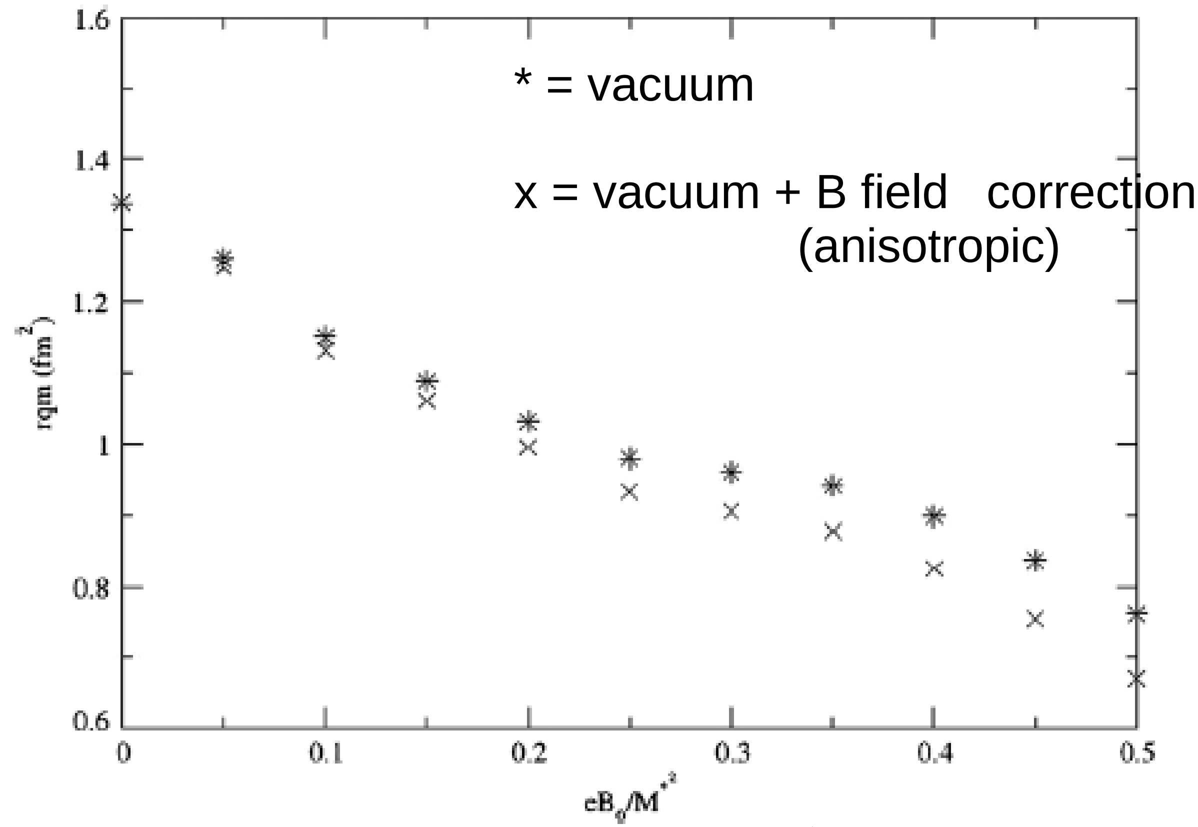
correspond to the zero momentum limit (external lines)

of a (momentum-dependent) form factor

K,Q → 0

From the form factors:
Corrections to rho/omega a.q.r. due to weak magnetic fields
In the plane perpendicular to the Magnetic field:

$$\langle r_\rho^2 \rangle (B_0) = -6 \frac{dF^E_{1,\rho}(Q^2)}{dQ^2}\bigg|_{Q=0} \equiv \langle r_\rho^2(M^*) \rangle + \frac{eB_0}{M^{*2}} \Delta \langle r_\rho^2(M^*) \rangle .$$



Result slightly dependent on the shape of the effective gluon propagator

FLB, PRD97 (2018)

B field
Along z axis

Unusual (“anomalous”)

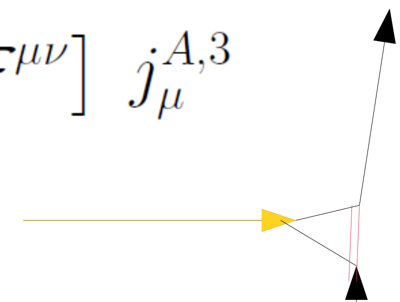
Vector mesons couplings to the axial quark current

Weak B

K=quark incoming momentum
Q=meson incoming momentum

$$\mathcal{L}_{vjaB} = \frac{(eB_0)}{M^{*2}}\epsilon_{ij3}\frac{F^B_{vja}(K,Q)}{M^{*2}}\left[\epsilon^{12\rho\mu}K_\rho Q_\nu \cdot V^i_\nu + 2\epsilon_{12\rho\nu}K^\rho \mathcal{F}^{\mu\nu}_i\right] j^{A,j}_\mu$$

$$+ \frac{(eB_0)}{M^{*2}}\frac{F^B_{vja}}{3M^{*2}}\left[\epsilon^{12\rho\mu}K_\rho Q_\nu \cdot V_\nu + 2\epsilon_{12\rho\nu}K^\rho \mathcal{F}^{\mu\nu}\right] j^{A,3}_\mu$$



Small with respect to
The pion axial coupling

But with similar (equal)
Momentum dependence to the
constituent quark axial form factor

Also Wess-Zumino-Witten
term
That might lead to
Quantization of currents

$$n\Gamma = -\frac{i}{240\pi^2}\int d^4K\, d^4Q\, \epsilon_{\sigma\rho\mu\nu}F^{vja}(K,Q)K_\sigma \mathcal{F}^i_{\rho\mu}(Q) j^{A,i}_\nu(K,K+Q),$$

Other WZW terms only with mesons (local) fields
(same limit as NJL model, with different values/structure for coupling constants)

$$\begin{aligned}
\mathcal{L}_{mix,B} &= \frac{(eB_0)}{M^{*2}} G^{B,1}_{v-a} i\epsilon_{12\mu\nu} M^{*2} i\epsilon_{ij3} V^{\mu}_{i} \bar{A}^{\nu}_{j}(K)\delta(Q+K) \\
&+ \frac{(eB_0)}{M^{*2}} G^{B,1}_{v-a-\pi} i\epsilon_{12\mu\nu} M^{*} \left(\pi_3(Q) V^{\mu} \bar{A}^{\nu} + T_{ijk}\pi_i V^{\mu}_{j} \bar{A}^{\nu}_{k}\right)
\end{aligned}$$

Vector- axial mixing
Induced by pion

Three-meson coupling
Usually considered
In medium calculations

Vector-axal mixing

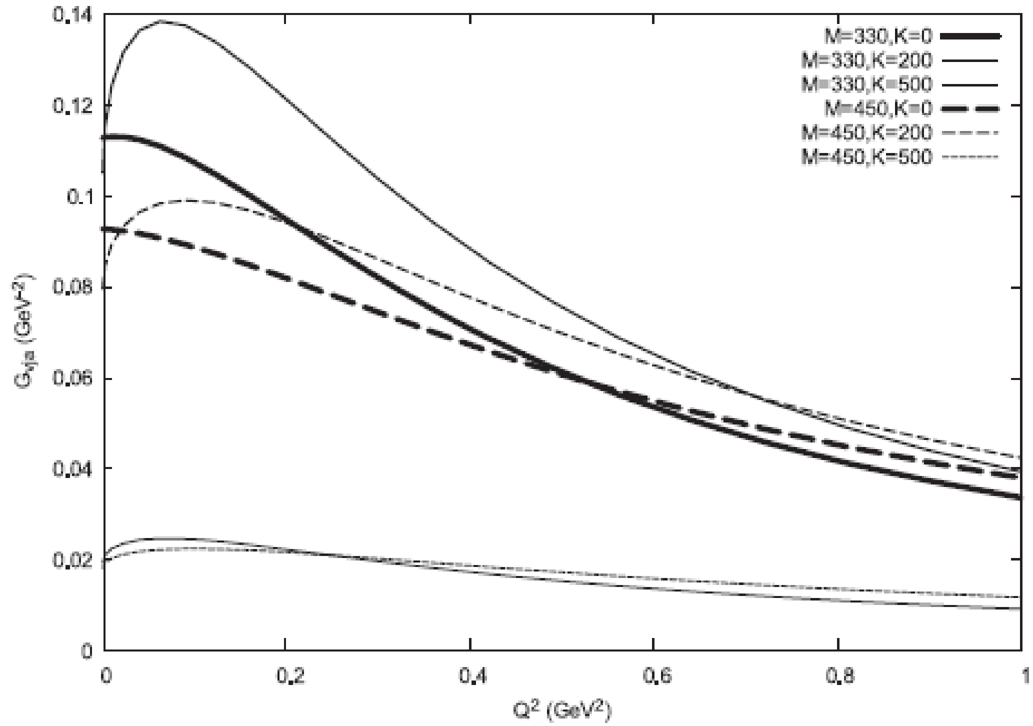
Two-meson coupling
Only possible in a medium

Or in the presence of
3rd particle

For conservation of momentum

Increase of
External momenta
(rho and constituent quark)

Lead to fast decrease of
Gvja



$$F(K,Q;B_0) = F(K,Q) + f\frac{(eB_0)}{M^{*2}}F^B(K,Q),$$

Weak magnetic field
Correction to the
Axial a.q.r of the rho
meson

$$\Delta_A^B \langle r_\rho^2 \rangle \sim \frac{\Delta_A \langle r_\rho^2 \rangle}{10}.$$

$$\Delta_A < r_\rho^2 > \sim \frac{< r_\rho^2 >}{10} \quad \text{at} \quad M^* \sim 0.35\text{GeV}$$

Meson sector
~ NJL model

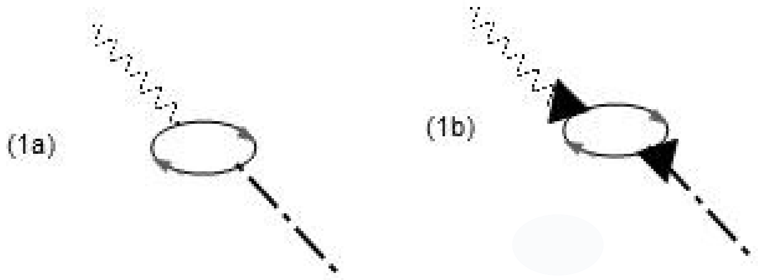
Still in terms of local mesons fields:
Mixing vector mesons
(Or axial mesons)
And Vector Meson Dominance (VMD)
From effective (Lagrangian) couplings

Coleman-Glashow (1964)
Goldhaber, Fox, Quigg, (1969)

$$\langle \rho^0 | H | \omega \rangle = -4520 \pm 600 \text{ MeV}^2.$$

Calculation with same grounds as the vector - NJL model

Expansion of quark determinant
With a background photon field:



This also suggests vector meson dominance: (VMD)
different MIXING couplings
between rho/omega and the photon

Quadratic terms

Thomas, Coon, Biswas, McNamee, Krein, Schildknecht, O'Connel, and other

$$\mathcal{L}_{\mathrm{VMD}} = \underbrace{-g_{\rho A} V_3^{\mu} A_{\mu} - g_{\omega A} V_{\mu} A^{\mu}} - g_{F\rho} \mathcal{F}^3_{\mu\nu} F^{\mu\nu} - g_{F\omega} \mathcal{F}_{\mu\nu} F^{\mu\nu},$$

$$g_{\rho A} = 3 g_{\omega A}$$

$$g_{F\rho} = 3 g_{F\omega}$$

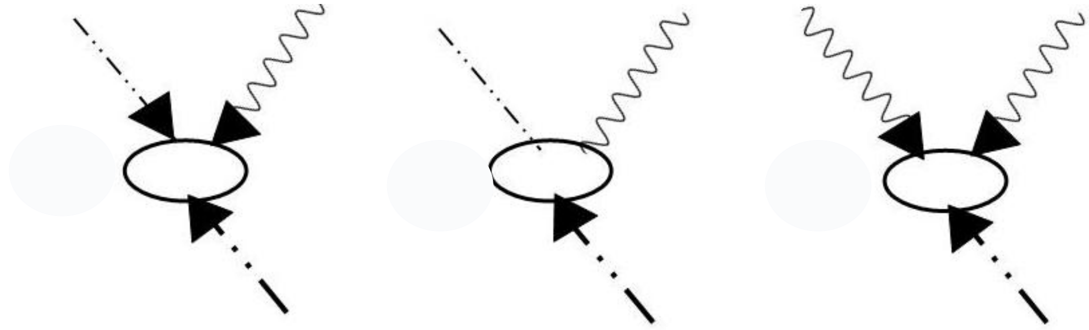
This procedure eliminates
The photon mass
from expansion of determinant
And the non gauge invariant VMD couplings
FLB, JPG (2020)

Kroll, B. Lee, Zumino

To redefine **the fields**
It restores gauge invariance

$$A_{\mu} = c\tilde{A}_{\mu}, \qquad V^3_{\mu} = \tilde{V}^3_{\mu} + \frac{ce}{2f_{\mathrm{v}}}\tilde{A}_{\mu}, \qquad V_{\mu} = \tilde{V}_{\mu} + \frac{ce}{6f_{\mathrm{v}}}\tilde{A}_{\mu},$$

Higher order couplings



$F_{\mu\nu}$. Photon

$\mathcal{F}^{\mu\nu}$ $\mathcal{F}_i^{\mu\nu}$ Vector mesons

$\mathcal{G}^{\mu\nu}$ $\mathcal{G}_i^{\mu\nu}$ Axial mesons

$$\mathcal{L}_F = g_{F\rho\omega}(F^{\mu\nu}\mathcal{F}^3_{\nu\rho}\mathcal{F}^\rho_\mu + F^{\mu\nu}\mathcal{G}^3_{\nu\rho}\mathcal{G}^\rho_\mu) - g_{FF\omega}F_{\mu\nu}F^{\nu\rho}\mathcal{F}^\mu_\rho - g_{FF\rho}F_{\mu\nu}F^{\nu\rho}\mathcal{F}^{3,\mu}_\rho$$

VMD induced by background photon field

3rd order terms

Mechanism for Vector or axial mesons mixings

Leading vector mesons and photon interactions

Yield both:
Vector mesons mixings and **VMD**

Induced by background photons

The non-explicitely U(1) gauge invariant couplings above become gauge invariant by considering leading derivative couplings.

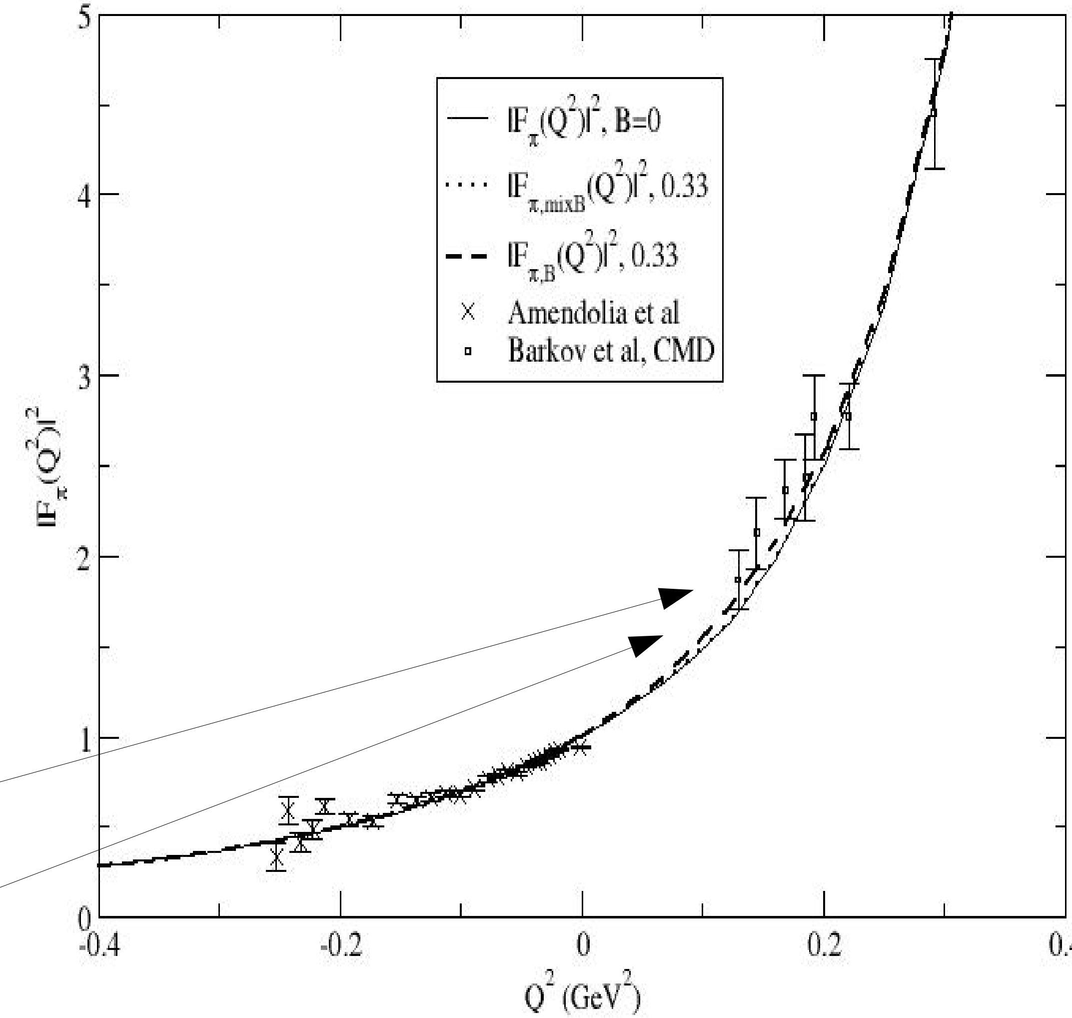
FLB, JPG 47 (2020) 115102

Background Photon interaction contributions to pion form factor

- No magnetic field in the e+e- reactions

- Background photons might induce rho-omega mixing

$$e^+e^- \rightarrow \pi^+\pi^-$$



mixing VMD

$$\mathcal{L}_F = g_{F\rho\omega}(F^{\mu\nu}\mathcal{F}^3_{\nu\rho}\mathcal{F}^\rho_\mu + F^{\mu\nu}\mathcal{G}^3_{\nu\rho}\mathcal{G}^\rho_\mu) - g_{FF\omega}F_{\mu\nu}F^{\nu\rho}\mathcal{F}^\mu_\rho - g_{FF\rho}F_{\mu\nu}F^{\nu\rho}\mathcal{F}^{3,\mu}_\rho$$

$$\mathcal{L}^B_F = \left(\frac{eB_0}{M^{*2}}\right) g^B_{F\rho\omega}(\mathcal{F}^{i=3}_{\mu=2,\rho}\mathcal{F}^\rho_{\nu=1} + \mathcal{G}^{i=3}_{\mu=2,\rho}\mathcal{G}^\rho_{\nu=1}) - \left(\frac{eB_0}{M^{*2}}\right) g^B_{FF\rho}F^{\mu=2,\rho}\mathcal{F}^{i=3,\nu=1}_\rho - \left(\frac{eB_0}{M^{*2}}\right) g^B_{FF\omega}F^{\mu=2,\rho}\mathcal{F}^{\nu=1}_\rho$$

Photons must be extremely abundant..
To be tested:

Can onshell photons induce Vector mesons mixings?

Final remarks

The method has a starting point the QCD Lagrangian to obtain hadrons couplings

It yields many aspects of low energy (maybe intermediary energies) phenomenology
With good resulting numerical values for observables

Most of constituent quark coupling constants are UV finite

Relatively weak magnetic field and photons induce
anisotropic mesons couplings to quarks and among mesons

It allows directly and naturally to compute in medium effects

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Thank you for your attention!