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# Gluon condensate as a part of a hadron

**dedicated to Wanda Doborzyńska-Głazek and Jerzy Głazek, my late parents**

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A simplified mean-field approximation to a renormalization group treatment of light-front Hamiltonian formulation of QCD suggests that quarks may be bound through condensation of gluons inside hadrons. In a hadron rest frame, the approximate picture of mesons and baryons closely resembles constituent quark models with harmonic oscillator potentials, but the picture differs from the models by the option of a systematic analysis in QCD.

S. D. Głazek, *Reinterpretation of gluon condensate in dynamics of hadronic constituents*, IFT/11/05.

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# Time-honored plan:

$$
\begin{aligned}
\mathcal{L}_{QCD} &\to \mathcal{H}_{QCD} \\
H_{QCD} &= \int d^3x \, \mathcal{H}_{QCD} \\
H_{QCD}|\psi\rangle &= E\,|\psi\rangle \\
E &= \sqrt{m_h^2 + \vec{p}^{\,2}} \\
|\psi\rangle &= |h\rangle \\
U(t_2, t_1) &= e^{-iH(t_2 - t_1)}
\end{aligned}
$$

**etc.**

# Time-honored problem:

$$
\begin{array}{rcl}
H & \to & H^R + CT^R \\
H^R + CT^R & \to \; RG \; \to & H_\lambda \\
H_\lambda & = & ? \\
g_\lambda & \sim & \dfrac{1}{\ln \frac{\lambda}{\Lambda_{QCD}}} \\
|\Omega\rangle & = & ?
\end{array}
$$

## Input:

**RG** $\to$ **SRG** $\to$ **RGPEP** $\to$ **PT + NPT**

Wilson 1964 Głazek-Wilson 1993 Acta Phys. Polon. 1998 . . .

Wegner 1994

| | | |
|---|---|---|
| RG | "*integrate out*" | high energies (small den.) |
| SRG | "*rotate in*" | high energies (den. $> \lambda$) |
| RGPEP | $\leftrightarrow$ | $q_s = U_s\, q_0\, U_s^\dagger\,, \quad s = 1/\lambda^2$ |
| NPT RGPEP | $\leftrightarrow$ | $\frac{d}{ds} H_s = [[H_{free}, H_{sP}], H_s]$ |
| | | $H_0 = H^R + CT^R$ |
| IMF $\leftrightarrow$ CMS | $\leftrightarrow$ | Light Front, Dirac 1949 |
| $\lvert\Omega\rangle$ | $=$ | $\lvert 0\rangle$ |
| $\varphi^2 = \langle\Omega\lvert\frac{\alpha_s}{\pi}G^2\rvert\Omega\rangle$ | $=$ | ? (*cosmology*?) |

**RGPEP** = **R**enormalization **G**roup **P**rocedure for **E**ffective **P**articles

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# Fock space convergence ?

$$[H^R + CT^R](q_0) \quad = \quad \sum_I \; c_{0I} \prod_{i \in I} q_{0i}$$

RGPEP form factors
$$H_s(q_s) \quad = \quad \sum_I f_s \, c_{sI} \prod_{i \in I} q_{si}$$

$$U_s \, q_0 \, U_s^\dagger \quad = \quad q_s$$

quantum fields $\quad \psi(q_0),\, A(q_0) \quad \to \quad \psi(q_s),\, A(q_s)$

$$|h\rangle \; = \; \sum_I \phi_{h0}(I) \prod_{i \in I} q_{0i}^\dagger |0\rangle \quad \to \quad |h\rangle \; = \; \sum_I \phi_{hs}(I) \prod_{i \in I} q_{si}^\dagger |0\rangle$$

$$U_{s_1}\,, \quad U_{s_2}\,, \quad W_{s_2 s_1} \; = \; U_{s_2} U_{s_1}^\dagger$$

$$q_{s_2} \quad = \quad W_{s_2 s_1} \, q_{s_1} \, W_{s_2 s_1}^\dagger$$

equations for scale-evolution in $s$

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# Constituent Quark Model hypothesis in QCD

$s_c \sim 1/\Lambda^2_{QCD}$ :

$$|M\rangle_{s_c} = \sum_{12} \psi_{s_c}(12)\,|12\rangle_{s_c}$$

$$|B\rangle_{s_c} = \sum_{123} \psi_{s_c}(123)\,|123\rangle_{s_c}$$

$s \lesssim s_c$ : $\quad |12G\rangle_s = W_{ss_c}\,|12\rangle_{s_c} \quad , \qquad |123G\rangle_s = W_{ss_c}\,|123\rangle_{s_c}$

$$|M\rangle_s = \sum_{12G} \psi_s(12G)\,|12G\rangle_s$$

$$|B\rangle_s = \sum_{123G} \psi_s(123G)\,|123G\rangle_s$$

drawings

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# Effective eigenvalue problem

$$H_s|h\rangle_s = E\,|h\rangle_s$$

$$_s\langle 12G|H_s|M\rangle_s = E_M\,\psi_s(12G)$$

$$_s\langle 123G|H_s|B\rangle_s = E_B\,\psi_s(123G)$$

$H_s = ?$ NR gauge symmetry $m + \frac{-i\vec{\nabla}^{\,2}}{2m} \;\to\; m + \frac{\left(-i\vec{\nabla} - g_s\vec{A}\right)^2}{2m}$

1) the Schwinger gauge $A^\mu = \frac{1}{2}\,(x - x_G)_\nu G^{\nu\mu} + ...$

2) color-transport factors $T_i = e^{-ig\int_{\underline{x}}^{x_i} dx_\mu A^\mu}$

3) crude mean field (Abelian) Głazek-Schaden 1987

$$\langle G|g_s^2\vec{A}^{\,2}(\vec{x}\,)|G\rangle \sim \frac{1}{4}\langle G|g_s^2 G^{\mu\nu 2}|G\rangle\,(\vec{x} - \vec{x}_G)^2 \quad\to\quad \varphi^2\,(\vec{x} - \vec{x}_G)^2$$

gauge symmetry restores translational symmetry $\to \vec{x}_G$ drops out

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# Mesons

$$\mathcal{M}_{q\bar{q}}^2 = 4m^2 + 4\left[\vec{k}^{\,2} + \frac{1}{2}m^2\left(\frac{\pi\varphi}{3m}\right)^2 \frac{1}{2}\left(i\,\frac{\partial}{\partial\vec{k}}\right)^2\right]$$

$$k^\perp = \frac{\kappa^\perp}{2\sqrt{x(1-x)}}$$

$$k^z = \frac{2x-1}{2\sqrt{x(1-x)}}\,m$$

$$P = p_1 + p_2\,, \quad x = p_1^+/P^+$$

$$p_1^\perp = xP^\perp + \kappa^\perp\,, \quad p_2^\perp = (1-x)P^\perp - \kappa^\perp$$

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# Baryons

$$\mathcal{M}_{3q}^2 = 9m^2 + 6\,\vec{K}^{\,2} + \frac{9}{2}\,\vec{Q}^{\,2} - 3m^2\left(\frac{\pi\varphi}{3m}\right)^2 \frac{5}{8}(\Delta_K^2/2 + 2\Delta_Q/3)$$

$$x_i = p_i^+/P^+\,, \qquad p_3^\perp = x_3 P^\perp + q^\perp\,,$$

$$p_2^\perp = x_2 P^\perp - \frac{x_2}{1-x_3}\,q^\perp - \kappa^\perp\,, \quad p_1^\perp = x_1 P^\perp - \frac{x_1}{1-x_3}\,q^\perp + \kappa^\perp$$

$$Q^\perp = \sqrt{\frac{2}{9x_3(1-x_3)}}\;q^\perp\,, \quad Q^z = \sqrt{\frac{2}{9x_3(1-x_3)}}\;(2x_3 - x_1 - x_2)\,m$$

$$K^\perp = \sqrt{\frac{1-x_3}{6x_1x_2}}\;\kappa^\perp\,, \quad K^z = \sqrt{\frac{1-x_3}{6x_1x_2}}\;\frac{x_1-x_2}{1-x_3}\,m$$

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# Right values for CQM

$$\omega_M = \frac{\pi\varphi}{3m}, \qquad \omega_B = \sqrt{\frac{5}{8}}\,\omega_M$$

$$\varphi^2_{vacuum} = \langle\Omega|(\alpha_s/\pi)G^{\mu\nu c}G^c_{\mu\nu}|\Omega\rangle \leftrightarrow \varphi^2 = \frac{\langle G|(\alpha_s/\pi)G^{\mu\nu c}G^c_{\mu\nu}|G\rangle}{\langle G|G\rangle}$$

# LF wave functions for constituent quarks

$$\psi_{qH} = N\,\exp\left\{-\frac{1}{2n_H m\omega_H}\left[\left(\sum_{i=1}^{n_H} p_i\right)^2 - (n_H m)^2\right]\right\}$$

$s \sim 1/\Lambda^2_{QCD}$ , $n_M = 2$ , $n_B = 3$

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## Hadron form factors at small $Q^2$

$$F_{quarks} = F(Q^2)$$

$$F_{hadron} = F_{quarks\,G} \sim e^{\frac{1-<xq>}{<xq>} Q^2/(2n_H m\omega_H)} F(Q^2) \quad ?$$

## Hadron structure functions

$$W_{Q\lambda} \leftrightarrow DGLAP \qquad ?$$

## Comment on AdS/QCD

right variable for Brodsky-Teramond holography $\quad k^\perp = \frac{\kappa^\perp}{2\sqrt{x(1-x)}}$

Hypotheses: 1) 5th dimension $\leftrightarrow$ quark size $\sqrt{s}$ in RGPEP ?

2) $G$-induced oscillator $\leftrightarrow$ soft wall models in IR ?

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# Conclusion

- Reinterpretation of the gluon condensate (quark condensate) implications
- Constituent phenomenology including the glue (sea) component
- RGPEP method: PT and NPT
- Boosts and rotations in spectrum: new variables $\vec{k}$, $\vec{K}$, $\vec{Q}$
- LF holography and soft wall model via RGPEP scale parameter?

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