Perturbative QCD with Quark and Gluon Condensates

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* PQCD is formally exact and successful at high Q^2

  Precocious scaling, the constituent quark model, ... indicate that perturbative methods may be relevant also at low Q^2 Yu. Dokshitzer, ICHEP-98

  ⇒ Consider alternative perturbative expansions of QCD

* PQCD is specified by $\mathcal{L}_{QCD}$ together with:
  - the renormalization scheme ($Q^2 \to \infty$, thoroughly studied)
  - the perturbative ground state (hardly mentioned ?!)

* Expanding around the empty vacuum $a|0\rangle = 0$ is a choice that is not mandated by theory
  - It works well in QED: We were lucky to expand around a state that is close to the true vacuum

* Hadron physics is believed to be governed by a non-trivial QCD vacuum which contains quark and gluon 'condensates'

  $\langle F_{\mu\nu} F^{\mu\nu} \rangle \neq 0$, $\langle \bar{\psi}\psi \rangle \neq 0$: Chiral symmetry spont. broken

⇒ Formulate a PQCD based on a perturbative vacuum which contains $q\bar{q}$ and gg pairs

  Formally as justified as standard PQCD

- Particles in the |in⟩ and ⟨out| states only affect on-shell PQCD propagators: The $i\varepsilon$ prescription

Interference term between on-shell propagator in loop with on-shell quark in vacuum

- The addition of on-shell external particles preserves gauge symmetry Hoyer & Rathsman, hep-ph/0011209

- Perturbative boost invariance is lost if particles with $p \neq 0$ are added (Lorentz invariance is formally restored in the sum to all orders in α_s)

- Promising proposal Cabo et al, Mod Phys Lett A10, 2413 (95)
  hep-th/9909057
  Hoyer, hep-ph/0203236

$$S_q^{AB}(p) = \delta^{AB}\left[\frac{i\not{p}}{p^2+i\varepsilon} + C_q (2\pi)^4 \delta^4(p)\right]$$

$$D_g^{ab,\mu\nu} = -g^{\mu\nu}\delta^{ab}\left[\frac{i}{p^2+i\varepsilon} + C_g (2\pi)^4 \delta^4(p)\right]$$

- The modifications are formally legal: Arise from a specific perturbative vacuum with $q\bar{q}$, gg pairs

- Lorentz invariance preserved since only $p=0$ particles are added ($m_q = 0$)

* It is straightforward to calculate Feynman diagrams using the modified propagators, but the physical interpretation is non-trivial

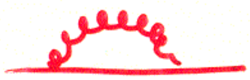
  Expect only hadrons as asymptotic states

* $\langle F_{\mu\nu} F^{\mu\nu} \rangle \sim$  $= 12 g^2 N (N^2-1) C_g^2 \, [1+\mathcal{O}(\alpha_s)]$

  Only 4-gluon coupling contributes

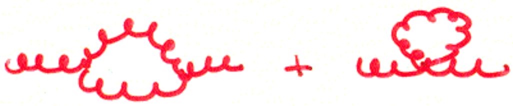
  $\langle \bar{\psi} \psi \rangle \sim$  $= -4N C_q \, [1+\mathcal{O}(\alpha_s)]$

* Massless current quark acquires constituent mass M_q



$$M_q^3 - 2g^2 \frac{N^2-1}{2N} C_g M_q = \pm 4 g^2 \frac{N^2-1}{2N} C_q$$

* Gluon gets tachyonic constituent mass M_g



$$M_g^2 = -2 g^2 N C_g$$

* Axial vector current is conserved: $m_\pi = 0$

Constituent quark mass cancelled by $q\bar{q}$ interaction

⇒ Verify "non-perturbative" Goldstone theorem perturbatively

It's a brave new world:

- Potentially closer to hadron physics than standard PQCD
- Interpretation requires new conceptual insights