DOES HIGH -ENERGY BEHAVIOR DEPEND ON QUARK MASSES ?

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Is it possible to get non-zero (bound state)mass in massless QCD?

Coleman & E. Weinberg (1973)

"Normal" massless QCD: $L_0 = -\frac{1}{4}F^2 + i\tilde{\psi}\gamma\partial\psi + g\,\tilde{\psi}\gamma A\psi$

Renormalization: $g \to g(\mu) = F(\mu/\Lambda)$, Λ = fundamental scale parameter ("dimensional transmutation") $\to M \sim \Lambda$

Chiral symmetry breaking: $\langle\tilde{\psi}\psi\rangle \neq 0$. No new scale.

In finite theory (N=4 SYM): $g \to g$.

No fundamental scale parameter. No massive particles (without (super) symmetry breaking).

Physical quantities are invariants of the Renormalization Group

$$M(g, \mu) = M(g', \mu')$$

$$(g', \mu') \rightarrow g(\mu)$$

$$[\mu^2 \partial/\partial\mu^2 + \beta(g^2)\partial/\partial g^2]M = 0$$

$$M(g, \mu) = c\,\mu^2 \exp(-K(g^2))$$

$$\partial K(g^2)/\partial g^2 = 1/\beta(g^2)$$

$$\mu^2 \partial g^2/\partial\mu^2 = \beta(g^2)$$

Scattering Amplitude

$$T(s, t) = F(s, t; g^2, \mu^2)$$

$$d\,[T|_{(g,\mu)\to g(\mu)}]/d\mu = 0$$

$$g(\mu) \sim 1/\log(\mu/\Lambda) \text{ at } \mu\to\infty$$

Hadron masses:

$$M^2_i = C_i\,\mu^2 \exp(-K(g^2)) \to C_i\,\Lambda^2 \sim \exp(-c/g^2)$$

$$T(s,0) = H(s/\Lambda^2; \{C_i\})$$

T(s,0) may not exist if massless particles survive in the spectrum (pions in the Bogoliubov-Goldstone mode).

Natural condition:
$g = 0 \rightarrow T = 0$

$$T_{forward} = H[\,(s/\mu^2)\exp(c/g^2)\,],\; c > 0.$$

! $g^2 \rightarrow 0 \sim s \rightarrow \infty$!

$$\lim T(g^2 \rightarrow 0) = \lim T(s \rightarrow \infty) = 0$$

Consequences
(awful but theoretically admissible)

At $s \to \infty$:

$\sigma_{tot} < const/s$

$d\sigma/dt\,(t = 0) < const/s^2$

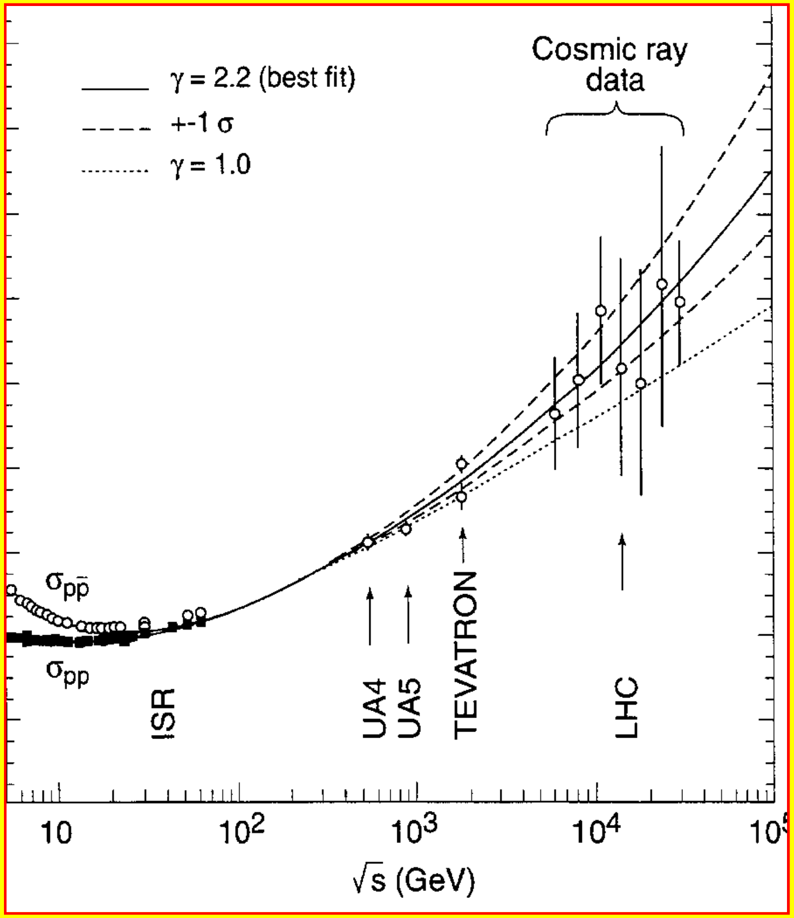
General lower bounds

(Jin-Martin, 1964)

$\sigma_{tot} \geq const / s^6 (\log s)^2$

If true, the data imply a huge "turn-off scale": $\sqrt{s}_{\text{turn-off}} > O$ (10 Te V) ~$100000\Lambda_{qcd}$ (?!)

No intelligible mechanism in QCD



"Rescue": massive QCD

- $L_0 \rightarrow L_0 + m\, \tilde{\psi}\psi$
- *Two RG-invariant mass scales* :
- $\Lambda_1 = \mu \exp(-K(g)) \sim \exp(-1/g^2),\ c' > 0$
- $\Lambda_2 = m \exp(L(g)) \sim (1/g^2)^{c''},\ c'' > 0$
- $\partial L(g)\ \partial g = \gamma_m(g) / \beta(g)$
- $\gamma_m(g) = -\, m^{-1} \mu\, \partial m / \partial \mu$
- *Important: mass scales are namely Lagrangian parameters, not "dynamically generated masses".*

The trick with the free-field limit does not pass through

$$T(s,0,\ldots.) = \Phi\,(\,s\,/\,\Lambda^2{}_1\,;\,\Lambda^2{}_2/\,\Lambda^2{}_1)$$

$$\lim_{g \to 0} T = \Phi\,(\infty;\infty) = 0$$

$$\lim_{s \to \infty} T = \Phi\,(\infty;\Lambda^2{}_2/\,\Lambda^2{}_1) = ?$$

Two limits are generally different

An example

$$\mathrm{Im}\,T\,(s,0) = (s/\Lambda^2{}_2)\log^2(s/\Lambda^2{}_1)$$

$$\mathrm{Im}\,T\,(s,0) \to \infty \text{ at } s \to \infty$$

$$\mathrm{Im}\,T\,(s,0) \to \mathit{const}\,(g^2)^c\,\mathit{exp}(-1/(\beta_0\,g^2)) \to 0$$

$$\text{at } g \to 0$$

Conclusion:

Non-zero current quark mass in QCD is a necessary condition to get infinitely rising cross – sections . **[?]**