String Breaking Mechanism Revisited

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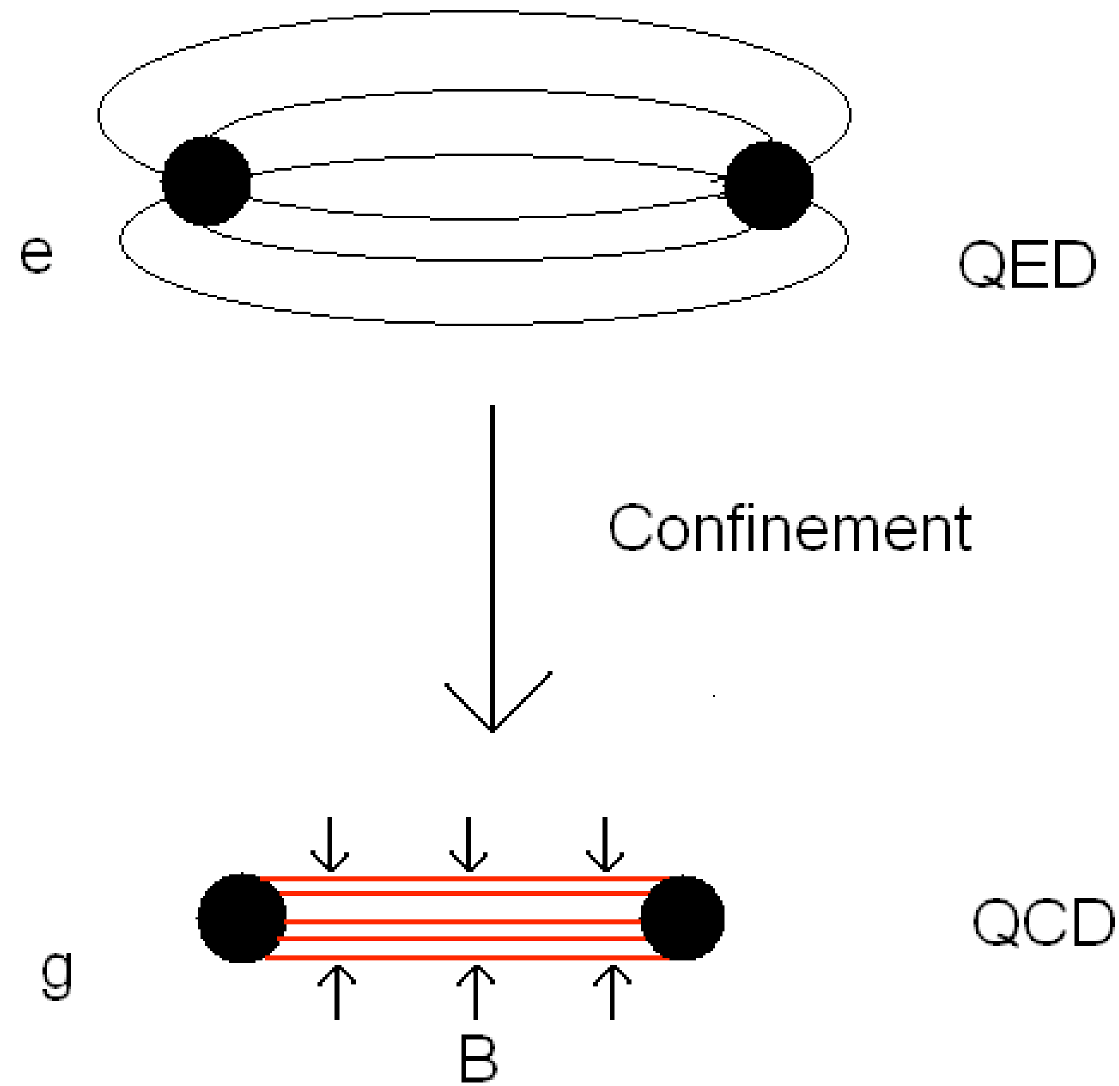
Outline

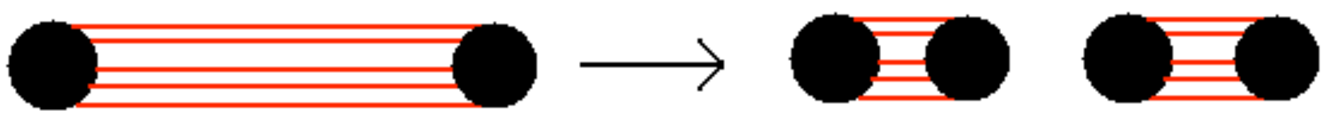
- String breaking / Schwinger mechanism
- Conflict with experiment, possible resolution
- Collective quantization of string Hamiltonian
- Prediction / explanation of thermal spectrum
- Future work with model

Color electric field lines of quark-antiquark pair



String breaking

- Energy in string can be converted into new quark-antiquark pair
- Created pair cancels out field



Schwinger mechanism

$$P(E_t) \propto e^{\frac{2\pi E_t^2}{g \mathcal{E}}}$$

- Vacuum "decay" probability from imaginary part of Euler-Heisenberg effective Lagrangian
- Interpreted as probability for virtual quark with transverse energy E_t to tunnel to real quark state
- In QED, calculated for uniform field without back-reaction. In QCD, back reaction exactly cancels field in a region → Still uniform.

Conflict with experiment

- String breaking mechanism predicts Gaussian E_t spectrum
- Experiment shows thermal spectrum
- Thermalization unlikely in elementary collisions

Resolution?

- Bialas (1996) showed string breaking + Gaussian fluctuations in string tension = thermal spectrum
- Unable to fully justify why this type of fluctuation would be expected
- Further work in the area (Florkowski 1998), but nothing conclusive

String tension

$$\sigma = \frac{1}{2}\left(E^{2}_{A} + B^{2}_{A} \right) = \frac{1}{4}\, g^{2} + B_A$$

- since Gauss' law gives:

$$E_A = \frac{g}{2}$$

- The ½ comes from prefactor of SU(3) generators

Collective Coordinate Approach

- Guided by precendent :
  - Heavy nuclei excitations modeled collectively
  - Competition of Coulomb repulsion, strong interaction, and rotation / vibration leads to spectrum of excited states which can be probed experimentally
- Similar interplay between vacuum pressure and field energy density

Choice of Collective Coordinates

- Initial guess of using field strength and area leads to problematic solution
- Instead, use radius and root of field
- Nice feature: “correct” units

$$r = \sqrt{\frac{A}{\ }}; \quad \tilde{p} \equiv \bar{\mathcal{E}}$$

$$[r, p] = i$$

Quantized String Hamiltonian and Solutions

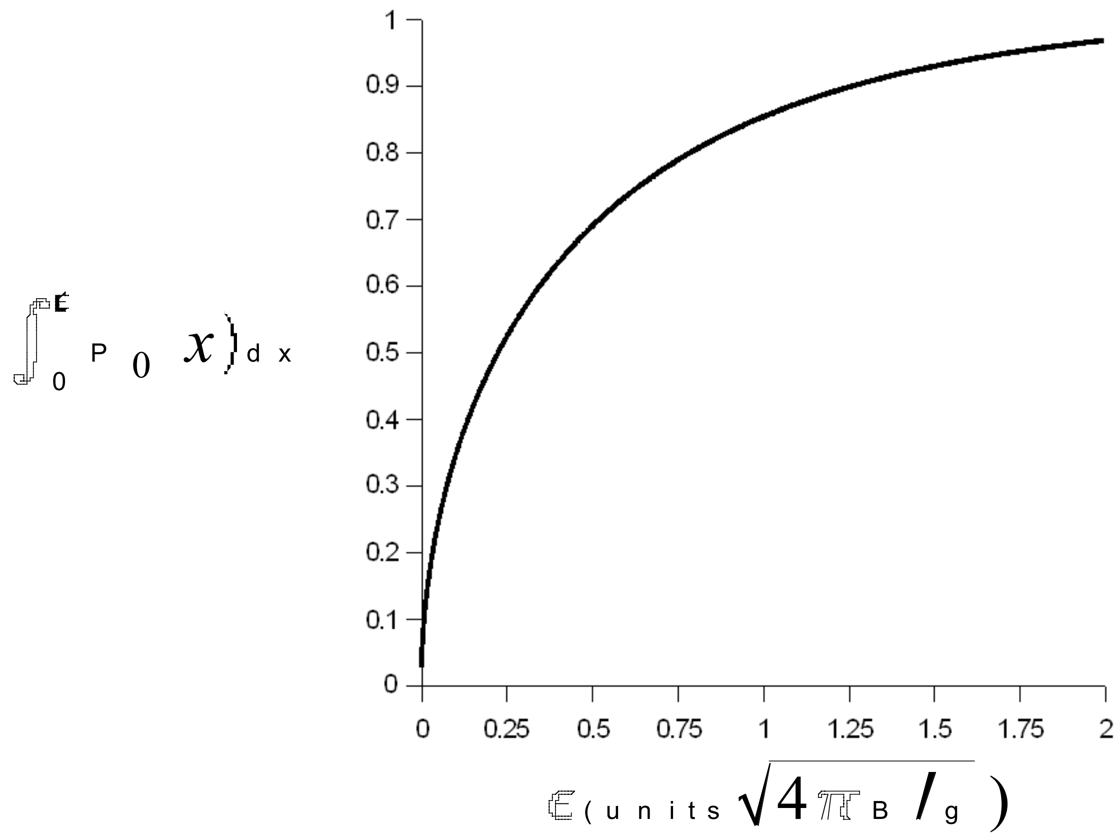
$$\left(\frac{1}{4} g \quad \tilde{p}^2 + B \pi r^2\right) \psi_n \quad \sigma_n \psi_n$$

$$_n = \sqrt{gB \quad \pi}\left(n \quad \frac{1}{2}\right)$$

$$\psi_n(\tilde{p}) = H_n \quad \tilde{p} \left(\frac{g}{4 \pi B}\right)^{1/4} \Big) e^{-p^2 \sqrt{g} \; 16 \; \pi B}$$

Probability density for color field

$$P_n(\epsilon) \propto \frac{1}{\sqrt{\epsilon}} H_n^2\left(\left(\frac{g\,\epsilon^2}{4\pi B}\right)^{1/4}\right) e^{-\sqrt{g\,4\pi B}}$$



Folding

- Now have P(ε) and P(E_t)
- Can fold them to give overall probability of production and hence yield
- Result is:

$$N(E_t) \propto e^{E_t/T}$$

$$T = \left(\frac{g B}{16\pi}\right)^{1/4} = \sqrt{\frac{\sigma_0}{2\pi}}$$

Comparison to experiment

- Substitution of σ = 0.9 Gev/fm gives
  T = 170 MeV
- Experimental value
  T = 160 MeV

Other Consequences

- Higher excited modes of string
- Possible explanation of growth of T with s
- Examine expected "charge" on higher modes; ropes?:

$$\langle Q \rangle \quad \langle \tilde{p}^2 r^2 + r^2 p^2 \rangle \propto \left(n + \frac{1}{2} \right)^2$$

Possible extensions

- Inclusion of rotations and vibrations
- Regge Trajectories (determine string tension to begin with)
- Excitation spectrum of string in collisions

Conclusions

- QCD provides two competing interactions in string model of quark-antiquark pairs
- Quantization of resulting Hamiltonian gives probabilistic value of color electric field
- Folding probability with Schwinger mechanism yields thermal spectrum in excellent agreement with experiment
- Several possible ways to expand study of this model