The String Breaking Mechanism

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Purpose

Address a particular shortcoming of the string model in a novel way
Outline

• Brief intro to MRS
• Schwinger mechanism of string breaking
• Predictions conflict with observed spectrum
• Collective quantization of string Hamiltonian
• Thermal spectrum is expected
• Much left to do 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
Noteworthy excursions\textsuperscript{1}

- Yo-yo mode oscillations
- Transverse radius $\sim 0.5$ fm
- Cascades estimated from statistical consideration
- Gluonic excitations / butterfly modes

Schwinger mechanism

\[ P(E_t) \propto e^{-\frac{2\pi E_t^2}{g\epsilon}} \]

- Vacuum decay probability from imaginary part of Euler-Heisenberg effective Lagrangian
- Probability for virtual quark pair 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 \( \rightarrow \) Still uniform.

Conflict with experiment

- String breaking mechanism predicts Gaussian $E_t$ spectrum
- Experiment shows thermal spectrum
- Thermalization unlikely in elementary collisions – few rescatterings
Resolution?

- Bialas\(^1\) 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\(^2\), but nothing conclusive

String tension

\[ \sigma = \frac{1}{2} \epsilon^2 A + BA = \frac{1}{4} g \epsilon + BA \]

since Gauss' law gives:

\[ \epsilon A = \frac{g}{2} \]

(factor \( \frac{1}{2} \) comes from SU(3) generators)
Collective Coordinate Approach

• Guided by precedent:
  – 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
Why collective coordinates?

• Useful for simplification of many body problem without loss of quantum details
• Heavy nuclei consist of many nucleons allowing application of this approach
• String consists of large number of virtual gluons, so method should be valid
Choice of Collective Coordinates

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

\[ r = \sqrt{\frac{A}{\pi}}; \quad \tilde{p} = \sqrt{\epsilon} \]

\[ [r, \tilde{p}] = i \]
Quantized String Hamiltonian and Solutions

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

\[
\sigma_n = \sqrt{gB \pi (n + \frac{1}{2})}
\]

\[
\psi_n (\tilde{p}) = H_n (\tilde{p} \left( \frac{g}{4\pi B} \right)^{1/4}) e^{-\tilde{p}^2 \sqrt{g/16\pi B}}
\]
Probability density for color E field

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

\[ \int_0^\epsilon P_0(x) \, dx \]
Folding

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

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

$$T = \left( \frac{gB}{16 \pi} \right)^{1/4} = \sqrt{\frac{\sigma_0}{2 \pi}}$$
Comparison to experiment

- Substitution of $\sigma = 0.9$ Gev/fm gives $T = 170$ MeV
- Experimental value $T = 170$ MeV
- Some authors give lower value; may be explained by expansion of system

Other Consequences

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

\[ \langle Q \rangle \propto \langle \tilde{p}^2 r^2 + r^2 \tilde{p}^2 \rangle \propto (n + \frac{1}{2})^2 \]
Future extensions

- Inclusion of full 3-D dynamics
- Check consistency with Regge trajectories
- Explore 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