Motion of Confined Particles

David E. Miller and Dirk Rollmann

Universität Bielefeld, Germany

Penn State University, USA

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Abstract

We carry out numerical evaluations of the motion of classical particles in Minkowski space $\mathcal{M}^4$ which are confined to the inside of a bag. In particular, we analyze the structure of the paths evolving from the breaking of the dilatation symmetry, the conformal symmetry and the combination of both together. The confining forces arise directly from the corresponding nonconserved currents. We demonstrate in our evaluations that these particles under specific initial conditions move toward the interior of the bag.

Outline of this Talk

1. **Dilatation Current D^μ and Conformal Currents $K^{\mu,\alpha}$ in $\mathcal{M}^4$.**

2. **Broken Symmetries from finite Trace T^μ_μ.**

3. **Confining Forces inside the Bag.**

4. **The Confinement of the Particles inside the Bag.**

5. **Numerical Evaluations of the Motion in $\mathcal{M}^4$.**

6. **Summary and Conclusions.**

1. Dilatation Current D^μ and Conformal Currents $K^{\mu,\alpha}$ in $\mathcal{M}^4$.

Defined by the Energy-Momentum Tensor $T^{\mu\nu}(x)$,

where $\alpha, \mu, \nu \;=\; 0,1,2,3$ in the positive time metric as follows:

a. Dilatation Current:

$$D^\mu(x) \;=\; x_\nu \, T^{\mu\nu}(x).$$

b. Conformal Currents:

$$K^{\mu\alpha}(x) \;=\; (2x^\alpha x_\nu \text{ - } \mathbf{g}^\alpha_\nu x^2) T^{\mu\nu}(x).$$

The basic equations for these Currents are:

c. $\partial_\mu D^\mu(x) \;=\; T^\mu_\mu;$

d. $\partial_\mu K^{\mu\alpha}(x) \;=\; 2x^\alpha T^\mu_\mu.$

2. Broken Symmetries from $T^{\mu}_{\mu} \neq 0$.

This situation implies the contrapositive statement of Noether's Theorem, which yields from the nonconserved currents the broken symmetries.

a. When the $D^{\mu}(x)$ is not conserved, then the Scale symmetry is violated.

b. When the $K^{\mu,\alpha}(x)$ are not conserved, then Conformal symmetry gets broken.

c. Physically the breaking of a symmetry arises from the presence of forces.

d. Some well known examples are the broken translational symmetries which are caused by linear or transverse forces and the broken rotational symmetries which arise with the torques. We have previously presented a discussion in 1+1 dimensional Space-Time [D. Rollmann, D. E. Miller, 2014].

3.Confining Forces inside the Bag.

The Bag Model has $T^{\mu}_{\mu} = 4B$, whereby B is the "Bag Constant", which is a space-time independent constant. It has the units of the Pressure or Energy Density.

a. The attractive force along the Worldline has the form $D^{\mu}x_{\mu}$, which we shall call the "*Dyxle Force*".

b. The conformal currents all together with $T^{\mu}_{\mu} \neq 0$ provide FOUR different path changing Forces which we shall refer to collectively as the "*Fourspan*"

Comment: $T^{\mu}_{\mu} = g_{\mu\nu}T^{\mu\nu}$ for which $T^{\mu\nu}$ has the diagonal $(+B, -B, -B, -B)$, which with the positive-time metric, with the positive energy density and the inward pressure yields the trace value $4B$. In the following we refer to the constituent Particles as "Partons".

4. The Confinement of the Particles inside the Bag

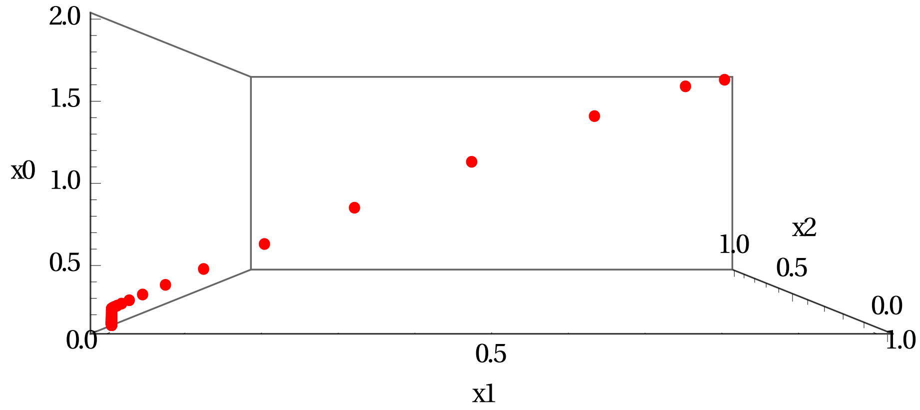
For the Hadron formation in the Bag Model we take M_h as the Mass of the Hadron and V_h as the hadronic Volume. Then the hadronic Energy Density is $\epsilon_h = \frac{M_h}{V_h}$.

In the case of the Bag Model it has been found [H.Satz,2012] that $\epsilon_h = 4B$. There it was shown that the hadronic Energy Density has one part "Bag Energy Density" and three parts constituent (Parton) kinetic Energy Density. We have seen above that this value is the same as T^{μ}_{μ} for the Bag Model.

5. Numerical Evaluations of the Motion in $\mathcal{M}^4$

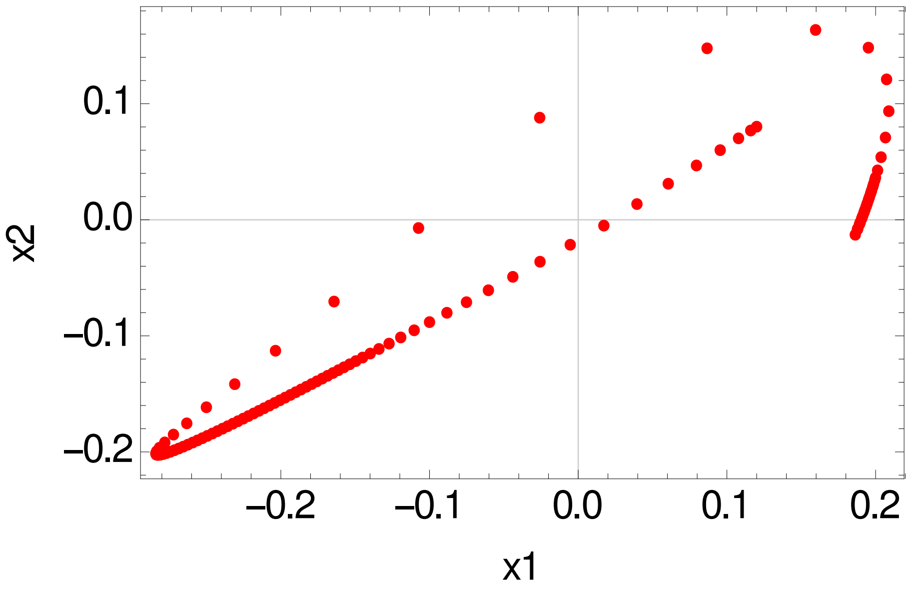
a. The Dyxle Force acts along the worldline.

We present here the results with a Parton of Mass of $0.1 GeV$ of a numerical Evaluation. The Dyxle Force alone pulls the Parton toward the origin. We choose the Bag Constant $B = 0.1\ GeV^4$. We take the initial Values: $x_0 = 1.0fm, x_1 = x_2 = x_3 = 0.5fm$.



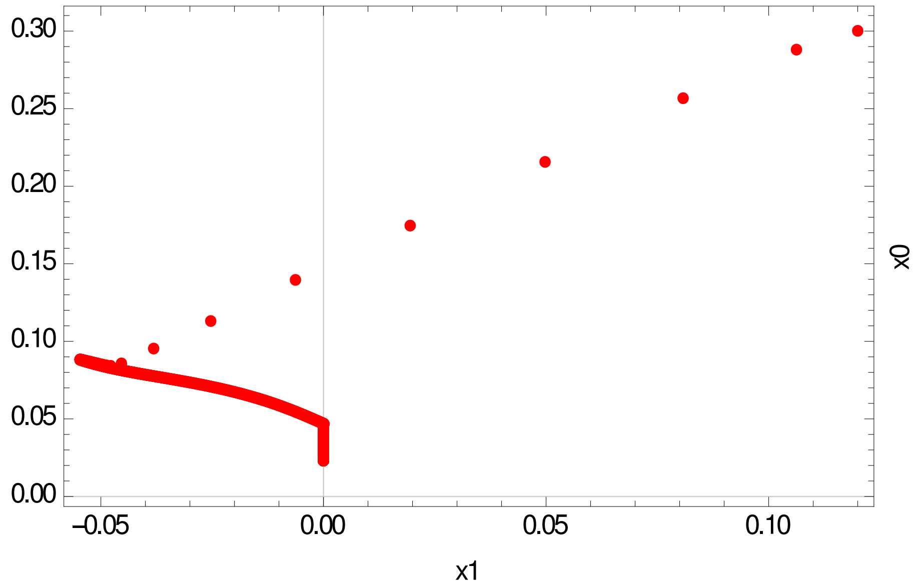
b. The Fourspan is the Combination of the four Forces.

The Fourspan acts to divert the direction of the parton. We choose a smaller value of the Bag Constant $B = 0.01\ GeV^4$. We take the initial Values:
$x_0 = 0.04\ fm, x_1 = 0.12 fm$
$x_2 = 0.08 fm, x_3 = 0.06 fm$.



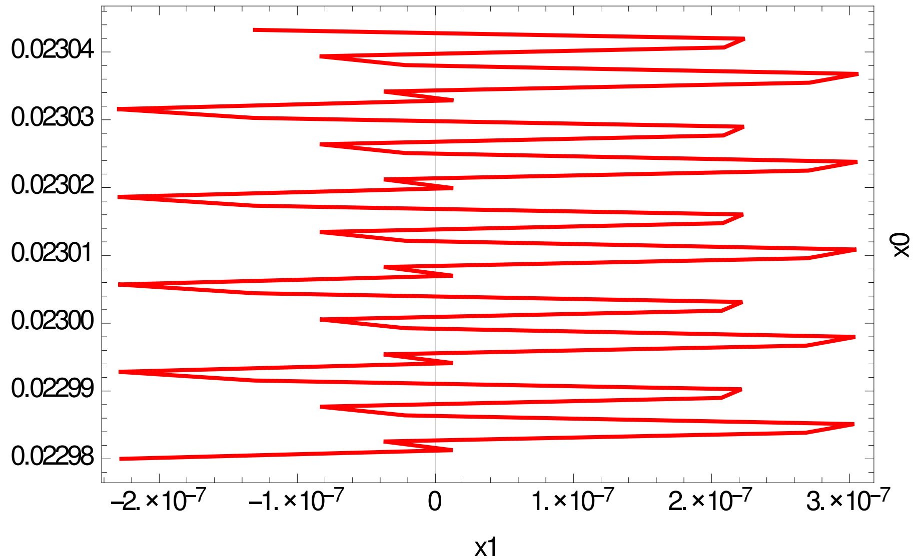
c. The Confining Forces are combined.

The combination of the Dyxle Force with the Fourspan is shown here. We choose the value of Bag Constant $B = 0.1\ GeV^4$. We take the initial Values:
$x_0 = 0.3 fm, x_1 = 0.12 fm$
$x_2 = 0.08 fm, x_3 = 0.1 fm$.



d. The Confining Forces are combined near the Origin.

We take only the last 50 Values from the previous Evaluation. Thus we choose the value of Bag Constant $B = 0.1\ GeV^4$. We take the initial Values:
$x_0 = 0.3 fm, x_1 = 0.12 fm$
$x_2 = 0.08 fm, x_3 = 0.1 fm$.



6. Summary and Conclusions

In this talk we have presented our results on the motion of the internal Constituents (Partons) inside a confining Structure (Bag). The confining physical Nature of the Bag has led to symmetry breakings which provide physical Forces. Under certain given Conditions we find a resulting Motion toward the chosen Center of the Bag.

References

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