Time Evolution of the Distribution of Matter in Hard Particle Production

{ Ben Meiring & W.A Horowitz }   University of Cape Town

Introduction

We use the Schwinger-Keldysh **finite-time** formalism applied to an interacting scalar field theory to derive a perturbative expression for the **energy momentum tensor** associated with the production of **an off-shell particle**, in an effort to analytically probe the regime of finite-time physics.

We want to extend these ideas to derive expressions for **off-shell jet production in perturbative QCD**.

The Big Idea

We want to understand off-shell particles in real time.

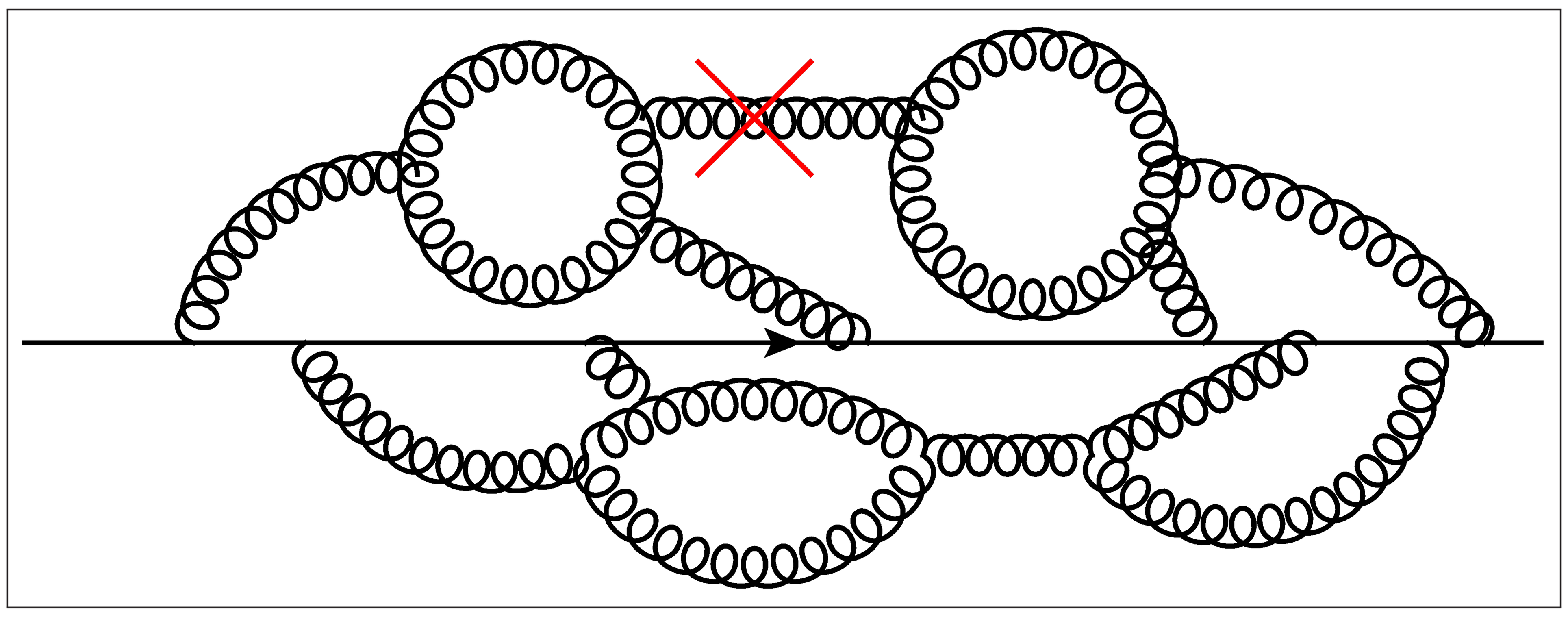
Our approach is through finding the expectation of the **energy momentum tensor** $\hat{T}_{\mu\nu}$, yielding a real time result. **Our 2 part plan:**

- Pick a scalar theory, and calculate $\hat{T}_{\mu\nu}(x)$.
- Using our new insight, do the same in perturbative QCD.

Why is this useful?

- Insights into **the behaviour of weakly coupled QCD systems** during the early stages of the collision.
- The construction of an **"early time pQCD"/"late time AdS/CFT" model** for light quark energy loss.
- **A repeatable method** of analytically probing **non-linear** differential equations.

Method



What does an off-shell particle look like?

We take the lagrangian of 2 uncharged scalar fields with weak Yukawa coupling,

$$\mathcal{L} = \frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{2}m_\phi^2\phi^2 + \frac{1}{2}(\partial_\mu\psi)^2 - \frac{1}{2}m_\psi^2\psi^2 + \lambda\psi\phi\psi, \quad (1)$$

and find the single particle expectation

$$\langle\psi|\hat{T}_{\mu\nu}(x)|\psi\rangle = \langle\psi|T_C\left(e^{-i\int_C d^4z\,\hat{H}_I}\hat{T}_{I\mu\nu}(x)\right)|\psi\rangle \quad (2)$$

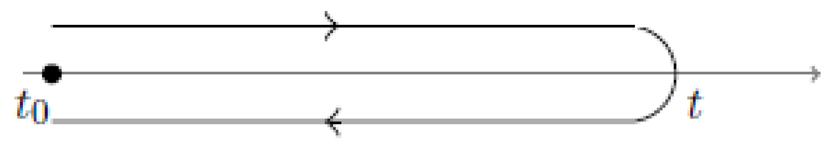


Figure 1: Schwinger-Keldysh contour used to find expectation values.

This is a perturbative expansion along the contour given by **Figure 1**. This gives us a window into the properties of the full interacting theory in real time. Our goal here was to find the first order perturbation to the relativistic **dispersion relation** $E^2 = \vec{p}^2 + m^2 + \#\lambda^2$ for a single ψ particle moving through the interacting theory vacuum.

The plot below shows the leading order expectation $\langle\psi|\phi(x)\phi(x)|\psi\rangle$, indicating the behaviour of the induced ϕ field surrounding a propagating ψ particle in the interacting vacuum.

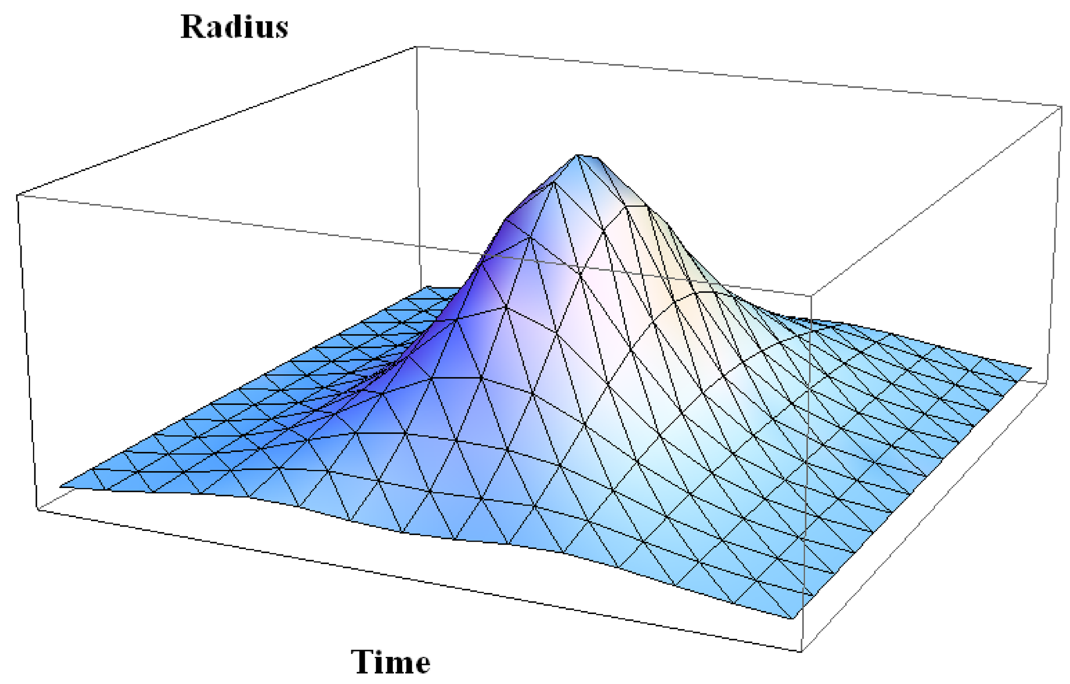


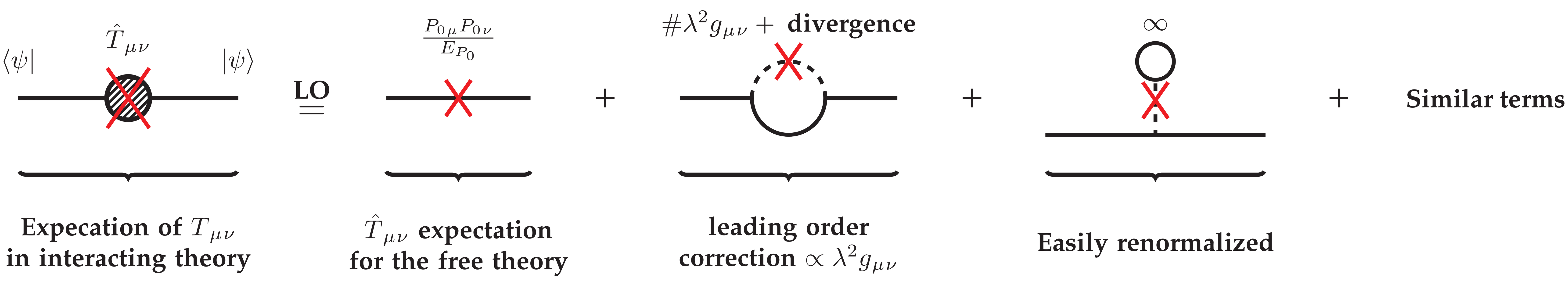
Figure 2: $\langle\psi|\phi(x)\phi(x)|\psi\rangle$ to order λ^2 as a function of radial distance and time, with scale not intended to be taken seriously.

The next step is to **repeat this process for QCD**. After some work we expect to gain physical insight into the momentum distribution for high energy jets in heavy ion collisions.

Results

We have constructed the **building blocks for the first order calculation** of the **energy momentum tensor**, but we have run into divergences. We are optimistic that a standard renormalization scheme will take care of these. **Our calculation of $\langle\psi|\hat{T}_{\mu\nu}(x)|\psi\rangle$ is given diagramatically below** with operator:

$$\langle\psi|\hat{T}_{\mu\nu}(x)|\psi\rangle = \langle\psi|\partial_\mu\phi\partial_\nu\phi + \partial_\mu\psi\partial_\nu\psi - g_{\mu\nu}\mathcal{L}|\psi\rangle \quad (3)$$



Here **a red X** indicates the field on which the relevant operator is measured. The similar terms contain variations of the same diagrams with the operators attached to different legs and vertices. The same approach can be used if we choose to scale up the number of initial particles.

References

[1] Narindra, A. (2013) Expectation value of the quantum stress-energy tensor. African Institute for Mathematical Sciences.

[2] Gelis, F. The initial stages of high energy heavy ion collisions. ipht.cea.fr/Pisp/francois.gelis/Physics/habilitation-thesis.pdf

Contact Information

Meiring mrnben002@myuct.ac.za

Horowitz wahorowitz@gmail.com