Semiholography in heavy ion collisions

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Doktoratskolleg Particles and Interactions

1 Introduction

- In heavy ion collisions in the LHC and RHIC **Quark-gluon plasma** (QGP), a state of deconfined strongly interacting matter, is produced.
- Currently, the evolution is described in two separate stages:
  - Early times ($t \lesssim 0.1 fm/c$) can be described by the **Color-Glass Condensate** (CGC). The strong coupling, α_s, is perturbatively small and the hard gluons have a high occupation number, $\mathcal{O}(\alpha_s^{-1})$. This can be modelled via classical Yang-Mills (YM).
  - Later ($t \approx 1 fm/c$) after the QGP droplet has formed, it undergoes **hydrodynamic evolution**, as can be inferred from e.g. the low value of the specific viscosity, ($\frac{\eta}{s} \approx \frac{1}{4\pi}$). This can be modelled by a holographic theory.
- **Semiholographic models** aim to bridge this gap by coupling classical YM to a holographic sector via marginal operators. Scalar operators are considered here.

2 The toy model

Combined action: $S = S_{YM}[A_\mu] + W_{CFT}[\phi]$. They are coupled by sourcing one another self-consistently, as can be seen from their equations of motion:

- YM: $D_\mu F^{\mu\nu} = \frac{\beta}{Q_s^3} D_\mu(\hat{\mathcal{H}} F^{\mu\nu})$
- AdS4 (dual to CFT):

$$R_{MN} - \frac{1}{2} R G_{MN} - 3 G_{MN} = \kappa T^{\phi}_{MN}.$$

$$\nabla^M \nabla_M \phi = 0\,,$$

$$\phi = -\frac{\beta}{4 N_c Q_s^3} \underbrace{F_{\mu\nu} F^{\mu\nu}}_{\text{source}} + \ldots + z^3 \frac{\kappa}{2L^2} \underbrace{\mathcal{H}}_{\text{response}} + \mathcal{O}(z^3 \log(z))$$

Full **energy momentum tensor** (EMT) is $T^{\mu\nu} = t^{\mu\nu}_{YM} + t^{\mu\nu}_{hol} - \frac{\beta}{Q_s^3} \hat{\mathcal{H}} h$.

This is **conserved in flat space**: $\partial_\mu T^{\mu\nu} = 0$.

To simplify calculations, we impose homogeneity, isotropy and work in $2+1$ dimensions. Furthermore, we have:

- **Gauge field**: Consider only $SU(2)$ with color space locking, i.e. only non-zero components $A_1^1 = A_2^2 = f(t)$.
- **Metric ansatz**:

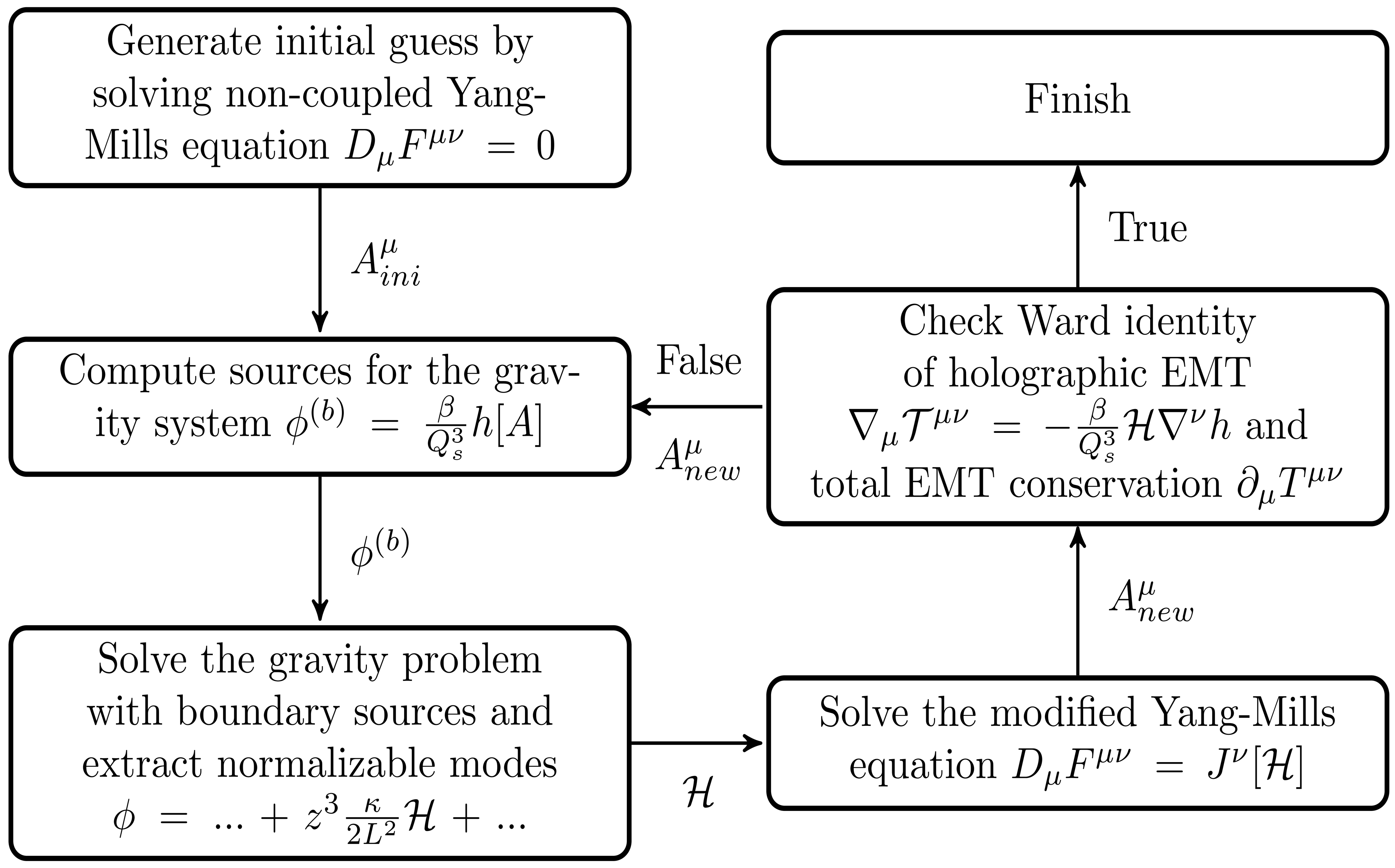
$$ds^2 = -A(z,t) dt^2 - 2 \frac{dt dz}{z^2} + S(z,t)^2 (dx_1^2 + dx_2^2)$$

References

[1] C. Ecker, A. Mukhopadhyay, F. Preis, A. Rebhan, A. Soloviev arXiv:1806.01850

[2] A. Kurkela, A. Mukhopadhyay, F. Preis, A. Rebhan, A. Soloviev arXiv:1805.05213

3 Solution Procedure

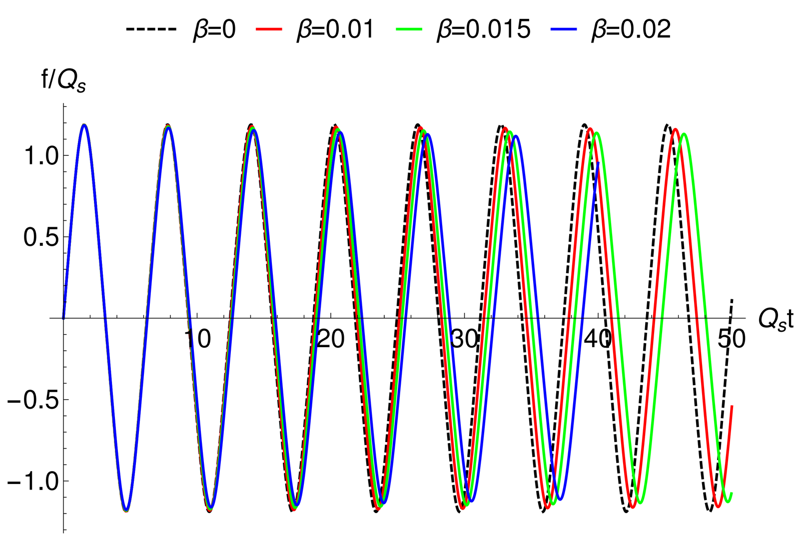


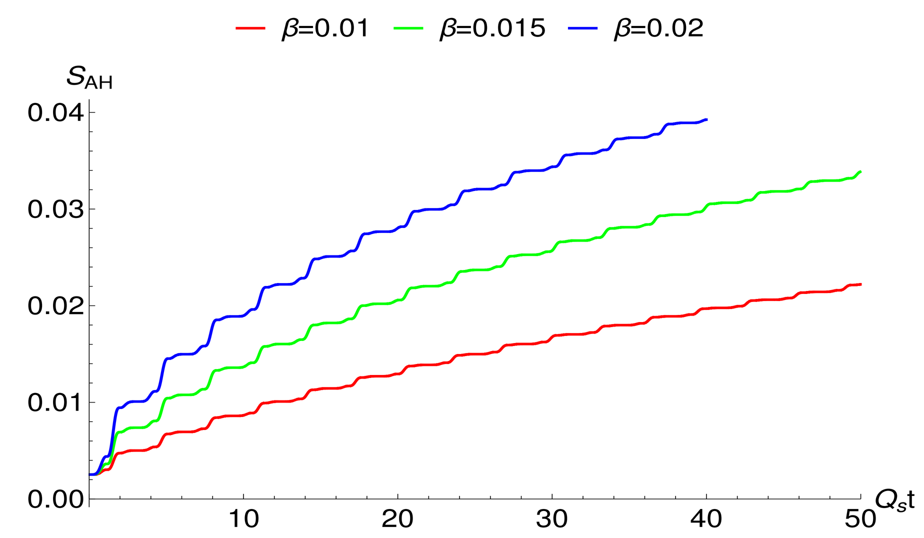
4 Results

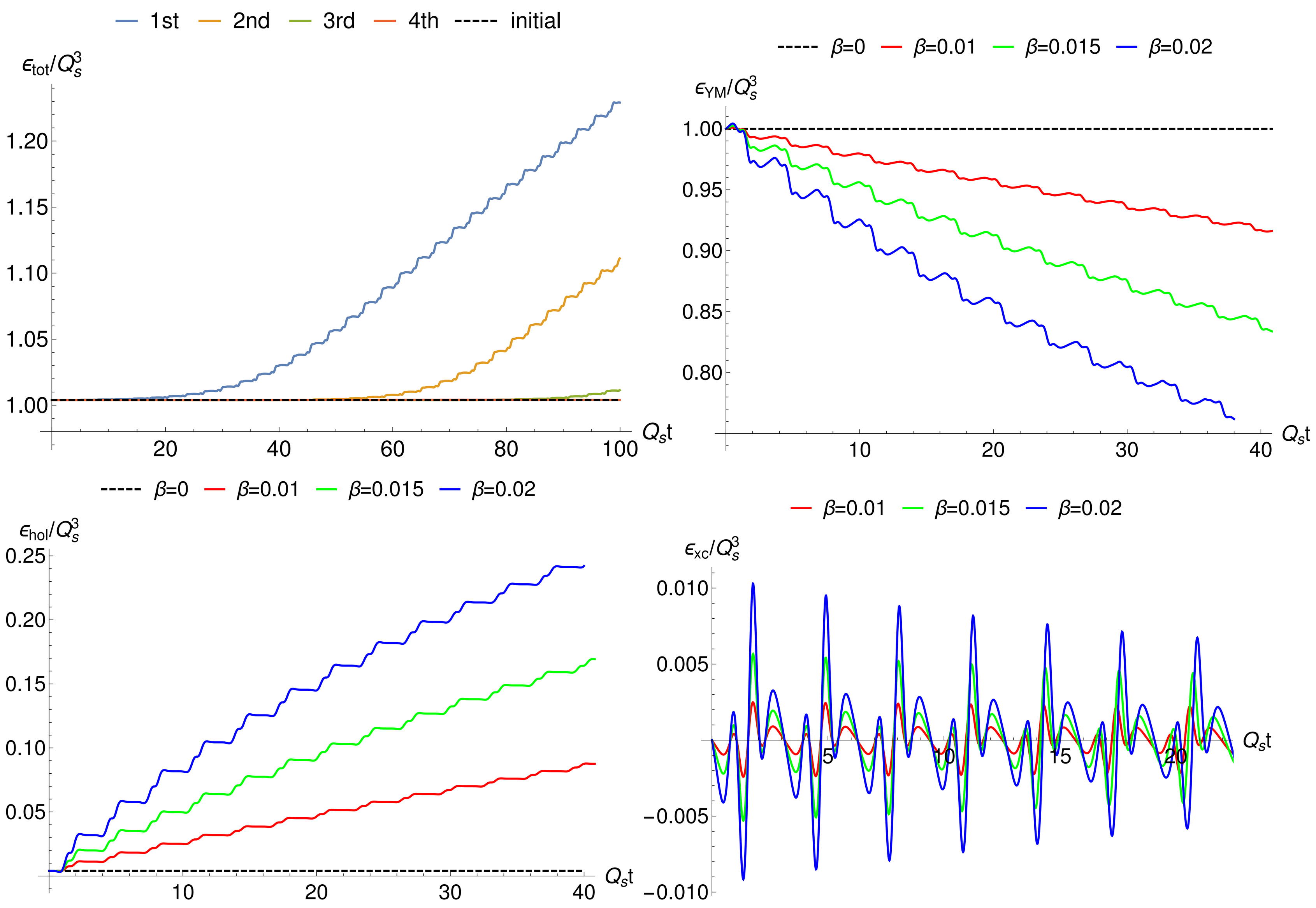
- The plots show how changing the coupling β changes the dynamics.
- **Energy is drained** from the YM sector and fed to the black hole (irrespective of sign of β)!

Left: the gauge field f is plotted with increasing β. The frequency and amplitude steadily decrease, indicating that the YM sector is losing energy.

Right: the black hole horizon grows, indicating that energy and entropy increase.







Top left: Total energy for $\beta = 0.01$ as function of time for subsequent iterations. Notice that the convergence improves with each iteration.

Top right: The energy density of the YM sector against time. Notice that increasing the coupling drains the energy density faster.

Bottom left: The energy density of the holographic sector.

Bottom right: The exchange energy as a function of time.

5 Summary

- Consistent coupling of classical Yang-Mills theory to a gravity dual of a strongly coupled field theory.
- This is the first successful implementation of a **self-consistent numerical AdS/CFT simulation** involving a backreacted dynamical boundary source far from equilibrium.
- Energy flows from YM to the strongly coupled sector, resulting in black hole growth.

Contact & Funding

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