A3: Strings and QCD

Collaborative Research Centre 676

Universität Hamburg and DESY

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Staff Members and aim of the project

Strings

V. Schomerus
J. Teschner
I. Papadimitriou (PostDoc)
N.N. (PhD)

QCD

J. Bartels
L. Lipatov
M. Salvadore (PostDoc)
M. Hentschinski (PhD)
A. Mischler (PhD)

AIM

Improve our understanding of String theory and of QCD at high energy by means of the tools provided by dualities connecting gauge and string theories (AdS/CFT).

Some recent results

- Dilaton operator (anomalous dimensions) of trace operators ($\mathrm{Tr}(ZYYZY\ldots)$) in $N=4$ SYM is equivalent to an integrable spin chain Hamiltonian;
- Similar integrable structure found in the worldsheet theory of strings on $\mathrm{AdS}_5 \times \mathrm{S}^5$;
- Precise identification of dual states possible:
  excitations on the spin chain (Magnons) are dual to certain soliton solutions in string theory.

Short distance effect (anomalous dimension $\leftrightarrow$ leading twist) associated with the Bjorken limit: $Q^2 \propto s,\ Q^2 \to \infty$.
The Regge limit ($s \to \infty,\ t$ fixed) offer a much richer structure.
It also presents integrable structures.

The dynamics of QCD in the Regge limit simplifies largely.

ROUGH IDEA:

The light-cone ($x^{\pm} = x^0 \pm x^1$) and transverse ($x^i, i = 2, 3$) dynamics decouple.

- The light-cone dynamics provides powers of $\log(s)$ which sum up to the Regge behaviour s^{α};
- the transverse dynamics determines the Regge trajectory $\alpha(t)$ and "deforms" the power-like behaviour.

Perturbative approach

- If $s >> -t >> \Lambda_{QCD} \Rightarrow$ perturbation theory;
- The Leading Logs $(\alpha_s \log s)^n$ give the BFKL Pomeron ($\mathbb{P}$):

$$\mathcal{A}_{ab\to a'b'}(s,t) \xrightarrow{\text{LL}} \langle bb'|s^{1+\mathcal{H}}|aa'\rangle$$

- The BFKL Hamiltonian $\mathcal{H}$ acts in the transverse space;
- It encodes two interacting Reggeized gluons ($\mathbb{RG}$);
- $\mathbb{RG}$s are the effective d.o.f. relevant at high energy;
- They live in $2+1$ dimensions, $\log(s)$ plays the role of time;
- $\mathcal{H}$ is Moebius invariant: $[\mathcal{H}, \mathfrak{sl}(2,\mathbb{C})] = 0$ (subalgebra of the Virasoro algebra);
- $\mathcal{H}$ is holomorphic separable: $\mathcal{H} = h + h^*$.

Beyond LL

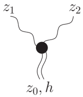
- Next-to-LL: $\alpha_s(\alpha_s \log s)^n$.
  $\mathcal{H}$ is known. Moebius invariance is broken due to the running of α_s. Interesting to study $N = 4$ SYM ($\beta = 0$).
- Generalized-LL: 2 $\mathbb{RG} \to n$ $\mathbb{RG}$ (BKP equations):
  - Moebius invariance: $[\mathcal{H}_n, \mathfrak{sl}(2,\mathbb{C})] = 0$;
  - Integrable in the large N_c limit.
- Extended-GLL: Field theory of interacting $\mathbb{RG}$s in $2+1$ dimensions.
  The known transition vertices are Moebius symmetric.

There seem to be more symmetries than those inferred from the QCD Lagrangian.

The EGLL resembles a CFT

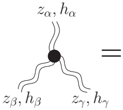
- $\Phi_{00}(z,\bar{z}) \to \mathbb{RG}$ operator;
- $\mathcal{O}_{h\bar{h}}(z,\bar{z}) \to \mathbb{P}$ (2 $\mathbb{RG}$) operator (quasiprimary).

The $\mathbb{P}$ wave function is interpreted as the correlation function:



$$= \left(\frac{z_{12}}{z_{10}z_{20}}\right)^{h}\left(\frac{\bar{z}_{12}}{\bar{z}_{10}\bar{z}_{20}}\right)^{\bar{h}} = \langle \Phi_{00}(z_1,\bar{z}_1)\Phi_{00}(z_2,\bar{z}_2)\mathcal{O}_{h\bar{h}}(z_0,\bar{z}_0)\rangle$$

The triple $\mathbb{P}$ vertex looks like a CFT correlation function:



$$= V(\alpha \to \beta,\gamma) = V(h_\alpha; h_\beta, h_\gamma) \times \prod_{i<j} z_{ij}^{-\Delta_{ij}}\ \bar{z}_{ij}^{-\bar{\Delta}_{ij}}$$

Tempting to identify:

$$V(\alpha \to \beta,\gamma) = \langle \mathcal{O}_{h_\alpha\bar{h}_\alpha}(z_\alpha,\bar{z}_\alpha)\mathcal{O}_{h_\beta\bar{h}_\beta}(z_\beta,\bar{z}_\beta)\mathcal{O}_{h_\gamma\bar{h}_\gamma}(z_\gamma,\bar{z}_\gamma)\rangle$$

Questions

- Can we identify a CFT which describe this high energy behaviour of QCD / $N = 4$ SYM?
- Can we, using AdS/CFT, identify a dual string theory?
- Can we use this correspondence in order to improve our understanding of both QCD at high energy and of string theory?

First steps

- Let's start with $\mathcal{N} = 4$ SYM.
  - Similar to QCD but simpler (no running of α_s);
  - $\mathcal{N} = 4$ SYM $\equiv$ IIB on $\mathrm{AdS}_5 \times S^5$ is the best known example of AdS/CFT correspondence.
- Identification of suitable gauge invariant operators and computation of correlation functions in the Regge limit (different from QCD, there is no matter).
- BFKL operator at NLL known only in the forward direction ($t = 0$); Moebius invariance and integrability at NLL are still hot open issues!