Fields and Strings Laboratory

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EPFL

Lab presentation for 3rd year students

Questions

- What are the possible particle interactions compatible with Quantum Mechanics and Special Relativity?
- What is the structure of space and time at the smallest scale?
- What happens when we scatter particles at high energy?

At the FSL, we explore these questions using the language of Quantum Field Theory and String Theory.
In particular, we use the Conformal Bootstrap and the S-matrix Bootstrap.

Quantum Gravity

Quantum Gravity

General Relativity is a low energy effective field theory that requires UV completion.

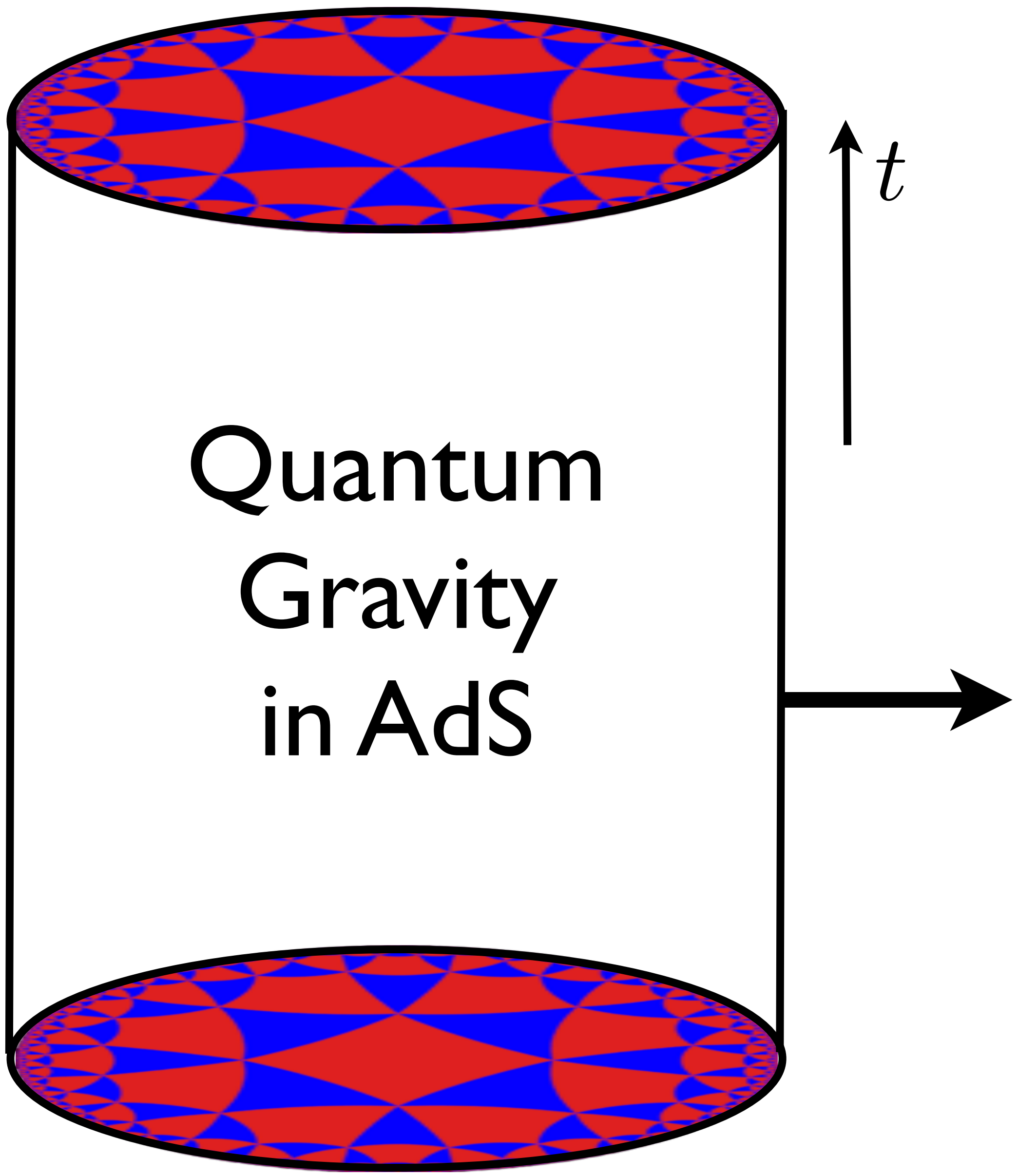
$$E_P = \sqrt{\frac{\hbar c^5}{G}} \approx 1.2 \times 10^{19} GeV \qquad \ell_P = \sqrt{\frac{\hbar G}{c^3}} \approx 1.6 \times 10^{-35} m$$

Definition: a quantum theory of gravity is a quantum mechanical theory (unitary time evolution) whose low energy dynamics is well described by General Relativity.

In particular, it should have the same low lying energy spectrum.

QG in a box: Anti-de Sitter space

['97 Maldacena]



Quantum Gravity in AdS

Conformal Field Theory (CFT) at the boundary of spacetime

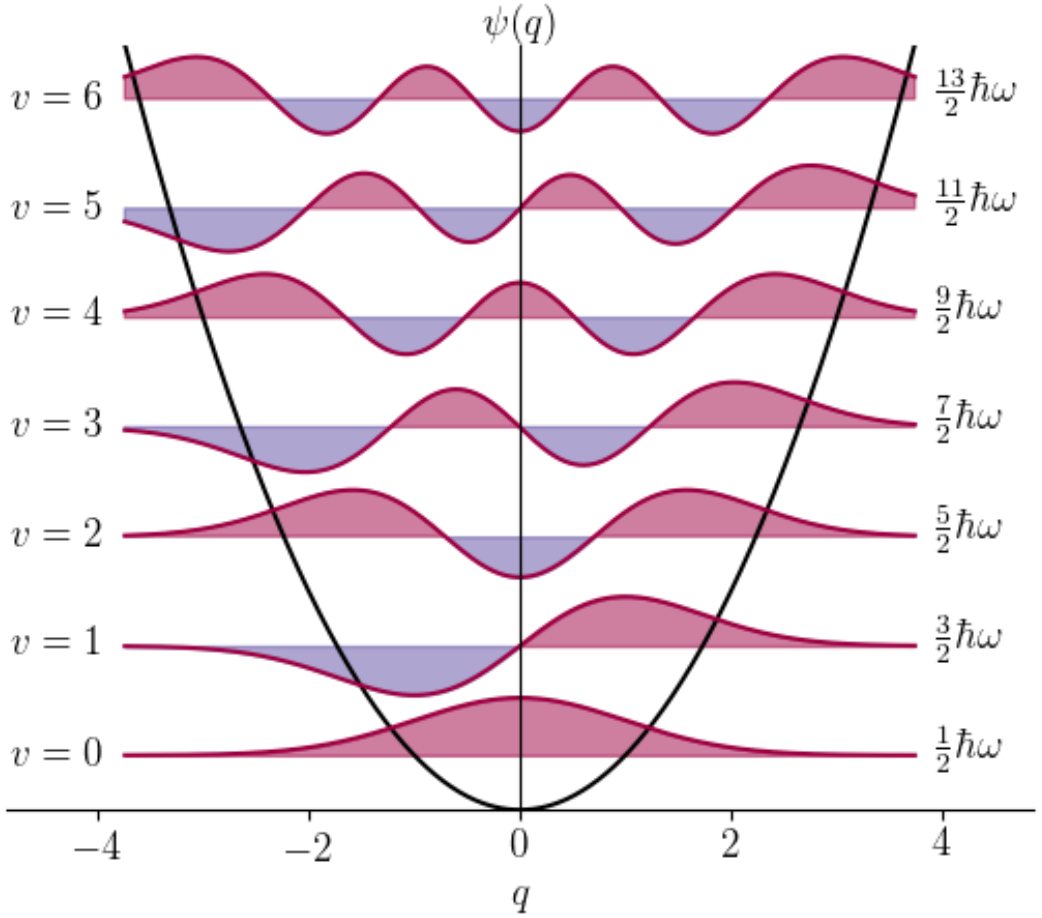
The low energy spectrum of gravitons in AdS_{d+1} appears naturally in CFT_d. Indeed, some CFTs are holographic quantum theories of gravity.

Spacetime from Quantum Mechanics

Harmonic oscillator

Bosonic

$$E = \hbar\omega\left(n + \frac{1}{2}\right) \qquad n = 0, 1, 2, \ldots$$



Fermionic

$$E = \hbar\omega\left(n - \frac{1}{2}\right) \qquad n = 0, 1$$

Can spacetime be an effective description of many coupled harmonic oscillators?

Spacetime from Quantum Mechanics

BMN model: ['02 Berenstein, Maldacena, Nastase]

$$\left\{\begin{array}{lcll} 9N^2 \text{ bosonic oscillators} & \to & 9\ N\times N \text{ hermitian matrices } X^r\,, & r=1,2,\ldots,9 \\ 8N^2 \text{ fermionic oscillators} & \to & 8\ N\times N \text{ complex matrices } \psi_\alpha\,, & \alpha=1,2,\ldots,8 \end{array}\right.$$

$$[(X^r)_{mn},(P^s)_{m'n'}] = i\,\delta_{rs}\delta_{mm'}\delta_{nn'} \qquad \{(\psi_\alpha)^\dagger_{mn},(\psi_\beta)_{m'n'}\} = \delta_{\alpha\beta}\delta_{mm'}\delta_{nn'}$$

$$H = \frac{1}{2}\mathrm{Tr}\left[\sum_{r=1}^{9}(P^r)^2 + \frac{1}{3^2}\sum_{r=1}^{3}(X^r)^2 + \frac{1}{6^2}\sum_{r=4}^{9}(X^r)^2 + \frac{1}{2}\sum_{\alpha=1}^{8}\psi^\dagger_\alpha\psi_\alpha\right]$$

$$+\mathrm{Tr}\left[i\frac{g}{3}\sum_{r,s,t=1}^{3}\epsilon_{rst}X^rX^sX^t - \frac{g^2}{4}\sum_{r,s=1}^{9}[X^r,X^s]^2 + \underset{\uparrow}{g}\sum_{\alpha,\beta=1}^{8}\sum_{r=1}^{9}\left(\psi^\dagger_\alpha[X^r,\psi_\beta]\underset{\uparrow}{\Sigma^r_{\alpha\beta}} + \psi_\alpha[X^r,\psi_\beta]\underset{\uparrow}{\Theta^r_{\alpha\beta}} + h.c.\right)\right]$$

coupling known matrices (fixed by symmetry)

What is the ground state (and excitations) at strong coupling?

Conjecture: spacetime description emerges in the limit $N\to\infty\,,\quad g^2N\to\infty\,.$

There are black holes for $T > T_c = 0.1059$ ['14 Costa, Greenspan, JP, Santos]

To know more

- Webpage https://www.epfl.ch/labs/fsl/
- Lecture: **What is Quantum Field Theory?** https://tube.switch.ch/channels/4f8a22b1

FSL members (Fall 2023)

- **Postdocs**:
  - Xiang Zhao
  - Vassilis Papadopoulos
  - Gregoire Mathys
- **PhD students**:
  - Kelian Häring (CERN)
  - Manuel Loparco
  - José Matos (Porto Univ.)
  - Antoine Vuignier
  - New student
- **Master students:**
  - Melvyn Nabavi
  - Ayla Rossboth
  - Yannis Ulrich

Plan for Physics Projects

Plan for Physics Projects

- Winter semester
  - Mathematics for Theoretical Physics (Group theory, Lie algebras …) - List of math problems
  - Study book material, solve problems and present on the blackboard during weekly meetings
  - Small project at the end

- Summer semester
  - Study some topics in QFT
  - Study review papers, solve problems and work on small research project

Master Programme in HET

https://het.epfl.ch/master-programme

First and second semester

Quantum Physics III and IV
Quantum Field Theory I and II
Relativity and Cosmology I and II
Physics Projects I and II
[Statistical Physics III and IV, Particle Physics I and II, …]

Third semester

Advanced Quantum Field Theory
Gauge Theories and the Standard Model
Conformal Field Theory and Gravity

Fourth semester

Master thesis

Essential courses

- Quantum Field Theory I & II
- Relativity and Cosmology I & II
- Quantum Physics III & IV

How to apply

- Apply at https://www.epfl.ch/labs/fsl/teaching/ until the end of May (you will need to upload a short CV and transcript of grades at EPFL)

- Selection process will take place in June.

- Main selection criteria are grades (especially in theoretical physics courses) and interview.