Physics 253b Final Project Topics

You are asked to choose one of the following topics, with a few other students in the class as a team. Treat it as a problem set in which you will formulate your own problem and come up with its solution, guided by the suggested references. You should write up your findings in the form of an expository term paper, and give a 30 minute presentation (per person) on it. The presentation can be done collaboratively, whereas the term paper should be written individually.

The suggested references should serve as a starting point for your exploration of the subject. You should by no means limit yourself to the suggested reference, nor feel obligated to understand/present everything in the reference. The goal of your term paper should be to explain one single nontrivial result on the topic of your choice in a self-contained manner. The presentation should be done in blackboard style (use slides only if you need to show numerical plots and/or computer codes), and you should be prepared to reproduce the derivation of key steps and claims, if asked. AVOID giving broad overviews or merely paraphrasing results without your own derivation/arguments.

The final presentations will be scheduled in the week of May 1 (precise schedule TBD). The term paper will be due at the end of the exam period. The number in the parenthesis below is the cap on the maximal number of people in the team on the topic.

1. (5) Explore constraints on the non-perturbative S-matrix from unitarity and analyticity assumptions.

Paulos, Penedones, Toledo, van Rees, Vieira, "The S-matrix Bootstrap II: Two Dimensional Amplitudes", 10.1007/JHEP11(2017)143; "The S-matrix Bootstrap III: Higher Dimensional Amplitudes", arXiv:1708.06765. Guerrieri, Penedones, Vieira, "Bootstrapping QCD Using Pion Scattering Amplitudes", Phys. Rev. Lett. 122, 241604 (2019).

2. (4) Why naively power-counting-renormalizable field theories are actually renormalizable, either from the viewpoint of canceling divergences with counter terms in perturbation theory (BPHZ), or from the viewpoint of Wilsonian renormalization group (Polchinski).

K. Hepp, "Proof of the Bogoliubov-Parasiuk theorem on renormalization", Comm. Math. Phys. 2(4): 301-326 (1966). W. Zimmermann, "Convergence of Bogoliubov's method of renormalization in momentum space", Comm. Math. Phys. 15(3): 208-234

(1969). Itzykson and Zuber, *Quantum Field Theory* (1980), Chapter 8. J. Polchinski, "Renormalization and Effective Lagrangians," Nucl. Phys. B231 (1984), 269-295.

3. (3) Batalin-Vilkovisky formalism: what it is, why/when it is necessary, and how it is used to prove the perturbative renormalizability of Yang-Mills theory.

Weinberg, the Quantum Theory of Fields Volume II, section 15.9 and chapter 17.

4. (4) Explore a solvable model of quark confinement: the two-dimensional QCD in the limit of large number of colors.

G. 't Hooft, "A Two-Dimensional Model for Mesons," Nucl. Phys. B75 (1974), 461-470. C. G. Callan, Jr., N. Coote and D. J. Gross, "Two-Dimensional Yang-Mills Theory: A Model of Quark Confinement," Phys. Rev. D13 (1976), 1649.

5. (3) Renormalization group analysis of two-dimensional nonlinear sigma models.

C. G. Callan, Jr., E. J. Martinec, M. J. Perry and D. Friedan, "Strings in Background Fields," Nucl. Phys. B262 (1985), 593-609. A. A. Tseytlin, "Conformal Anomaly in Two-Dimensional Sigma Model on Curved Background and Strings," Phys. Lett. B178 (1986), 34. Callan, Thorlacius, "Sigma models and string theory", Providence 1988, Proceedings, Particles, strings and supernovae, vol. 2, 795-878 (file available at https://www.damtp.cam.ac.uk/user/tong/string/sigma.pdf)

6. (3) A numerical study of Wilsonian renormalization group flow in the Kondo model.

Wilson, "The renormalization group: Critical phenomena and the Kondo problem", Rev. Mod. Phys. 47, 773 (1975).

7. (3) A rigorous treatment of Wilsonian renormalization group flow and fixed point in a fermionic model.

Giuliani, Mastropietro, Rychkov, "Gentle introduction to rigorous Renormalization Group: a worked fermionic example", arXiv:2008.04361.

8. (6) Explore Ising field theory or (the much more difficult) Yang-Mills theory viewed as critical points of Euclidean field theories on the lattice. Note that in this approach, quantitative determination of field theoretical observables typically require substantial numerics, e.g. evaluating the path integral on a truncated lattice using Monte Carlo methods.

M. E. J. Newman, G. T. Barkema, "Monte Carlo Methods in Statistical Physics", Clarendon Press 1999. Wilson, "Confinement of quarks", Phys. Rev. D 10, 2445

(1974). Morningstar, Peardon, "The glueball spectrum from an anisotropic lattice study", Phys.Rev.D60:034509 (1999). Lucini, Rago, Rinaldi, "Glueball masses in the large N limit", JHEP 1008:119 (2010).

9. (3) The connection between the QCD theta angle and the neutron electric dipole moment. (This involves in an essential way the analysis of chiral anomalies and chiral perturbation theory which will be discussed towards the very end of the semester.)

Crewther, Di Vecchia, Veneziano, Witten, "Chiral Estimate of the Electric Dipole Moment of the Neutron in Quantum Chromodynamics", Phys.Lett.B 88 (1979) 123, Phys.Lett.B 91 (1980) 487 (erratum). Pospelov, Ritz, "Theta Vacua, QCD Sum Rules, and the Neutron Electric Dipole Moment", Nucl.Phys. B573 (2000) 177. Hook, "TASI Lectures on the Strong CP Problem and Axions", arXiv:1812.02669.

10. (4) Explore the effect of instantons on physical observables in non-Abelian gauge theories.

't Hooft, "Computation of the quantum effects due to a four-dimensional pseudoparticle", Phys. Rev. D 14, 3432 (1976); Erratum Phys. Rev. D 18, 2199 (1978).

11. (4) Effective field theory and RG analysis of fermi surface.

J. Polchinski, "Effective field theory and the Fermi surface," [arXiv:hep-th/9210046 [hep-th]]. Metlitski, Max A., David F. Mross, Subir Sachdev, and T. Senthil. "Are non-Fermi-liquids stable to Cooper pairing?" Phys. Rev. B 91, 115111 (2015) [arXiv:1403.3694]. I. Esterlis, H. Guo, A. A. Patel and S. Sachdev, "Large N theory of critical Fermi surfaces," Phys. Rev. B103 (2021) no.23, 235129 [arXiv:2103.08615 [cond-mat.str-el]].

12. (4) c/a-theorems and the irreversibility of RG flow.

A. B. Zamolodchikov, "Irreversibility of the Flux of the Renormalization Group in a 2D Field Theory," JETP Lett. 43 (1986), 730-732. Z. Komargodski and A. Schwimmer, "On Renormalization Group Flows in Four Dimensions," JHEP12 (2011), 099 [arXiv:1107.3987 [hep-th]].