

## Progress in QFT 2 course

Sept 8 **Extension 1** – Very quick review, vacuum polarization via Feynman rules, quick review of Path Integral formulas, vacuum polarization via functional techniques, functional differentiation again.

Sept 10 **Extension 2** – Perturbation theory via functional derivation, completing the vacuum polarization example, the determinant of a differential operator  $\det(D^2 + m^2)$ ,  $\det = \exp \text{tr} \ln$  identity, integrating out the scalar field, renormalization and effective Lagrangian.

Sept 15 **Extension 3** – Heat kernel method, Fermion path integral, Functional differentiation with anticommuting sources, Grassmann numbers, Spin statistics theorem, Dirac algebra, ordering in Feynman diagrams, gauge invariance example.

Sept 17 **Extension 4** – Chiral fermions, left and right fields, Majorana mass, spin sums for fermions and photon, traces of gamma matrices.

Sept 22 **Extension 5** – Practical group theory,  $SU(2)$  and  $SU(N)$ , representations and transformation rules, constructing invariants, extracting predictions

Sept 25 **Gauge theory 1** – Nonabelian gauge symmetry, the Yang Mills lagrangian, path integral quantization, problem with propagator, simple example of factoring out symmetry, constraining the path integral.

Sept 29 – **Gauge theory 2** – Review of path integral quantization, QED example, covariant gauges, Fadeev-Popov trick, ghosts, Yang Mills example, Feynman rules for Yang Mills.

Oct 1 – **Gauge theory 3** – running coupling in QED,  $1/\epsilon$  determines logs, charge renormalization in Yang Mills, vacuum polarization, oddities of dimensional regularization, calculating casimirs.

Oct 6 – **Gauge theory 4** – ghost and fermion contributions to running coupling, the overall beta function, matching across mass thresholds, scheme dependence, higher orders.

Oct 8 – **Gauge theory 5** –  $g=2$  from Dirac equation, calculating  $g=2$  and the vertex correction.

Oct 15 – **Effective field theory 1** – What is effective field theory, locality, QED effective Lagrangian, the energy expansion, linear sigma model, a low energy calculation and its effective Lagrangian

Oct 20 – **Effective field theory 2** – the exponential representation, recalculating the scattering amplitude, path integral connection, integrating out at tree level, start of matching.

Oct 22 – **Effective field theory 3** – Integrating out scalar, heat kernel, general form of effective  $L$ , which parameters to use, matching the effective theory and the full theory.

Oct 27 – **Effective field theory 4** – Power counting, Weinberg theorem, measuring vs matching, Rules of EFT, relevance of sigma model, explicit symmetry breaking, Wilson and EFT.

Oct 29 – **Effective field theory 5** – The operator product expansion, weak interaction example, the background field method,  $\phi^4$  example, heat kernel, perturbative expansion.

Nov 3 – **Effective field theory 5 continued** – background field renormalization of the sigma model. **Anomalies 1** – currents in path integrals, path integrals and symmetries, scale invariance in the Standard Model, The trace anomaly, calculating the path integral jacobian

Nov 5 – **Anomalies 2** obtaining the trace relation, Feynman diagram approach, interpreting the trace anomaly, the simplest derivation via running charge, axial U(1) problem, starting the chiral anomaly calculation.

Nov 10 – **Anomalies 3** shift of integration variable, the pi to 2 gamma story, anomalies and gauge currents, and **Standard Model 1** quantum numbers, U(1) ambiguity, anomaly conditions, hypercharge assignments

Nov 12 **Standard Model 2** – Adding the Higgs, Gauge boson masses, Gauge currents for fermions, Math: doublet = anti-doublet, Yukawa couplings

Nov 17 **Standard Model 3** – Diagonalizing mass matrices, Neutrino masses and see saw mechanism, diagonalizing neutrino masses,  $V_{CKM}$  and  $V_{PMNS}$ , tree level weak decays.

Nov 19 **Standard Model 4** – the pion/kaon story, external sources method, enhanced symmetry, the effective Lagrangian, quark masses

Nov 24 **Standard Model 5** – rare weak decays, inputs into W,Z physics, STU and precision tests, arguments for new physics beyond the Standard Model

Dec 1 **Supersymmetry 1** Weyl spinors, Wess-Zumino model, SUSY charges, SUSY algebra, auxiliary fields, superspace, chiral superfield, vector superfield, superpotential, F-terms and D-terms, SUSY model building

Dec 3 **Supersymmetry 2** – properties of SUSY, the case for weak scale SUSY, construction of the MSSM, R parity, supersymmetry breaking, hidden sector, soft SUSy breaking, the Higgs sector,, EWSB, the mu problem, flavor issues.

Dec 8 **Gravity 1** – Gauging Lorentz transformations, Spin transformation for fermions, local Lorentz invariance, vierbein, fermions and the spin connection, covariant derivative, forming the curvature, Einstein action and equations

Dec 10 **Gravity 2** – review of gauge theory construction, exploring the action, higher invariants of the curvature, quantization and Feynman rules, background field renormalization, gravity as an effective field theory