

Flavour Physics

Warwick Week Graduate Lectures

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April 2023

Lecture 1: Flavour in the SM

- Introduction
- Flavour in the Standard Model
- Quark Model History
 - Isospin
 - Strangeness
 - GIM mechanism and charm
 - P and CP violation
- The CKM mechanism
 - CKM parametrisation and hierarchy
 - Unitarity Triangles
 - The Jarlskog Invariant and matter-antimatter asymmetry

Lecture 2: Mixing and CP violation

- Neutral Meson Mixing
 - Time-evolution of coupled systems
 - Differences in mixing parameters between neutral meson states
- B -meson production, experiments and techniques
 - B -factories: BaBar, Belle and Belle-II
 - LHCb
 - Flavour Tagging
 - Dalitz analysis

- CP violation
 - Types of CP violation
 - The “master” equations for generalised meson decays

Lecture 3: Measuring the CKM parameters

- Measurements of CKM matrix element magnitudes
 - $V_{ud}, V_{us}, V_{cd}, V_{cs}, V_{tb}$
 - Measurements of Unitarity Triangle sides ($V_{ub}, V_{cb}, V_{td}, V_{ts}$)
 - Tensions in $R(D^{(*)})$
- Measurements of CKM matrix angles
 - The angles α, β, γ and ϕ_s
- CP violation in the kaon system
- Global constraints on the CKM matrix and the unitarity triangle(s)
- T violation and CPT
- Electric and magnetic dipole moments

Lecture 4: Flavour Changing Neutral Currents

- Effective Theories
- Flavour Changing Neutral Current (FCNC) processes
- Experimental constraints from FCNCs
 - Constraints from B -mixing ($\Delta F = 2$ FCNCs)
 - Constraints from $b \rightarrow s$ transitions ($\Delta F = 1$ FCNCs)
- Minimal Flavour Violation
- Lepton Flavour Violation
- Future Flavour Violation Experiments

Reading Material

This course has been taught previously by Tom Blake (material [here](#)) and Tim Gershon (material [here](#)). There is another excellent set of similar lectures given by Niels Tuning (material [here](#)). For a more theoretical / phenomenological perspective then I suggest the excellent lecture notes from Alex Lenz (material [here](#)).

Lecture Notes (from other sources)

- Nikhef lecture notes (mostly experimental point of view), *Niels Tuning*, <https://www.nikhef.nl/h71/Lectures/2015/ppII-cpviolaFon-29012015.pdf>
- IPPP lecture notes on Heavy Flavour and Effective Field Theories (more theoretical), *Alex Lenz*, <https://www.precision.hep.phy.cam.ac.uk/wp-content/people/mitov/lectures/Gradua>
- ESHEP lecture notes (more theoretical) <https://arxiv.org/abs/1704.03753>
- Zurich lecture course (a bit of both) <https://www.physik.uzh.ch/en/teaching/PHY568/FS2016.html>
- A. J. Buras, “Weak Hamiltonian, CP violation and rare decays,” <https://arxiv.org/abs/hep-ph/9806471>
- A. J. Buras, “Flavor physics and CP violation,” <https://arxiv.org/abs/hep-ph/0505175>
- G. Isidori, “Flavor physics and CP violation,” <https://arxiv.org/abs/1302.0661>
- Y. Grossman, “Introduction to flavor physics,” <https://arxiv.org/abs/1006.3534>
- Y. Nir, “Flavour physics and CP violation,” <https://arxiv.org/abs/1010.2666>
- M. Neubert, “Effective field theory and heavy quark physics,” <https://arxiv.org/abs/hep-ph/0512222>

PDG reviews

The Particle Data Group (PDG) provide a host of useful material (particularly values of branching-fractions, cross-sections and pretty much every particle physics related observable you can think of). They also have some really great reviews, aimed at the level of a typical PhD student.

- B -mixing
<http://pdg.lbl.gov/2021/reviews/rpp2021-rev-b-bar-mixing.pdf>
- D -mixing
<http://pdg.lbl.gov/2021/reviews/rpp2021-rev-d-dbar-mixing.pdf>
- Quark model
<http://pdg.lbl.gov/2021/reviews/rpp2021-rev-quark-model.pdf>
- CKM matrix
<http://pdg.lbl.gov/2021/reviews/rpp2021-rev-ckm-matrix.pdf>
- CP-violation
<http://pdg.lbl.gov/2021/reviews/rpp2021-rev-cp-violation.pdf>
- V_{ub} , V_{cb}
<http://pdg.lbl.gov/2021/reviews/rpp2021-rev-vcb-vub.pdf>
- CKM angles
<http://pdg.lbl.gov/2021/reviews/rpp2021-rev-ckm-angles.pdf>

Other reviews

- G. Isidori, “Flavor physics and CP violation”
<https://arxiv.org/abs/1302.0661>
- T. Blake, T. Gershon and G. Hiller, “Rare b hadron decays at the LHC”
<https://arxiv.org/abs/1501.03309>
- T. Gershon and V. Gligorov, “ CP violation in the B system”
<https://arxiv.org/abs/1607.06746>

Books

Most introductory particle physics books will contain chapters on flavour physics. There are also a few specialist books available

- “CP violation”, I. I. Bigi and A. I. Sanda
- “CP violation”, G. C. Branco, L. Lavoura and J. P. Silva
- “Effective Field Theories in Flavour Physics”, T. Mannel

Other useful resources

- Particle Data Group (PDG)
<http://pdg.lbl.gov>
<http://pdglive.lbl.gov> (Particle Listings)

- Heavy Flavour Averaging Group
<https://hflav.web.cern.ch>
<https://arxiv.org/abs/1909.12524>
- CKMfitter
<http://ckmfitter.in2p3.fr>
- UTfit
<http://www.utfit.org/UTfit>
- LHCb Public Results page
http://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/Summary_all.html
- Belle II Document Server
<https://docs.belle2.org>

Reference list

This is a list of all references used in the lecture course. There are some stunning papers in this list (and also some absolutely seminal works that are very hard to penetrate). If you read them all then you are more dedicated than I!

References

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- [26] D0, S. Abachi *et al.*, *Observation of the top quark*, Phys. Rev. Lett. **74** (1995) 2632, [arXiv:hep-ex/9503003](https://arxiv.org/abs/hep-ex/9503003).