Highlights from Tuesday

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Future Challenges in Nonleptonic B-Decays
MITP Mainz, 18/01/2019

Talks concerning theory of decay amplitudes in the heavy-quark expansion (QCDF, pQCD)

M Beneke, T Huber, Yu-Ming Wang, Cai-Dian Lu

This is **not** a summary of these talks, in particular omissions do not imply criticism.

What I knew before Tuesday

QCD is the correct theory of strong interactions

5 quark masses & 1 coupling
dynamical mass generation, chiral symmetry in Nambu-Goldstone mode

causality/analyticity & unitarity

Mathematically, this fixes all hadronic matrix elements, such that non-QCD physics (CKM, BSM…) can be probed through hadronic B-decays. In practice, limited ability to compute.

(Finding laws of physics vs finding their solutions)

1) 'Does the charm loop factorize in the heavy-quark limit' is a question within theory. But relevant for ability to compute, hence interpretation of experiment, BSM searches, etc

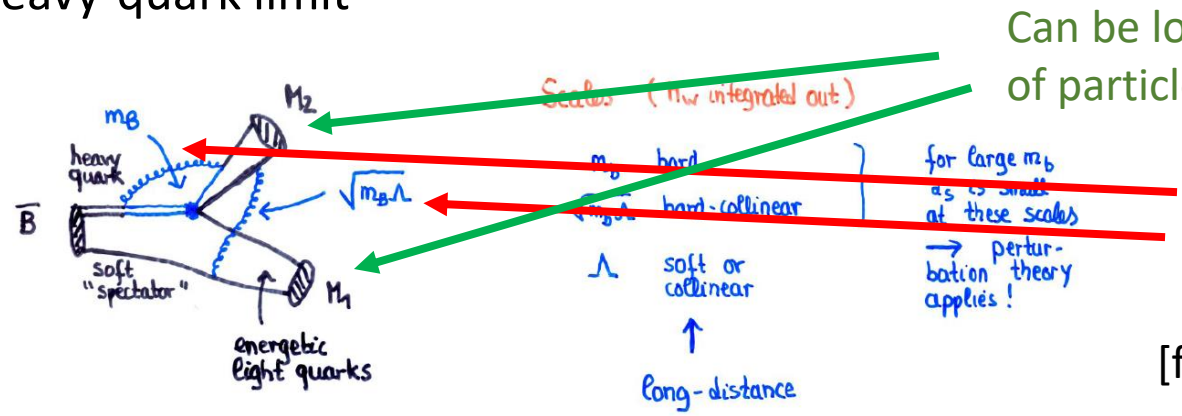
2) Qualitatively distinct from building models of hadronic dynamics where often aim is to reproduce features in the data in the absence of exact calculations

In my view
Conflating these can cause unnecessary confusion, and possibly misdirected efforts, too.

Modelling should always complement (and certainly be consistent) with what is already exactly known.

Basic picture

B->M1 M2 matrix elements of the weak Hamiltonian simplify in the heavy-quark limit



Result: Naïve factorization plus unambiguously calculable corrections for **infinite** b-quark mass

- Absorptive parts are O(alpha_s): generally small CP asymmetry.
- Loop suppression of penguin amplitudes
- Generically agrees w/ experimental picture (O(100) observables)

Residual dependence on form factors and LCDA (from elsewhere)

Corrections to the heavy-quark limit scale as Λ/m_b. Second source of strong phases; generally do not factorize.

Main phenomenological limitation. Most in need of attention

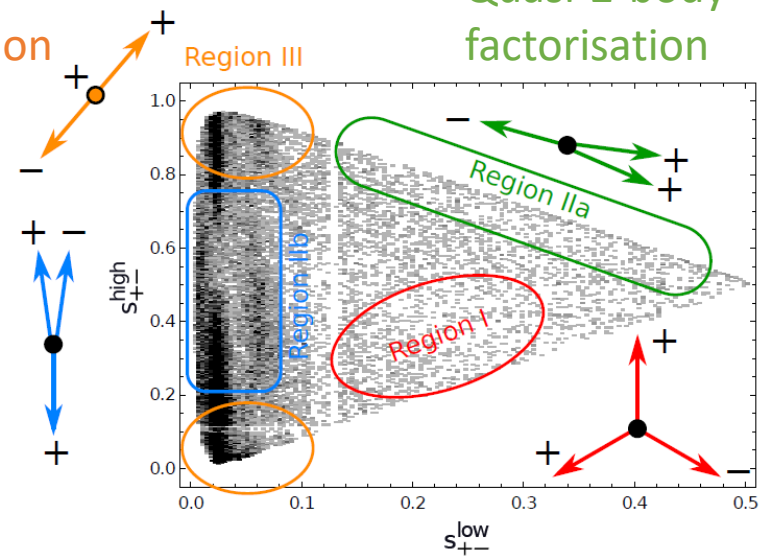
Three-body final states

Eg B $\rightarrow \pi^+\pi^+\pi^-$

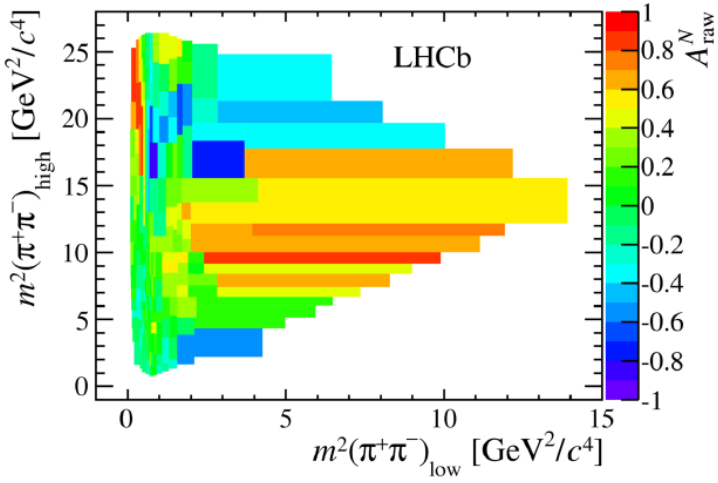
[figs from T Huber/T Gershon talks]

No factorisation

Quasi-2-body factorisation



Quasi-2-body factorisation



No factorisation

Distinct factorisation formalism

Very large direct CP asymmetries even in the regions where factorization applies. (Formally power corrections.)

Some news and highlights

1) There are as many flavour amplitudes (terms in the QCD factorization notation) as topological amplitudes (M Beneke's talk)

The QCDF 'basis' is special in that some of the amplitudes vanish in the heavy-quark limit (and are suppressed in the real world)

2) NNLO accuracy available for most leading-power amplitudes
Ongoing and planned work on calculable, chirally enhanced power corrections (a_6)

More highlights

Concise and clear summary of **settled** controversies around the heavy-quark expansion. In particular, **all** leading-power amplitudes factorize.

As a corollary, the huge resonant contributions to inclusive b->s l l do not constitute a violation of duality; rather there simply is no parton-hadron duality for this process.

Discussion of outstanding issues in the pQCD approach

Comprehensive survey of approaches to 3-body charmless final states (T Huber talk).

Some challenges/open issues

1) Improve knowledge of B-meson light-cone distribution amplitudes (specificially, inverse moment λ_B)
   - Experiment (Belle 2 B -> ɣlν; maybe LHCb B -> lllν), probes directly the relevant moments
   - Light-cone sum rules (-> Danny van Dyk's slides)
   - Ultimately, on the lattice? In HQET or in full QCD?

2) Electromagnetic effects. Conceptually different because while hadrons (and leptons) are colour singlets, they aren't electrically neutral
   - Long-distance QED can probe the internal structure of the hadrons
   - QED corrections could be sizable (Sudakov suppression with tight cuts on accompanying photons)

Some challenges/open issues

3) Better description of power corrections

- Eg, light-cone sum rules specifically for p.c.
- Most important for colour-suppressed tree and long-distance charm penguin (large Wilson coefficient C_1)
- non-power-like dependence on Λ/m_b ?
- duality violation?

4) Large and strongly phase-space dependent CP asymmetries in 3-body decays

- Difficult to understand from heavy-quark limit point of view
- Can this be understood in terms of hadronic states? Dispersion relations? (see Wednesday, Thursday, and Friday morning discussion)
- If so, how can this be consistently combined with the heavy-quark expansions, keeping the ‘good’ bits / avoiding double counting?