Thoughts on benchmark modes for the Physics case for Flavour Physics and related detector designs Working Group 6.

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Outline of the talk

- Scope of the Flavour Physics working (WG6).
- Thoughts to define flagship decay modes.
- Generalities on detector design related to Flavour Physics.
- Organisation of the working group.

0. Scope of the Flavour Physics working

- Understand the experimental precision with which rare decays of *c*- and *b*-hadrons and CP violation in the heavy-quark sector could be measured with 10^{12} *Z*, as well as the potential sensitivity to new physics, and compare to the ultimate potential of the (soon to be) running LHCb upgrade and Belle II experiments.

- The very same objective stands for the rare lepton decays.

- Examine the physics reach of lepton flavour violating processes and neutrino-related Physics unique to the FCC-*ee*.

- Stimulate the thinking on beyond standard observables.

- What would like to do/see with/in 10^{12} *Z*? makes a nice playground to start with. Uli Haisch kindly accepted to commission the exercise. Slides appended and some flashed here.

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Ideas for flavour studies with FCC-ee

Uli Haisch
Oxford University

FCC-ee/TLEP physics workshop (TLEP7), 19-21 June 2014, CERN

1. Thoughts to define flagship decay modes.

- There are two main dedicated flavour (mostly *b*) physics (FP) experiments to be operated in the HEP landscape of 2020.
- I tried to distinguish in that talk the foreseeable FP landscape at the FCC-*ee* horizon.
- Belle II should explore deeply/widely the B_d and B_u meson systems. Might also run above the Υ(5S) threshold but can't resolve the oscillation of B_s meson.
- LHCb sees all species of *b*-particles (and charm in abundance) and is especially good at rare decays with muons and fully charged decay modes. Less efficient for electrons, neutrals, missing energy, hadronic multibody decays.
- The latter highs and lows define a path to complete the picture in the event nothing new is observed meanwhile.

1. Thoughts on flagship decay modes.

- A possible/appealing realm for FCC-*ee* in the classic flavours is therefore provided by the following quadriptyque most likely unique to FCC-*ee*:

  1) Any leptonic or semileptonic decay mode involving B_s, B_c or *b*-baryon, including electrons.

  2) Any decay mode involving B_s, B_c or *b*-baryon with neutrals.

  3) Multibody (means 4 and more) hadronic *b*-hadron decays.

  4) Lepton Flavour violation processes / FCNC.

- Try to highlight a flagship mode for each category in the following. Disclaimer: this mode is not to be the most appealing one physics-wise.

1. Thoughts on flagship decay modes.

1) Any leptonic or semileptonic decay mode involving B_s, B_c or b-baryon, including electrons, in no particular order:

- $B_{d,s} \to ee, \mu\mu, \tau\tau$: if the second will be mostly covered by LHCb, the first can be searched for with a similar precision. The latter $B_s \to \tau\tau$ is most likely unique to FCC-ee and subjected to third family specific couplings.

- $|V_{ub}|$ from semileptonic decays: this is (and will be for a long time) dominated by theoretical uncertainties. In particular, inclusive measurement (disregarding a specific final state) is currently limited by the extrapolation to low lepton energies. The large boost experienced at the Z definitely helps to reduce that uncertainty. Can also be accessed theory-free through ratios of rare decays.

- There is definitely the need of a thorough theoretical exploration at first to assess the limiting theory uncertainty on most of these subjects.

1. Thoughts on flagship decay modes.

1) Any leptonic or semileptonic decay mode involving *Bs*, *Bc* or *b*-baryon, including electrons, in no particular order: (cont'ed)

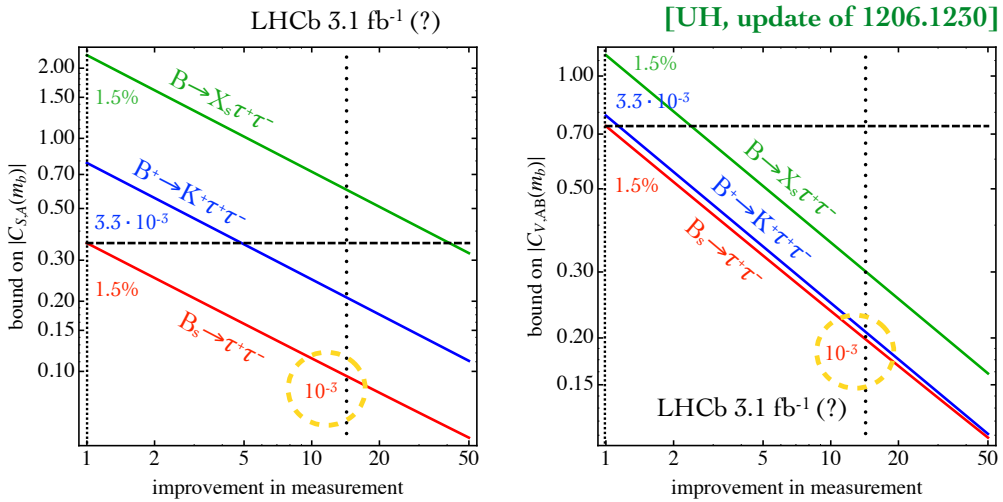
- Leptonic decays in direct annihilation $B_{u,c} \to \mu\nu_\mu, \tau\nu_\tau$. The latter is a chance to get $|V_{cb}|$ with mild theoretical uncertainties.

- Digressing from the *Z*, can we measure $|V_{cb}|$ (and $|V_{ub}|$) at the *WW* pair threshold? Physics interest in the running of the matrix elements.

$$\text{Flagship Mode}: \; B_s \to \tau^+\tau^- .$$

1) Flagship Mode : $B_s \to \tau^+\tau^-$.

$B_s \to \tau^+\tau^-$: The unbounded



$B_s \to \tau^+\tau^-$ best probe of scalar & vector operators of form $\bar{s}b\bar{\tau}\tau$

2) Any decay mode involving *Bs*, *Bc* or *b*-baryon with neutrals.

- $B_{d,s} \to \gamma\gamma$: quite appealing.

- $B_s \to K_S K_S$: *CP* violation studies. Also interesting for downstream tracking of V^0 in general.

- $B_s \to X\nu\nu$: very rare FCNC complementing the B_d at *B*-factories.

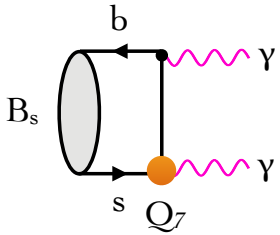
- Just restrict to provocative final states. CP violation-wise, much more w/ π^0, K_S, η, η' ...

$$\text{Flagship Mode : } B_s \to \gamma\gamma.$$

2) # Flagship Mode : $B_s \to \gamma\gamma$.

Ample room for exotic new physics entering via 1PI diagrams

$B_s \to \gamma\gamma$: Heavy to light



$$\mathrm{Br}\,(B_s \to \gamma\gamma)_{\mathrm{SM}} \propto \left| V_{ts}^* V_{tb}\, C_7\, \frac{m_{B_s}}{\lambda_{B_s}} \right|^2$$

+ subleading power from 1PI graphs

- Double-radiative decay also offers possibility to determine properties of B_s-meson light-cone distribution amplitude, in particular of its inverse moment λ_{Bs}
- Combining $B_s \to \gamma\gamma$ with $B \to \gamma l\nu$, $B_s \to \phi\gamma$, … into global fit might allow to cancel common hadronic uncertainties

Further theoretical studies needed to strengthen physics case

3) Multibody (4 and more) hadronic *b*-hadron decays.

- $B_s \to \psi\eta'$ *or* $\eta_c\Phi$*:* flavour tagging required for weak mixing phase.
- $B_{d,s,u,c} \to 4h+$: interesting per se in a standard flavour physics case but also for dark portal explorations (can proceed through two scalars)...
- $B_s \to D_sK$: brought in by Roy Aleksan. PID definitely required to isolate the signal.
- ...

Flagship Mode : $B_s \to D_s^{\pm} K^{\mp}$.

4) Lepton Flavour violation processes.

• Direct LFV processes: $Z \to e\mu, e\tau, \tau\mu$. Given the statistics we're speaking about, tree-level effects are interesting to tackle. In terms of model constraints, this can be far richer than the current or foreseeable reach for $\mu \to e\gamma$ *or* $\tau \to \mu\gamma$ *etc...*

• Related to the large $\tau\tau$ production at the Z pole: $\tau \to e\gamma, \mu\gamma, eee, \mu\mu\mu$. both LFV and Majorana neutrino. In the latter case, possibly rich like-sign dilepton searches in *b*-hadron decays as well.

$$\text{Flagship Mode : } e^+e^- \to \tau^{\pm}\ell^{\mp}.$$

4)

Flagship Mode : $e^+e^- \to \tau^\pm \ell^\mp$.

LFV: Using 10^{12} Z decays

$\mathrm{Br}\,(Z \to \tau e) < 9.8 \cdot 10^{-6}$
$\mathrm{Br}\,(Z \to \tau \mu) < 1.2 \cdot 10^{-5}$ — LEP, 4 · 10^6 Z decays

[Wilson, talks at DESY-ECFA LC workshops '98 & '99]

$\mathrm{Br}\,(Z \to \tau e) < [1.3, 6.5] \cdot 10^{-8}$
$\mathrm{Br}\,(Z \to \tau \mu) < [0.4, 2.2] \cdot 10^{-8}$ — GigaZ, O(10^9) Z decays

my naive extrapolation

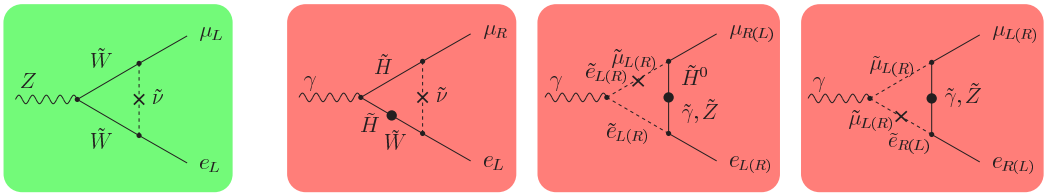
$\mathrm{Br}\,(Z \to \tau l) < \mathcal{O}(10^{-10} - 10^{-11})$ — FCC-ee, O(10^{12}) Z decays

Improvement of bounds by 5 orders of magnitude seem possible

4)

Flagship Mode : $e^+e^- \to \tau^\pm \ell^\mp$.

LFV: Using 10^{12} Z decays



$\delta^{\tilde{\nu}\,12}_{LL}$ $\quad$ $\delta^{\tilde{\nu}\,12}_{LL}\, m_\mu \tan\beta$ $\quad$ $\delta^{\tilde{\nu}\,12}_{LL(RR)}\, m_\mu \tan\beta$ $\quad$ $\delta^{\tilde{\nu}\,12}_{LR}\, m_{\tilde{\gamma},\tilde{Z}}$

for large mass insertions $\delta^{\tilde{\nu}\,13}_{LL}$ ($\delta^{\tilde{\nu}\,23}_{LL}$) & light sneutrinos of around 70 GeV one gets $Br(Z\to\tau l) \sim Br(\tau\to l\gamma) = O(10^{-8})$

$\tau\to l\gamma$ bounds can by avoided allowing for largish $Z\to\tau l$ rates

Note: much more on Uli's slides appended at the agenda.

2. Generalities on detector design related to Flavour Physics.

- Most of the detector requirements of the Flavour Physics case are common to the other working groups but a dedicated particle identification π, K, p. Common at least to EWK, Higgs and top Physics:

  - Excellent vertexing performance for Heavy Flavours (c, b and τ) selection.
  - Excellent momentum resolution for invariant mass discriminations.
  - High granularity electromagnetic calorimeter, pointing and energy. π^0/γ separation.

2. Generalities on detector design related to Flavour Physics.

- Most of the detector requirements of the FP case are common to the other working groups but a dedicated particle identification π, K, p.

- Area 4 (multibody fully hadronic b-hadron decays) previously defined would require a powerful particle identification. $B_s \rightarrow D_s K$ can be a prototype for it.

- On top of that, any time-dependent analysis will require flavour tagging. Specifically, B_s time-dependent analyses do need same-side kaon tagging. A prototype for this can be again $B_s \rightarrow D_s K$ or above-mentioned modes for weak mixing phase determination as $B_s \rightarrow \psi\eta'$ *or* $\eta_c \Phi$.

- Aside of this, K_S are central for CP violation studies and the mode mentioned above can be a valuable benchmark for V^0 tracking.

- ...

3. Organisation of the working group

- The working group activity is actually starting now.
- All the thoughts given hereabove (and others) will be examined critically in the WG kick-off meeting, to be held wednesday, the 3rd of September, 16:00 (CET).
- Meanwhile, 1) start to gather small teams exp/theory on the flagship modes (to be readjusted as long as the work goes). 2) make a platform for thinking beyond standard observables.
- A distribution list is set up. You're very welcome to join it : *fcc-ee-FlavourPhysics@cern.ch*
- A twiki page gathers (will gather) the progresses: *https://twiki.cern.ch/twiki/bin/viewauth/FCC/FCCeeFlavourPhysics*

3. Conclusion and outlook.

- This talk gathers few thoughts we had on flavour-related benchmark modes where unique precision could be obtained at FCC-*ee*.

- Detector-wise: excellent vertexing and tracking, high granularity calorimetry are required in the core physics case. The specific detector study brought by Flavour Physics case lies in the hadron identification detectors needs. Possible benchmark modes addressed.

- WG6 is getting active now.

- First actions:

  - build-up theo-exp small teams on the obvious selected topics.
  - meeting to refine strategy on the less obvious and forgotten modes.
  - document the strategy by beginning of fall.