

Discussion of the *Flavours* chapter of
the FCC CDR book #7 :
FCC-ee Physics and Experiments.

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- Scientific context (Flavour-wise) for the Study.
 - Scientific materials gathered so far.
 - A tentative table of contents of the Chapter.
 - Discussion of specific studies available so far.
 - Forthcoming studies.
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- Disclaimer: what follows is very much in progress.

1) Scientific context

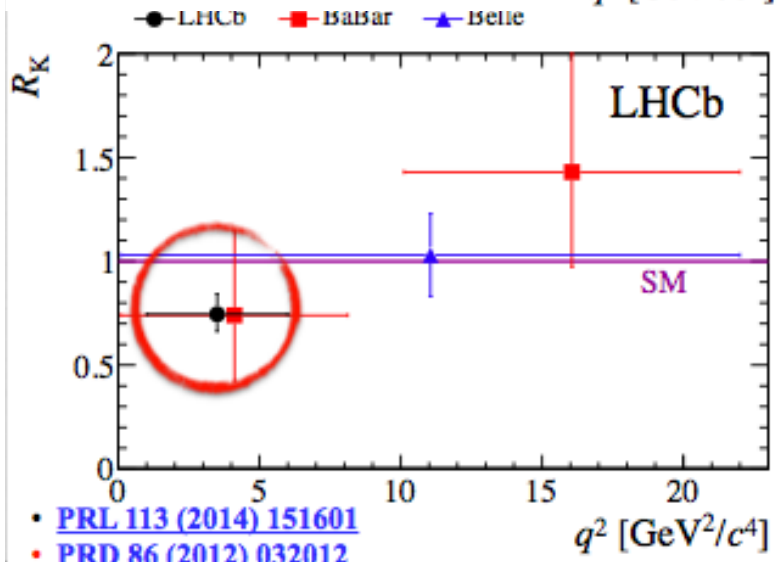
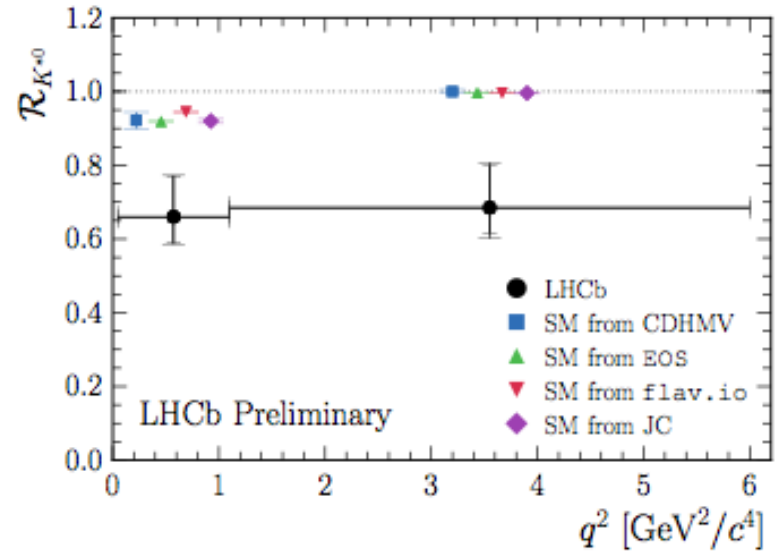
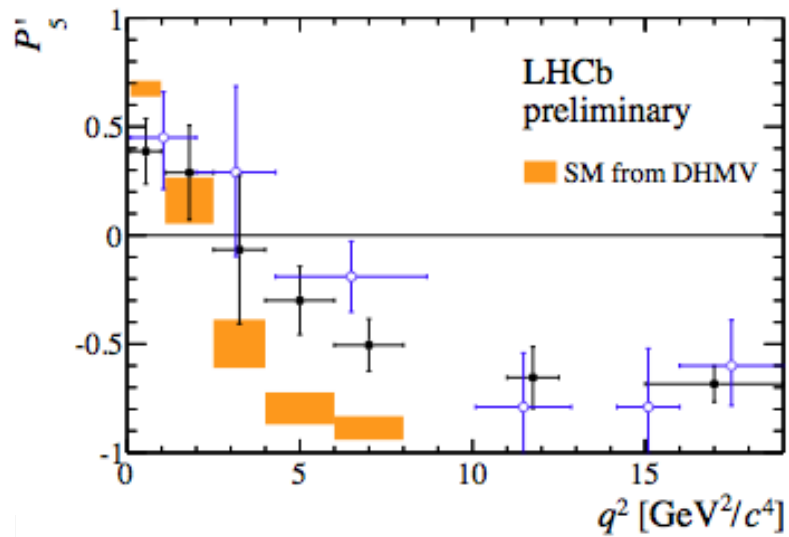
- There are persistent departures of the measurements of the FCNC decays $b \rightarrow s l^+ l^-$ w.r.t. the SM / QCD predictions. They are consistent among experiments (Belle, LHCb and others) as far as the angular distributions of the mode $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ are concerned.
- LHCb sees consistent departures to lepton universality in the ratios:

$$R_K = \frac{B^0 \rightarrow K e^+ e^-}{B^0 \rightarrow K \mu^+ \mu^-} \times \frac{B^0 \rightarrow K J/\Psi (\rightarrow \mu^+ \mu^-)}{B^0 \rightarrow K J/\Psi (\rightarrow e^+ e^-)}$$

$$R_{K^*} = \frac{B^0 \rightarrow K^*(892) e^+ e^-}{B^0 \rightarrow K^*(892) \mu^+ \mu^-} \times \frac{B^0 \rightarrow K^*(892) J/\Psi (\rightarrow \mu^+ \mu^-)}{B^0 \rightarrow K^*(892) J/\Psi (\rightarrow e^+ e^-)}$$

- Comments on theoretical and experimental challenges: the former analyses do have theoretical uncertainties (long distance QCD). The latter have experimental challenges (q^2 dependence / double ratio).

1) Scientific context: some results.



- [PRL 113 \(2014\) 151601](#)
- [PRD 86 \(2012\) 032012](#)
- [PRL 103 \(2009\) 171801](#)

- See S. Bifani's talk [here](#)
- And many fits to come ...

1) Scientific context: FCC-ee landscape.

- The companion decay modes $B^0 \rightarrow K^{*0} e^+e^-$ (angular analysis) and mostly $B^0 \rightarrow K^{*0} \tau^+\tau^-$ are important ingredients to interpret the discrepancy (if real): unique at FCC-ee.
- The available statistics for the former at FCC-ee is beyond competition.
- The latter requires partial reconstruction, *i.e.* the use of the production and decay vertices to solve the kinematics of the decay. But the SM branching fraction can likely only be attained at FCC-ee.
- This is possibly an inevitable subject for the next years. There are other tensions though.
- The mode $B^0 \rightarrow K^{*0} \tau^+\tau^-$ has received a special attention in the FCC-ee context.

2) Scientific material gathered so far.

- Five meetings of the Flavour Physics working group have been held after a case has been built relative to the anticipated results of the soon to be running LHCb upgrade and Belle II experiments.

<http://indico.cern.ch/event/313708/contribution/25/material/slides/0.pdf>

- This served as a basis for a kick-off discussion meeting to criticize and eventually amend / refine / enhance the Physics scope of the WG. Held in September 2014.

<https://indico.cern.ch/event/336998/>

- A provisional strategy/hierarchy has been defined and contacts have been taken to initiate the phenomenological and experimental studies. Four other meetings followed where actual work was reported.

<https://indico.cern.ch/event/359433/>

<https://indico.cern.ch/event/380986/>

<https://indico.cern.ch/event/403492/>

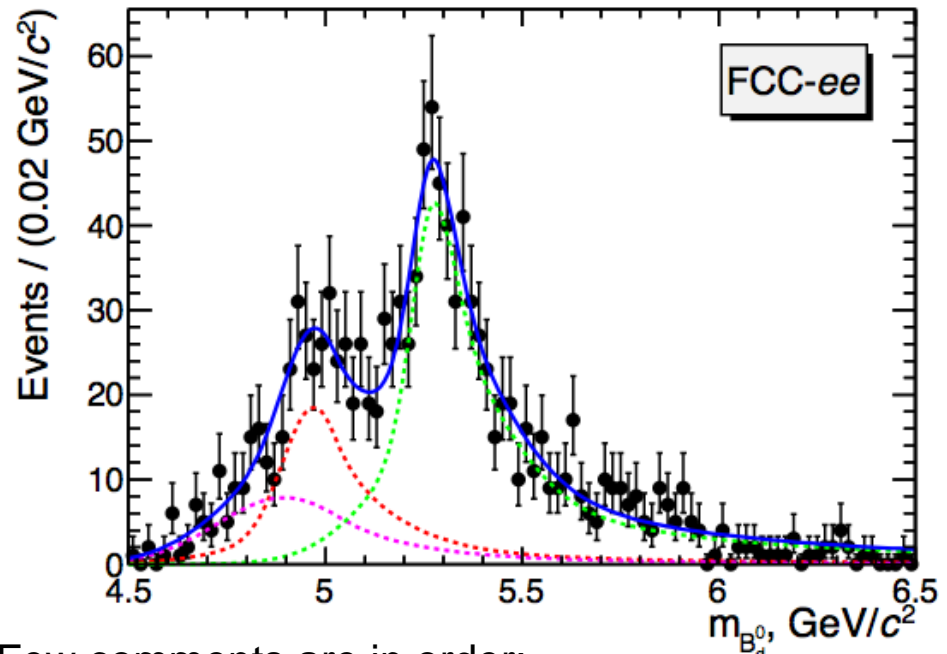
<https://indico.cern.ch/event/462662/>

3) Tentative table of contents of Flavours chapter.

- 1 Installation of a Flavour Physics case at FCC-*ee*
- 2 The anticipated landscape after LHCb upgrade and Belle II experiments
- 3 Rare decays and lepton universality violation
 - 3.1 $b \rightarrow s\ell^+\ell^-$ phenomenology
 - 3.2 Experimental sensitivity for $B^0 \rightarrow K^*(892)\tau^+\tau^-$
 - 3.3 Search for $B^0 \rightarrow \tau^+\tau^-$
- 4 Lepton Flavour violation in Z decays
- 5 CP violation in the quark sector
 - 5.1 The γ angle measurement with $B_s \rightarrow D_s^\pm K^\mp$
 - 5.2 Search for CP violation in neutral B meson mixings
 - 5.3 Perspectives for the CKM global fit
 - 5.4 Perspectives for the search for BSM Physics in $\Delta F = 2$ transitions CKM global fit
- 6 Additional studies: LFV in τ decays , c - and b -hadron spectroscopy, exclusive decays of the Z boson
- 7 Requirements for the detector design and performance

4) The documented studies - $B^0 \rightarrow K^{*0} \tau^+\tau^-$

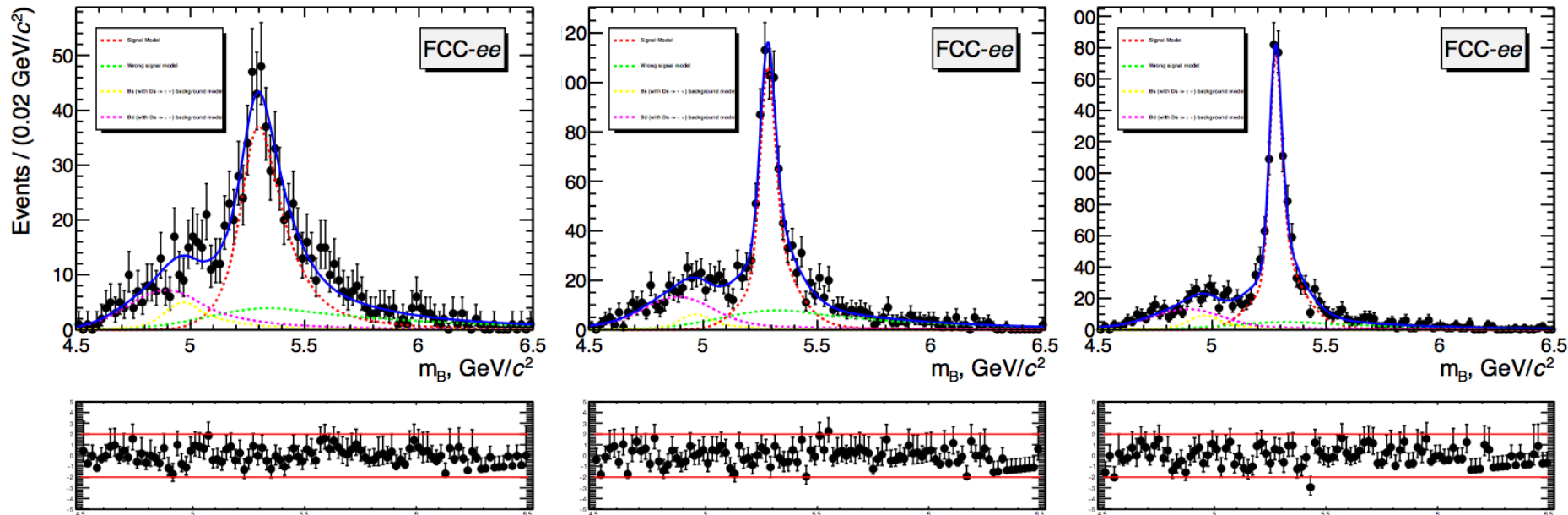
- Makes use of partial reconstruction technique to solve the kinematics of the decay. Sensitivity relies on vertexing performance
- Backgrounds: (pink) and (red) (signal in green).
- Conditions: baseline luminosity, SM calculations of signal and background BF, vertexing and tracking performance as ILD detector. **Momentum** \rightarrow 10 MeV, **Primary vertex** \rightarrow 3 μm , **SV** \rightarrow 7 μm , **TV** \rightarrow 5 μm



Few comments are in order:

- At baseline luminosity, 10^3 events of reconstructed signal. Angular analysis possible.
- With an ALEPH-like vertex detector performance, the signal peak can't be resolved.
- Another interesting and more challenging mode is $B_s \rightarrow \tau^+\tau^-$ (Marseille - tuples with the same parametric detector have been produced).

4) The documented studies - $B^0 \rightarrow K^{*0} \tau^+ \tau^-$



Performance / Conditions	ILD-like	ILD / 2	ILD / 4
Efficiency of the identification of the correct solution (%)	42.3	52.6	62.0
Invariant mass resolution (core) [MeV/c ²]	42(1)	36(1)	27(1)

4) The documented studies - $B^0 \rightarrow K^{*0} \tau^+\tau^-$

- The Physics perspectives are the sensitivity on the measurements of the branching fraction (differential in q^2), the angular analysis of the decay and the LFU studies.
- BF meas. sensitivity to be estimated w.r.t. vertex performance. Likely yet to vary mildly since wrong solutions of signal events can still be counted.
- As soon as we go to angular observables, the angular resolution will provide additional constraints.
- We are on our way to it (experimental and phenomenology-wise). A paper including tau polarisation information is basically written (L. Vale et al.).

4) The documented studies - cLFV in Z decays

- Lepton Flavour-Violating Z decays in the SM with lepton mixing are typically

$$\mathcal{B}(Z \rightarrow e^\pm \mu^\mp) \sim \mathcal{B}(Z \rightarrow e^\pm \tau^\mp) \sim 10^{-54} \text{ and } \mathcal{B}(Z \rightarrow \mu^\pm \tau^\mp) \sim 4 \cdot 10^{-60}$$

- Any observation of such a decay would be an **indisputable evidence for New Physics**.
- Current limits at the level of $\sim 10^{-6}$ (from LEP and recently ATLAS, e.g. [DELPHI, Z. Phys. C73 (1997) 243] [ATLAS, CERN-PH-EP-2014-195 (2014)])
- The FCC-ee high luminosity Z factory would allow to gain up to **six orders of magnitude ... Complementary to the direct search for steriles**.
- Explored with FCC-ee in mind in [De Romeri et al. JHEP 1504 (2015) 051]. It happens that the **final states with taus are the most appealing**.

4) The documented studies - LFV in Z decays

- There are actually three processes competing in the ball park we can address with a final state with a tau and a beam energy light lepton
 - The lepton Flavour-Violating Z decays
 - The SM $Z \rightarrow \tau^+\tau^-$
 - The SM $Z \rightarrow l^+l^-$ ($l \rightarrow W^* \nu$ and $W^* \rightarrow \tau \nu$)
- Following Mogens Dam's study reported [here](#) :

The SM process $Z \rightarrow \tau^+\tau^-$ provides a limit on cLFV process which goes linearly with the momentum resolution. Which is asymptotically limited in turn by the beam energy spread (~ 30 MeV at 45 GeV, ~ 20 MeV at 90°). This makes the former limit pretty fundamental.

The latter process in the list [Durieux et al. [arXiv:1512.03071](#)] is interesting per se (BSM enhancements) and can be distinguished from the two others by its kinematical properties: a partial reconstruction technique would make the job.

5) Ongoing studies.

- The search for the decay $B_s \rightarrow \tau^+\tau^-$. Signal tuples are available. A group is working on it.
- Document the $B^0 \rightarrow K^{*0} \tau^+\tau^-$ studies (th/exp).
- Document the cLFV in Z decays on the experimental part. Strengthen the case of the SM candle $Z \rightarrow l^+l^-$ ($l \rightarrow W^* \nu$ and $W^* \rightarrow \tau \nu$)
- CKM γ angle sensitivity with $B_s \rightarrow D_s K$. Signal and background tuples are available.
- CPV in neutral B -mesons mixing. A group (from Philippines) is starting.
- Prospective CKM fits.
- ...

6) Timeline as conclusions.

- A WG meeting will be held after Berlin FCC week to pave the required experimental studies.
- We plan a mini-workshop in the Fall to gather the whole contributions for the corresponding
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