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

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Outline

- 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.

- Disclaimer: what follows is very much in progress.

1) Scientific context

- There are persistent departures of the measurements of the FCNC decays $b \to s\ \ell^+\ell^-$ 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 $B^0 \to K^{*0}\ \mu^+\mu^-$ are concerned.

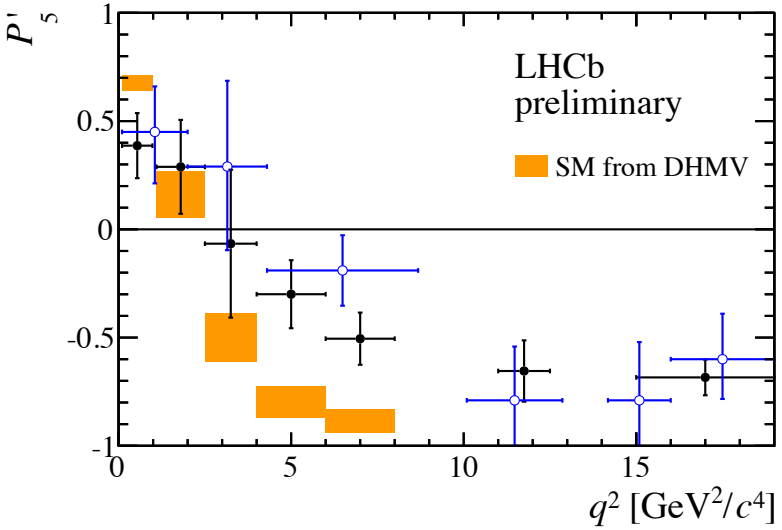
- LHCb sees consistent departures to lepton universality in the ratios:

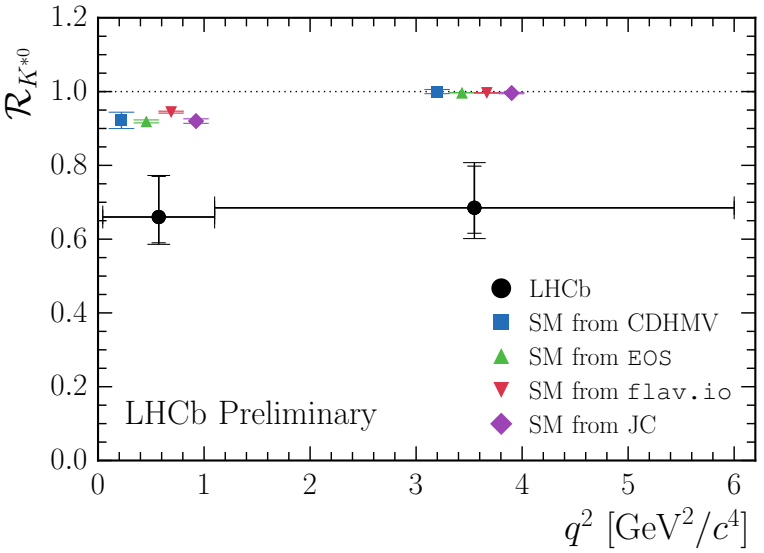
$$R_K = \frac{B^0 \to K e^+ e^-}{B^0 \to K \mu^+ \mu^-} \times \frac{B^0 \to K J/\Psi(\to \mu^+\mu^-)}{B^0 \to K J/\Psi(\to e^+e^-)}$$

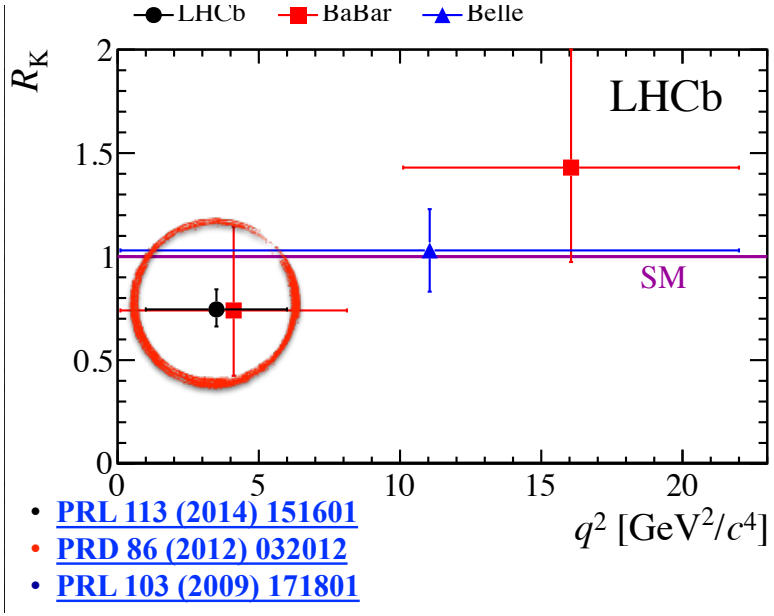
$$R_{K^*} = \frac{B^0 \to K^*(892) e^+ e^-}{B^0 \to K^*(892) \mu^+ \mu^-} \times \frac{B^0 \to K^*(892) J/\Psi(\to \mu^+\mu^-)}{B^0 \to K^*(892) J/\Psi(\to e^+e^-)}$$

- 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 $B^0 \to K^{*0}\ e^+e^-$ (angular analysis) and mostly $B^0 \to K^{*0}\ \tau^+\tau^-$ 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 $B^0 \to K^{*0}\ \tau^+\tau^-$ 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 $b \to s\ell^+\ell^-$ **phenomenology**

3.2 Experimental sensitivity for $B^0 \to K^*(892)\tau^+\tau^-$

3.3 Search for $B^0 \to \tau^+\tau^-$

4 Lepton Flavour violation in Z **decays**

5 CP **violation in the quark sector**

5.1 The γ **angle measurement with** $B_s \to D_s^{\pm}K^{\mp}$

5.2 Search for CP **violation in neutral** B **meson mixings**

5.3 Perspectives for the CKM global fit

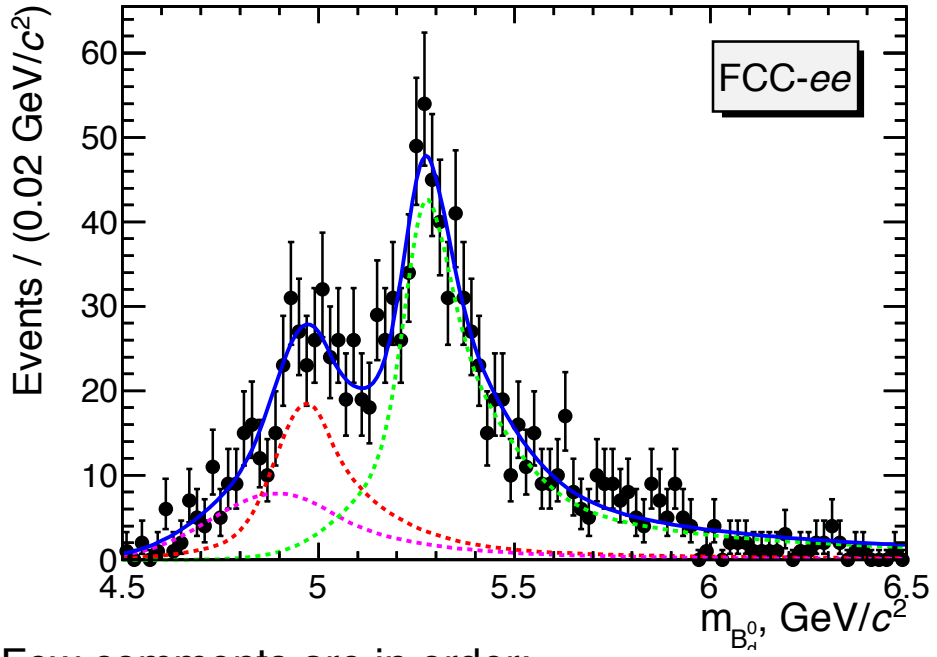
5.4 Perspectives for the search for BSM Physics in $\Delta F = 2$ **transitions CKM global fit**

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 - $B^0 \to K^{*0}\ \tau^+\tau^-$

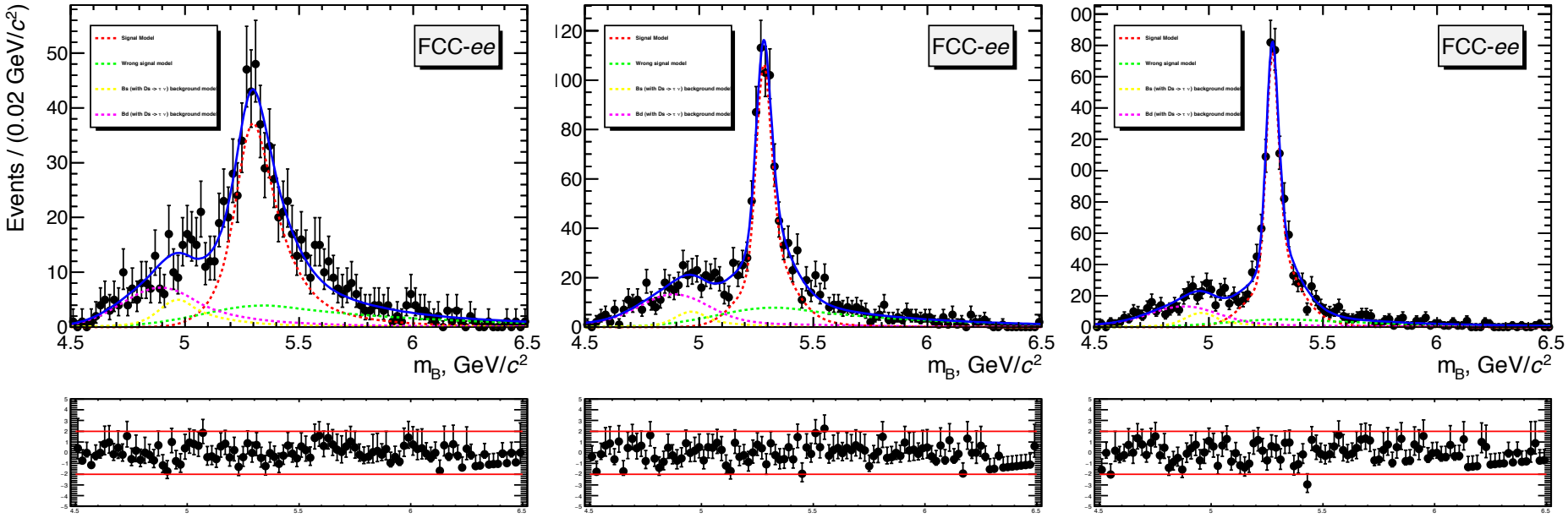
- Makes use of partial reconstruction technique to solve the kinematics of the decay. Sensitivity relies on vertexing performance
- Backgrounds: (pink) and (red) (signal in green).
- Conditions: baseline luminosity, SM calculations of signal and background BF, vertexing and tracking performance as ILD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



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 $B_s \to \tau^+\tau^-$ (Marseille - tuples with the same parametric detector have been produced).

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



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 - $B^0 \to K^{*0}\ \tau^+\tau^-$

- 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

$$\mathcal{B}(Z \to e^{\pm}\mu^{\mp}) \sim \mathcal{B}(Z \to e^{\pm}\tau^{\mp}) \sim 10^{-54} \text{ and } \mathcal{B}(Z \to \mu^{\pm}\tau^{\mp}) \sim 4.10^{-60}$$

- Any observation of such a decay would be an indisputable evidence for New Physics.

- Current limits at the level of ~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 $Z \to \tau^+\tau^-$
  - The SM $Z \to l^+l^-$ ($l \to W^*\nu$ and $W^* \to \tau\ \nu$)

- Following Mogens Dam's study reported here :

The SM process $Z \to \tau^+\tau^-$ 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 $B_s \rightarrow D_sK$. 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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