Overview of the Flavours Physics group activities

J. F. Kamenik,
Jozef Stefan Institute
&
S. Monteil,
Université Blaise Pascal – LPC-IN2P3-CNRS,

Outline of the talk

- Scope of the Flavour Physics working (WG6).
- The definition of the benchmark modes.
- Physics Work Packages for WG6.
- Lepton Flavour Violating Z decays as one example of realisation.

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.

0. Scope of the Flavour Physics working

- Some references related to WG6:

- Foreseeable landscape of Flavour Physics after LHCb upgrade and Belle II experiment: follow this link.

- Thoughts on the flavour Physics benchmark modes: follow this link.

- The kick-off meeting of the WG6 was held the 3rd of September with the main objective to examine critically that Physics Case. A typical audience of ~20 participants, mostly on the phenomenology side. Some of the conclusions given inline in this talk. Link to the agenda.

1. The definition of the benchmark modes.

- There are two main dedicated flavour (mostly *b*) physics (FP) experiments to be operated in the HEP landscape of 2020.

- 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.

- 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.

- The latter highs and lows define a path to complete the picture in the event nothing new is observed meanwhile. And there are more flavour subjects with intrinsic interest for FCC-*ee*.

1. The definition of the benchmark modes.

- A possible/appealing realm for FCC-*ee* in the classic flavours is therefore provided by the following quadriptych 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.

- We highlighted one flagship mode for each category in order to build the Physics Work Packages. Disclaimer: this mode is not to be the most appealing one physics-wise.

1. The definition of the benchmark 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.

- 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.

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

- $B_{d,s} \to \gamma\gamma$: theoretically difficult.
- $B_s \to K_S K_S$: *CP* violation studies. Also interesting for downstream tracking of V^0 in general.
- $B \to Xll$: rare FCNC complementing the B_d at *B*-factories.

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

- $B_s \rightarrow \psi\eta'$ *or* $\eta_c\Phi$*:* flavour tagging required for weak mixing phase.
- $B_s \rightarrow D_sK$: PID definitely required to isolate the signal.

4) Lepton Flavour violation processes.

- Direct LFV processes: $Z \rightarrow e\mu, e\tau, \tau\mu$. 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 $\mu \rightarrow e\gamma$ *or* $\tau \rightarrow \mu\gamma$ *etc...*

2. Work Units for Flavours.

- WU4.1: Lepton Flavour Violation studies in $Z \rightarrow e\mu, e\tau, \tau\mu$
  - Institutes: LPC Clermont, LPT Orsay.
  - Proponents: A. Abada, V. De Romeri, S.Monteil, A. Texeira.
  - Goals: a) revisit and complete the phenomenological study relating the observed branching fractions (BF) to the mass of the hypothetical sterile neutrinos. b) estimate the experimental limit

- WU1.2: Angular analysis of the decay mode $B_s \rightarrow \tau\tau$
  - Institutes: Advanced contacts.
  - Proponents:
  - Goals: a) phenomenological study of the angular analysis. b) exploration of partial reconstruction techniques. c) estimate the precision on BF and angular parameters.

- WU3.1: *CP*-violating phases γ and ϕ_s from $B_s \rightarrow D_s K$
  - Institutes: Advanced contacts
  - Proponents:
  - Goals: a) Compare the Physics reach w.r.t. LHCb upgrade result. b) characterize signal yields and background separation in different detector scenarii to evaluate in particular the PID

- Other workpackages are likely to come along the warming-up of the WG activity. In particular, we strongly believe that top and Higgs Flavour Violation studies should bring valuable WG6 inputs to the design study.

- The next working group meeting will be devoted for a part to assess in particular these questions.

3. A focus on LFV studies at the *Z* pole.

- Study the reach of the indirect search of sterile neutrinos through Lepton Flavour Violating *Z* decays.

- SM extended to additional sterile neutrinos (having a non-vanishing mixing with the active states)

$$\mathrm{BR}(Z \to l_1^{\mp} l_2^{\pm}) = \frac{\alpha_W^3}{192\pi^2(1-2\mathrm{s}_\mathrm{W}^2)} \frac{M_Z}{\Gamma_Z} |\mathcal{V}(M_Z^2)|^2 \approx 10^{-6} |\mathcal{V}(M_Z^2)|^2. \quad (17)$$

with the latter form factor embedding the details of the interactions.

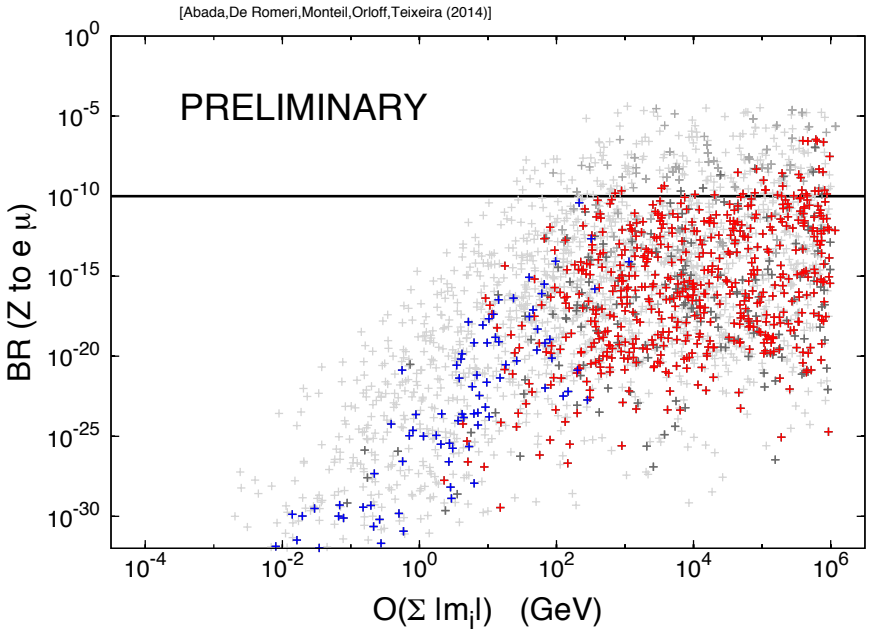
- The BF are predicted with two models being investigated:
  - Inverse Seesaw scenario (w/ 6 additional states).
  - Effective scenario with one additional Majorana neutrino.

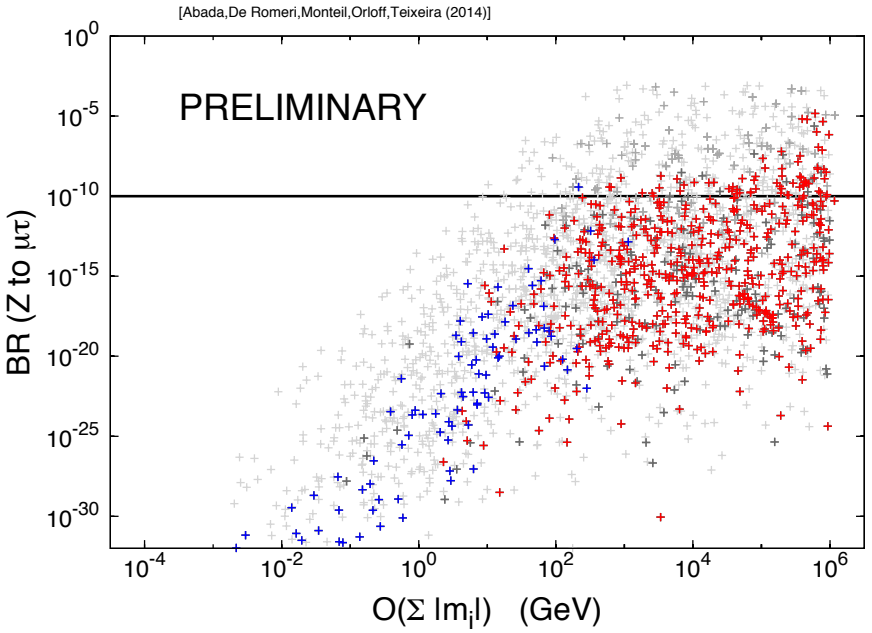
  and compared to the present data constraints.

- Advanced work (on the phenomenological side) with preliminary results, shown in the next couple of slides. Note and paper in preparation.

3. A focus on LFV studies at the *Z* pole.

- Inverse Seesaw scenario



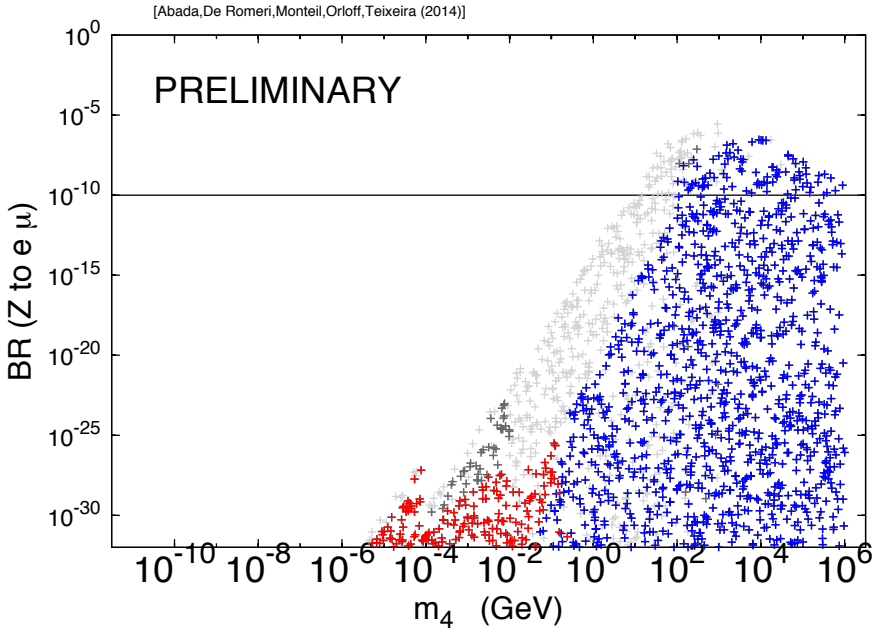


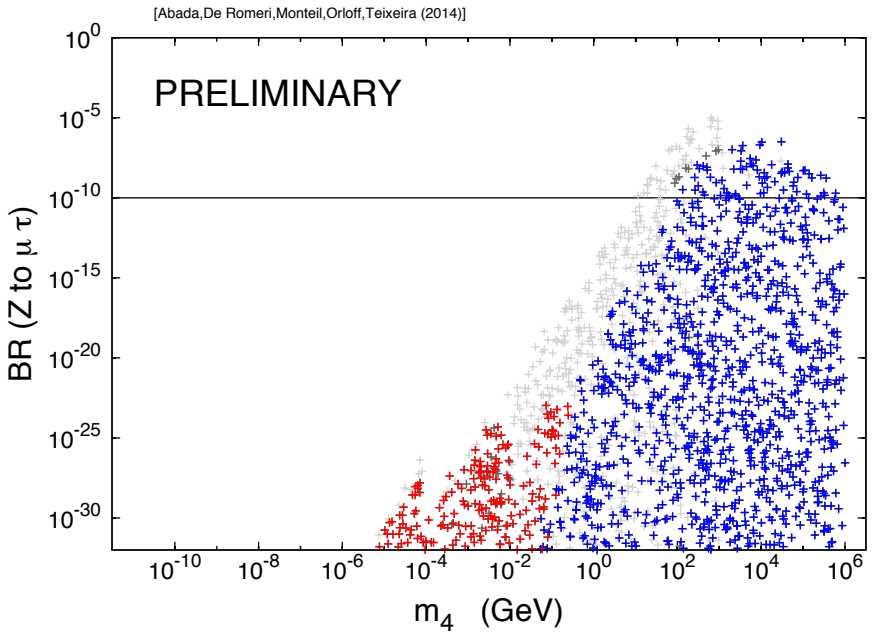
- Colour code for the data constraints (not exhaustive): neutrino oscillation and EW measurements (light grey), leptonic and semileptonic hadron decays (grey), LFV experiments and double beta (dark grey), Cosmology (red).

- The blue points correspond to the realisations of the parameter space not disfavoured by any of the above-mentioned constraints.

3. A focus on LFV studies at the *Z* pole.

- One additional sterile (Majorana)





- Colour code for the data constraints (not exhaustive): neutrino oscillation and EW measurements (light grey), leptonic and semileptonic hadron decays (grey), LFV experiments and double beta (dark grey), Cosmology (red).

- The blue points correspond to the realisations of the parameter space not disfavoured by any of the above-mentioned constraints.

Conclusions

- Initial workpackages have been defined and soon to be advertized on the web page. More to come hopefully in a near future.
- Aim to gather small teams exp/theory on the benchmark modes (to be readjusted as long as the work goes). Secondary aim is to have a platform for thinking beyond standard observables. Please get in touch with us if you're interested.
- A distribution list is set up. You're welcome to join it : *fcc-ee-FlavourPhysics@cern.ch*
- The second meeting will be held in December.
- A twiki page gathers the progresses of the Working Group: *https://twiki.cern.ch/twiki/bin/viewauth/FCC/FCCeeFlavourPhysics*