Summary of the

ECFA FLAV WG1 Activities

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Outline

1. Setting the scene
2. Results highlights
3. Focus topics
4. Report and plans

1) Setting the scene

- Flavour Physics has a vibrant experimental programme for this decade and the next one:

  - Belle II experiment w/ SuperKEKB aiming at 50 /ab, with possible upgrade to 250 /ab,
  - LHCb Upgrade I successfully gathering data these days, 50 /fb,
  - LHCb Upgrade II, proposed and very desirable to make a full exploitation of HL-LHC, targeting 300 /fb

- The Flavour case for the next project has to be examined in the light of the anticipated precisions of these experiments.

- The WG1-FLAV has held four meetings or workshops in the three years of the mandate. Started by reviewing the opportunities at the different e+e- machine.

1) Setting the scene

- Not only a game of numbers; but it requires a high-luminosity Z factory (10^{13} Z, 20 times Belle II statistics) to provide a relevant continuation of the Flavour program:

Attribute	$\Upsilon(4S)$	pp	Z^0
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section		✓	
Negligible trigger losses	✓		✓
Low backgrounds	✓		✓
Initial energy constraint	✓		(✓)

- Yet, one area where expertises among communities can be shared and added are the $|V_{cb}|$ and $|V_{cs}|$ measurement from WW threshold. Dedicated Focussed Topic (FT) as another field of application of Flavour Tagging.

- Another synergetic area: TeraZ and Flavours from the initial FCCee program. Now also a pillar of precision for CEPC (white paper in 2023).

2) Flashing studies — The physics avenues

- Rare semileptonic, leptonic, radiative decays:
  - $b \to s\tau^+\tau^-$, e.g. $B^0 \to K^{*0}\ \tau^+\tau^-$ (Vertex Detector requirements)
  - $b \to s\nu\nu$, e.g. $B_s \to \phi\nu\nu$
  - $B_c \to \tau\nu$; $b \to s(d)\ \ell\ell$, [$Bs \to \phi\mu\mu$ here]; $b \to s,d\ \gamma$ (Calo det. req.);

- CKM profile and *CP* violation studies:
  - The CKM γ angle, e.g. $B_s \to D_sK$; semileptonic asymmetries (*CP* breaking in mixing).
  - The CKM α angle, e.g. $B^0 \to \pi^0\pi^0$ (Calo detector requirements)
  - The matrix elements V_{ub} ($B^+ \to \tau^+\nu$) and V_{cb}, V_{cs} w/ *WW*

- Tau Physics:
  - Lepton flavour violating τ decays
  - Lepton-universality tests in τ decays.

- Charm Physics (opened, but not in time for this WS):
  - The rare decays, e.g. $D \to \pi(\pi)\nu\nu$, $D^0 \to \gamma\gamma$
  - The hadronic decays, $D^0 \to \pi^0\pi^0$, $D^+ \to \pi^+\pi^0$ …

2) Flashing few studies — Tau physics

- Tau Physics: Lepton Flavour Universality

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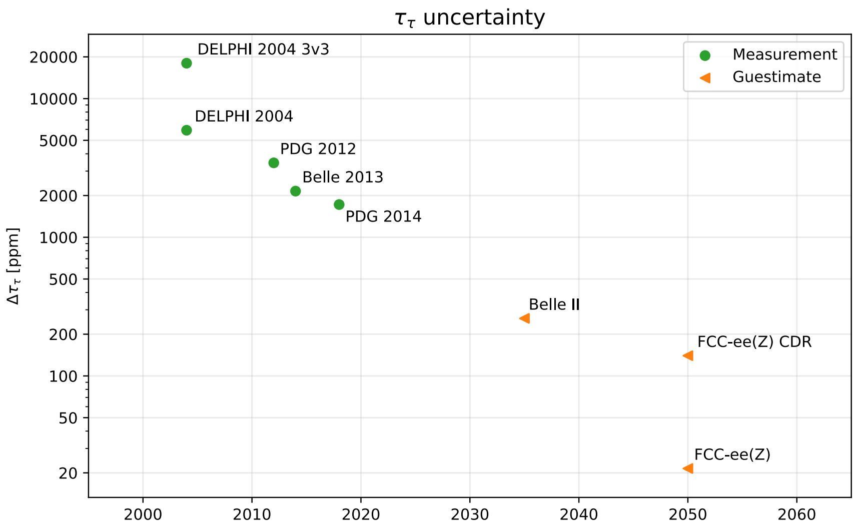
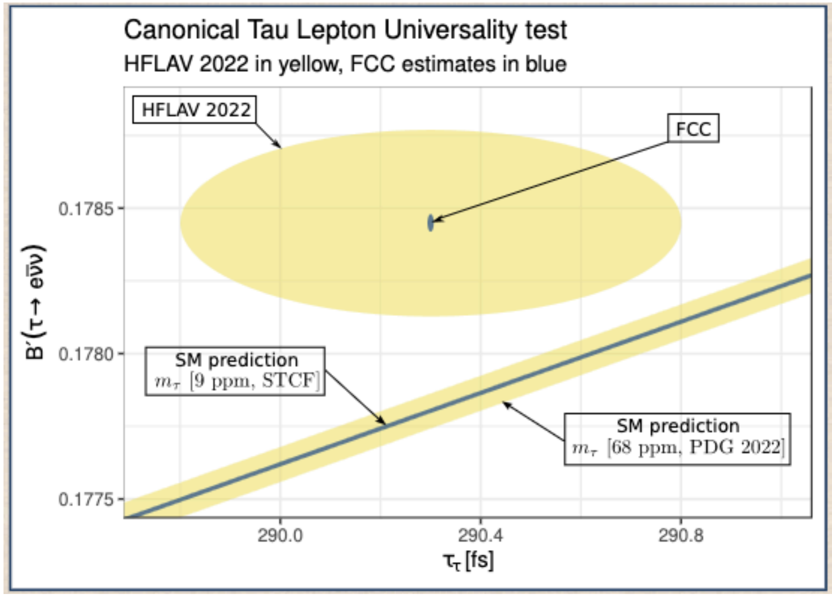


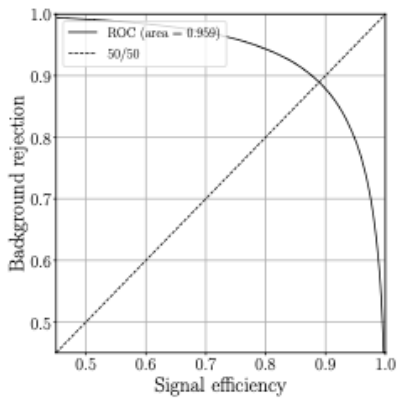


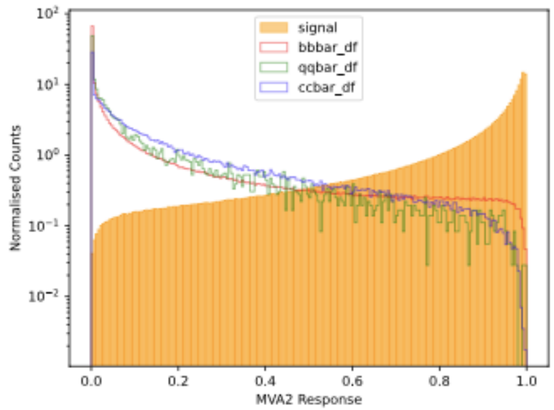
Comment: B-factories did not improve LEP measurements (Belle II did). FCC-ee has better experimental conditions than LEP and about 5× the nominal Belle II tau pairs (and boosted).

Bottomline: lifetime resolution obtained with three-prongs decays. Orders of magnitude improvements w.r.t. the stator the art. Same is true for Lepton-Flavour violating tau decays.

2) Flashing few studies — $b \to s\nu\nu$,

- EWP in the SM, portal to BSM:





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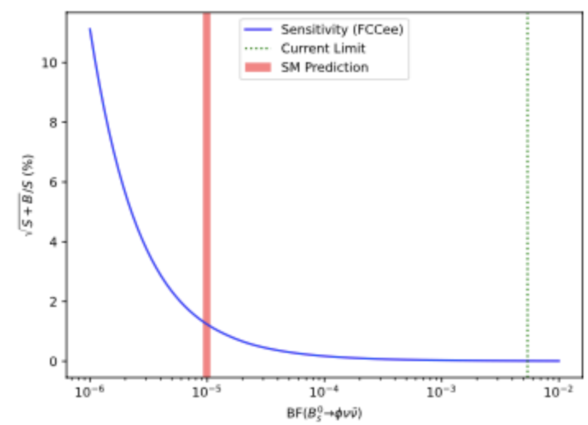
$B_s^0 \to \phi \nu \bar{\nu}$ Efficiency and Sensitivity

First indication of such a transition came from Belle II in 2023

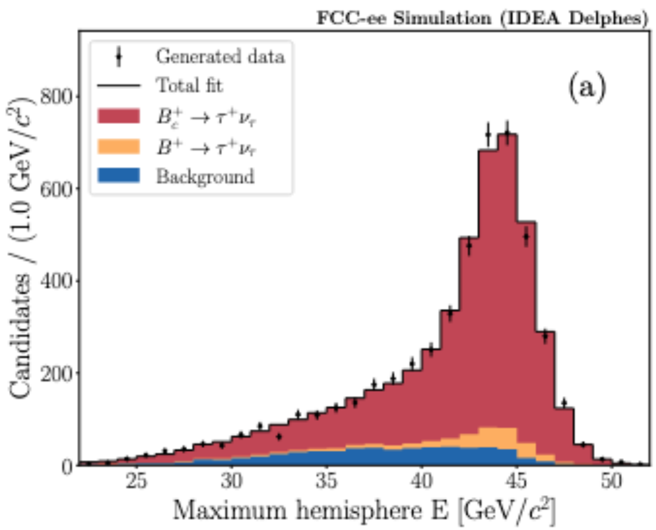
For an optimal BDT1 and BDT2 cut at the SM predicted BF:

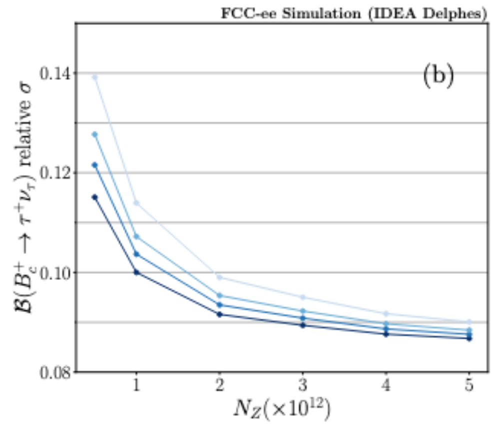
- Signal efficiency $\sim 11\%$
- $b\bar{b}$ efficiency $\sim 10^{-4}\%$
- $c\bar{c}$ efficiency $\sim 10^{-6}\%$
- $q\bar{q}$ efficiency $\sim 10^{-7}\%$
- Signal:Background ratio $\sim 1:9$
- Sensitivity $\sim 1.2\%$



2) Flashing few studies — Leptonic decays

- $B_c \rightarrow \tau^+\nu$: another fundamental test of third generation couplings. Lepton universality in quark transitions. Counterpart of R_{D,D^*}. Reference here [2105.13330, see also 2007.08234]





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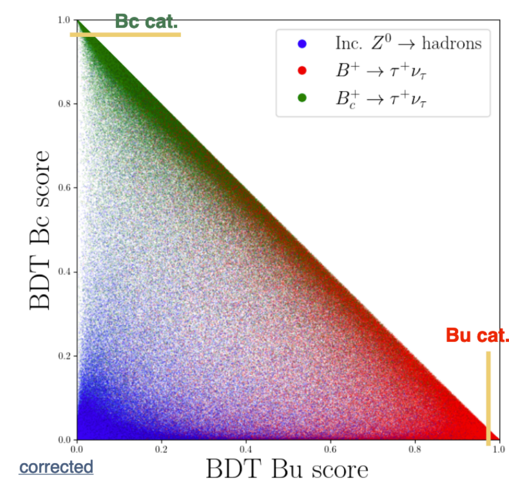
Bottomline: few percent precision mostly limited yet by the knowledge of the normalising BF($J/\psi\mu\nu$).

- $B^+ \rightarrow \tau^+\nu$: access $|V_{ub}|$ with the only knowledge of the decay constant.

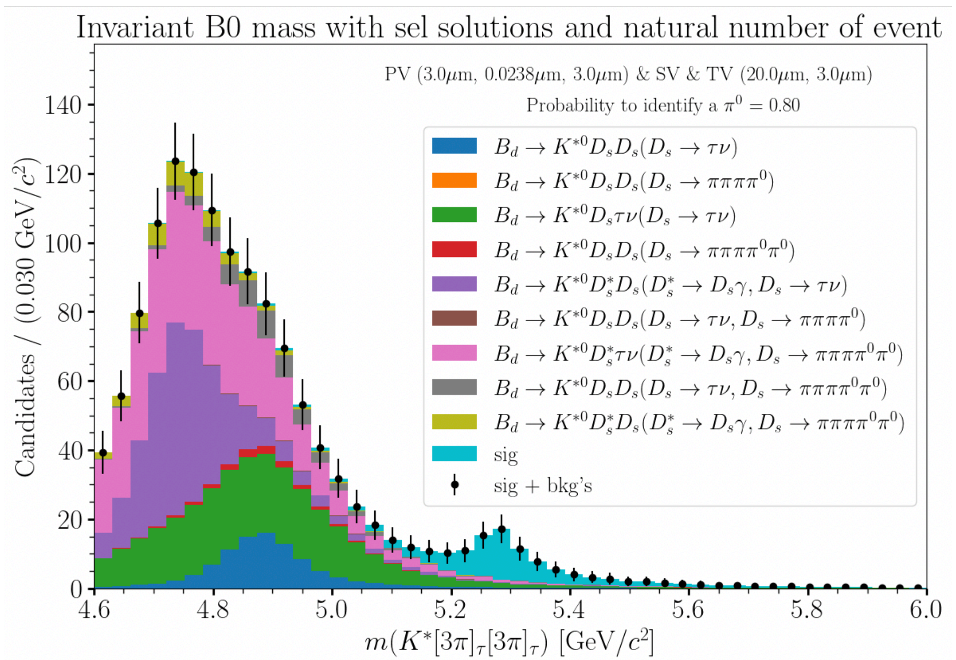
Bottomline: *2305.02998* makes the synthesis of both analyses.

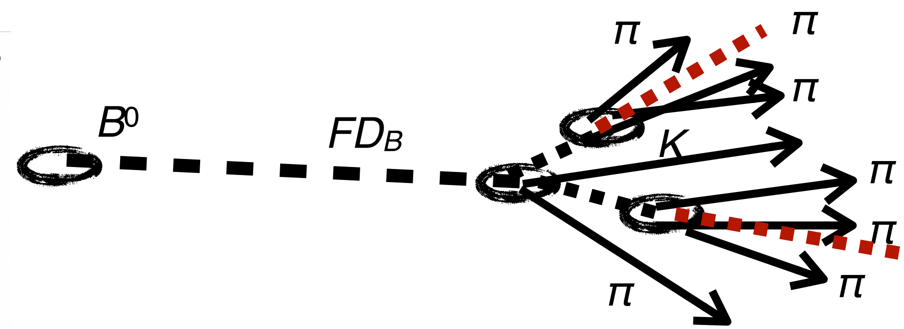


3) A word on focussed topic: $B^0 \to K^{*0}\ \tau^+\tau^-$

- Topological reconstruction + selection

Link to the materials





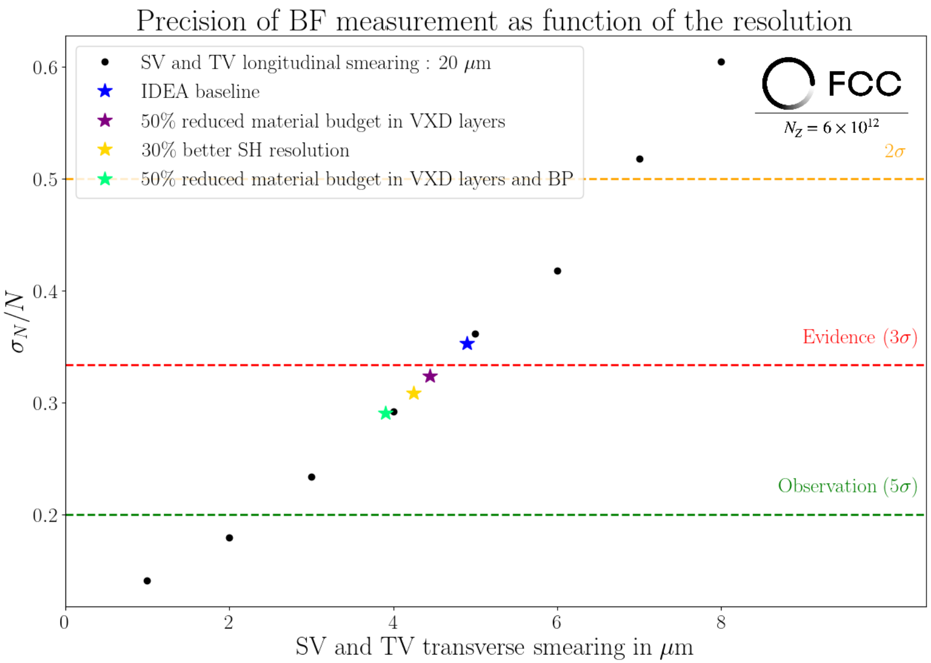
Decay	BF (SM/meas.)	Intermediate decay	BF_had	Additional missing particles
Signal : $B^0 \to K^*\tau\tau$	1.30×10^{-7}	$\tau \to \pi\pi\pi\nu$, $K^* \to K\pi$	9.57×10^{-11}	
Backgrounds $b \to c\bar{c}s$:				
$B^0 \to K^{*0}D_sD_s$	2.78×10^{-4}	$D_s \to \tau\nu$	5.79×10^{-10}	2ν
		$D_s \to \tau\nu, \pi\pi\pi\pi^0$	6.52×10^{-10}	ν , π^0
		$D_s \to \pi\pi\pi\pi^0$	7.35×10^{-10}	$2\pi^0$,
		$D_s \to \tau\nu, \pi\pi\pi\pi^0\pi^0$	5.47×10^{-9}	ν , $2\pi^0$
		$D_s \to \pi\pi\pi 2\pi^0$	5.17×10^{-8}	$4\pi^0$,
$B^0 \to K^{*0}D_sD_s^*$	8.78×10^{-4}	$D_s \to \tau\nu$	1.83×10^{-9}	2ν, γ/π^0
		$D_s \to \pi\pi\pi\pi^0\pi^0$	1.63×10^{-7}	$4\pi^0$, γ/π^0
Backgrounds $b \to c\tau\nu$:				
$B^0 \to K^{*0}D_s\tau\nu$	9.17×10^{-6}	$D_s \to \tau\nu$	3.59×10^{-10}	2ν
$B^0 \to K^{*0}D_s^*\tau\nu$	2.03×10^{-5}	$D_s \to \pi\pi\pi\pi^0\pi^0$	7.51×10^{-9}	$\nu, \gamma, 2\pi^0$

- Emulate different vertexing performance and check out the physics sensitivity.

3) A word on focussed topic: $B^0 \rightarrow K^{*0}\ \tau^+\tau^-$

Link to the materials

- Emulate different vertexing performance and check phys. sensitivity:
  - Then compare with IDEA baseline vertex detector
  - Then adjust performance to see what can be gained



- Lesson: the beam pipe material (0.06%) is the main limitation of the resolution for this physics! [Actually, low momenta pions, multiple Colombian scatterings]. Evocation of several vacua as done in LHCb.

3) A word on focussed topic (FT): CKM*WW (Vcb)*

- See the talk by Uli Einhaus here two days ago about the study.

- Motivations:
  - Longstanding tension b/w exclusive / inclusive decays
  - Limitation of the interpretation of CKM profile

rescaled to SM — Now,

after LHCb-U1 and Belle II — 2030

after LHCb U2 and Belle III — 2040

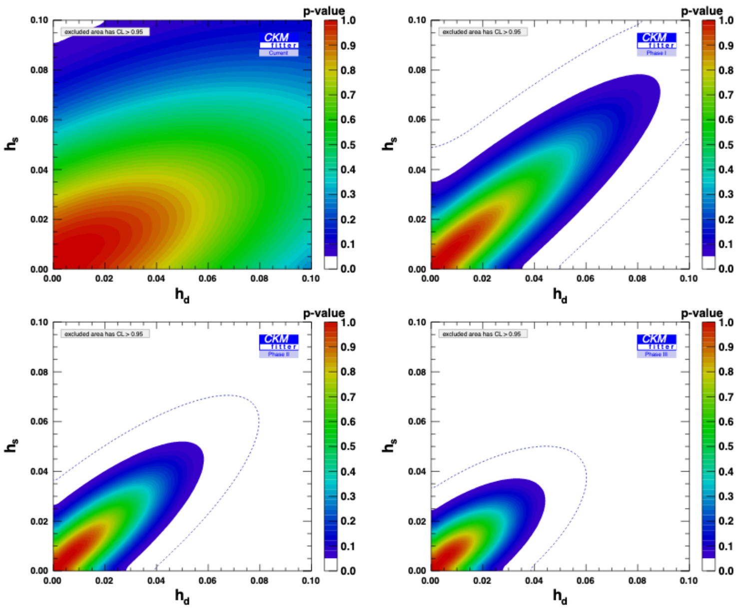


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ) contours.

Bottlenecks:
— Vcb precision (FT).
— LQCD mixing hadr. parameters.

Assessment of the theoretical LQCD precision program in the next decade will make it to the report.

4) Plans and outlook

- Reminder: contributions that did not make it till this WS but are advanced enough: to be posted by October 20th.

- The case for Flavours Physics at high-luminosity circular colliders is made, at the places where the Z pole is unique (missing energy, boosted taus, boosted taus in b decays),

- The opportunity of large W datasets is explored to measure V_{cb}, V_{cs}

- Some detector requirements are placed (vertexing, PID). The calorimetry requirements have to be examined quantitatively.

- The charm physics avenue is currently explored and might come as mature enough to be mentioned. Other avenues are not yet opened, such as spectroscopy, where the exquisite tracking precision and the capacity to measure neutrals shall make marvels.