Introduction to the Flavour & QCD session

mostly based on hep-ex:2106.01259, EPJ+.

Stéphane Monteil,
Clermont University, LPC-IN2P3-CNRS.

Outline

- Flavours@FCC-ee: setting the scene.
- Overview of some studies performed so far (and that will not be discussed today):
  - Rare decays.
  - CKM profile.
  - Tau Physics.
- Outlook.

1) FCC-ee specifics for Flavour Physics.

A- Particle production:

- About 15 times the Belle II anticipated statistics for B^0 and B^+.
- All species of *b*-hadrons are produced.
- Expect ~4.10^9 B_c-mesons assuming $f_{B_c}/(f_{B_u}+f_{B_d}) \sim 3.7 \cdot 10^{-3}$

Working point	Lumi. / IP [10^{34} cm^{-2}.s^{-1}]	Total lumi. (2 IPs)	Run time	Physics goal
Z first phase	100	26 ab^{-1} /year	2	
Z second phase	200	52 ab^{-1} /year	2	150 ab^{-1}

Particle production (10^9)	B^0 / $\overline{B}^0$	B^+ / B^-	B^0_s / $\overline{B}^0_s$	Λ_b / $\overline{\Lambda}_b$	$c\overline{c}$	τ^-/τ^+
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-*ee*	300	300	80	80	600	150

1) FCC-ee specifics for Flavour Physics.

B- The Boost at the *Z*:

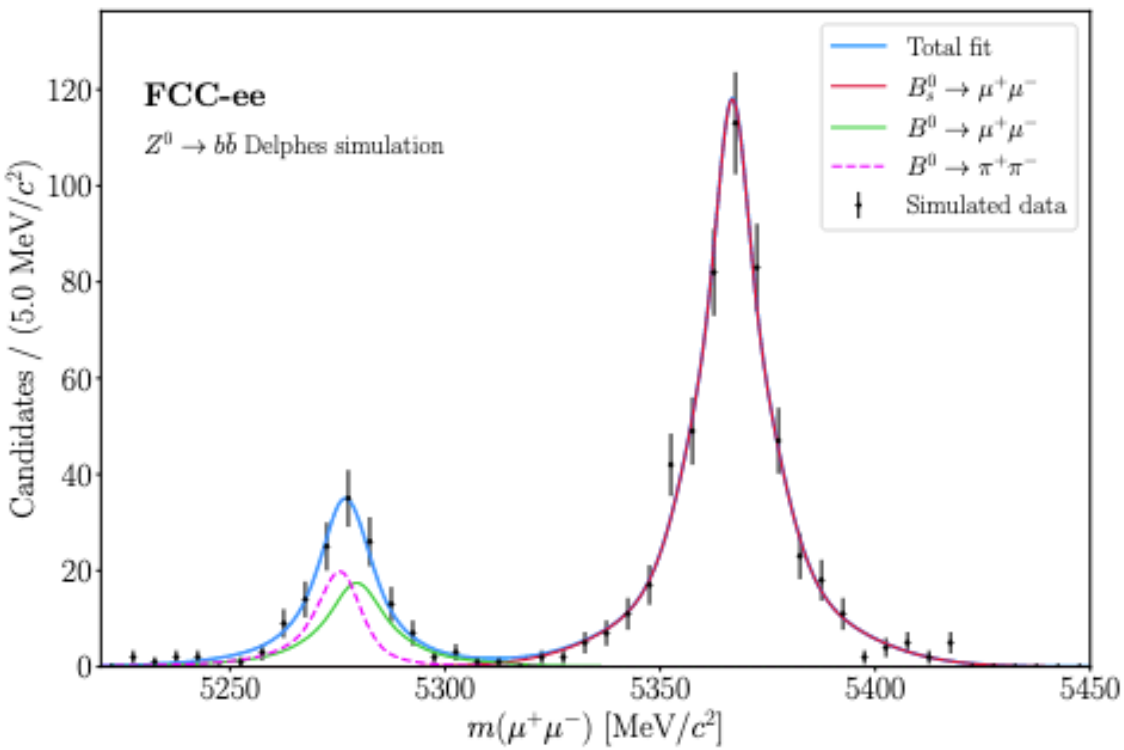
- Fragmentation of the *b*-quark: $\langle E_{X_b} \rangle = 75\% \times E_{\text{beam}}; \langle \beta\gamma \rangle \sim 6.$
- Makes possible a topological rec. of the decays w/ miss. energy.

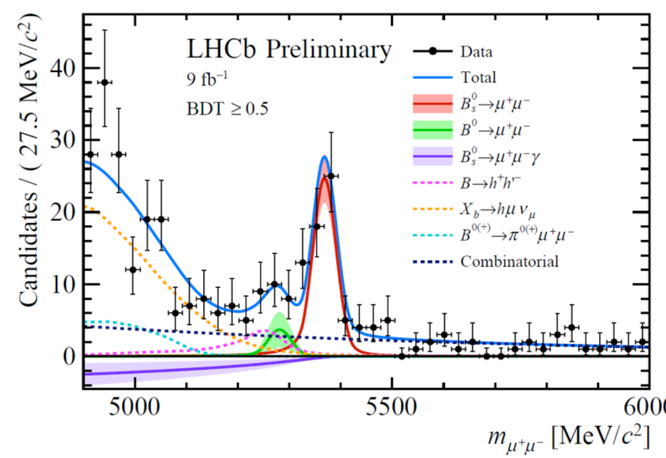
C- Comparison w/ LHCb and Belle II. Advantageous attributes:

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

1) FCC-ee specifics for Flavour Physics.

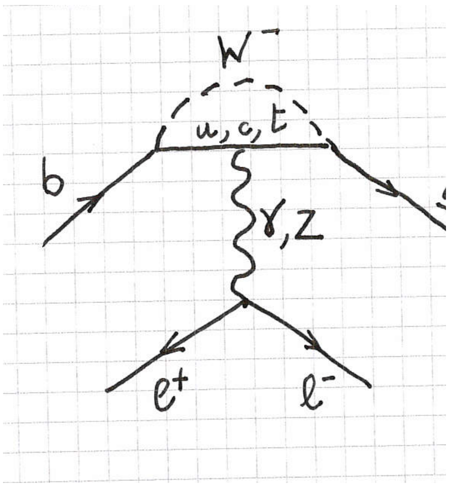
D- Detector performance: exquisite tracking is necessary and at reach.
Invariant-mass resolution as it is in the current state of fast simulation:

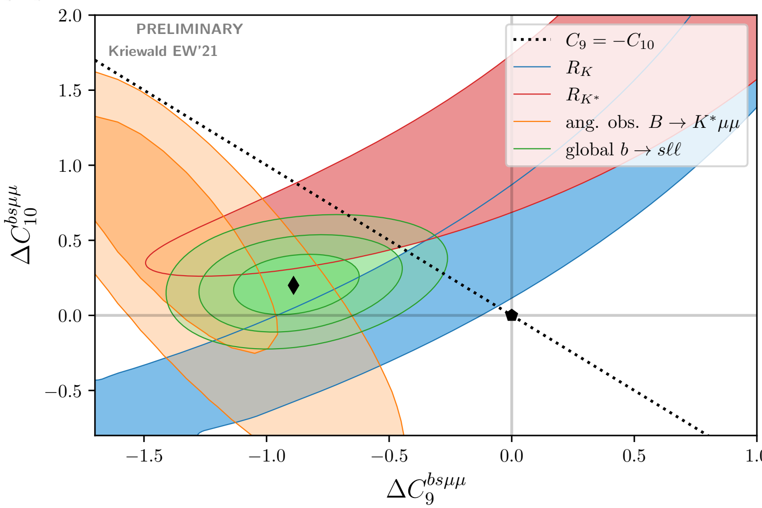


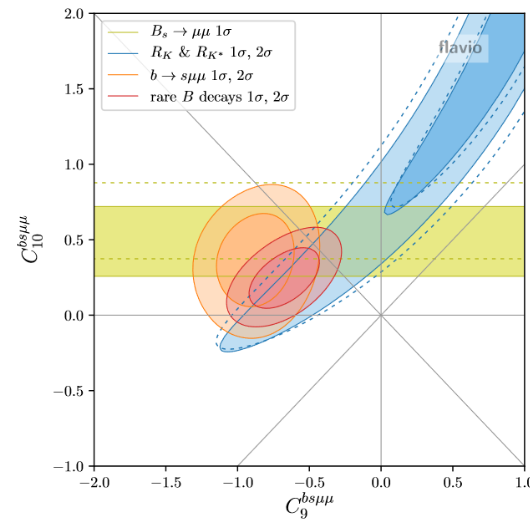


Ultra-high resolution calorimetry and vertexing are in addition highly desirable. Performance to be determined in the Feasibility Study Phase.

2) Overview of the studies: Rare decays & Friends







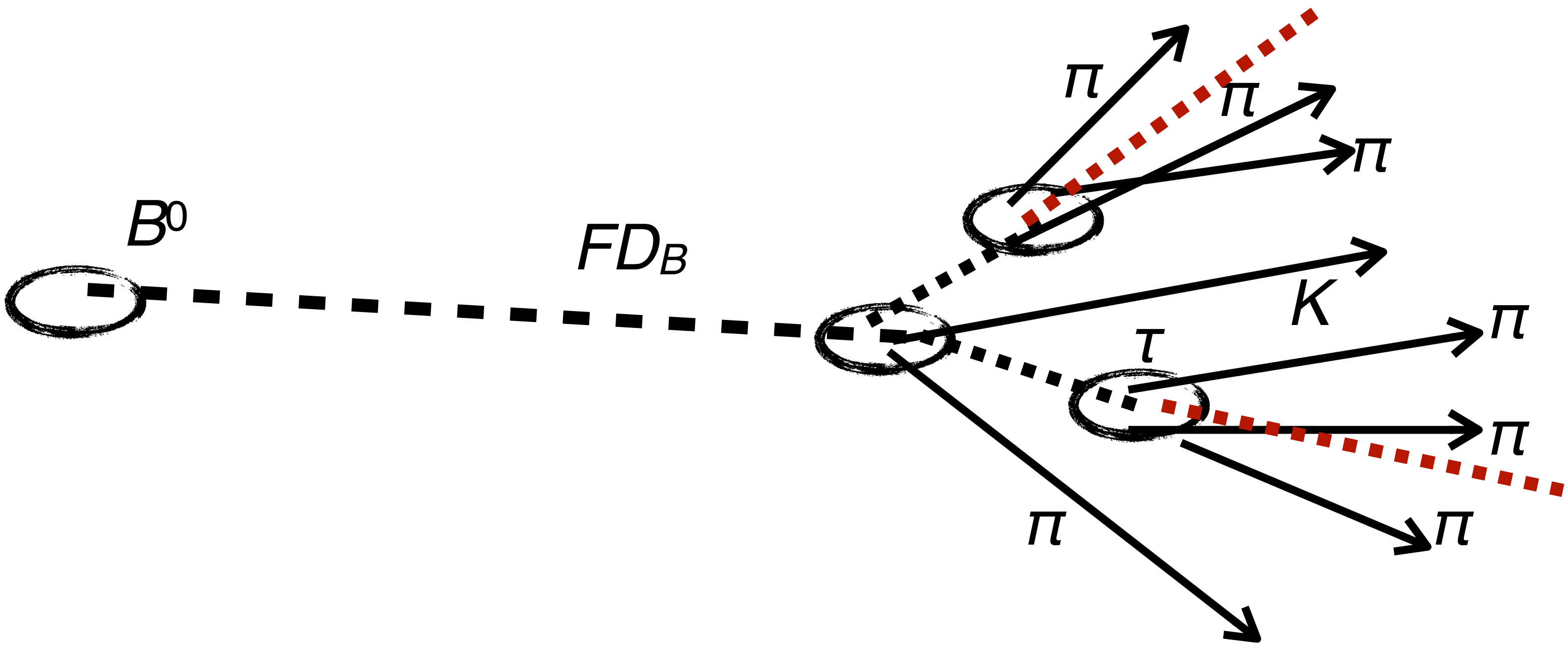
- Multiple global fits in the literature (I picked here 2012.13241 and arXiv:2103.13370, many others around). Significance of the departure with SM flirts with 5 standard deviations.

- They all tell the same: the anomalies provide a consistent pattern and require a modification of the SM C_9.

- How to go further with indirect measurements ? Final states with tau lepton is a promising way forward. FCC-ee likely unique to address these searches. Two flashed here Bc2taunu and b2stautau.

2) Overview of the studies: Rare decays & Friends

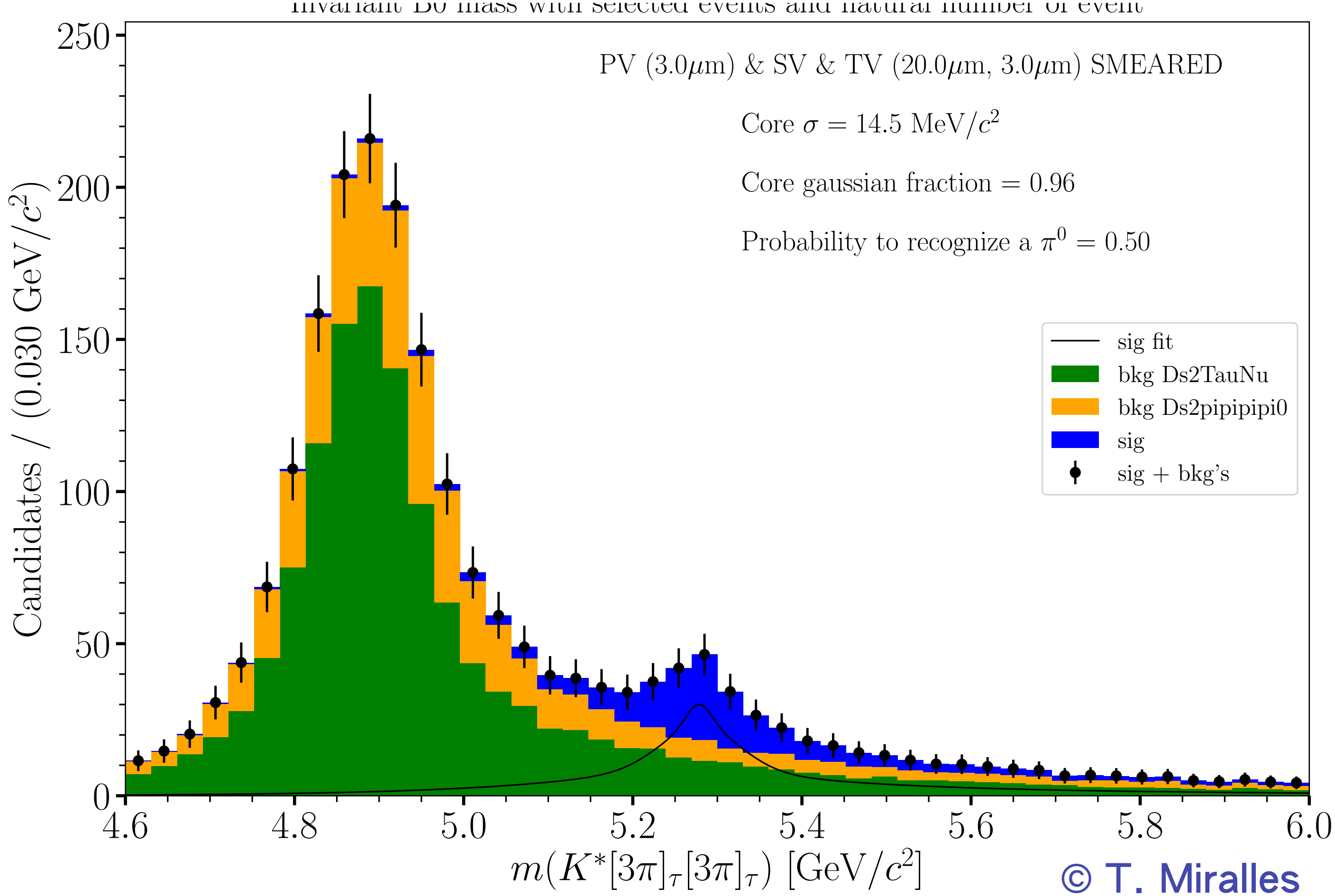
- $B^0 \to K^{*0}\ \tau^+\tau^-$.



- Six momentum components to be searched for:
  - B^0 momentum direction from $K\pi$ fixes 2 d.o.f.
  - τ momenta direction fixes 4 d.o.f.
  - Mass of the τ provides 2 additional constraints
  - The system is in principle over-constrained.

2) Overview of the studies: Rare decays & Friends

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



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2) Overview of the studies: Rare decays & Friends

- $B^0 \rightarrow K^{*0}\ \tau^+\tau^-$: executive summary

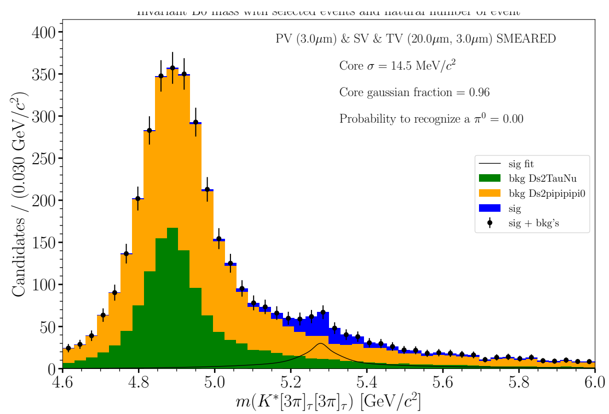
- IDEA Delphes card.

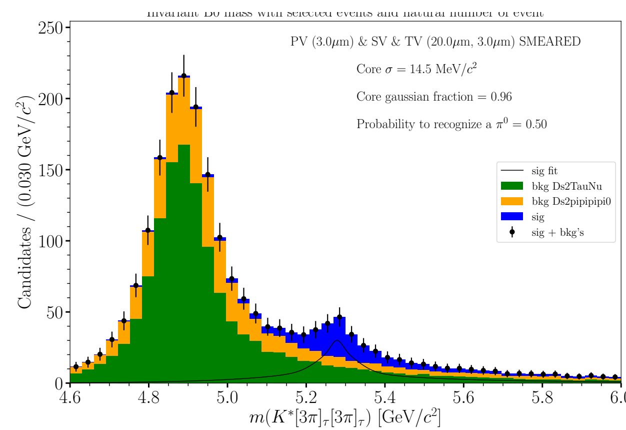
- Vertexing performance from smearing: allows to assess the required performance.

- Study w/ background has started. No selection cut yet beyond the topological reconstruction efficiency (note ALEPH pi0 reconstruction eff. for the time being).

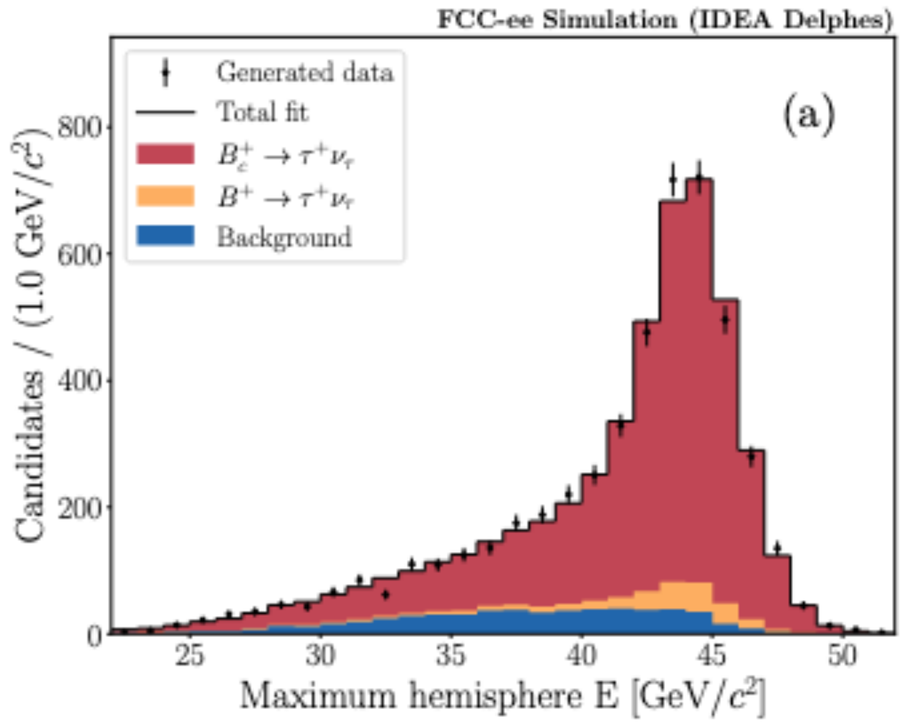
- O(200) events at SM value.

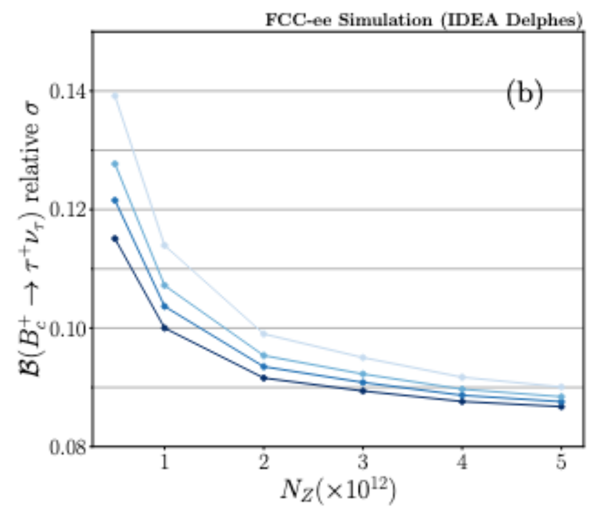
- Outlook: actual vertex detector geometries to be assessed.





- $B_c \to \tau^+\nu$: another fundamental test of lepton universality. Counterpart of R_{D,D^*}. A promising study lies here [hep-ex:2007.08234]

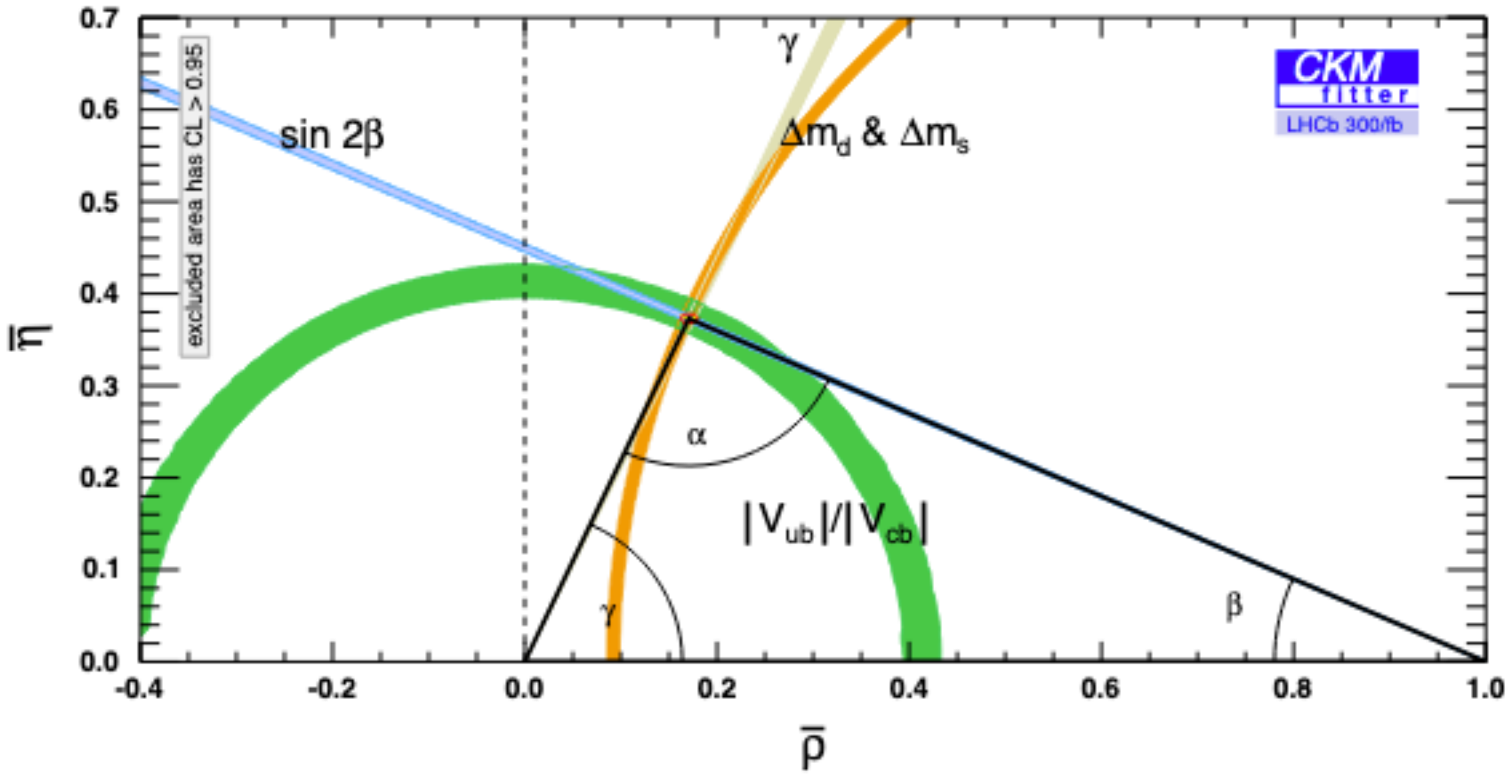




Bottomline: few percent precision mostly limited by the knowledge of the BF Bu2JPsimunu.

2) Overview of the studies: CKM profile & Friends

- The possible status of the CKM profile in the late 2030s (LQCD expected improvements in; LHCb-biased view)



- Belle II will add up to this.

2) Overview of the studies: CKM profile & Friends

- Another projection is the model-independent search for BSM CPV phases in mixing processes

hep-ph 2006.04824

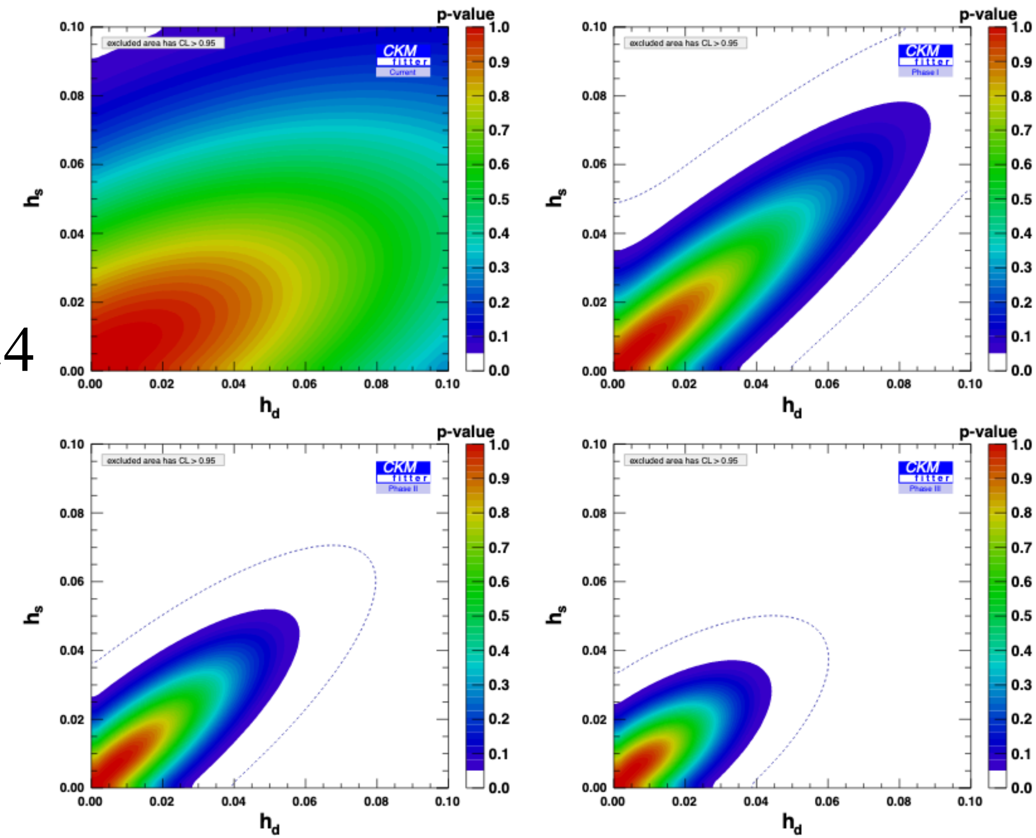


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

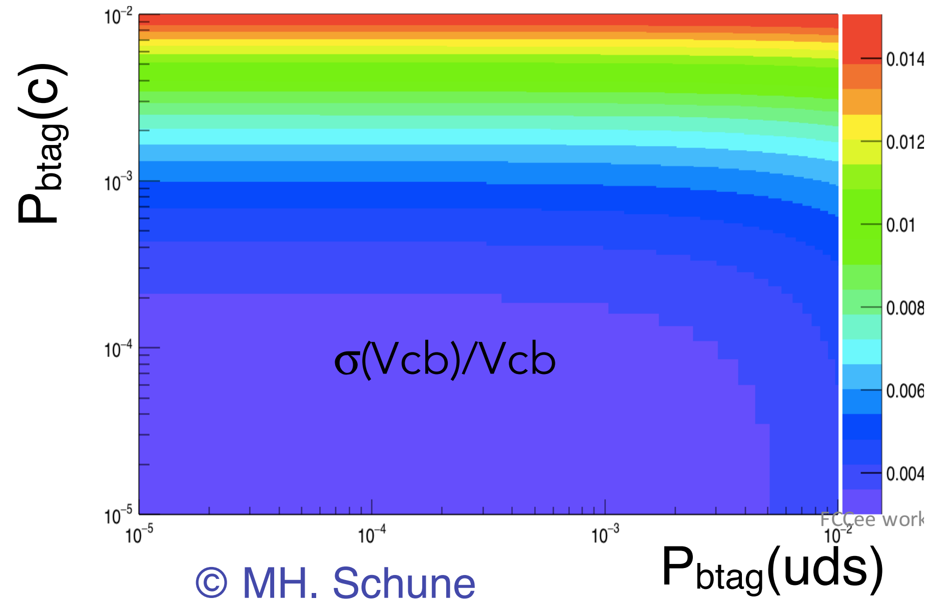
- Bottleneck in precision: Vcb and LQCD mixing parameters.

2) Overview of the studies: CKM profile & Friends

- $|V_{cb}|$ measurement: the WW threshold. First look here.

Eff. \ *q*-jet	*b*-jet	*c*-jet	*uds*-jet
b-tag	25 %		
c-tag	10 %	50 %	2 %

- Numbers picked from *Tracking and Vertexing at Future Linear Colliders: Applications in Flavour Tagging* — Tomohiko Tanabe. ILD@ILC. IAS Program on High Energy Physics 2017, HKUST



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- With these state-of-the-art inputs, precision on $|V_{cb}|$ improves from 1.9% (current) to 0.4%. Ultimate statistical precision is $O(10^{-4})$.

- Actual study in order. A driver for the *b*- and *c*- tagging performance.

2) Overview of the studies: CKM profile & Friends

- Sub-degree gamma angle measurement at reach :

Measurement of CP violation with $B_s \rightarrow D_s K$

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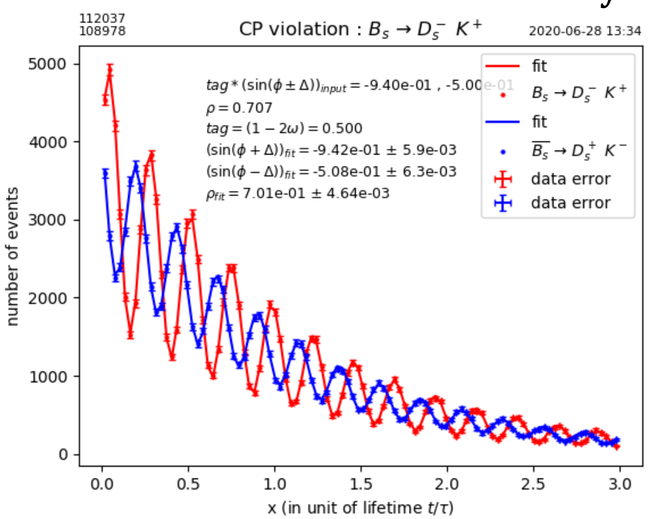
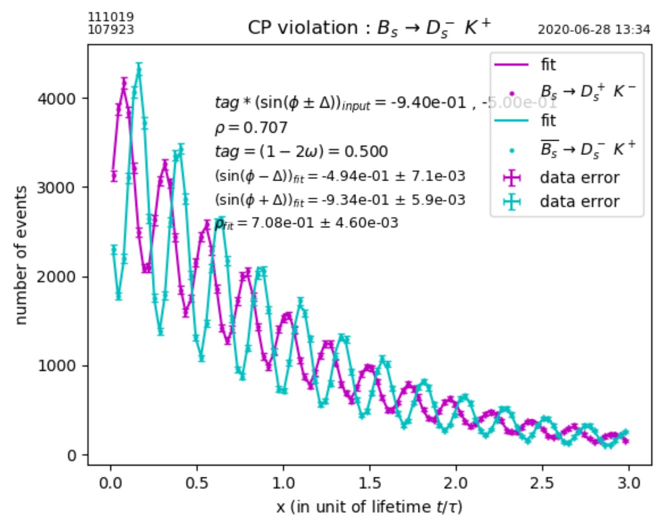
$$\int Ldt = 150\ ab^{-1}$$

PDG: $\gamma = (71.1^{+4.6}_{-5.3})^\circ$





Result 3 :

$\delta(\rho) \approx 3.2 \times 10^{-3}(stat.)$

$\delta(sin^2\phi_{CKM}) \approx \delta(sin^2\gamma) \approx 5 \times 10^{-3}(stat.) \cong \delta(\gamma) \approx 0.4^\circ\ (stat.)$

Potential statistical gain of factor 4-5 with $D_s^\pm \rightarrow K^{*0}K^\pm, \phi\rho^\pm$, ... but background needs to be studied (see later)+
Additionnal potential gain (another factor ~2) with $B_s \rightarrow D_s^{*\pm}K^\mp, D_s^\pm K^{*\mp}, D_s^{*\pm}K^{*\mp}$, most modes including γ(s)

- Several null tests of the SM accessible (more today).

2) Overview of the studies: Tau lepton physics

- Touched so far through the lepton universality studies and Lepton Flavour violating decays (LFV Z and tau directly).

Observable	Measurement	Current precision	FCC-ee stat.	Possible syst.	Challenge
m_τ [MeV]	Threshold / inv. mass endpoint	1776.86 ± 0.12	0.004	0.04 (?)	Mass scale
τ_τ [fs]	Flight distance	290.3 ± 0.5 fs	0.001	0.04	Vertex detector alignment
$B(\tau \to e\nu\nu)$ [%]	Selection of $\tau^+\tau^-$, identification of final state	17.82 ± 0.05	0.0001	0.003	Efficiency, bkg, Particle ID
$B(\tau \to \mu\nu\nu)$ [%]		17.39 ± 0.05			

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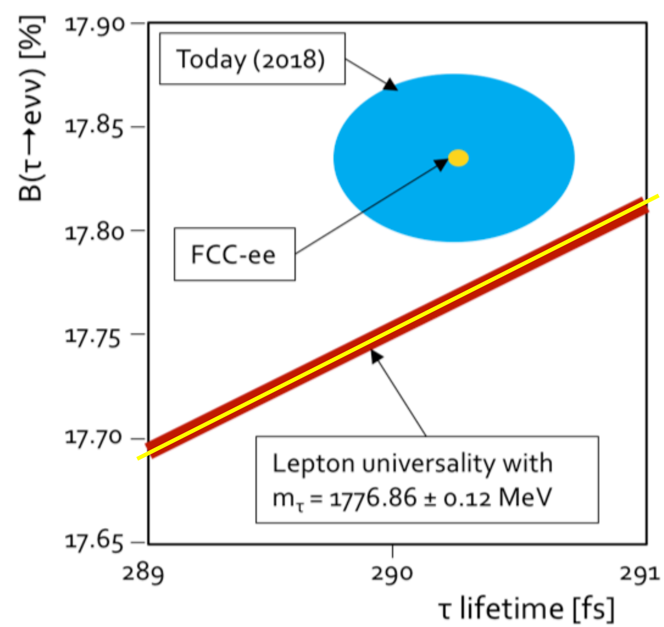
Necessary ingredients:

- Mass
- Lifetime
- Leptonic branching fractions



2) Overview of the studies: Tau lepton physics

- A non-exhaustive Tau Physics advantages and prospects :
  - About 200 billions of tau pairs at the Z
  - About 3 times the Belle II anticipated statistics but with a 25 boost !
  - Beyond EWPO (polarisation), stringent lepton universality tests. Global improvement can be two orders of magnitude w.r.t. state of the art.
  - Three orders of magnitude w.r.t. state of the art in sensitivity for LFV Z decays. One order of magnitude for actual LFV tau decays.
  - Hadronic branching fractions, spectral functions, strong coupling constant: the QCD program with tau is rich.

3) Outlook

- Flavour Physics defines shared (vertexing, tracking, calorimetry) and specific (hadronic PID) detector requirements. The feasibility study entangles the Physics performance and detector concepts.

- A lot to be done to go beyond exploratory studies.

11:40 → 12:45 **Heavy Flavour, Taus, and QCD: Physics and Detector Contraints**

Président de session: Stephane Monteil (Laboratoire de Physique de Clermont - UCA/IN2P3)

11:40 **Introduction to the Heavy Flavour, Tau and QCD session**

Orateur: Stephane Monteil (Laboratoire de Physique de Clermont - UCA/IN2P3)

11:50 **CP violation and determination of the bs "flat" unitarity triangle at FCCee** ¶

Orateur: Emmanuel PEREZ (CERN)

12:10 **Study of a rare Heavy Flavour particle decay at FCC-ee including tau particles in the Final State**

Orateur: Tristan Miralles

12:30 **Perspectives for high-precision αS(mZ^2) determinations @ FCC-ee**

Orateur: Luc Poggioli (LPNHE Paris)