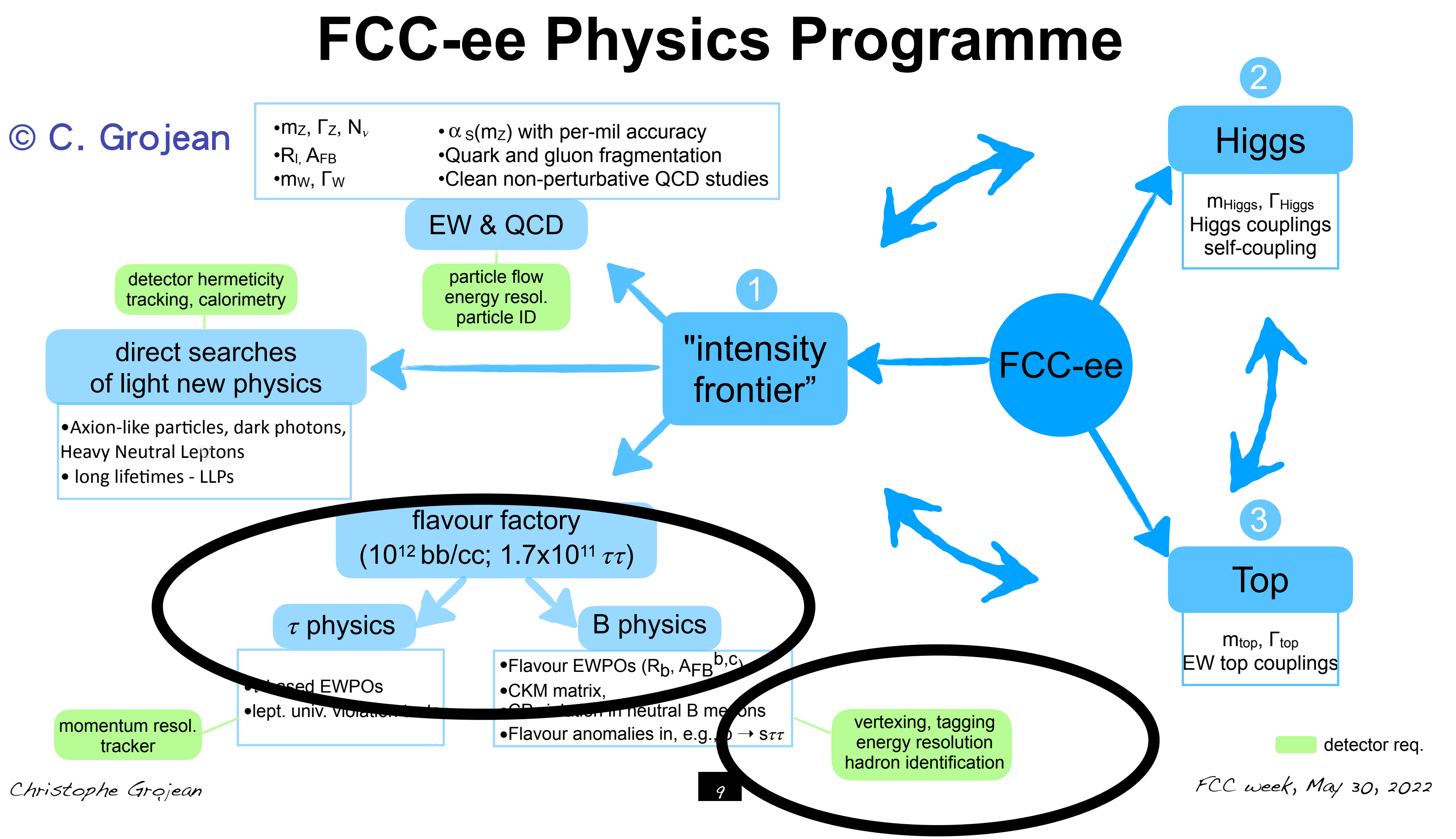
Review of Flavour-related activities at FCC-ee (and ECFA)

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

Outline

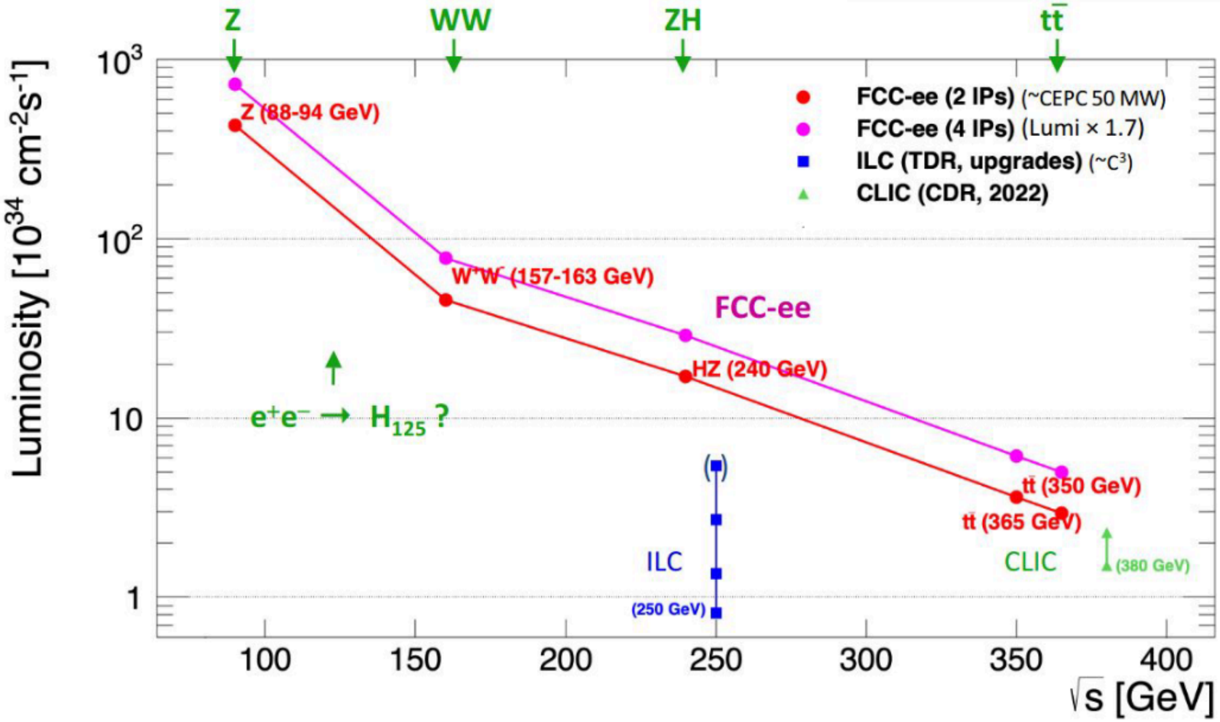
1. FCC-ee physics programme
2. Flavours@FCC-ee: setting the scene
3. Review of current activities
4. Connection to the ECFA Study
5. Connecting the dots: Flavours, EWPO@Z and top
6. Summary

1. FCC-ee machine and expts — executive summary



- Probable imo that Flavour Physics requirements are the most demanding.

1. FCC-ee operation



- We‘re speaking of 10^5 *Z*/s , 10^4 *W*/h, 1.5 10^3 *H* and top /d, in a very clean environment: no pile-up, controlled beam backgrounds, *E* and *p* constraints, ~w/o trigger loss.

- In particular, you do the LEP in a minute! Some Flavour measurements are still dominated by LEP experiments.

2) FCC-ee ABCD specifics for Flavour Physics.

A- Particle production at the *Z* pole:

- About 15 times the nominal Belle II anticipated statistics for B^0 and B^+.
- All species of *b*-hadrons are produced.

Working point	Z, years 1-2	Z, later	WW, years 1-2	WW, later	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163		240	340–350	365
Lumi/IP ($10^{34}\,\mathrm{cm^{-2}s^{-1}}$)	70	140	10	20	5.0	0.75	1.20
Lumi/year ($\mathrm{ab^{-1}}$)	34	68	4.8	9.6	2.4	0.36	0.58
Run time (year)	2	2	2	–	3	1	4
Number of events	6×10^{12} Z		2.4×10^{8} WW		1.45×10^{6} ZH + 45k WW $\rightarrow$ H	1.9×10^{6} $t\bar{t}$ +330k ZH +80k WW $\rightarrow$ H	

Particle species	B^0	B^-	B_s^0	Λ_b	B_c^+	$c\bar{c}$	$\tau^-\tau^+$
Yield (10^9)	740	740	180	160	3.6	720	200

Table 1: Particle abundances for $6\cdot10^{12}$ Z decays. Charge conjugation is implied.

2) FCC-ee ABCD specifics for Flavour Physics.

B- The Boost at the *Z*: $\langle E_{X_b} \rangle = 75\% \times E_{\rm beam}; \langle \beta\gamma \rangle \sim 6.$

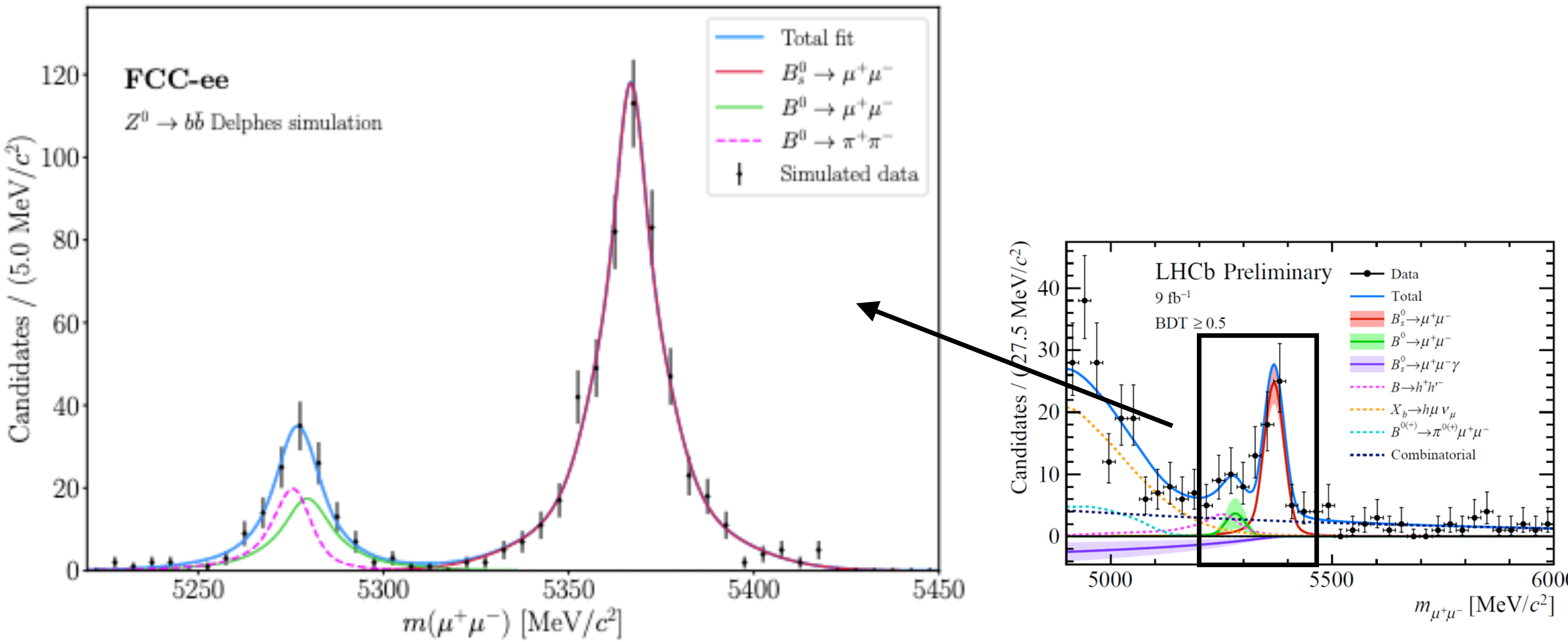
- Fragmentation of the *b*-quark:
- Makes possible a topological rec. of the decays w/ miss. energy.

C- Versatility : the *Z* pole does not saturate all Flavour possibilities. Beyond the obvious flavour-violating Higgs and top decays, the *WW* operation will enable to collect several 10^8 *W* decays on-shell AND boosted. Direct access to CKM matrix elements.

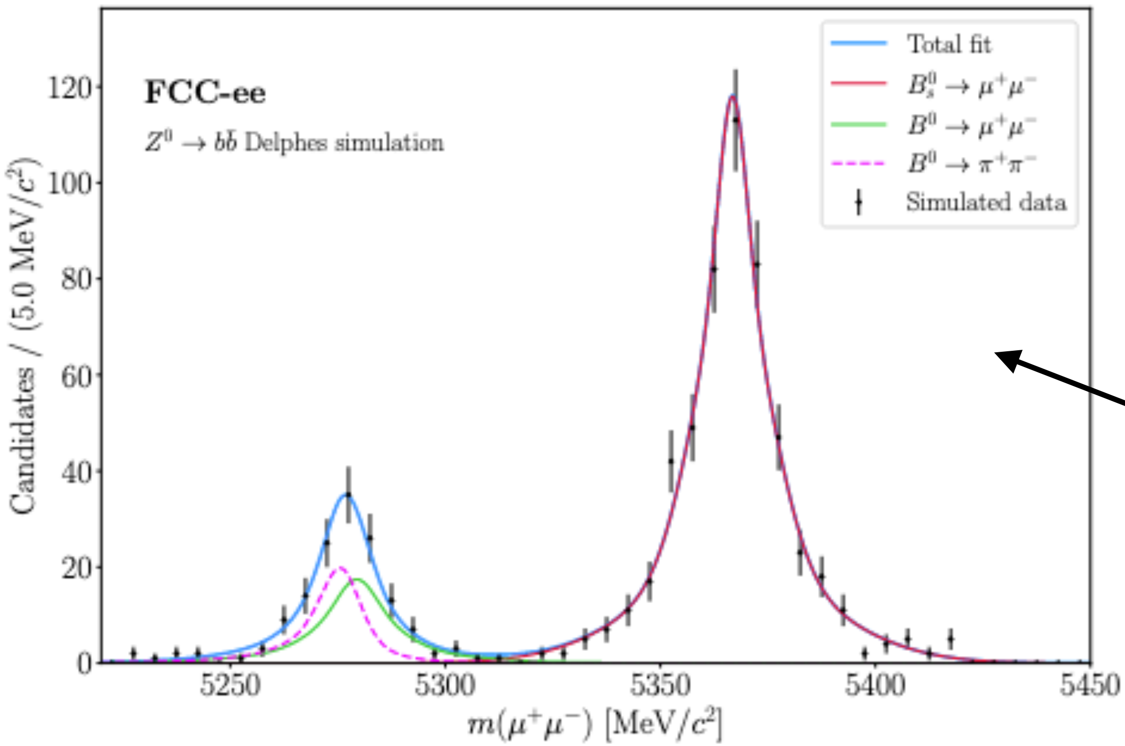
D- Comparison w/ LHC and B-factory. Advantageous attributes:

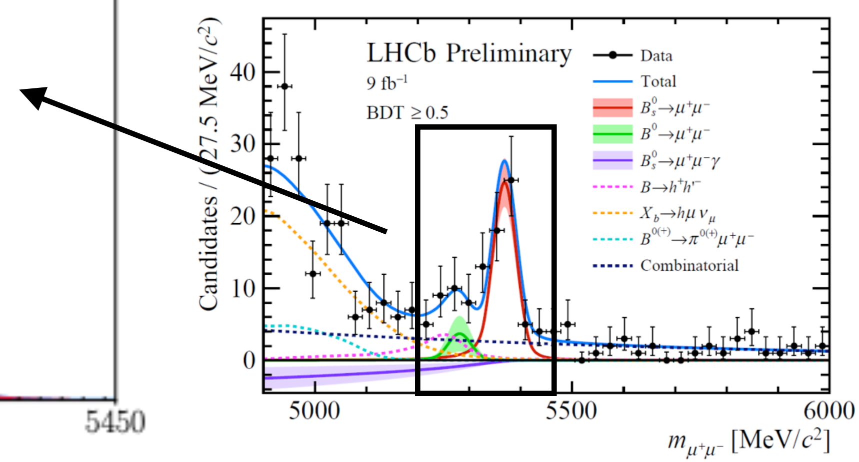
Attribute	$\Upsilon(4S)$	pp	Z^0
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section		✓	
Negligible trigger losses	✓		✓
Low backgrounds	✓		✓
Initial energy constraint	✓		(✓)

2) FCC-ee ABCD specifics for Flavour Physics.



Invariant-mass resolution is a must: exquisite tracking is necessary and at reach. Invariant-mass resolution as it is in the current state of IDEA fast simulation:





Seems granted w/ state-of-the-art tracker. Ultra-high resolution calorimetry is in addition desirable to touch high performance for modes w/ neutrals

2) FCC-ee ABCD specifics for Flavour Physics.

Final remarks on this chapter -

Advantageous attributes / detector requirements

- The boost of the Z makes the b-flavoured (tau) particles fly ~3 (2) mm on average. Flavour Physics successful if those are resolved with high precision in particular when the mom. of the tracks is low
—> go beyond the state-of-the art.
- *CP* violation studies requires excellent K_S and neutral pions reconstruction. In order to make full advantage of the available statistics, exquisite energy and angular reconstruction in calorimetry
—> go beyond the state-of-the art.
- Hadronic p / K / π Particle identification has to come from the dE/dx (dN/dx) or a Cerenkov detector to fit in front of the ECAL
—> go beyond the state-of-the art.

Four IPs provides opportunities for a flavour-oriented detector concept.

3) Reviews of current activities (Feasibility Study)

- A look back:

  - The Flavour Program was not explored in the very-initial works about FCC-ee (but a mention to tau final states). It is now part of the program on its own right.

  - The case has to be thought of out of the anticipated very-rich experimental landscape at the horizon 2040 : there are LHCb Upgrade 2 (not yet approved but highly desirable — 300 /fb), Belle II (some thoughts about Belle III — 250 /ab) and STFC.

  - The question was: is there a valuable addition to the Flavour physics case that will be developed in the next two decades?

  - The answer is: YES. Focus was put on the study of modes that are likely unique to FCC-ee. It happens in addition that there is no place where FCC-ee does not compete valuably, and hence provides at least a useful comparison.

3) Reviews of current / foreseen activities (Feasibility Study)

- Rare semileptonic decays and leptonic decays:
  - $b \to s\tau^+\tau^-$, e.g. $B^0 \to K^{*0}\ \tau^+\tau^-$. (case for mid-term review)
  - $b \to s\nu\nu$, e.g. $B_s \to \phi\nu\nu$
  - $Bc \to \tau\nu$; $b \to s(d)\ \ell\ell$

- *CP* violation studies:
  - The CKM γ angle, e.g. $B_s \to D_s K$.
  - The semileptonic asymmetries (*CP* breaking in mixing).
  - The CKM α angle, e.g. $B^0 \to (\pi^0\pi^0)$.
  - The matrix elements V_{ub} and V_{cb} ….

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

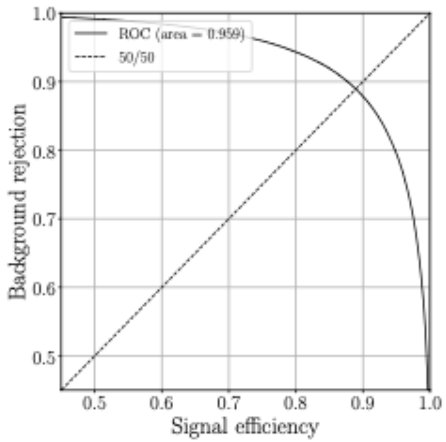
- Charm Physics:
  - The rare decays, e.g. $D \to \pi\nu\nu$, $D^0 \to \gamma\gamma$
  - The hadronic decays, $D^+ \to \pi^+\pi^0$ …

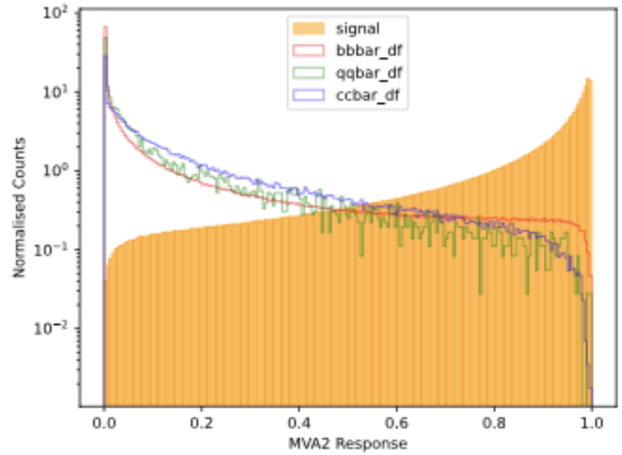
3) Reviews of current / foreseen activities (Feasibility Study)

- I will flash some of the recent studies published and discuss the others in the ECFA-related section of this talk.

3) Reviews of current activities (Feasibility Study)

- Flashing some of the recent studies:





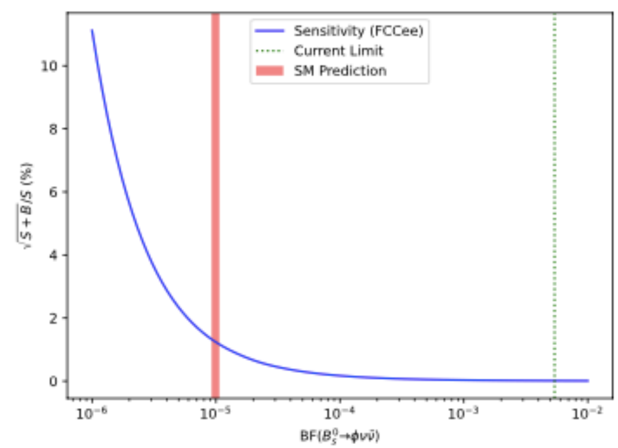
© A. Wiederhold, M. Kenzie
arXiv:2309.11353

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

First indication of such a transition just came from Belle II

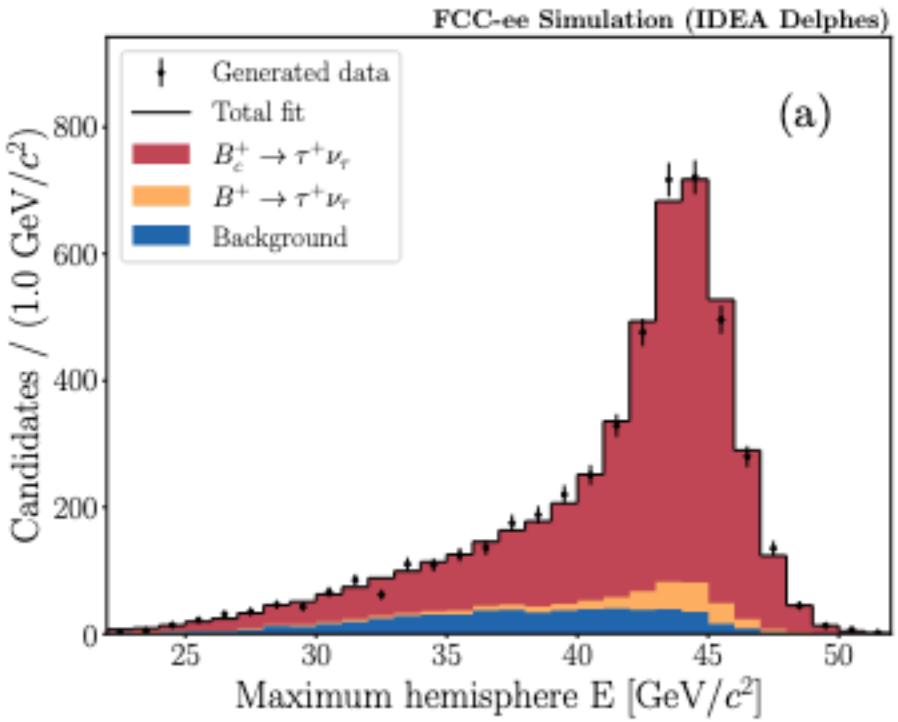
For an optimal BDT1 and BDT2 cut at the SM predicted BF:

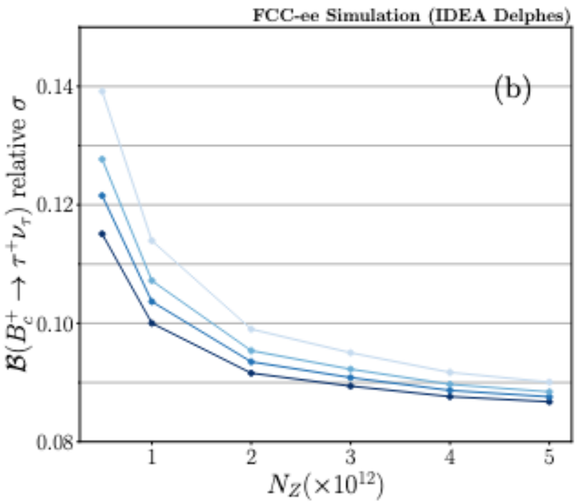
- Signal efficiency $\sim 11\%$
- $b\bar{b}$ efficiency $\sim 10^{-4}\%$
- $c\bar{c}$ efficiency $\sim 10^{-6}\%$
- $q\bar{q}$ efficiency $\sim 10^{-7}\%$
- Signal:Background ratio $\sim 1:9$
- Sensitivity $\sim 1.2\%$



3) Reviews of current activities (Feasibility Study)

- $B_c \to \tau^+\nu$: another fundamental test of lepton universality. Counterpart of R_{D,D^*}. A promising study lies here [2105.13330, see also 2007.08234]



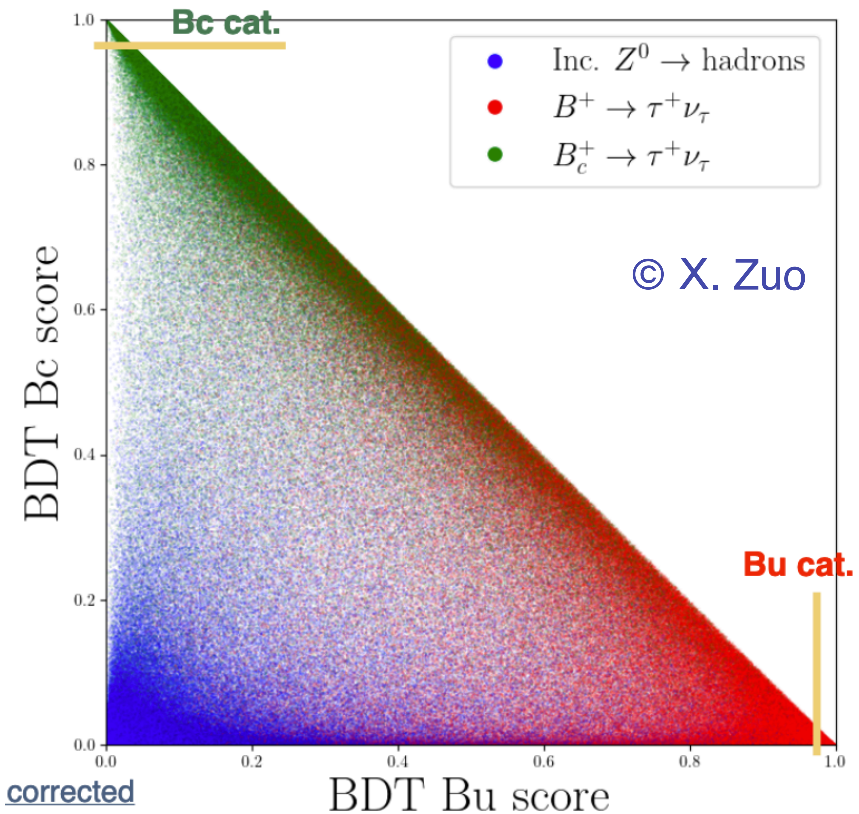


© X. Zuo et al.

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

FCC

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



© X. Zuo et al.

Bottomline: similar yields / purities as for $B_c \rightarrow \tau^+\nu$. A paper out. *arXiv 2305.02998* that makes the synthesis of both analyses.

3) Reviews of current activities (Feasibility Study)

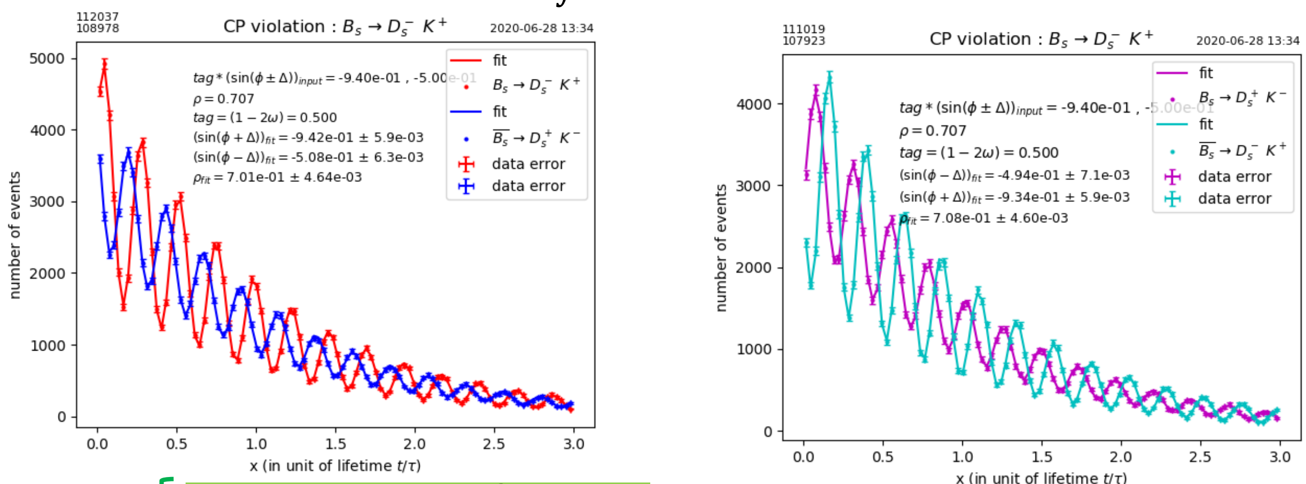
- Sub-degree gamma angle measurement with just one mode :

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

$\int L dt = 150\ ab^{-1}$

PDG: $\gamma = (71.1^{+4.6}_{-5.3})°$

© R. Aleksan



Result 3 :

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

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

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

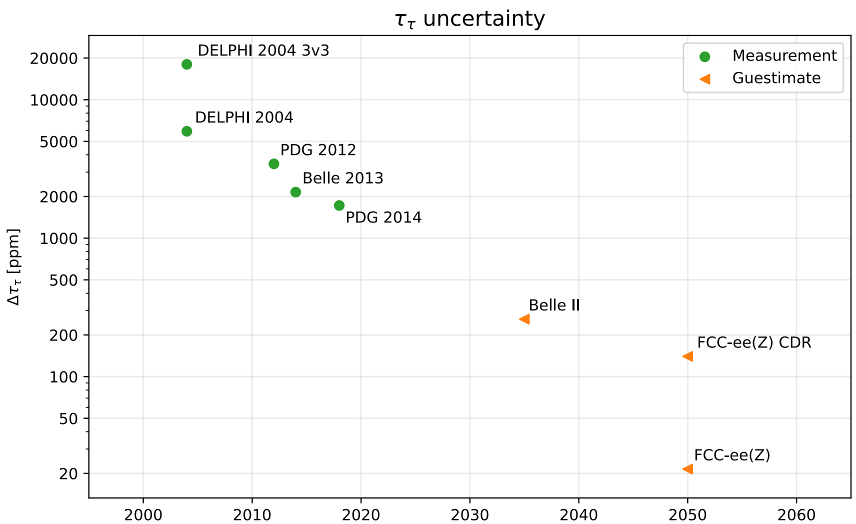
- A lot more to do with neutrals !

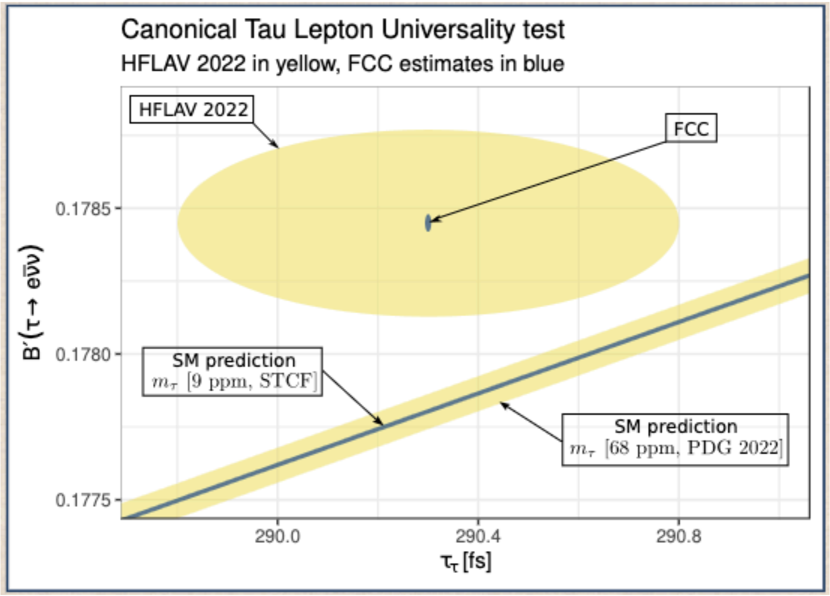
- Several null tests of the SM accessible w/ unprecedented precision, *e.g.* semileptonic asymmetries, ϕ_s in penguin-dominated diagrams …

3) Reviews of current activities (Feasibility Study)

- Tau Physics: Lepton Flavour Universality

© A. Lusiani





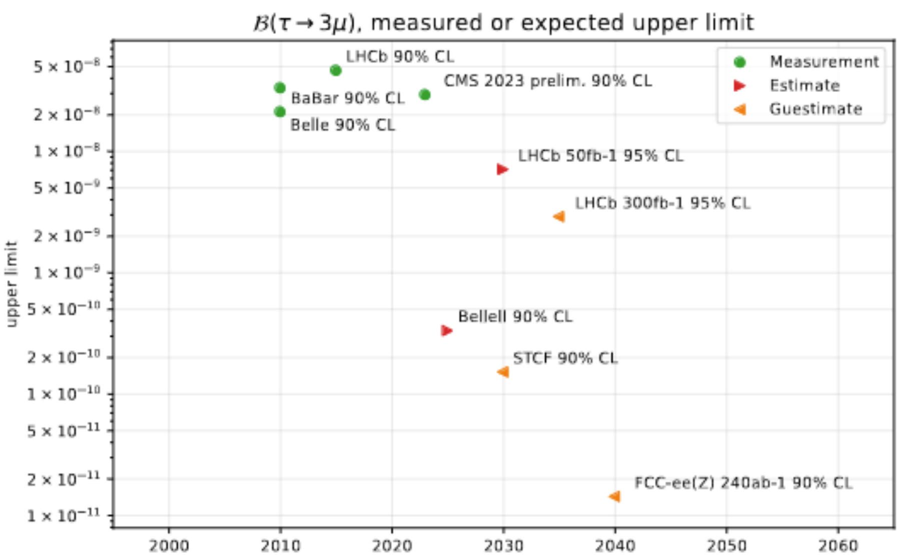
Comment: B-factories did not improve LEP measurements (Belle II might). FCC-ee has much better LEP experimental conditions (much better) and about 5× the Belle II tau pairs.

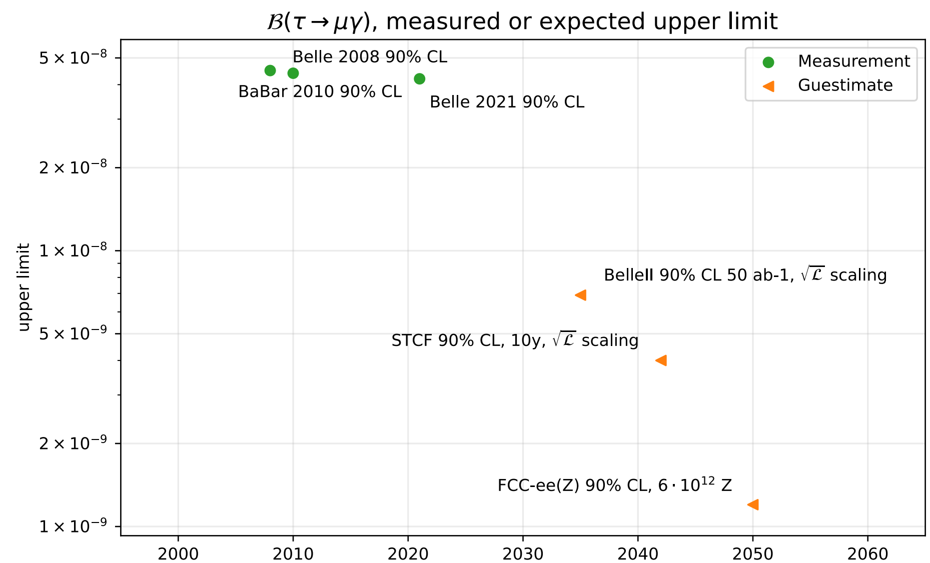
Bottomline: lifetime resolution obtained with three-prongs decays. Orders of magnitude improvements.

3) Reviews of current activities (Feasibility Study)

- Tau Physics: Lepton Flavour Violation

© A. Lusiani





Bottomline: improve sensitivity by about two orders of magnitude.

4) Connection to the ECFA study

- Goals of the study (my synthesis):
  - Assessing merits of the EW-Higgs-top factories on the market.
  - Gathering the community into shared interest studies.
  - Address detector requirements and trigger key detector R&Ds
- Six Physics groups: Flavour Physics is one of them.
- In order to engage the community, several so-called Focus Topics (FT) are defined. The Flavour group coordinates two of them.
- I'll give some more details on those two.

4) Connection to the ECFA study: FT WWCKM

- At the horizon of the next electron collider, the knowledge of the CKM profile is expected to have been deeply revisited by LHCb and Belle II/III.

- The CKM angle γ might be known at the sub-degree precision; as will the angle β.

- One relevant figure of merit to devise the possible bottlenecks in precision that would alter the global interpretation of the CKM profile is a quasi-model-independent analysis of the BSM contributions in neutral kaon and beautiful-meson mixing phenomena.

- Bottomline: one needs the matrix element $|V_{cb}|$ at a much-higher precision than what semileptonic *B* decays can provide. The next couple of slides to justify the statement. $|V_{cb}|$ is the normalisation of the UT in the SM and beyond (in a large class of BSM models).

- Longstanding tensions in exclusive / inclusive determinations to be fixed!

4) Connection to the ECFA study: FT WWCKM

- Model-independent approach to constrain BSM Physics in neutral meson mixing processes

$$\langle B_q \,|\, \mathcal{H}^{\rm SM+NP}_{\Delta B=2} \,|\, \bar{B}_q \rangle \equiv \langle B_q \,|\, \mathcal{H}^{\rm SM}_{\Delta B=2} \,|\, \bar{B}_q \rangle \times (\mathrm{Re}(\Delta_q) + i\,\mathrm{Im}(\Delta_q))$$

$$\mathrm{Re}(\Delta_q) + i\mathrm{Im}(\Delta_q) = r_q^2 e^{i2\theta_q} = 1 + h_q e^{i\sigma_q}$$

Soares & Wolfenstein, PRD 47, 1021 (1993)
Deshpande, Dutta & Oh, PRL77, 4499 (1996)
Silva & Wolfenstein, PRD 55, 5331 (1997)
Cohen et al., PRL78, 2300 (1997)
Grossman, Nir & Worah, PLB 407, 307 (1997)

Assumptions:

✓only the short distance part of the mixing processes might receive NP contributions.

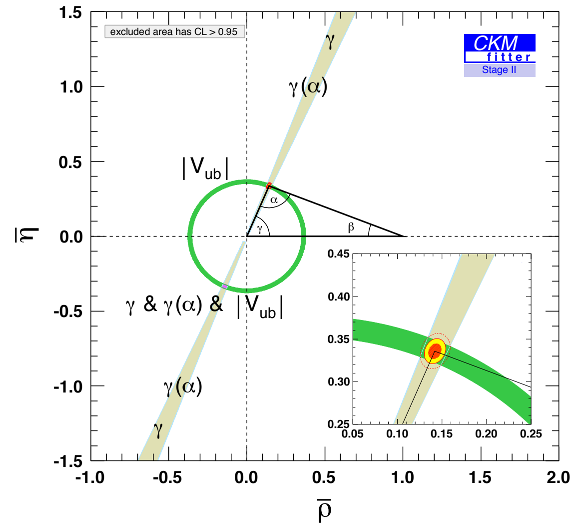
✓Unitary 3x3 CKM matrix (Flavour violation only from the Yukawas-MFV hypothesis).

✓ tree-level processes are not affected by NP (so-called SM4FC: $b \to f_i f_j f_k$ ($i \neq j \neq k$)). As a consequence, the quantities which do not receive NP contributions in that scenario are:

$$|V_{ud}|,\ |V_{us}|,\ |V_{ub}|,\ |V_{cb}|,\ B^+ \to \tau^+ \nu_\tau \text{ and } \gamma$$

4) Connection to the ECFA study: FT WWCKM

- The unitarity triangle: fixing CKM parameters w/ $|V_{ub}|$, $|V_{cb}|$ and gamma. This is the anticipated landscape after Belle II and LHCb Upgrade I.



- Knowing the CKM parameters, one can introduce the constraints of the *B* mixing observables depending on the NP complex number (here parameterised as Δ).

parameter	prediction in the presence of NP
Δm_q	$\lvert\Delta_q^{\rm NP}\rvert \times \Delta m_q^{\rm SM}$
2β	$2\beta^{\rm SM} + \Phi_d^{\rm NP}$
$2\beta_s$	$2\beta_s^{\rm SM} - \Phi_s^{\rm NP}$
2α	$2(\pi - \beta^{\rm SM} - \gamma) - \Phi_d^{\rm NP}$
$\Phi_{12,q} = {\rm Arg}[-\frac{M_{12,q}}{\Gamma_{12,q}}]$	$\Phi_{12,q}^{\rm SM} + \Phi_q^{\rm NP}$
A_{SL}^q	$\frac{\Gamma_{12,q}}{M_{12,q}^{\rm SM}} \times \frac{\sin(\Phi_{12,q}^{\rm SM}+\Phi_q^{\rm NP})}{\lvert\Delta_q^{\rm NP}\rvert}$
$\Delta\Gamma_q$	$2\lvert\Gamma_{12,q}\rvert \times \cos(\Phi_{12,q}^{\rm SM} + \Phi_q^{\rm NP})$

4) Connection to the ECFA study: FT WWCKM

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \left(\frac{4.5\,\text{TeV}}{\Lambda}\right)^2,$$

$$\sigma = \arg(C_{ij}\, \lambda^{t*}_{ij}),$$

hep-ph 2006.04824

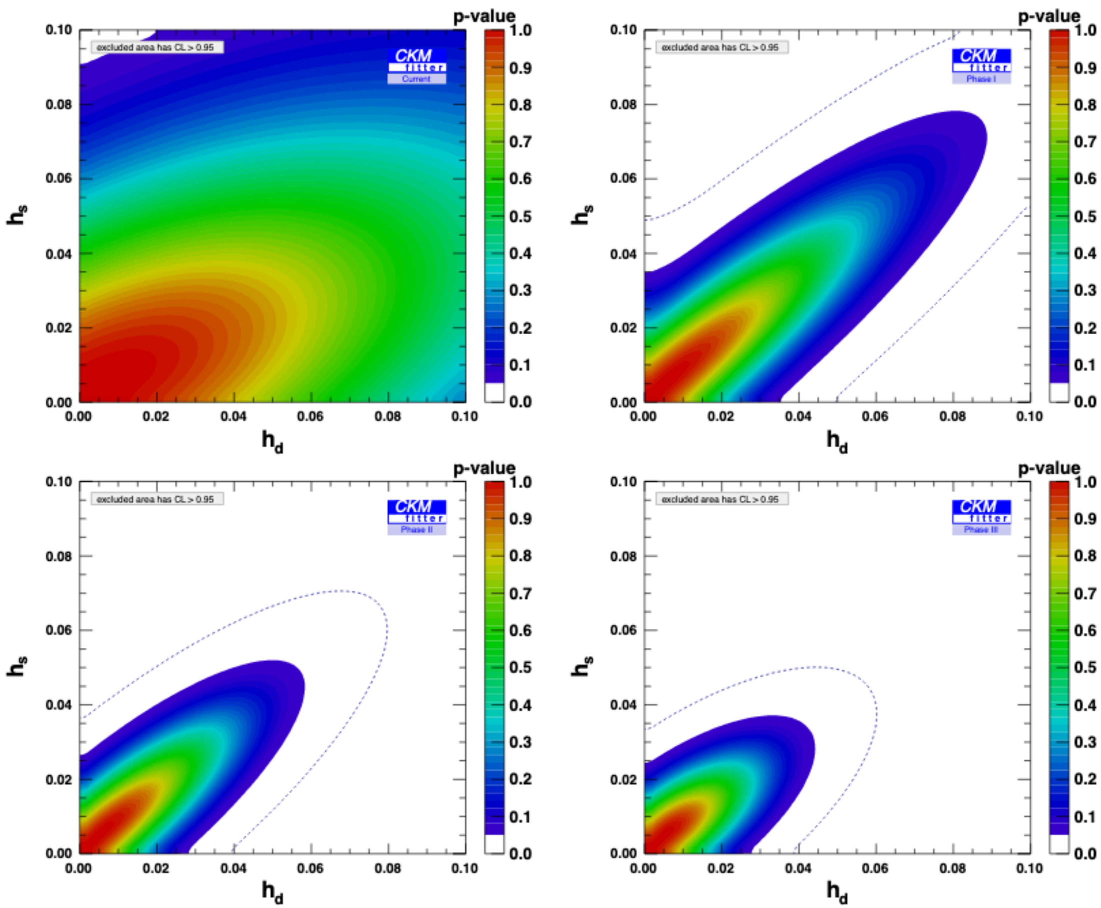


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

4) Connection to the ECFA study: FT WWCKM

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \left(\frac{4.5\,\text{TeV}}{\Lambda}\right)^2,$$

$$\sigma = \arg\left(C_{ij}\, \lambda^{t*}_{ij}\right),$$

hep-ph 2006.04824

rescaled to SM — Now,

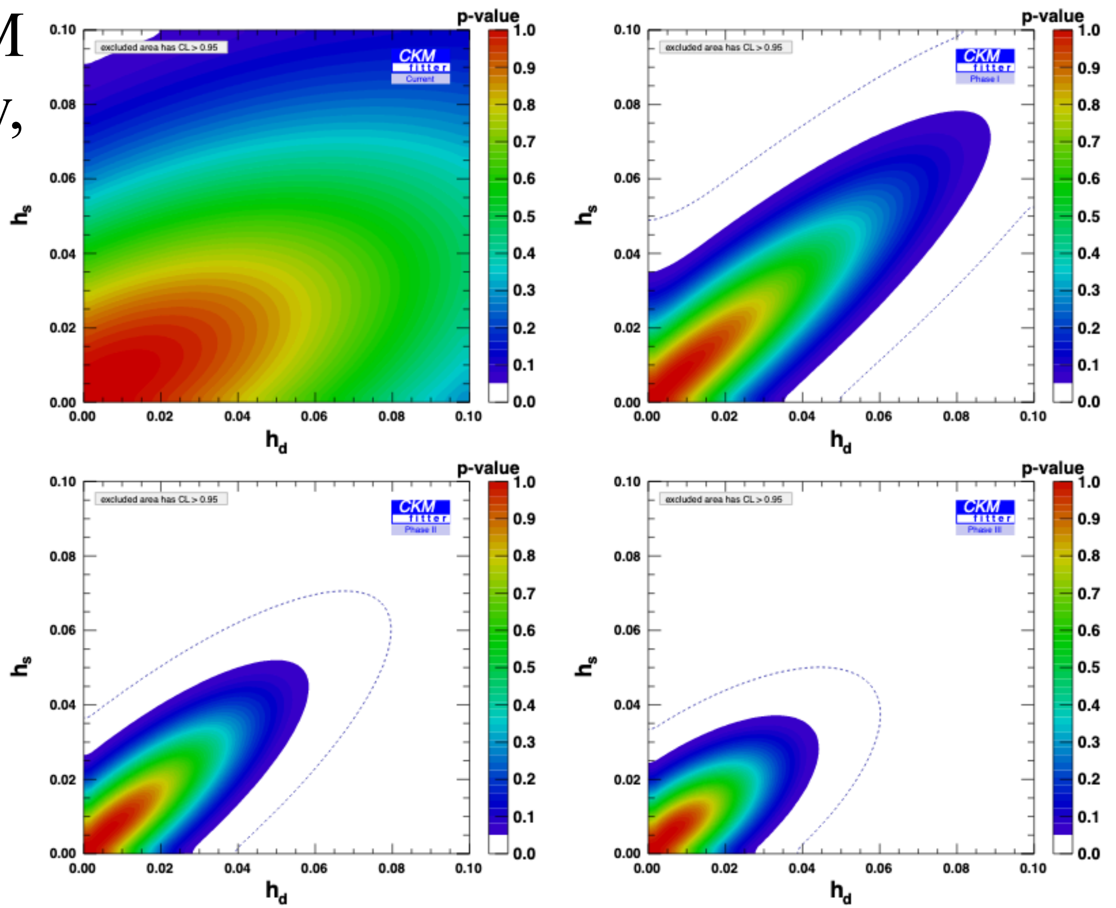


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

4) Connection to the ECFA study: FT WWCKM

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \left(\frac{4.5\,\text{TeV}}{\Lambda}\right)^2,$$

$$\sigma = \arg\left(C_{ij}\,\lambda_{ij}^{t*}\right),$$

hep-ph 2006.04824

rescaled to SM — Now,

after LHCb-U1 and Belle II — 2030

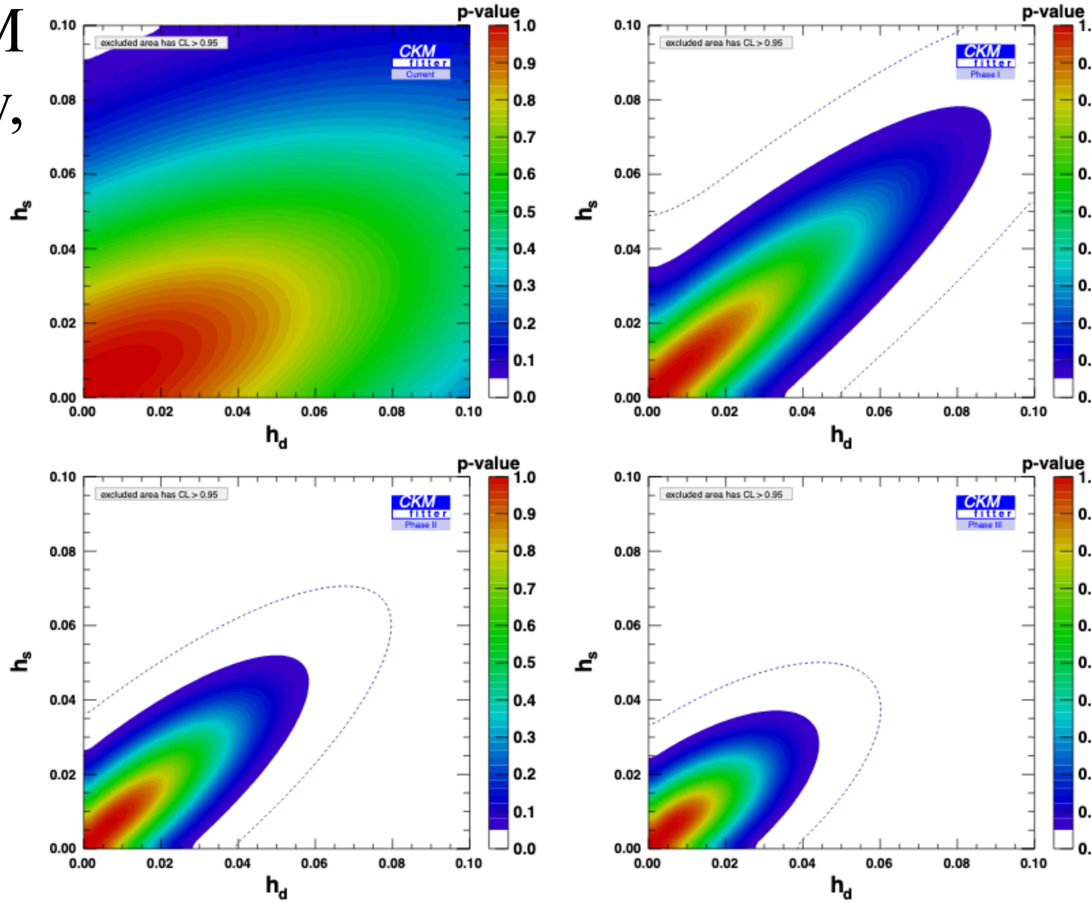


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

4) Connection to the ECFA study: FT WWCKM

FCC

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \left(\frac{4.5\,\text{TeV}}{\Lambda}\right)^2,$$

$$\sigma = \arg\left(C_{ij}\, \lambda^{t*}_{ij}\right),$$

hep-ph 2006.04824

rescaled to SM — Now,

after LHCb-U1 and Belle II — 2030

after LHCb U2 and Belle III — 2040

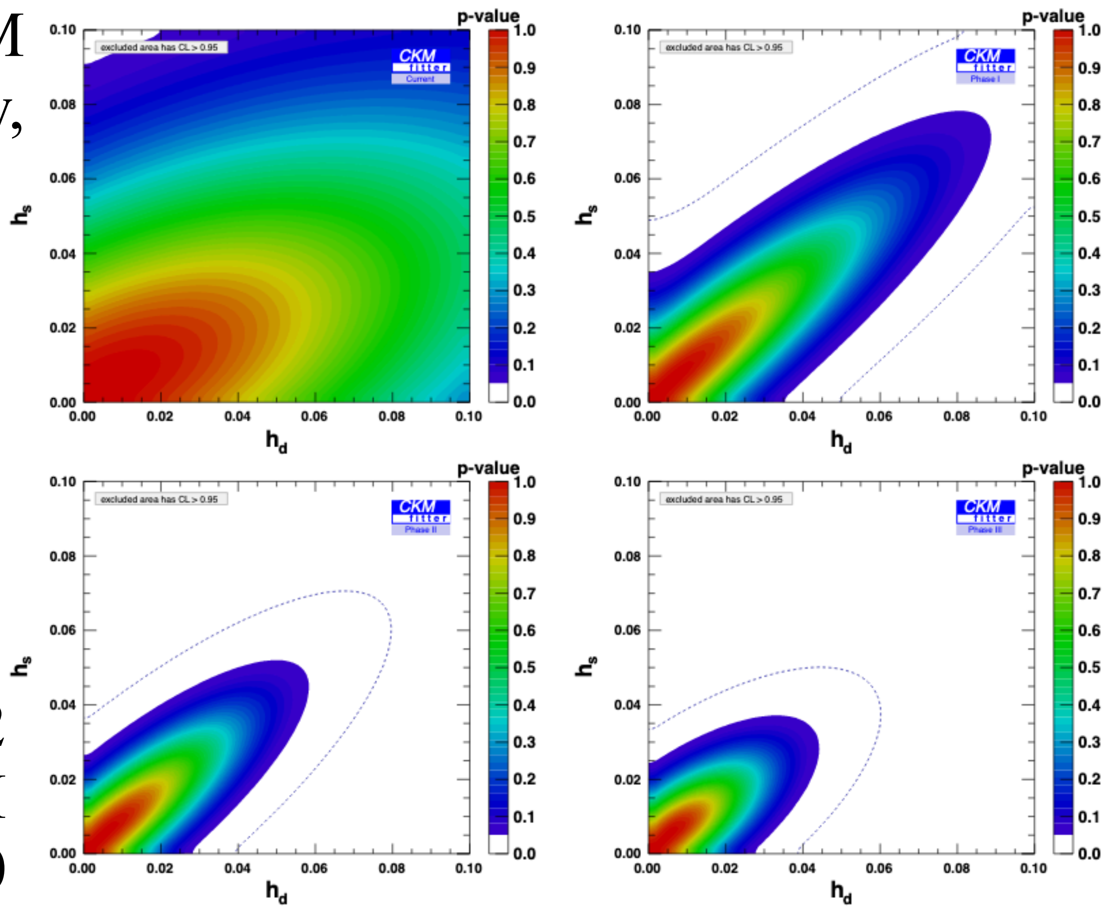


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda^t_{ij}|^2} \left(\frac{4.5\,\text{TeV}}{\Lambda} \right)^2 ,$$

$$\sigma = \arg\left(C_{ij}\, \lambda^{t*}_{ij}\right),$$

hep-ph 2006.04824

rescaled to SM — Now,

after LHCb-U1 and Belle II — 2030

after LHCb U2 and Belle III — 2040

Vcb improved LQCD not

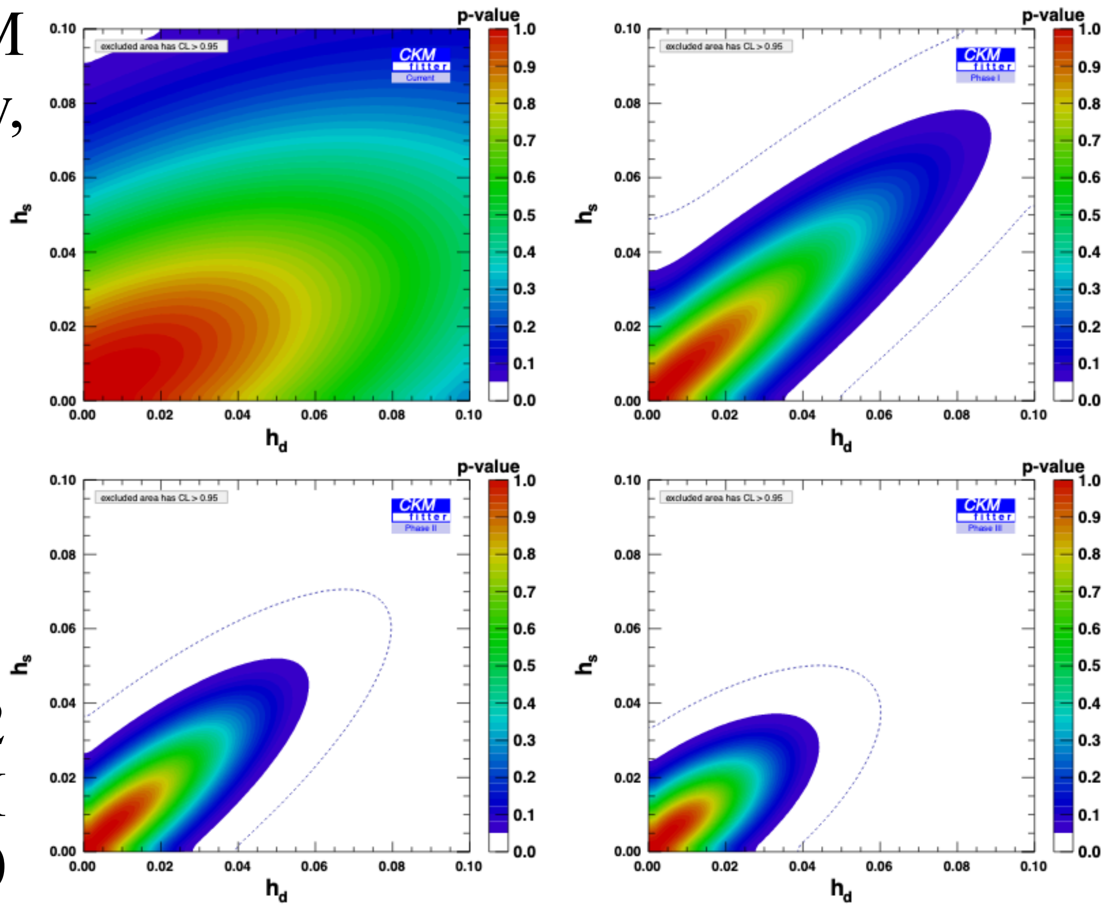


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

4) Connection to the ECFA study: FT WWCKM

- A team has defined the methodology of the prospective study and some members will actually explore it: P. Koppenburg, S. Monteil, U. Einhaus (DESY, ILC), M. Selvaggi (CERN, FCC), P. Goldenzweig (KIT, BelleII), M. Bordone (CERN, TH), D. Marzocca (Trieste, TH), Z. Ligeti (Berkeley, TH). More contributors welcome!

- Preliminaries:
  - What is the ultimate precision on Vcb (and Vcs, and the other matrix elements! if possible) from Belle-II and LHCb? ILC / FCC-ee reach.
- From W decays:
  - Review of the state-of-the-art Flavour Tagging (FT) algorithms (detector requirements?)
  - FT calibration methods and related systematics.
  - Estimate the precision reachable in all accessible CKM matrix elements.
- Extra: What about *Z* pole: semileptonic, $B_c \to \tau\nu$? Assessing LQCD precision ! Might be useful for *B* Physics and beyond …

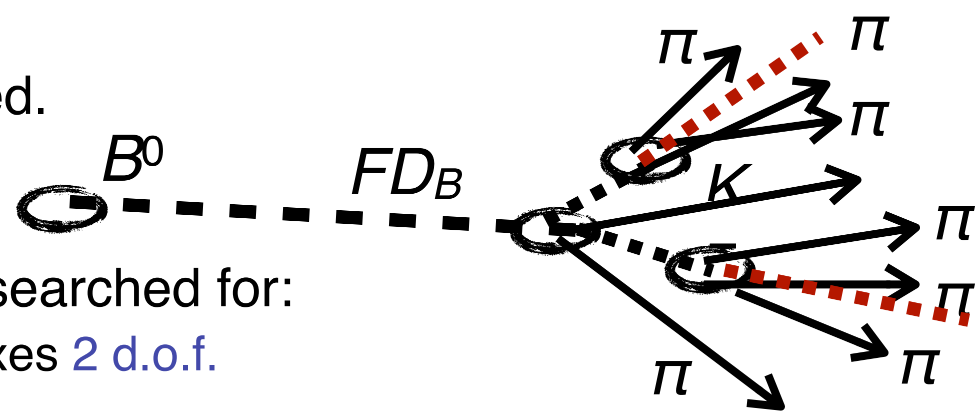
4) Connection to the ECFA study: FT $b \to s\tau^+\tau^-$ / $b \to s\nu\nu$

The scope:

- Semileptonic decays (Electroweak penguins in the SM) with tau in the final states are not measured. First evidence for neutrinos just out!
- One of the flavour physics sectors that are beyond the reach of the current experimental programme(s). Boost at the *Z* / case for luminosity at the Z (FCC-ee).
- Occupied some space as a change of paradigm for the search of New Physics from the Flavour problem(s).
- The canonical decays with taus places ultra-demanding requirements on the vertex detector (fully solvable kinematics provided the decay vertices are known).
- We thought to place the transition $b \to s\nu\nu$ as another study in this FT to complement the knowledge of $b \to sll$ transitions at large.

4) Connection to the ECFA study: FT $b \to s\tau^+\tau^-$ / $b \to s\nu\nu$

- $B^0 \to K^{*0}\ \tau^+\tau^-$: some vertices indeed.



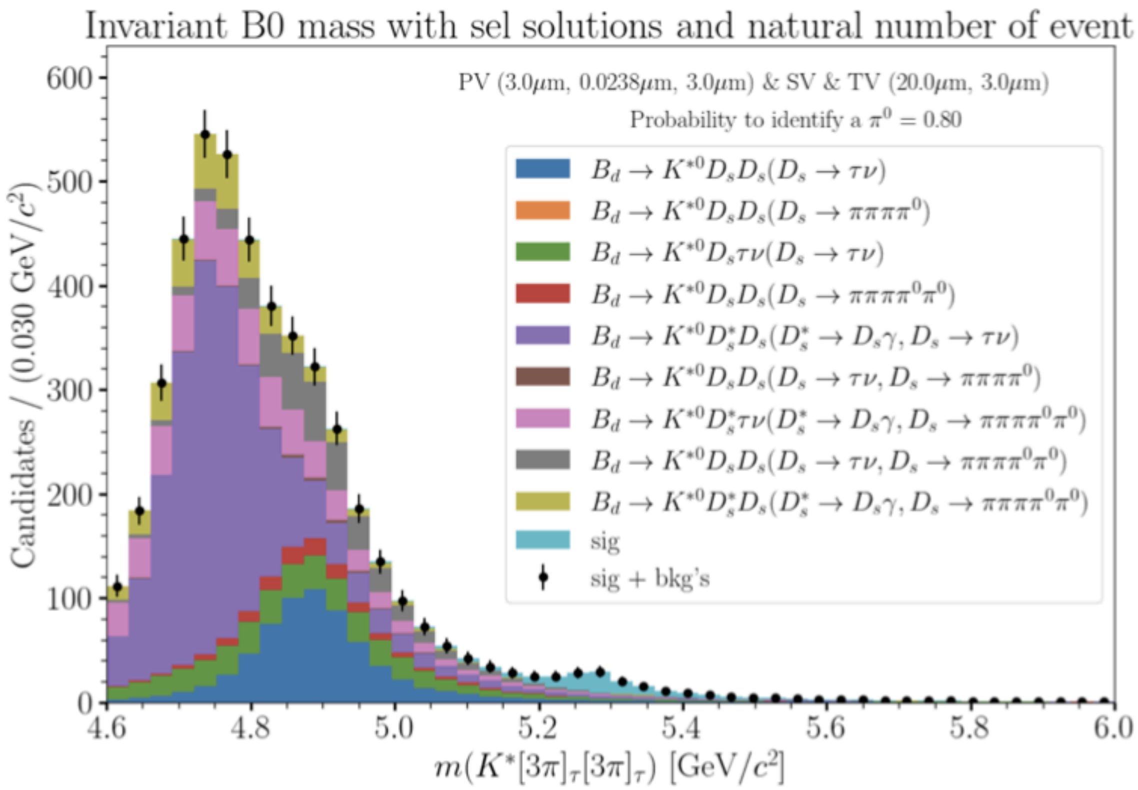
- Six momentum components to be searched for:
  - B^0 momentum direction from $K\pi$ fixes 2 d.o.f.
  - τ momenta direction fixes 4 d.o.f.
  - Mass of the τ provides 2 additional constraints
  - Since both tau legs provide quadratic equations, one ends up w/ 4 solutions.
  - Yet, the system is over-constrained and in principle fully solvable.

- $B^0 \to K^{*0}\ \tau^+\tau^-$: some backgrounds as well

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 $b \to c\bar{c}s$:				
$B^0 \to K^{*0} D_s D_s$	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}	$4\pi^0$,
$B^0 \to K^{*0} D_s D_s^*$	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}	$\nu, \gamma, 2\pi^0$

4) Connection to the ECFA study: FT $b \to s\tau^+\tau^-$ / $b \to s\nu\nu$

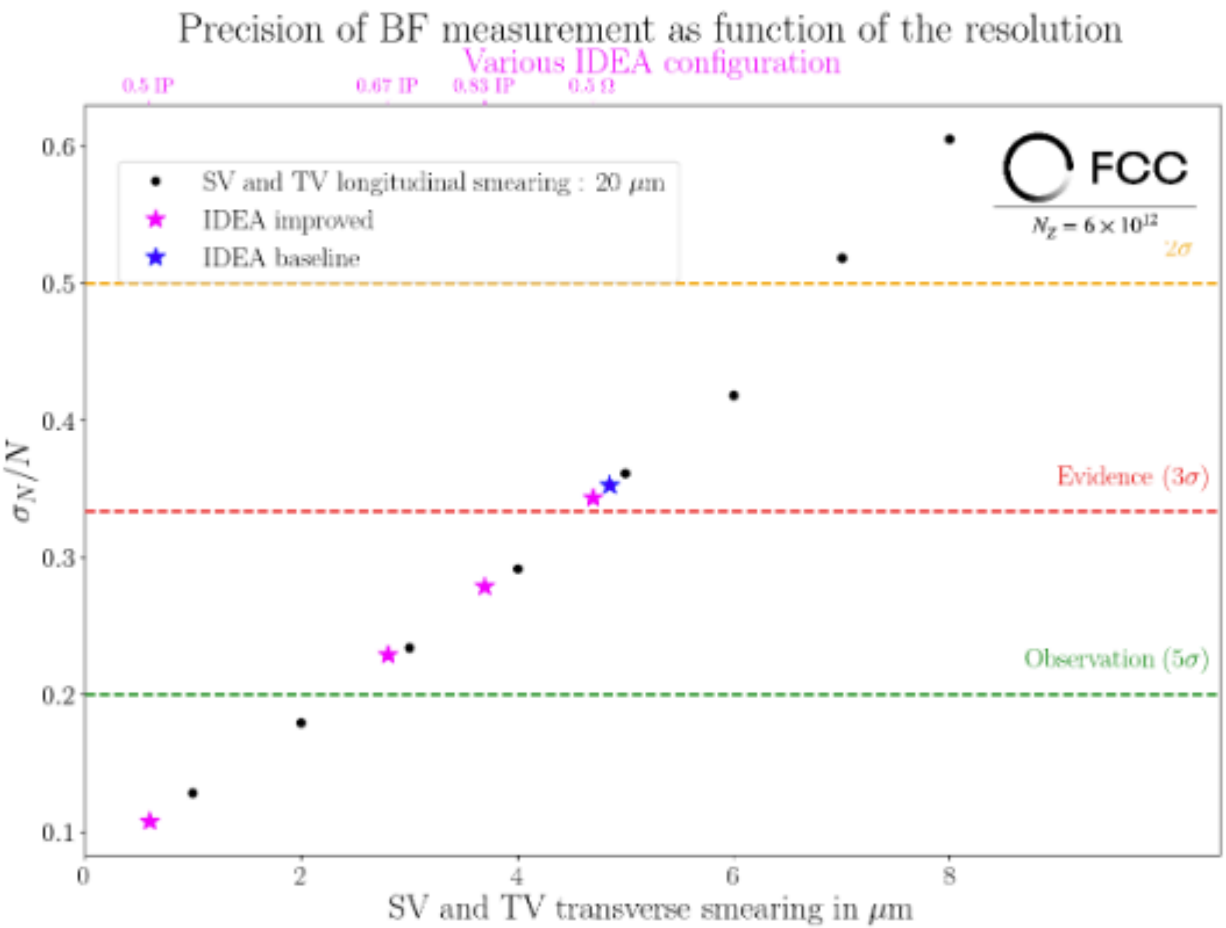
- $B^0 \to K^{*0}\ \tau^+\tau^-$: topological reconstruction + selection



- $B^0 \to K^{*0}\ \tau^+\tau^-$: we could see unambiguously the SM signal with this emulated detector! But it is an arbitrarily good one.

4) Connection to the ECFA study: FT $b \to s\tau^+\tau^-$ / $b \to s\nu\nu$

- $B^0 \to K^{*0}\ \tau^+\tau^-$: Checking how much to improve a vertex detector design? The IDEA example @ FCC-ee.



4) Connection to the ECFA study: FT $b \to s\tau^+\tau^-$ / $b \to s\nu\nu$

- A team has defined the methodology of the prospective study and some members will actually explore it: Ex-officio: P. Goldenzweig, P. Koppenburg, D. Marzocca, SM, T. Miralles (Clermont), A. Wiederhold (Warwick), M. Kenzie (Cambridge), E. Manoni (Perugia, Belle II), P. Goldenzweig (KIT, Belle II), F. Palla (Pisa, vtx), Paula Collins (CERN, vtx), J. Kamenik (JSI, TH), Luiz Vale Silva (IFIC,TH).

- It shall be checked how the performance of the vertexing:
  - Distance of the first layer to IP (beam pipe radius), bending of the detector, pitch size, material budget, cooling etc…
  - Note: bottleneck for resolution for these modes is likely: always low momenta final state tracks hence multiple coulombian scattering. Material reduction
  - Short term: complete fast simulation studies. For different detector design concepts. Change of parameters (design agnostic) to assess the target performance. Next: actual geometries / detector concepts in full simulation studies.

- French (also non-french) contributions would be most useful in this area.

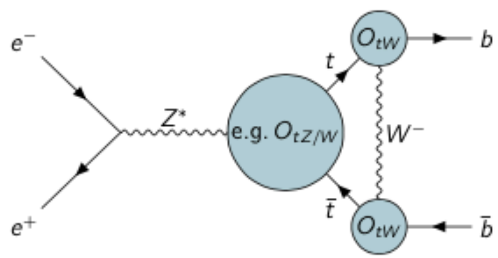
5) Connecting the dots: EWPO at the Z pole

FCC

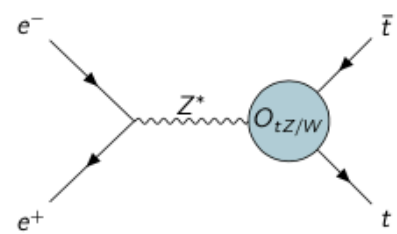
Motivation I

- Possible anomalies translate over a range of energy scales: from Z-pole to top threshold
- Heavy-quark EW measurements as a **probe for new physics** with a common set of dimension-6 operators

$\mathcal{O}(m_Z) \sim 90$ GeV



$\mathcal{O}(m_t) \sim 350$ GeV to 365 GeV



Today:

- Measurements at the Z-pole with $4.2 \cdot 10^{12}$ $Z \to q\bar{q}$ (4 IPs):
  - $R_b = \frac{\sigma_{b\bar{b}}}{\sigma_{\text{had.}}}$
  - $A^b_{\text{FB}} = \frac{N_{\text{F}} - N_{\text{B}}}{N_{\text{F}} + N_{\text{B}}}$

$\rightarrow$ Likely **dominated by systematic uncertainties**

$\rightarrow$ Explore Tera-Z regime with **exclusive b-hadron decay reconstruction as new tagger**

© L. Roehrig et al.

Novel methods in order

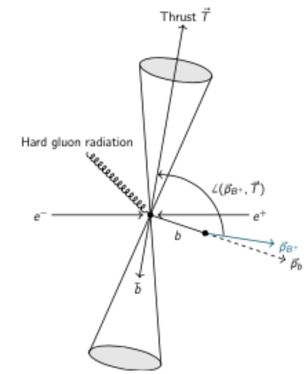
5) Connecting the dots: EWPO at the Z pole

© L. Roehrig et al.

Exclusive b-hadron decays

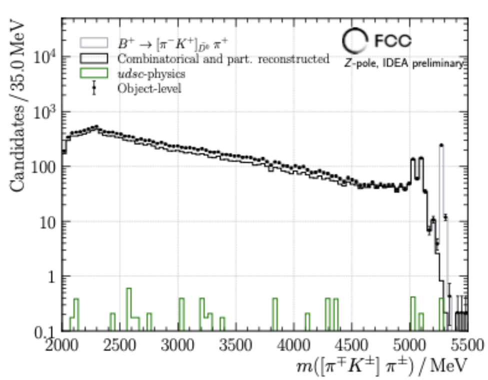
- LEP $\sigma_{\text{syst.}}$ dominated by *udsc*-physics and hemisphere correlations
- With Tera-Z $\sigma_{\text{stat.}}$ in reach: measurement limited by systematic uncertainties
- Reconstruct exclusive b-hadron: determine quark-flavour with 100 % purity
  $\rightarrow$ Stick to **ultra-pure mass region** to assess remaining systematic uncertainties $\rightarrow \varepsilon_b = 1\,\%$

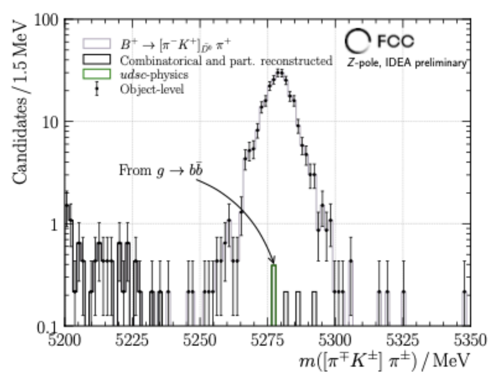
Observable	R_b	A^b_{FB}
b-hadrons	B^+, B^0_d, B^0_s, Λ^0_b	B^+, Λ_b
Knowledge of...	Flavour	Flavour, $\vec{p}$ & Q
	Remove *udsc*-physics contribution	
Advantages		Overcome mixing dilutions and hemisphere confusion
Remaining $\sigma_{\text{syst.}}$	Hemisphere correlation C_b	QCD corrections



- C_b and QCD corrections evaluated on **Full Simulation sample** and forced decays ($B^\pm \rightarrow [K^+\pi^-]_{\bar{D}^0}\,\pi^+$)

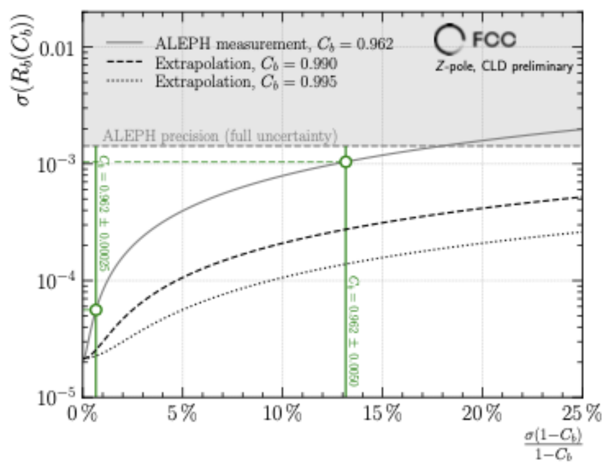
- Here: $B^+ \rightarrow [K^+\pi^-]_{\bar{D}^0}\,\pi^+$ with $E_B > 20$ GeV to reduce background



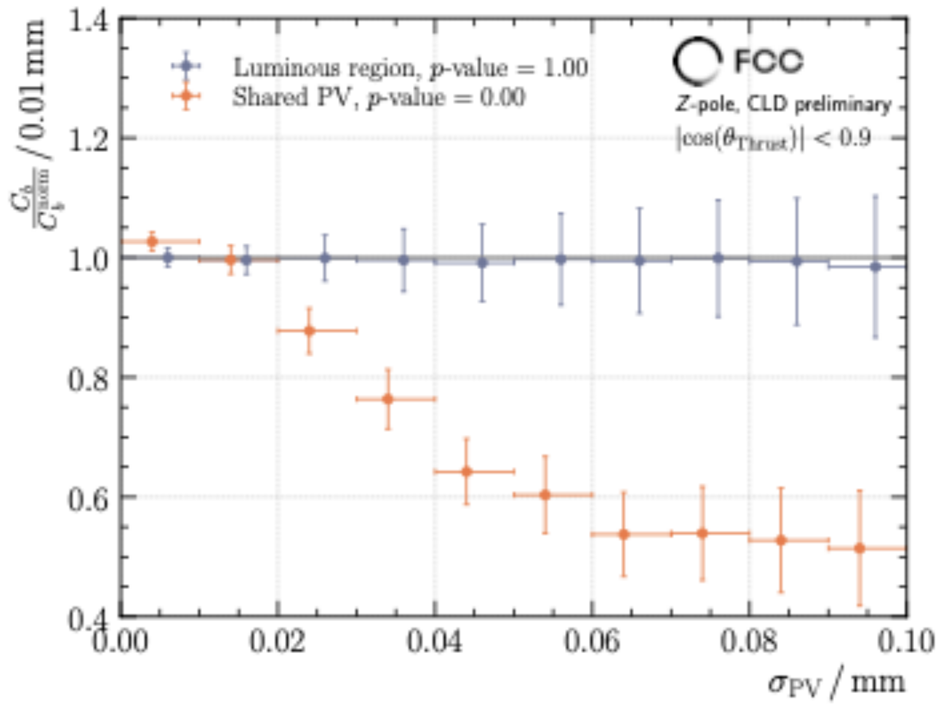


5) Connecting the dots: EWPO at the Z pole

- Understanding hemisphere correlations as the ultimate systematics
- LEP found that PV resolution was driving the correlation. LEP did separate PV measurement per hemisphere.
- At FCC-ee, one can use the luminous region to reduce the correlation.



© L. Roehrig et al.



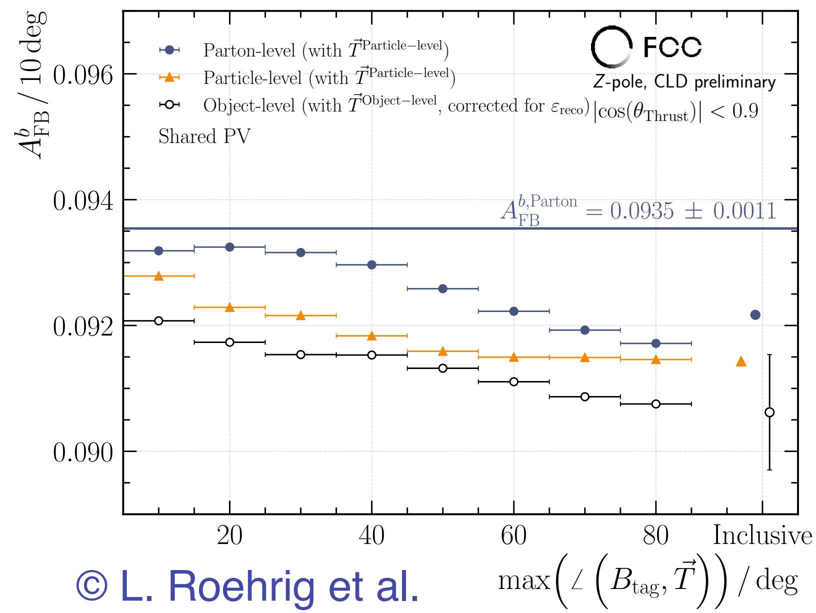
- Exclusive decays at a tagger can also help to reduce the systematic uncertainties on the bb forward-backward asymmetry

- Light quark contamination and mixing dilution are removed by the performance of the tagger.

- Remaining uncertainty to tackle are therefore QCD corrections. Can be controlled by the angle b/w thrust and the b-hadron candidate.

- Seems as well promising.

- Work in progress!



© L. Roehrig et al.

6) Summary

- Flavour Physics provides several areas to engage in the Feasibility Study, with consequences on the desirable detector concepts. Major requirements for calorimetry and vertexing.

- Generation of your favorite decay with EvtGen is available.

- Common analysis tools are steadily being put in place (secondary vertex finding available!).

- Several platforms as well where to contribute. To get in touch:

  - FCC-ee Flavour group: G. Isidori, J. Kamenik, A. Lusiani, SM.
    - FCC-PED-PhysicsGroup-Flavours-admin@cern.ch
  - ECFA Flavour group: P. Goldenzweig, D. Marzocca, SM.
    - ECFA-WHF-WG1-FLAV-conveners@cern.ch

7) Back-up

- Example: degree alpha measurement : a study to get started.

- The alpha angle can be measured through an isospin analysis from $B^0 \to (\pi\pi)^{+-/00}$. The knowledge of parameter S^{00} , that can be accessed from time-dependent studies, allows to lift degeneracies among solutions.

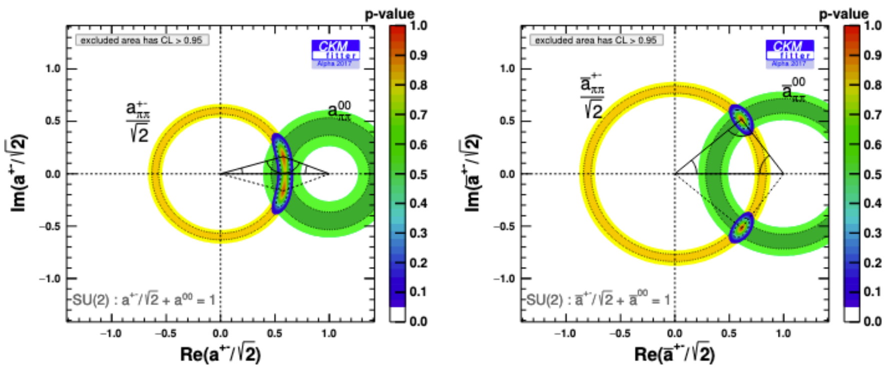


Figure 4: *Constraint on the reduced amplitude $a^{+-} = A^{+-}/A^{+0}$ in the complex plane for the $B \to \pi\pi$ (left) and $\bar{B} \to \pi\pi$ systems (right). The individual constraint from the $B^0(\bar{B}^0) \to \pi^+\pi^-$ observables and from the $B^0(\bar{B}^0) \to \pi^0\pi^0$ observables are indicated by the yellow and green circular areas, respectively. The corresponding isospin triangular relations $a^{00} + a^{+-}/\sqrt{2} = 1$ (and CP conjugate) are represented by the black triangles.*

- Accessible through Dalitz decays of the π^0 in $B^0 \to (\pi^0\pi^0)$. Vertex is there. Statistics too [O(10k)]. A possible case study for EM calo. design.

7) Back-up

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

- The feasibility study will be used to systematically address the physics case while placing requirements on the detectors. Hadron particle identification deserves a special treatment and Flavour physics is at the heart of it.

- All studies at the Z pole shown above are made for 5.10^{12} Z decays. Most of flavour observables will remain statistically limited. More would be desirable ! The machine study from two IPs to four IPs is positive and would bring about a factor 2 (1.7) in integrated luminosity.

- Four experiments can as well allow for different experiment designs, including a flavour-oriented concept.

- Engage and reach out to make this plan happening.

4) Connection to the ECFA study: FT WWCKM

- *WW* threshold. Marginal correction to the *B* scale.

- The study requires first flavour tagging performance. They do exist in the context of ILC and FCC collaborations at somehow different stages of maturity but all with simulations.

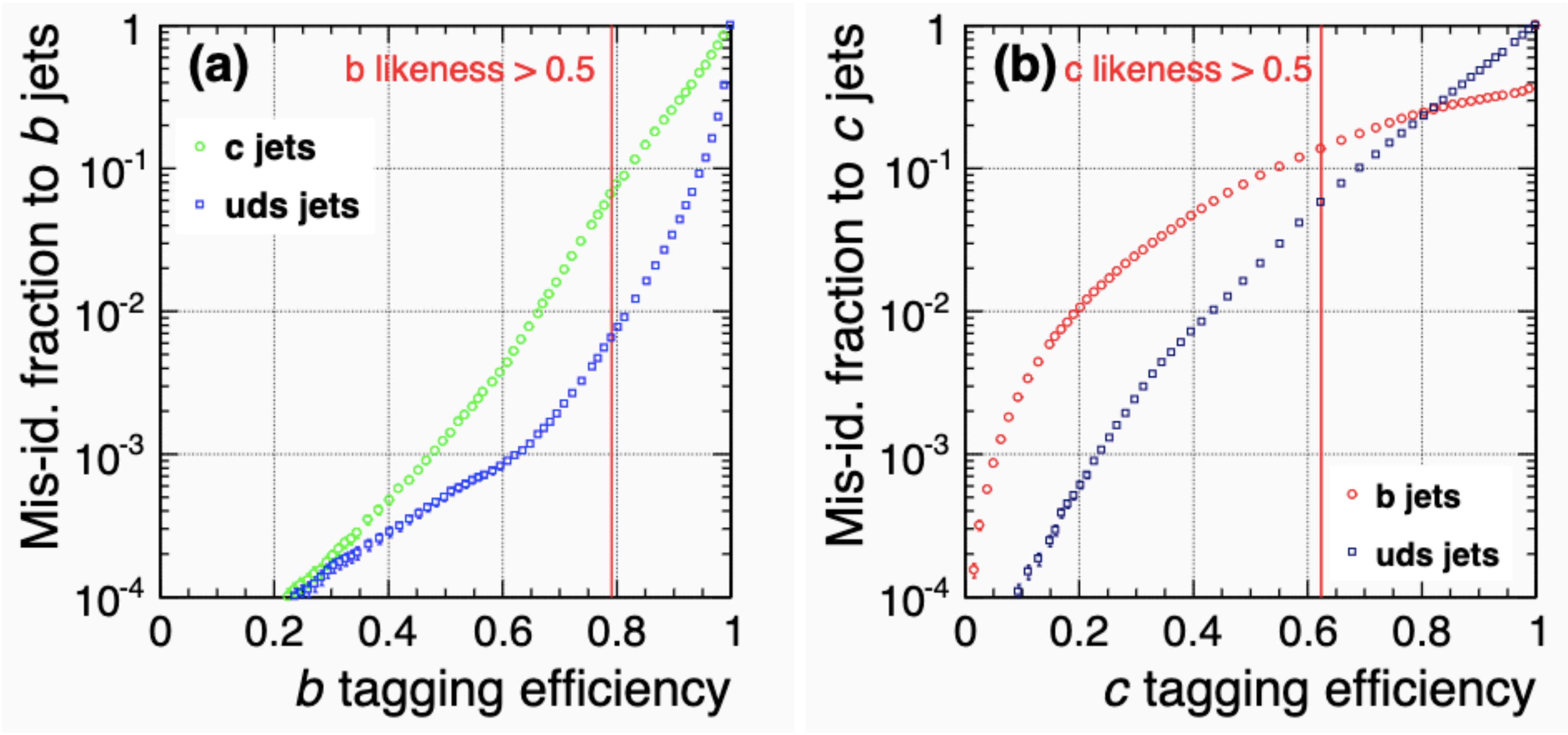
- Here the jet flavour tagging experts are central.

- First stage: rapid estimates of precision can be obtained in the context of the different machines from the performance of the jet flavour tagging performance.

- Second stage: fast then full simulations with the algorithms.

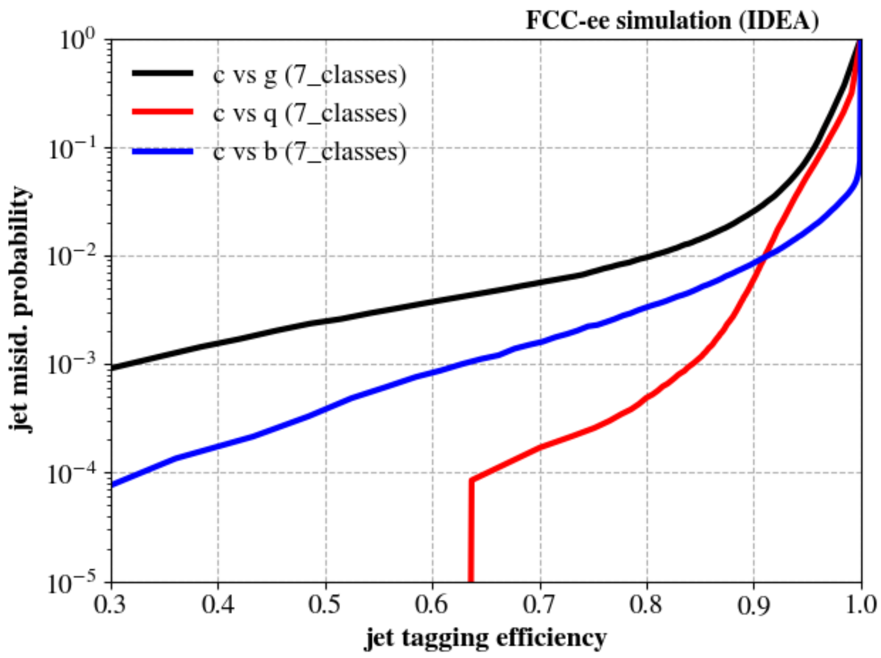
4) Connection to the ECFA study: FT WWCKM

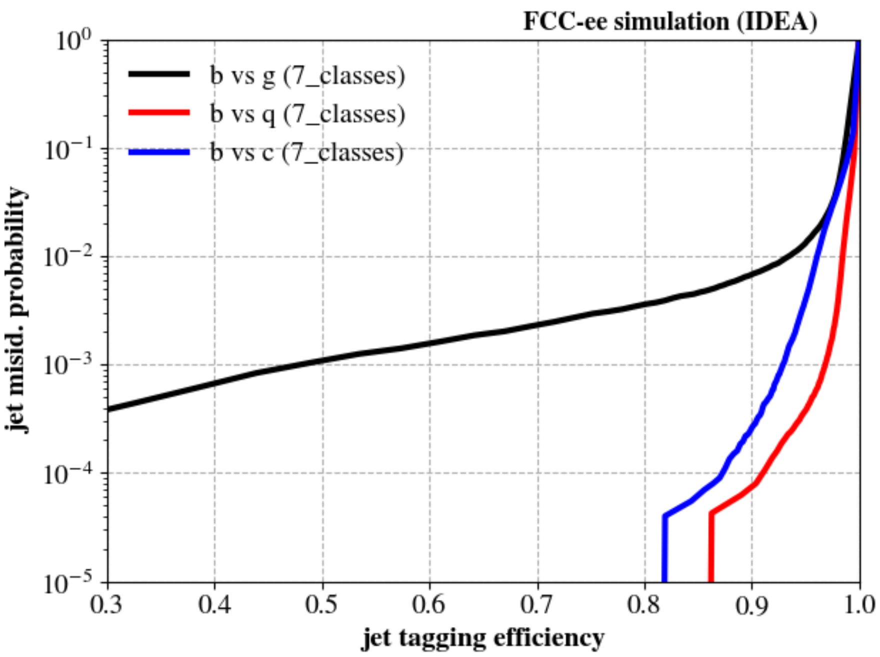
- Numbers picked from *Tracking and Vertexing at Future Linear Colliders: Applications in Flavour Tagging* — Tomohiko Tanabe. ILD@ILC. IAS Program on High Energy Physics 2017, HKU



4) Connection to the ECFA study: FT WWCKM

- From Michele Selvaggi



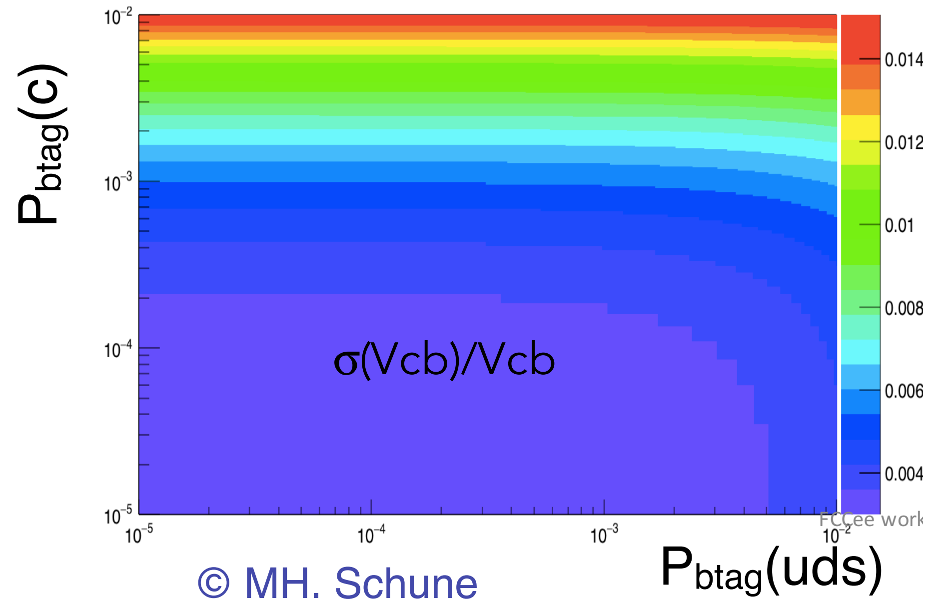


4) Connection to the ECFA study: FT WWCKM

- Emulating the jet tagging performance. Define a yield for *W* and count the signal and background.

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

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



© MH. Schune

- 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