Introduction to Flavours at FCC-ee

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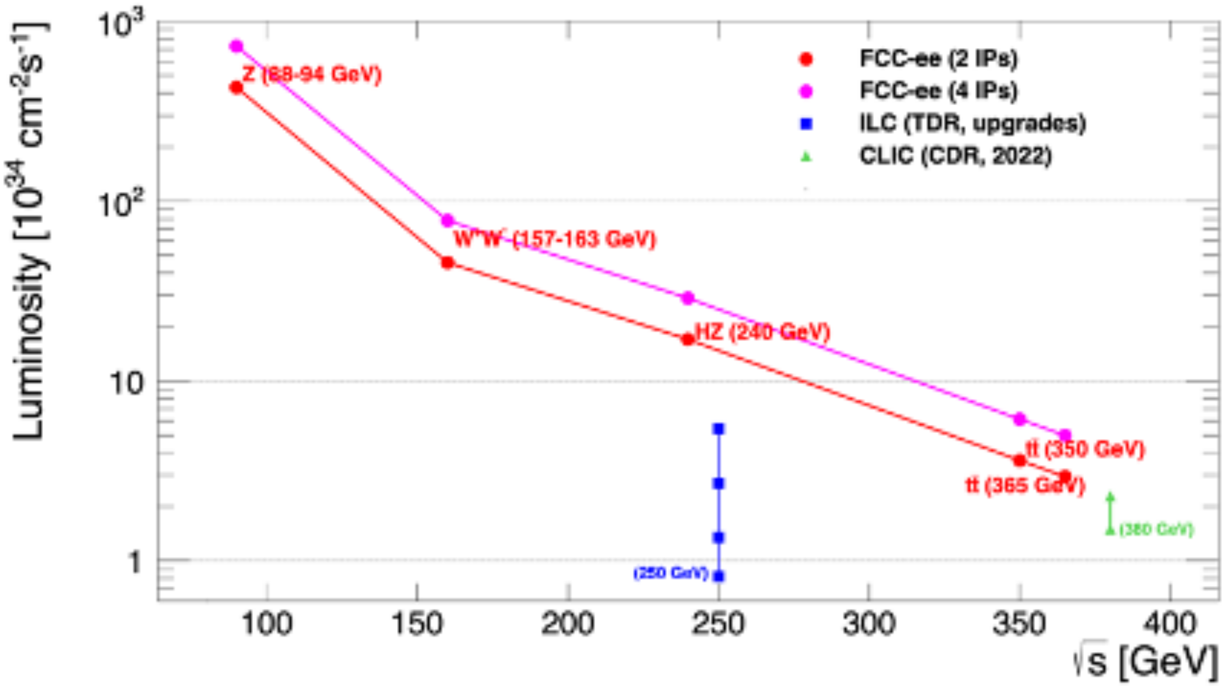
For Flavour groups (G. Isidori, J. Kamenik, A. Lusiani)

Outline

1. Flavours@FCC-ee: setting the scene.
2. The design study legacy and the next questions.
3. Physics avenues and benchmark modes for detector requirements definitions.
4. Outlook.

1) FCC-ee main features



- 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.
- Flavours at all thresholds but the Z pole is the focus. LEP1 in minutes. Luminosity is the name of the game.

1) 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.
- 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 $[10^{34}\ \mathrm{cm}^{-2}.\mathrm{s}^{-1}]$	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

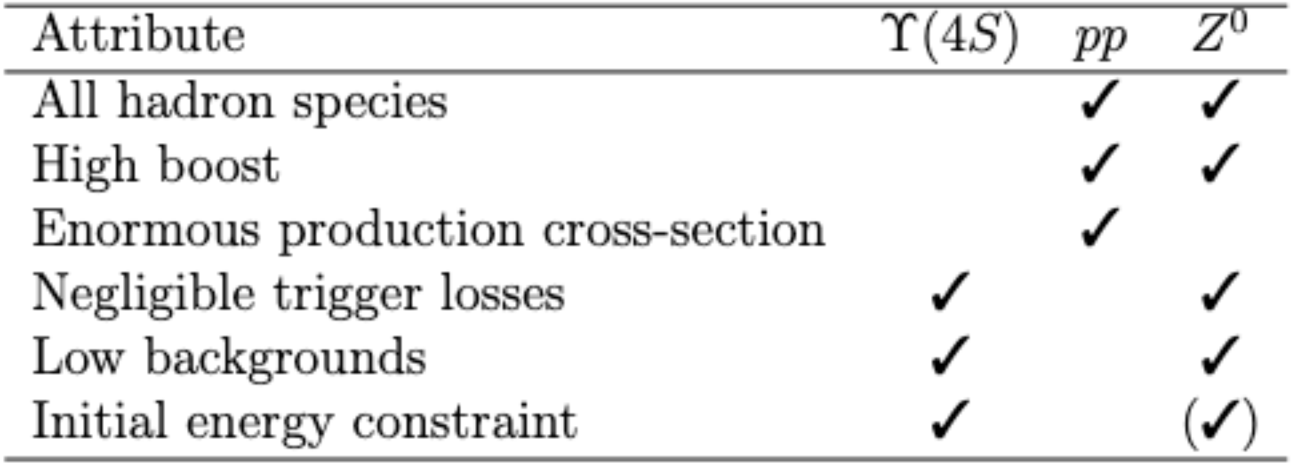
1) FCC-ee ABCD specifics for Flavour Physics.

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.

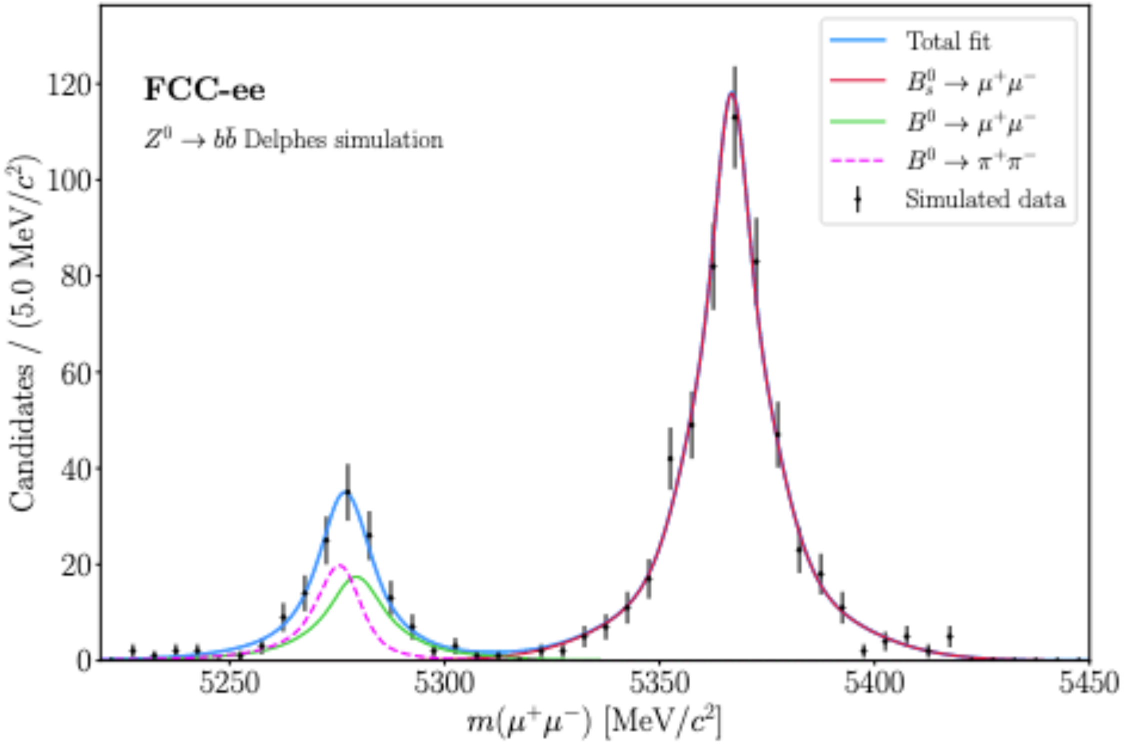
C- Versatility : the *Z* pole does not saturate all Flavour possibilities. Beyond the obvious flavour-violating Higgs and top decays, the *WW* operation will enable to collect several 10^8 *W* decays on-shell AND boosted. Direct access to CKM matrix elements $|V_{cb}|$ and $|V_{cs}|$.

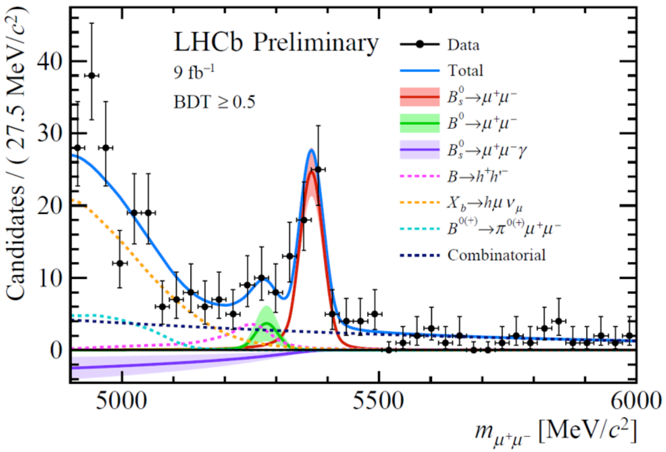
D- Comparison w/ LHC and B-factories. Advantageous attributes:



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

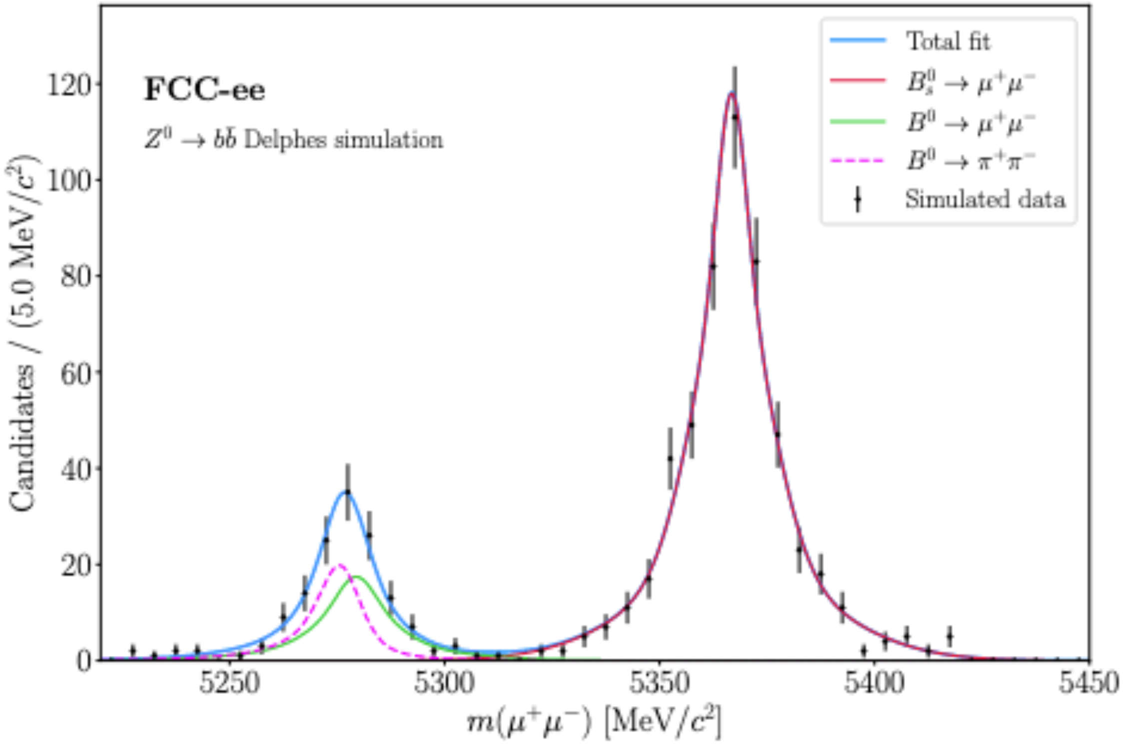
1) FCC-ee ABCD specifics for Flavour Physics.

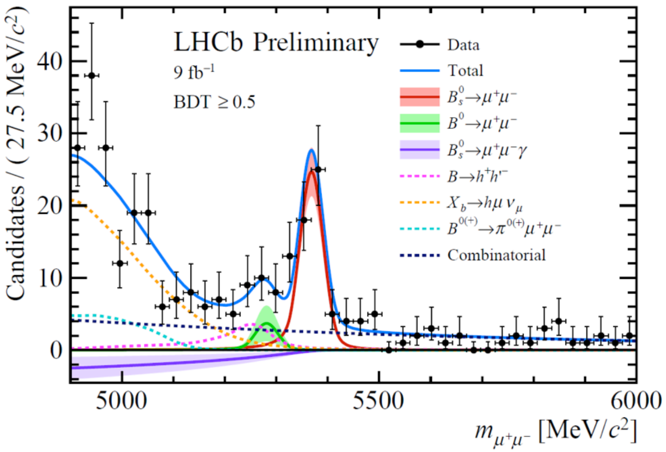




1) FCC-ee ABCD specifics for Flavour Physics.

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 physics w/ neutrals

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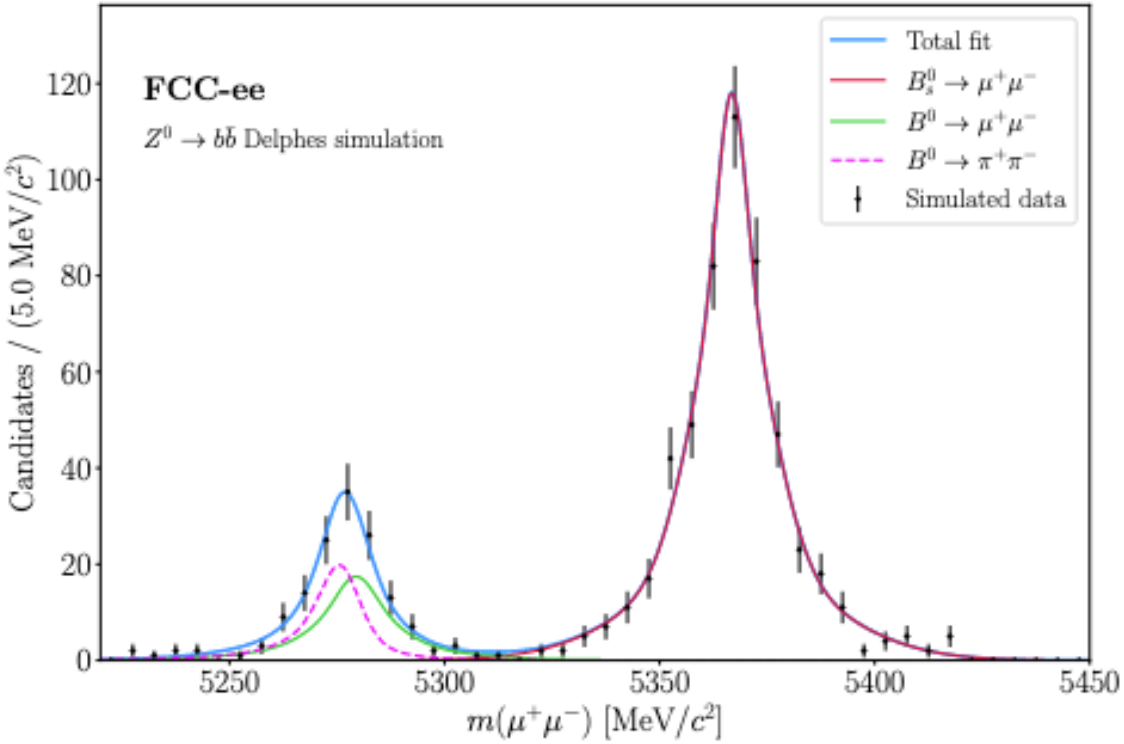

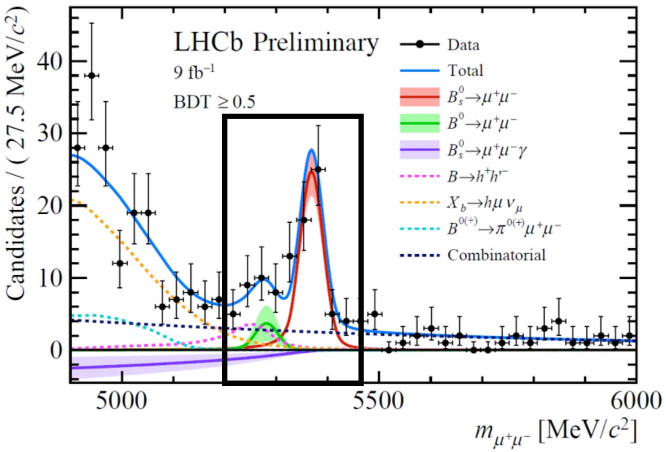

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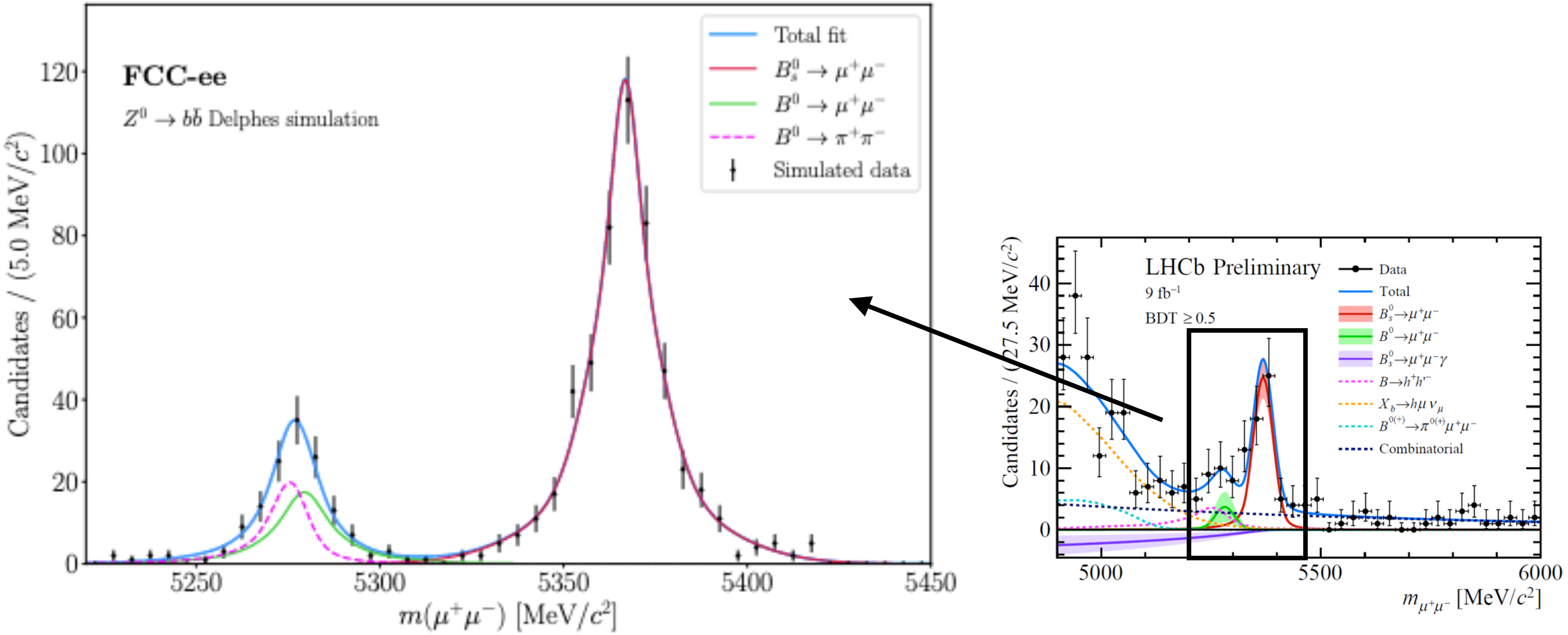


Seems granted w/ state-of-the-art tracker. Ultra-high resolution calorimetry is in addition desirable to touch high performance for physics w/ neutrals

1) FCC-ee ABCD specifics for Flavour Physics.

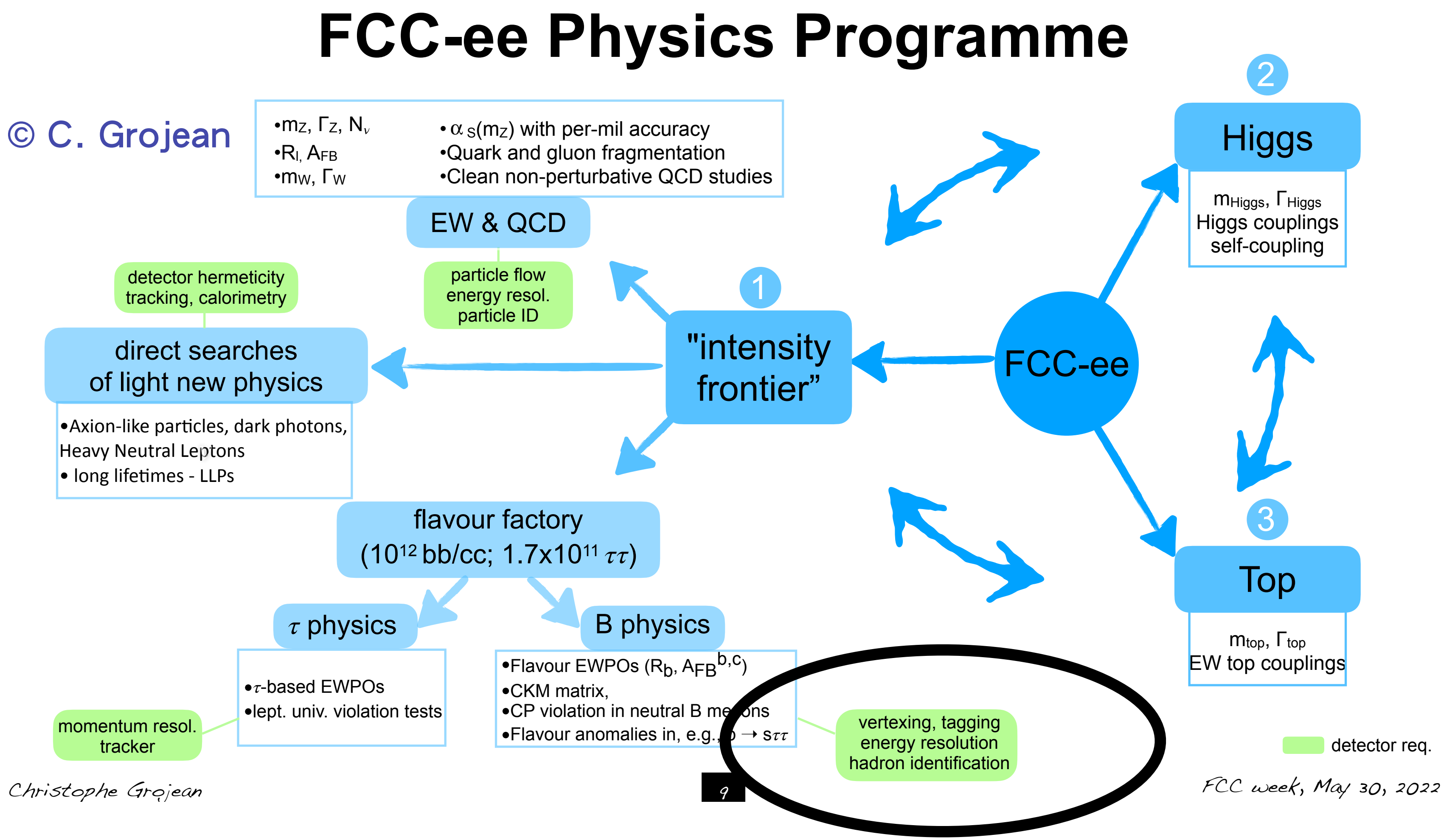
Final remarks on this section - Most of these advantageous attributes do require (or place requirement on) an adapted detector.

- The boost of the *Z* makes the *b*-flavoured (tau) particles fly ~3 (2) mm on average. High precision required to resolve rare decays with *ν* in particular when the mom. of daughter tracks is low:
  —> go beyond the state-of-the art for vertexing.

- *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:
  —> go beyond the state-of-the art for calorimetry.

- Hadronic *p* / *K* / *π* Particle identification has to come from the [d*E*/d*x* (d*N*/d*x*) + ToF] and / or a Cerenkov detector to fit in front of the ECAL:
  —> go beyond the state-of-the art.

1) FCC-ee machine and expts — executive summary



FCC-ee Physics Programme

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- m_Z, Γ_Z, N_ν
- R_l, A_{FB}
- m_W, Γ_W

- $\alpha_S(m_Z)$ with per-mil accuracy
- Quark and gluon fragmentation
- Clean non-perturbative QCD studies

EW & QCD

particle flow
energy resol.
particle ID

detector hermeticity
tracking, calorimetry

direct searches
of light new physics

- Axion-like particles, dark photons, Heavy Neutral Leptons
- long lifetimes - LLPs

1

"intensity frontier"

FCC-ee

2

Higgs

m_{Higgs}, Γ_{Higgs}
Higgs couplings
self-coupling

3

Top

m_{top}, Γ_{top}
EW top couplings

flavour factory
(10^{12} bb/cc; 1.7×10^{11} $\tau\tau$)

τ physics

- τ-based EWPOs
- lept. univ. violation tests

momentum resol.
tracker

B physics

- Flavour EWPOs (R_b, $A_{FB}^{b,c}$)
- CKM matrix,
- CP violation in neutral B mesons
- Flavour anomalies in, e.g., $b \to s\tau\tau$

vertexing, tagging
energy resolution
hadron identification

🟩 detector req.

Christophe Grojean

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FCC week, May 30, 2022

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

2) The legacy of the Design Study

- A look back:

  - The case was thought 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 Framework TDR published), Belle II (some thoughts about Belle III — 250 /ab) and STCF.

  - 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, if enough luminosity is provided, and hence provides at least a useful comparison.

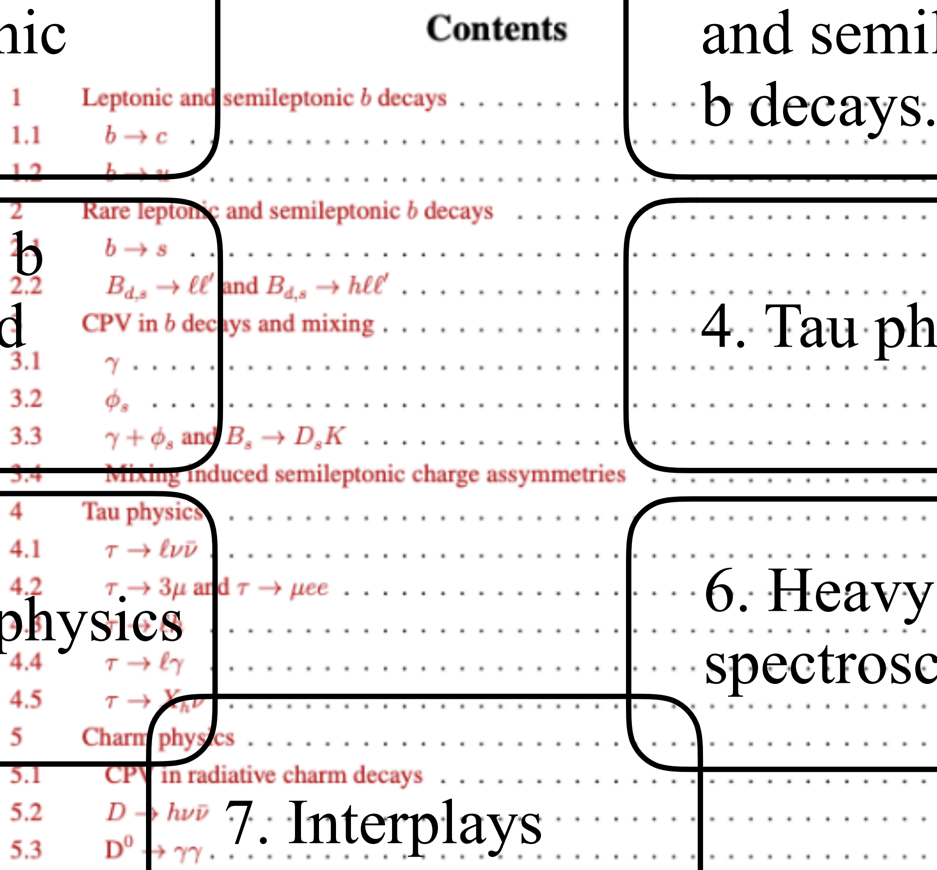
2) The legacy of the Design Study — Physics avenues.

- A look back: I tried to summarise in this slide a number of related written contributions beyond CDR with experimental content. More pheno and CEPC available. A summary presentation can be found here.
  - Decays intertwining 3rd generations fermions:
    - $b \rightarrow s\tau^+\tau^-$: [1705.11106, 2106.01259]
    - $B_c \rightarrow \tau^+\nu$: [2105.13330, see also 2007.08234]
  - CKM studies:
    - $|V_{ub}|$, $|V_{cb}|$: [2105.13330, here]
    - CKM angles: [2107.05311, 2107.02002, 2205.07823]
    - CPV semileptonic asymmetries, global fits: [2006.04824]
  - cLepton-Flavour-Violating Z decays [1412.6322], Tau properties [2107.12832]

3) Benchmarks for the feasibility study

- The desirable physics avenues

From G. Isidori & J. Kamenik roadmap



Contents

1. Leptonic and semileptonic b decays.

2. Rare leptonic and semileptonic b decays.

3. CPV in b decays and mixings

4. Tau physics

5. Charm physics

6. Heavy flavour spectroscopy

7. Interplays

3) Benchmarks for the feasibility study

- The desirable physics avenues

1. Leptonic and semileptonic b decays.
2. Rare leptonic and semileptonic b decays.
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7. Interplays

3) Flavour benchmarks for the feasibility study

- Objectives (in general):
  - Strengthen the studies at hand and get them documented.
  - Given the current person power, focus on observables providing significant detector requirements.
  - Address quantitatively the desirable luminosity figure and the interest of 4 IP. Note: as far as CKM is concerned, there is an interplay with in particular the necessary LQCD improvements.
  - Enrich the physics case by addressing sensitivity studies on new observables (in particular in avenues not explored so far) and interplays with other groups.

3) Flavour benchmarks for the feasibility study

- Objectives (in general and for this WS):
  - Strengthen the studies at hand and get them documented.
  - Given the current person power, focus on observables providing significant detector requirements. [Alberto, Tristan, tomorrow].
  - Address quantitatively the desirable luminosity figure and the interest of 4 IP. Note: as far as CKM is concerned, there is an interplay with in particular the necessary LQCD improvements. [Luiz today, Tristan]
  - Enrich the physics case by addressing sensitivity studies on new observables (in particular in avenues not explored so far) and interplays with other groups. [Jure, Lukas, Lars, Zbigniew]

6) Outlook

- 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.

- 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.

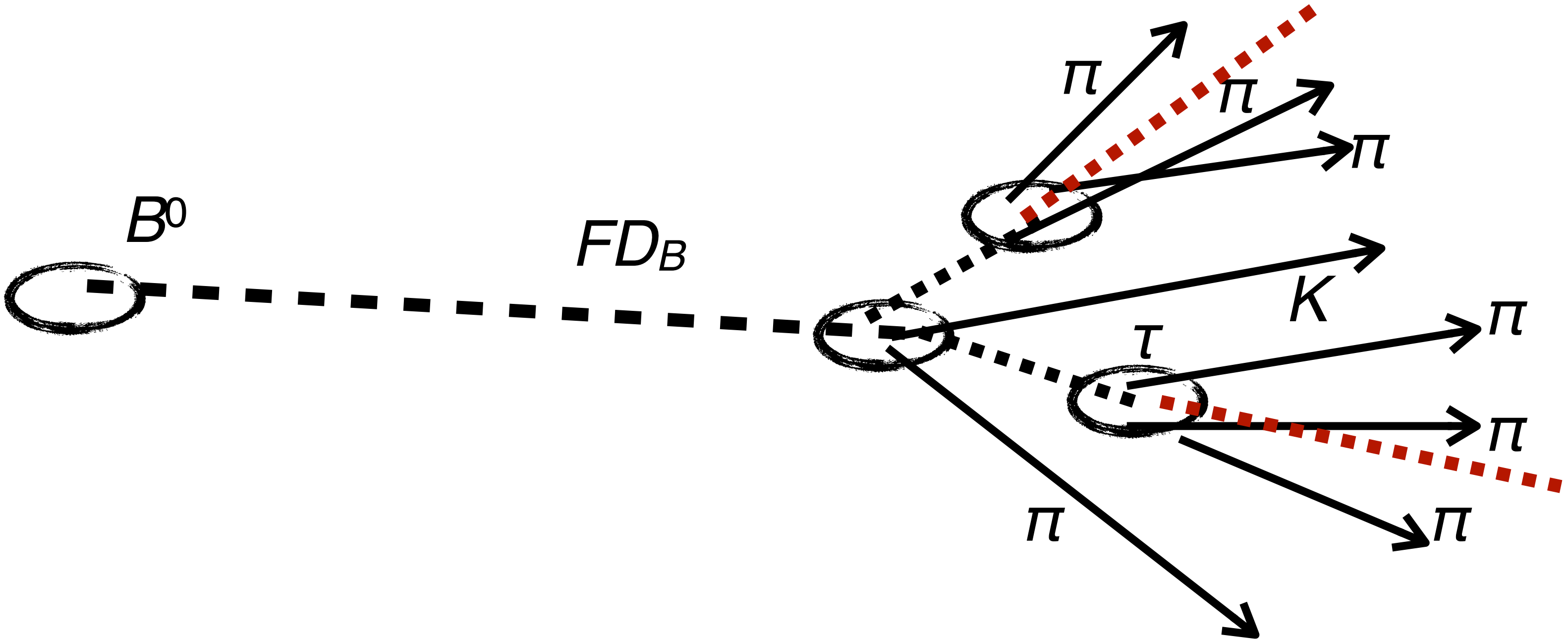
- Four experiments can as well allow for different experiment designs, including flavour-oriented concepts.

- Engage and reach out to make this plan happening. The experimental flavour physics working group has been set up. Here to subscribe:
  - https://e-groups.cern.ch/e-groups/EgroupsSubscription.do?egroupName=FCC-PED-PhysicsGroup-Flavours
  - Meeting of the Flavour performance WG is soon to be announced

Back-ups

The legacy of the Design Study: Rare decays

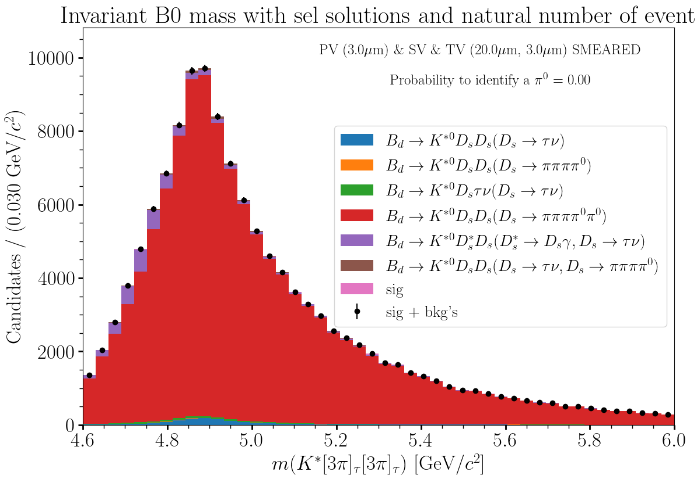
- $B^0 \to K^{*0}\ \tau^+\tau^-$.



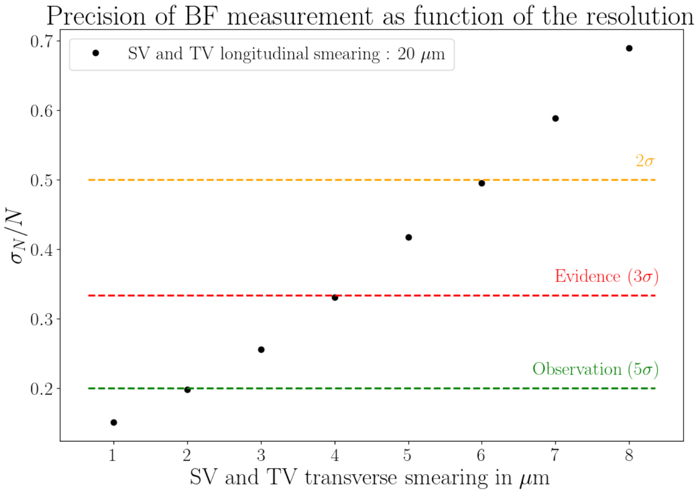
- Six momentum components to be searched for:
  - B^0 momentum direction from $K\pi$ fixes 2 d.o.f.
  - τ momenta direction fixes 4 d.o.f.
  - Mass of the τ provides 2 additional constraints
  - Since both tau legs provide quadratic equations, one ends up w/ 4 solutions.
  - Yet, the system is over-constrained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

The legacy of the Design Study: Rare decays

- $B^0 \to K^{*0}\ \tau^+\tau^-$: a couple of backgrounds that an adequate vertexing can't discriminate alone (Status at Liverpool).



- $B^0 \to K^{*0}\ \tau^+\tau^-$: but that an additional selection can cut



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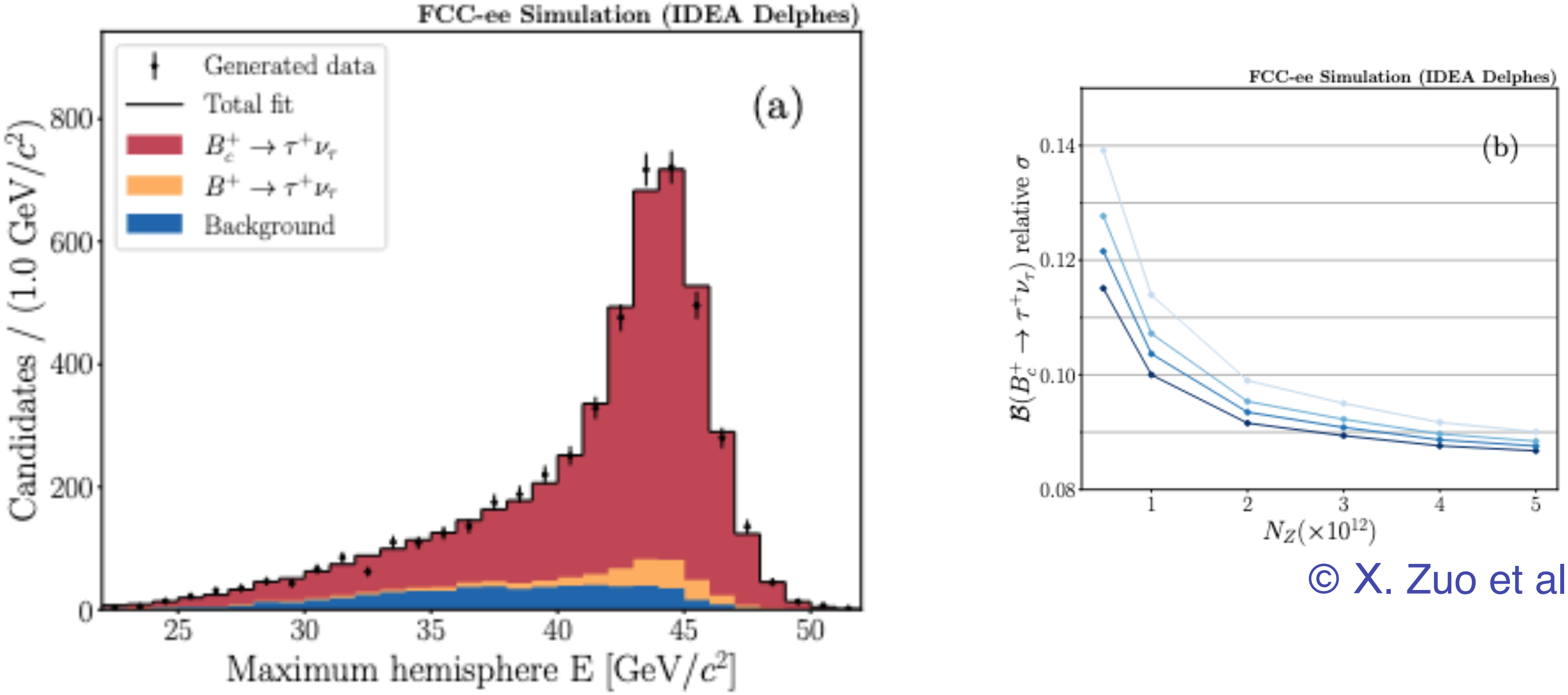
The legacy of the Design Study: Rare decays

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



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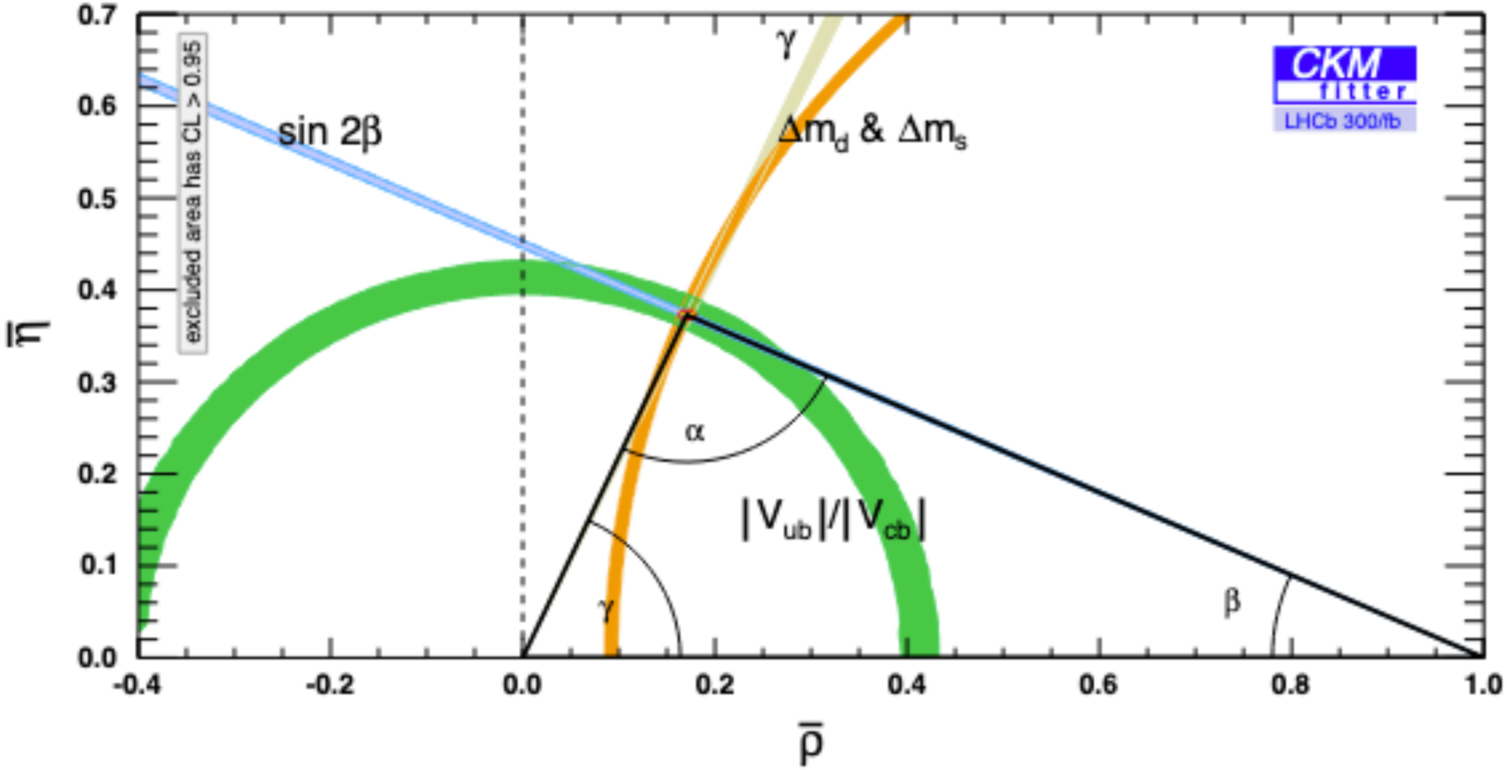
Bottomline: few percent precision mostly limited yet by the knowledge of the normalisation BF ($J/\psi\mu\nu$).

The legacy of the Design Study: CKM

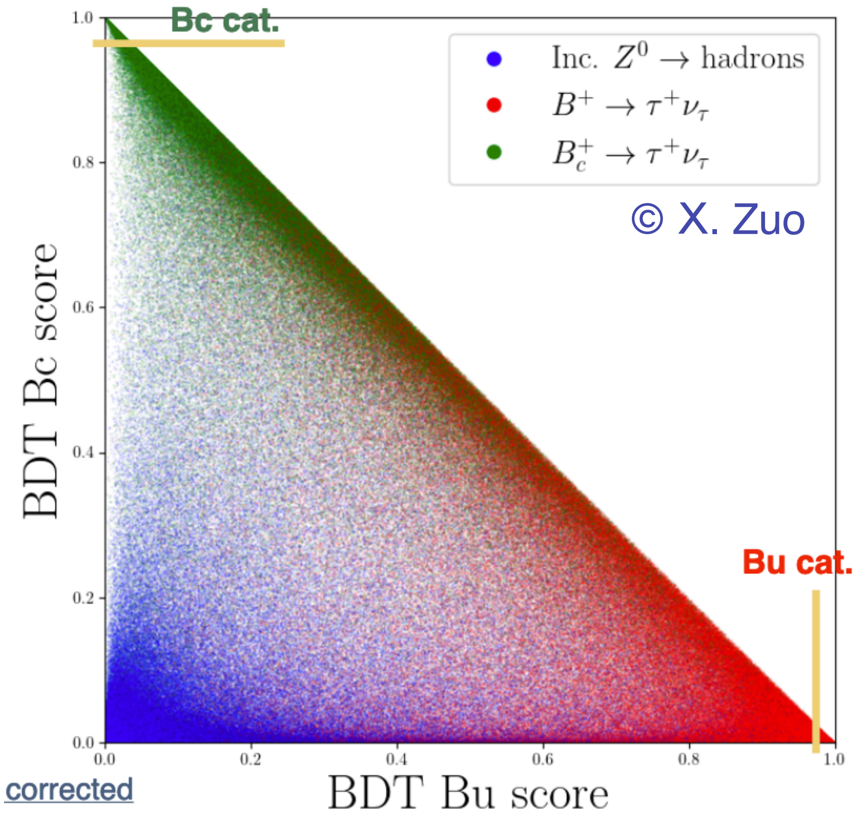
- CKM profile is at the heart of the Flavour programme. Possible status of the CKM profile in the late 2030s assuming SM is valid (Lattice-QCD expected improvements in; LHCb-biased view).



- Belle II will add up to this. The question is: can we do better ?

The legacy of the Design Study: CKM (|V_{ub}|)

- *$B^+ \rightarrow \tau^+\nu$:* access |$V_{ub}$| with the only knowledge of the decay constant. Work in progress building on [hep-ex:2105.13330].



Bottomline: similar yields / purities as for *$B_c \rightarrow \tau^+\nu$. A paper to come soon.*

The legacy of the Design Study: CKM [gamma]

- Sub-degree gamma angle measurement at reach :

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

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

PDG: $\gamma = (71.1^{+4.6}_{-5.3})°$

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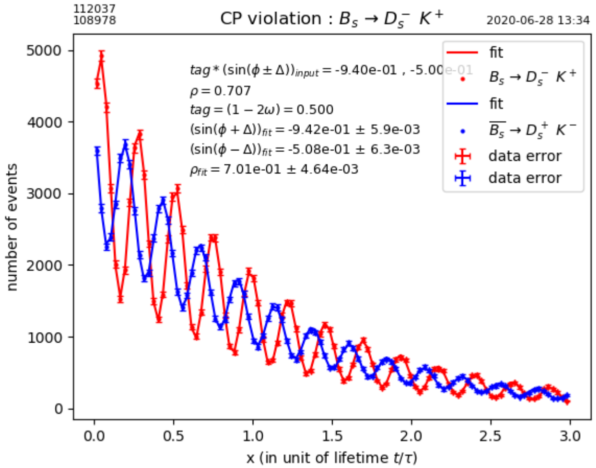
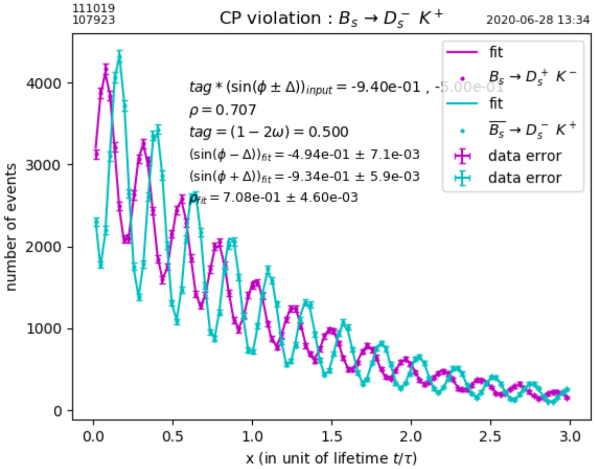




Result 3 :

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

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

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 …

The legacy of the Design Study: CKM (a_{sl} (d,s))

- Setting the scene: *CP* violation in mixing can be measured by looking at flavour-specific decays and the *CP*-violating observable defined by:

$$a_{\rm fs} = \frac{\Gamma(\bar{B}^0_q \to B^0_q \to f) - \Gamma(B^0_q \to \bar{B}^0_q \to \bar{f})}{\Gamma(\bar{B}^0_q \to B^0_q \to f) + \Gamma(B^0_q \to \bar{B}^0_q \to \bar{f})}$$

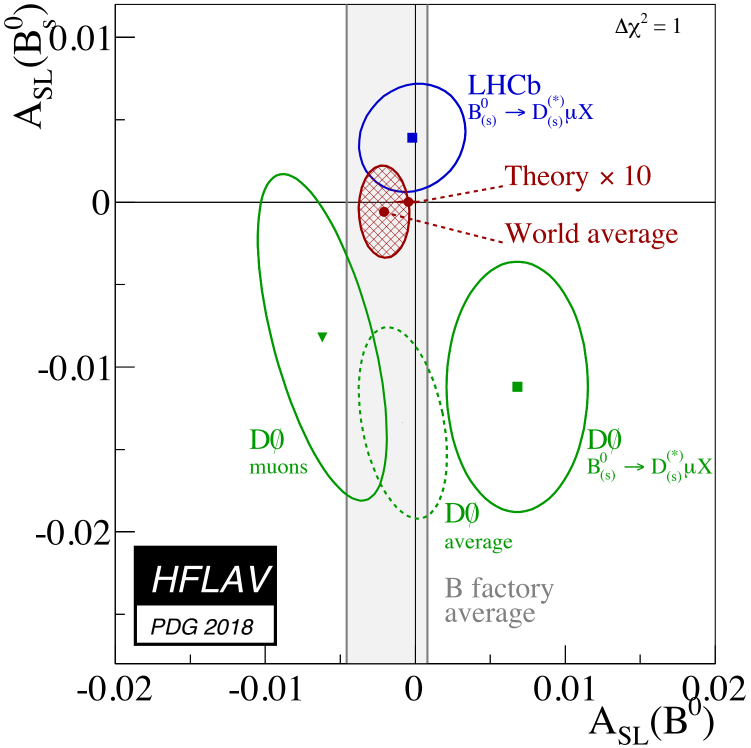
- The SM predictions reads:

$$a^d_{\rm sl} = -(4.7 \pm 0.6) \times 10^{-4}\,,$$
$$a^s_{\rm sl} = +(2.22 \pm 0.27) \times 10^{-5}.$$

CKMfitter

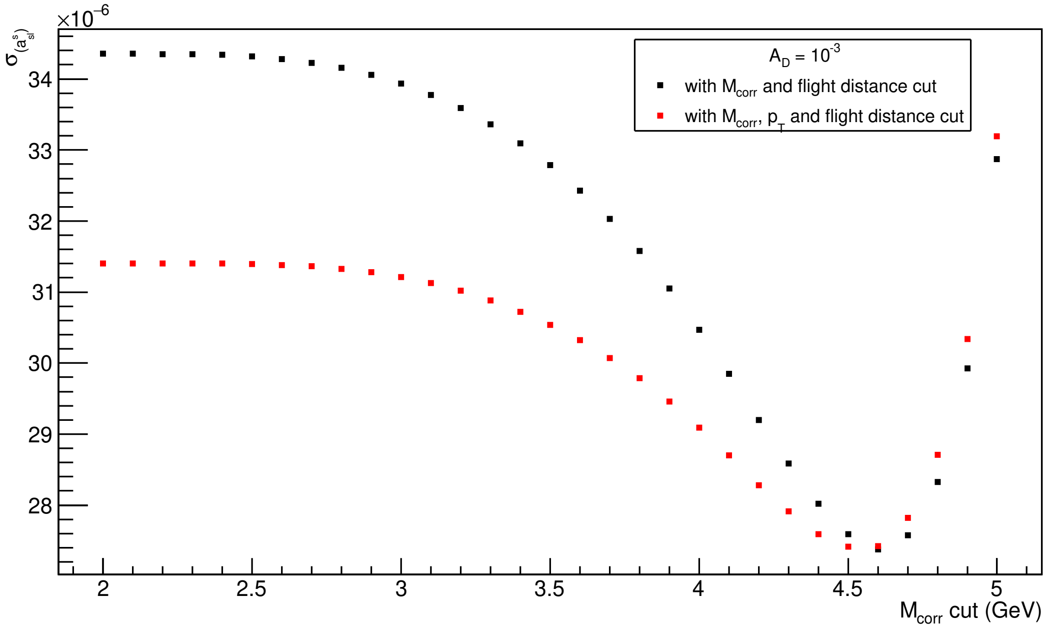
- Focus here on B_s (in for a penny…)

- The state of the art is at the level of few per mil precision.



The legacy of the Design Study: CKM (a_{sl} (d,s))

- Uncertainty scaling with one dimensional cut:



- Order of magnitude of the precision is at the level of the SM prediction. This exploratory study has to be ironed further. *e.g.* methods with the detection asymmetry precision has still to be determined.

- The most challenging flavour specific asymmetry seems at reach if SM prediction is considered.

Legacy of the Design Study: NP in mixings

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

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

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

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: $b \rightarrow f_i f_j f_k$ (i≠j≠k)). As a consequence, the quantities which do not receive NP contributions in that scenario are:

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

Legacy — putting this altogether: NP in mixings

Bottlenecks in the interpretation of CKM profile meas. identified (true already for LHCb U2) (2006.04824): $|V_{cb}|$ (normalisation matters) and QCD mixing parameters (not only decay constants and bag factors from LQCD; eta parameters as well).

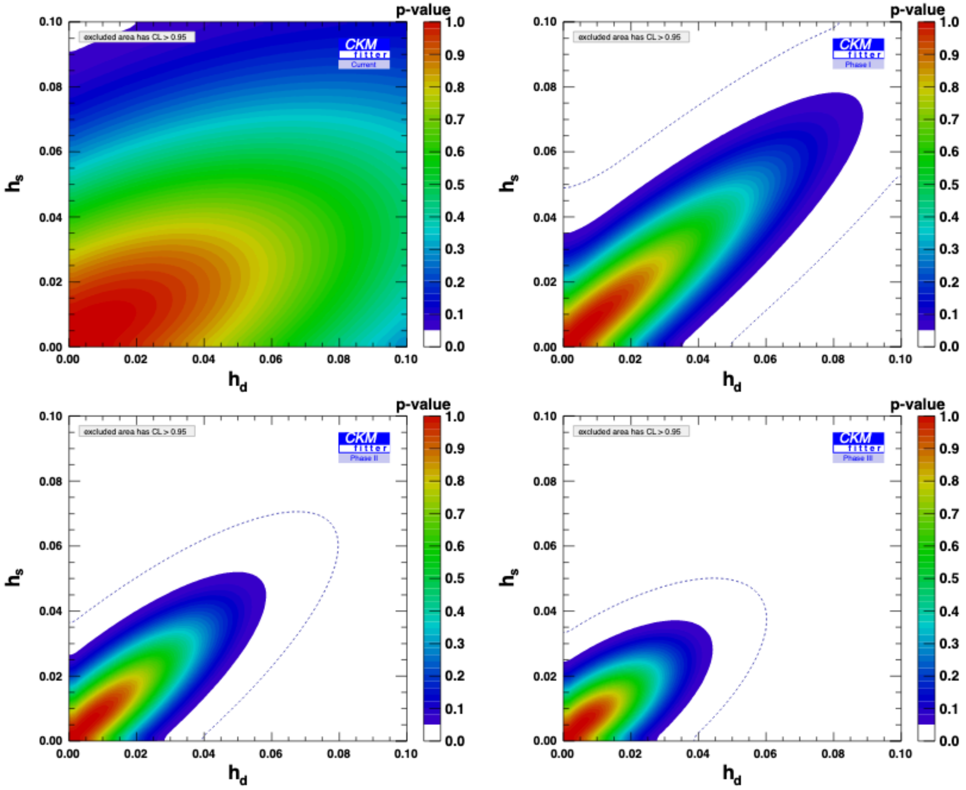


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

Legacy of the Design Study: NP in mixings

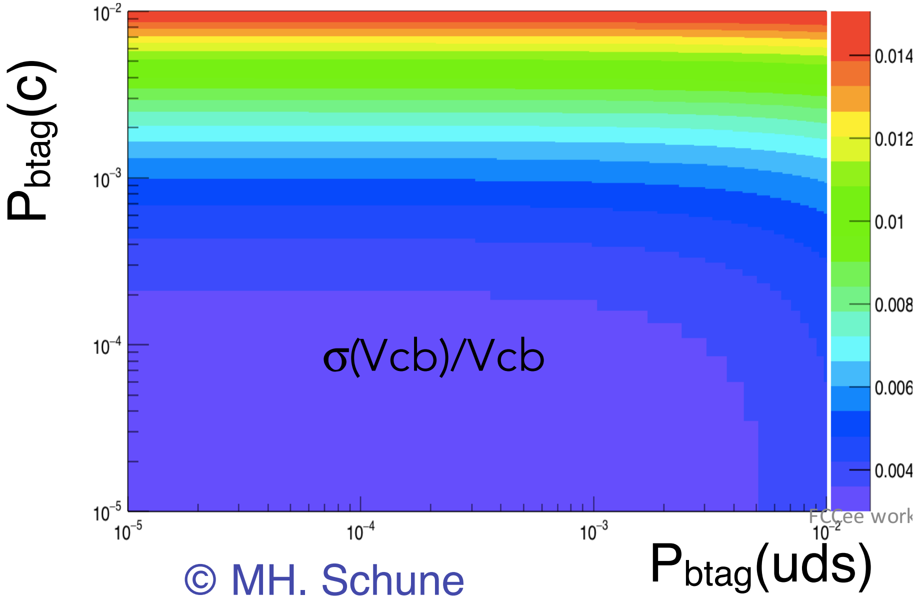
- Why am I insisting on showing this?
  - Back in early 2010s, the *B*-factories results had established the KM paradigm as a tremendous success of the SM.
  - Yet, a single measurement at the time (it was the first observation of $B^+ \rightarrow \tau^+ \nu$:) came and has shaken the edifice.
  - It was receiving a “natural” explanation with additional amplitudes contributing to the neutral meson mixing processes.
  - The precision improved and SM stroke back but the precision nowadays is yet limited at 25% on the BF.
  - Re-enforces the need to get that measurement better and the quasi-model-independent NP in mixings at the adequate precision.

Legacy of the Design Study: NP in mixings

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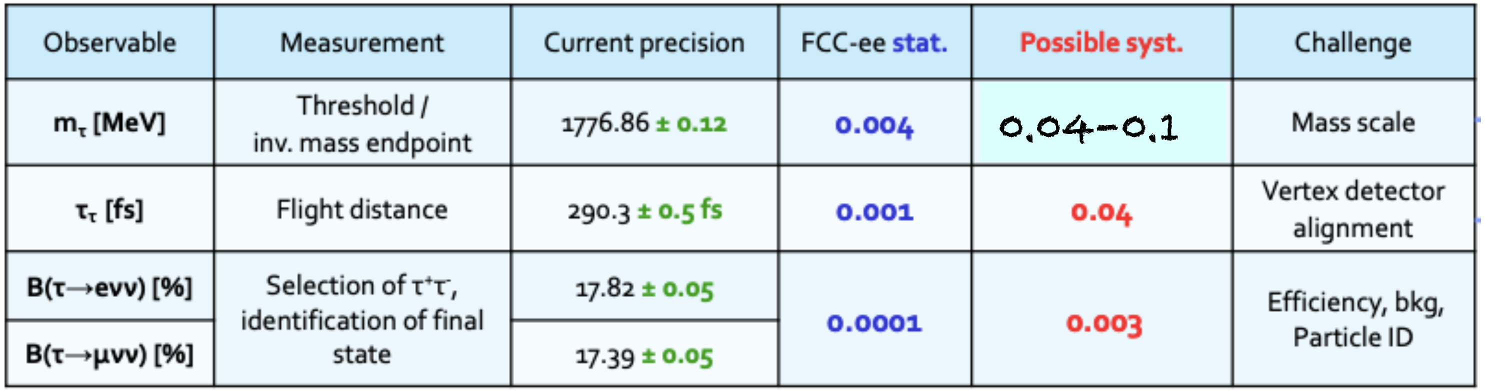
- With these state-of-the-art inputs, precision on $|V_{cb}|$ improves from 1.9% (current) to 0.4%. Ultimate statistical precision is $O(10^{-4})$.

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

Legacy of the Design Study: 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	0.04–0.1	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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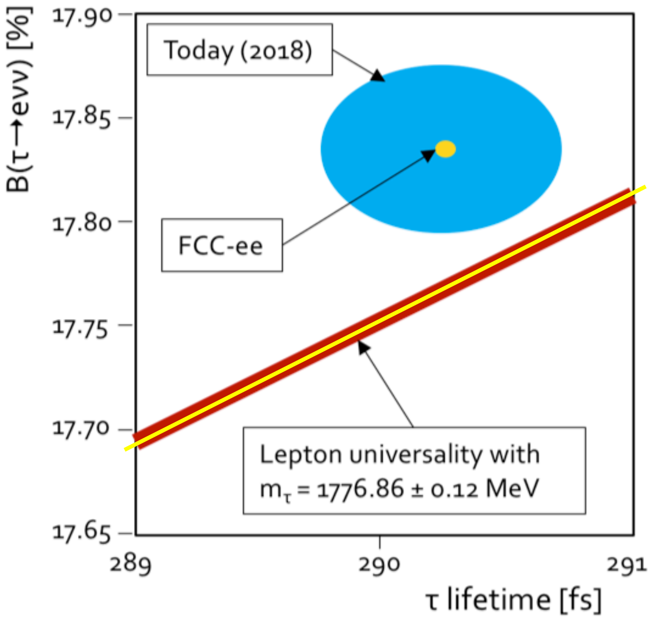
Necessary ingredients:

- Mass
- Lifetime
- Leptonic branching fractions



Legacy of the Design Study: cLFV Z decays

- Lepton Flavour-Violating Z decays in the SM with lepton mixing are typically $< 10^{-50}$.

- Any observation of such a decay would be an indisputable evidence for New Physics. FCC-*ee* exploration [JHEP 1504 (2015) 051].

- $Z \to \tau\mu$ is likely unique to FCC-ee.

- The dominant background is ($Z \to \tau\tau$), where one tau decays into a close-to-beam-energy lepton. The search is limited by the momentum resolution. A lot of phenomenology to explore yet.

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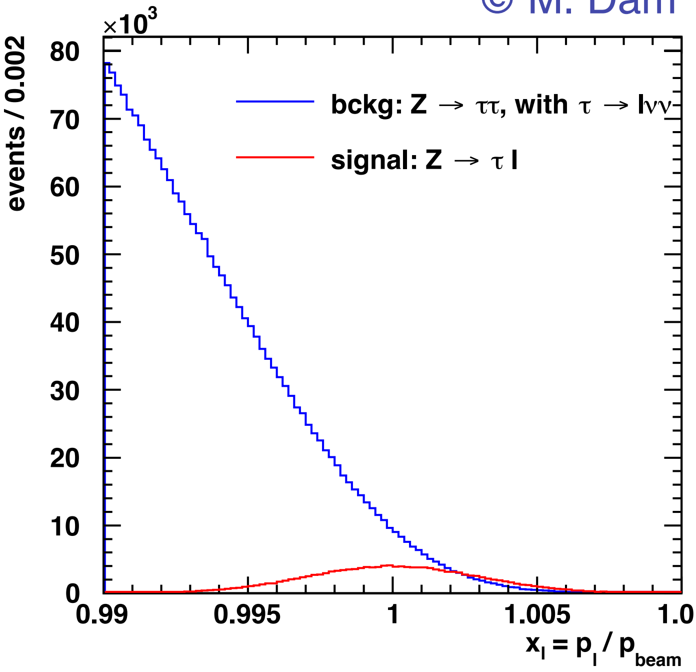


Bottomline: With the expected tracking performance at FCC-*ee* , the current limits are pushed by three orders of magnitude.

Legacy of the Design Study: Tau lepton physics

- A non-exhaustive Tau Physics advantages and prospects :
  - About 200 billions of tau pairs at the *Z* pole.
  - 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.
  - 2-3 orders of magnitude w.r.t. state of the art in sensitivity for LFV Z decays. 1-2 orders of magnitude for actual LFV tau decays.
  - Hadronic branching fractions, spectral functions, strong coupling constant: the QCD program with tau is rich.

Towards benchmarks in the feasibility study

- Aparté: other physics avenues that we'll have to address in conjunction with other working groups

7. Heavy flavours EWPO Rb,c and AFB(bb,cc)

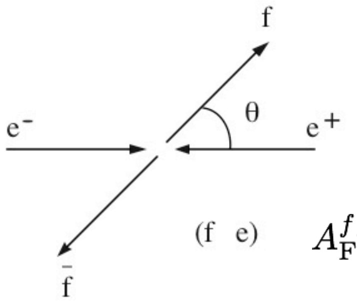
8. Connecting b, HF EWPO and top observables

4) Aparté about Avenue 7.

- The measurement of the forward-backward asymmetry of the *b* quark in *Z* decays is primarily meant for *Ab* determination, since muons will drive the determination of $\sin^2\theta_W$.

$$\frac{\mathrm{d}\sigma^f}{\mathrm{d}\cos\theta} = \sigma^f_{\mathrm{tot}} \cdot [\frac{3}{8}(1+\cos^2\theta) + A^{f\bar{f}}_{\mathrm{FB}}\cos\theta]$$

$$A^{f\bar{f}}_{\mathrm{FB}} = \frac{N_F - N_B}{N_F + N_B} \text{ with } N_F = \int_0^1 \frac{\mathrm{d}\sigma_{f\bar{f}}}{\mathrm{d}\cos\theta} \cdot \mathrm{d}\cos\theta$$



$$A^{f\bar{f}}_{\mathrm{FB}} \propto A_e \cdot A_f \propto \frac{g^e_V g^e_A}{(g^e_V)^2 + (g^e_A)^2} \cdot \frac{g^f_V g^f_A}{(g^f_V)^2 + (g^f_A)^2}$$

- Explore exclusive *b*-hadron decays (B^+ *or* Λ_b) reconstruction to benefit of the *Z* pole statistics, *e.g.* $B^- \rightarrow D^0\pi^-$, $D^0\pi^-\pi^+\pi^-$ [10^{-2}] followed by $D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^+\pi^-$, $K_S^0\pi^+\pi^-$ [15.10^{-2}], $\Lambda_b \rightarrow \Lambda_c\pi^+$, $\Lambda_c\pi^+\pi^-\pi^-$ [10^{-2}] followed by $\Lambda_c \rightarrow p K^-\pi^+$ [$7.\ 10^{-2}$] —> A billion of them.

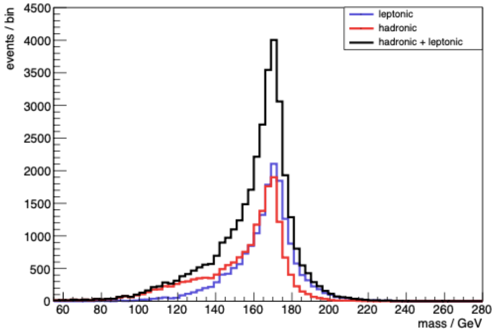
- Limitations of LEP-like measurements of A_{FB}(b) are overcome: mixing dilution with lepton tags, purity of the sample, QCD corrections (gluon radiations).

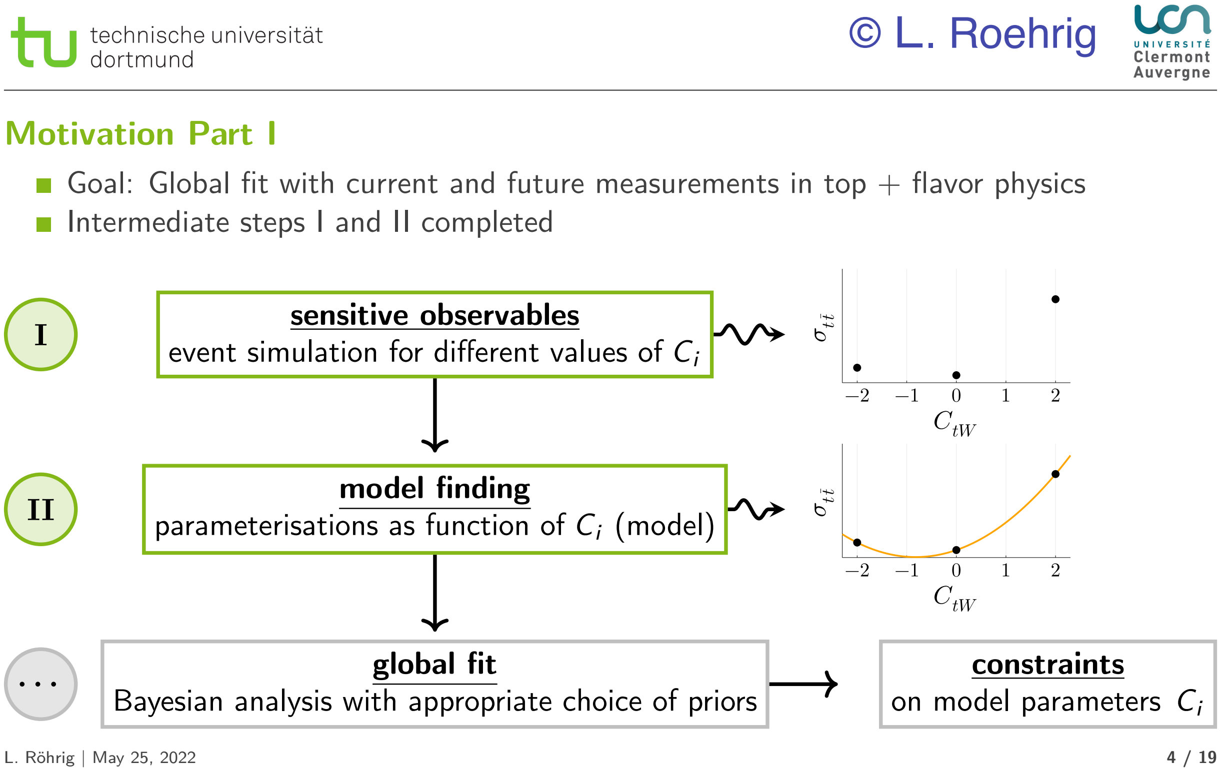
- Same rationale / virtues for the Z —> bb partial width (for correlations systematics).

4) Aparté about Avenue 8.

- Embrace top quark, *Z* pole and Flavour observables to operate a SMEFT analysis. Exercised first with top quark:

Very first look at simulated ttbar events





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Motivation Part I

- Goal: Global fit with current and future measurements in top + flavor physics
- Intermediate steps I and II completed

I — **sensitive observables**: event simulation for different values of C_i

II — **model finding**: parameterisations as function of C_i (model)

… — **global fit**: Bayesian analysis with appropriate choice of priors → **constraints** on model parameters C_i

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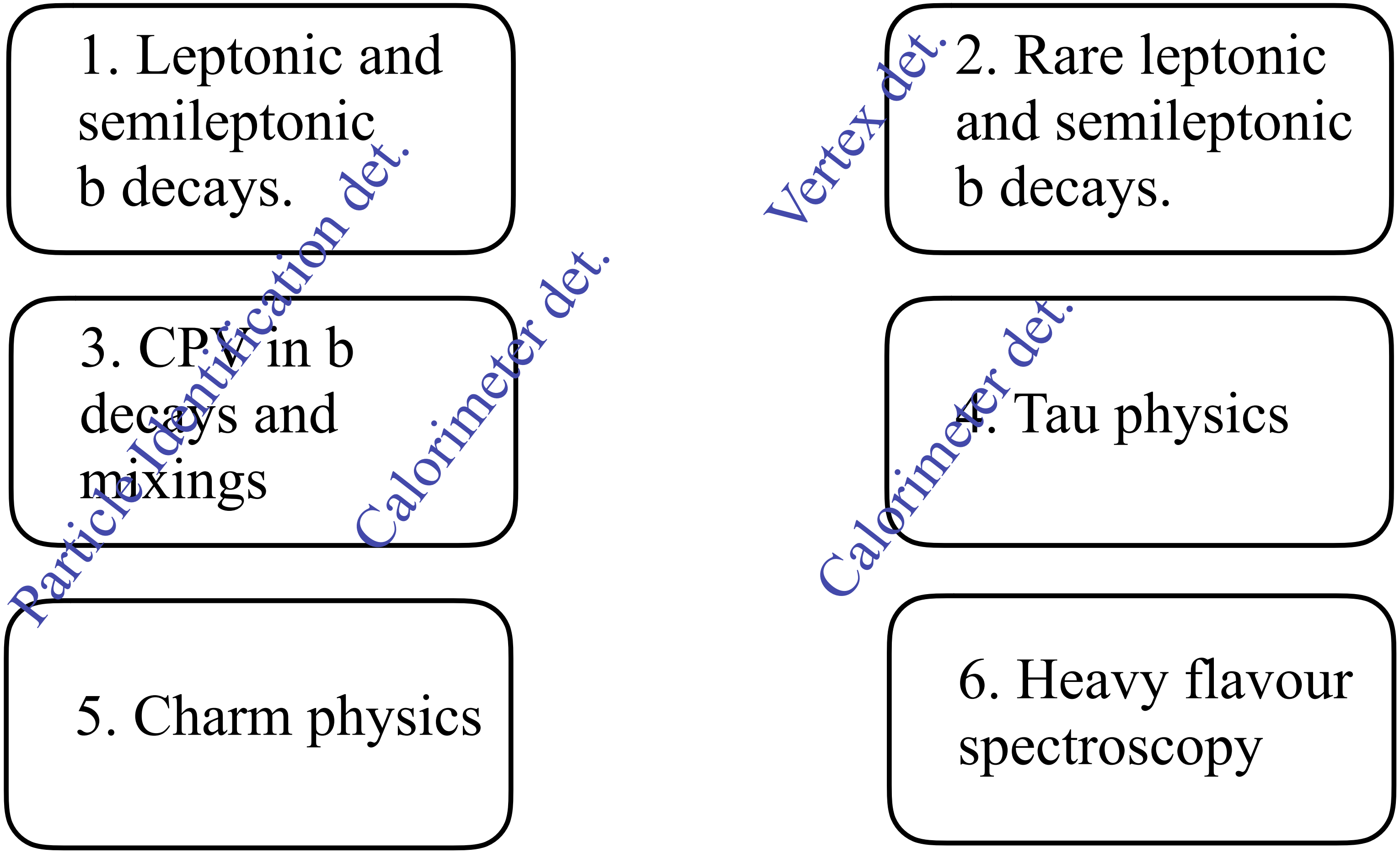
4) Towards benchmarks in the feasibility study

- The physics avenues and the detector requirements



1. Leptonic and semileptonic b decays.

2. Rare leptonic and semileptonic b decays.

3. CPV in b decays and mixings

4. Tau physics

5. Charm physics

6. Heavy flavour spectroscopy

4) Towards benchmarks in the feasibility study

- 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.

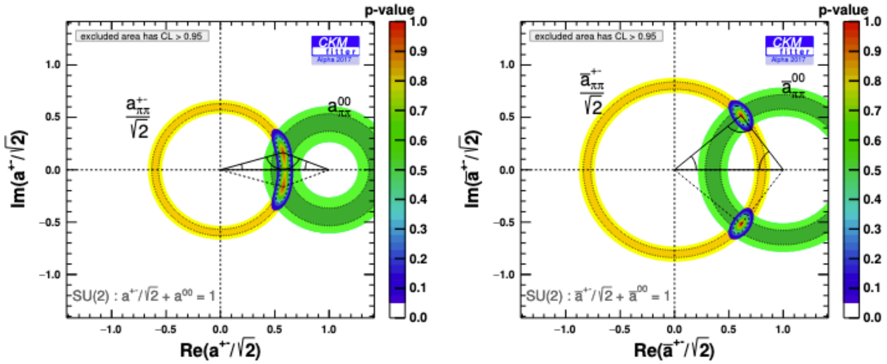


Figure 4: *Constraint on the reduced amplitude* $a^{+-} = A^{+-}/A^{+0}$ *in the complex plane for the* $B \to \pi\pi$ *(left) and* $\bar{B} \to \pi\pi$ *systems (right). The individual constraint from the* $B^0(\bar{B}^0) \to \pi^+\pi^-$ *observables and from the* $B^0(\bar{B}^0) \to \pi^0\pi^0$ *observables 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.

4) Towards benchmarks in the feasibility study

- Ideas of benchmarks for detector requirements:
  - The vertex detector: $b \to s\tau^+\tau^-$. Most demanding. Vertex reconstruction at with low momentum particles.
  - The particle identification: $B_s \to DsK$. The exquisite separation of B_d and B_s makes PID relevant for partially reconstructed decays. Maybe charmless multibody *b*-hadrons decays are more demanding.
  - The calorimeter: $B^0 \to (\pi^0\pi^0)$, $b \to s,d\, ee$, radiative decays $b \to s,d\, \gamma$, [Everything is to be started here], $B_s \to D_sK$ again (D_s decays w/ π^0,γ) [introduced by Roy et al.]
- All the rest of the case to be used to assess the performance of the detector concepts.

5) Summary: matrices of actions / people

1. Leptonic and semileptonic decays

Mode	DELPHES study	Detector requirement	Institute
$B^+ \to \tau\nu$	✓		KIT
$B_c \to \tau\nu$	✓		KIT
$\lvert V_{cb}\rvert$ and $\lvert V_cs\rvert$ from WW	(✓)	tag., PID	
$\lvert V_{cb}\rvert$ and $\lvert V_{ub}\rvert$ from SL			

2. Rare leptonic and semileptonic decays

Mode	DELPHES study	Detector requirement	Institute
$B^0 \to K^{*0}\tau^+\tau^-$	✓	Vertex	Clermont
$b \to s\nu\overline{\nu}$	(✓)	Calorimeter	Warwick,IJCLab
$B_s \to \tau^+\tau^-$		Vertex	
$b \to s(d)\ell^+\ell^-$			
$B_{s,d} \to \ell^+\ell^-$	(✓)		

3. CPV in b decays and mixings

Mode	DELPHES study	Detector requirement	Institute
$B_s \to D_s^{\pm}K^{\mp}$	✓	PID, Calorimeter	CEA, CERN
$B_s \to \phi\phi$	✓	PID	CEA, CERN
$a_{\rm sl}^{(d,s)}$	(✓)		Clermont, MSU
$B^0 \to \pi^0\pi^0(\to e^+e^-\gamma)$		Calorimeter	

5) Summary: matrices of actions / people

- To state the obvious from these matrices, the critical aspect is person power.
- The way out can come with joint PhD. or post-doc projects LHC/FCC.
- This can also come from more senior physicists, provided this does not require a significant training.
- In order to get that, analysis tools making the analyst feeling at home are in order. To accompany the gigantic efforts by the FCC sw and PED teams, the Flavour group shall provide easy to use discriminate variables functors to design straightforward selections.
- More widely, a (certainly) successful model is to gather small TH / EXP groups and target an actual publication related to the project.