CKM matrix elements from W decays

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Motivation

The **knowledge of CKM matrix elements**, V_{cb} and V_{ub} in particular, is **crucial** to derive the strongest possible constraints on new physics from rare meson decays and meson mixing observables.

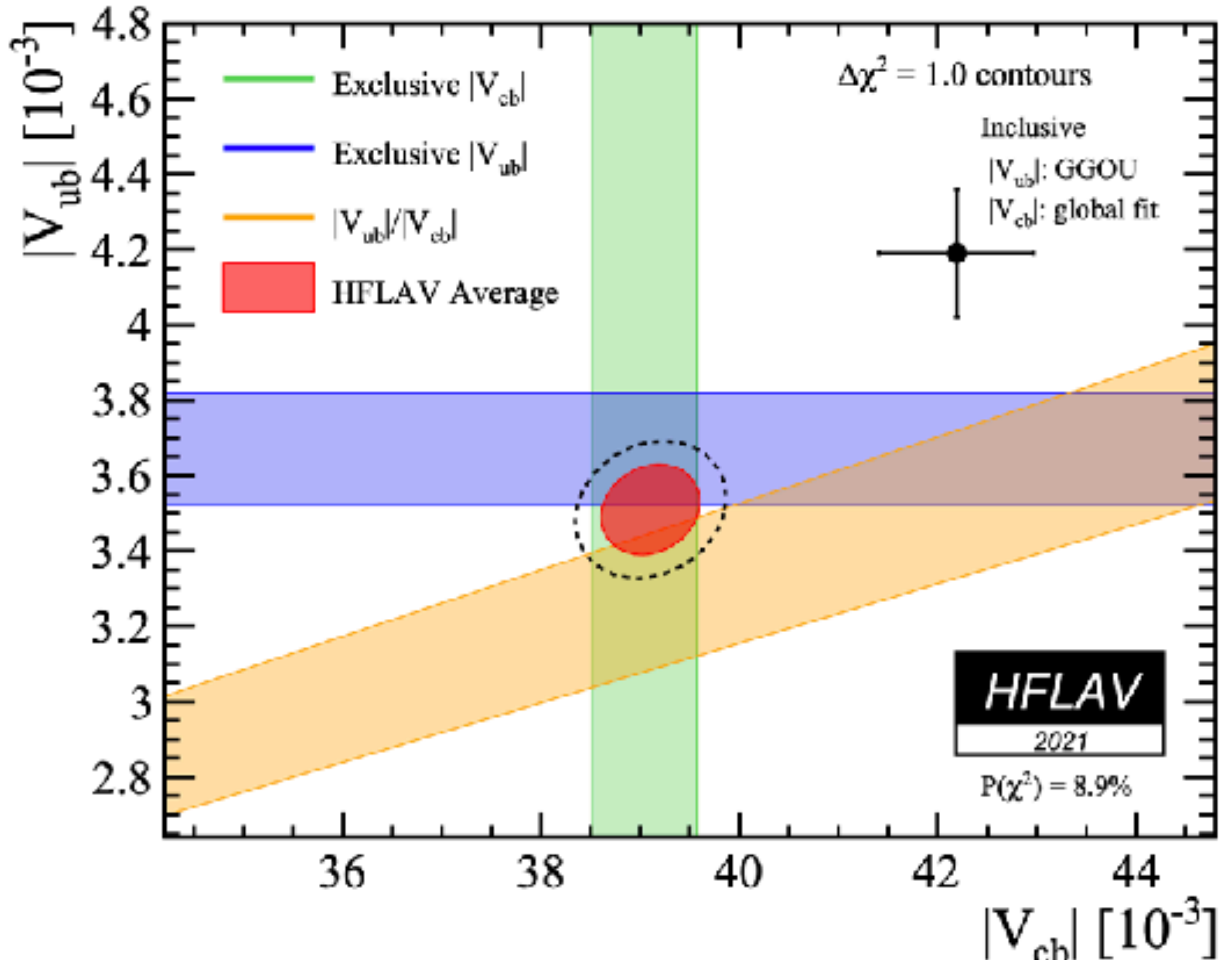
The extraction of **V_{cb} from semileptonic B decays** will be **limited by systematics**:

[2006.04824]	Central values	Current [18]	LHCb 50/fb, Belle II 50/ab Phase I	LHCb 300/fb, Belle III 250/ab Phase II
$\lvert V_{cb}\rvert_{W\to cb} \times 10^3$	42.26	±0.58	±0.60 *	±0.44 *

This will **hamper the New Physics sensitivity** of the precision measurements from rare processes

* Include expected lattice precision in 10y [1808.10567]

Furthermore, at present the V_{cb} extraction from **inclusive vs. exclusive** decays are in **tension**.



Example [from 2006.04824]

Let us consider New Physics contributions in **$B_{s,d}$ mixing**

$$M_{12} = (M_{12})_{\rm SM} \times (1 + h_{d,s} e^{2i\sigma_{d,s}})$$

$\sigma_{d,s}=0$ for MFV New Physics

Only a minor improvement in sensitivity from Phase-I to Phase-III, despite the substantial increase in statistics.

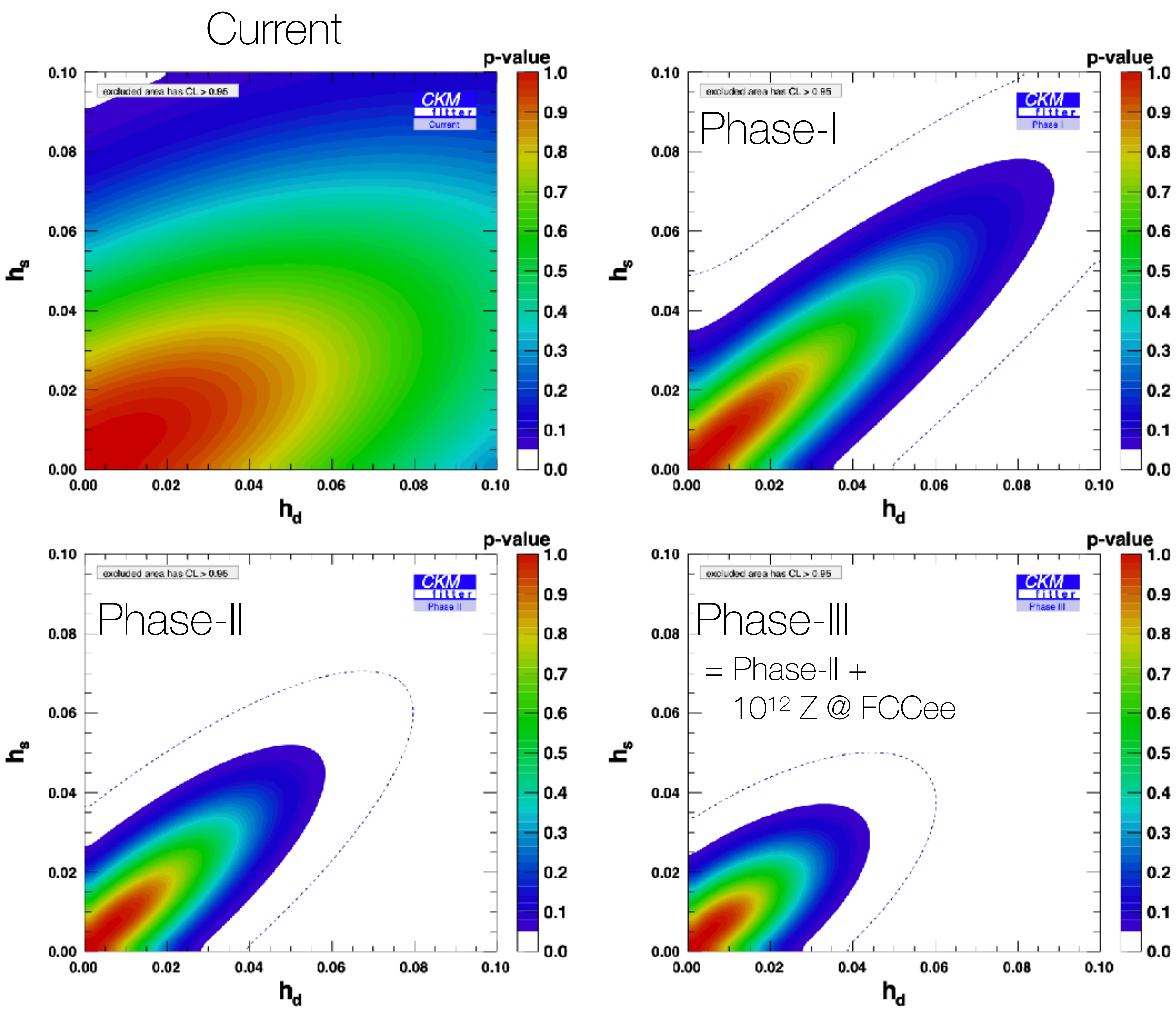
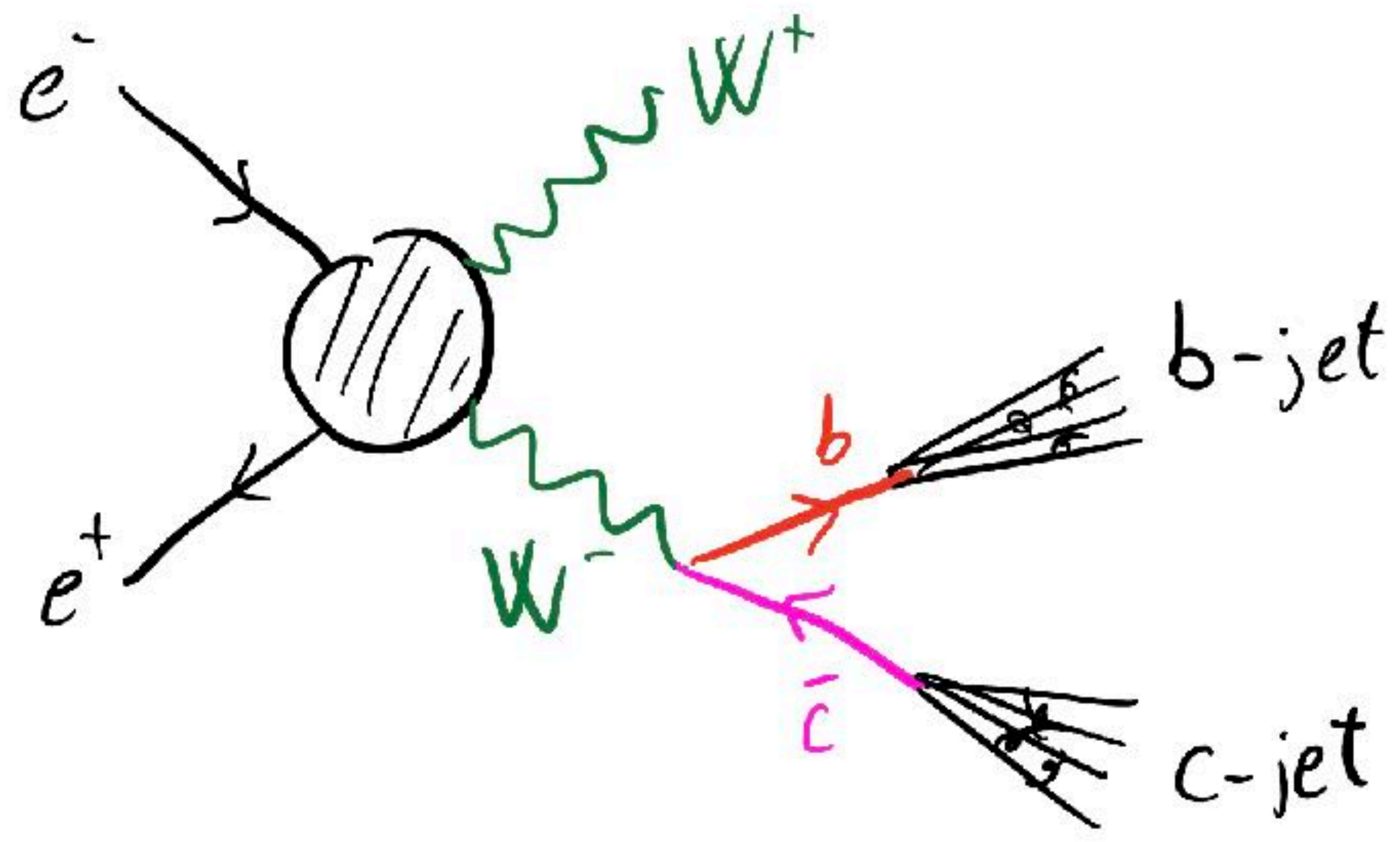


FIG. 2. Current (top left), Phase I (top right), Phase II (bottom left), and Phase III (bottom right) sensitivities to $h_d - h_s$ in B_d and B_s mixings, resulting from the data shown in Table I (where central values for the different inputs have been adjusted). The dotted curves show the 99.7% CL (3σ)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

Motivation



Extracting V_{cb} **directly from on-shell W decays** could provide:

1) A completely **independent measurement** of a crucial input for flavour physics.

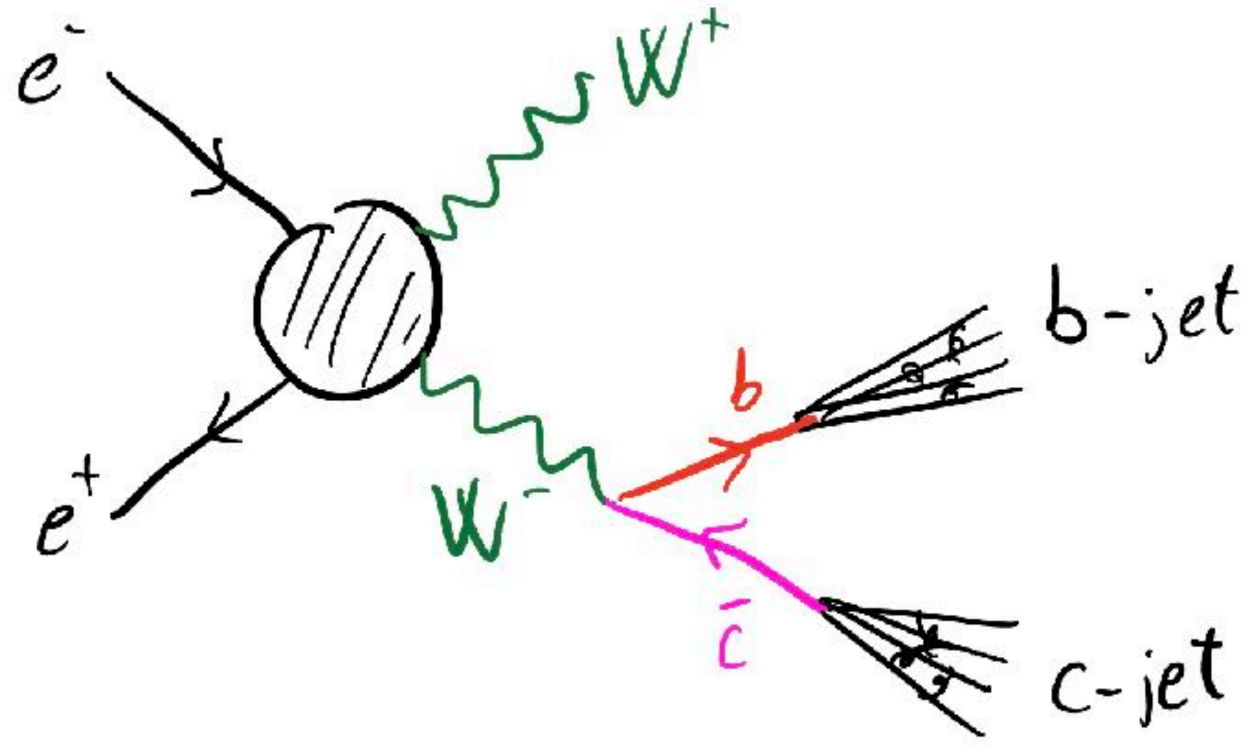
2) A measurement **independent from Lattice QCD** inputs: a possible benchmark for LQCD?

3) A way to **improve the precision** beyond the one from semileptonic B decays. **Quantify?**

The scope

Assuming **10^8 W** pairs:

$W^- \to$	$\bar{u}d$	$\bar{u}s$	$\bar{u}b$	$\bar{c}d$	$\bar{c}s$	$\bar{c}b$
$\mathcal{B}$	31.8%	1.7%	4.5×10^{-6}	1.7%	31.7%	5.9×10^{-4}
N_{ev}	64×10^6	3.4×10^6	900	3.4×10^6	63×10^6	118×10^3



All the other modes represent backgrounds for the c-b channel.

Crucial the **jet flavour tagging performance**: tagging efficiency and jet mis-id performance.

**** Other than Vcb, what could be the achievable precision on the other CKM matrix elements? ****

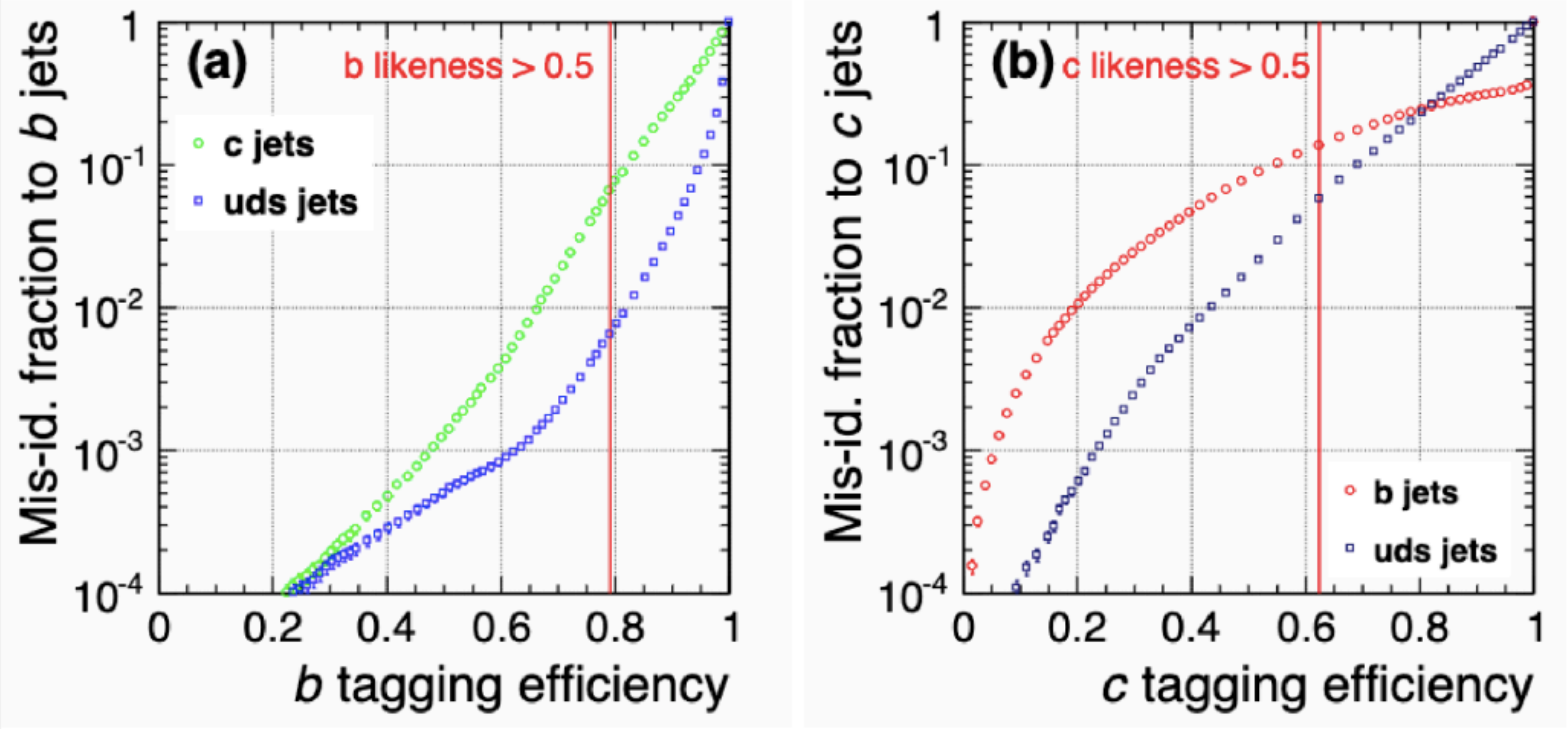
Assuming a "perfect jet flavour tagging", the statistical precision achievable in each CKM ME would be:

N_W	$\|V_{ud}\|$	$\|V_{us}\|$	$\|V_{ub}\|$	$\|V_{cd}\|$	$\|V_{cs}\|$	$\|V_{cb}\|$
10^6	0.063 %	0.27 %	17 %	0.27 %	0.063	1.5 %
10^7	0.020 %	0.086 %	5.3 %	0.086 %	0.020	0.46 %
10^8	0.0063 %	0.027 %	1.7 %	0.027 %	0.0063	0.15 %
10^9	0.0020 %	0.0086 %	0.53 %	0.0086 %	0.0020	0.046 %

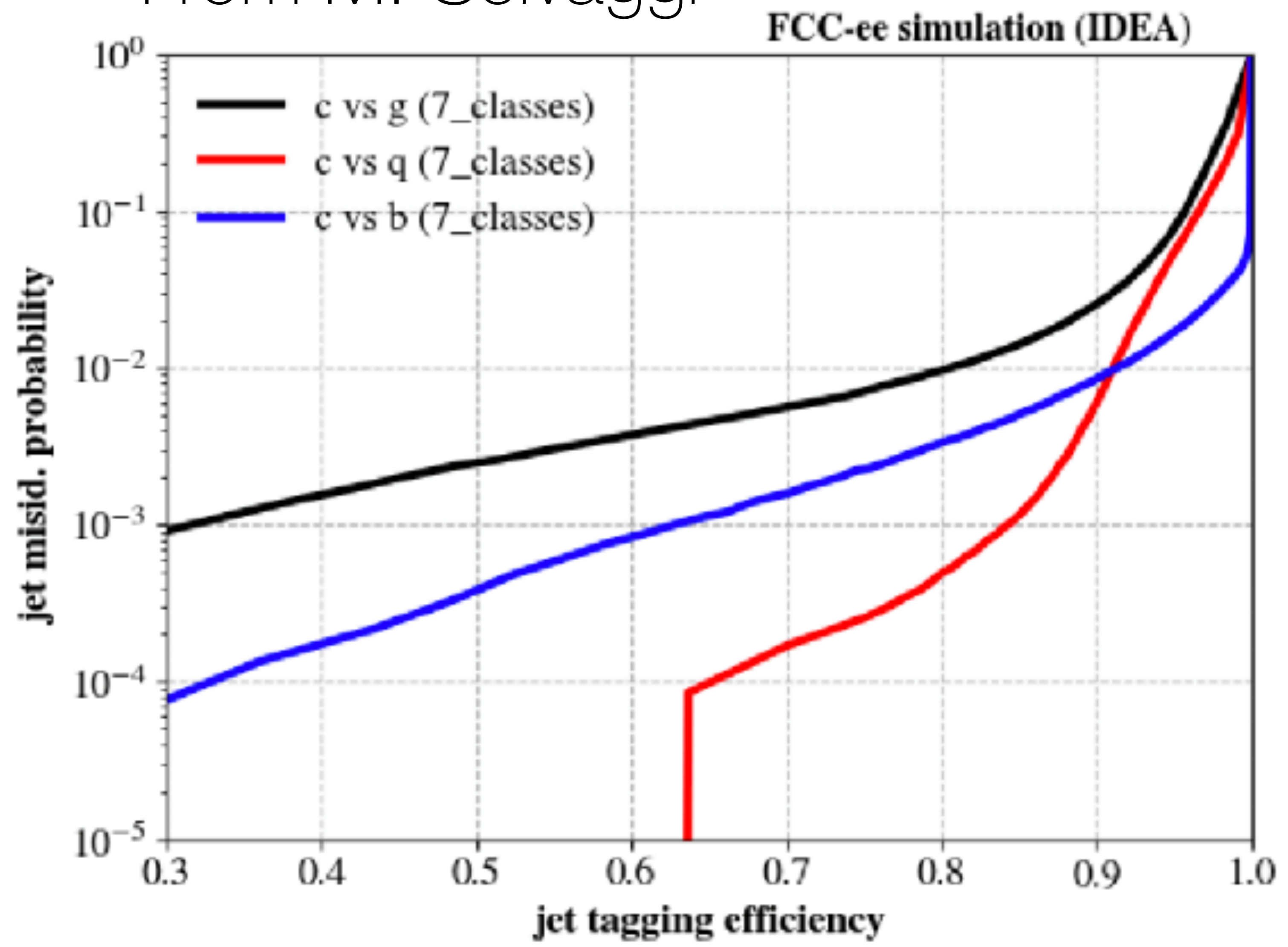
Table 2: Theoretical upper limit on the statistical precision $\delta_{V_{ij}}$ in each CKM matrix element from W decays, as function of the total number of W pairs produced, N_W, assuming 100% reconstruction efficiency.

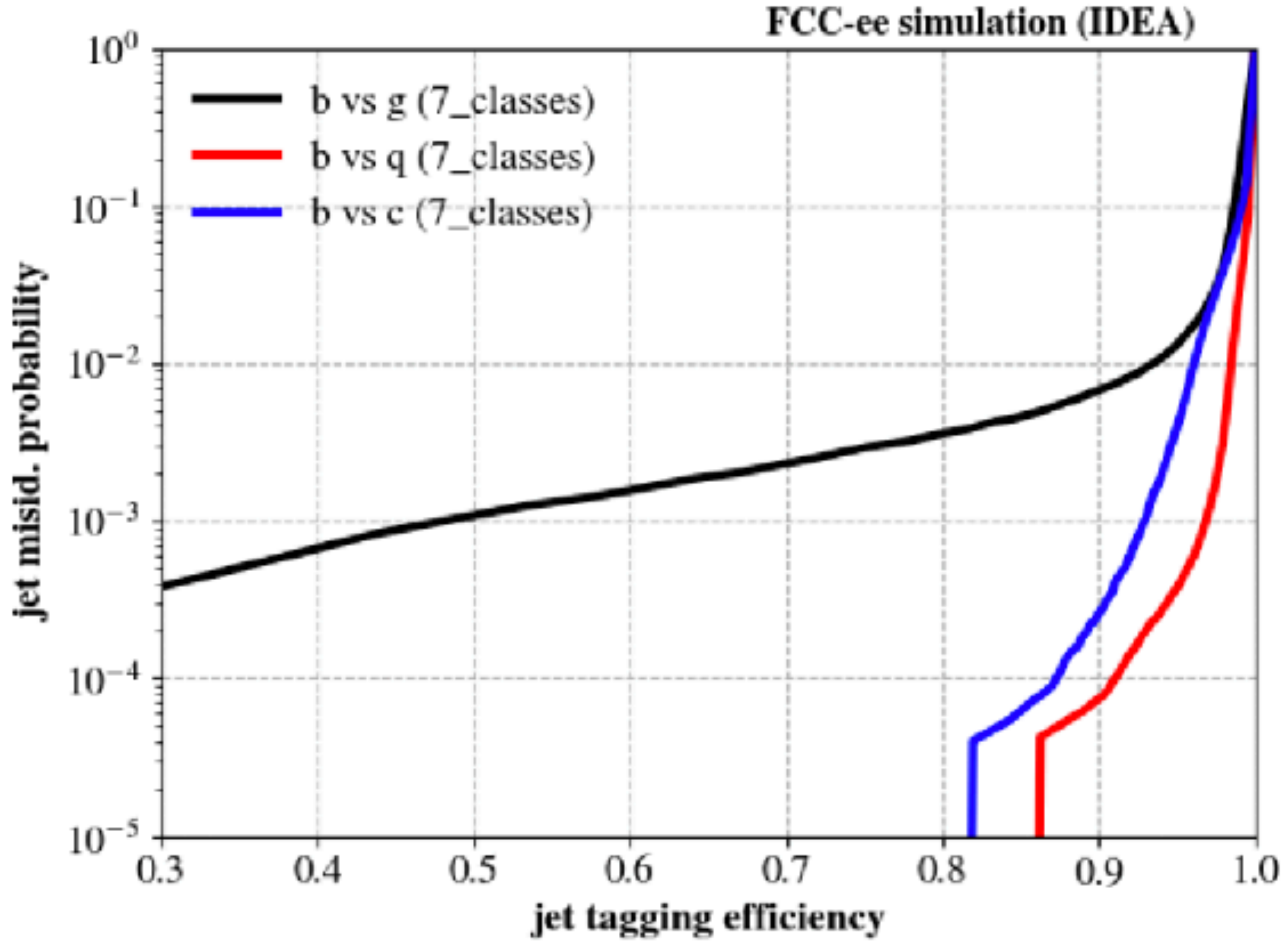
Flavour Tagging performance

- 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



From M. Selvaggi





A first estimate

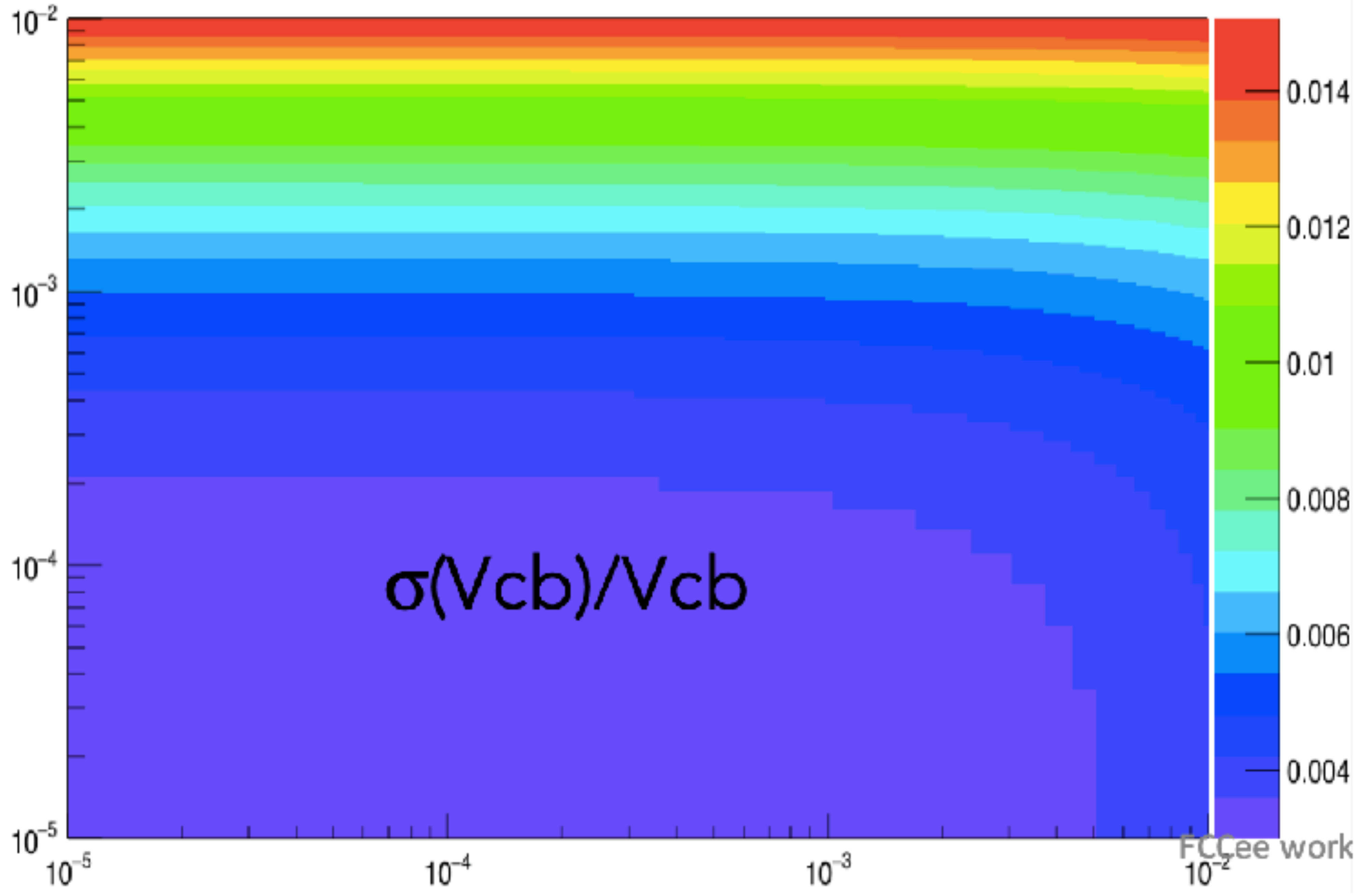
From Marie-Hélène Schune 's talk at FCCee workshop in January 2020

	b	c	uds
Eff b-jet tagger	25%		
Eff c-jet tagger	10%	50%	2%

Numbers inspired by:

ILD@ILC
Tracking and Vertexing at Future Linear Colliders: Applications in Flavour Tagging
Tomohiko Tanabe (U Tokyo)
IAS Program on High Energy Physics 2017, HKUST

bTag_c



bTag_uds

relative precision on Vcb 0.4 % ?
(now 1.5%)

Very first look !

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Discussion inputs

Preliminaries:

- What is the **ultimate precision on V_{cb}** (and $\mathbf{V_{cs}}$, and the other matrix elements) from Belle-II and LHCb?
- Are the **motivations** presented here enough?

From W decays:

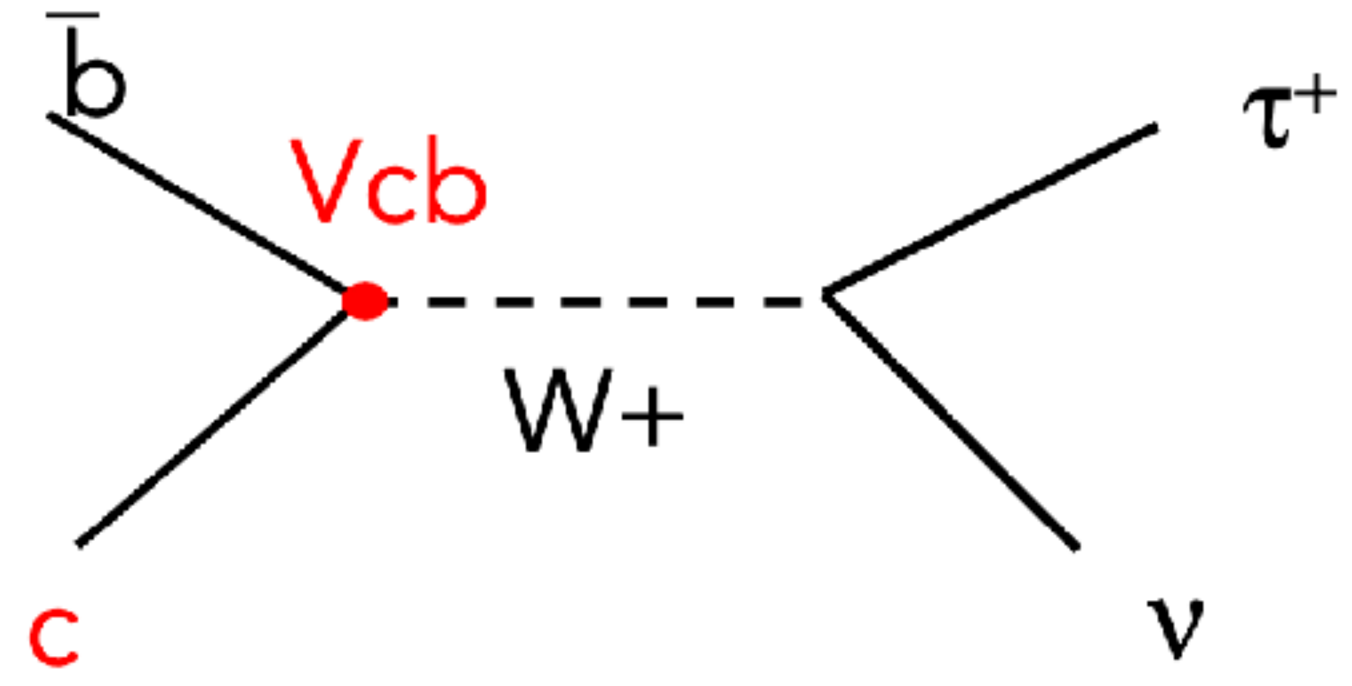
- Review of the **state-of-the-art Flavour Tagging** (FT) algorithms (**detector requirements?**)
- FT **calibration** methods and related **systematics**.
- Estimate the precision reachable in **all accessible CKM matrix elements**.

Extra:

- What about **Z pole**: assess what is possible (e.g. 1% precision on V_{cb} from $B_c \to \tau\nu$) ?

Extra

V_{cb} from $B_c \rightarrow \tau\nu$



$$\Gamma_{SM}(P^+ \to \ell^+\nu_\ell) = \frac{G_F^2}{8\pi}|V_{Qq}|^2 f_P^2 M_P m_\ell^2 (1 - \frac{m_\ell^2}{M_P^2})^2$$

with NP :
$$\Gamma_{H^\pm}(P^+ \to \ell^+\nu_\ell) = \Gamma_{SM}(P^+ \to \ell^+\nu_\ell) \times \left(1 - \frac{\tan^2\beta}{M_H^2} M_P^2\right)^2$$

Large missing energy
Use of the other hemisphere

About 20 10^6 $B_c \rightarrow \tau\nu$ with $\tau \rightarrow e/\mu\nu$ produced

1% precision should be achievable

$$\frac{N_{B_c}}{N_{B_u}} = \frac{f(b \to B_c)}{f(b \to B_u)} \left|\frac{V_{cb}}{V_{ub}}\right|^2 \left(\frac{f_{B_c}}{f_{B_u}}\right)^2 \frac{m_{B_c}}{m_{B_u}} \frac{\tau_{B_c}}{\tau_{B_u}} \frac{(1 - \frac{m_\tau^2}{m_{B_c}^2})^2}{(1 - \frac{m_\tau^2}{m_{B_u}^2})^2} \sim 1$$

	B_u	B_c
Mass	~5280 MeV	~6275 MeV
Lifetime	~1.5 ps	~0.5 ps

$\Rightarrow$ discrimination should be possible

Use of $B_c(2S) \rightarrow B_c\,\pi\pi$?

FCCee workshop January 2020