Future experimental prospects

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- Motivation and players
- Semi-leptonic b-hadrons decays
- Other ways

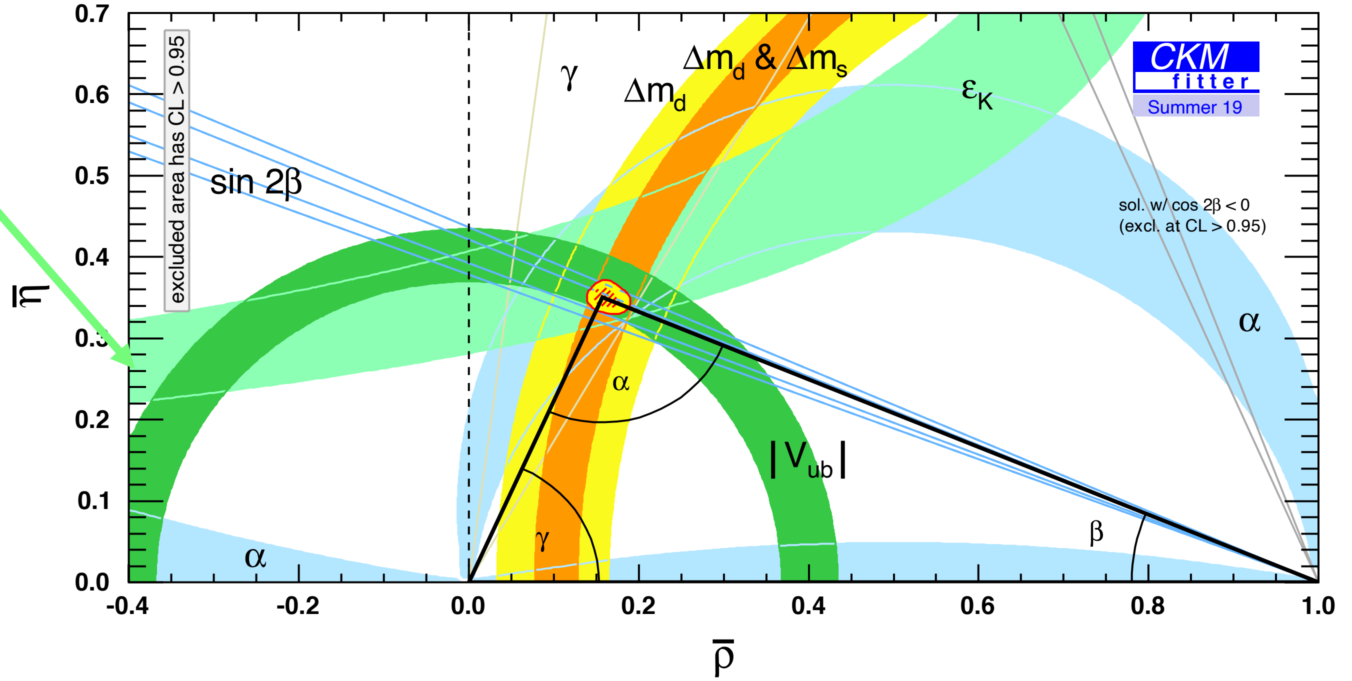
Thanks to Racha, Patrick, Florian and Paolo : many plots are coming from their slides.

Apologies for all the missing references

Motivation and players

A precise knowledge is important

$\propto V_{cb}^4$



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

Crucial for indirect NP searches
Neutral meson mixing

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

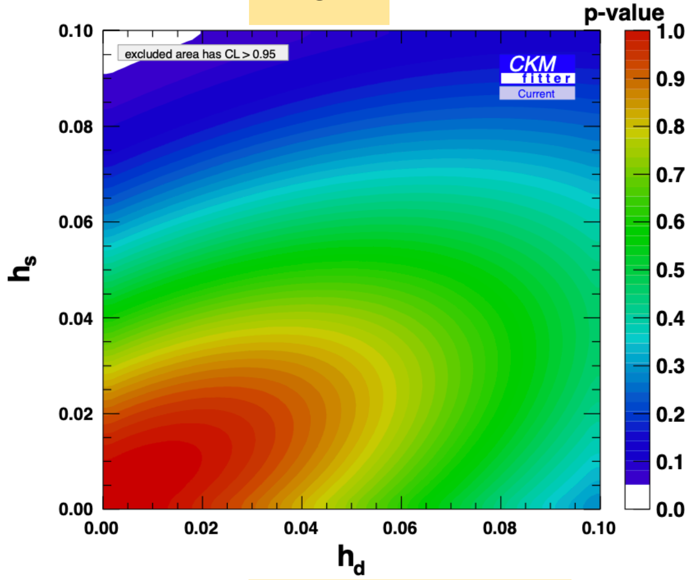
$$\frac{C_{ij}^2}{\Lambda^2}$$

$$\lambda_{ij}^t = V_{ti}^* V_{tj}$$

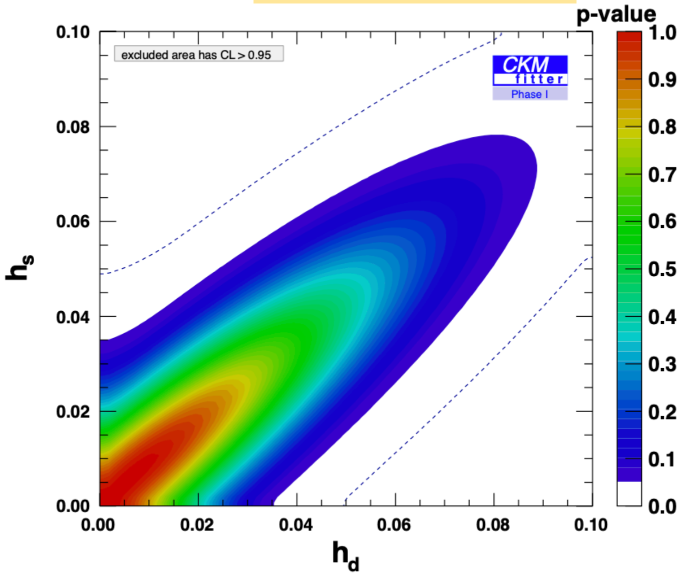
$$\sigma = \arg\left(C_{ij}\, \lambda_{ij}^{t*}\right),$$

arXiv:2006.04824

Now

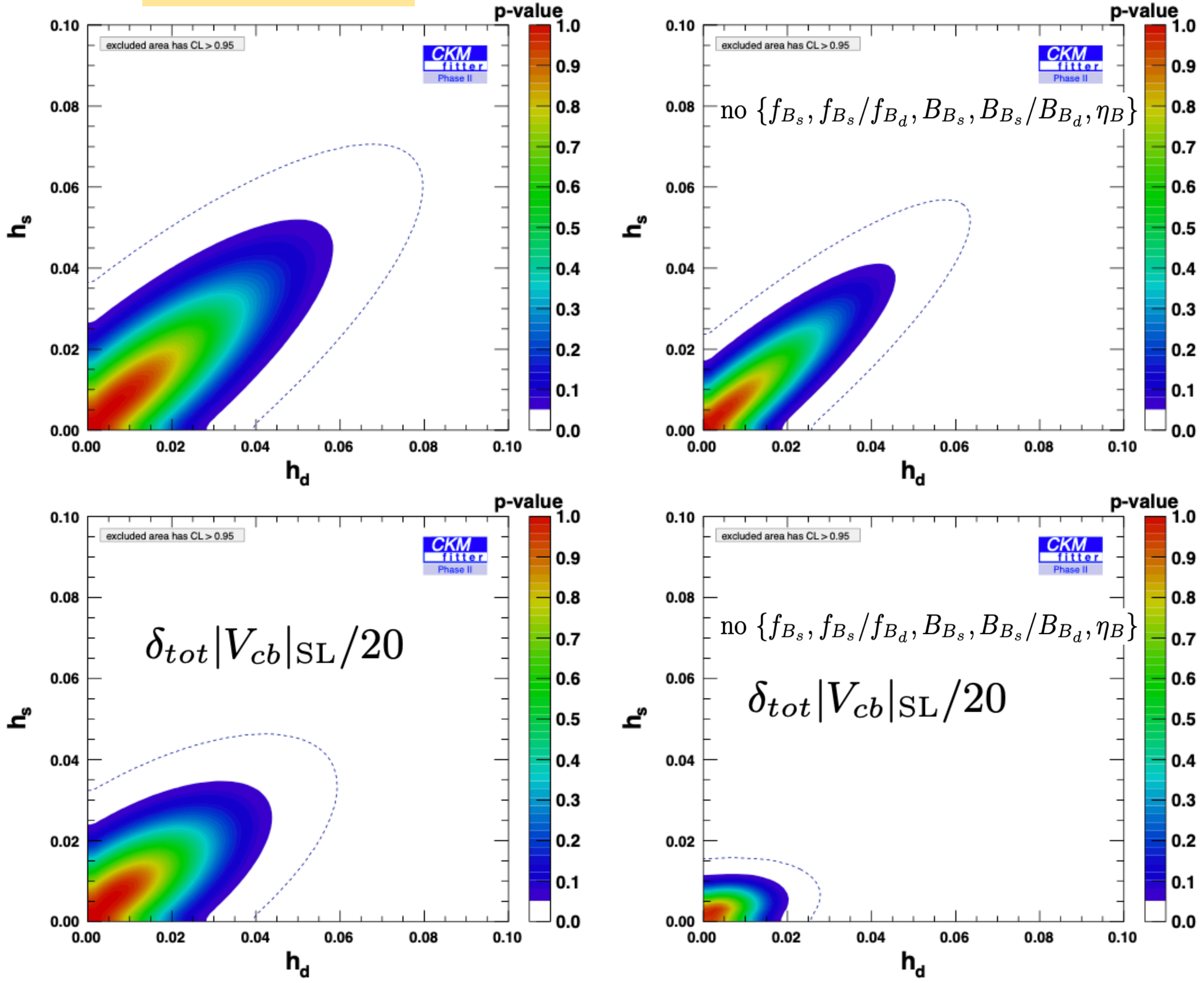


End of 2020s

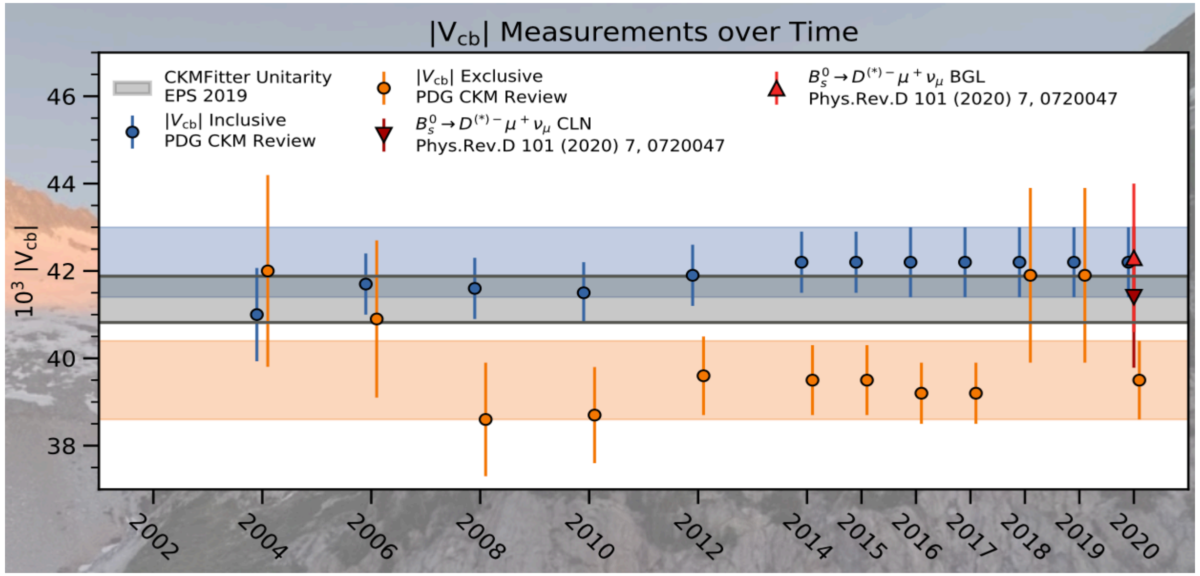


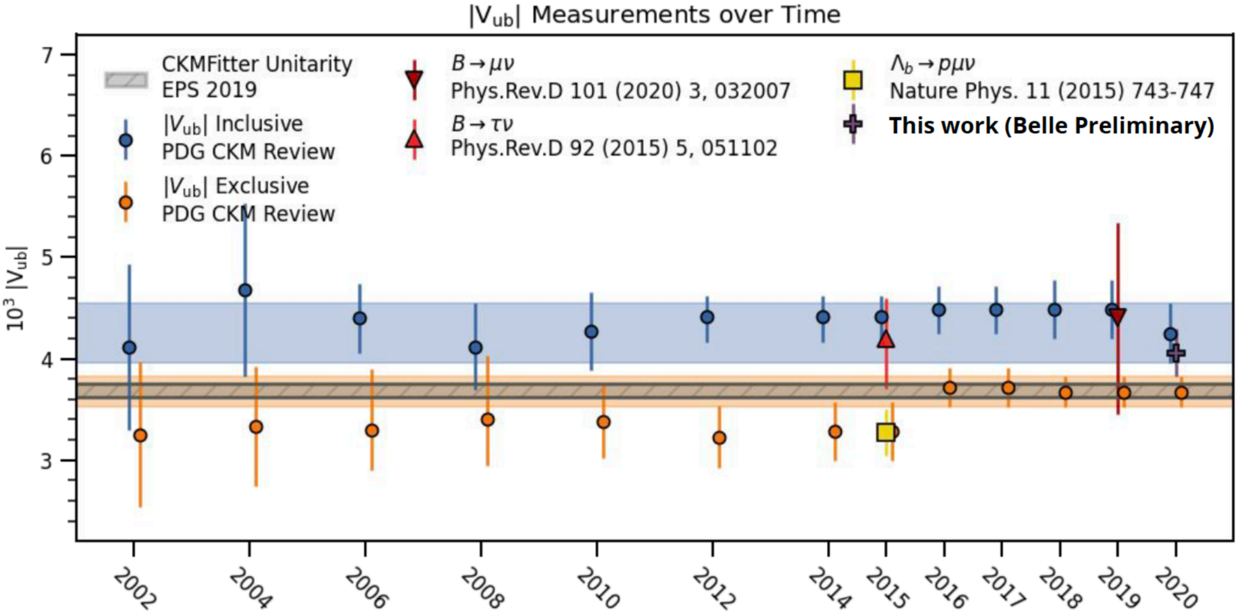
End of 2030s

σ(Vcb) = 1%

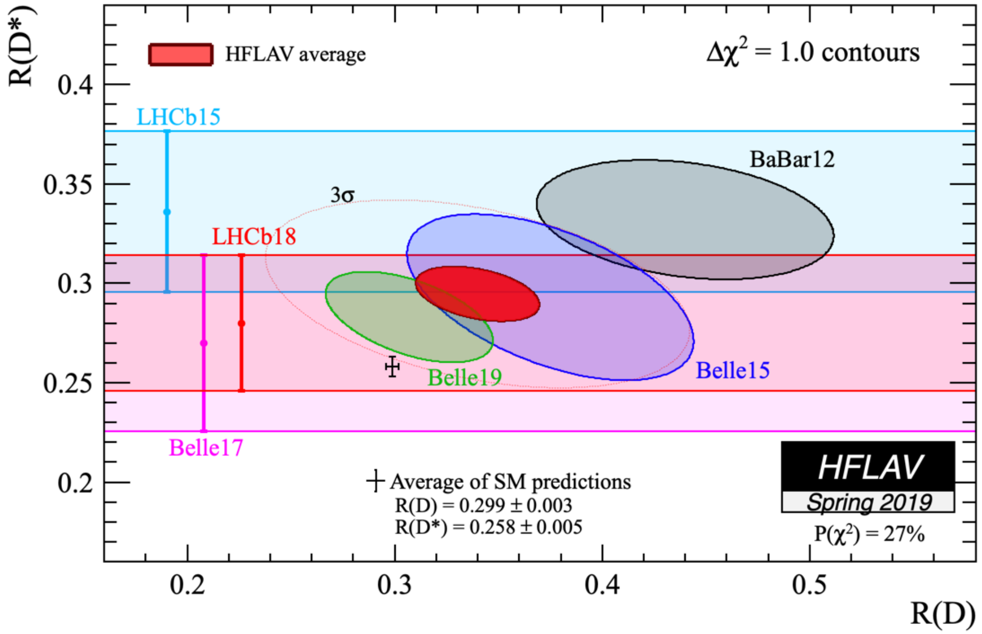


Tensions ….

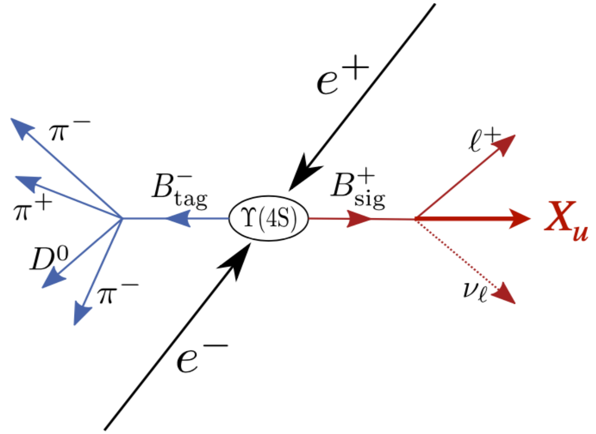


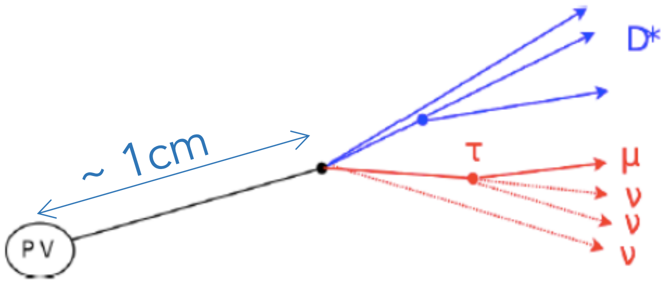


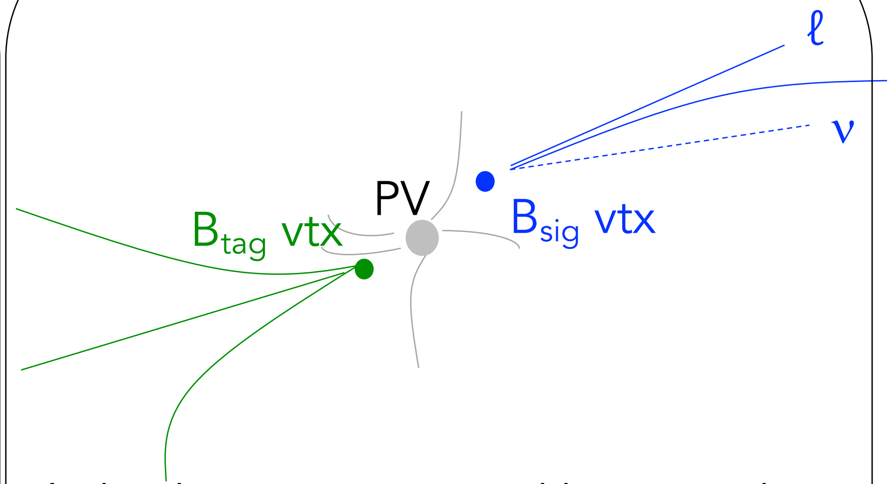
Study of $B \rightarrow D^{(*)} l \nu$ decays is crucial



BFactories (Belle-II)	LHCb	FCCee







BFactories (Belle-II)

Beam energy const. + tag-side
→ kinematical constraints

Inclusive decays

Access to absolute BR

BaBar & Belle ~ 1.1 ab^{-1}

Belle-II (ICHEP2020 schedule) :
10 ab^{-1} in 2025, 50 ab^{-1} in 2031

LHCb

Very large boost→ flight distance reconstruction
→ kinematical constraints

All b-hadrons species

No access to absolute BR

LHCb: 9fb^{-1} at hand

LHCb-Upgrade 1 (soft. trigger) :
at the end of Run3 (2024) : 23 fb^{-1}
at the end of 2020s : 50 fb^{-1}
LHCb-Upgrade 2 : 300 fb^{-1}

FCCee

Flight distance reco. and beam+other hemisphere
→ kinematical constraints

All b-hadrons species

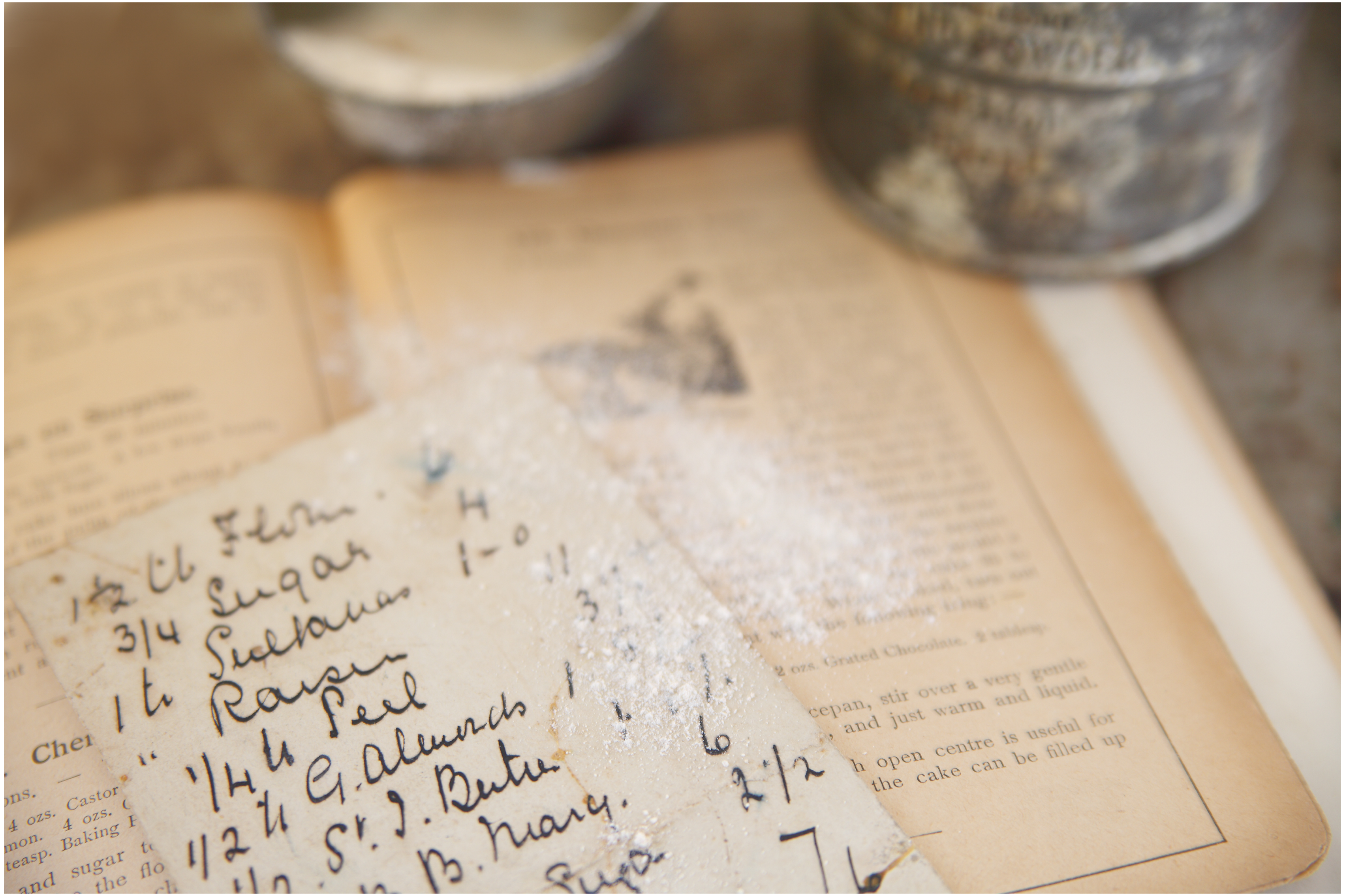
Access to absolute BR

FCCee (from late 2030)

5 10^{12} Z^0

1.5 10^8 WW

Traditional recipes : semileptonic decays

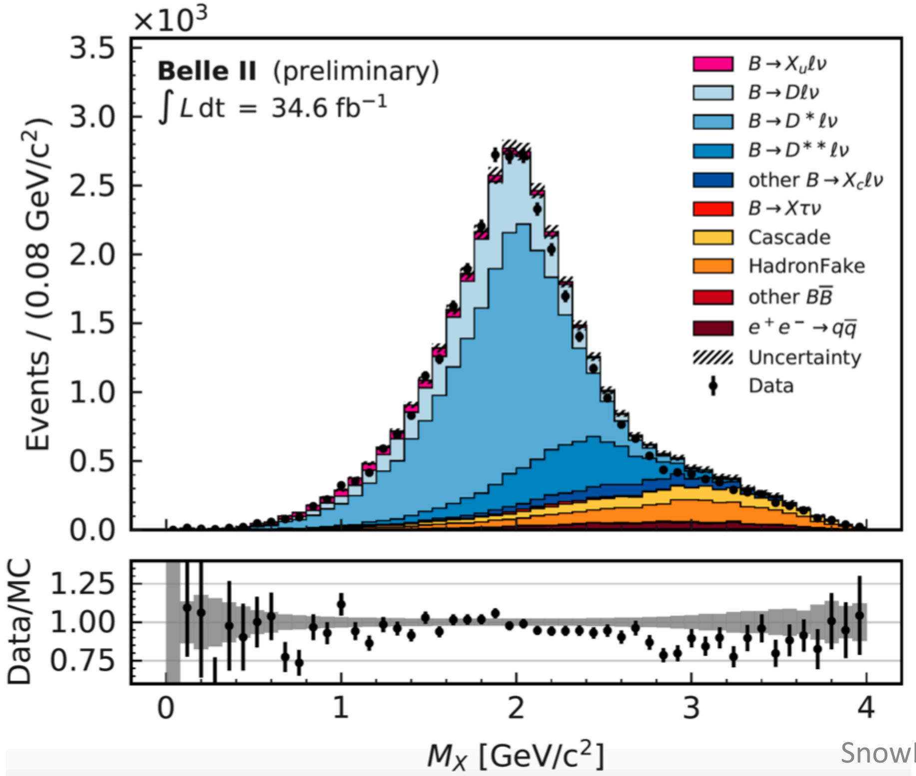


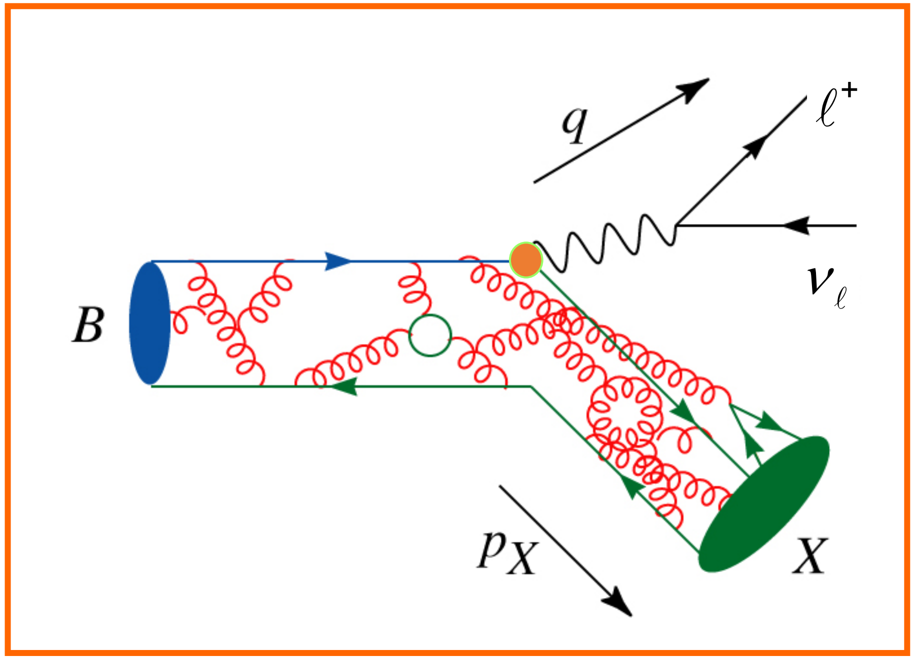
$|V_{cb}|$: inclusive determinations

Not a statistical issue : latest inclusive measurements from 2010

Kinematical constraints from other B reconstruction

New : Belle II analysis with M_x moments





$$|V_{cb}| = (42.2 \pm 0.8) \times 10^{-3}$$ PDG

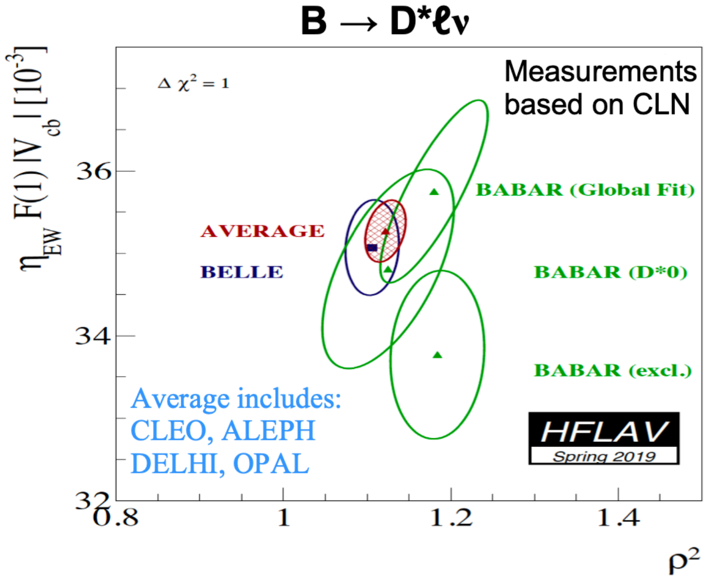
To come : Belle II analysis with q^2 moments

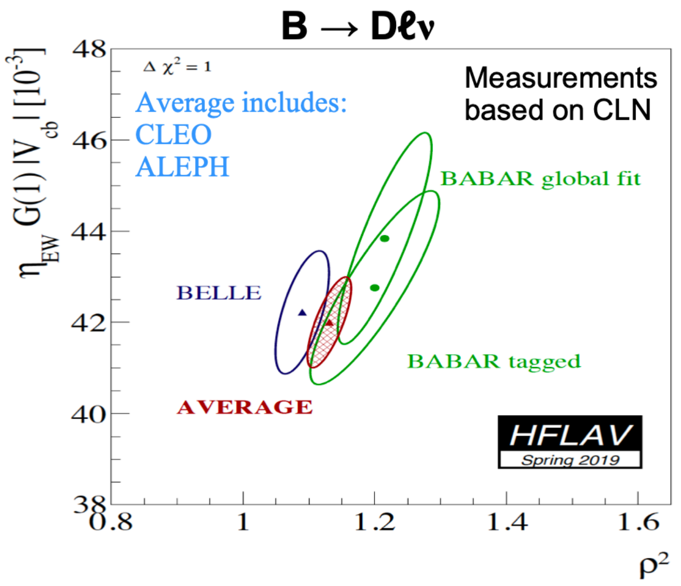
$|V_{cb}|$: exclusive determinations

Quite a bunch of recent results

B→D$^{(*)}$lν

B→ D*lν extremely clean samples, B→ Dlν less clean (D* feed-down)
FF parametrization
Measurement of the differential rates





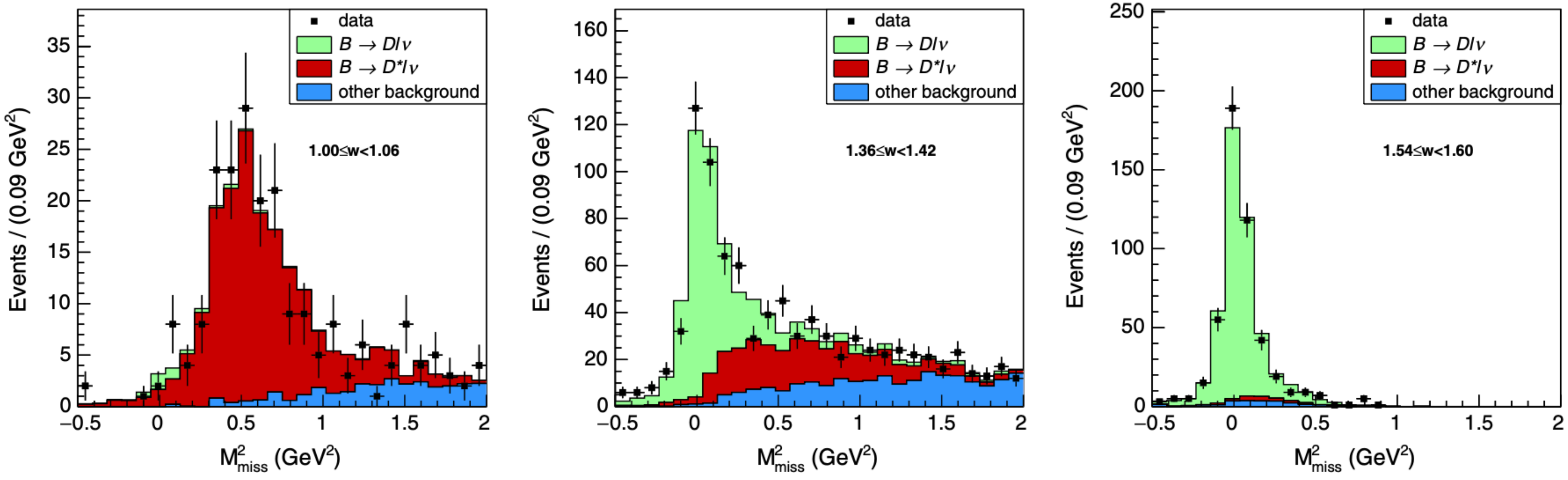
$$\eta_{EW}\mathcal{F}(1)|V_{cb}| = (35.27 \pm 0.38) \times 10^{-3}$$
$$\rho^2 = 1.122 \pm 0.024$$
$$R_1(1) = 1.270 \pm 0.026$$
$$R_2(1) = 0.852 \pm 0.018$$

$$\eta_{EW}\mathcal{G}(1)|V_{cb}| = (42.00 \pm 1.00) \times 10^{-3}$$
$$\rho^2 = 1.131 \pm 0.033$$

$$|V_{cb}| = (38.76 \pm 0.42_{exp} \pm 0.55_{th}) \cdot 10^{-3}$$

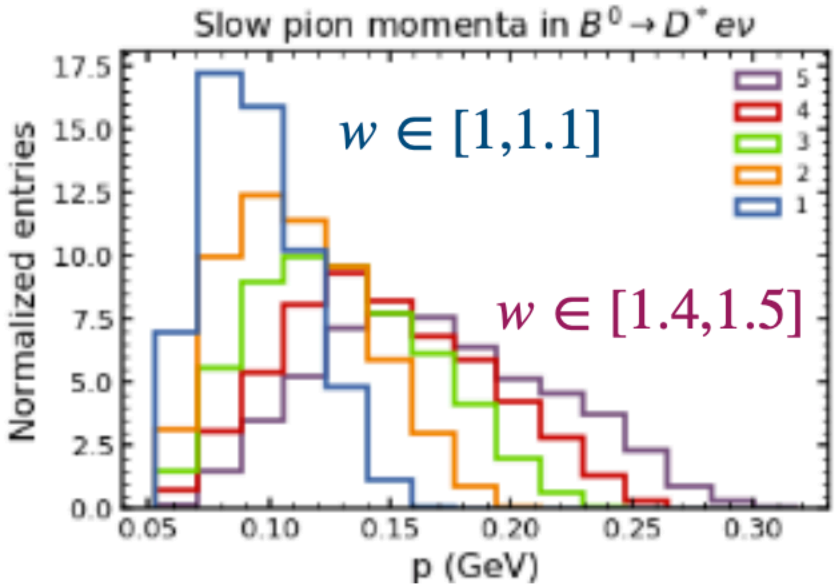
$$|V_{cb}| = (39.58 \pm 0.94_{exp} \pm 0.37_{th}) \cdot 10^{-3}$$

Belle B→ Dlν



In the (interesting) region w = 1, the soft pion from D* decay is particularly soft : inclusive reconstruction ?

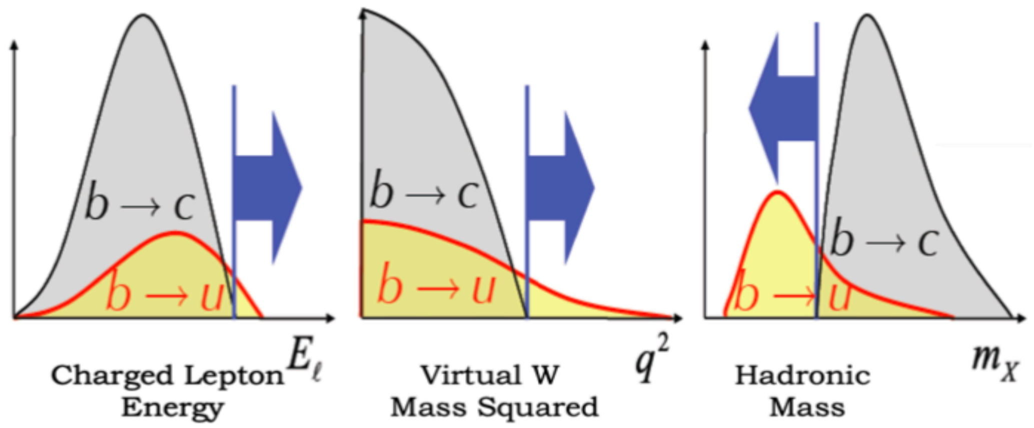
Florian Bernlochner



Combined HQET fits of B→D*lν and B→Dlν

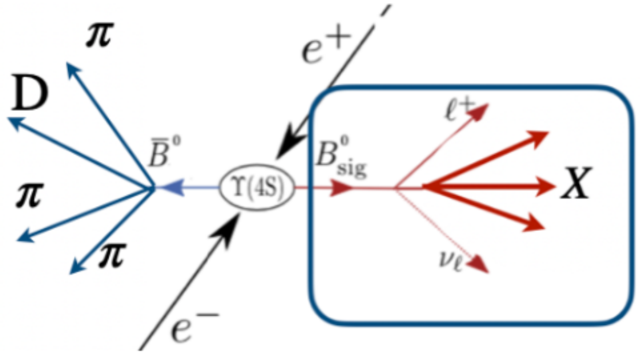
$|V_{ub}|$: inclusive determinations

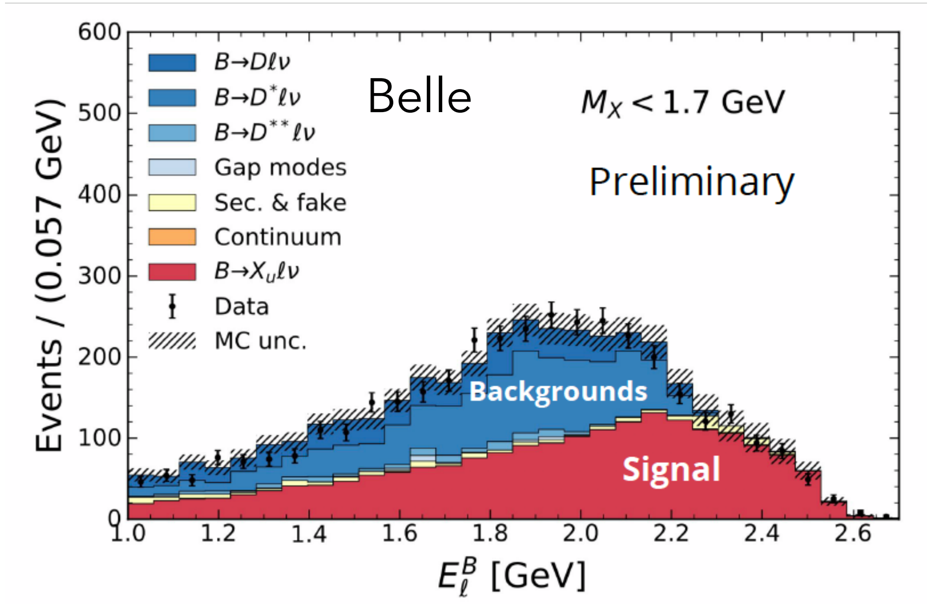
HQET breaks down due to experimental cuts



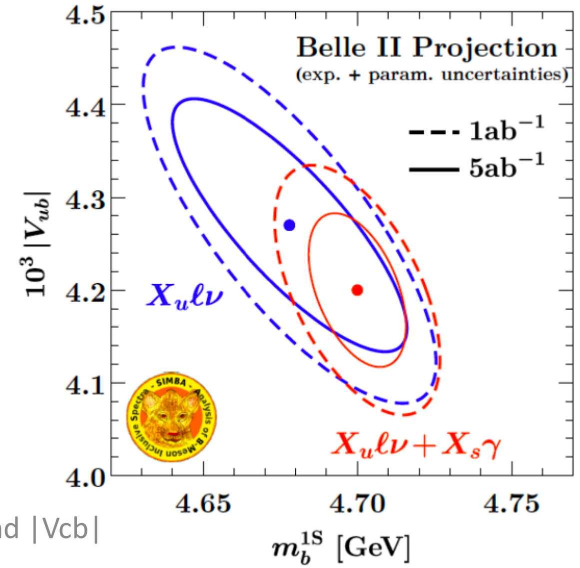
More information, higher purity reconstructing the other B.

→ Future





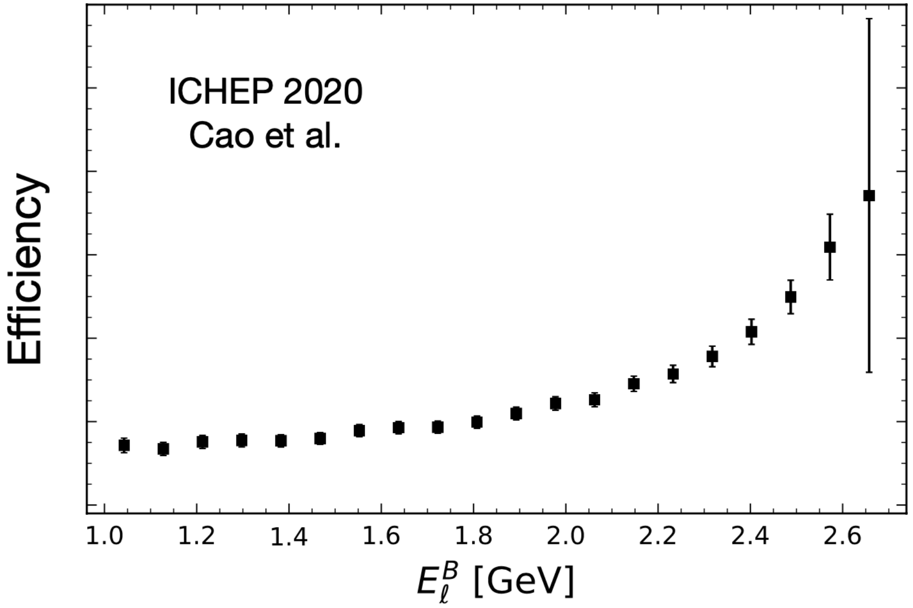
Global fit combining B → $X_u l\nu$ and B → $X_s\gamma$



	Statistical	Systematic (reducible, irreducible)	Total Exp	Theory	Total
$\lvert V_{ub}\rvert$ inclusive					
605 fb^{-1} (old B tag)	4.5	(3.7, 1.6)	6.0	2.5−4.5	6.5−7.5
5 ab^{-1}	1.1	(1.3, 1.6)	2.3	2.5−4.5	3.4−5.1
50 ab^{-1}	0.4	(0.4, 1.6)	1.7	2.5−4.5	3.0−4.8

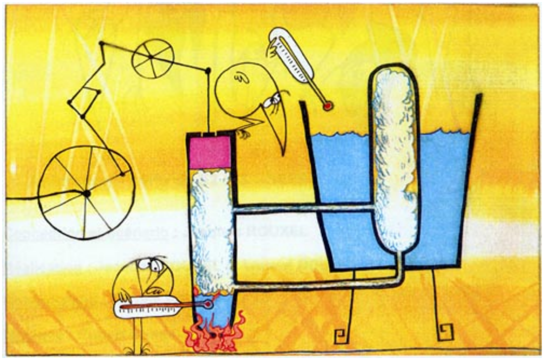
probably conservative

Even with modern technics, the reduction of the huge b->c background has significant consequences on the systematics uncertainties



Use more modern technics:

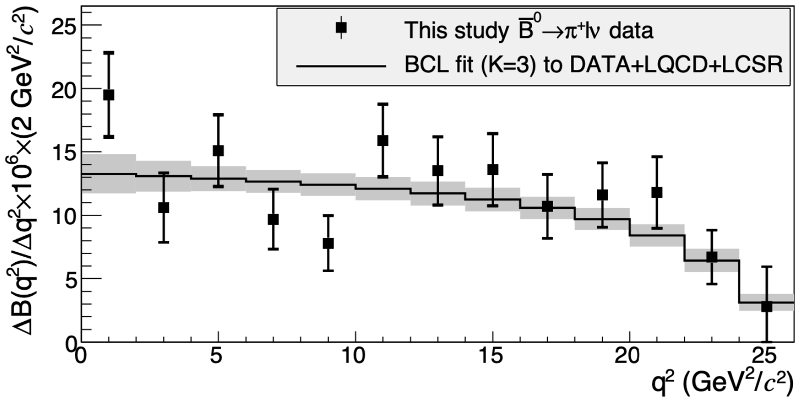
- Adversarial Networks
- Aspiration Networks with which one can explicitely avoid to shape a variable of interest.

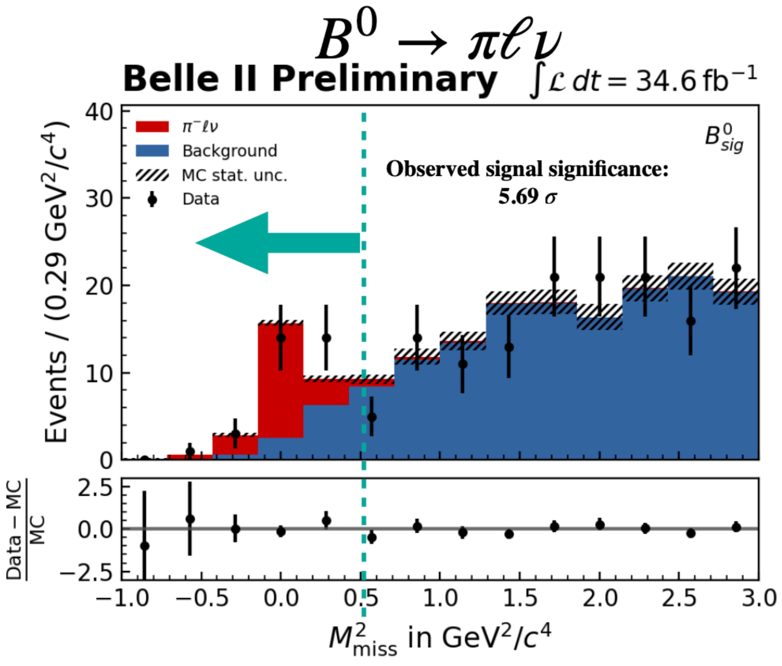


$|V_{ub}|$: exclusive determinations

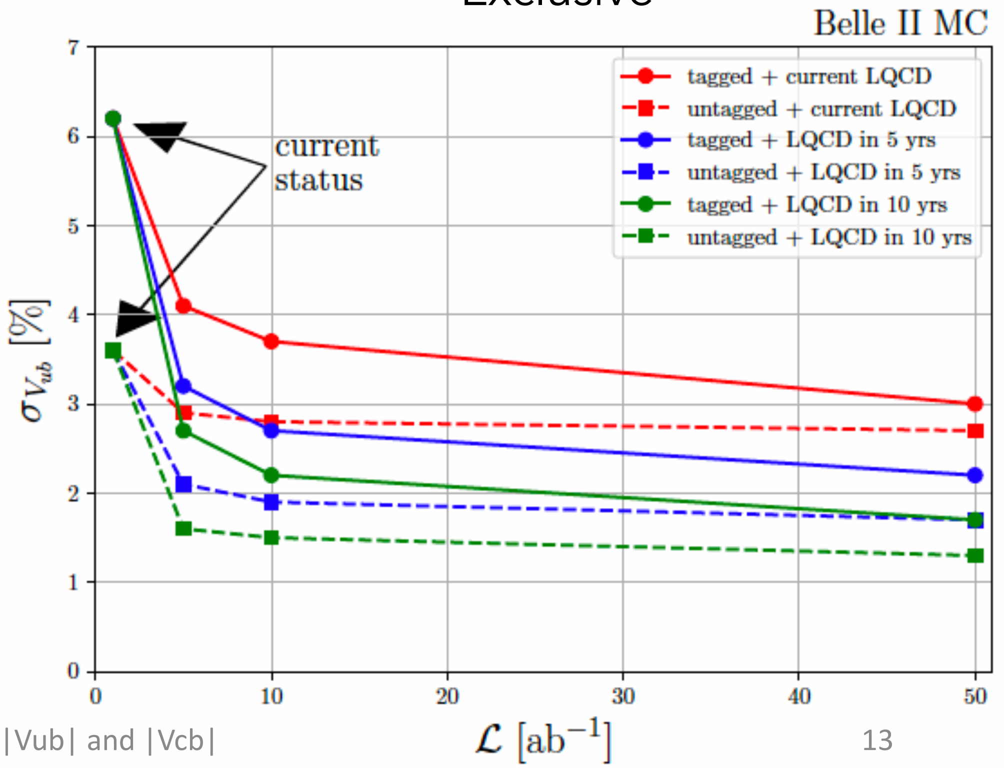
Belle PhysRevD.88.032005

Differential BF





Exclusive



$|V_{ub}|/|V_{cb}|$ by LHCb

$$\frac{\mathcal{B}(\Lambda_b \to p\mu^-\overline{\nu}_\mu)_{q^2>15\,\mathrm{GeV}^2/c^4}}{\mathcal{B}(\Lambda_b \to \Lambda_c\mu\nu)_{q^2>7\,\mathrm{GeV}^2/c^4}}$$

$$\frac{\mathcal{B}(B_s^0 \to K^-\mu^+\nu_\mu)_{q^2<7}}{\mathcal{B}(B_s^0 \to D_s^-\mu^+\nu_\mu)_{\mathrm{Full}\ q^2}} \qquad \frac{\mathcal{B}(B_s^0 \to K^-\mu^+\nu_\mu)_{q^2>7}}{\mathcal{B}(B_s^0 \to D_s^-\mu^+\nu_\mu)_{\mathrm{Full}\ q^2}}$$

$B_s^0 \to K^+\mu^-\nu$ vs $\Lambda_b^0 \to p\mu\nu$

Decay	Λ_b^0	B_s^0
theory error	5%	$\sim 5\%$
prod frac	20%	10%
BF	4×10^{-4}	1×10^{-4}
$\mathcal{B}(X_c)$ error	$\pm 5\%$	$\pm 2.8\%$
background	Λ_c^+	$\Lambda_c^+, D_s, D^+, D^0$

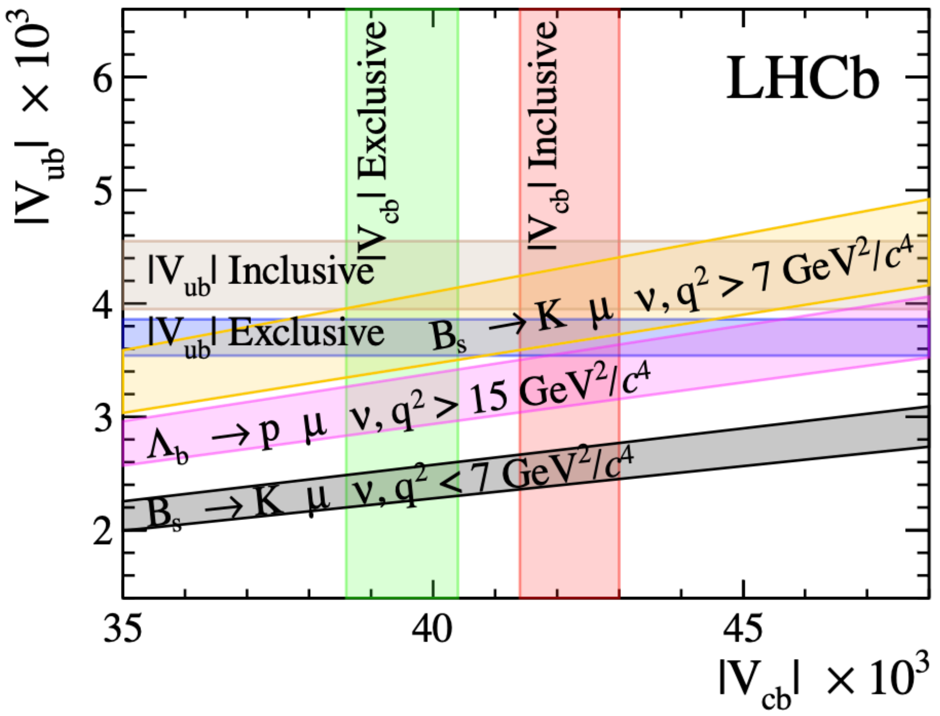
Importance of X_c BF measurements

Importance of FF knowledge for the backgrounds

2012 data !

$$\frac{|V_{ub}|}{|V_{cb}|} = 0.083 \pm 0.004 \pm 0.004$$

$$|V_{ub}|/|V_{cb}|(\mathrm{high}) = 0.0946 \pm 0.0030\,(\mathrm{stat})^{+\,0.0024}_{-\,0.0025}\,(\mathrm{syst}) \pm 0.0013\ (D_s) \pm 0.0068\ (\mathrm{FF})$$



Basem Khanji@ Implications workshop (Fall 2020)

With more statistics: differential measurements with fine q2 binning (very high-q2 region theoretically promising for B_s)

Ultimate experimental precision : 1% probably limited by the tracking efficiency due to different number of charged tracks in the numerator and denominator. Explore different normalisation strategies ?

Other ways to access $|V_{cb}|$ and $|V_{ub}|$ decays

Purely leptonic decays ?

$$\mathcal{B}(B^+ \to \ell^+ \nu_\ell) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B,$$

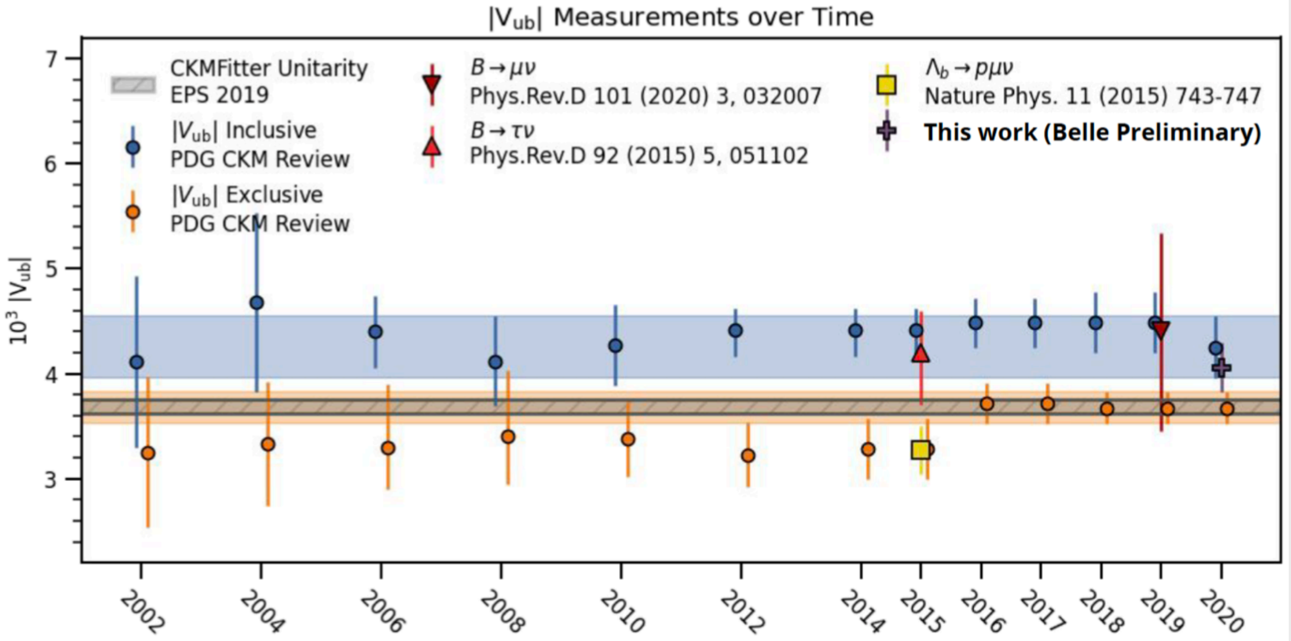
Theoretically cleaner
Experimentally challenging

In Phys Rev D 101, 032007 (2020) (B→μν) fB = 184 (4) MeV

$$|V_{ub}| = (4.4^{+0.8}_{-0.9} \pm 0.4 \pm 0.1) \times 10^{-3},$$

$$N_f = 2+1+1: \qquad f_B = 190.0(1.3)\ \text{MeV}$$

FLAG review (2019)

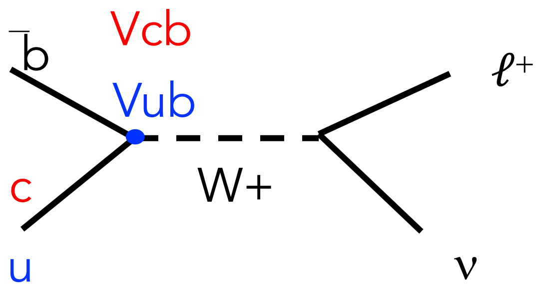


But NP ??!

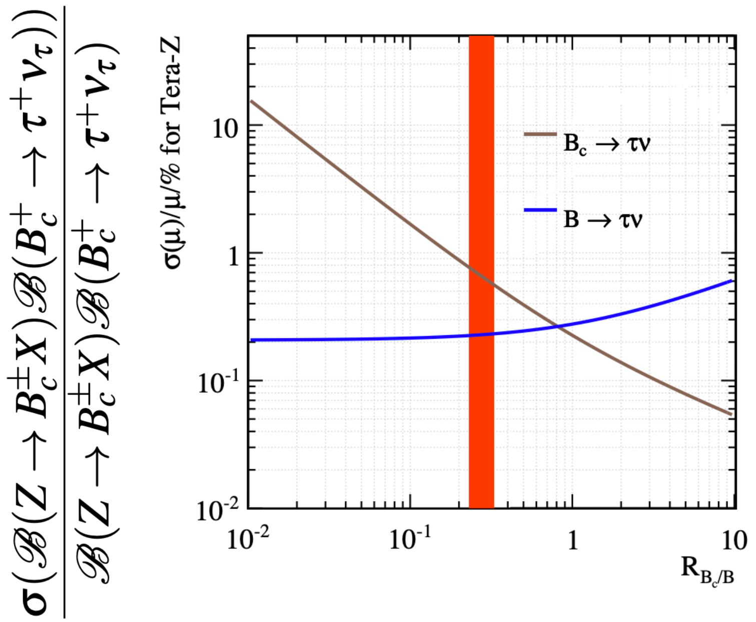
B→ μν competitive in future ?

And FCCee:

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



CEPC study (arXiv:2007.08234)



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

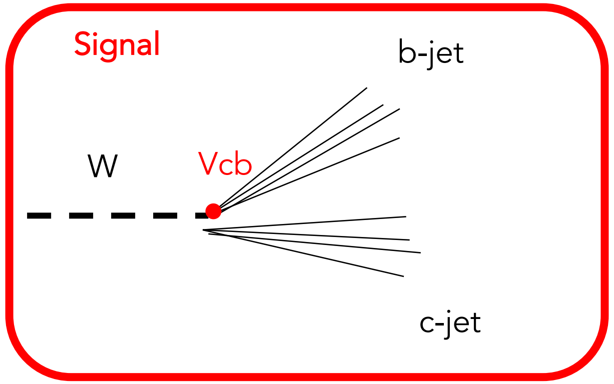
$|V_{cb}|$ at 1% (B_c production knowledge to be improved)

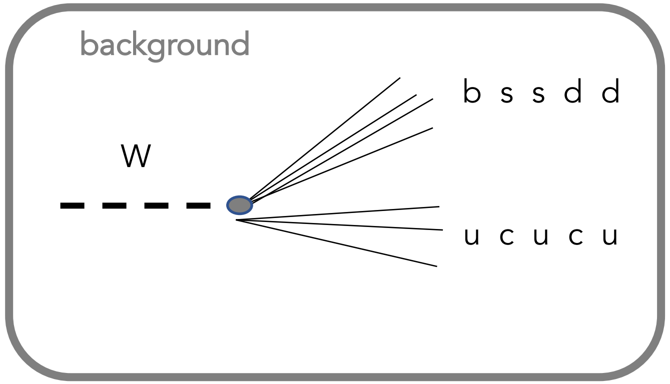
$|V_{cb}|$: from the W decays ?

$\sqrt{s}$=162 GeV : L~3 10^{35} collect 12/ab
45-60 10^6 WW decays

$\sqrt{s}$=240 GeV : L~0.7 10^{35} collect 5/ab
80 10^6 WW decays

$\sqrt{s}$=365 GeV : L~ 10^{34} collect 1.65/ab
20 10^6 WW decays

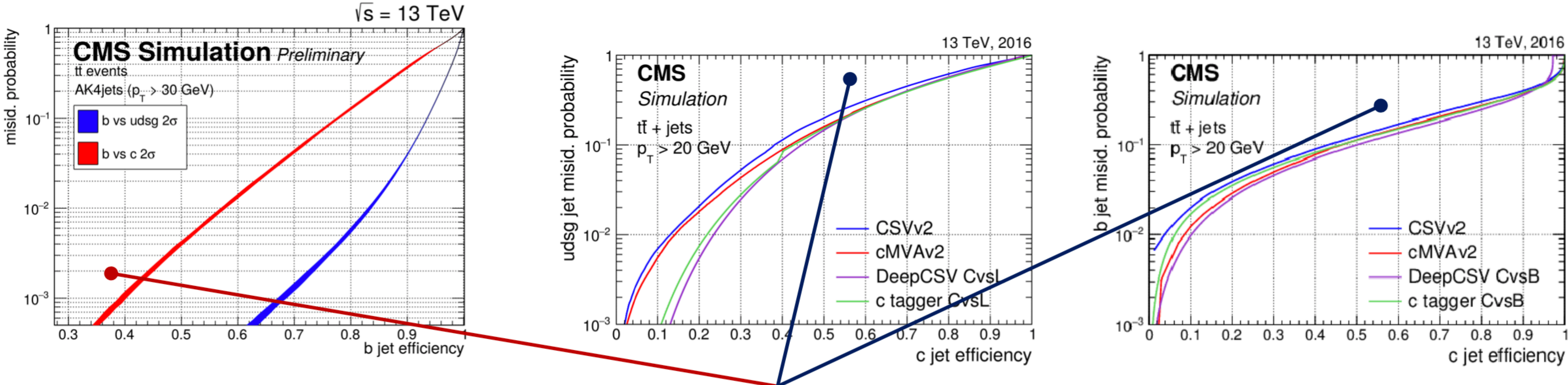




$|V_{cb}|$ = (41.0 ± 1.4) × 10^{-3} ➔ BR = 5.6 10^{-4} (1.7 10^5 W→cb @FCCee)

$|V_{ub}|$ = (3.82 ± 0.24) × 10^{-3} ➔ BR = 4.9 10^{-6} (1.5 10^3 W→ub @FCCee)

Name of the game : b-jet, c-jet, light jet flavor tagging



First tag $\boldsymbol{\varepsilon_b}$**=40% and** $\boldsymbol{\varepsilon_c}$**=10**$^{\mathbf{-3}}$ $\boldsymbol{\varepsilon_{uds}}$**=10**$^{\mathbf{-5}}$ Second tag with $\boldsymbol{\varepsilon_c}$**=60% and** $\boldsymbol{\varepsilon_b}$**=0.1** $\boldsymbol{\varepsilon_{uds}}$**=0.2**

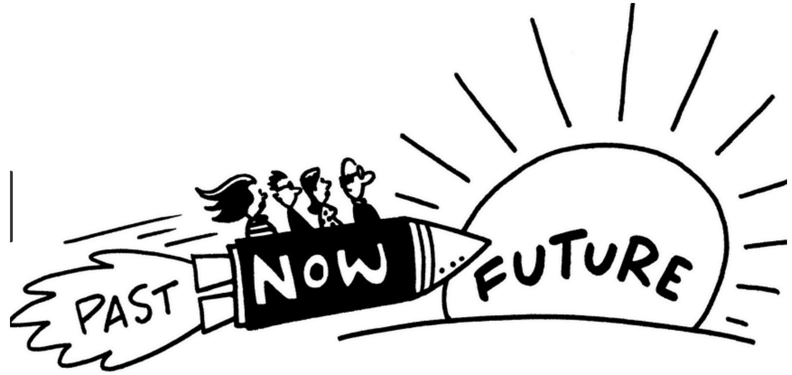
@FCCee: N(W→cs,cd)≈20k N(W→cb)≈50k ➔ direct **Δ** $|V_{cb}|$ (stat) (FCCee) → 0.2%(rel)

Summary

Most of the progresses : close theoretical/experimental collaborations

- Importance of X_c BF knowledge (BES3, Belle II)
- Need to better study the anatomy of $B \rightarrow DX \ell \nu$ decays
- Larger samples → differential measurements with fine binning, use only the cleaner modes

- $|V_{cb}|$
  - currently limited by theoretically knowledge at 1.5 - 2%.
  - Use of W decays with FCCee : below 1% ?
  - Pure B_c leptonic decays (CEPC study) at 1 % ?
- $|V_{ub}|$
  - Belle-II : 1-2 % with semileptonic decays
  - $|V_{ub}|/|V_{cb}|$ with 1% precision (Upgrade II dataset) ?
  - Pure B^+ leptonic decays : 1% (Belle2, FCCee) ?



V_{xb}^{excl} V_{xb}^{incl} V_{xb}