Global fit to CKM data

Belle II Physics Week

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The University of Melbourne

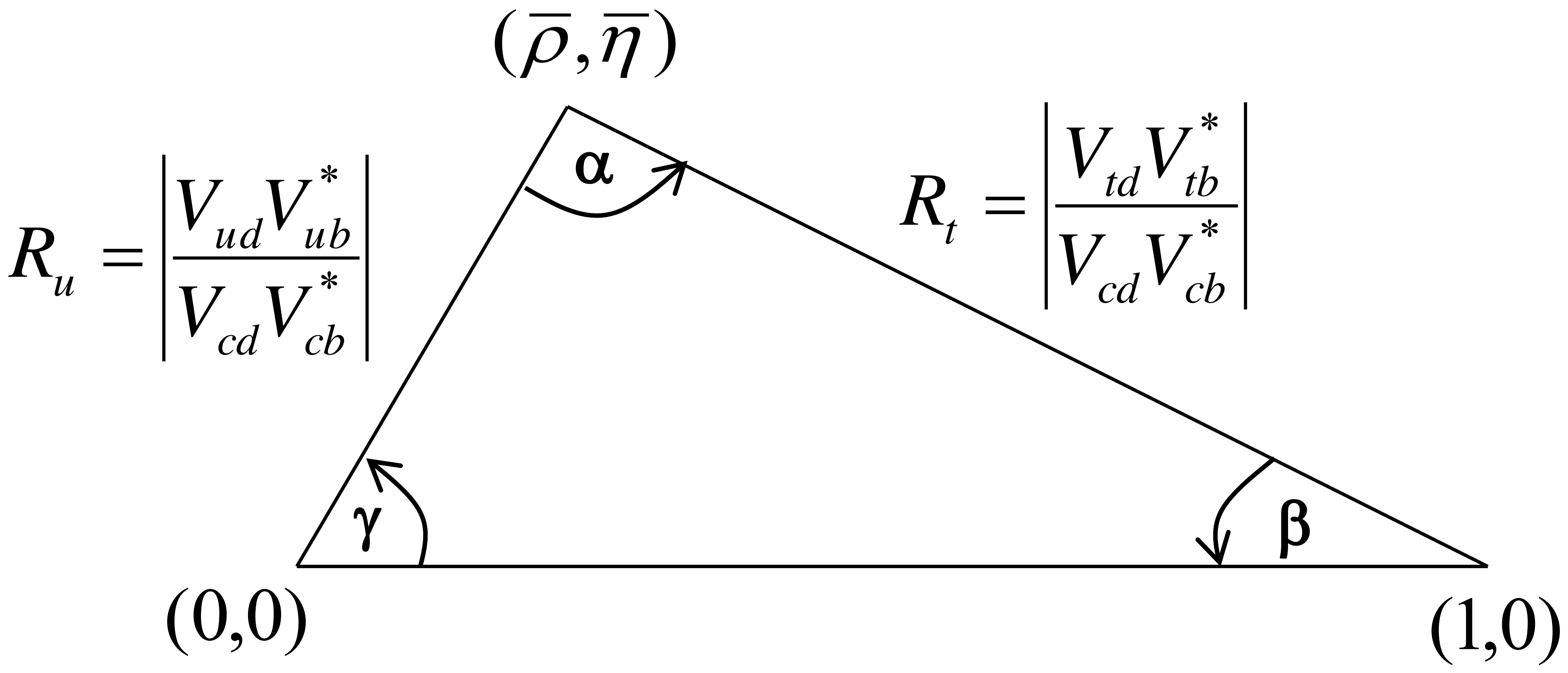
CP Violation & the Unitarity Triangle

The SM describes the mixing of quarks of different generations through the weak force.

$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

3 Generations, 1 Phase: single source of CPV in the SM.

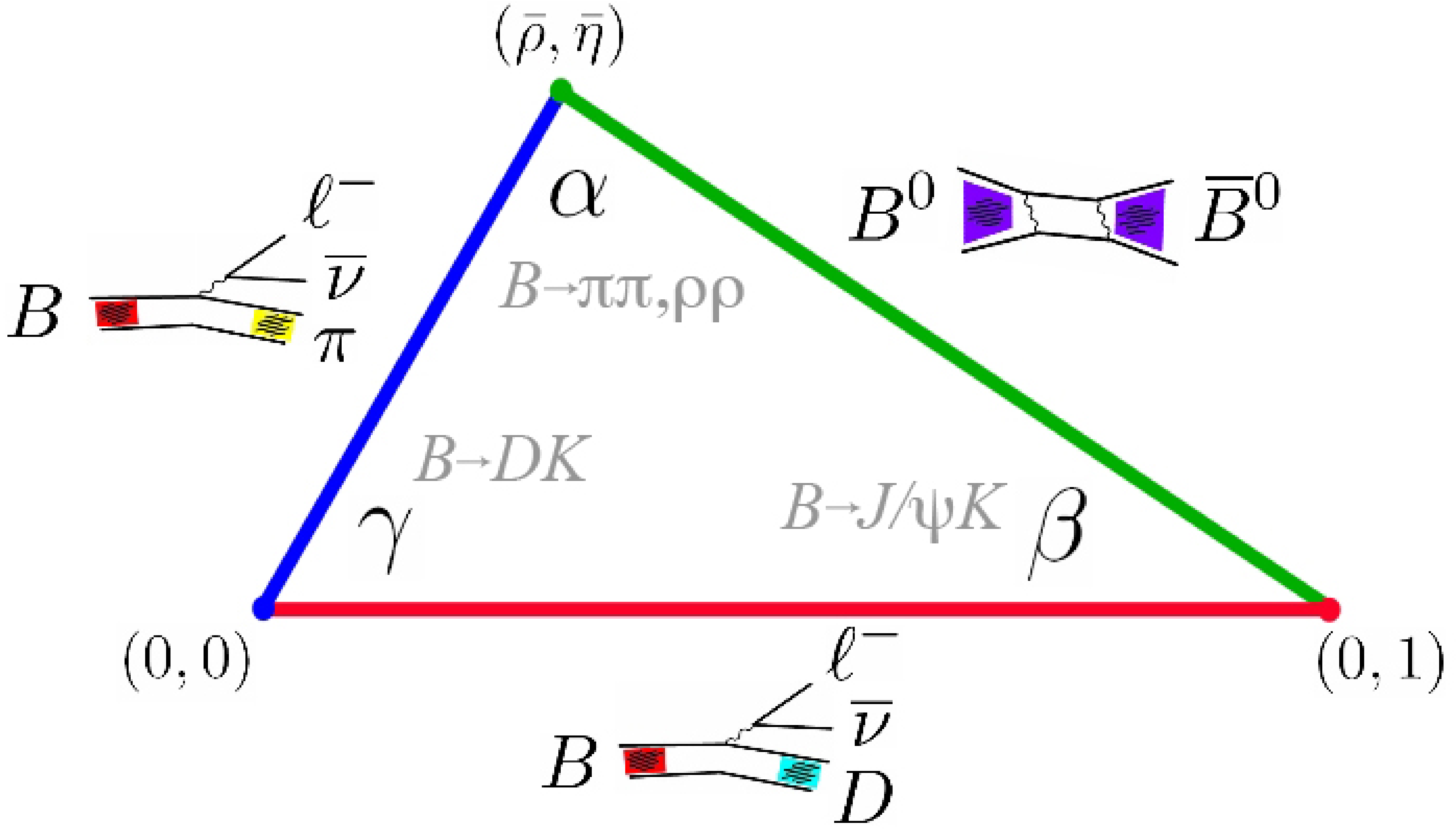
Wolfenstein parameterisation: Phase invariant, conserving CKM matrix unitarity at any order in λ.

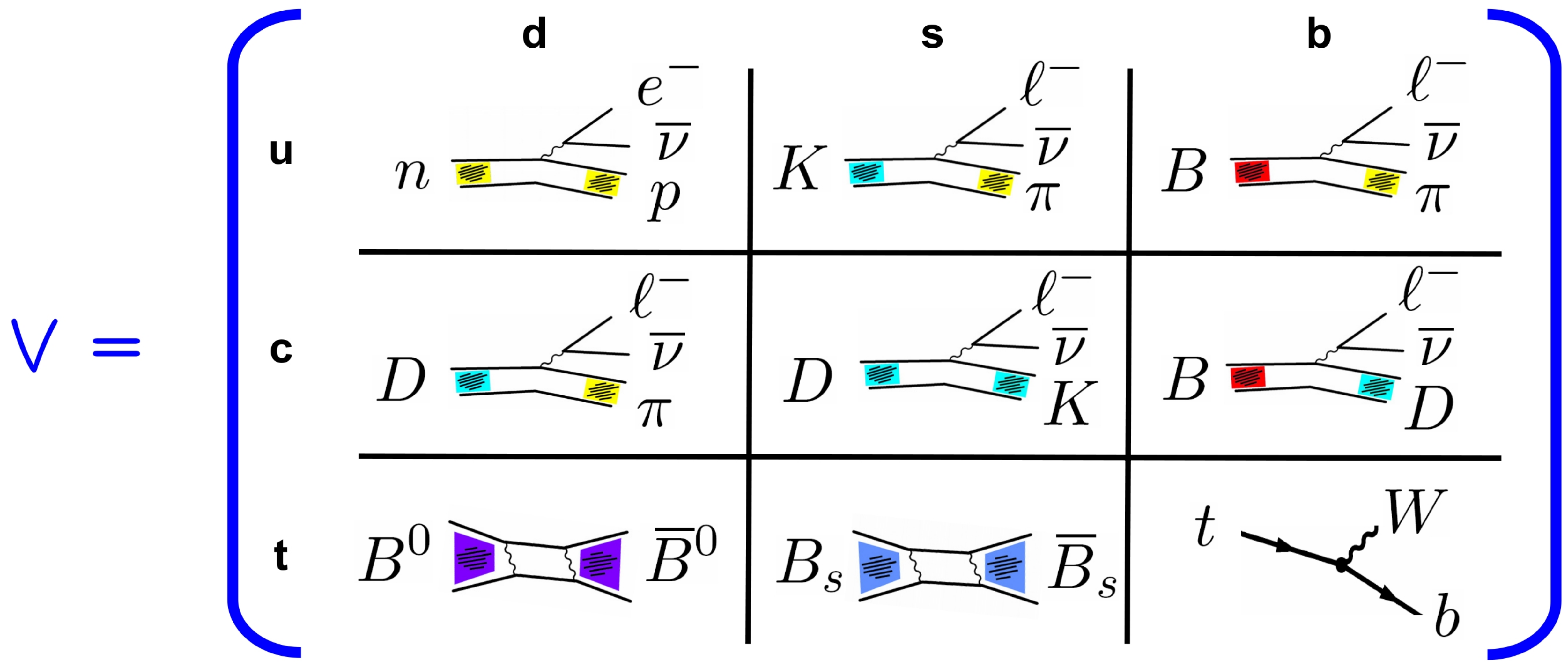


4 free parameters relating the 9 CKM elements (magnitude & phase)

$$\lambda^2 \equiv \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad A^2\lambda^4 \equiv \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2} \qquad \bar{\rho} + i\bar{\eta} = -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

Important Decays in the Combination





$B \to \pi\pi, \rho\rho$	Φ_2	$B \to D\, l\, \nu\, /\, b \to c\, l\, \nu$	$\|V_{cb}\|$ via Form factor / OPE
$B \to D^{(*)} K^{(*)}$	Φ_3	$B \to \pi\, l\, \nu\, /\, b \to u\, l\, \nu$	$\|V_{ub}\|$ via Form factor / OPE
$B \to J/\psi\, K_s$	Φ_1	$M \to l\, \nu\, (\gamma)$	$\|V_{UD}\|$ via Decay constant f_M
$B_s \to J/\psi\, \Phi$	β_s	ε_K	(ρ, η) via B_K
$K \to \pi\, \nu$ anti-ν	ρ, η	$\Delta m_d, \Delta m_s$	$\|V_{tb}\, V_{t\{d,s\}}\|$ via Bag factor B_B
		$B_{(s)} \to \mu+\, \mu-$	$\|V_{t\{d,s\}}\|$ via Decay constant f_B

Observables with very different properties

Tree: e.g., $|V_{ub}|$, Φ3
Loop: e.g., Δm_d, Δm_s, ε_K, sin(2β)
CP-*conserving*: e.g., $|V_{ub}|$, Δm_d, Δm_s
CP-*violating*: e.g., γ, ε_K, sin(2β)

Exp. uncs.: e.g., α, sin(2β), γ
Syst. uncs.: e.g., $|V_{ub}|$, $|V_{cb}|$, ε_K, Δm_d, Δm_s

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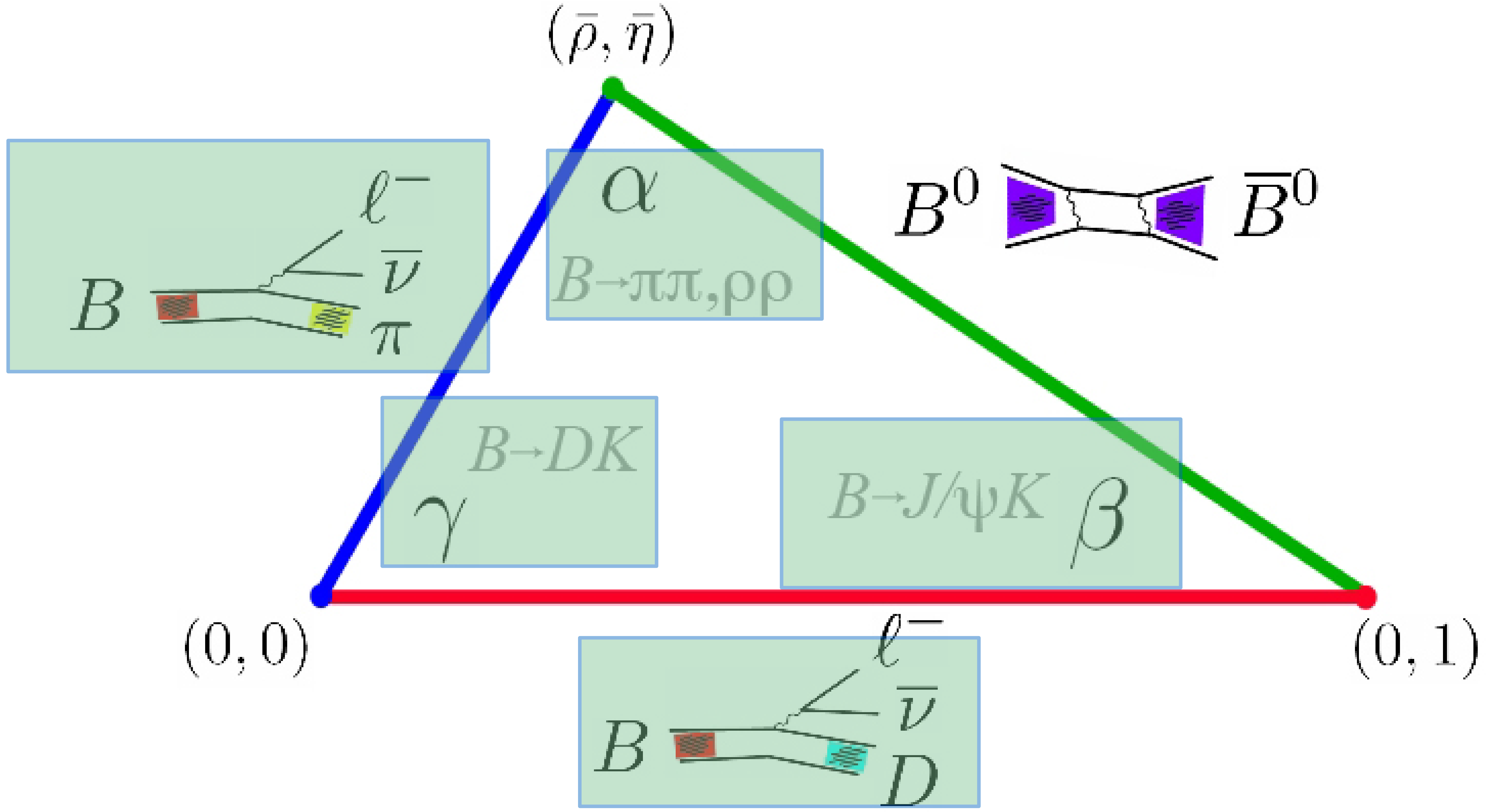

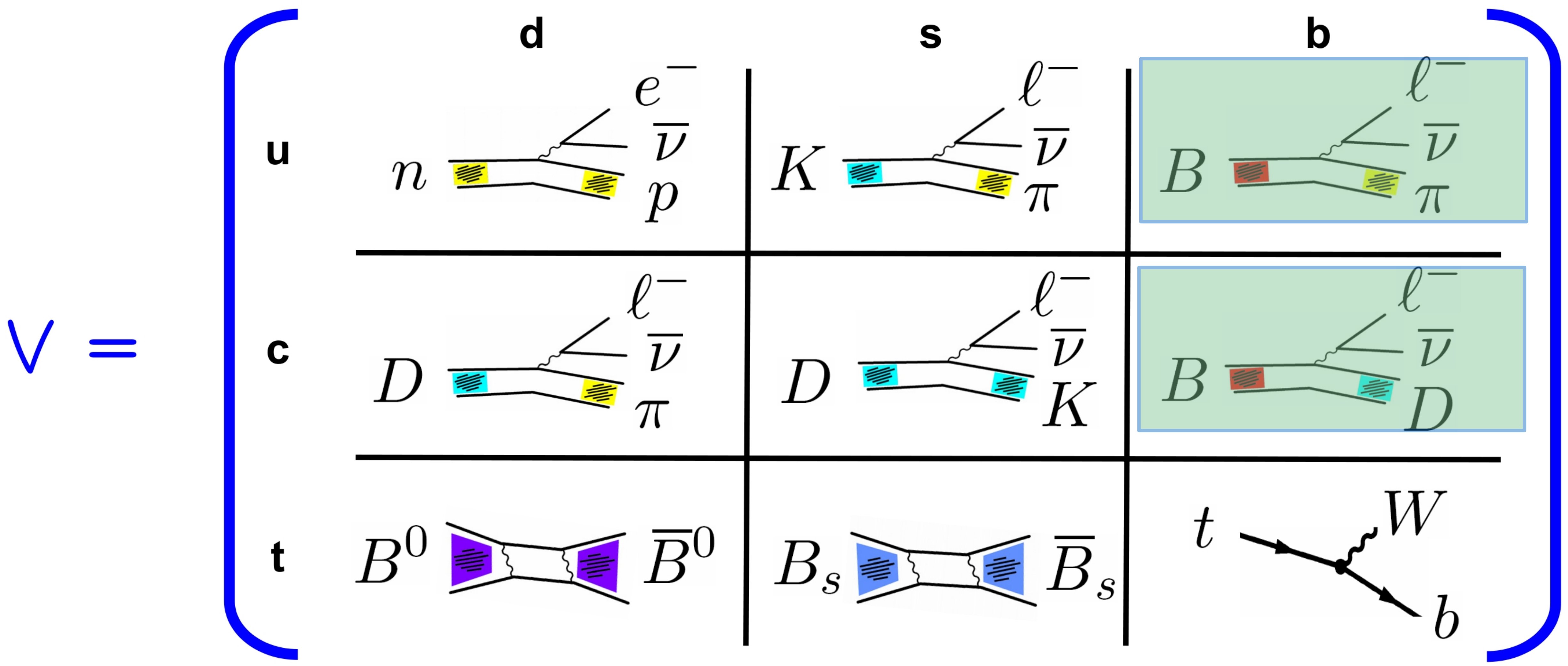

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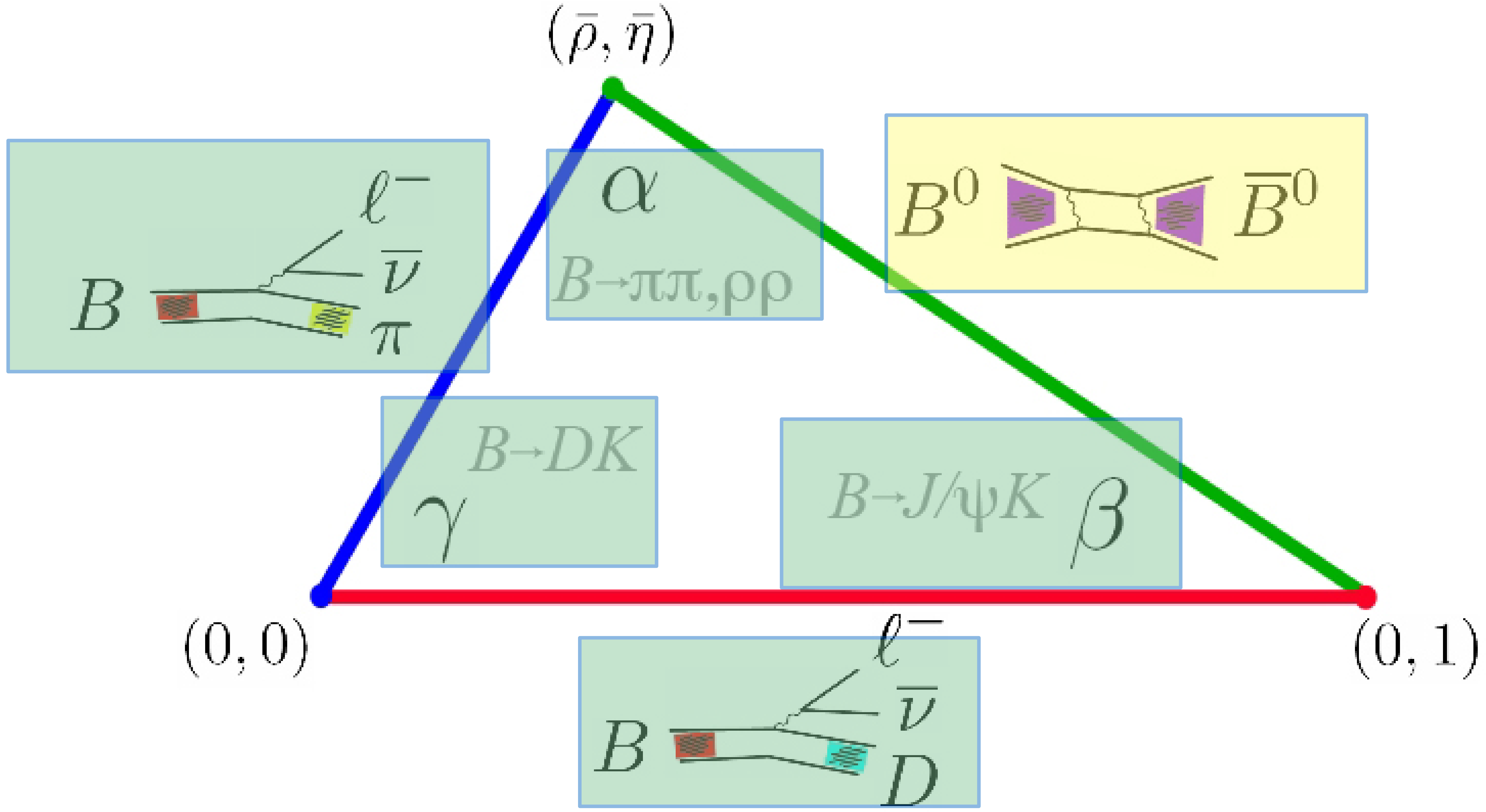

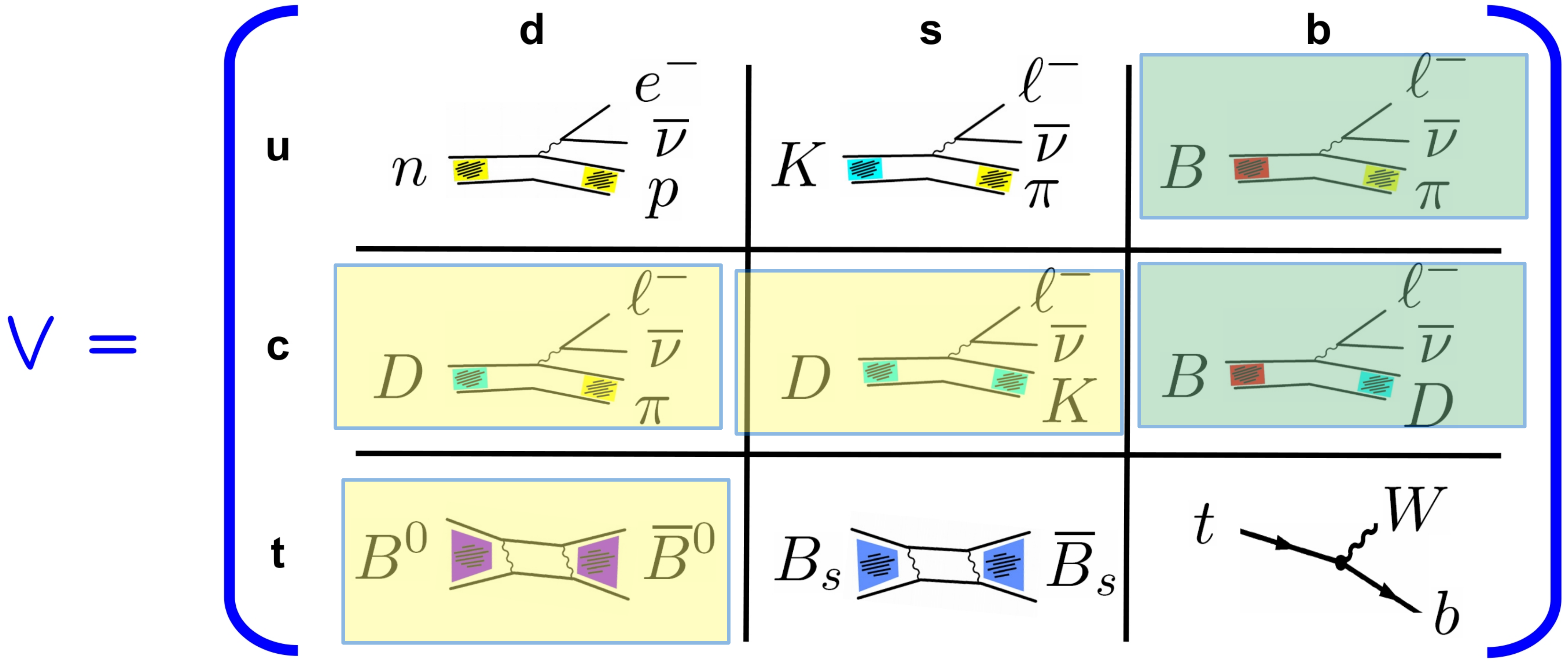

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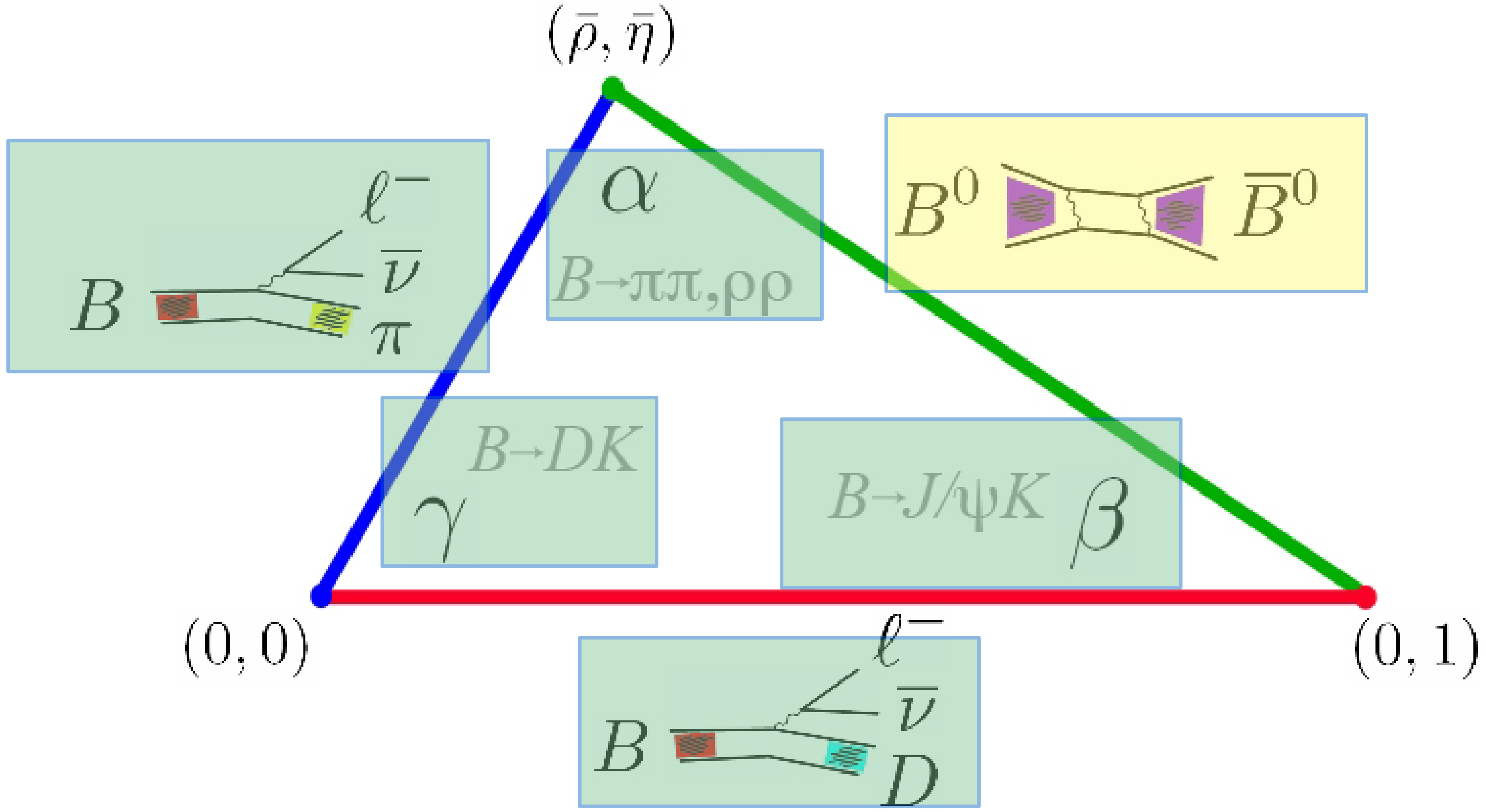

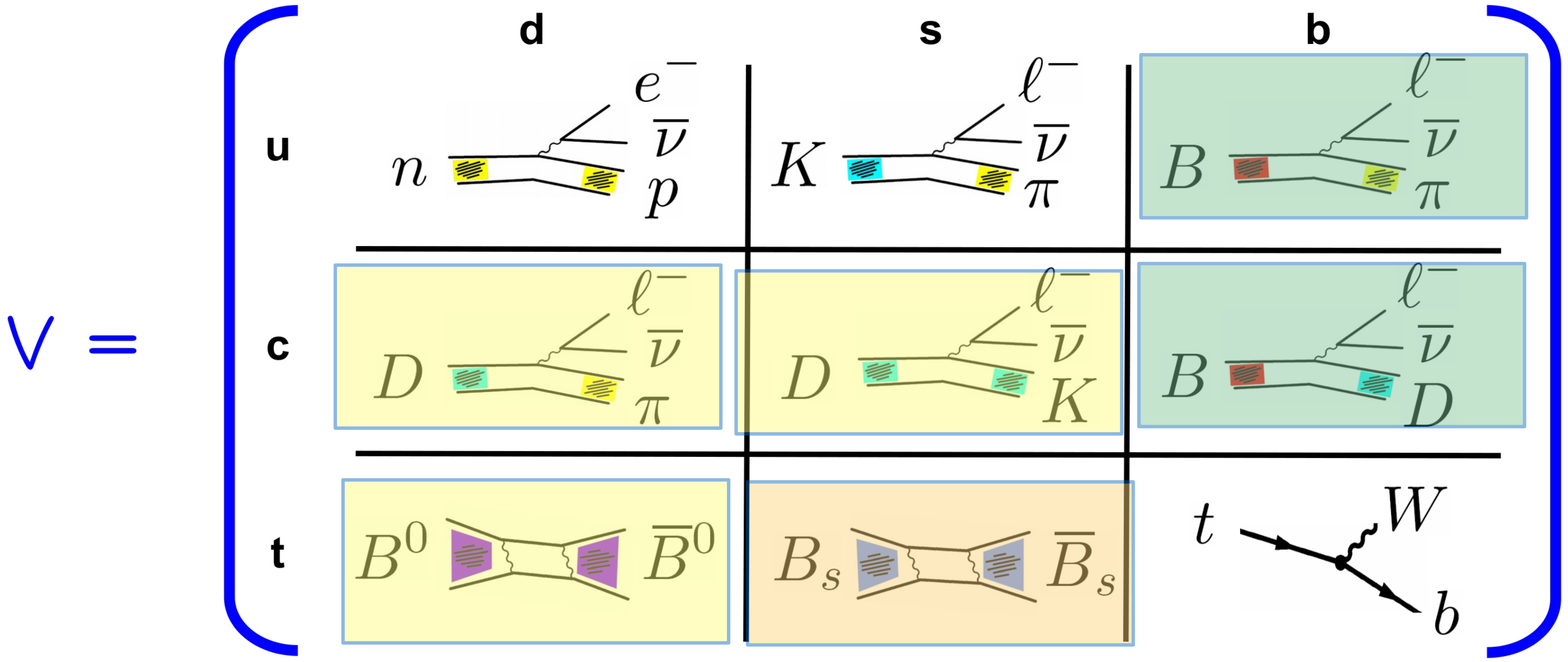

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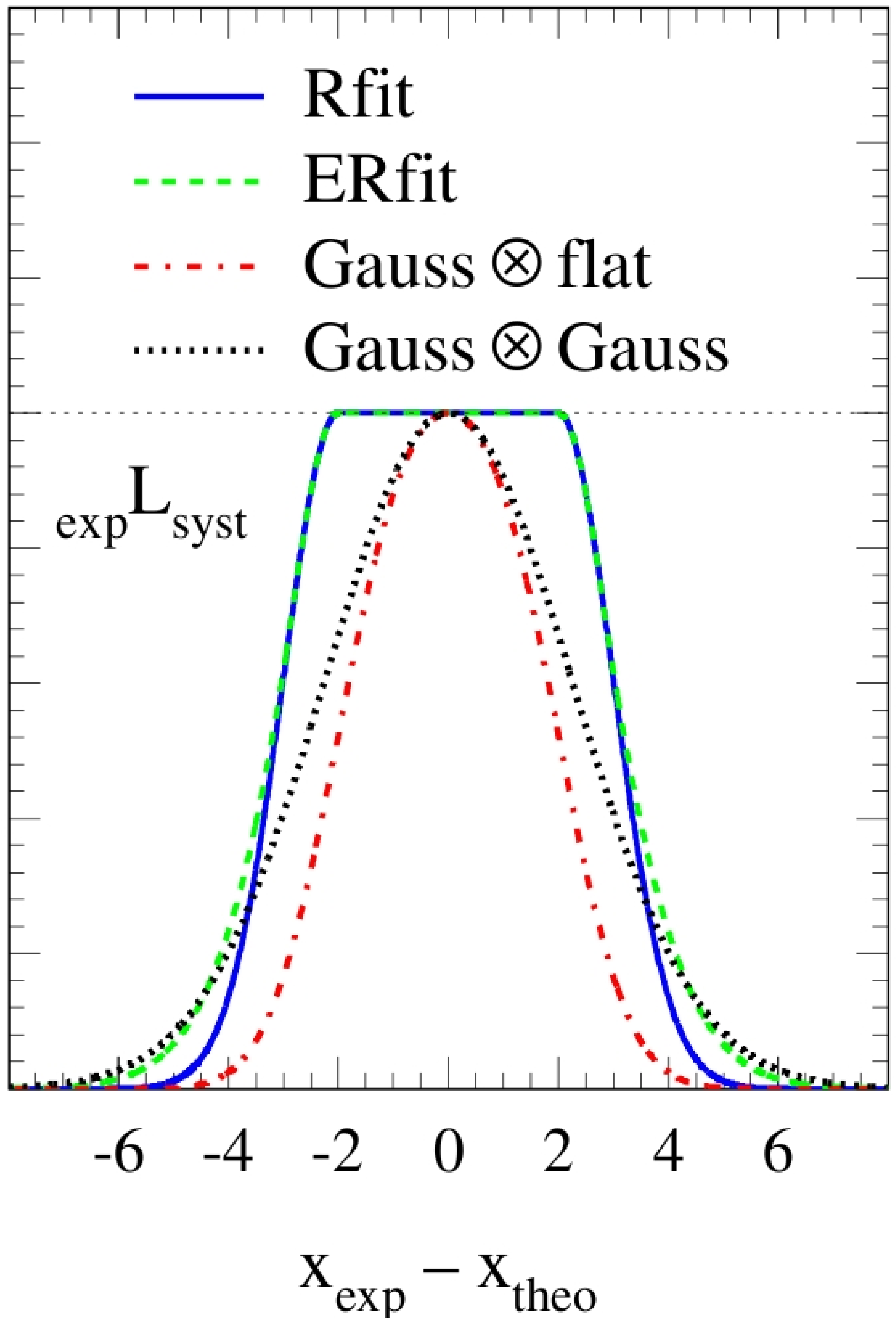
CKMfitter Methodology

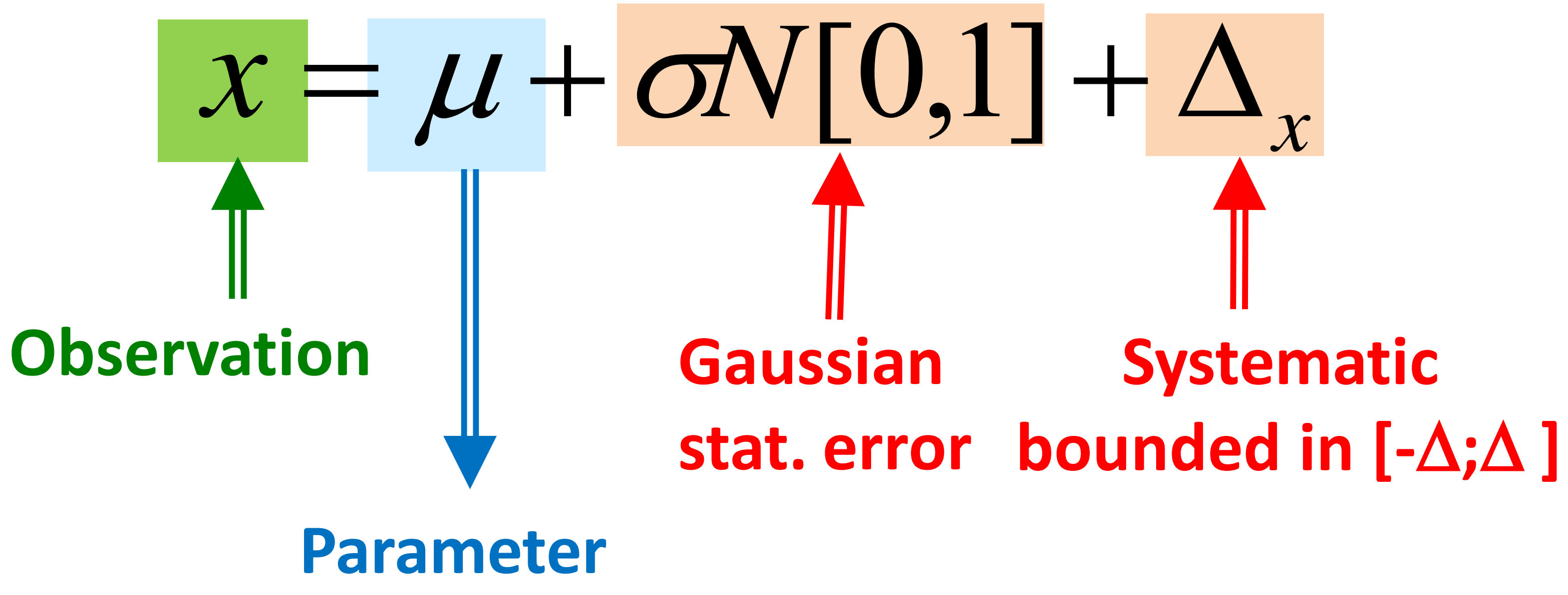
- Global fit to CKM parameters q = $(A,\lambda,\bar\rho,\bar\eta\ldots)$
- Use Frequentist approach to build (p-value) functions
  - In the case of Gaussian (Experimental) uncertainties

$$\mathcal{L}(q) = \prod_{\mathcal{O}} \mathcal{L}_{\mathcal{O}}(q) \qquad \chi^2(q) = -2\ln\mathcal{L}(q) = \sum_{\mathcal{O}} \left(\frac{\mathcal{O}_{\text{th}}(q) - \mathcal{O}_{\text{exp}}}{\sigma_{\mathcal{O}}}\right)^2$$

  - Estimator $\hat{q}$ maximum likelihood:
    - $\boldsymbol{\chi^2(\hat{q}) = \min_q \chi^2(q)}$
  - Confidence level for a given q_0 obtained from $\boldsymbol{\Delta\chi^2(q_0) = \chi^2(q_0) - \min_q \chi^2(q)}$

- Dedicated **Range Fit (RFit)** scheme for the treatment of theoretical systematics. Theoretical systematics are considered as additional nuisance parameters.





$$x = \mu + \sigma N[0,1] + \Delta_x$$

Input

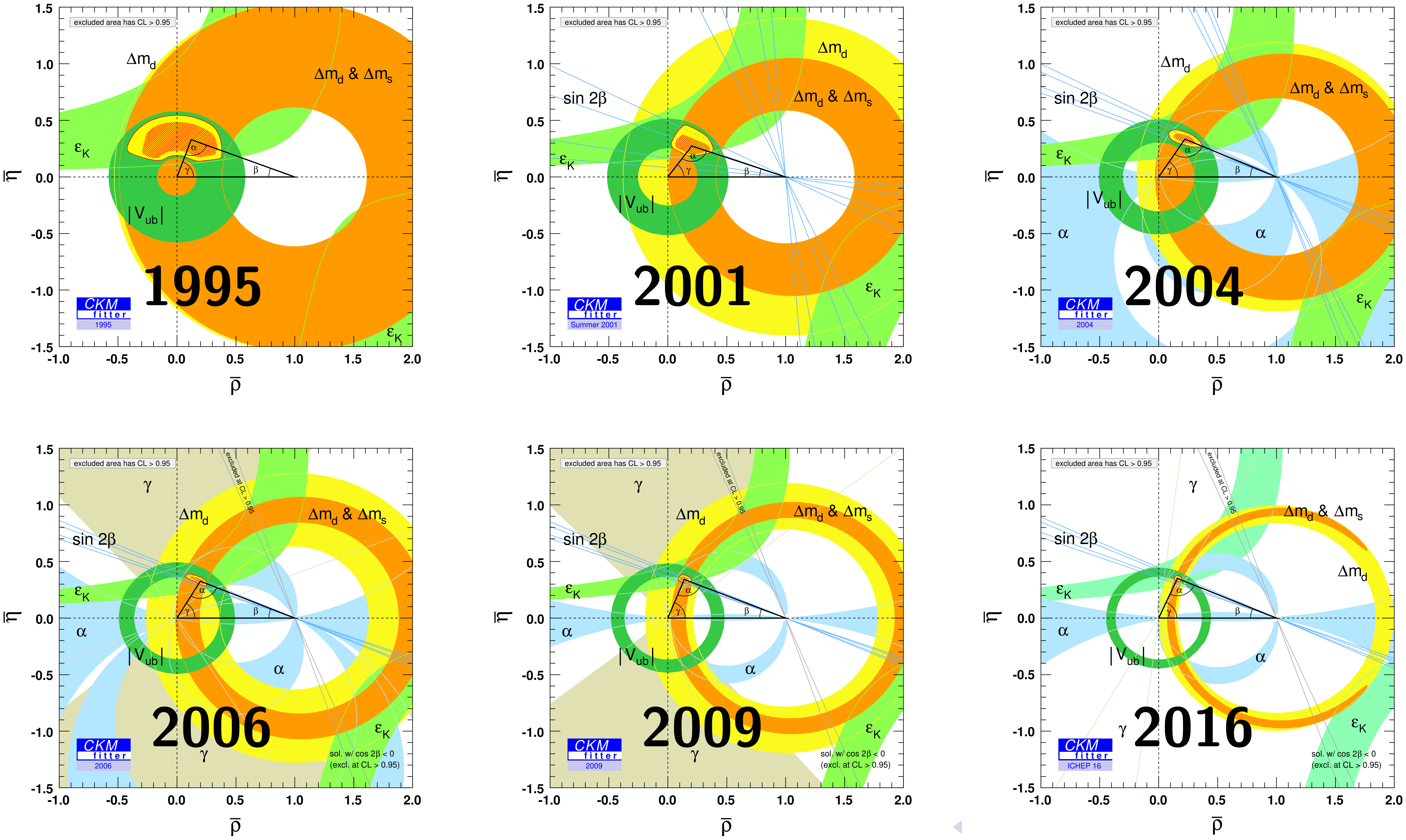
Data = weak ⊗ QCD → need hadronic inputs; often LQCD with our own Rfit-based averaging scheme.

- **black**: no change;
- **blue**: slight change;
- **red**: update since ICHEP'16

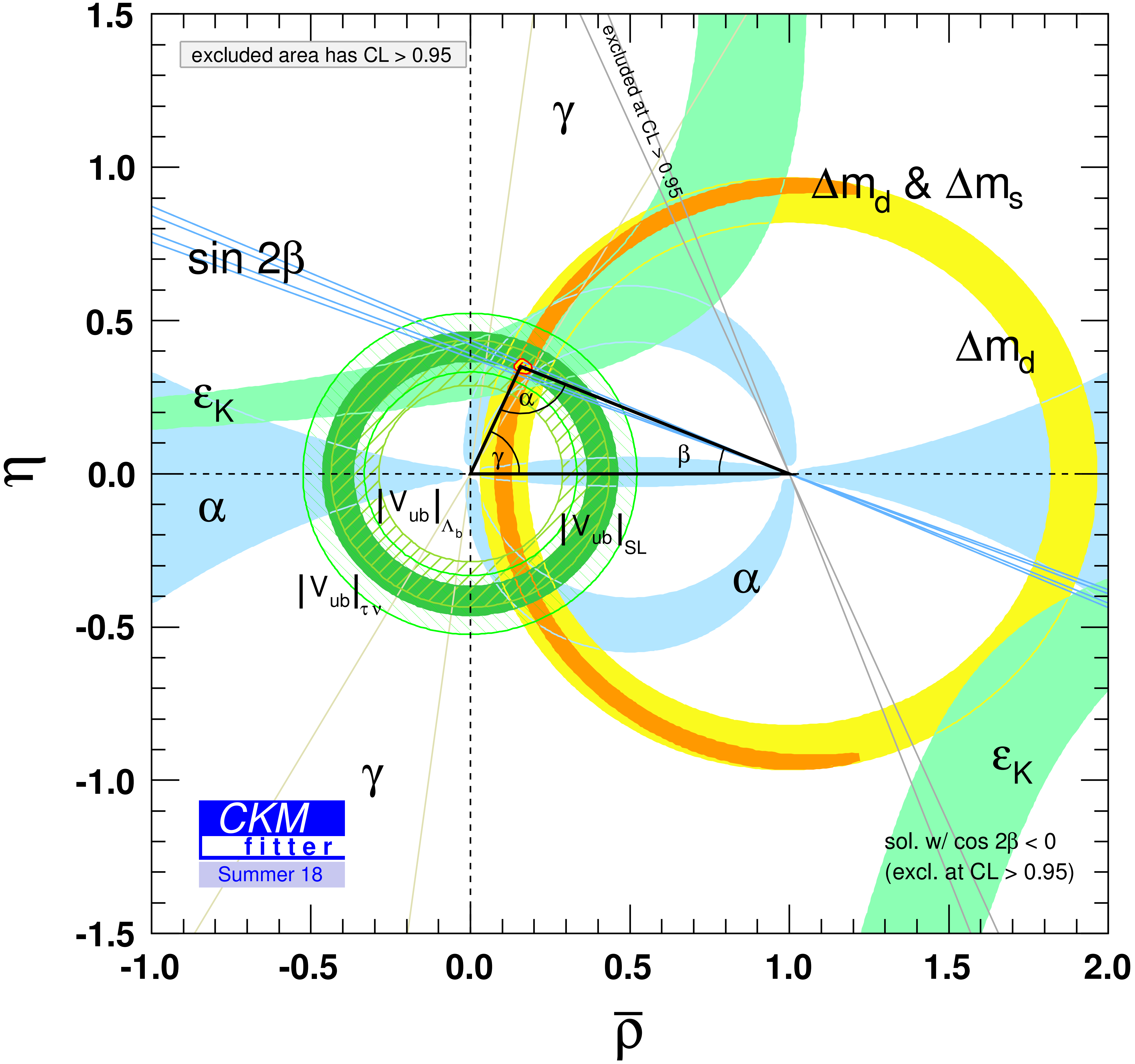
CKM	Process	Observables			Theoretical inputs		
$\|V_{ud}\|$	$0^+ \to 0^+ \beta$	$\|V_{ud}\|_{\text{nucl}}$	=	$0.97420 \pm 0 \pm 0.00021$	Nuclear matrix elements		
$\|V_{us}\|$	$K \to \pi \ell \nu$	$\|V_{us}\|_{\text{SL}} f_+^{K\to\pi}(0)$	=	0.2165 ± 0.0004	$f_+^{K\to\pi}(0)$	=	$0.9681 \pm 0.0014 \pm 0.0022$
	$K \to e\nu$	$\mathcal{B}(K \to e\nu)$	=	$(1.582 \pm 0.007) \cdot 10^{-5}$	f_K	=	$155.6 \pm 0.2 \pm 0.6$ MeV
	$K \to \mu\nu$	$\mathcal{B}(K \to \mu\nu)$	=	0.6356 ± 0.0011			
	$\tau \to K\nu$	$\mathcal{B}(\tau \to K\nu)$	=	$(0.6960 \pm 0.0096) \cdot 10^{-2}$			
$\frac{\|V_{us}\|}{\|V_{ud}\|}$	$K \to \mu\nu / \pi \to \mu\nu$	$\frac{\mathcal{B}(K \to \mu\nu)}{\mathcal{B}(\pi \to \mu\nu)}$	=	1.3367 ± 0.0029	f_K/f_π	=	$1.1959 \pm 0.0007 \pm 0.0029$
	$\tau \to K\nu / \tau \to \pi\nu$	$\frac{\mathcal{B}(\tau \to K\nu)}{\mathcal{B}(\tau \to \pi\nu)}$	=	$(6.438 \pm 0.094) \cdot 10^{-2}$			
$\|V_{cd}\|$	νN	$\|V_{cd}\|_{\text{not lattice}}$	=	0.230 ± 0.011			
	$D \to \mu\nu$	$\mathcal{B}(D \to \mu\nu)$	=	$(3.74 \pm 0.17) \cdot 10^{-4}$	f_{D_s}/f_D	=	$1.175 \pm 0.001 \pm 0.004$
	$D \to \pi\ell\nu$	$\|V_{cd}\| f_+^{D\to\pi}(0)$	=	0.1426 ± 0.0019	$f_+^{D\to\pi}(0)$	=	$0.621 \pm 0.016 \pm 0.012$
$\|V_{cs}\|$	$W \to c\bar{s}$	$\|V_{cs}\|_{\text{not lattice}}$	=	$0.94^{+0.32}_{-0.26} \pm 0.13$			
	$D_s \to \tau\nu$	$\mathcal{B}(D_s \to \tau\nu)$	=	$(5.55 \pm 0.24) \cdot 10^{-2}$	f_{D_s}	=	$247.8 \pm 0.3 \pm 2.0$ MeV
	$D_s \to \mu\nu$	$\mathcal{B}(D_s \to \mu\nu)$	=	$(5.39 \pm 0.16) \cdot 10^{-3}$			
	$D \to K\ell\nu$	$\|V_{cs}\| f_+^{D\to K}(0)$	=	0.7226 ± 0.0034	$f_+^{D\to K}(0)$	=	$0.741 \pm 0.010 \pm 0.012$
$\|V_{ub}\|$	semileptonic B	$\|V_{ub}\|_{\text{SL}}$	=	$(3.98 \pm 0.08 \pm 0.22) \cdot 10^{-3}$	form factors, shape functions		
	$B \to \tau\nu$	$\mathcal{B}(B \to \tau\nu)$	=	$(1.08 \pm 0.21) \cdot 10^{-4}$	f_{B_s}/f_B	=	$1.205 \pm 0.004 \pm 0.006$
$\|V_{cb}\|$	semileptonic B	$\|V_{cb}\|_{\text{SL}}$	=	$(41.8 \pm 0.4 \pm 0.6) \cdot 10^{-3}$	form factors, OPE matrix elements		
$\|V_{ub}/V_{cb}\|$	semileptonic Λ_b	$\frac{\mathcal{B}(\Lambda_p \to p\mu^-\bar{\nu})_{q^2>15}}{\mathcal{B}(\Lambda_p \to \Lambda_c\mu^-\bar{\nu})_{q^2>7}}$	=	$(0.947 \pm 0.081) \cdot 10^{-2}$	$\frac{\zeta(\Lambda_p \to p\mu^-\bar{\nu})_{q^2>15}}{\zeta(\Lambda_p \to \Lambda_c\mu^-\bar{\nu})_{q^2>7}}$	=	$1.471 \pm 0.096 \pm 0.290$
α	$B \to \pi\pi,\ \rho\pi,\ \rho\rho$	branching ratios, CP asymmetries			isospin symmetry		
β	$B \to (c\bar{c})K$	$\sin(2\beta)_{[c\bar{c}]}$	=	0.699 ± 0.017	subleading penguins neglected		
$\cos(2\beta)$	$B^0 \to D^{(*)}h^0$	$\cos(2\beta)$	=	0.91 ± 0.25			
γ	$B \to D^{(*)}K^{(*)}$	inputs for the 3 methods			GGSZ, GLW, ADS methods		
ϕ_s	$B_s \to J/\psi(KK, \pi\pi)$	$(\phi_s)_{b\to c\bar{c}s}$	=	-0.021 ± 0.031			
$V_{tq}^* V_{tq'}$	Δm_d	Δm_d	=	$0.5065 \pm 0.0019\ \text{ps}^{-1}$	$\hat{B}_{B_s}/\hat{B}_{B_d}$	=	$1.007 \pm 0.013 \pm 0.014$
	Δm_s	Δm_s	=	$17.757 \pm 0.021\ \text{ps}^{-1}$	$\hat{B}_{B_s}$	=	$1.327 \pm 0.016 \pm 0.030$
	$B_s \to \mu\mu$	$\mathcal{B}(B_s \to \mu\mu)$	=	$(2.8^{+0.7}_{-0.6}) \cdot 10^{-9} [\times(1 - 0.063)]$	f_{B_s}	=	$226.0 \pm 1.3 \pm 2.0$ MeV
$V_{td}^* V_{ts}$ and $V_{cd}^* V_{cs}$	ε_K	$\|\varepsilon_K\|$	=	$(2.228 \pm 0.011) \cdot 10^{-3}$	$\hat{B}_K$	=	$0.7567 \pm 0.0021 \pm 0.0123$
					κ_ε	=	$0.940 \pm 0.013 \pm 0.023$

Progress

- Long road for a better theoretical control (e.g., Lattice QCD), and more accurate data (LEP, KTeV, NA48, BaBar, Belle, CDF, DØ, LHCb, CMS, ...)



Overall results from 2018 (2019 update coming)



- Global fit remains excellent:
  ICHEP'16: p-value ~ 21% (1.3σ) →
  CKM'18: p-value ~ 51% (0.7σ)

$$A = 0.8403\,^{+0.0056}_{-0.0201}\ (2\%\ \text{unc.})$$

$$\lambda = 0.224747\,^{+0.000254}_{-0.000059}\ (0.07\%\ \text{unc.})$$

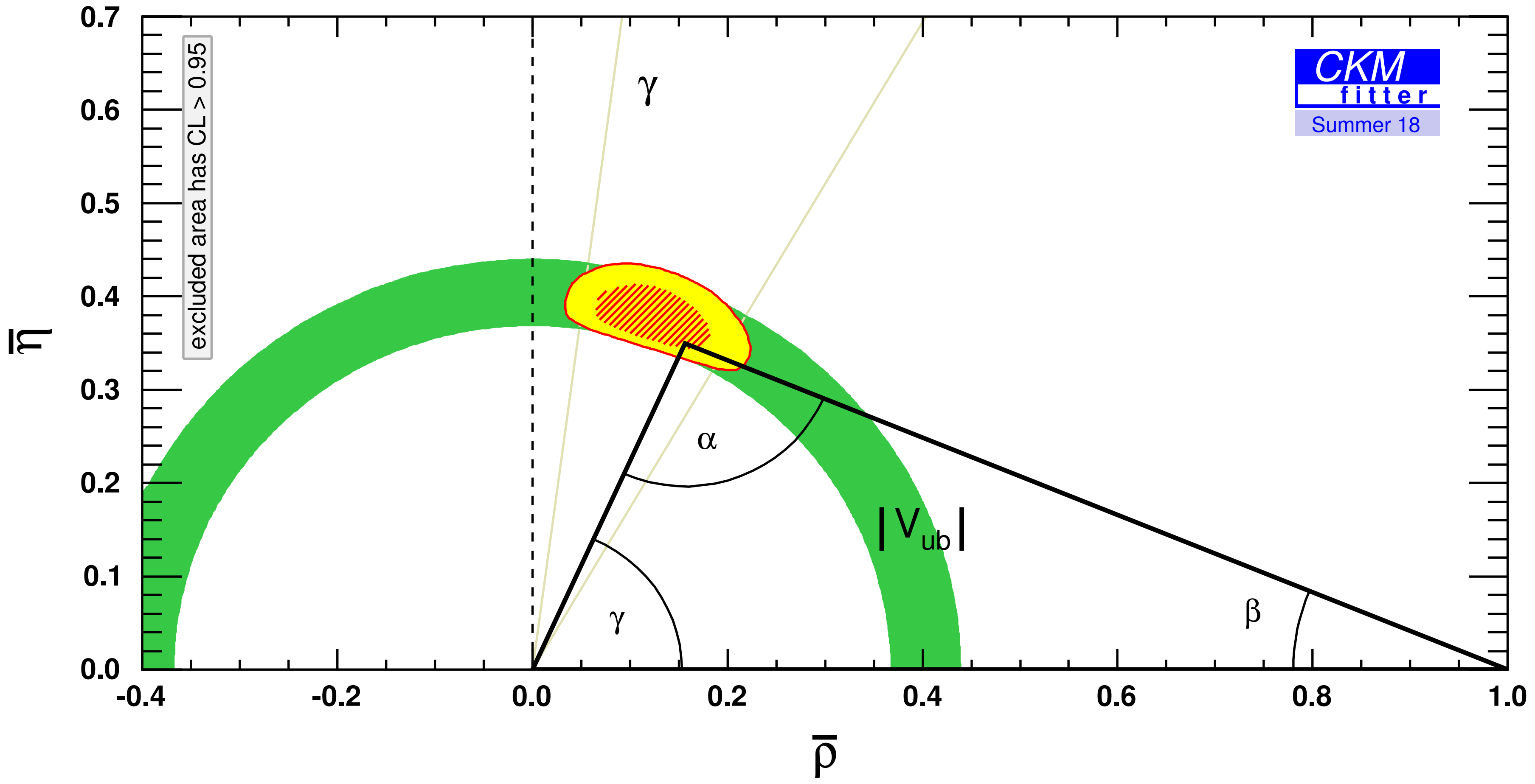
$$\bar{\rho} = 0.1577\,^{+0.0096}_{-0.0074}\ (5\%\ \text{unc.})$$

$$\bar{\eta} = 0.3493\,^{+0.0095}_{-0.0071}\ (2\%\ \text{unc.})$$

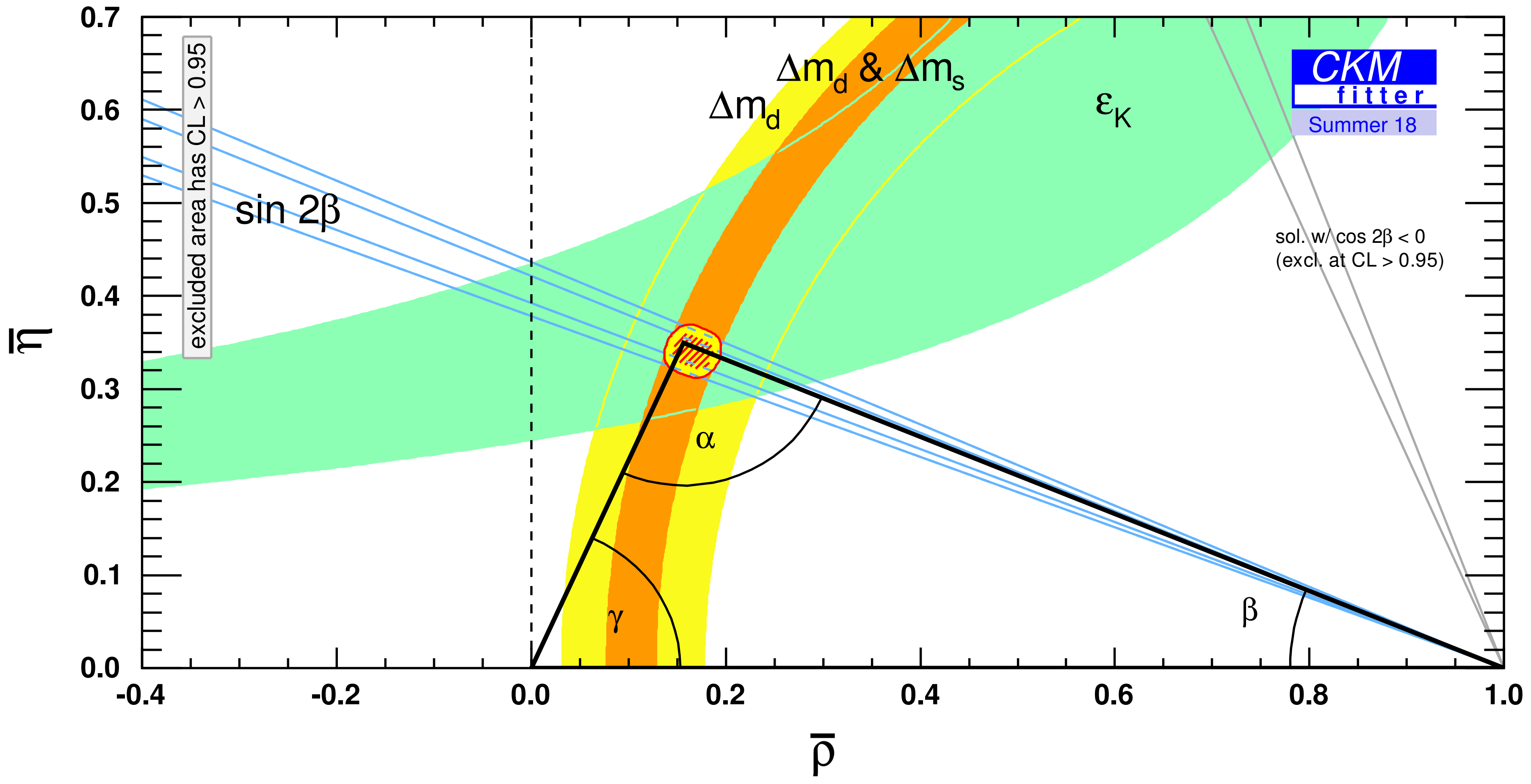
68% C.L. intervals

Consistency among classes of observables

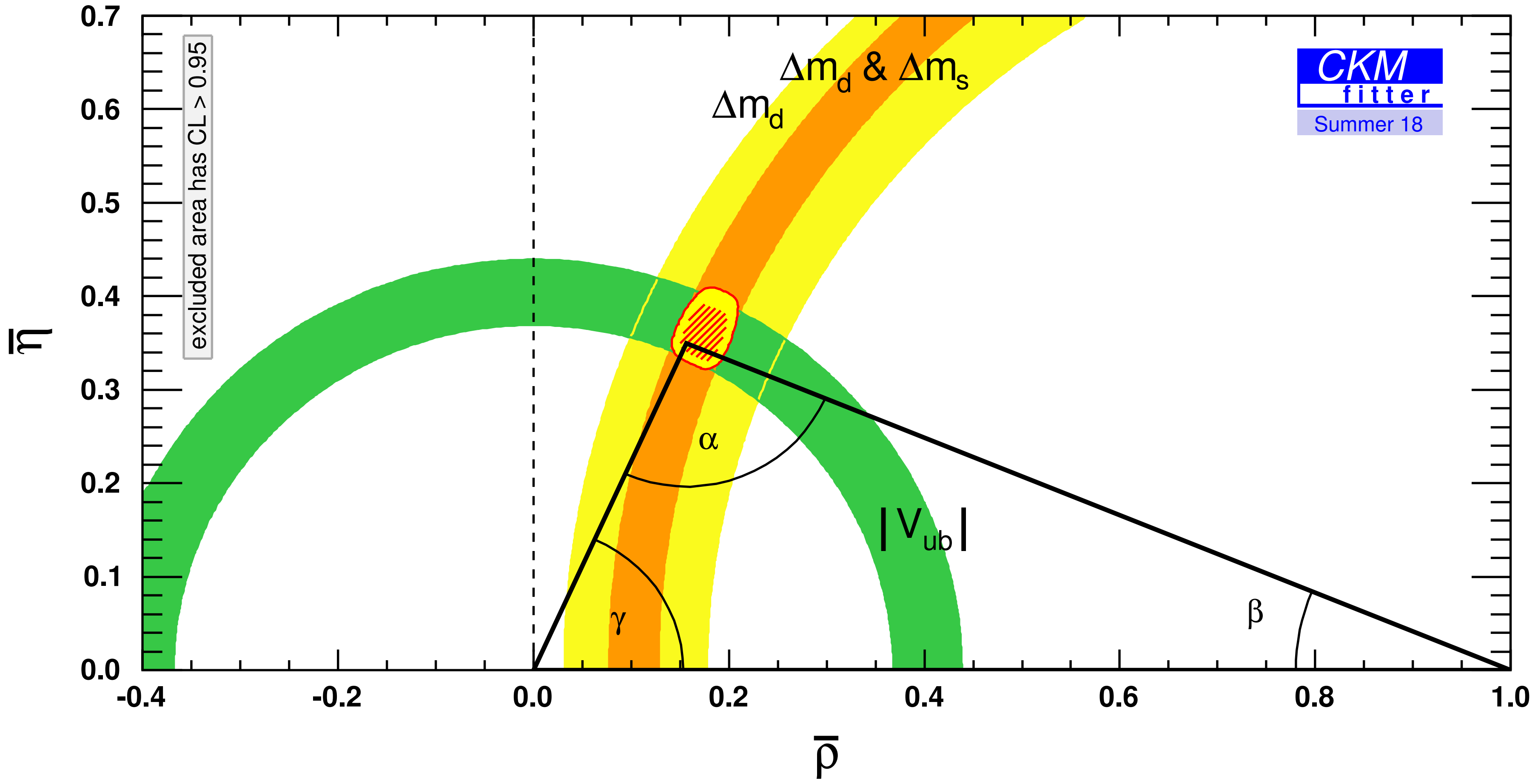
tree level



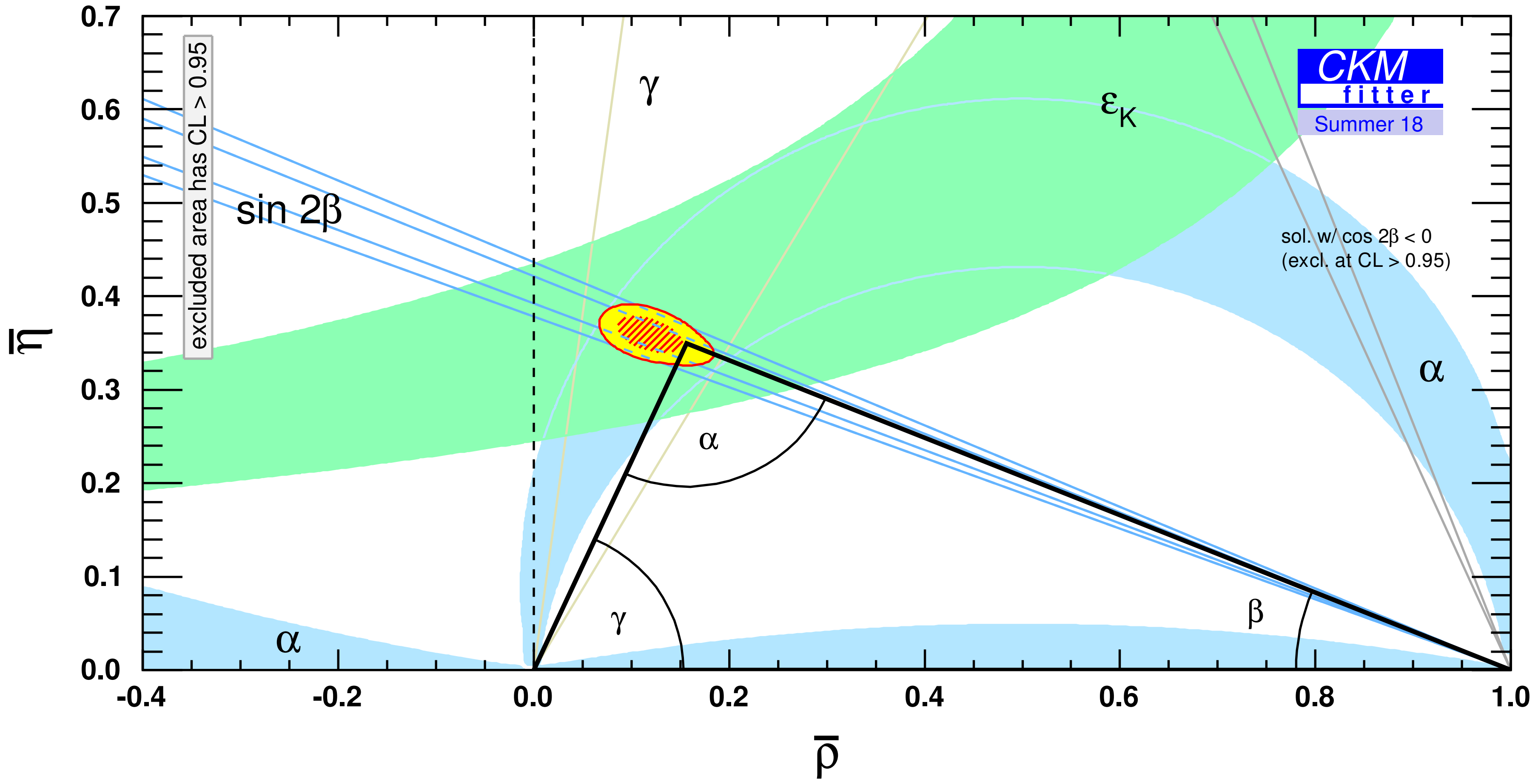
loop-induced



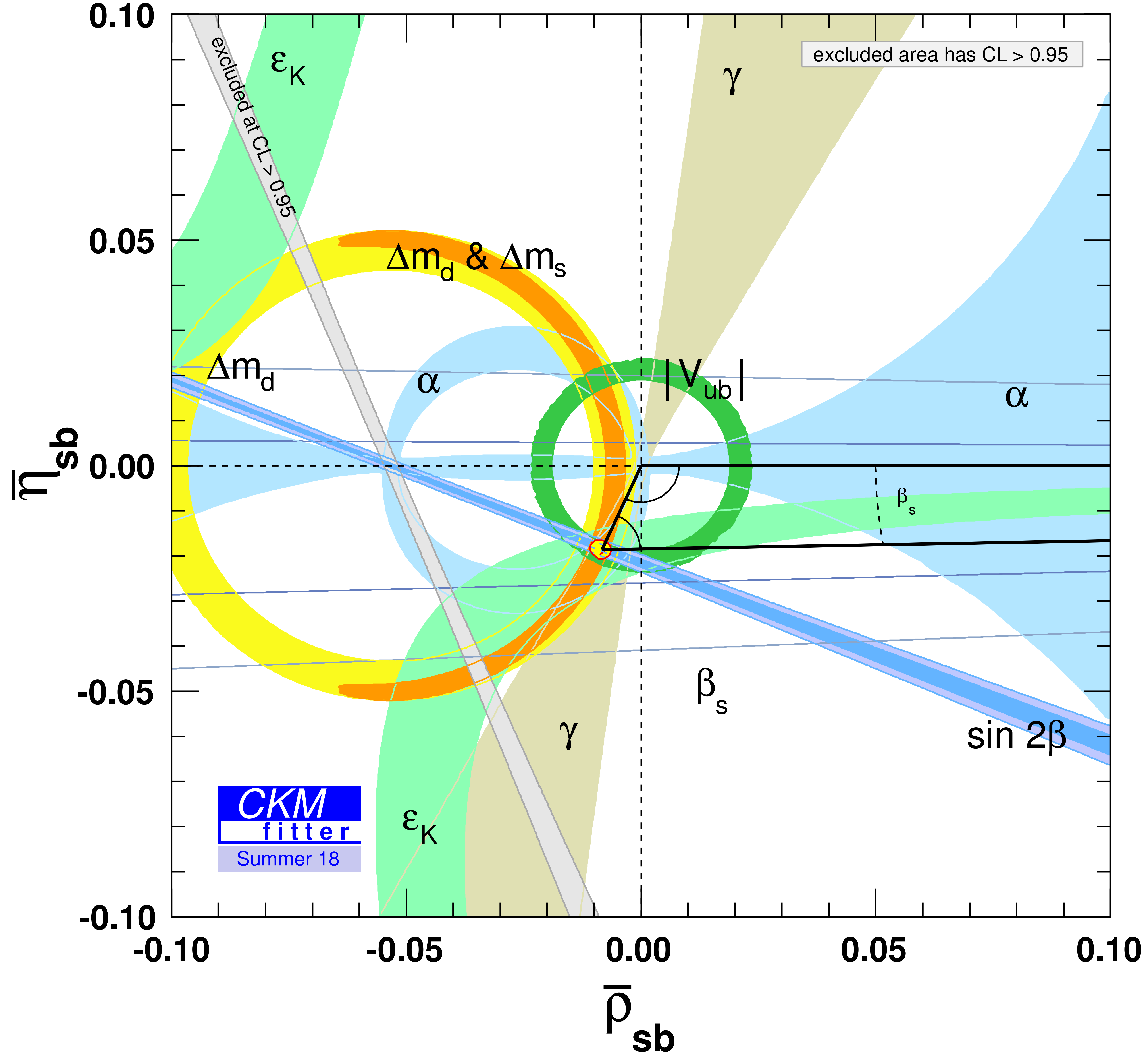
$\mathcal{CP}-$conserving



$\mathcal{CP}-$violating



Other Triangles: B_s



$$\bar{\rho}_{bs} + i\bar{\eta}_{bs} = -\frac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*}$$

$$(\lambda^4, \lambda^2, \lambda^2)$$

β_s easily visualized

$$\bar{\rho}_s = -0.00834\,^{+0.00035}_{-0.00056}$$

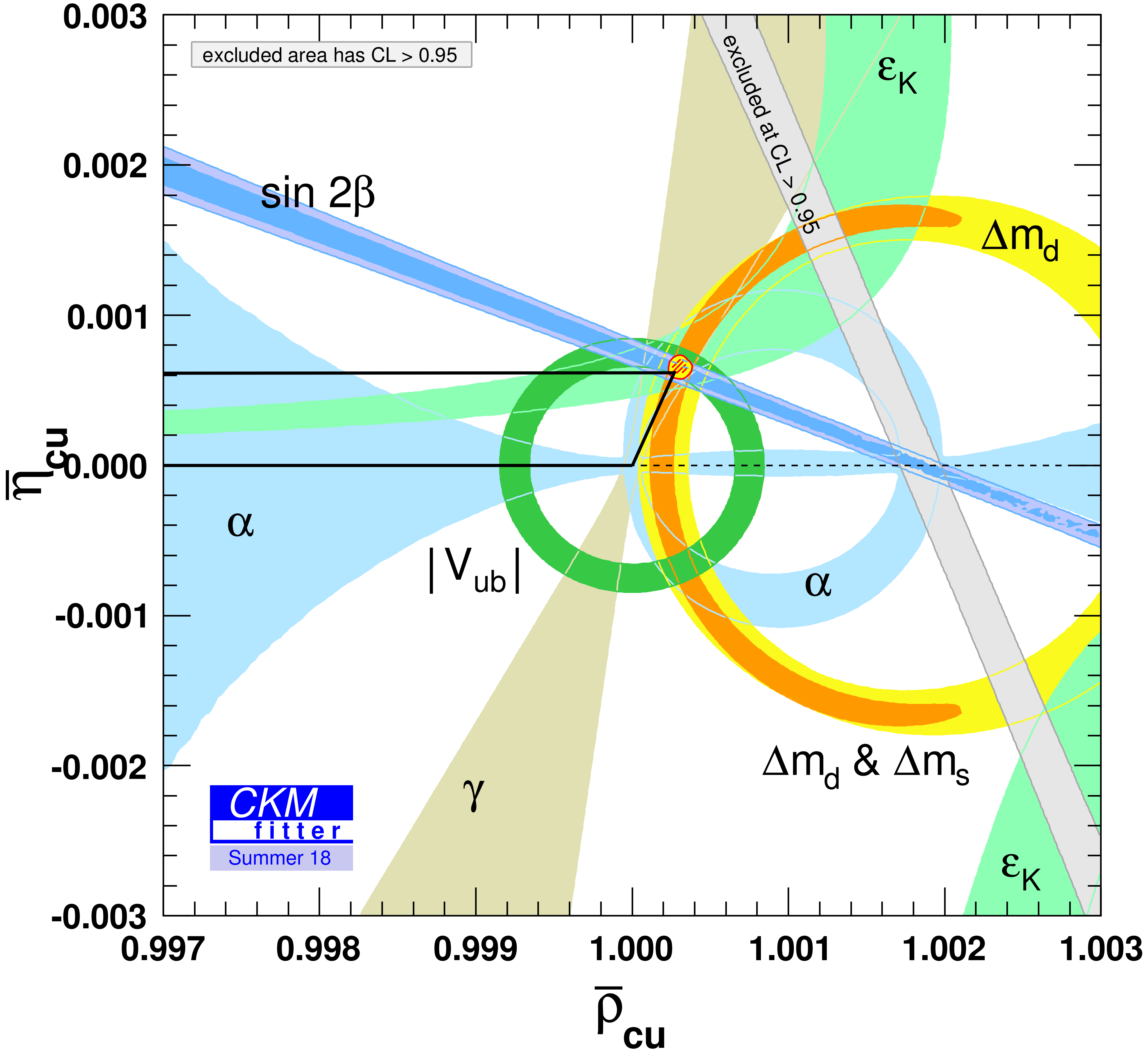
$$\bar{\eta}_s = -0.01861\,^{+0.00039}_{-0.00048}$$

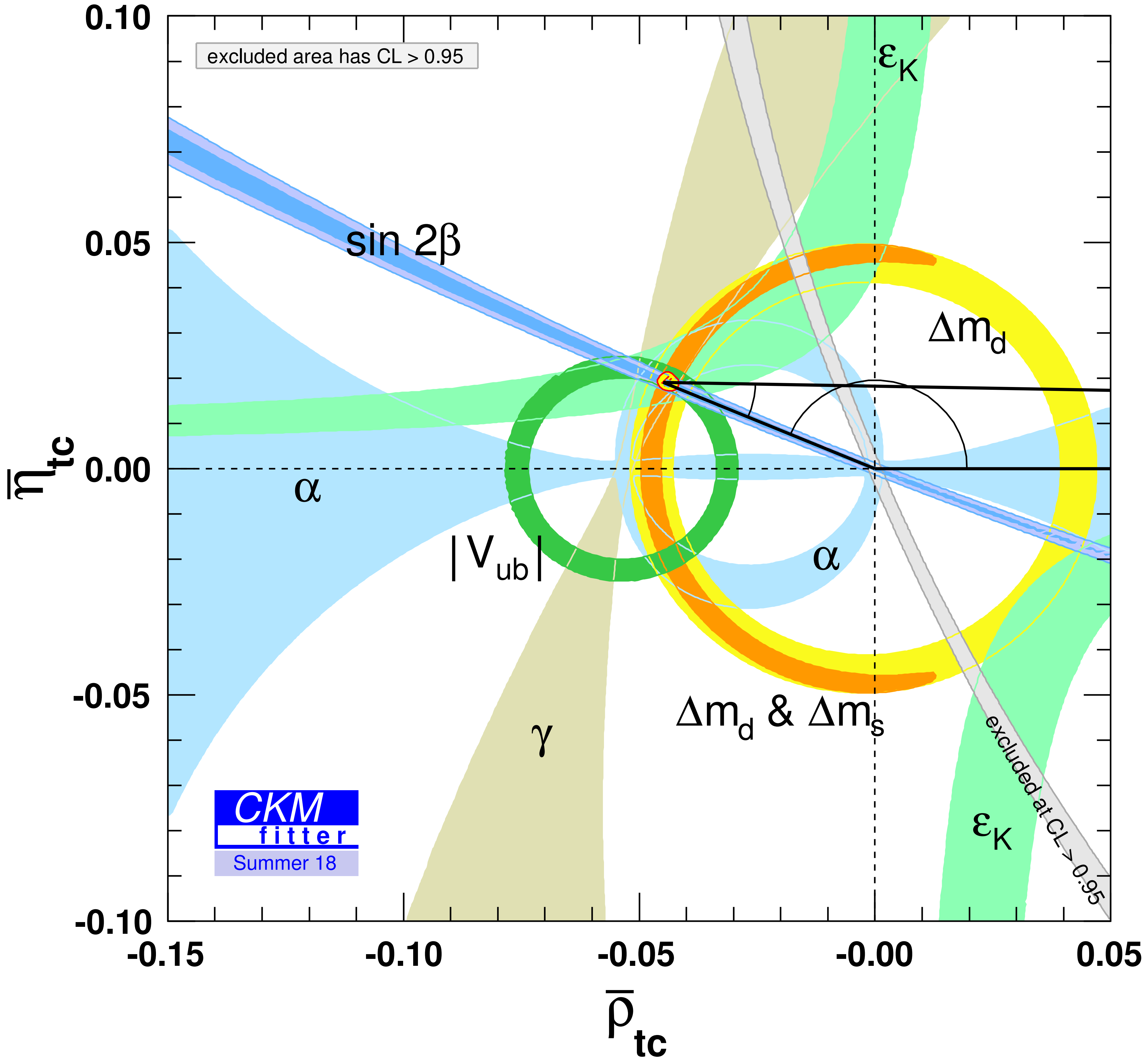
68% C.L. intervals

Other Triangles: Charm

$$\bar{\rho}_{cu} + i\bar{\eta}_{cu} = -\frac{V_{cd}V_{ud}^*}{V_{cs}V_{us}^*}$$
$$(\lambda, \lambda, \lambda^5)$$

$$\bar{\rho}_{tc} + i\bar{\eta}_{tc} = -\frac{V_{td}V_{cd}^*}{V_{ts}V_{cs}^*}$$
$$(\lambda^4, \lambda^2, \lambda^2)$$



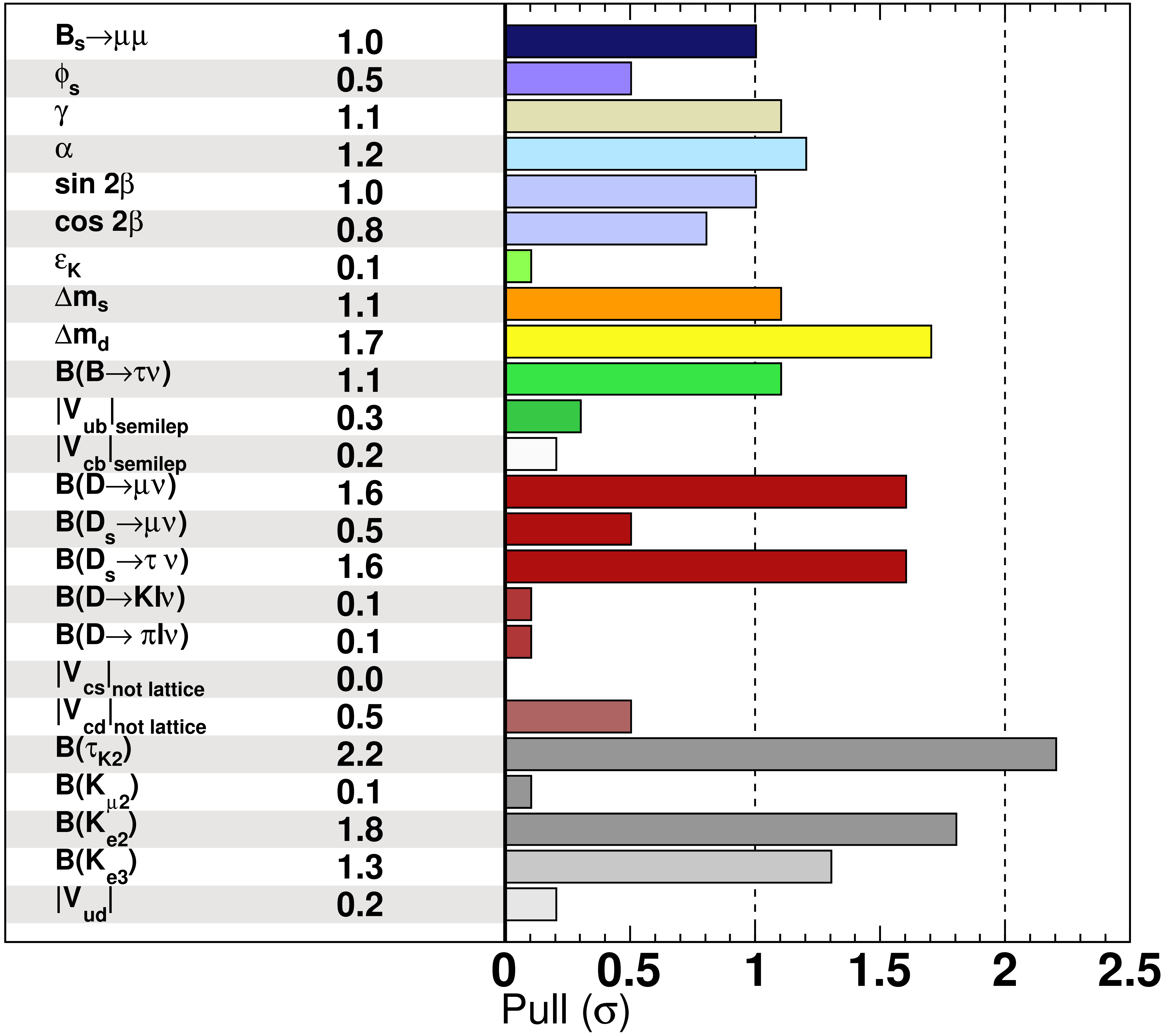


Pulls

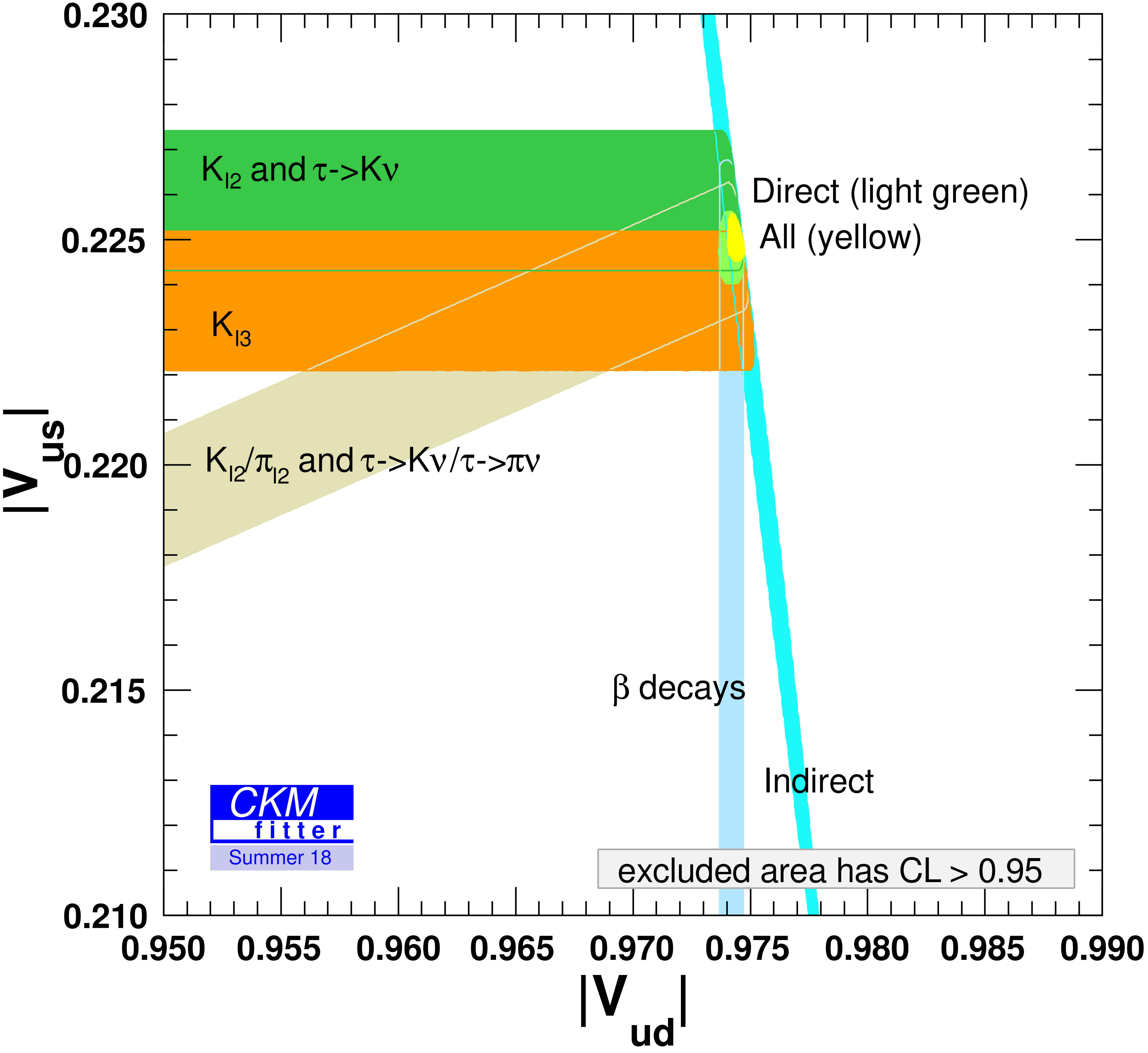
$$pull_{\mathcal{O}_{exp}} = \sqrt{\chi^2_{min} - \chi^2_{min,!\mathcal{O}_{exp}}},$$

$$!\,\mathcal{O}_{exp}\colon\ \chi^2_{min}\ \text{w/o}\ \mathcal{O}_{exp}$$

- Pulls for various inputs or parameters involved in the global fit.
- The plateau in the Rfit model for theoretical uncertainties sometimes leads to a vanishing pull.
- → No signs of NP within the CKM global fit paradigm analysis.



First 2 generations: $|V_{ud}|$ and $|V_{us}|$ plane



- $|V_{ud}|$ from nuclear transitions.
- K , π, τ decays.

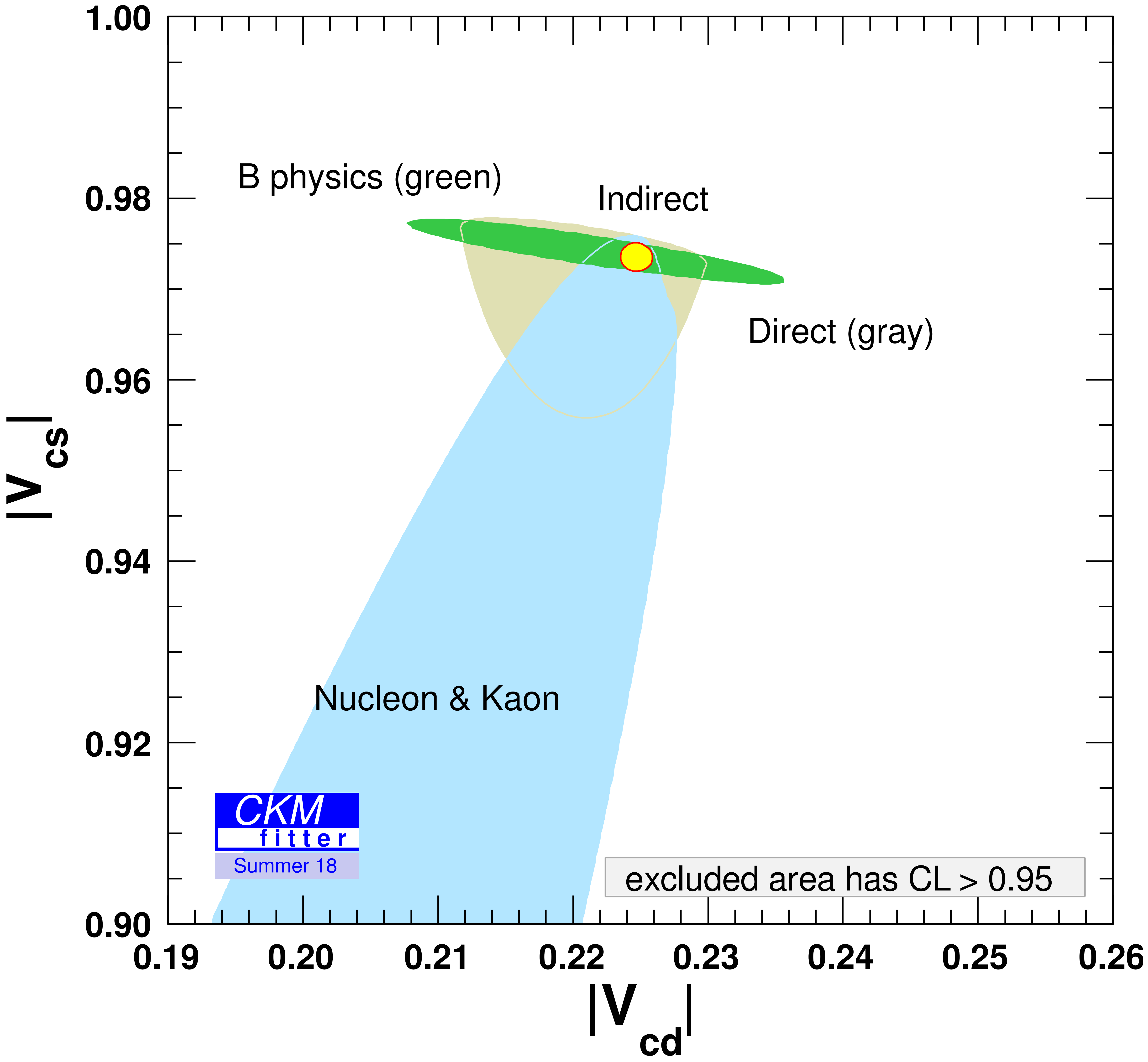
- Good agreement among different classes of inputs (indirect and direct).
- Pull in $|V_{us}|$f K→π(0) has decreased from 2.3σ to 1.3σ. Radiative corrections in check.

- Other recent interpretations find lack of unitarity in first row - keep an eye on this.

$$V_{ud}: \pm 0.007\% \text{ [ind.]}, \pm 0.004\% \text{ [comb.]}$$

$$V_{us}: \pm 0.3\% \text{ [ind.]}, \pm 0.07\% \text{ [comb.]}$$

First 2 generations: $|V_{cd}|$ and $|V_{cs}|$ plane



- Indirect constraints (from b and s transitions) are related to $|V_{cd}|$ and $|V_{cs}|$ through unitarity.

- Direct constraints combine **leptonic** and **semileptonic** D and D_s decays (recent measurements from BES III) & neutrino-nucleon scattering.
  - $f_+ D\rightarrow\pi(0)$, $f_+ D\rightarrow K(0)$, improved by 3x - 4x since 2016.

- Test of LQCD predictions for leptonic decays.

$$\mathcal{B}[M \to \ell\nu_\ell] = \frac{G_F^2 m_M m_\ell^2}{8\pi}\left(1-\frac{m_\ell^2}{m_M^2}\right)^2 |V_{q_u q_d}|^2 f_M^2 \tau_M (1+\delta_{em}^{M\ell 2})$$

$$V_{cd}\colon\ \pm 0.07\%\ [\text{ind.}],\ \pm 0.07\%\ [\text{comb.}]$$

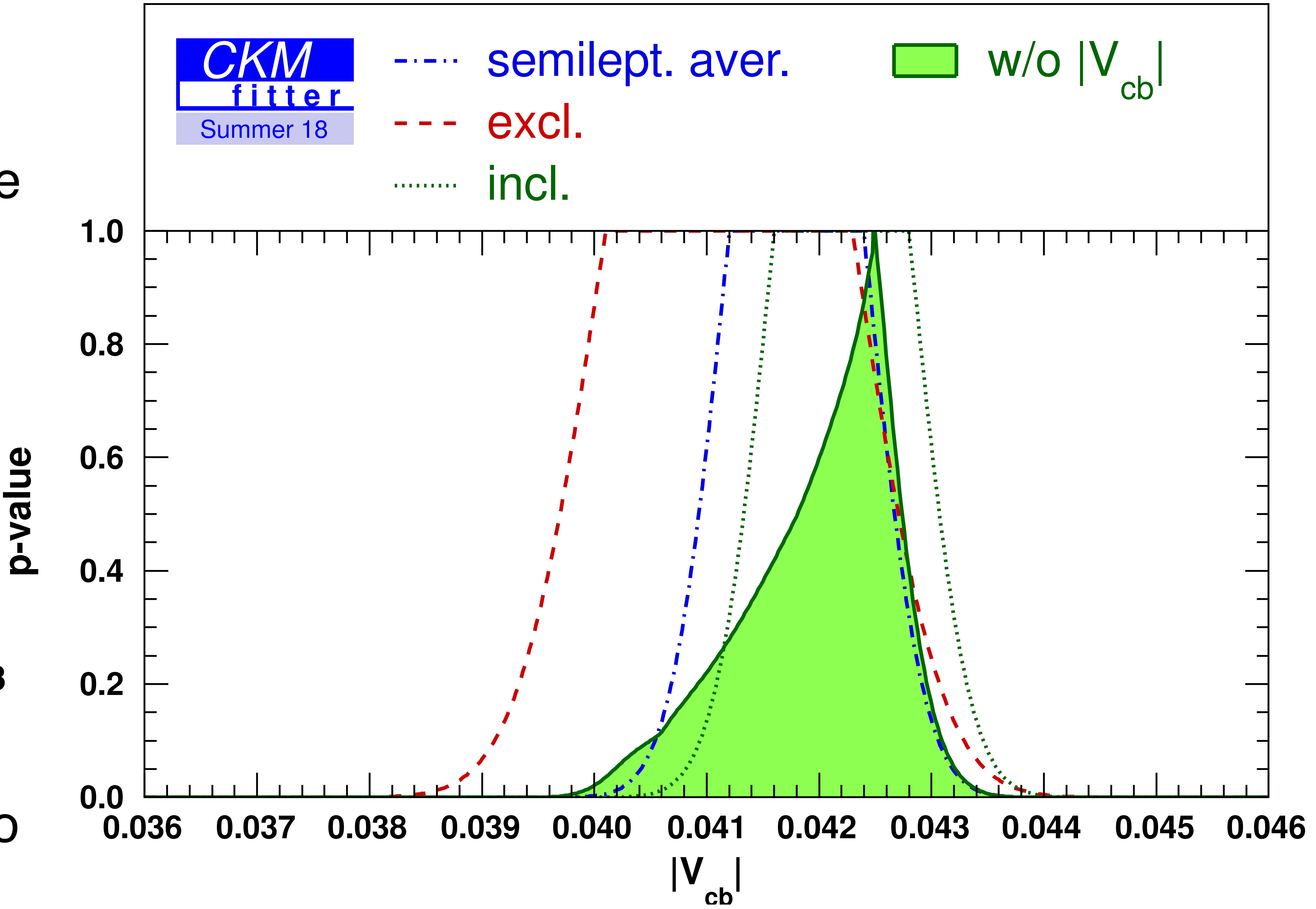
$$V_{cs}\colon\ \pm 0.006\%\ [\text{ind.}],\ \pm 0.006\%\ [\text{comb.}]$$

$|V_{cb}|$ and $|V_{ub}|$ semi-leptonic extractions

- Similar theo. frameworks for charmed and charmless modes, but different tools for **inclusive** (OPE in powers of 1/mb) and **exclusive** (HQET, Form Factors from Lattice QCD)

- Inclusive extraction:
  $|V_{cb}| = (42.2 \pm 0.4 \pm 0.6) \times 10^{-3}$ (m_b^{kin})

- Exclusive extraction (2018):
  $|V_{cb}| = (41.2 \pm 0.6_{(exp.)} \pm 0.9_{(LQCD)} \pm 0.2_{(EM)}) \times 10^{-3}$
  - Lots of activity in this area. New published 2019 results (Belle, BaBar) reduce this value to approximately
    $|V_{cb}| = (39.5 \pm 0.9) \times 10^{-3}$.



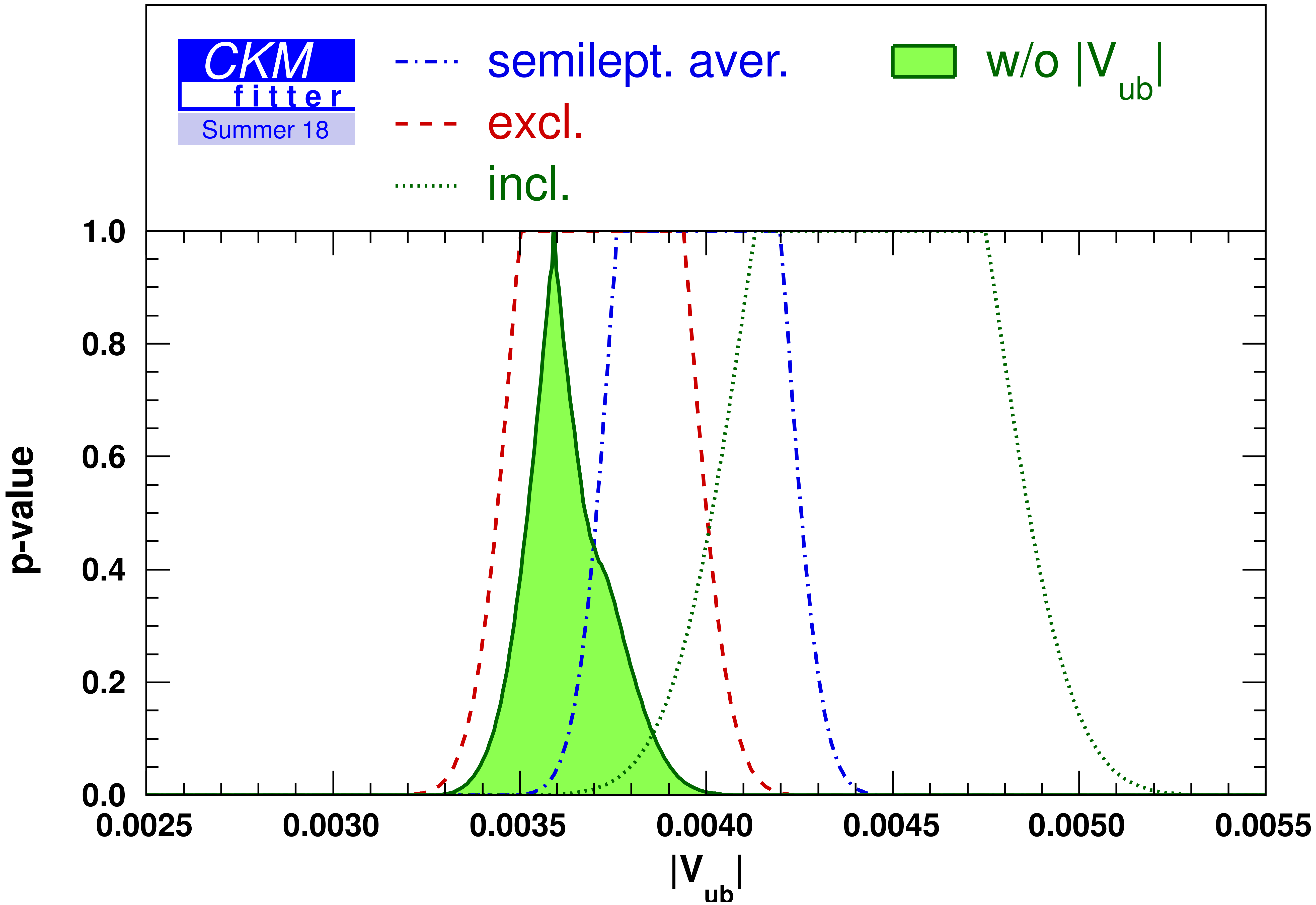
V_{cb}: $\pm 1.7\%$ [ind.]

$|V_{cb}|$ and $|V_{ub}|$ semi-leptonic extractions

- B → πlν: Simultaneous fit to Lattice and differential rates data:
  $|V_{ub}|$excl.= (3.72 ± 0.09 ± 0.22) × 10^{-3}

- BLNP (2018):
  $|V_{ub}|$incl.= (4.44 ± 0.17 ± 0.31) × 10^{-3}
  - 2019 value will be 5-10% lower due to BaBar update (~ **4.25 × 10^{-3}**).

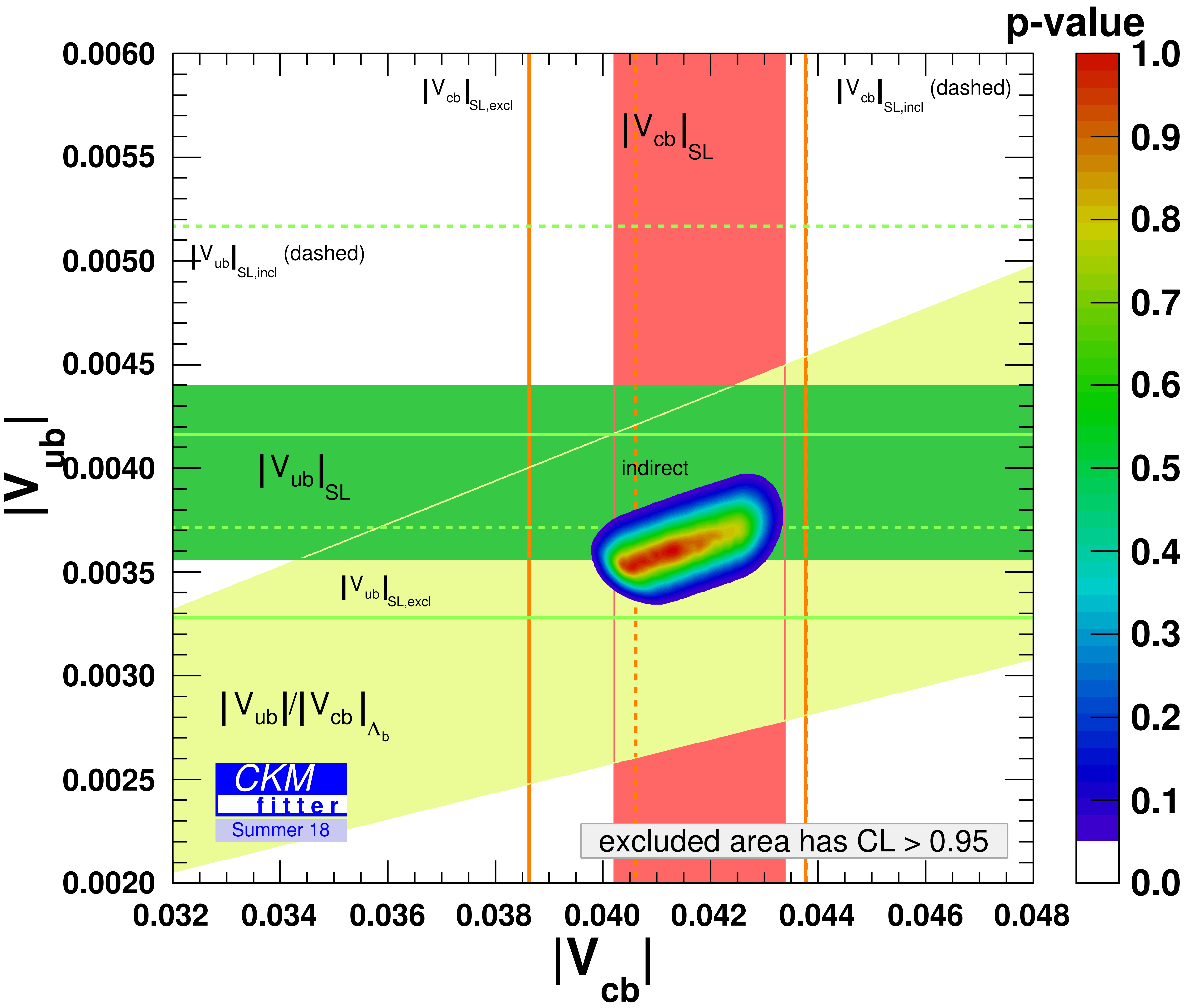
- Average did not change in 2018 but it will for 2019:
  $|V_{ub}|_{SL}$= (3.98 ± 0.08 ± 0.22)×10^{-3}
  - 2019 value will be lower (**~$|V_{ub}|$ = 3.82× 10^{-3}**)



V_{ub} ±3.9% [ind.]

$|V_{ub}|$ and $|V_{cb}|$ plane 2018

- Doesn’t look the same as the typical HFLAV figure - nuanced treatment of theory errors.



Φ_2 Angle

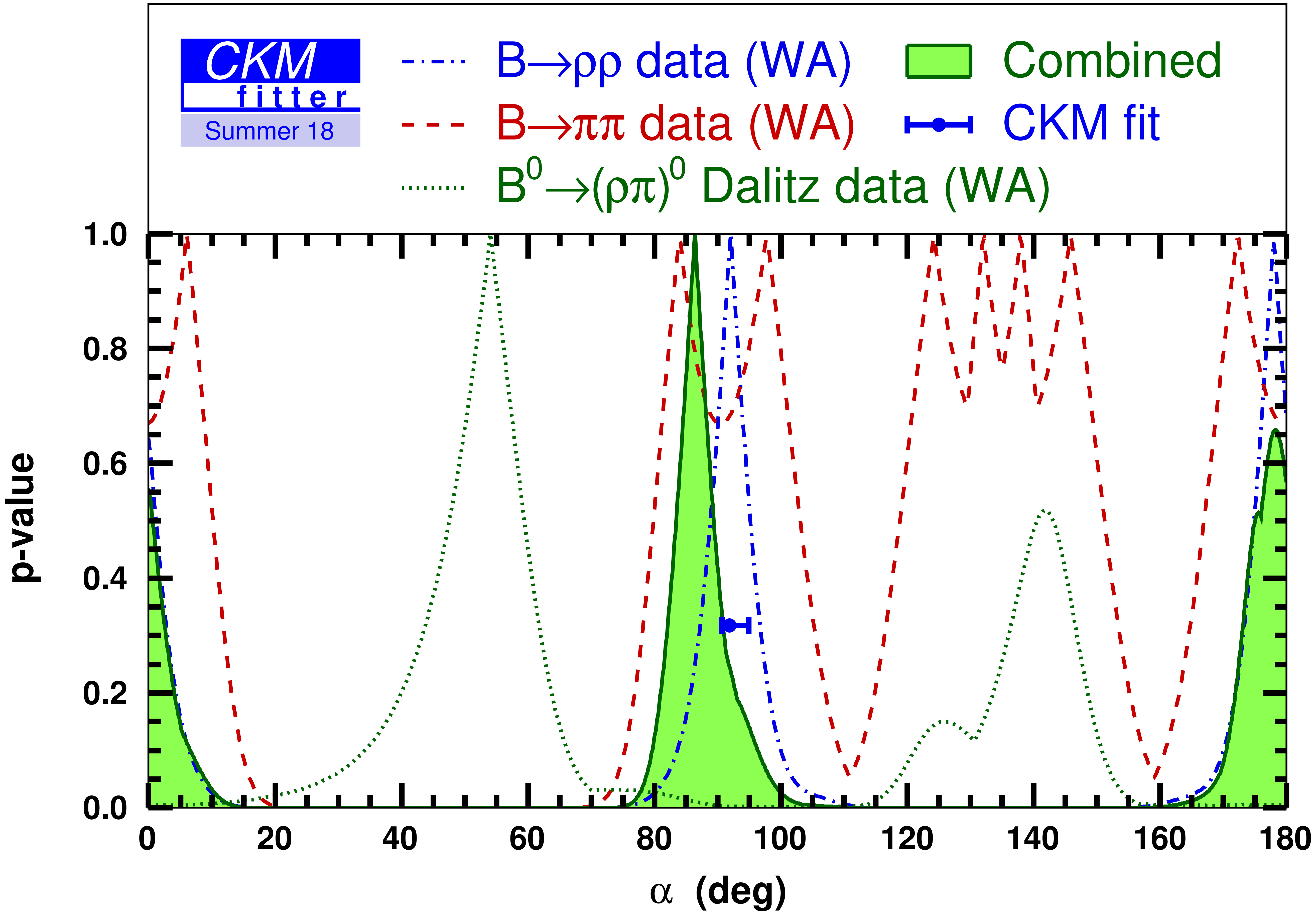
- Branching ratios and CP asymmetries for B → ππ, ρπ, ρρ
  - Isospin analysis constrains hadronic penguin and tree amplitudes
- As in previous editions:
  - Average dominated by B → ππ and B → ρρ
  - B → ππ,ρρ agree w/ α [ind.] → B → ρπ is in tension

CKM'18 edition

$$\alpha\ [\text{dir.}]\ (86.4^{+4.5}_{-4.3})^{o} \cup (-1.8^{+4.3}_{-5.1})^{o}$$

$$\alpha\ [\text{indir.}]\ (91.9^{+3.0}_{-1.2})^{o}$$

$$\alpha\ [\text{comb.}]\ (91.6^{+1.7}_{-1.1})^{o}$$

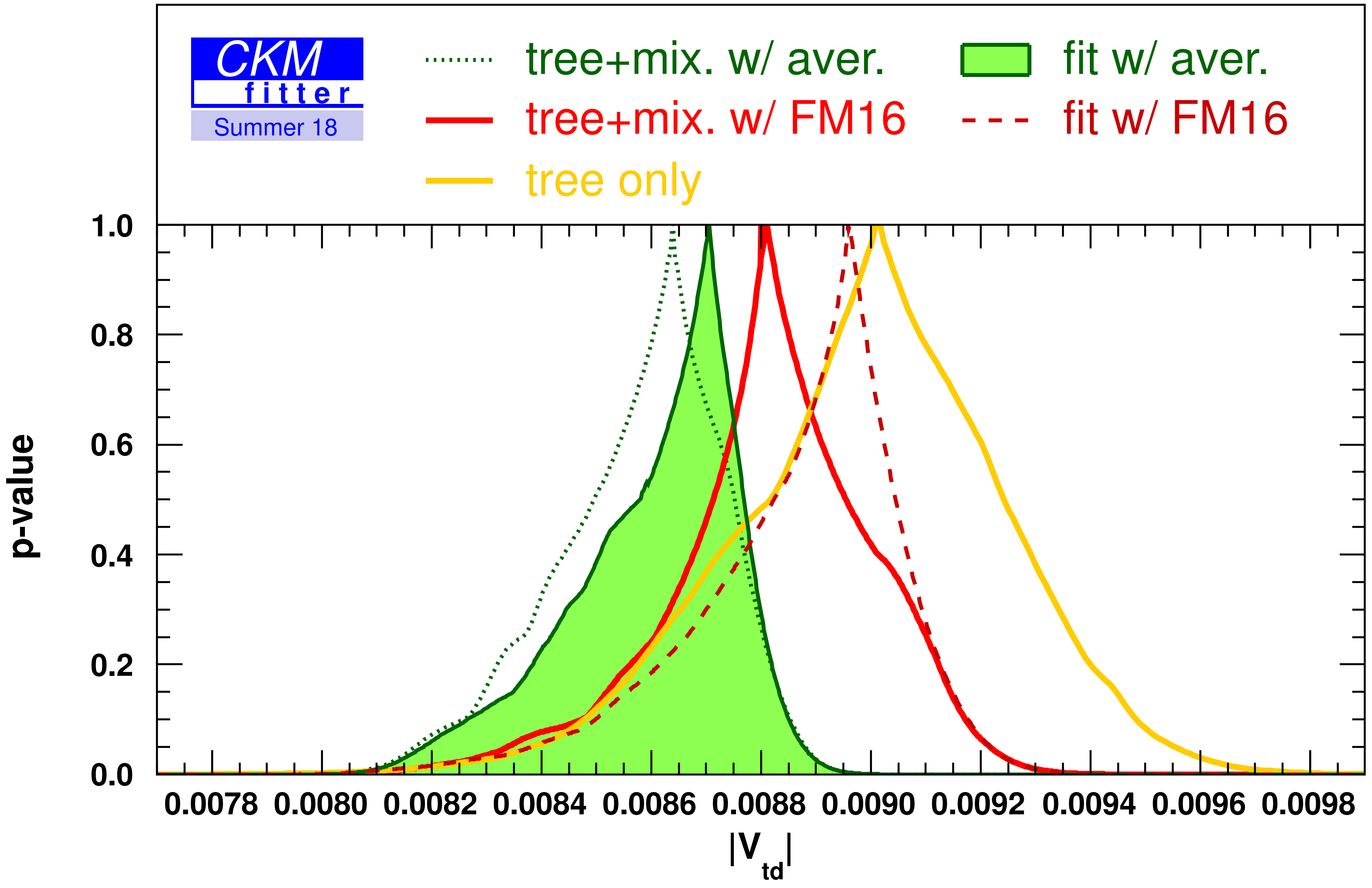


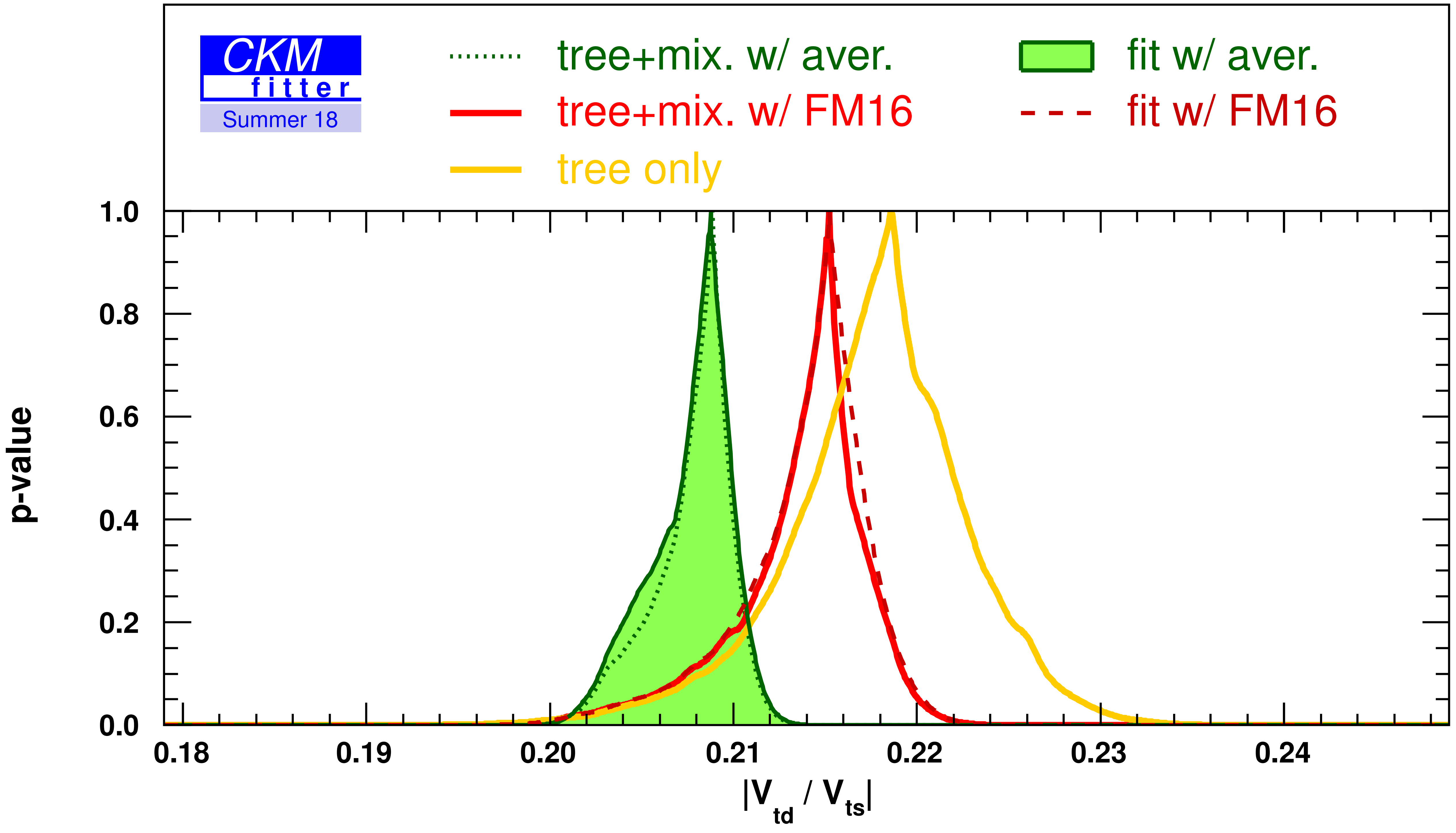
$|V_{td}|$ and $|V_{ts}|$

Aver., CKM'18: $\hat{B}_{B_s} = 1.327(16)(30)$, $\hat{B}_{B_s}/\hat{B}_{B_d} = 1.007(13)(14)$

FNAL-MILC'16: $\hat{B}_{B_s} = 1.443(78)(138)$, $\hat{B}_{B_s}/\hat{B}_{B_d} = 1.033(29)(48)$

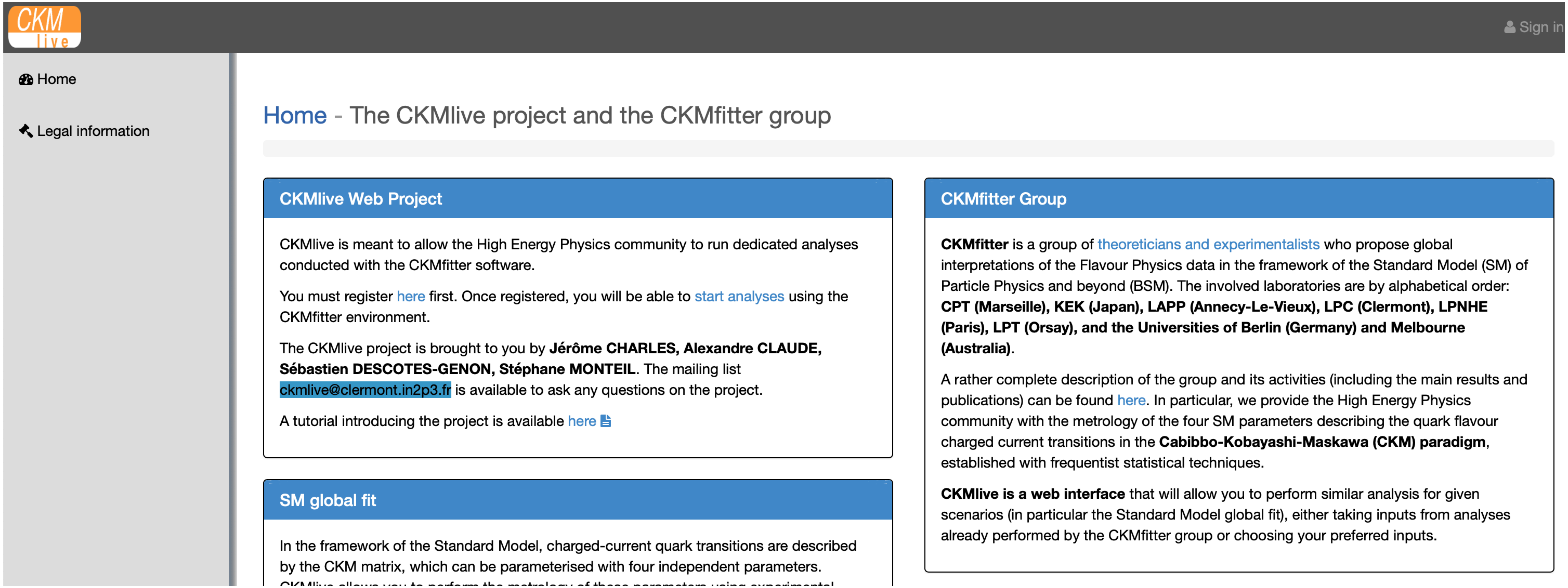
w.r.t. tree only,
p-v. $\in [0.4, 0.9]$





CKMlive

- Run dedicated CKM fits from CKMfitter package @ http://ckmlive.in2p3.fr
- User chooses the set of observables, and the values of the theoretical and experimental inputs, plus fitting parameters



Home - The CKMlive project and the CKMfitter group

CKMlive Web Project

CKMlive is meant to allow the High Energy Physics community to run dedicated analyses conducted with the CKMfitter software.

You must register here first. Once registered, you will be able to start analyses using the CKMfitter environment.

The CKMlive project is brought to you by **Jérôme CHARLES, Alexandre CLAUDE, Sébastien DESCOTES-GENON, Stéphane MONTEIL**. The mailing list ckmlive@clermont.in2p3.fr is available to ask any questions on the project.

A tutorial introducing the project is available here

SM global fit

In the framework of the Standard Model, charged-current quark transitions are described by the CKM matrix, which can be parameterised with four independent parameters.

CKMfitter Group

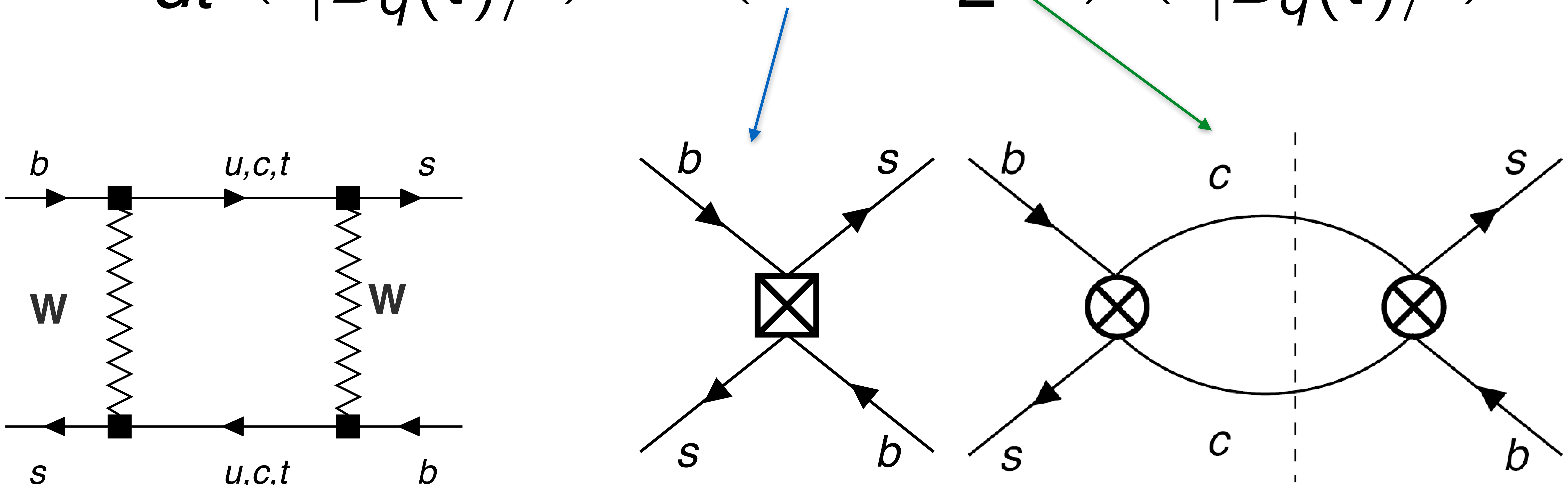
CKMfitter is a group of theoreticians and experimentalists who propose global interpretations of the Flavour Physics data in the framework of the Standard Model (SM) of Particle Physics and beyond (BSM). The involved laboratories are by alphabetical order: **CPT (Marseille), KEK (Japan), LAPP (Annecy-Le-Vieux), LPC (Clermont), LPNHE (Paris), LPT (Orsay), and the Universities of Berlin (Germany) and Melbourne (Australia)**.

A rather complete description of the group and its activities (including the main results and publications) can be found here. In particular, we provide the High Energy Physics community with the metrology of the four SM parameters describing the quark flavour charged current transitions in the **Cabibbo-Kobayashi-Maskawa (CKM) paradigm**, established with frequentist statistical techniques.

CKMlive is a web interface that will allow you to perform similar analysis for given scenarios (in particular the Standard Model global fit), either taking inputs from analyses already performed by the CKMfitter group or choosing your preferred inputs.

New Physics in mixing: past & future data

$$i\frac{d}{dt}\begin{pmatrix}|B_q(t)\rangle\\|\bar{B}_q(t)\rangle\end{pmatrix}=\left(M^q-\frac{i}{2}\Gamma^q\right)\begin{pmatrix}|B_q(t)\rangle\\|\bar{B}_q(t)\rangle\end{pmatrix}$$



- SM: C_{SM}/m_W^2
- NP: C_{NP}/Λ^2

- What is the scale Λ ? How different is C_{NP} from C_{SM} ?
- If deviation from SM seen → upper bound on Λ

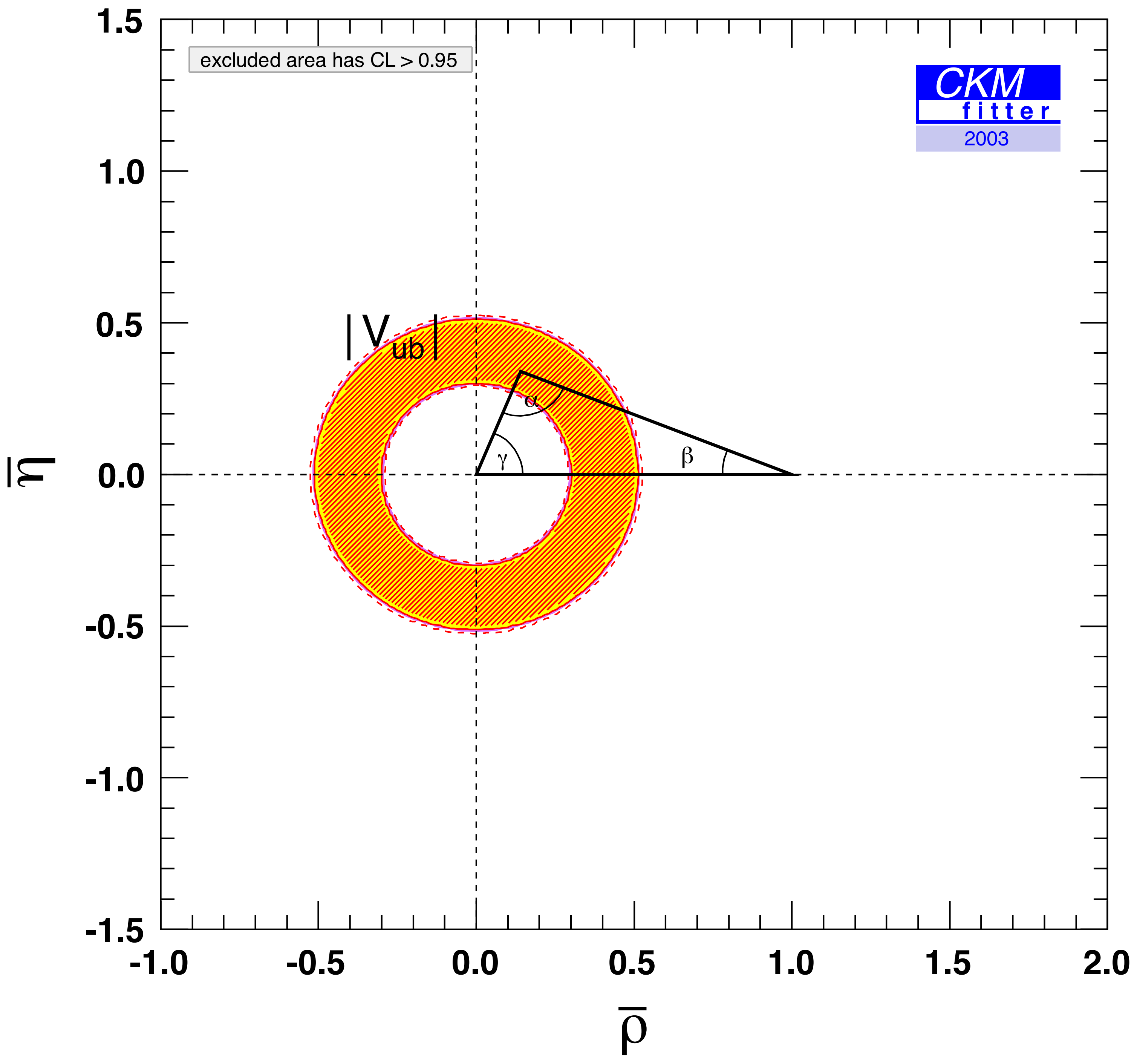
- Assume NP from Trees in negligible, test for NP in loops only - i.e. New Physics only enters M_{12}, the real part of the mixing Hamiltonian.
- 3 x 3 CKM matrix is unitary.

$$M_{12}=M_{12}^{SM}\times\left(1+he^{2i\sigma}\right)$$

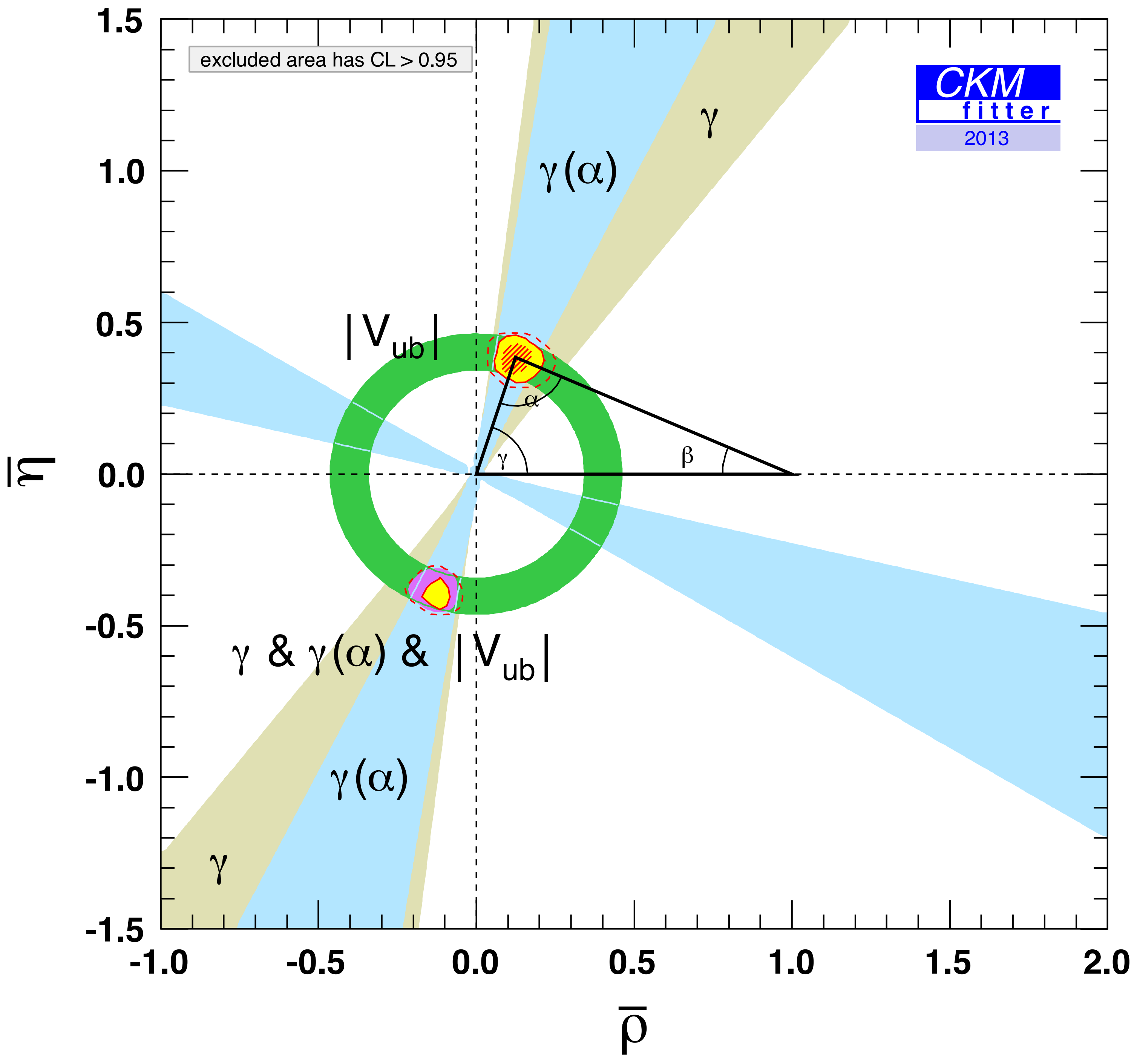
NP in B{d,s} & K mixing: Input

- Observables not affected by NP first used to constrain CKM: |Vud|, |Vus|, |Vcb|, |Vub|, Φ3 and Φ2=π–Φ3–Φ1eff((c anti-c)K)
- NP impact estimated from Meson mixing Δms, Δmd, |εK|, Lifetime difference ΔΓs, & semileptonic asymmetry A_{SL}, Time dep. CP asymmetries βs, Φ1, and Φ2 (decay-mixing interference)

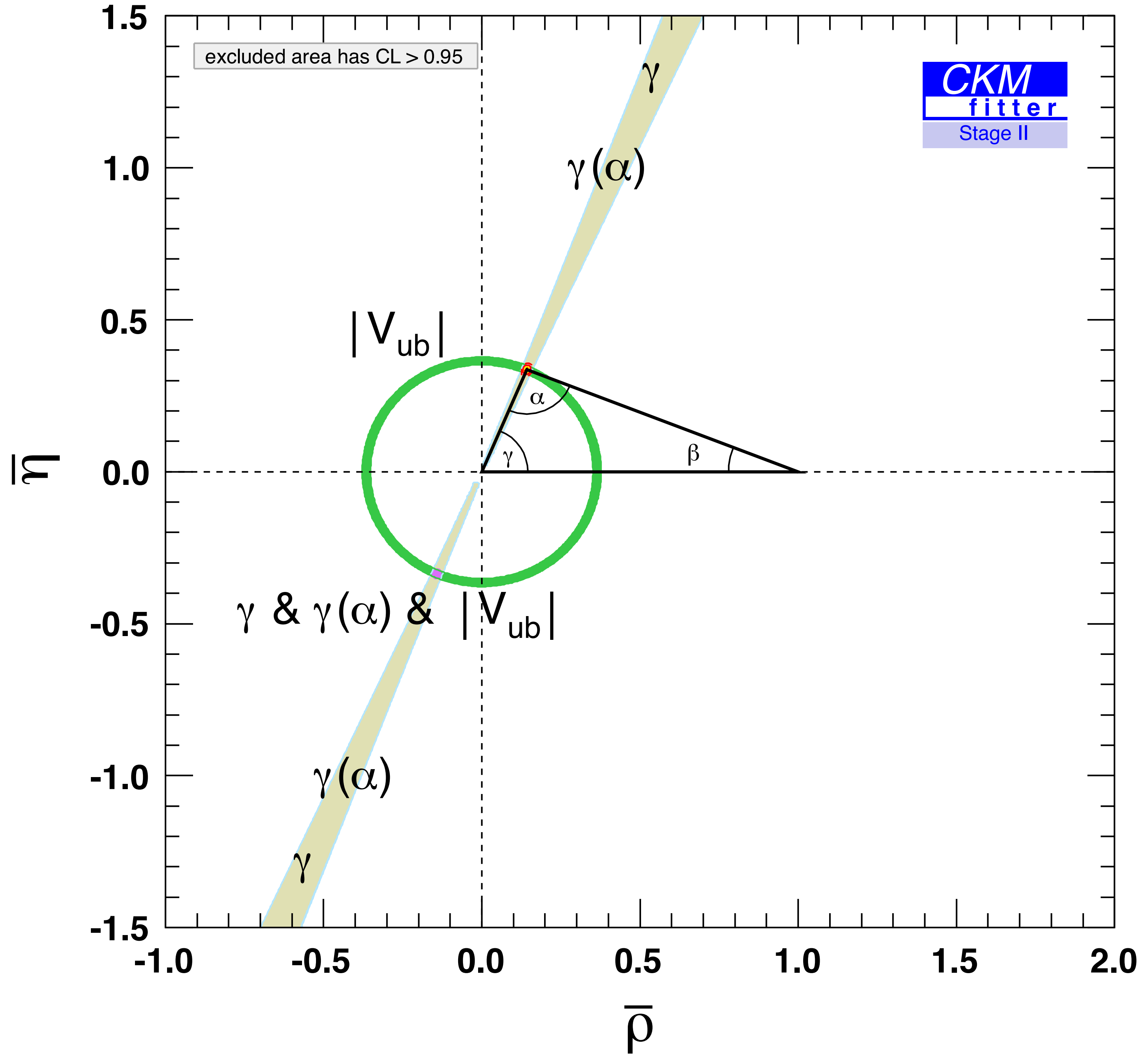
2003



2013



LHCb Upg.+ Belle II



NP in B{d,s} & K mixing: Input

- From the Belle II Physics Book.

Uncertainties expected on future measurements over the coming decade. Expecting (& need) Δ2-3% on $|V_{ub}|$.

- ***Scenario 1 - SM-like***
- ***Scenario 2 - WA like***

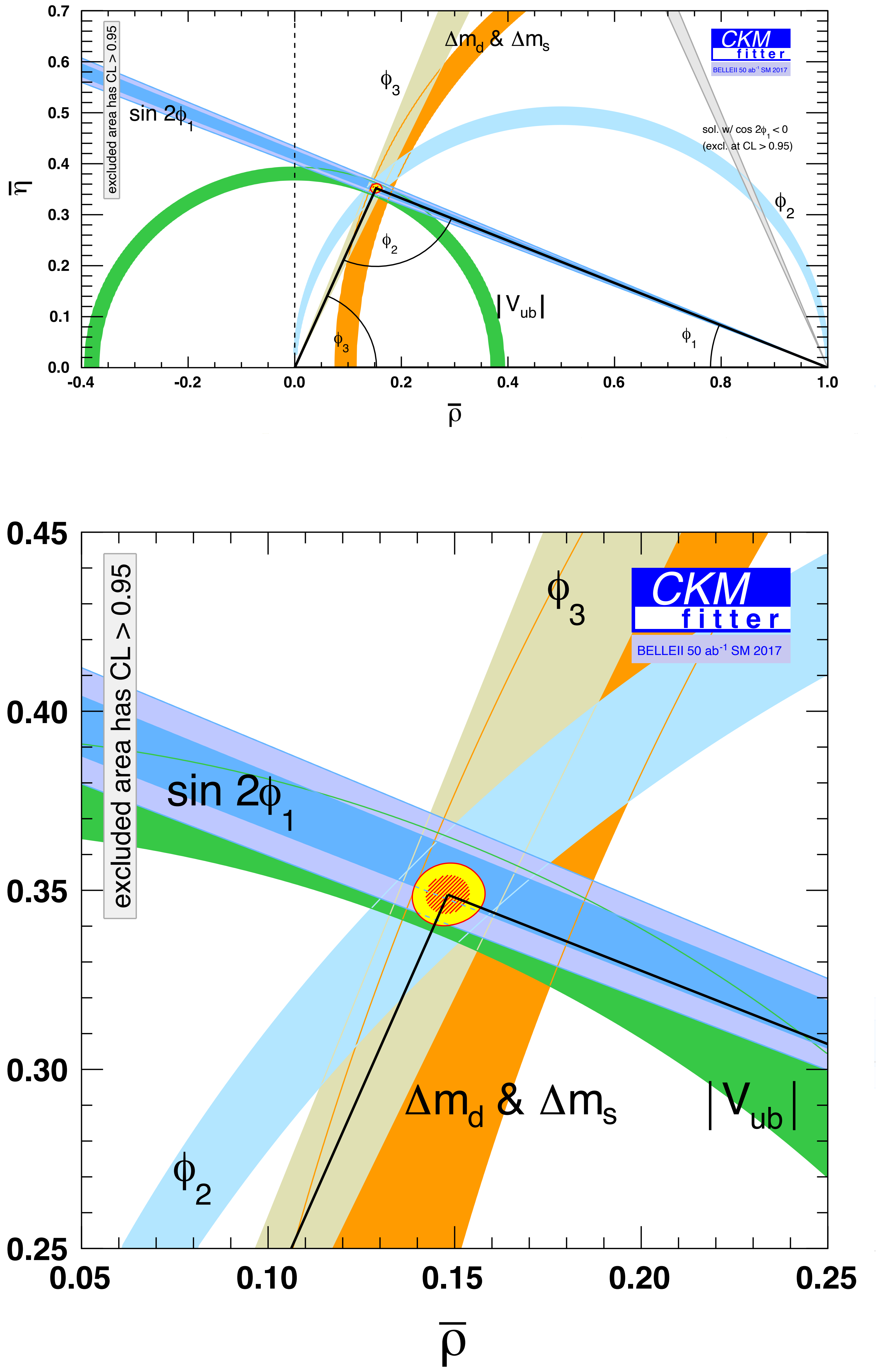
Input	Current 2016	Scenario (1) Belle II (+LHCb) 2025	Scenario (2) Belle II (+LHCb) 2025
$\vert V_{ub}\vert$(semileptonic)$[10^{-3}]$	$4.01 \pm 0.08 \pm 0.22$	± 0.10	3.71 ± 0.09
$\vert V_{cb}\vert$(semileptonic)$[10^{-3}]$	$41.00 \pm 0.33 \pm 0.74$	± 0.57	41.80 ± 0.60
$\mathcal{B}(B \to \tau\nu)$	1.08 ± 0.21	± 0.04	0.817 ± 0.03
$\sin 2\phi_1$	0.691 ± 0.017	± 0.008	0.710 ± 0.008
$\phi_3[^\circ]$	$73.2^{+6.3}_{-7.0}$	± 1.5 (± 1.0)	67 ± 1.5 (± 1.0)
$\phi_2[^\circ]$	$87.6^{+3.5}_{-3.3}$	± 1.0	90.4 ± 1.0
Δm_d	0.510 ± 0.003	-	-
Δm_s	17.757 ± 0.021	-	-
$\mathcal{B}(B_s \to \mu\mu)$	$2.8^{+0.7}_{-0.6}$	(± 0.5)	$3.31^{+0.7}_{-0.6}$ (± 0.5)
f_{B_s}	$0.224 \pm 0.001 \pm 0.002$	0.001	-
B_{B_s}	$1.320 \pm 0.016 \pm 0.030$	0.010	-
f_{B_s}/f_{B_d}	$1.205 \pm 0.003 \pm 0.006$	0.005	-
B_{B_s}/B_{B_d}	$1.023 \pm 0.013 \pm 0.014$	0.005	-
$\vert V_{cd}\vert(\nu N)$	0.230 ± 0.011	-	-
$\vert V_{cs}\vert(W \to c\bar{s})$	$0.94^{+0.32}_{-0.26} \pm 0.13$	-	-
f_{D_s}/f_{D_d}	$1.175^{+0.001}_{-0.004}$	-	-
$\mathcal{B}(D \to \mu\nu)$	0.374 ± 0.017	± 0.010	-
ϵ_K	2.228 ± 0.011	-	-
$\vert V_{us}\vert f_+^{K\to\pi}(0)$	0.2163 ± 0.0005	-	0.22449 ± 0.0005
$\mathcal{B}(K \to e\nu)$	1.581 ± 0.008	-	1.5689 ± 0.008
$\mathcal{B}(K \to \mu\nu)$	0.6355 ± 0.0011	-	0.6357 ± 0.0011
$\mathcal{B}(\tau \to K\nu)$	0.6955 ± 0.0096	-	0.7170 ± 0.0096
$\vert V_{ud}\vert$	0.97425 ± 0.00022	-	-

Belle II 50 ab^{-1}

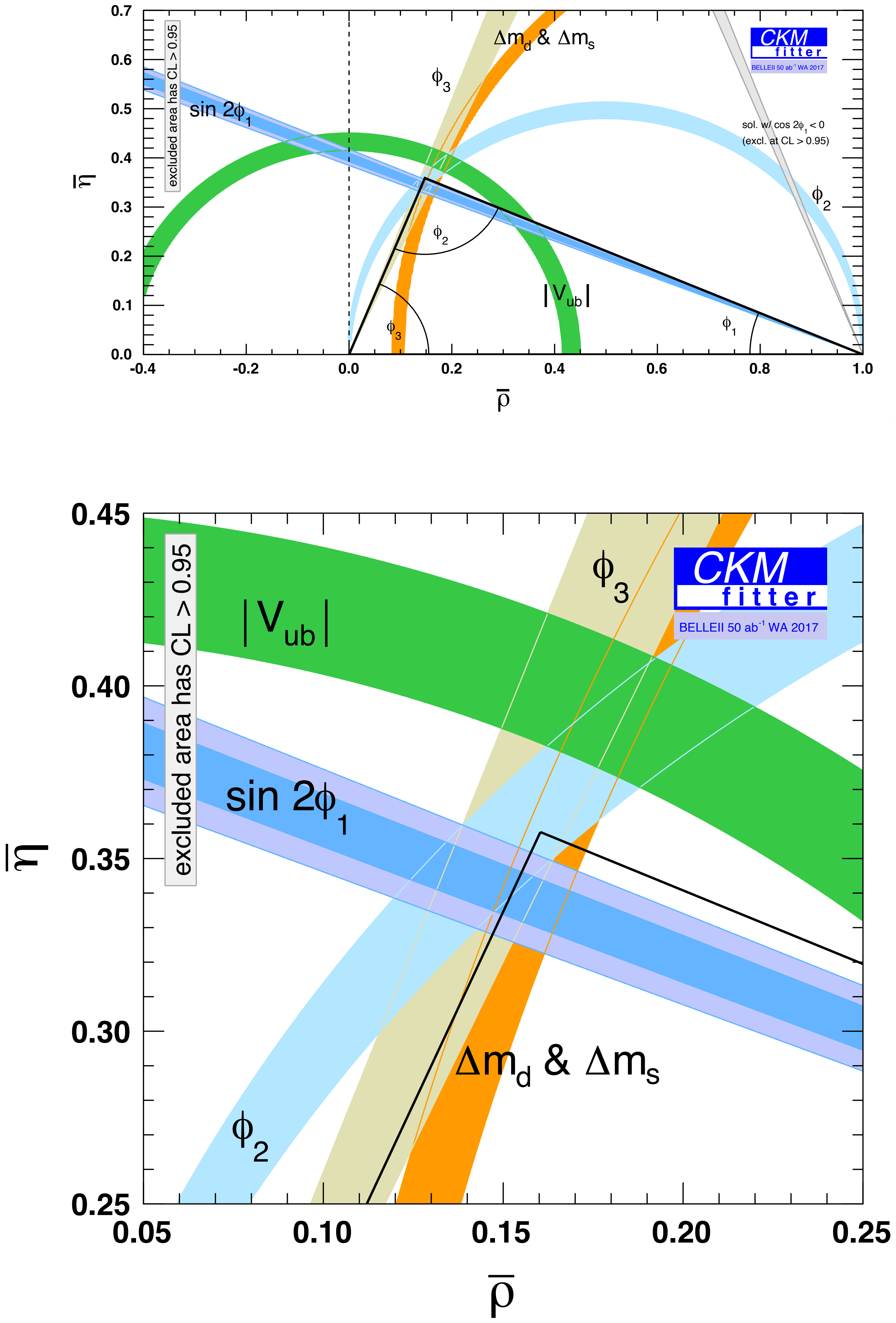
- Belle II+mixing from LHCb+LQCD
- Note: to get this far we rely on LQCD to make big advances in form factors, bag factors etc.
  - See theory chapter of book.

Input	Current WA	SM value Belle II
A	$0.8227^{+0.0066}_{-0.0136}$	$^{+0.0025}_{-0.0027}$
λ	$0.22543^{+0.00042}_{-0.00031}$	$^{0.00036}_{-0.00030}$
$\bar{\rho}$	$0.1504^{+0.0121}_{-0.0062}$	$^{+0.0054}_{-0.0044}$
$\bar{\eta}$	$0.3540^{+0.00069}_{-0.0076}$	$^{+0.0037}_{-0.00040}$

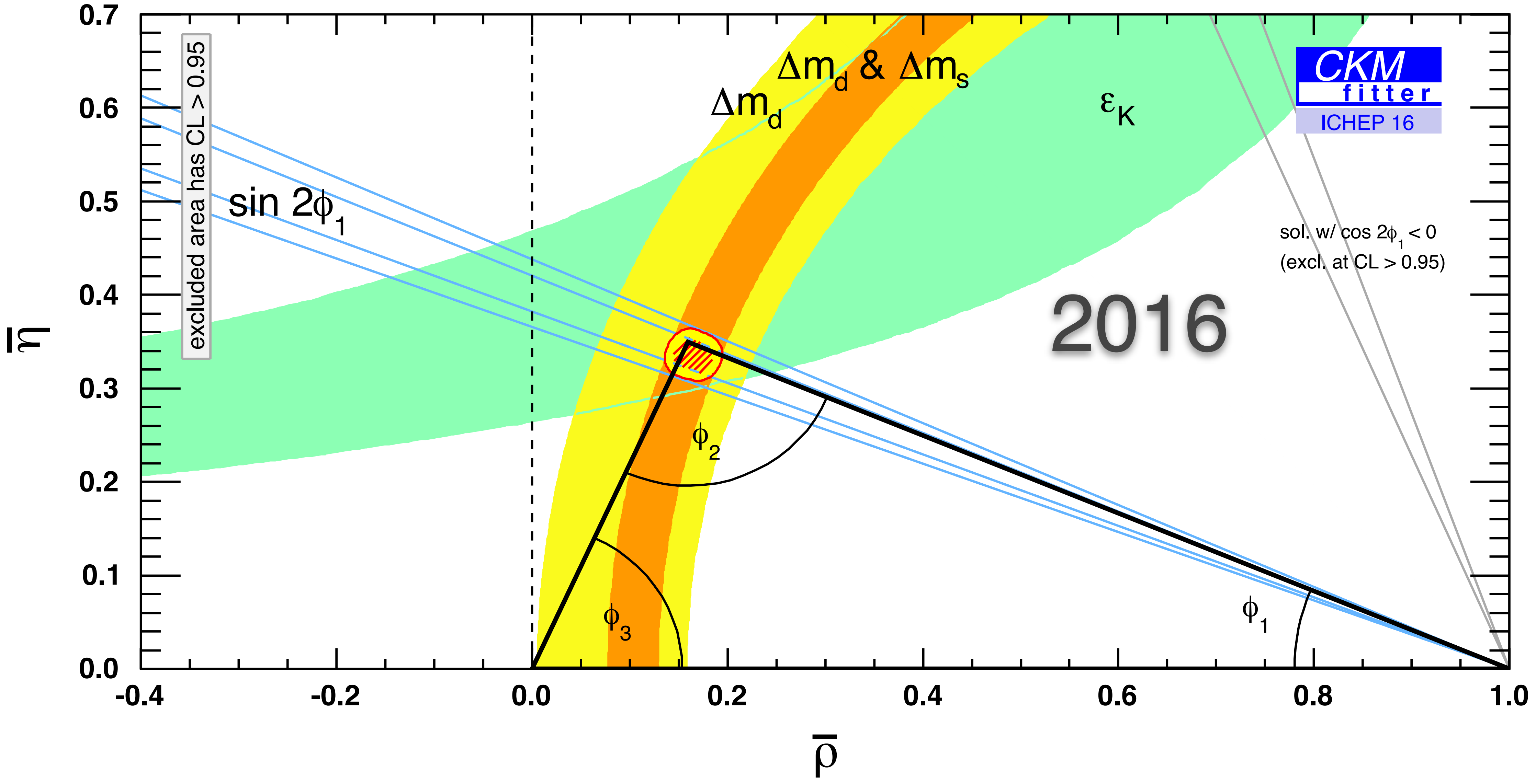
SM-like



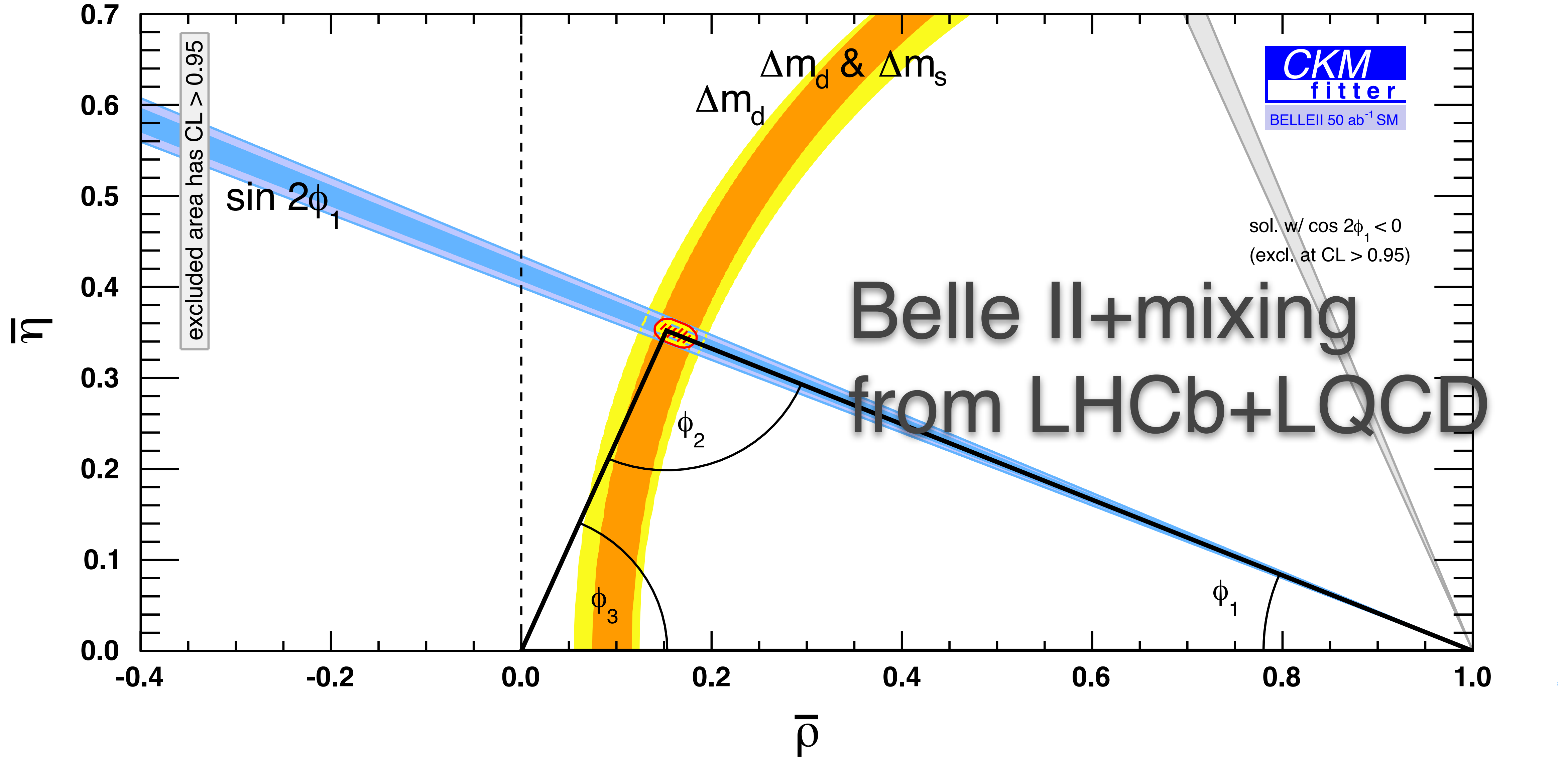
New-physics



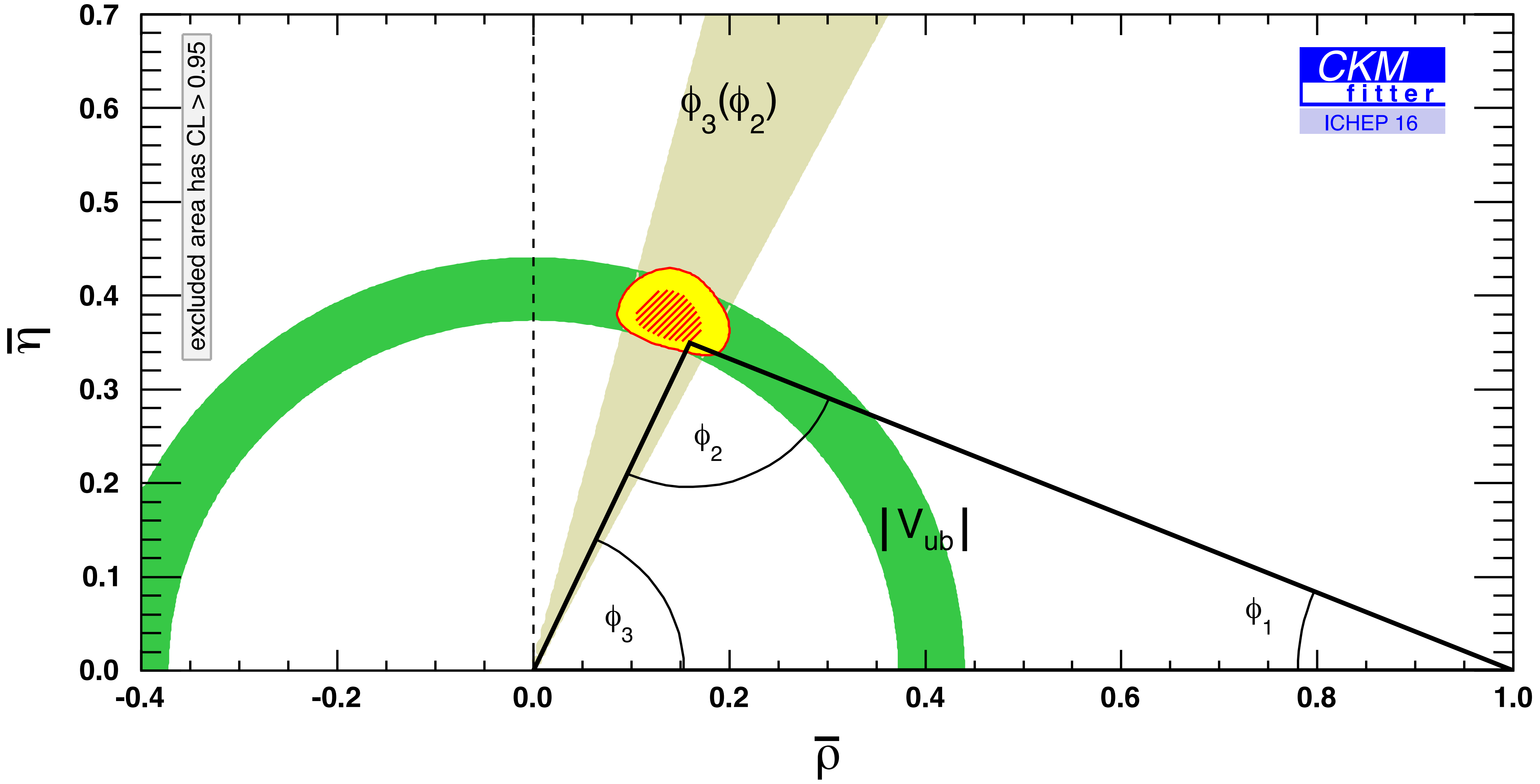
Loop, Tree

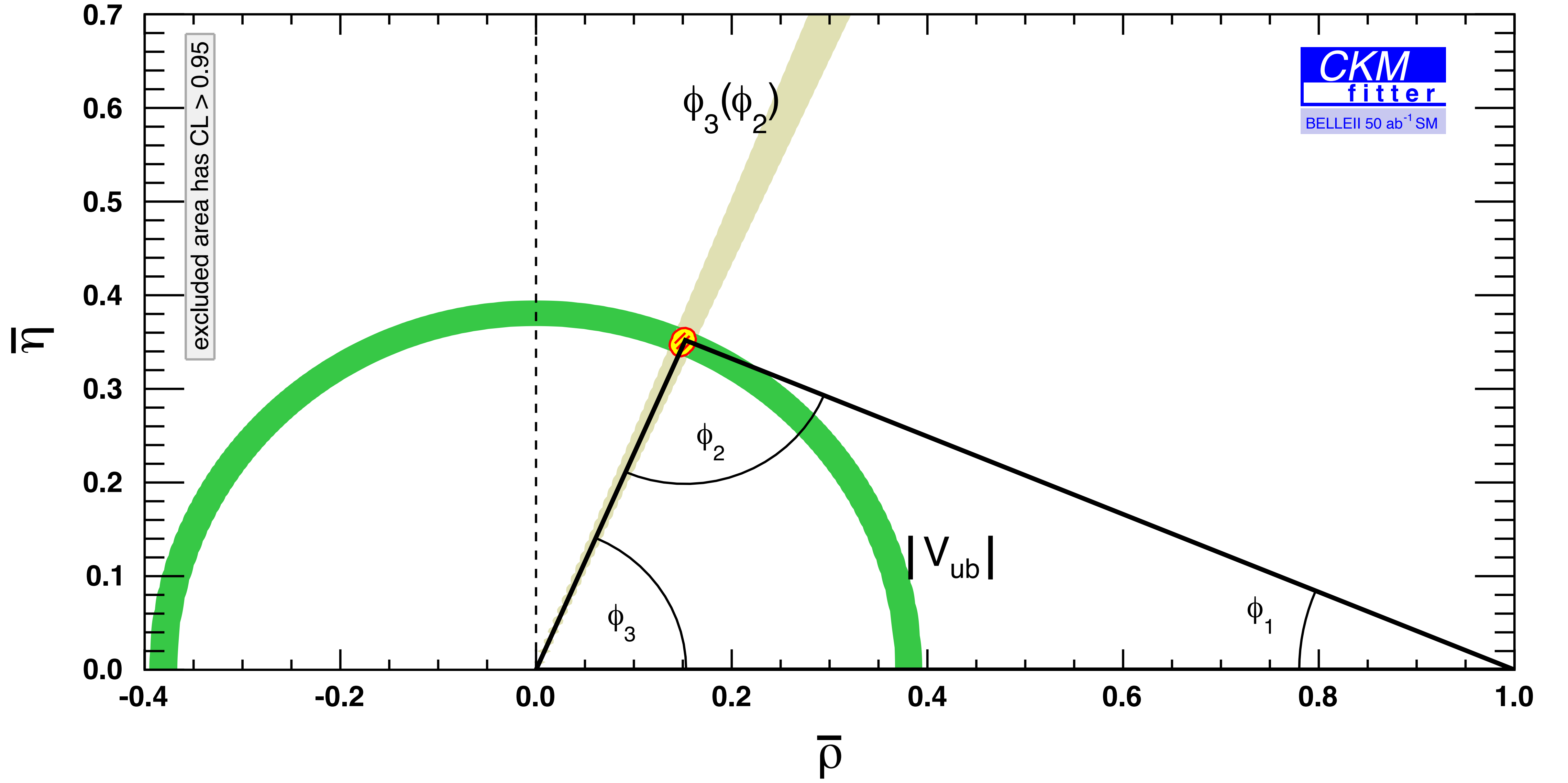


2016

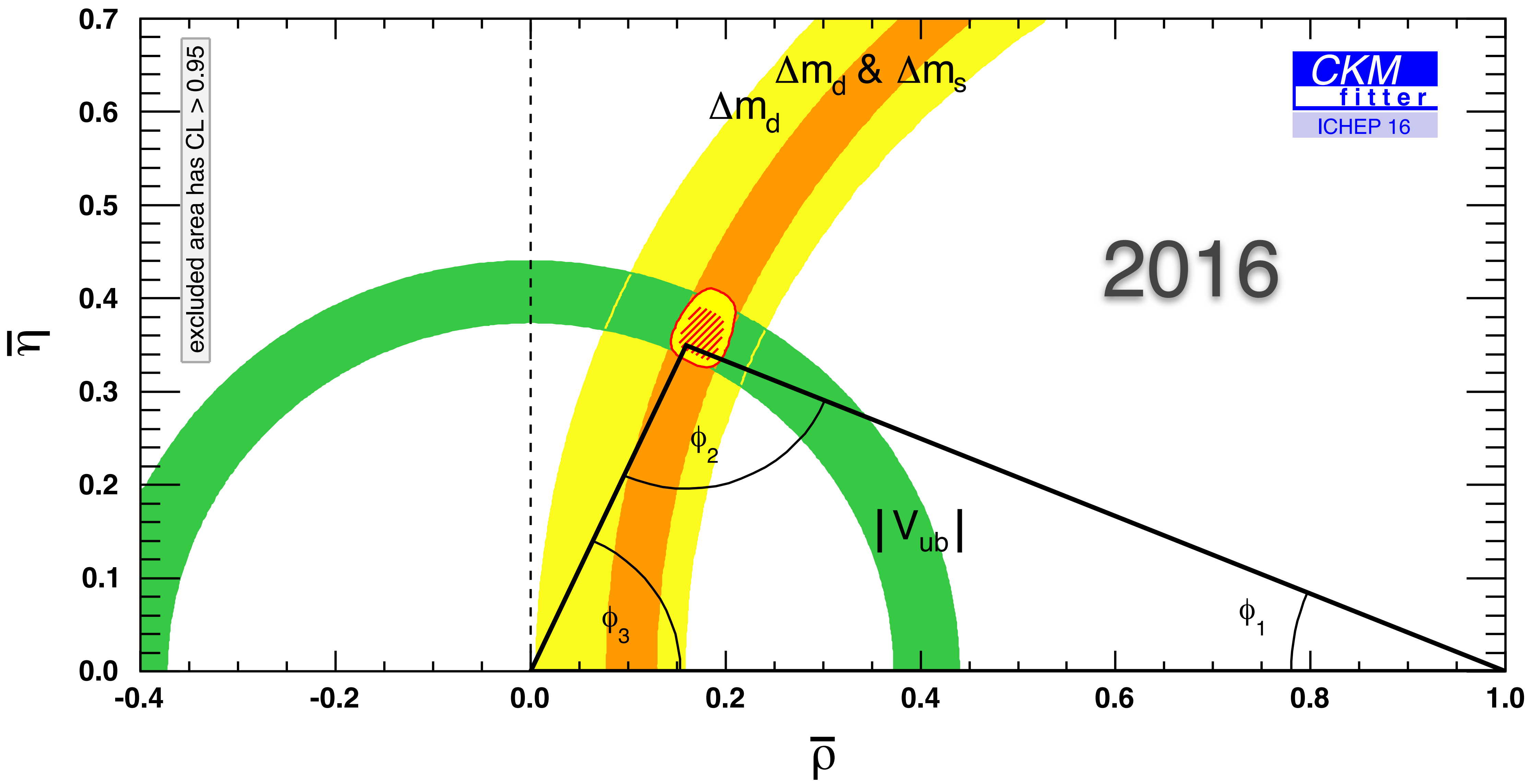


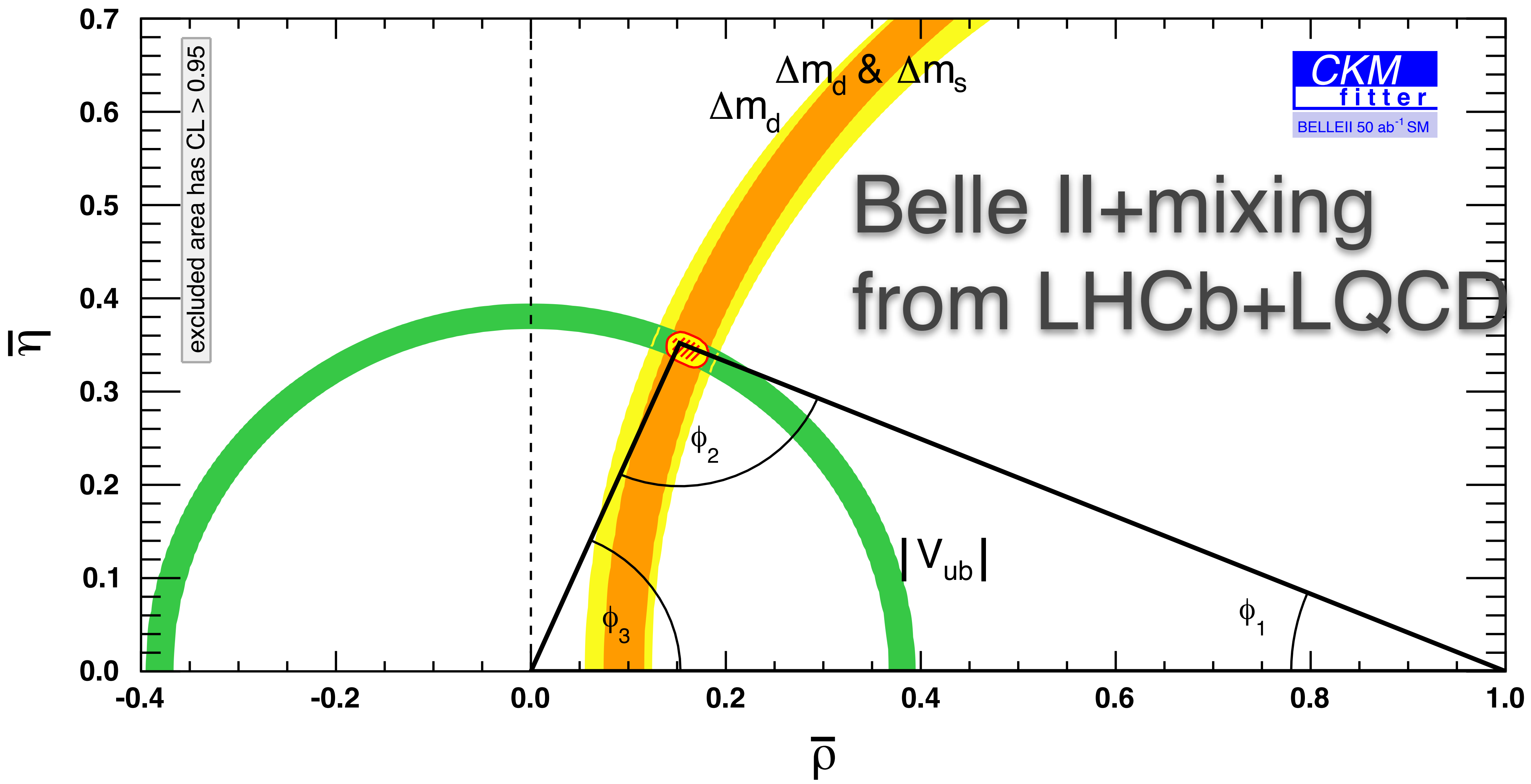
Belle II+mixing from LHCb+LQCD

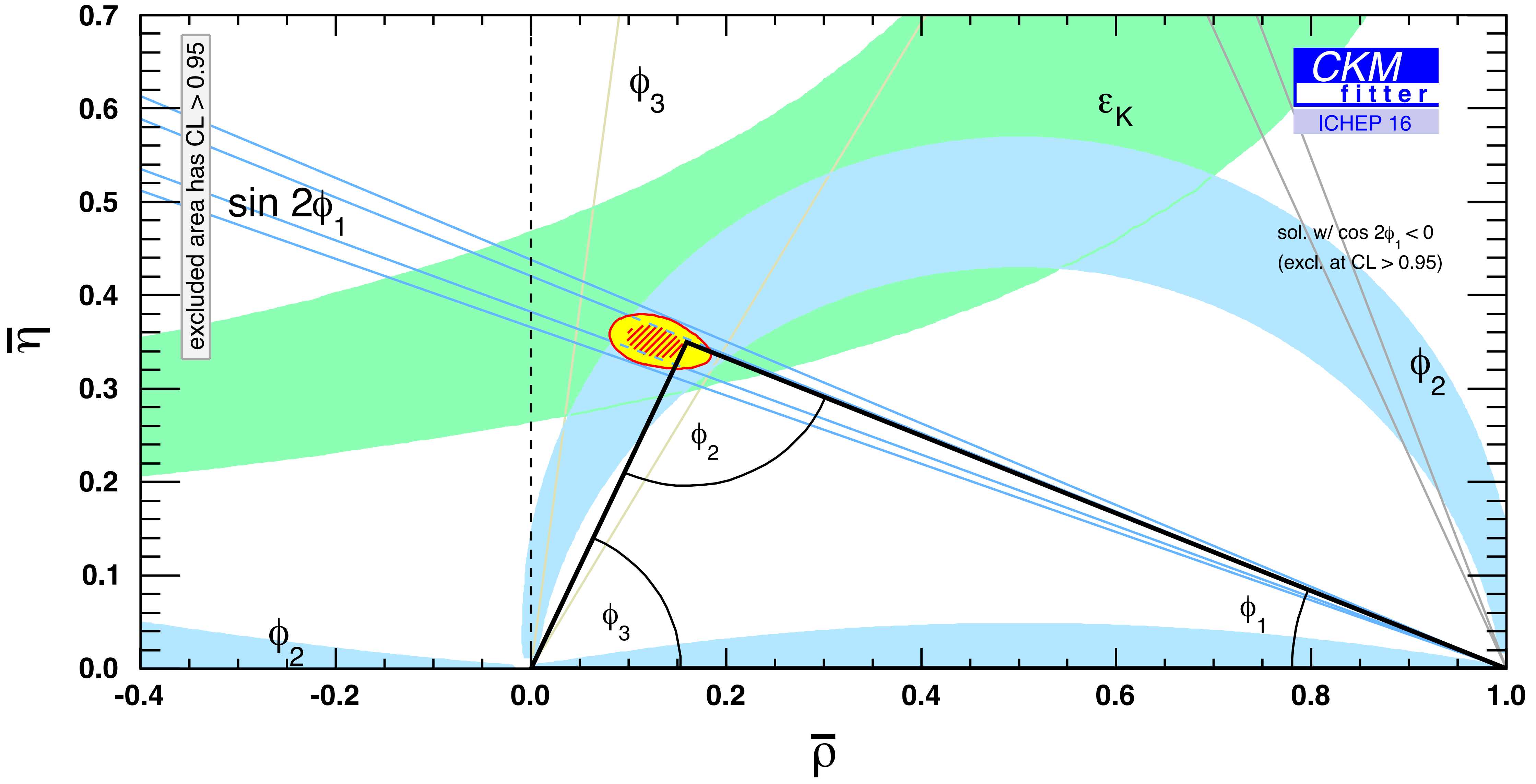


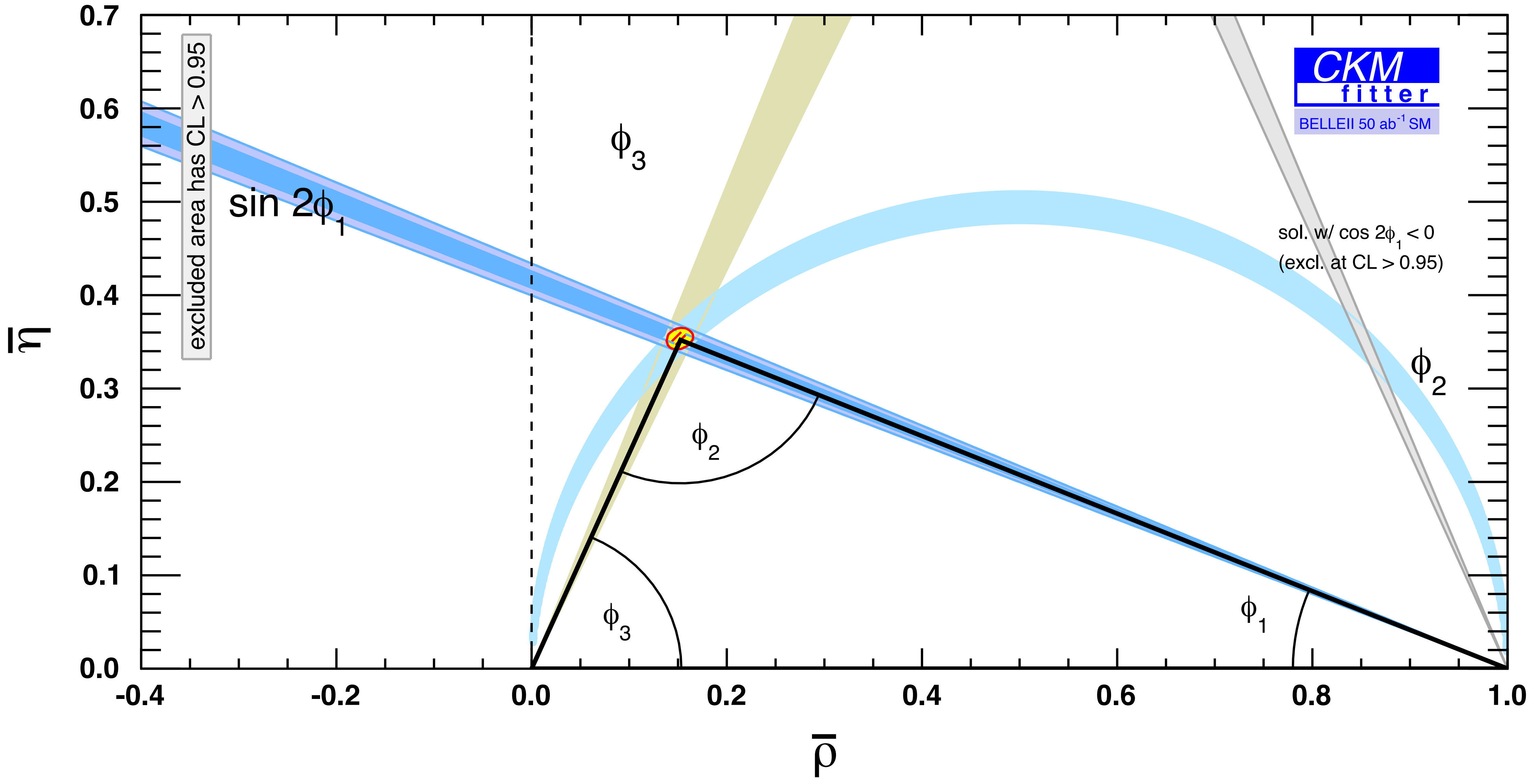


CP conserving, CP violating



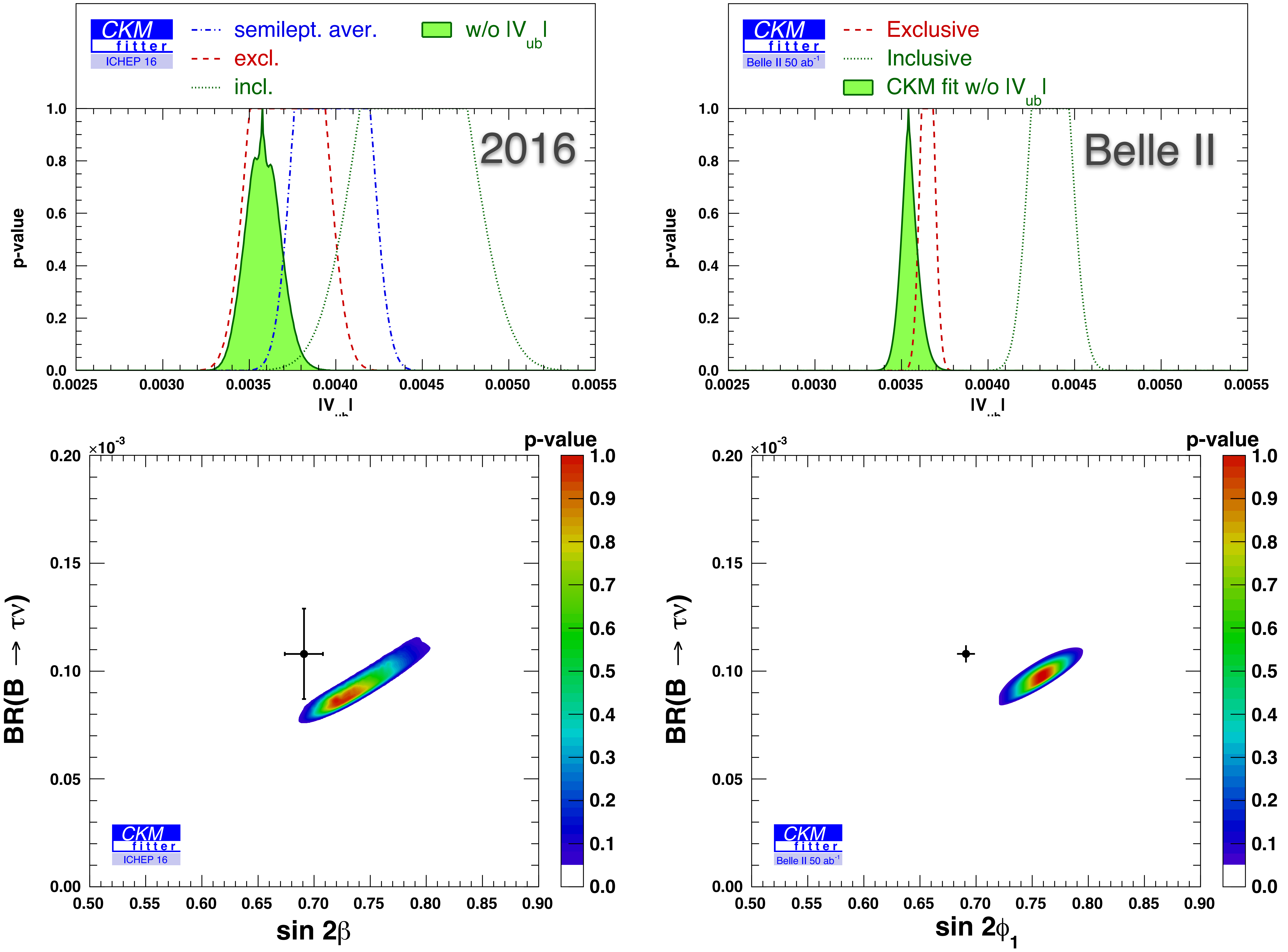




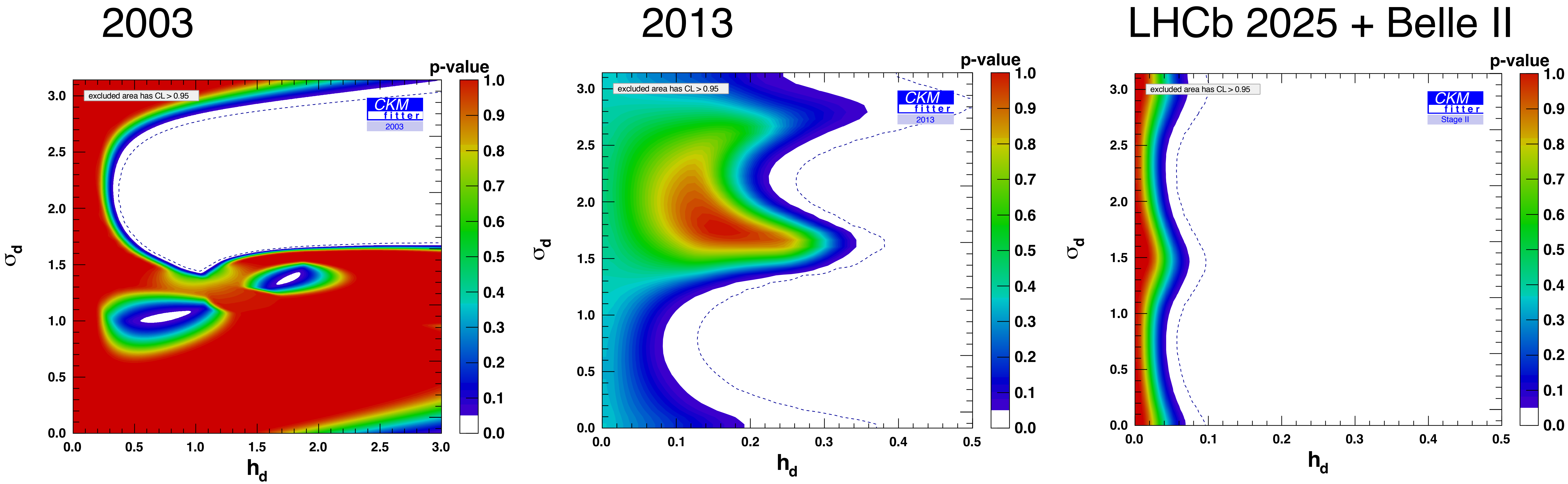


Belle II 50 ab^{-1}

- We can also perform tests against leptonic decays, e.g. constraining $|V_{ub}|$.



NP in B_d mixing: Fit results



- at 95% NP≲(many × SM) $\Longrightarrow$ NP≲(0.3 × SM) $\Longrightarrow$ NP≲(0.05 × SM)

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

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

By Stage II,
Λ ~ 20 TeV (**tree**)
Λ ~ 2 TeV (**loop**)

- Stage II: similar sensitivity to gluino masses explored at LHC 14TeV

Summary

- CKM global analysis find most constraints are in very good agreement.
  - … but some inputs are not so well resolved yet, implying systematically large uncertainties in combinations, e.g. $|V_{qb}|$

- The KM mechanism is obviously at work at O(10%) but there is still room for New Physics, particularly in the mixing of mesons. Multi TeV scale can be probed in loops.

- *Eagerly awaiting Belle II - the most comprehensive detector for UT precision tests.*