CKMFitter in the Belle II Era

B2TiP NP Workshop
October 2016

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Aim

- Prepare CKMFitter results based on Belle II, LHCb upgrade, and future LQCD projections.
- Provide various figures and Wolfenstein parameter precision expectations.
- Use a similar set of projections as that of Phys. Rev. D 89, 033016 (2014), with some updates.

Scenarios

1. Current world average/combination, 2015
2. Belle II only at current WA values
3. Belle II + LHCb + LQCD projections at current WA values
4. Belle II only at SM-like central values
5. Belle II + LHCb + LQCD projections at SM-like central values

Input data

Input	1: Current WA	2: WA value, Belle II Precision	3: WA value, Belle II+LHCb+LQCD precision	4: SM value, Belle II precision	5: SM value, Belle II+LHCb+LQCD precision
$\|V_{ub}\|$(semileptonic)$[10^{-3}]$	$4.01 \pm 0.08 \pm 0.22$	4.01 ± 0.10	id	3.71 ± 0.09	id
$\|V_{cb}\|$(semileptonic)$[10^{-3}]$	$41.00 \pm 0.33 \pm 0.74$	41.00 ± 0.57	id	41.80 ± 0.60	id
$\mathcal{B}(B \to \tau\nu)$	1.08 ± 0.21	1.08 ± 0.04	id	0.817 ± 0.03	id
$\sin 2\beta$	0.691 ± 0.017	0.691 ± 0.008	id	0.710 ± 0.008	id
$\gamma[^\circ]$	$73.2^{+6.3}_{-7.0}$	73.2 ± 1.5	73.2 ± 1.0	67 ± 1.5	67 ± 1.0
$\alpha[^\circ]$	$87.6^{+3.5}_{-3.3}$	87.6 ± 1.0	id	90.4 ± 1.0	id
Δm_d	0.510 ± 0.003	id	id	id	id
Δm_s	17.757 ± 0.021	id	id	id	id
$\mathcal{B}(B_s \to \mu\mu)$	$2.8^{+0.7}_{-0.6}$	id	2.8 ± 0.5	$3.31^{+0.7}_{-0.6}$	3.31 ± 0.5
f_{B_s}	$0.224 \pm 0.001 \pm 0.002$	id	0.224 ± 0.001	id*	id*
B_{B_s}	$1.320 \pm 0.016 \pm 0.030$	id	1.214 ± 0.010	id*	id*
f_{B_s}/f_{B_d}	$1.205 \pm 0.003 \pm 0.006$	id	1.205 ± 0.005	id*	id*
B_{B_s}/B_{B_d}	$1.023 \pm 0.013 \pm 0.014$	id	1.055 ± 0.005	id*	id*
$\|V_{cd}\|(\nu N)$	0.230 ± 0.011	id	id	id	id
$\|V_{cs}\|(W \to c\bar{s})$	$0.94^{+0.32}_{-0.26} \pm 0.13$	id	id	id	id
f_{D_s}/f_{D_d}	$1.175^{+0.001}_{-0.004}$	id	id	id	id
$\mathcal{B}(D \to \mu\nu)$	0.374 ± 0.017	0.374 ± 0.010	id	id	id
ϵ_K	2.228 ± 0.011	id	id	id	id
$\|V_{us}\|f_+^{K\to\pi}(0)$	0.2163 ± 0.0005	id	id	0.22449 ± 0.0005	id
$\mathcal{B}(K \to e\nu)$	1.581 ± 0.008	id	id	1.5689 ± 0.008	id
$\mathcal{B}(K \to \mu\nu)$	0.6355 ± 0.0011	id	id	0.6357 ± 0.0011	id
$\mathcal{B}(\tau \to K\nu)$	0.6955 ± 0.0096	id	id	0.7170 ± 0.0096	id
$\|V_{ud}\|$	0.97425 ± 0.00022	id	id	id	id

Wolfenstein parameter results

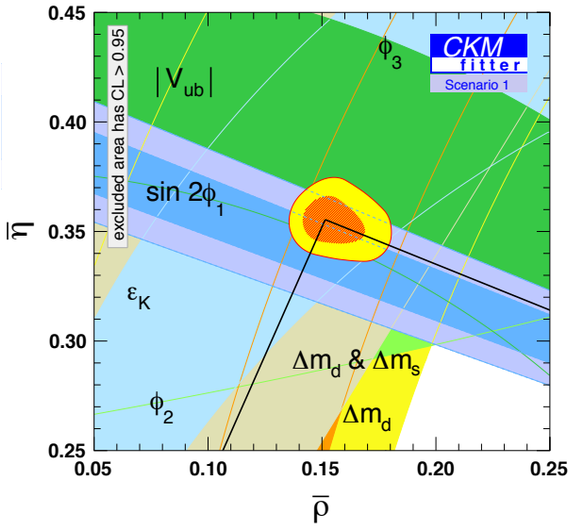
Input	1. Current WA	2. WA value, Belle II Precision	3. WA value, Belle II+LHCb+LQCD precision	4. SM value, Belle II precision	5. SM value, Belle II+LHCb+LQCD precision
A	$0.8227^{+0.0066}_{-0.0136}$	$0.8317^{+0.0059}_{-0.0063}$	$0.8280^{+0.0056}_{-0.0037}$	$0.8225^{+0.0025}_{-0.0027}$	$0.8227^{+0.0024}_{-0.0028}$
λ	$0.22543^{0.00042}_{-0.00031}$	$0.22547^{0.00042}_{-0.00028}$	$0.22546^{0.00042}_{-0.00029}$	$0.22543^{0.00036}_{-0.00030}$	$0.22541^{0.00035}_{-0.00030}$
$\bar{\rho}$	$0.1504^{0.0121}_{-0.0062}$	$0.1586^{0.0045}_{-0.0049}$	$0.1593^{0.0050}_{-0.0036}$	$0.1519^{+0.0054}_{-0.0044}$	$0.1517^{+0.0042}_{-0.0040}$
$\bar{\eta}$	$0.3540^{+0.00069}_{-0.0076}$	$0.3564^{+0.0041}_{-0.0039}$	$0.3578^{+0.0041}_{-0.0040}$	$0.3529^{+0.0037}_{-0.00040}$	$0.3525^{+0.0036}_{-0.00037}$

Overview of proposed plots

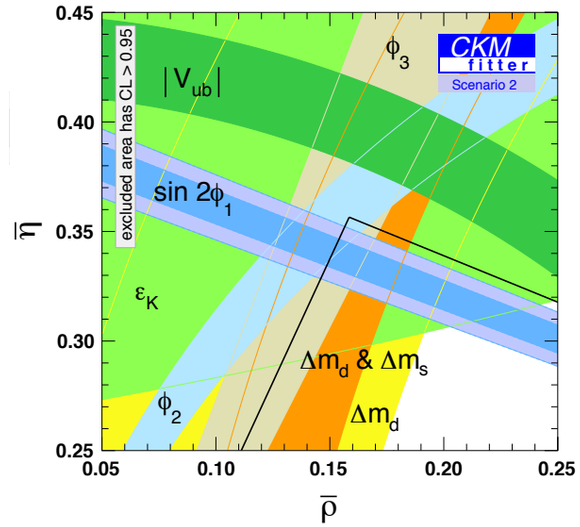
- **Global fits**
  - Full ρ η plane;
  - zoomed ρ η plane;
  - super zoomed ρ η plane: ρ[0.05,0.25], η[0.25,0.45]
- **Test fits**
  - Angles;
  - not angles;
  - CP conserving;
  - CP violating;
  - Tree;
  - Loop;
  - Vub exclusive or Vub inclusive

- **Impact on other planes (not complete)**
  - $|V_{ub}|$ Vs $|V_{cb}|$
  - $|V_{cd}|$ Vs $|V_{cs}|$
  - $|V_{td}|$ Vs $|V_{ts}|$

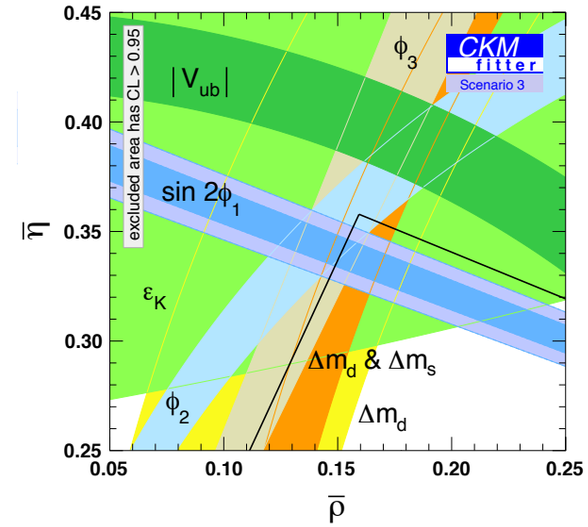
Example figures, zoomed into ρ / η solution



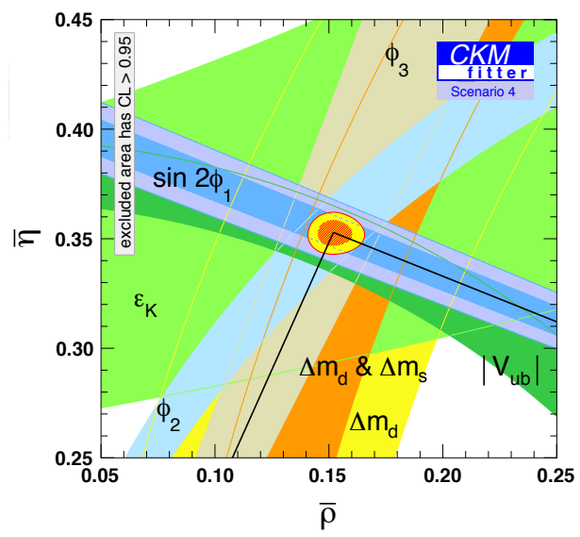
(a) Scenario 1



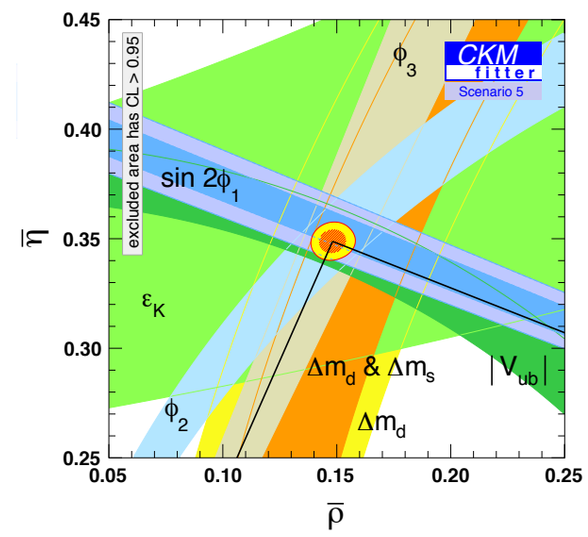
(b) Scenario 2



(c) Scenario 3



(d) Scenario 4



(e) Scenario 5

- Overlay of global fits (ρ η solution) in **1 vs 4 & 5** to better display impact.
- P-value for scenario **2 & 3** as they are NP-like: [Sc2=7.3×10^{-5}, Sc3=1.2×10^{-5}]

Phys. Rev. D 89, 033016 (2014)

- 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.

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

Future sensitivity to new physics in B_d, B_s and K mixings

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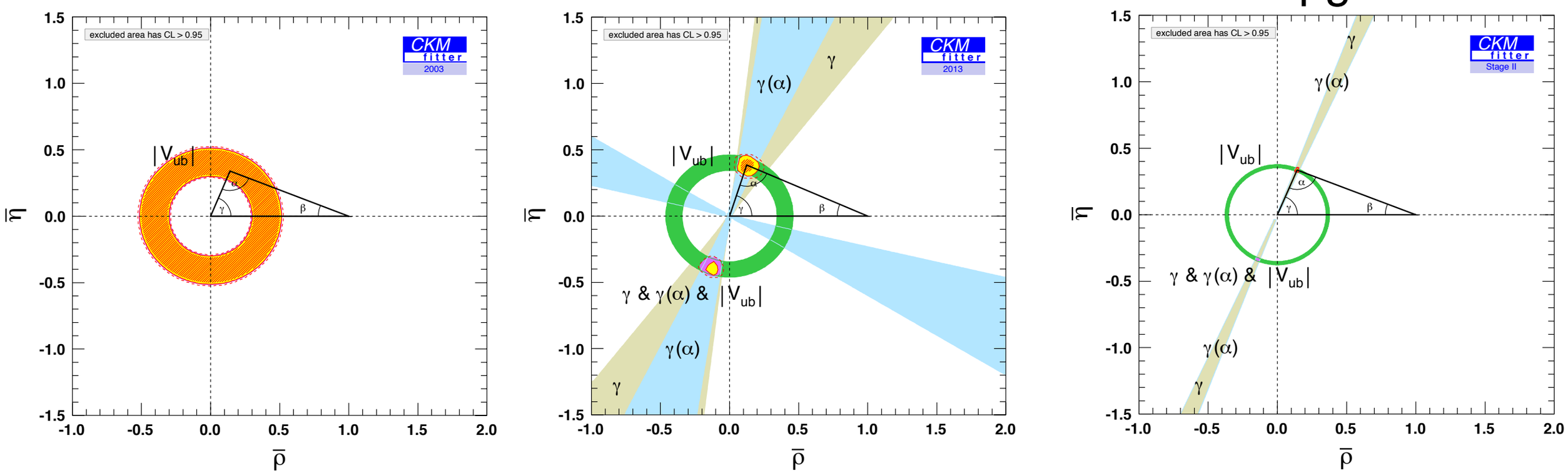
**for the CKMfitter Group*

We estimate, in a large class of scenarios, the sensitivity to new physics in B_d and B_s mixings achievable with $50\,\mathrm{ab}^{-1}$ of Belle II and $50\,\mathrm{fb}^{-1}$ of LHCb data. We find that current limits on new physics contributions in both $B_{d,s}$ systems can be improved by a factor of ~ 5 for all values of the CP violating phases, corresponding to over a factor of 2 increase in the scale of new physics probed. Assuming the same suppressions by CKM matrix elements as those of the standard model box diagrams, the scale probed will be about 20 TeV for tree-level new physics contributions, and about 2 TeV for new physics arising at one loop. We also explore the future sensitivity to new physics in K mixing. Implications for generic new physics and for various specific scenarios, such as minimal flavor violation, light third-generation dominated flavor violation, or $U(2)$ flavor models are studied.

NP in $B_{\{d,s\}}$ & K mixing: Input

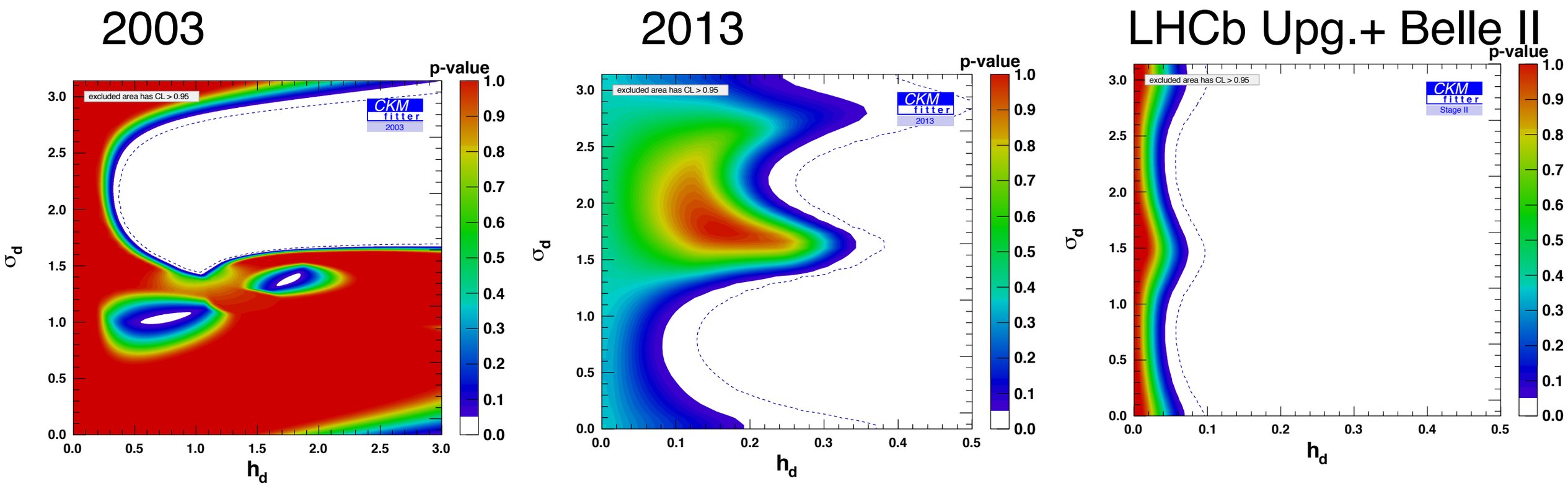
- Observables not affected by NP first used to constrain CKM:
  $|V_{ud}|$,$|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$, Φ_3 and $\Phi_2=\pi-\Phi_3-\Phi_{1eff}$((c anti-c)K)
- NP impact estimated from
  Meson mixing Δm_s, Δm_d, $|\varepsilon_K|$,
  Lifetime difference $\Delta\Gamma_s$, & semileptonic asymmetry A_{SL},
  Time dep. CP asymmetries β_s, Φ_1, and Φ_2 (decay-mixing interference)

2003 2013 LHCb Upg.+ Belle II



- Qualitative change after 2003: first Φ_3 and Φ_2 constraints

NP in B_d mixing: Fit results



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

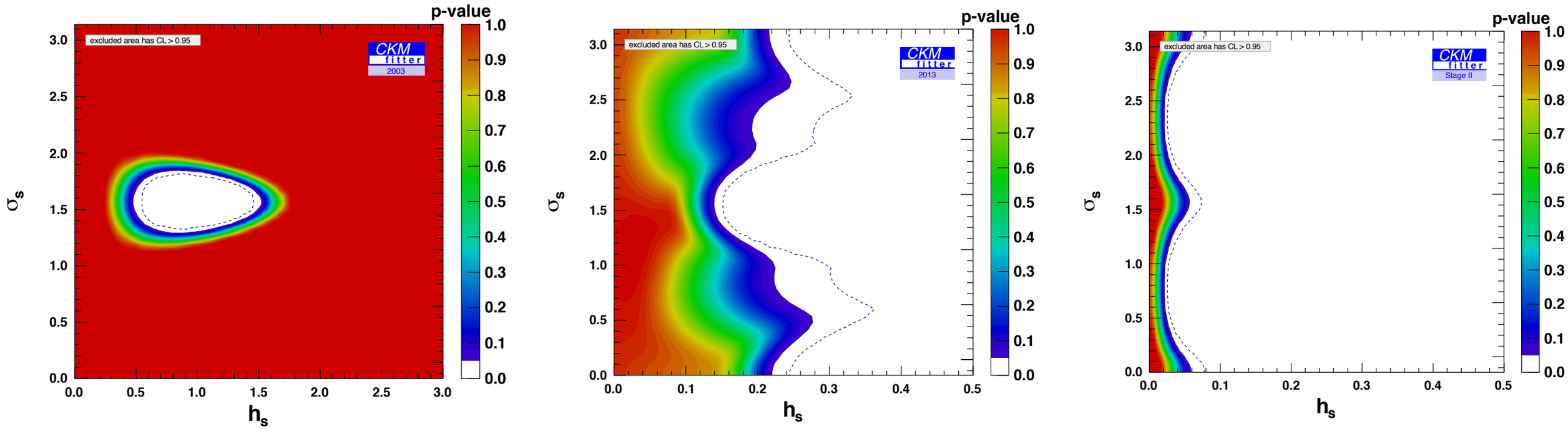
$$h \simeq 1.5 \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \frac{(4\pi)^2}{G_F \Lambda^2} \simeq \frac{|C_{ij}|^2}{|\lambda_{ij}^t|^2} \left(\frac{4.5 \text{ TeV}}{\Lambda} \right)^2$$

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

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

NP in B_s mixing: Fit results

2003 2013 LHCb Upg.+ Belle II



- At 95% NP≲(many × SM) ⟹ NP≲(0.3 × SM) ⟹ NP≲(0.05 × SM)

- Sensitivity now similar to that of B_d mixing, with precision to exceed B_d in the future → due to Δm_s.

Further model dependent studies are presented in the paper.

Summary

- Can show impact of Belle II in CKM fit.
- SM and non-SM scenarios can be considered.
- Impact on NP in mixing was done already - can take the results in the writeup.