Combination of measurements to constrain new physics

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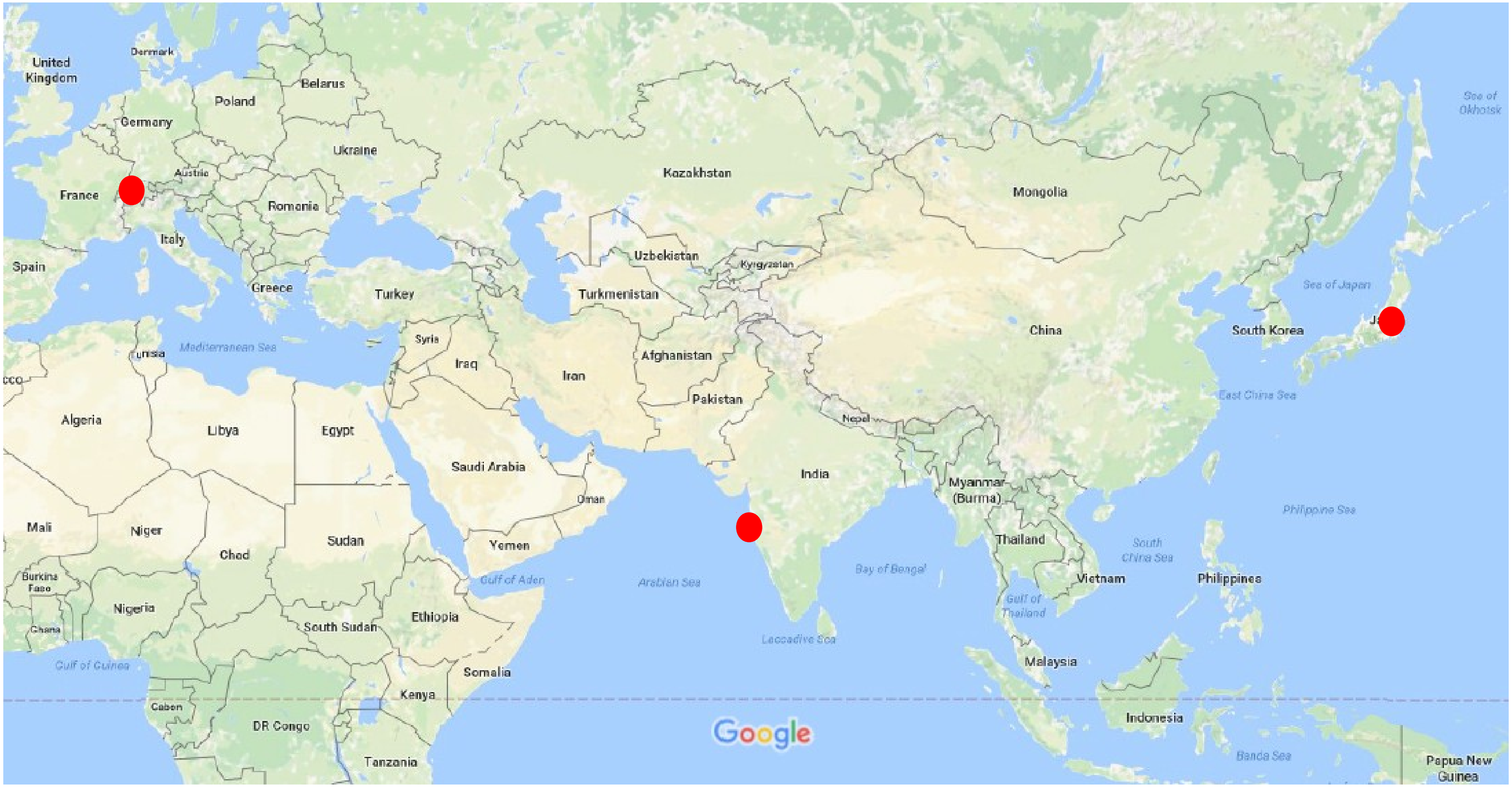


Introduction

In general, we search for NP indirectly in processes where SM contributions are suppressed, and so, small NP effects can become visible (or even dominant)

Phenomenologically, we can classify potential NP contributions as

- **$\Delta F = 2$ (neutral B mixing)**
  - 2nd order weak transition in SM, can be enhanced by NP
- **$\Delta F = 1$ (B decays)**
  - Loop suppression (NP can enter through trees, e.g. FCNC)
  - Helicity suppression (Vector-mediated SM transitions are small compared (pseudo) scalar-mediated NP)

Use few examples (popular global fits) and reflect on the measurements used and how they will evolve

[not mentioning about NP in tree-level decays, see for example M.Tanaka and R.Watanabe, arXiv:1608.05207 and coming B2TiP report

$$R_{D^{(*)}},\ R_{\pi} = \frac{B(B\to\pi\tau\nu)}{B(B\to\pi l\nu)},\ R_{ps} = \frac{B(B\to\tau\nu)}{B(B\to\pi l\nu)},\ R_{pl} = \frac{B(B\to\tau\nu)}{B(B\to\mu\nu)}\ldots$$

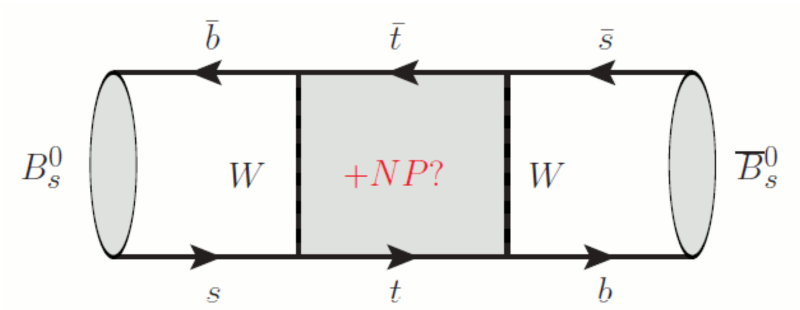
Sensitivity to new physics in B_d, B_s and K mixings

Ref : Z.Ligeti , M.Pappuci , CKMfitter
arXiv :1309.2293, arXiv :1501.05013

[See A.Perez's talk]

but also similar studies :
M. Ciuchini et al , hep-ph/0012308
M. Bona et al , hep-ph/051199 [See M.Bona's talk]
J. Laiho et al , arXiv :0910.2928
G.Eigen et al , arXiv :1503.02289

$\Delta F = 2$: New Physics



Evolution of $B^0_{(s)}$ system is described by $H = M - i\Gamma/2$
Off-diagonal terms M_{12}, Γ_{12} responsible for oscillations

- M_{12} dominated by (virtual) top boxes
  [affected by NP, e.g. if heavy new particles in the box]
- Γ_{12} dominated by tree decays into (real) charm states
  [affected by NP if changes in (constrained) tree-level decays]
- Tree level (4 diff flavours) processes not affected by NP

Model-independent parametrisation under the assumption only changes modulus and phase of M^d_{12} and M^s_{12}

$$\mathbf{M^q_{12} = (M^q_{12})_{SM} \times \Delta_q \qquad \Delta_q = |\Delta_q| e^{i\varphi^\Delta_q} = (1 + h_q\, e^{2i\sigma_q})}$$

affects Δm_q ($\Leftrightarrow |\Delta_q|$), a^q_{SL} ($\Leftrightarrow \Delta_q$), $\Delta\Gamma_q$ and φ_{B_q} ($\Leftrightarrow \varphi^\Delta_q$)

Δm_d, Δm_s, β, φ_s, a^d_{SL}, a^s_{SL}, $\Delta\Gamma_s$ to constrain Δ_d and Δ_s

$\Delta F = 2$: CKM projections

[CKMfitter, arXiv:1501.05013]

Observables not affected by NP, used to fix CKM:
$|V_{ud}|$, $|V_{us}|$, $|\mathbf{V_{ub}}|$, $|V_{cb}|$, $\boldsymbol{\gamma}$ and $\gamma(\alpha) \equiv \pi - \alpha - \beta$ (φ_{B_d} cancels)

Stage I: 7 fb^{-1} LHCb + 5 ab^{-1} Belle II

Stage II: 50 fb^{-1} LHCb + 50 ab^{-1} Belle II

	2013	Stage I		Stage II	
$\lvert V_{ud}\rvert$	$0.97425 \pm 0 \pm 0.00022$	id		id	
$\lvert V_{us}\rvert$ $(K_{\ell 3})$	$0.2258 \pm 0.0008 \pm 0.0012$	0.22494 ± 0.0006		id	
$\lvert\epsilon_K\rvert$	$(2.228 \pm 0.011) \times 10^{-3}$	id		id	
Δm_d [ps^{-1}]	0.507 ± 0.004	id		id	
Δm_s [ps^{-1}]	17.768 ± 0.024	id		id	
$\lvert V_{cb}\rvert \times 10^3$ $(b \to c\ell\bar\nu)$	$41.15 \pm 0.33 \pm 0.59$	42.3 ± 0.4	[17]	42.3 ± 0.3	[17]
$\lvert V_{ub}\rvert \times 10^3$ $(b \to u\ell\bar\nu)$	$3.75 \pm 0.14 \pm 0.26$	3.56 ± 0.10	[17]	3.56 ± 0.08	[17]
$\sin 2\beta$	0.679 ± 0.020	0.679 ± 0.016	[17]	0.679 ± 0.008	[17]
α (mod π)	$(85.4^{+4.0}_{-3.8})^\circ$	$(91.5 \pm 2)^\circ$	[17]	$(91.5 \pm 1)^\circ$	[17]
γ (mod π)	$(68.0^{+8.0}_{-8.5})^\circ$	$(67.1 \pm 4)^\circ$	[17, 18]	$(67.1 \pm 1)^\circ$	[17, 18]
β_s	$0.0065^{+0.0450}_{-0.0415}$	0.0178 ± 0.012	[18]	0.0178 ± 0.004	[18]
$\mathcal{B}(B \to \tau\nu) \times 10^4$	1.15 ± 0.23	0.83 ± 0.10	[17]	0.83 ± 0.05	[17]
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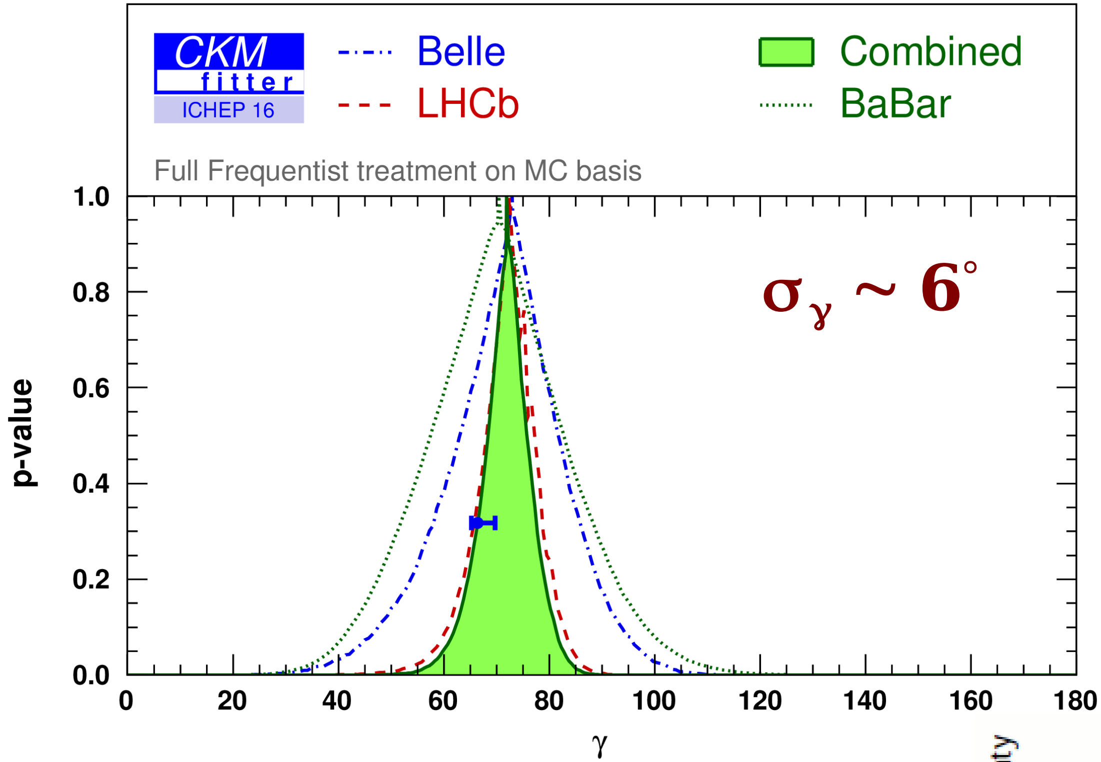
$A^d_{\rm SL} \times 10^4$	23 ± 26	-7 ± 15	[17]	-7 ± 10	[17]
$A^s_{\rm SL} \times 10^4$	-22 ± 52	0.3 ± 6.0	[18]	0.3 ± 2.0	[18]

Unlimited γ



$\sigma_\gamma \sim 6^\circ$

plethora

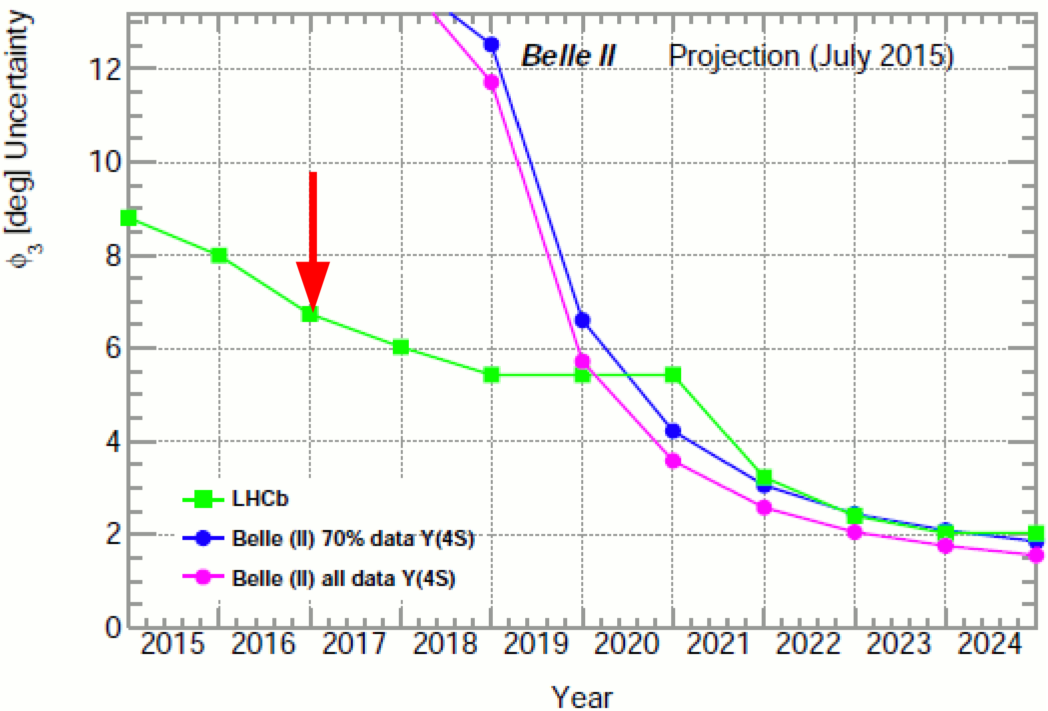
noun [S] • UK /ˈpleθ.ər.ə/ US /ˈpleθ.ɚ.ə/ FORMAL

C2 **a very large amount of something, especially a larger amount than you need, want, or can deal with:**

There's ***a*** *plethora* ***of*** *books about the royal family.*

The plethora ***of*** *regulations is both contradictory and confusing.*

[See D.Cervenkov's talk]

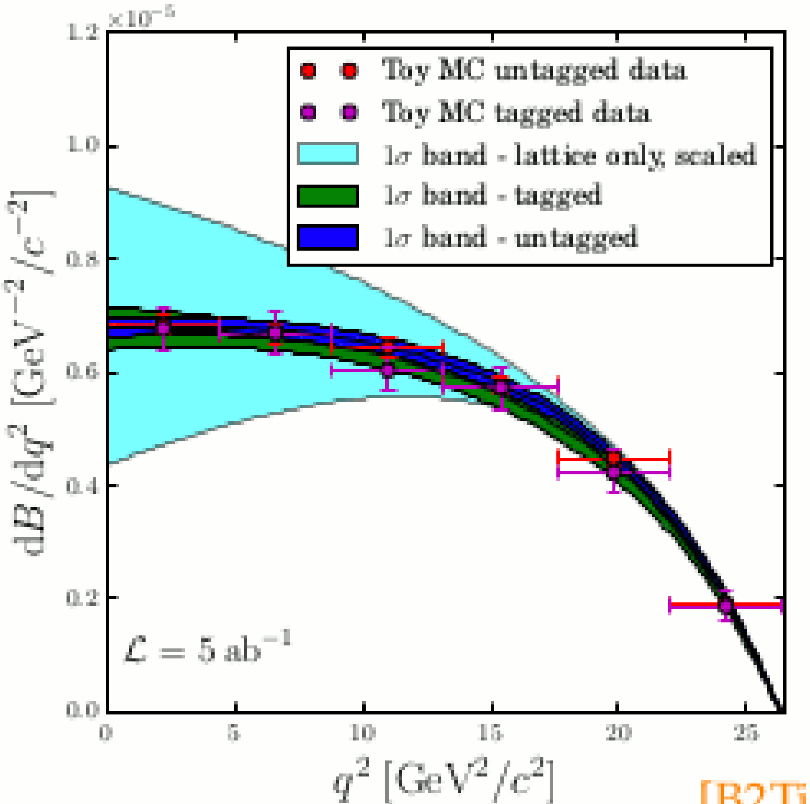


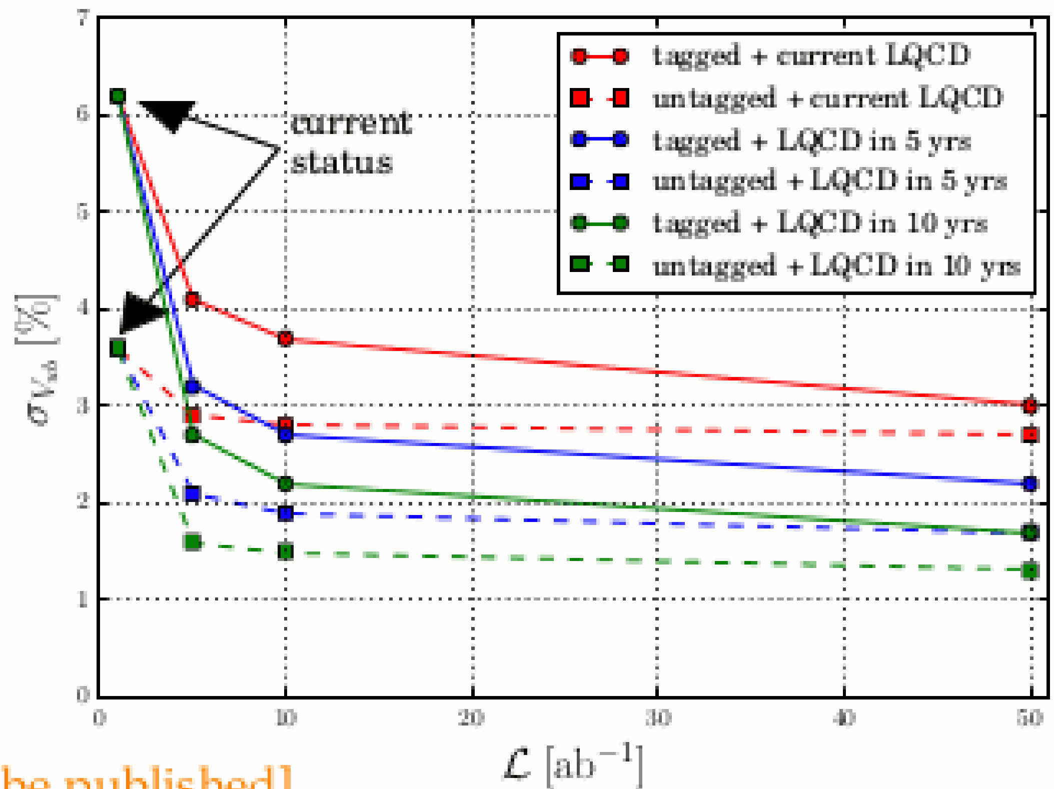
much more modes/ideas
⇒ see WG5's summary

(too) conservative estimate ⇒

$|V_{ub}|$ from $B \to \pi l \nu$ at Belle II [See M.Lubej's talk]

Toy MC studies based on Belle II MC, LQCD forecasts estimated at 5 years (5, 10 ab^{-1}) and 10 years (50 ab^{-1})





[B2TiP, to be published]

$|V_{ub}|^{\pi\ell\nu}$ from simultaneous fit for $\mathcal{L} = 5\ \mathrm{ab}^{-1}$, including lattice forecasts and error scaling.

$\delta_{|V_{ub}|^{\pi\ell\nu}}$ estimates for 5, 10 and 50 ab^{-1}:
Tagged: 3.2, 2.7 and 1.7 %
Untagged: 2.1, 1.9 and 1.3 %

LQCD forecasts: [A. Kronfeld, T. Kaneko, S. Simula]

$\Delta F = 2$: CKM projections

Observables not affected by NP, used to fix CKM:
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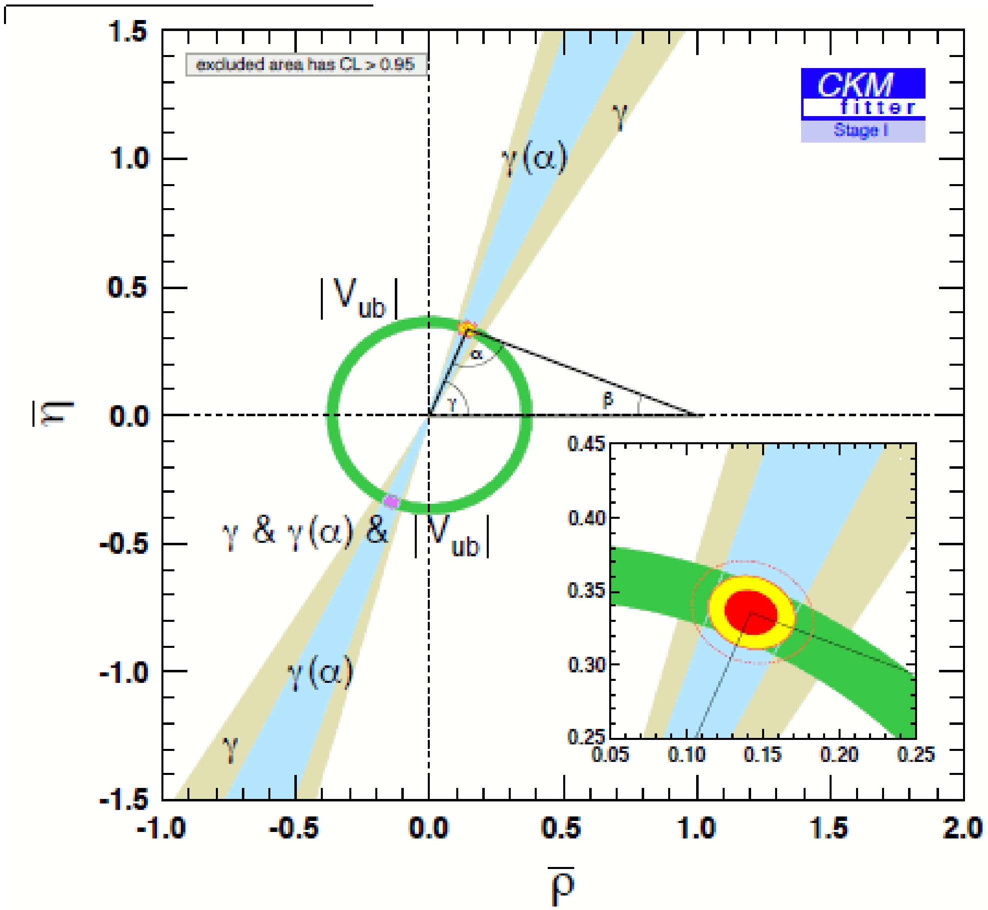
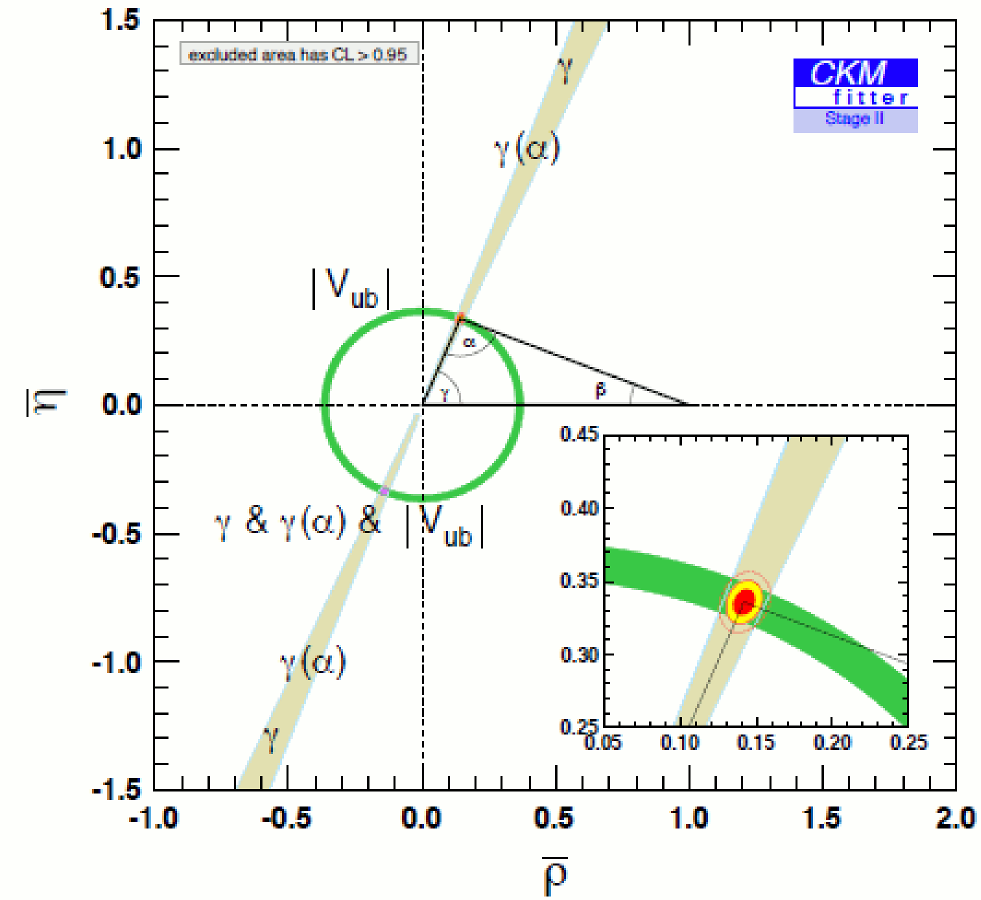


Stage I

$7\ \mathrm{fb}^{-1}$ LHCb + $5\ \mathrm{ab}^{-1}$ Belle II



Stage II

$50\ \mathrm{fb}^{-1}$ LHCb + $50\ \mathrm{ab}^{-1}$ Belle II

$\Delta F = 2$: NP fit

[CKMfitter, arXiv:1501.05013]

Δm_d, Δm_s, β, φ_s, a_{SL}^d, a_{SL}^s, $\Delta\Gamma_s$ to constrain Δ_d and Δ_s

		Stage I 7 fb^{-1} LHCb + 5 ab^{-1} Belle II		Stage II 50 fb^{-1} LHCb + 50 ab^{-1} Belle II	
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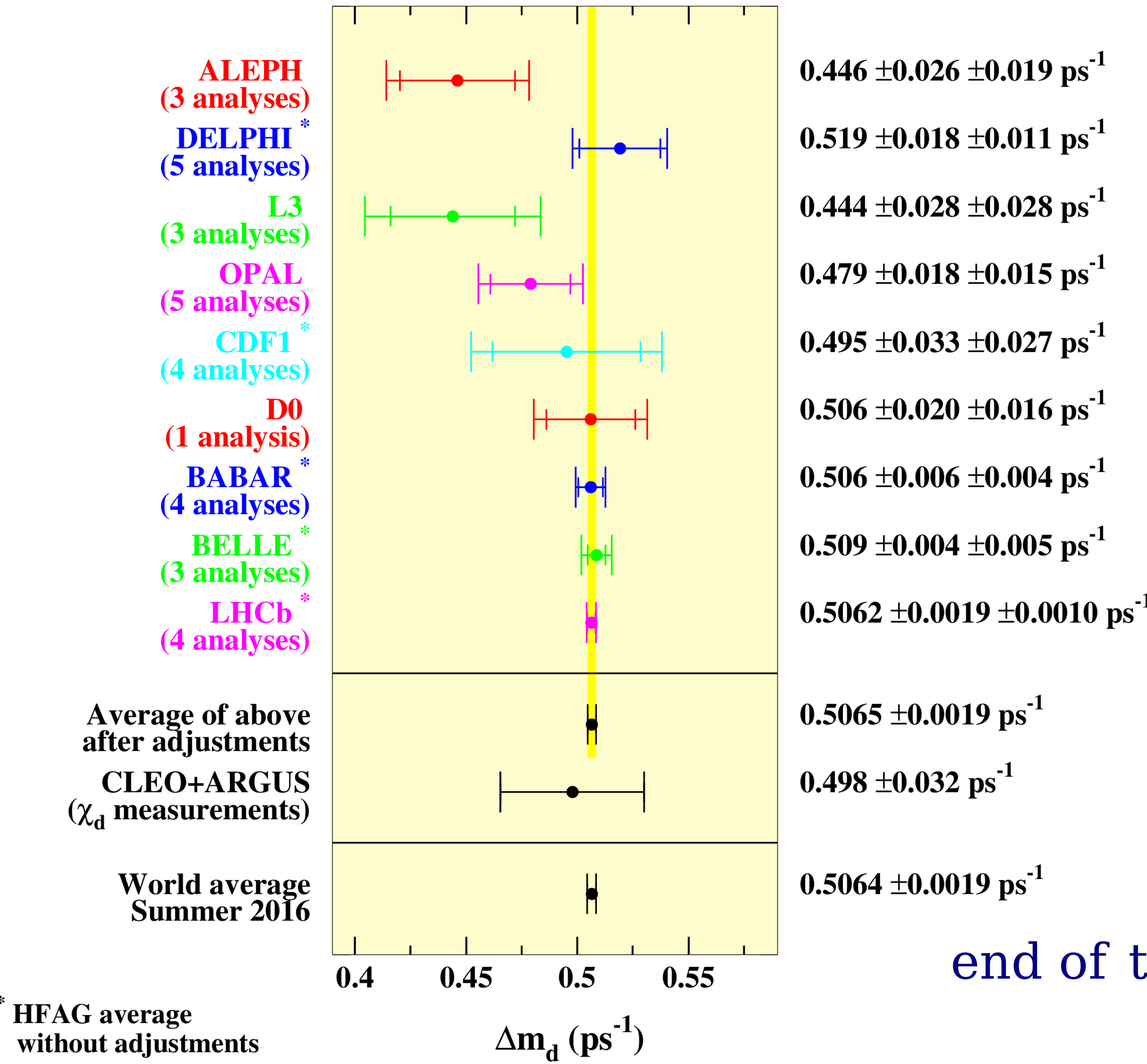
Δm_d



mostly single analysis with 152MBB

mostly single analysis with 3 fb^{-1}

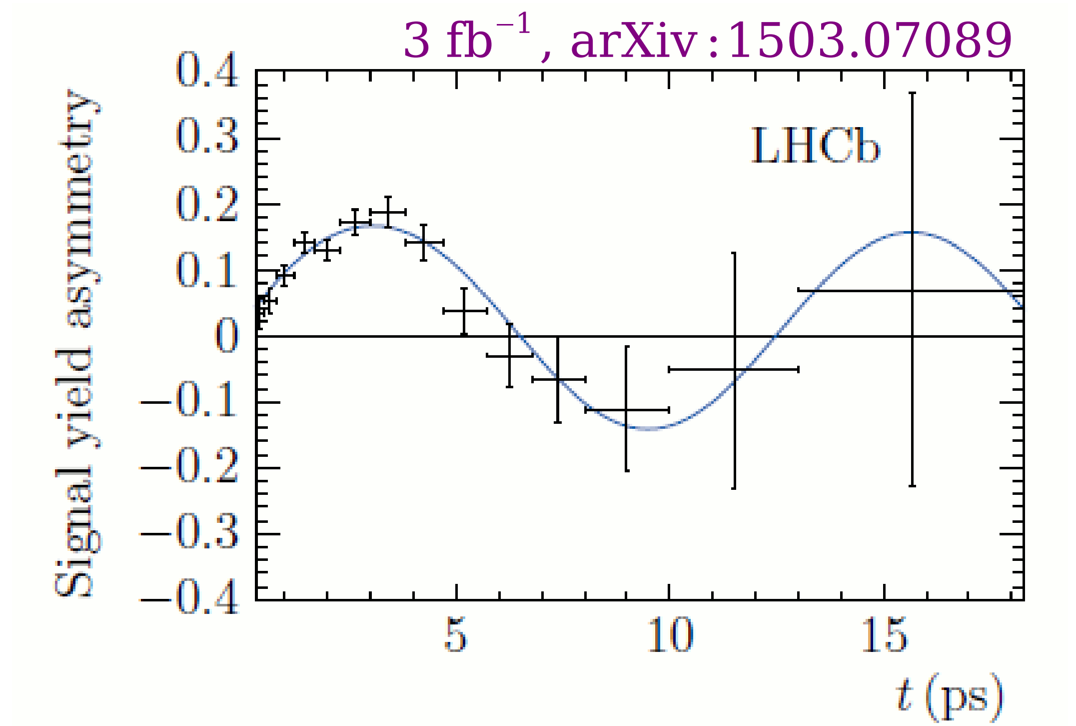
end of the road ?

Mixing-induced CP violation in $B \to J/\psi K^0$

$$A(t) = \frac{\Gamma(\bar{B}) - \Gamma(B)}{\Gamma(\bar{B}) + \Gamma(B)} \qquad S = \sin 2\beta \qquad C = 0$$

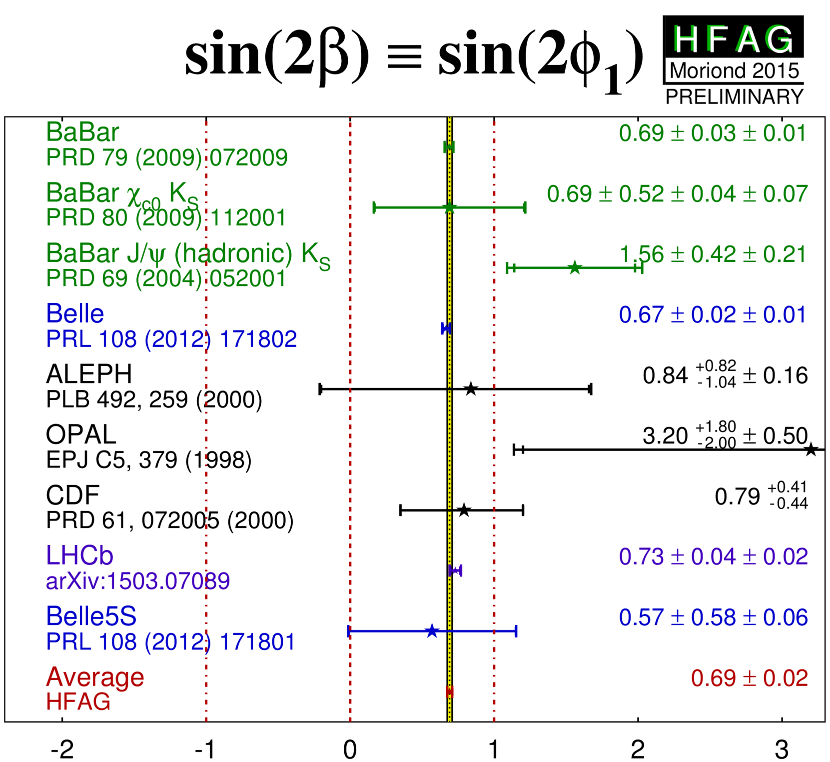
$$A(t) = S \sin(\Delta m_d t) - C \cos(\Delta m_d t)$$

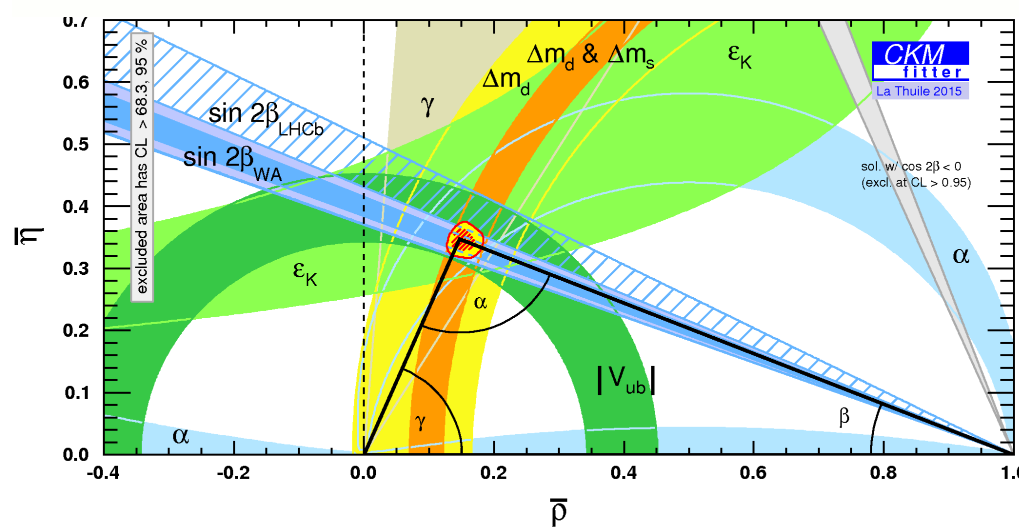
$$\boxed{\begin{array}{l} S = 0.731 \pm 0.035 \pm 0.020 \\ C = -0.038 \pm 0.032 \pm 0.005 \end{array}}$$



Belle : $0.67 \pm 0.02 \pm 0.01$

BaBar : $0.69 \pm 0.03 \pm 0.01$





$$\boxed{\beta = (21.9 \pm 0.7)^\circ}$$ **WA 2015**

Mixing-induced CP violation in $B_s \to J/\psi K K$

[See G.Cowan's talk]
[3 fb^{-1}, arXiv:1411.3104]

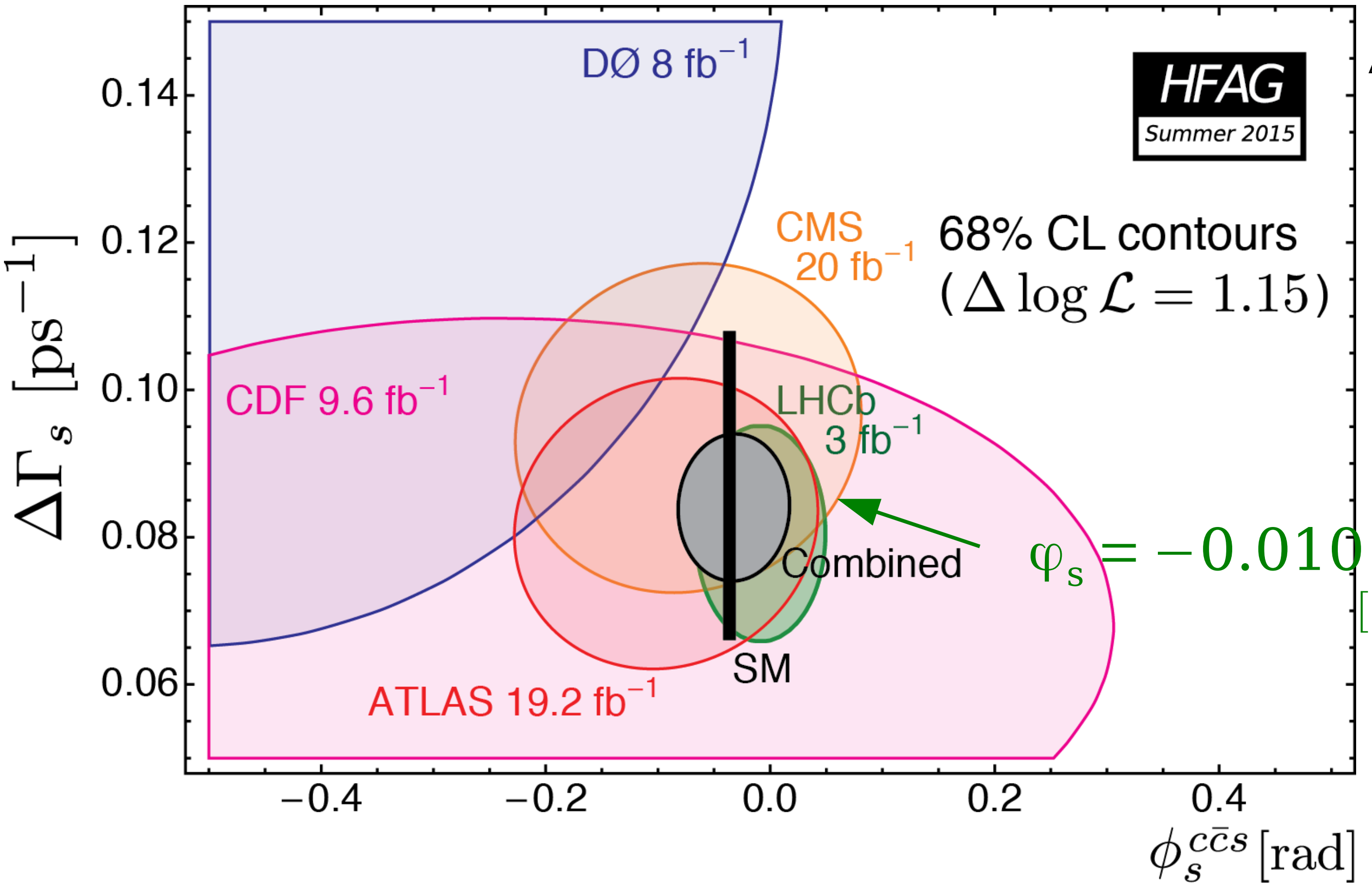
CP violating phase

$$\boxed{\varphi_s = -0.058 \pm 0.049 \pm 0.006}$$

CP violating in mixing or direct decay (no CPV: $|\lambda|=1$)

$$|\lambda| = 0.964 \pm 0.019 \pm 0.007$$

Decay width difference $\Delta\Gamma_s = (\Gamma_L - \Gamma_H) = 0.0805 \pm 0.0091 \pm 0.0032\ ps^{-1}$



$\Delta\Gamma_s(SM) = 0.087 \pm 0.021\ ps^{-1}$
$\varphi_s(SM) = -0.0363\ ^{+0.0012}_{-0.0014}$ rad

$\varphi_s = -0.010 \pm 0.039$ rad
[combined with $J/\psi\pi\pi$]

Semileptonic asymmetries

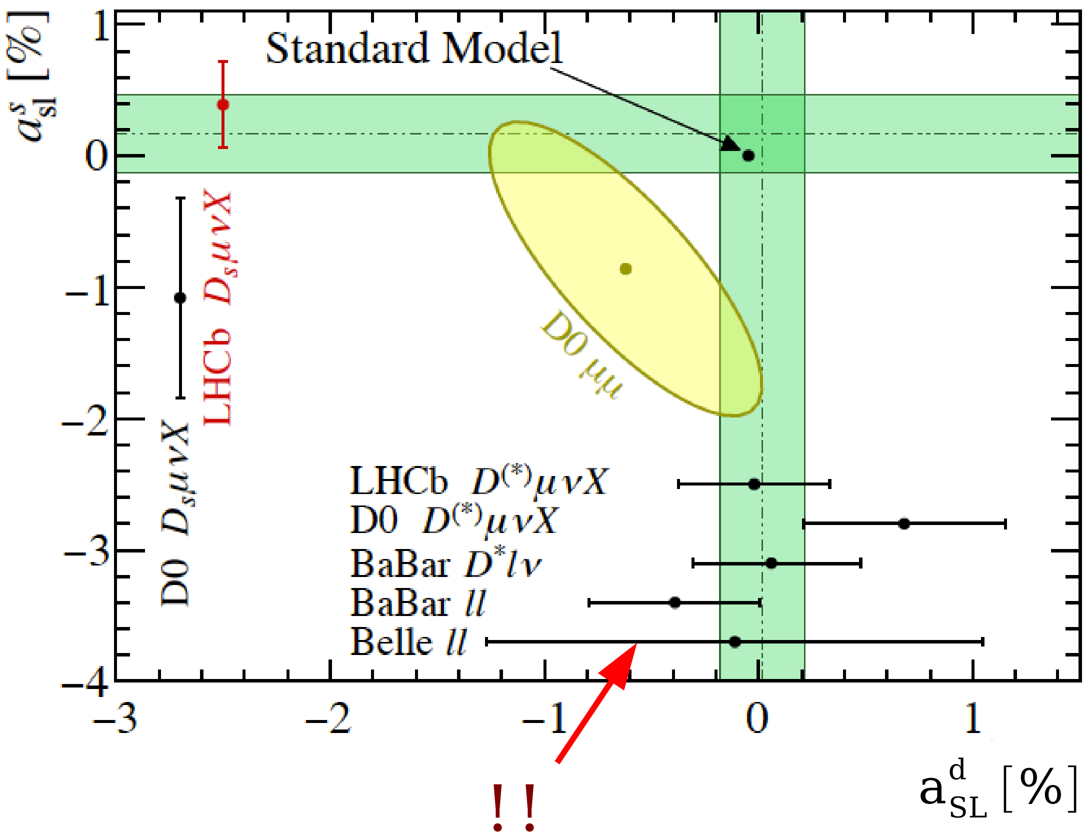
use semileptonic $B^0_{(s)}$ decays

[Phys.Rev.Lett.117(2016)061803]

$$a^s_{SL} = (0.39 \pm 0.26\,(\mathrm{stat}) \pm 0.20\,(\mathrm{syst}))\%$$

$$A_{CP} \equiv a_{SL} = \frac{\Gamma(\bar{B} \to B \to f) - \Gamma(B \to \bar{B} \to \bar{f})}{\Gamma(\bar{B} \to B \to f) + \Gamma(B \to \bar{B} \to \bar{f})}$$

$$A_{meas}(t) = \frac{a_{SL}}{2}\left(1 - \frac{\cos(\Delta m\, t)}{\cosh(\Delta\Gamma\, t/2)}\right)$$



Standard Model predictions

[A.Lenz, arXiv:1205.1444]

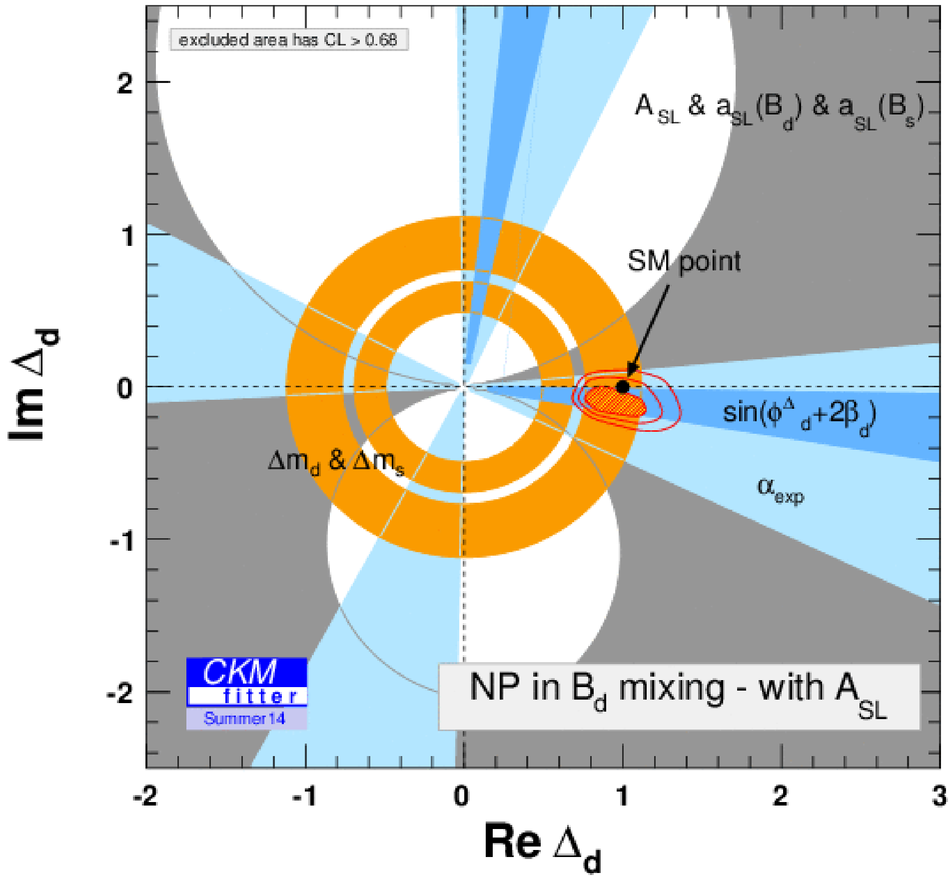
$$a^d_{SL} = (-4.1 \pm 0.6) \times 10^{-4}$$
$$a^s_{SL} = (+1.9 \pm 0.3) \times 10^{-5}$$

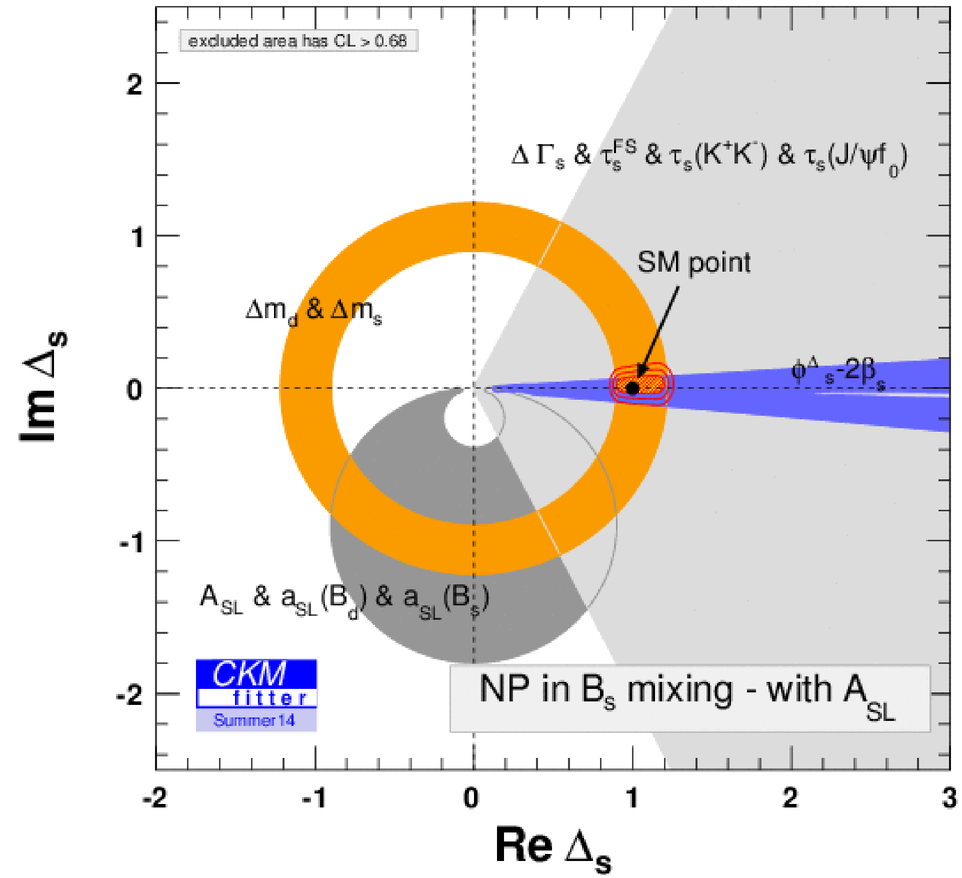
- **No tagging needed.** Time-dependent (B^0) or time-independent (B^0_s) SL asymmetry measurement
- 3σ tension coming from D0 dimuon asymmetry measurement

$\Delta F = 2$: Current constraints

[CKMfitter, arXiv:1501.05013]

$$M_{12} = M_{12}.\Delta, \; \Delta = |\Delta| e^{i\varphi^{\Delta}}$$





$$\Delta_d = 0.88^{+0.22}_{-0.10} + i\left(-0.11^{+0.07}_{-0.05}\right) \qquad \Delta_s = 1.01^{+0.17}_{-0.09} + i\left(+0.02 \pm 0.04\right)$$

Bounds/prospects for New Physics at:

- Stage I: 7 fb^{-1} LHCb + 5 ab^{-1} Belle II
- Stage II: 50 fb^{-1} LHCb + 50 ab^{-1} Belle II

$\Delta F = 2$: Inputs

[CKMfitter, arXiv:1501.05013]

	2003	2013	Stage I		Stage II	
$\|V_{ud}\|$	0.9738 ± 0.0004	$0.97425 \pm 0 \pm 0.00022$	id		id	
$\|V_{us}\|$ $(K_{\ell 3})$	$0.2228 \pm 0.0039 \pm 0.0018$	$0.2258 \pm 0.0008 \pm 0.0012$	0.22494 ± 0.0006		id	
$\|\epsilon_K\|$	$(2.282 \pm 0.017) \times 10^{-3}$	$(2.228 \pm 0.011) \times 10^{-3}$	id		id	
Δm_d [ps^{-1}]	0.502 ± 0.006	0.507 ± 0.004	id		id	
Δm_s [ps^{-1}]	> 14.5 [95% CL]	17.768 ± 0.024	id		id	
$\|V_{cb}\| \times 10^3$ $(b \to c\ell\bar{\nu})$	$41.6 \pm 0.58 \pm 0.8$	$41.15 \pm 0.33 \pm 0.59$	42.3 ± 0.4	[17]	42.3 ± 0.3	[17]
$\|V_{ub}\| \times 10^3$ $(b \to u\ell\bar{\nu})$	$3.90 \pm 0.08 \pm 0.68$	$3.75 \pm 0.14 \pm 0.26$	3.56 ± 0.10	[17]	3.56 ± 0.08	[17]
$\sin 2\beta$	0.726 ± 0.037	0.679 ± 0.020	0.679 ± 0.016	[17]	0.679 ± 0.008	[17]
α (mod π)	—	$(85.4^{+4.0}_{-3.8})^\circ$	$(91.5 \pm 2)^\circ$	[17]	$(91.5 \pm 1)^\circ$	[17]
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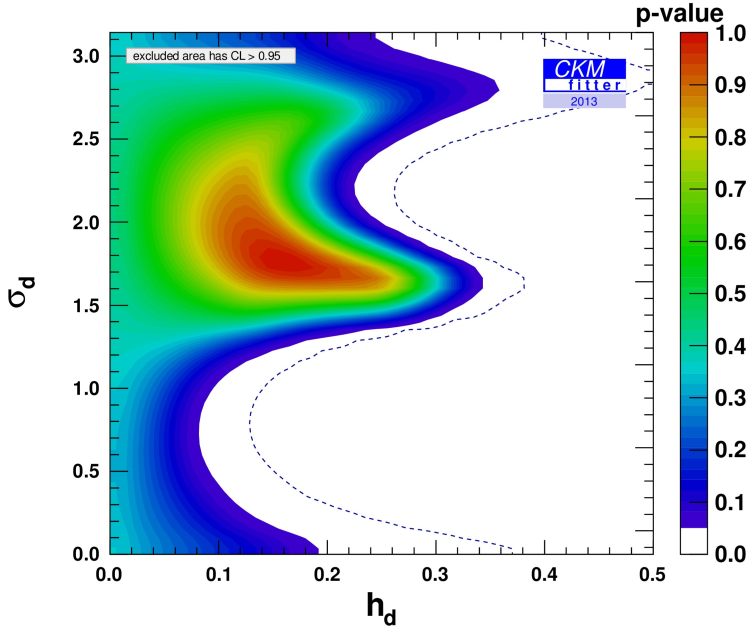
$A^d_{\mathrm{SL}} \times 10^4$	10 ± 140	23 ± 26	-7 ± 15	[17]	-7 ± 10	[17]
$A^s_{\mathrm{SL}} \times 10^4$	—	-22 ± 52	0.3 ± 6.0	[18]	0.3 ± 2.0	[18]
$\bar{m}_c$	$1.2 \pm 0 \pm 0.2$	$1.286 \pm 0.013 \pm 0.040$	1.286 ± 0.020		1.286 ± 0.010	
$\bar{m}_t$	167.0 ± 5.0	$165.8 \pm 0.54 \pm 0.72$	id		id	
$\alpha_s(m_Z)$	$0.1172 \pm 0 \pm 0.0020$	$0.1184 \pm 0 \pm 0.0007$	id		id	
B_K	$0.86 \pm 0.06 \pm 0.14$	$0.7615 \pm 0.0026 \pm 0.0137$	0.774 ± 0.007	[19, 20]	0.774 ± 0.004	[19, 20]
f_{B_s} [GeV]	$0.217 \pm 0.012 \pm 0.011$	$0.2256 \pm 0.0012 \pm 0.0054$	0.232 ± 0.002	[19, 20]	0.232 ± 0.001	[19, 20]
B_{B_s}	1.37 ± 0.14	$1.326 \pm 0.016 \pm 0.040$	1.214 ± 0.060	[19, 20]	1.214 ± 0.010	[19, 20]
f_{B_s}/f_{B_d}	$1.21 \pm 0.05 \pm 0.01$	$1.198 \pm 0.008 \pm 0.025$	1.205 ± 0.010	[19, 20]	1.205 ± 0.005	[19, 20]
B_{B_s}/B_{B_d}	1.00 ± 0.02	$1.036 \pm 0.013 \pm 0.023$	1.055 ± 0.010	[19, 20]	1.055 ± 0.005	[19, 20]
$\tilde{B}_{B_s}/\tilde{B}_{B_d}$	—	$1.01 \pm 0 \pm 0.03$	1.03 ± 0.02		id	
$\tilde{B}_{B_s}$	—	$0.91 \pm 0.03 \pm 0.12$	0.87 ± 0.06		id	

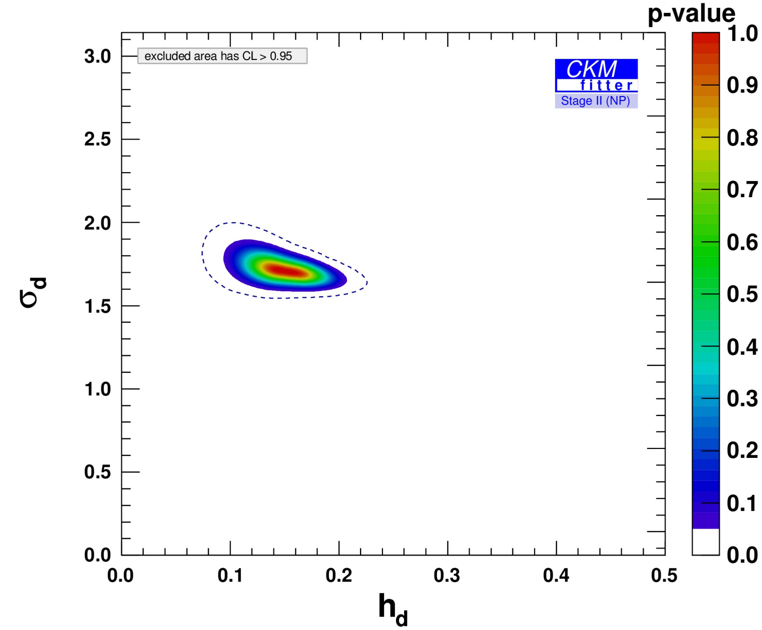
NB: No D0 A_{SL} input

$\Delta F = 2$: NP !!   ideal scenario...

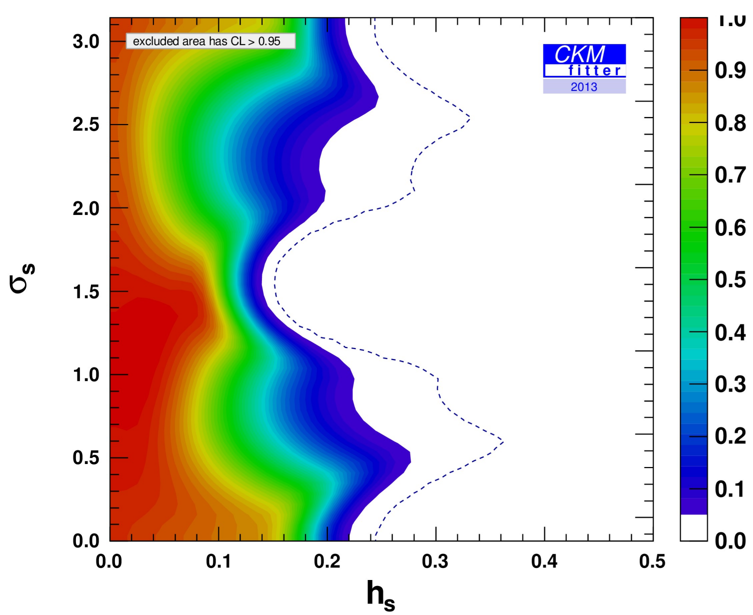
Hypothetical Stage II fits for NP, assuming that all future experimental results correspond to the current best-fit values of $\bar{\rho}$, $\bar{\eta}$, $h_{d,s}$, $\sigma_{d,s}$

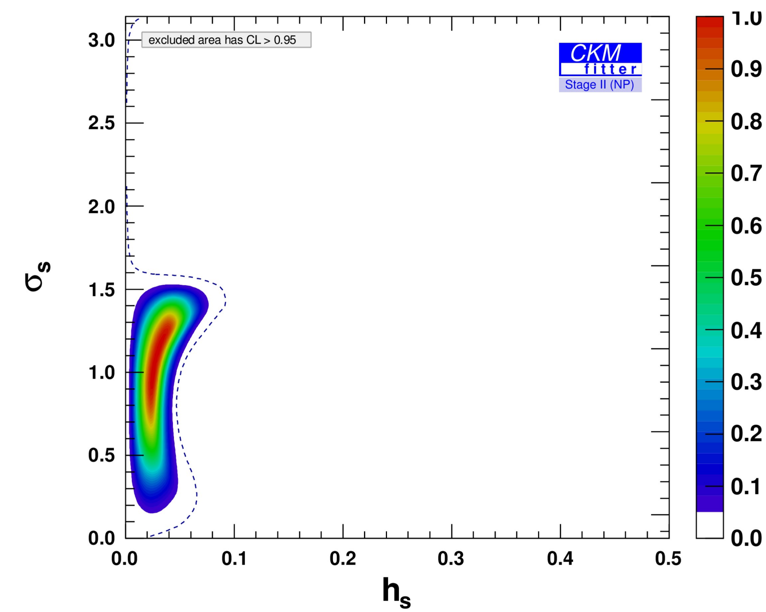
σ_d vs h_d





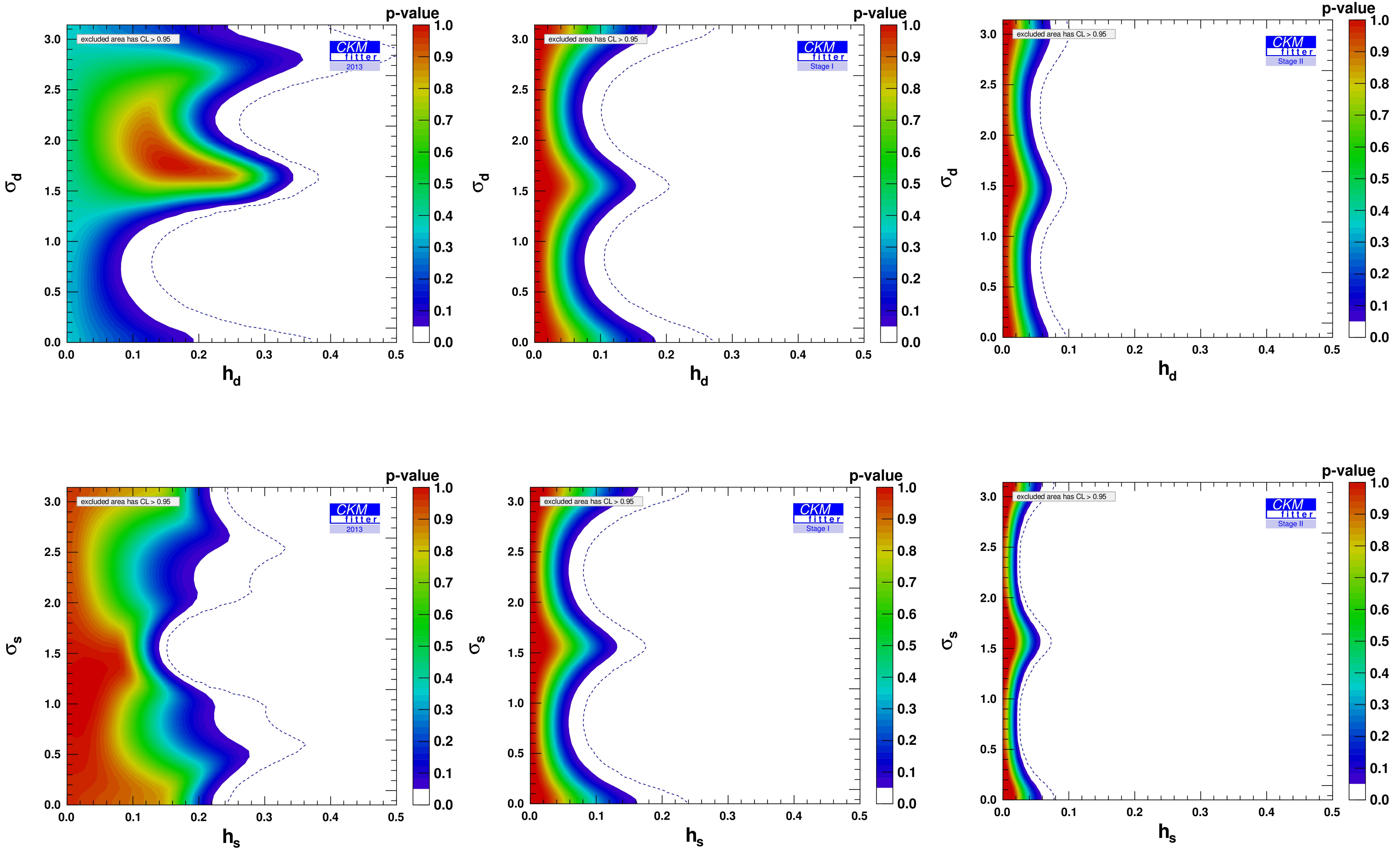
σ_s vs h_s





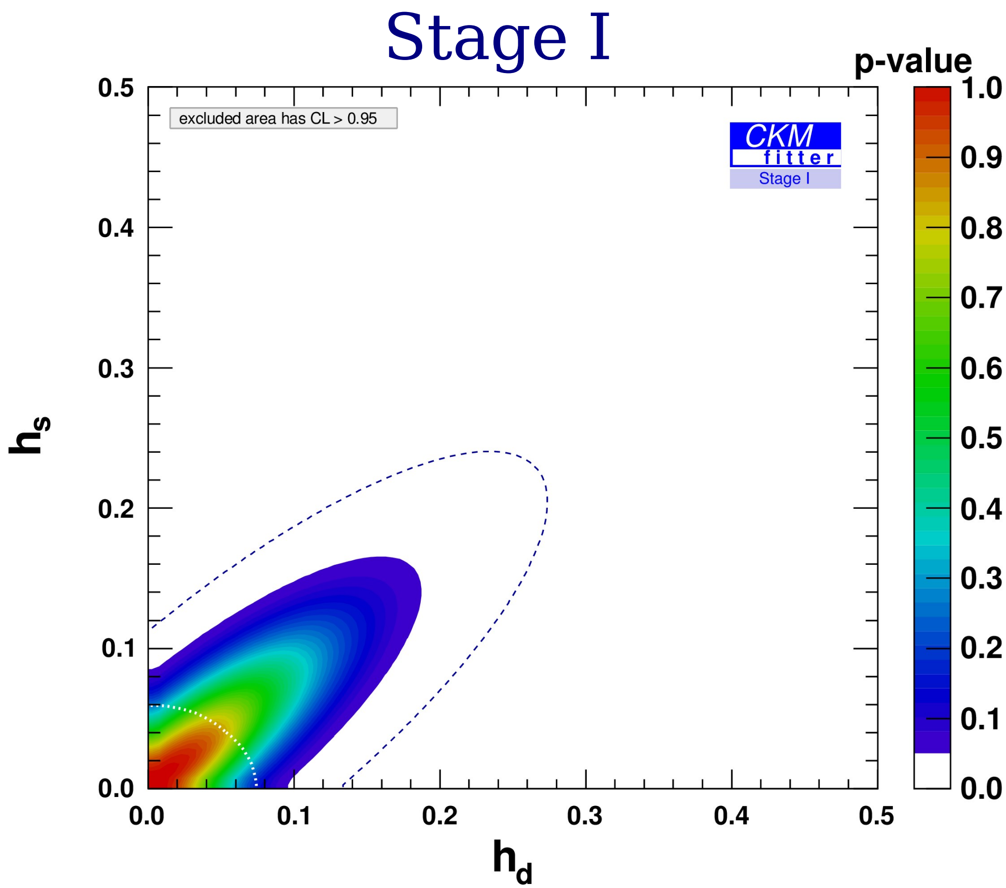
2013   **Stage II**

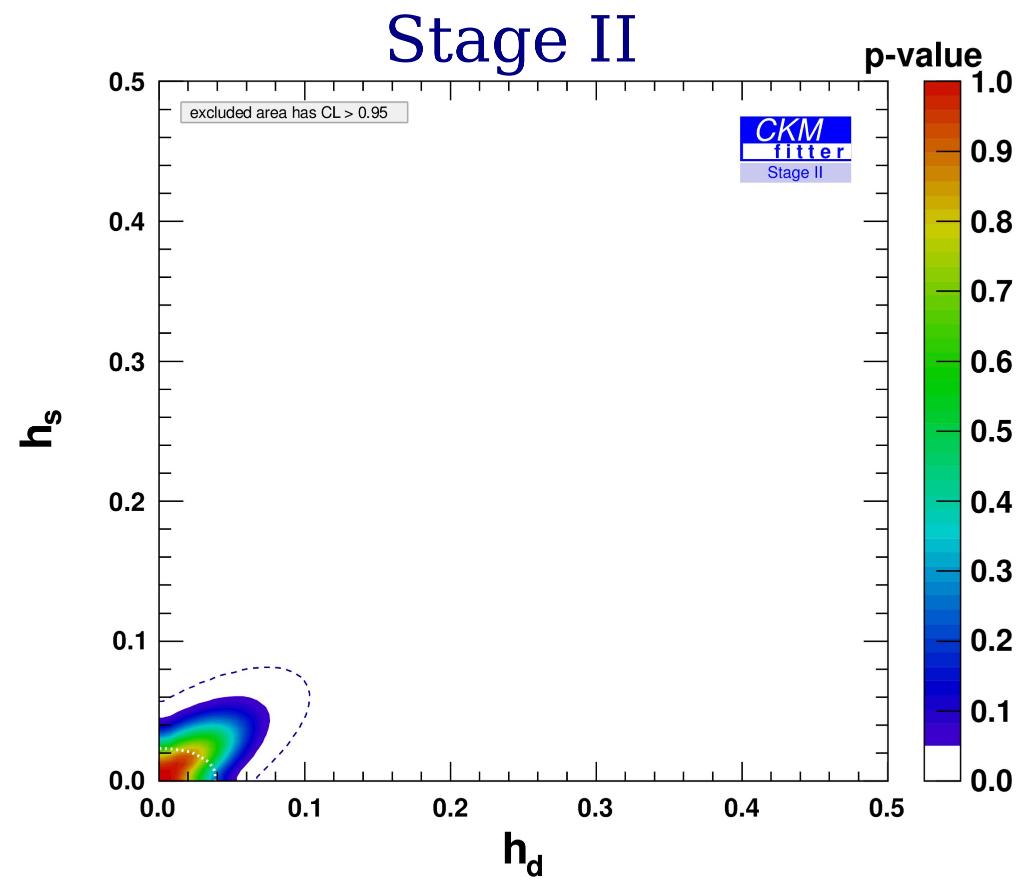
$\Delta F = 2$: bounds for $B_{d,s}$ mixings



2013 Stage I Stage II

$\Delta F = 2$: bounds on energy scale





NP contribution to the mixing

from $\dfrac{C_{ij}^2}{\Lambda^2}(\bar{b}_L \gamma^\mu q_{j,L})^2$

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

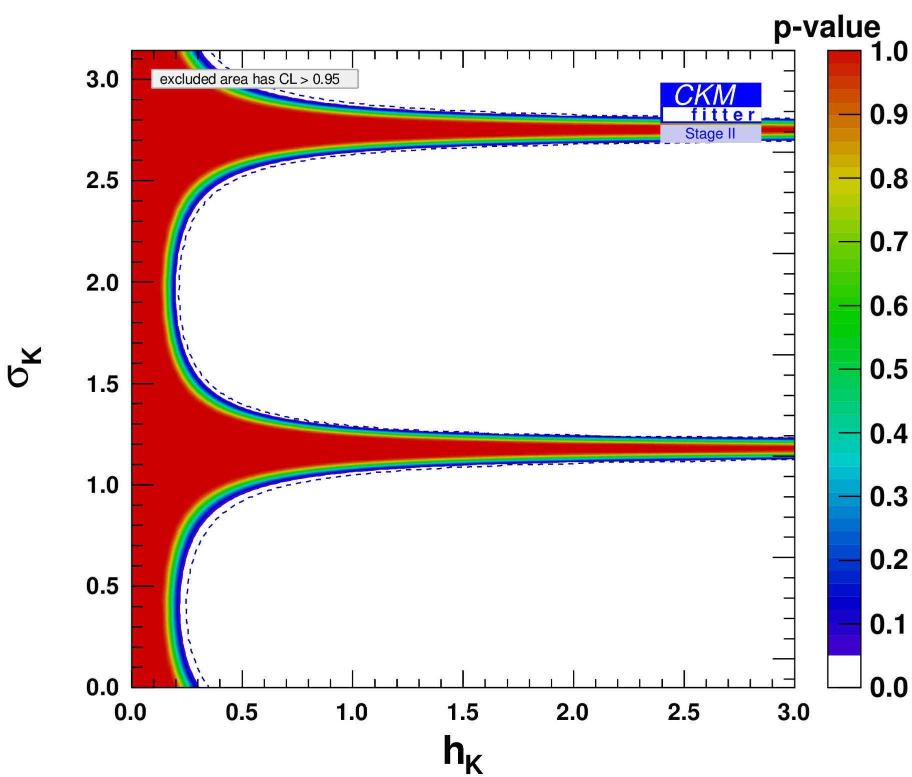
Couplings	NP loop order	Scales (in TeV) probed by B_d mixing	Scales (in TeV) probed by B_s mixing
$\lvert C_{ij}\rvert = \lvert V_{ti} V_{tj}^*\rvert$ (CKM-like)	tree level	17	19
	one loop	1.4	1.5
$\lvert C_{ij}\rvert = 1$ (no hierarchy)	tree level	2×10^3	5×10^2
	one loop	2×10^2	40

probe new particles with CKM-like couplings with masses, M, in the 10-20 TeV range if contribute at tree level ($\Lambda \sim M$), in 1-2 TeV range if enter with a loop suppression ($\Lambda \sim 4\pi M$)

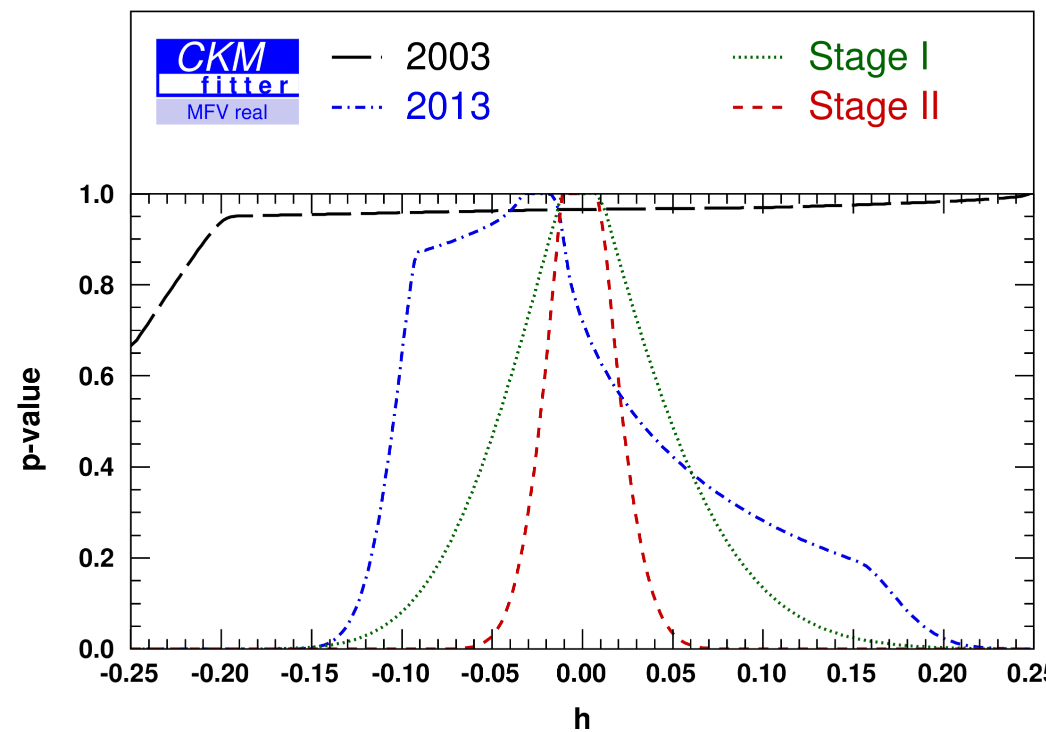
NP in K mixing, $\Delta F = 2$: ϵ_K

- K, B_d and B_s mixings in general not related
- ϵ_K not enough to bound NP in K mixing, even if NP only in tt box
- but in the case of MFV, possible to exploit all neutral mesons

$$h = h_d\, e^{2i\sigma_d} = h_s\, e^{2i\sigma_s} = h_K\, e^{2i\sigma_K} \text{ with } \sigma_i = 0 \pmod{\pi/2}$$



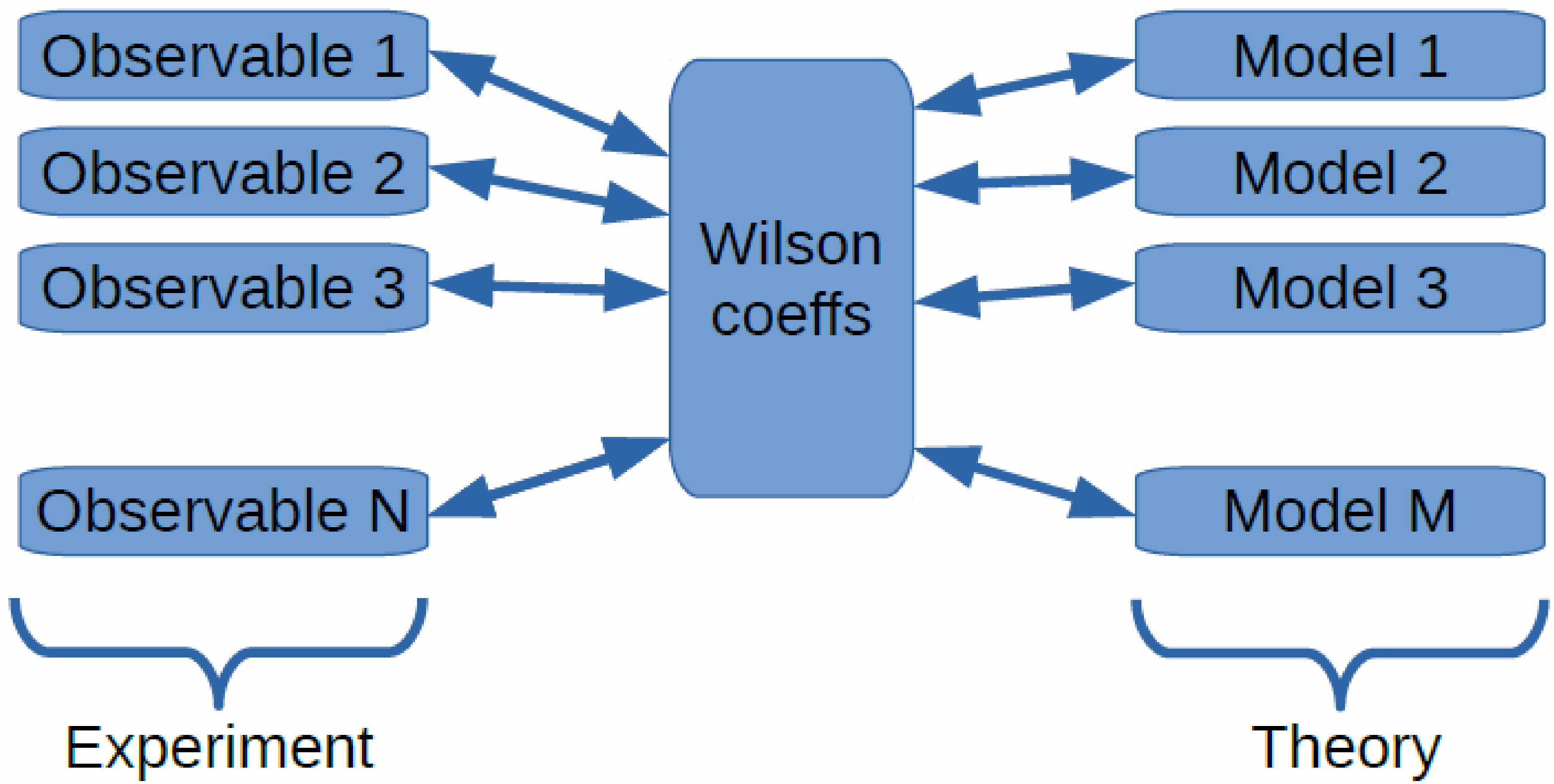
Arbitrary NP in tt K boxes - Stage II



MFV case

Sensitivity to new physics in rare B decays

References:
M.Ciuchini et al, arXiv:1512.07157
T.Hurth et al, arXiv:1603.00865
S.Descotes-Genon et al, arXiv:1510.04239
...

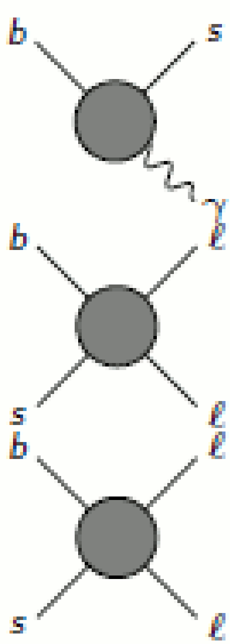


Effective field theory

- Model-independent description in effective field theory

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{\rm tb} V^*_{\rm ts} \sum_i \underbrace{\mathcal{C}_i \mathcal{O}_i}_{\text{Left-handed}} + \underbrace{\mathcal{C}'_i \mathcal{O}'_i}_{\text{Right-handed, } \frac{m_s}{m_b} \text{ suppressed}}$$

- Wilson coefficients $\mathcal{C}_i^{(\prime)}$ encode short-distance physics, $\mathcal{O}_i^{(\prime)}$ corr. operators



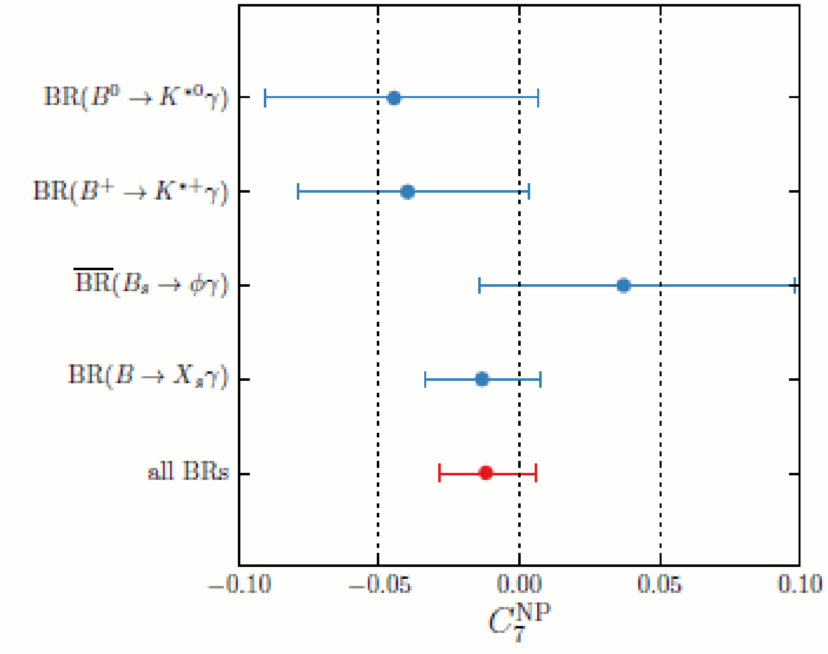
	$b \to s\gamma$	$B \to \mu\mu$	$b \to s\ell\ell$
$\mathcal{O}_7^{(\prime)}$ photon penguin	✓		✓
$\mathcal{O}_9^{(\prime)}$ vector coupling			✓
$\mathcal{O}_{10}^{(\prime)}$ axialvector coupling		✓	✓
$\mathcal{O}_{S,P}^{(\prime)}$ (pseudo)scalar penguin		✓	

NP changes short-distance C_i and/or add new long-distance ops O'_i

Constraints on NP from radiative B decays

A.Paul, D.Straub, arXiv:1608.02556

Observable	SM prediction		Measurement	
$10^4 \times \mathrm{BR}(B \to X_s\gamma)_{E_\gamma > 1.6\,\mathrm{GeV}}$	3.36 ± 0.23	[16]	3.43 ± 0.22	[19]
$10^5 \times \mathrm{BR}(B^+ \to K^*\gamma)$	3.43 ± 0.84		4.21 ± 0.18	[19]
$10^5 \times \mathrm{BR}(B^0 \to K^*\gamma)$	3.48 ± 0.81		4.33 ± 0.15	[19]
$10^5 \times \overline{\mathrm{BR}}(B_s \to \phi\gamma)$	4.31 ± 0.86		3.5 ± 0.4	[43, 44]
$S(B^0 \to K^*\gamma)$	-0.023 ± 0.015		-0.16 ± 0.22	[19]
$A_{\mathrm{CP}}(B^0 \to K^*\gamma)$	0.003 ± 0.001		-0.002 ± 0.015	[19]
$A_{\Delta\Gamma}(B_s \to \phi\gamma)$	0.031 ± 0.021		-1.0 ± 0.5	[4]
$\langle P_1\rangle(B^0 \to K^*e^+e^-)_{[0.002,1.12]}$	0.04 ± 0.02		-0.23 ± 0.24	[45]
$\langle A_T^{\mathrm{Im}}\rangle(B^0 \to K^*e^+e^-)_{[0.002,1.12]}$	0.0003 ± 0.0002		0.14 ± 0.23	[45]



Constraints on NP from radiative B decays

A.Paul, D.Straub, arXiv:1608.02556 [See talk of S.Sandilya]

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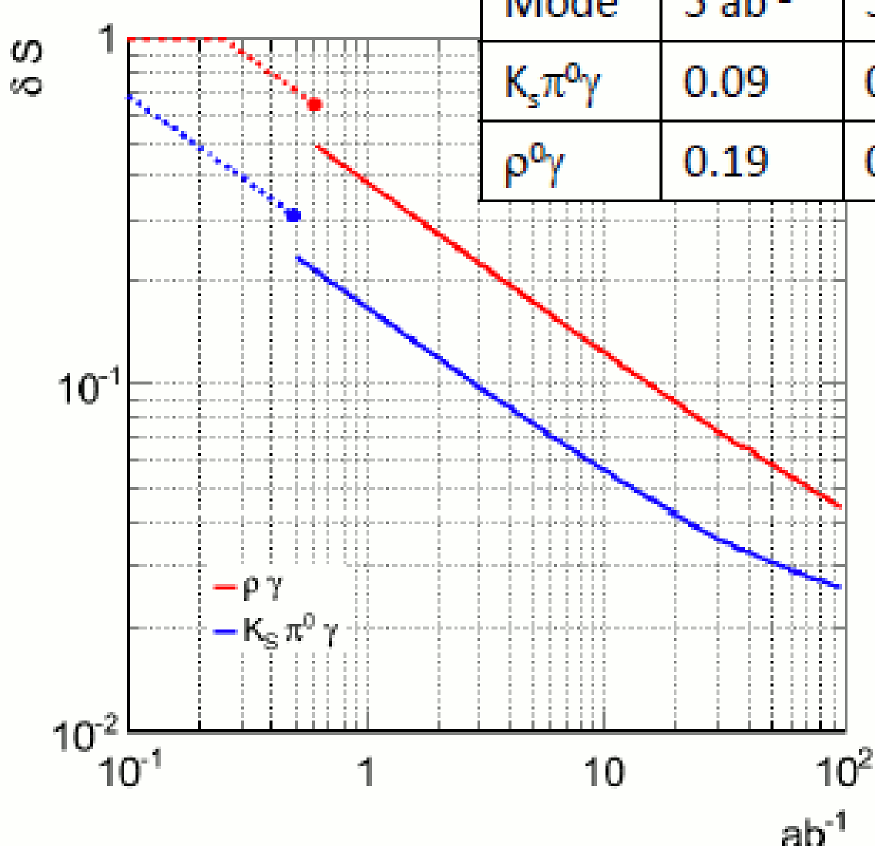
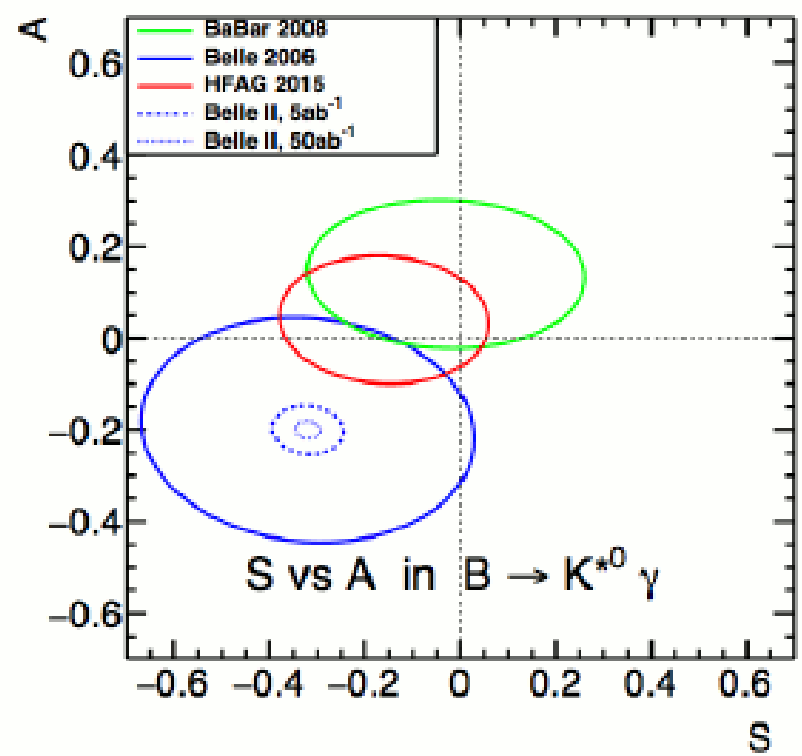
At Belle II, significant improvement in the determination of $A_{CP}(t)$ in $K_S^0\pi^0\gamma$ expected.

- Belle II vertex larger than Belle ($6 \to 11.5$cm)
- 30% more K_S with vertex hits available
- Effective tagging eff. 13% better

- Expected errors for ***S*** measurements of $K_s\pi^0\gamma$ and $\rho^0\gamma$.

Mode	5 ab^{-1}	50 ab^{-1}
$K_s\pi^0\gamma$	0.09	0.030
$\rho^0\gamma$	0.19	0.064





16σ deviation with 50 ab^{-1}.

Constraints on NP from radiative B decays

A.Paul, D.Straub, arXiv:1608.02556

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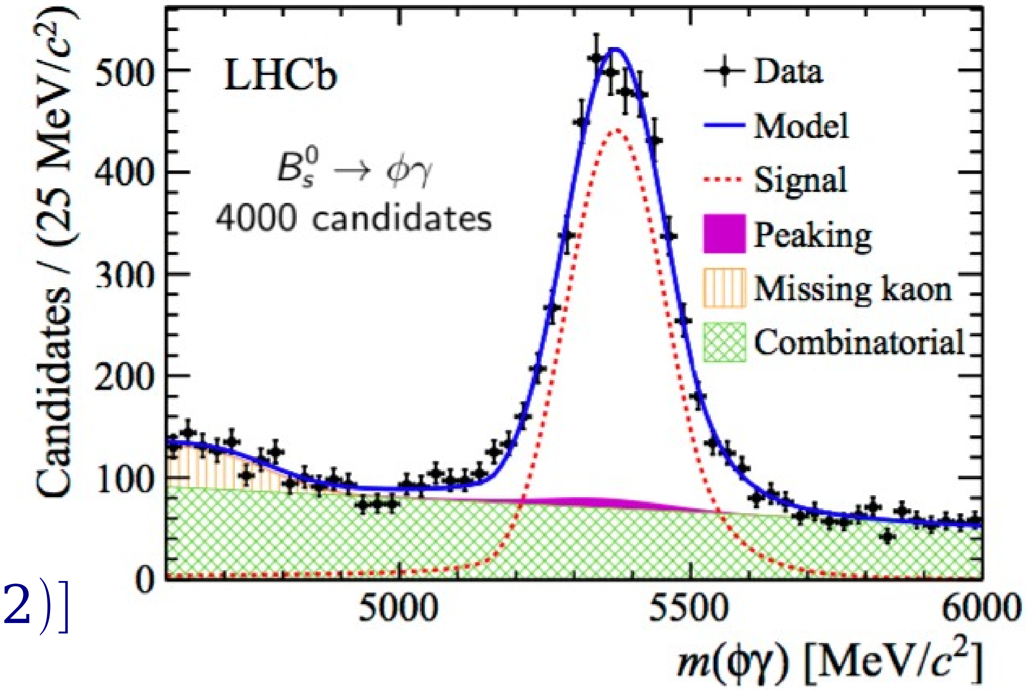
[See talk of A.Oyanguren]
[arXiv:1609.02032]



- Fit untagged decay-time rate

$$\Gamma_{B_s \to \gamma}(t) \propto [\cosh(\Delta\Gamma_s t/2) - \mathbf{A}^\Delta \sinh(\Delta\Gamma_s t/2)]$$

$$A^\Delta \simeq \sin 2\psi \cos\varphi_s \qquad \tan\psi \equiv \frac{A(\overline{B}_s^0 \to \varphi\gamma_R)}{A(\overline{B}_s^0 \to \varphi\gamma_L)}$$

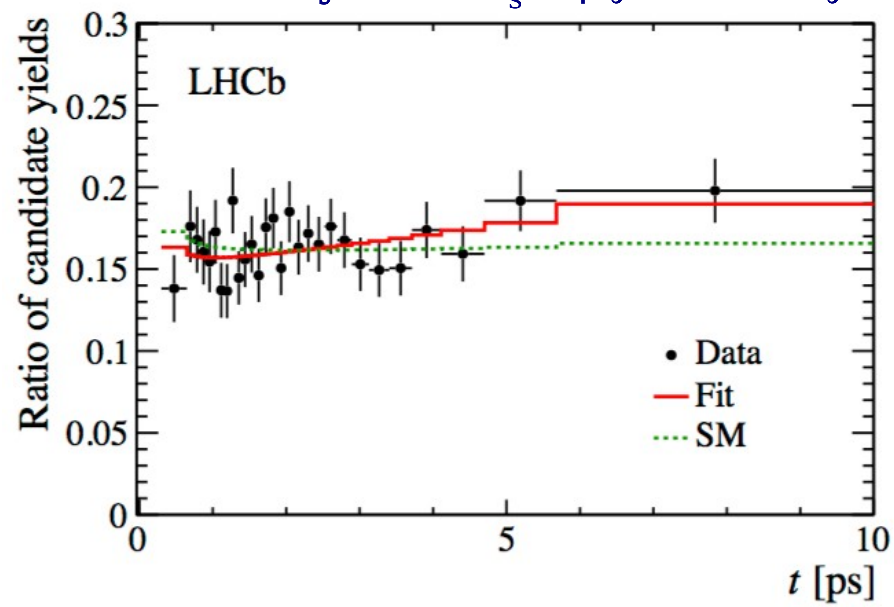
- Control acceptance by using $B^0 \to K^{*0}\gamma$ decays

$$\mathbf{A^\Delta = (-0.98\ {}^{+0.46}_{-0.52}\ {}^{+0.23}_{-0.20})}$$

to be compared with

$$A^\Delta_{SM} = 0.047\ {}^{+0.029}_{-0.025}$$

Ratio of yields $B_s \to \varphi\gamma / B^0 \to K^*\gamma$



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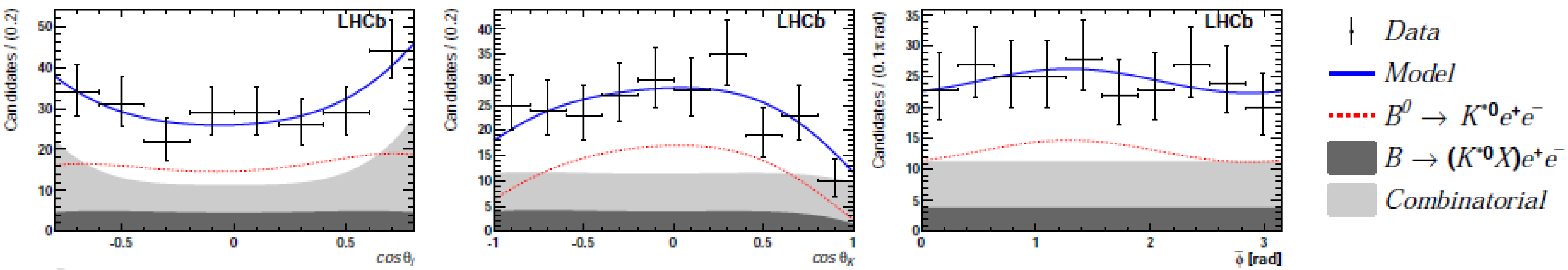
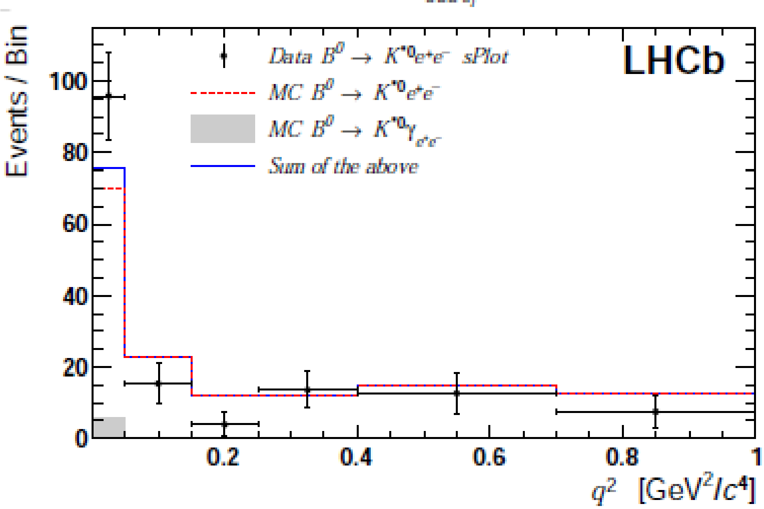
[LHCb, arXiv:1501.03038]
see F.Polci's talk

- Angular analysis of $B_d^0 \to K^* e^+ e^-$ at very low q^2 ($\in [0.002, 1.120]$ GeV^2)



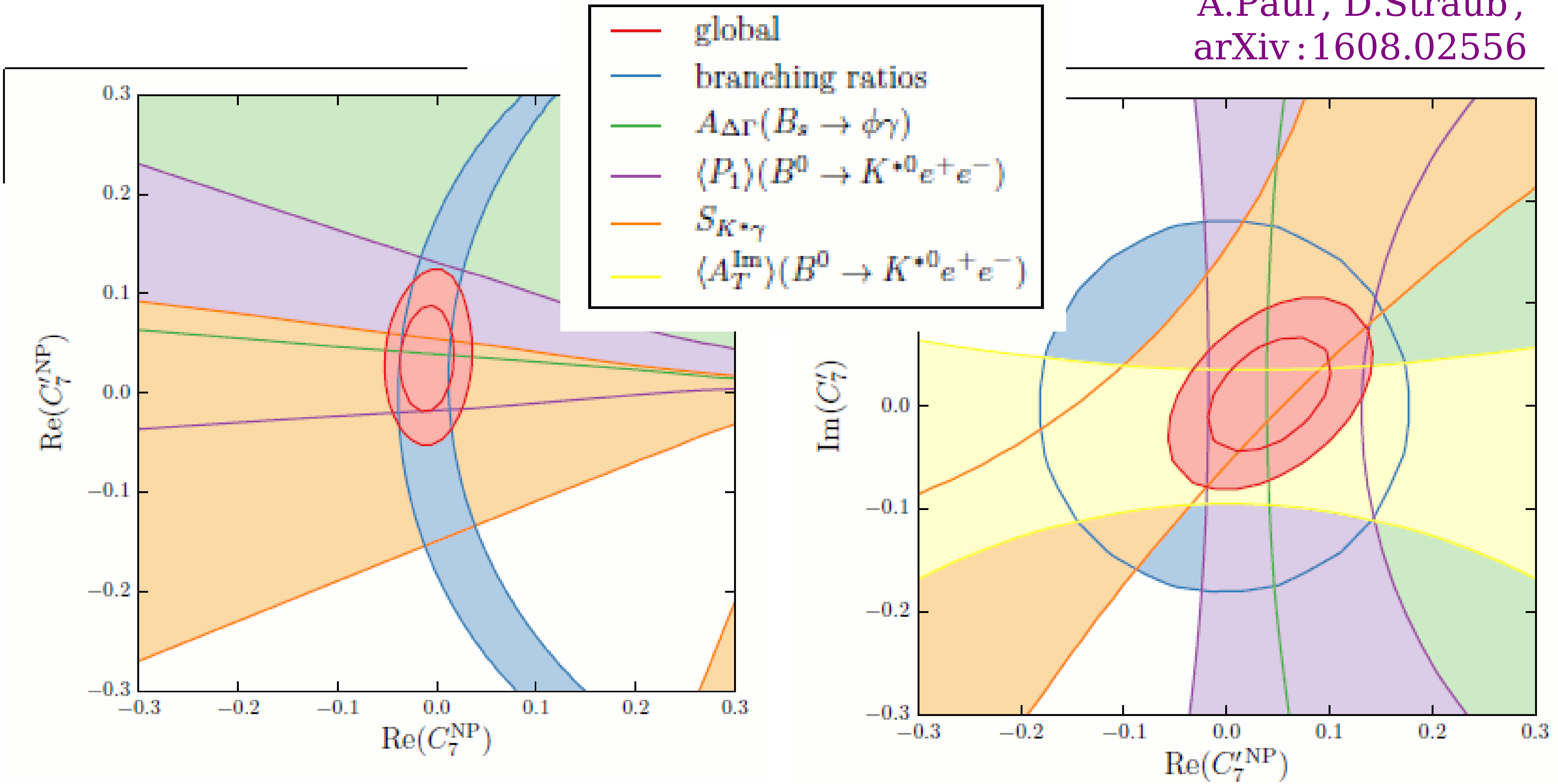


Observable	Measurement	SM prediction†
F_{L}	$+0.16 \pm 0.06 \pm 0.03$	$+0.10^{+0.11}_{-0.05}$
$A_{\mathrm{T}}^{(2)}$	$-0.23 \pm 0.23 \pm 0.05$	$0.03^{+0.05}_{-0.04}$
$A_{\mathrm{T}}^{\mathrm{Re}}$	$+0.10 \pm 0.18 \pm 0.05$	$-0.15^{+0.04}_{-0.03}$
$A_{\mathrm{T}}^{\mathrm{Im}}$	$+0.14 \pm 0.22 \pm 0.05$	$(-0.2^{+1.2}_{-1.2}) \times 10^{-4}$

S.Jager, J.M.Camalich [arXiv:1412.3283]

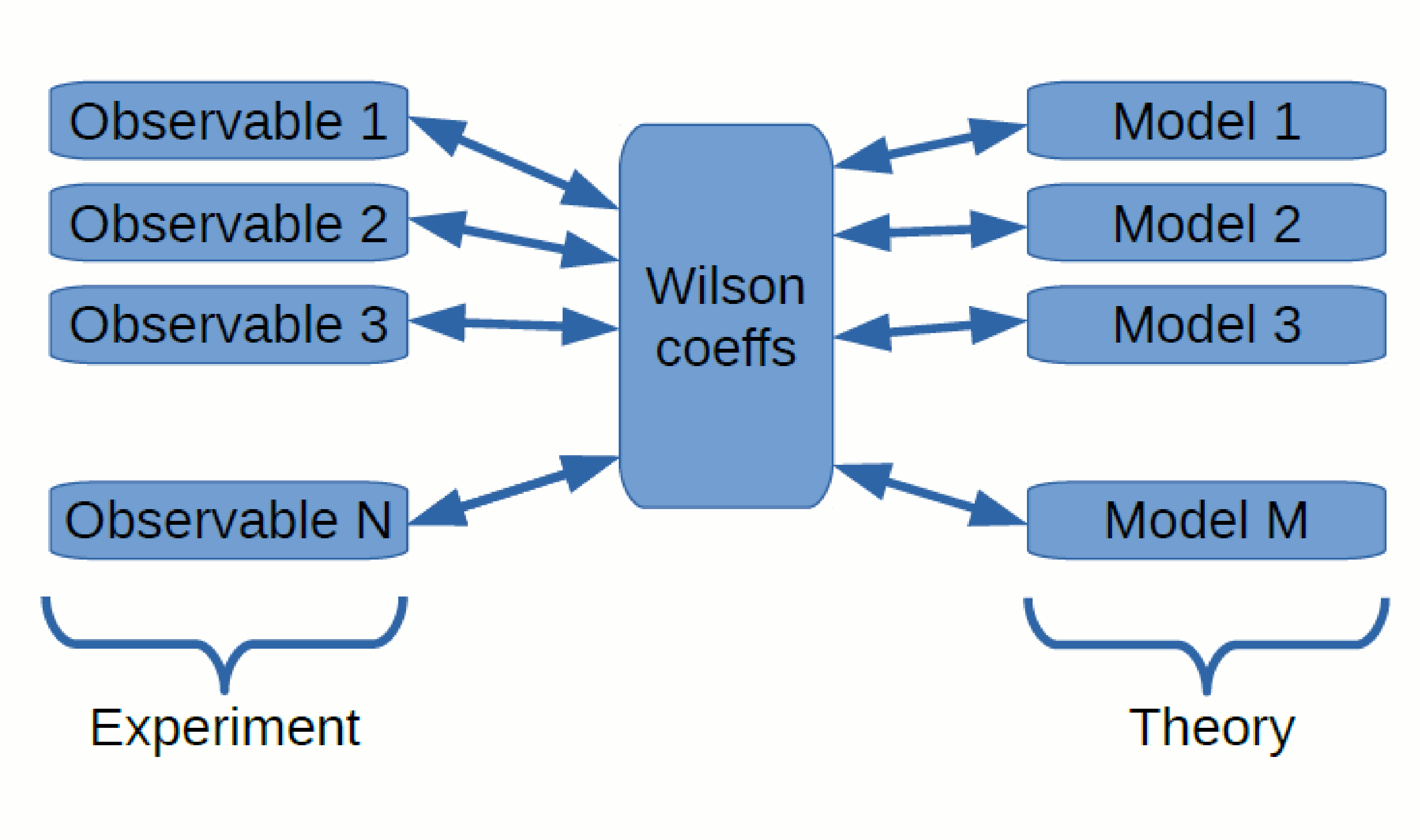
Constraints on NP from radiative B decays

A.Paul, D.Straub,
arXiv:1608.02556



- inclusive and exclusive branching ratios strongly constrain NP contributions to the real part of C_7
- more precise measurement of time-dependent CP asymmetry in $B \to K^* \gamma$
- improved measurements of the $B \to K^* e^+ e^-$ angular analysis at very low q^2
- measurements of radiative baryonic decays $\Lambda_b \to \Lambda^{(*)} \gamma$

Global fits including also $b \to s\, l^+ l^-$ (many more observables)



Global fits

Hurt, Mahmoudi, Neshatpour
arXiv:1603.00865

Global fits of the observables by minimization of

$$\chi^2 = (\vec{O}^{\rm th} - \vec{O}^{\rm exp}).(\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1}.(\vec{O}^{\rm th} - \vec{O}^{\rm exp})$$

$(\Sigma_{\rm th} + \Sigma_{\rm exp})^{-1}$ is the inverse covariance matrix

More than 100 observables relevant for leptonic and semileptonic decays:

- $\mathrm{BR}(B \to X_s \gamma)$
- $\mathrm{BR}(B \to X_d \gamma)$
- $\Delta_0(B \to K^* \gamma)$
- $\mathrm{BR}^{\rm low}(B \to X_s \mu^+ \mu^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s \mu^+ \mu^-)$
- $\mathrm{BR}^{\rm low}(B \to X_s e^+ e^-)$
- $\mathrm{BR}^{\rm high}(B \to X_s e^+ e^-)$
- $\mathrm{BR}(B_s \to \mu^+ \mu^-)$
- $\mathrm{BR}(B_d \to \mu^+ \mu^-)$
- $\mathrm{BR}(B \to K^{*+} \mu^+ \mu^-)$
- $\mathrm{BR}(B \to K^0 \mu^+ \mu^-)$
- $\mathrm{BR}(B \to K^+ \mu^+ \mu^-)$
- $\mathrm{BR}(B \to K^* e^+ e^-)$
- R_K
- $B \to K^{*0} \mu^+ \mu^-$: BR, F_L, A_{FB}, S_3, S_4, S_5, S_7, S_8, S_9 in 8 low q^2 and 4 high q^2bins
- $B_s \to \phi \mu^+ \mu^-$: BR, F_L, , S_3, S_4, S_7 in 3 low q^2 and 2 high q^2bins

calculations done using SuperIso program

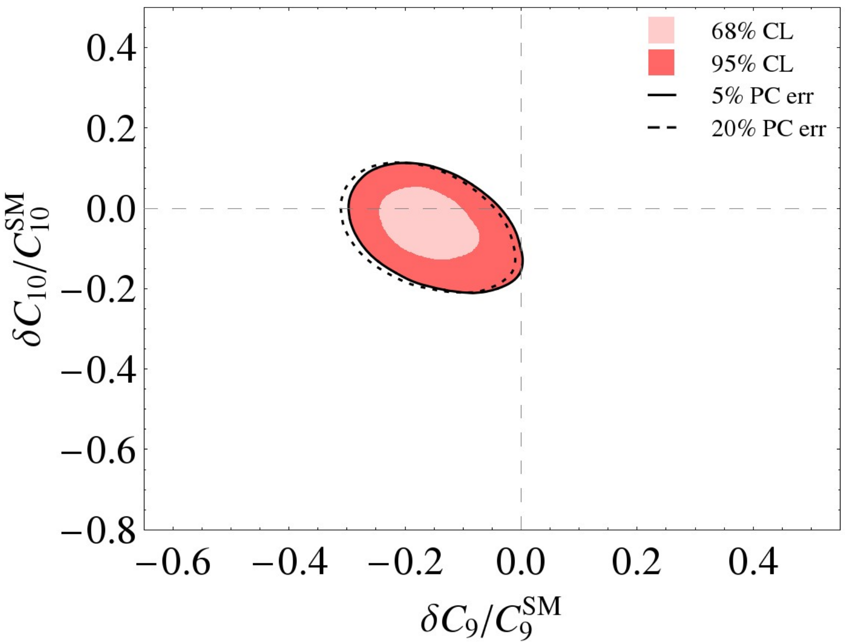
Global fits

Hurt, Mahmoudi, Neshatpour
arXiv:1603.00865

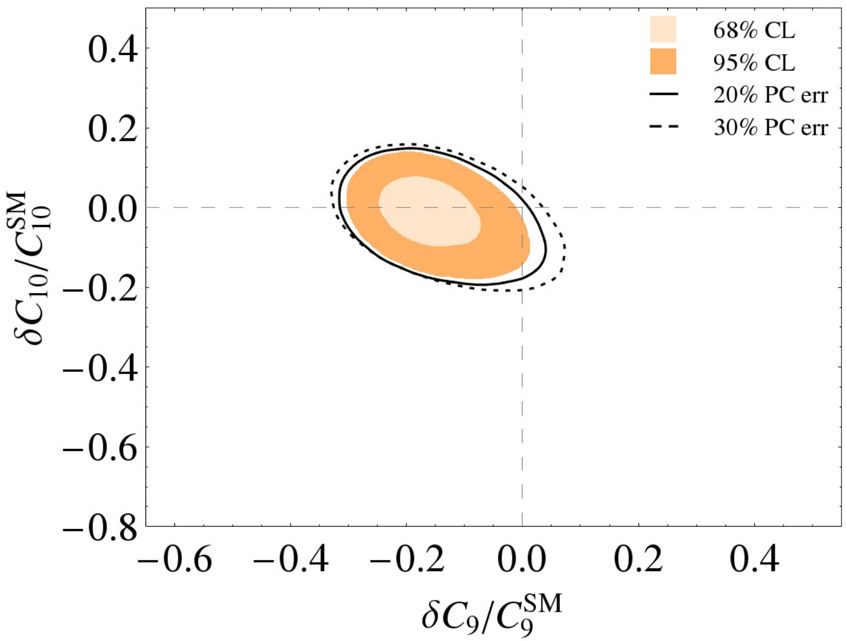
NP manifests itself in the shifts of the individual coefficients with respect to the SM values: $C_i(\mu) = C_i^{SM}(\mu) + \delta C_i$

Assuming NP to appear in two operators:

global fit results using full FF approach



global fit results using soft FF approach

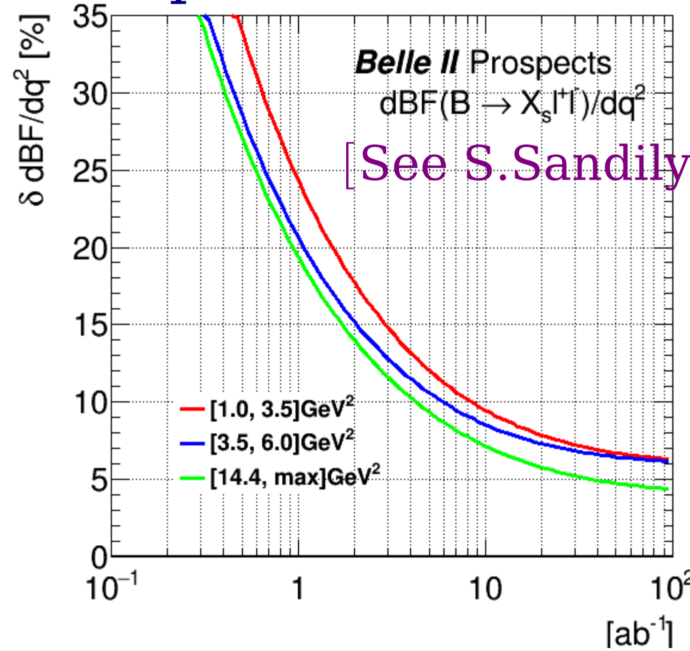


Global fits

[See T.Hurth's talk]

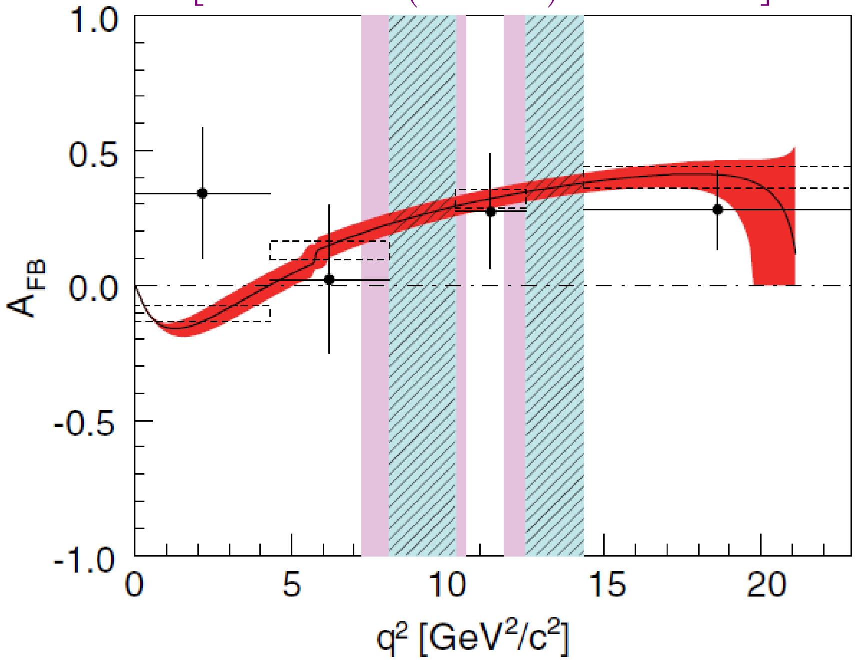
''Latest Belle measurement of branching ratio is based on less than 30% of the total luminosity'' Belle hep-ex/0503044

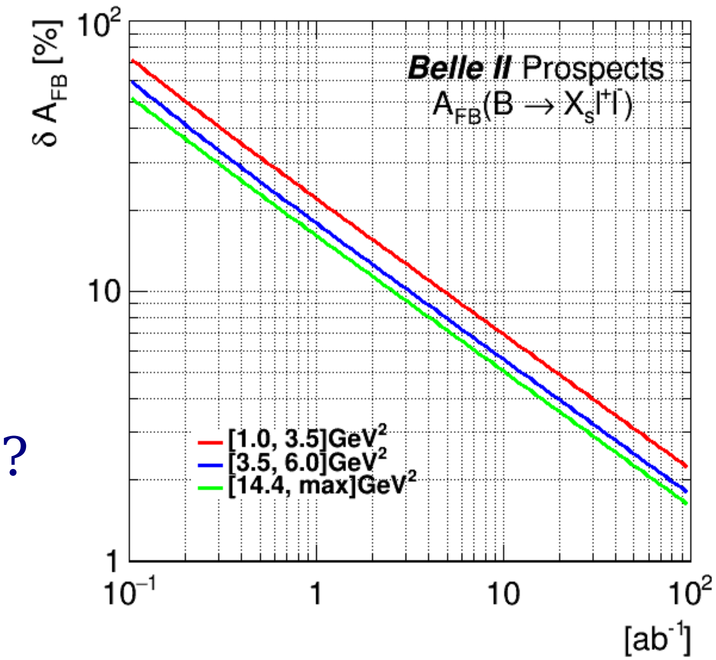
$\Rightarrow$ $B(Xs\mu\mu)_{\text{high } q^2}$, $B(Xs\mu\mu)_{\text{low } q^2}$, $B(Xsee)_{\text{high } q^2}$, $B(Xsee)_{\text{low } q^2}$



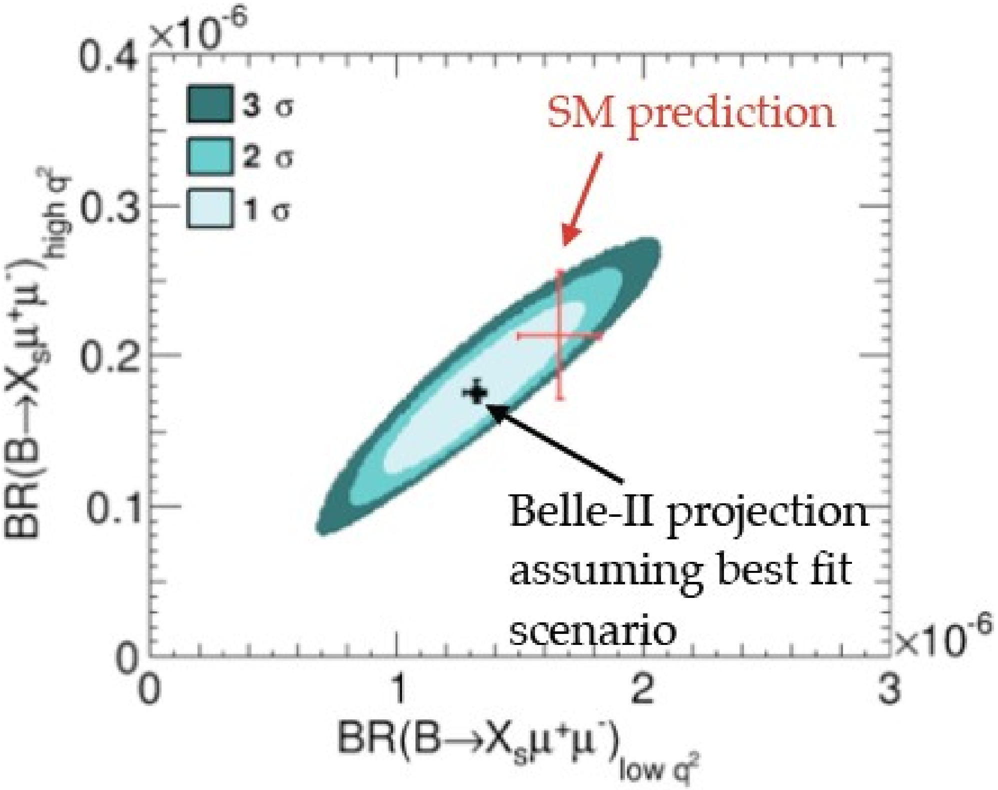
[See S.Sandilya's talk]

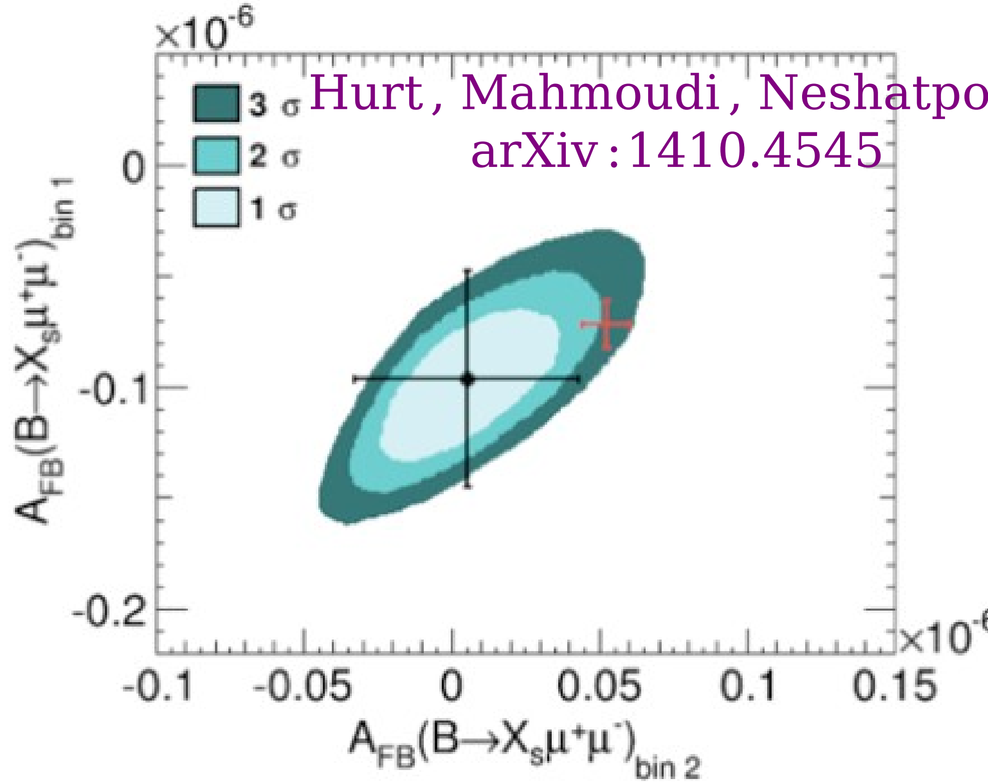
[Belle, sum-of-exclusive, full stat]
[PRD 93 (2016) 032008]





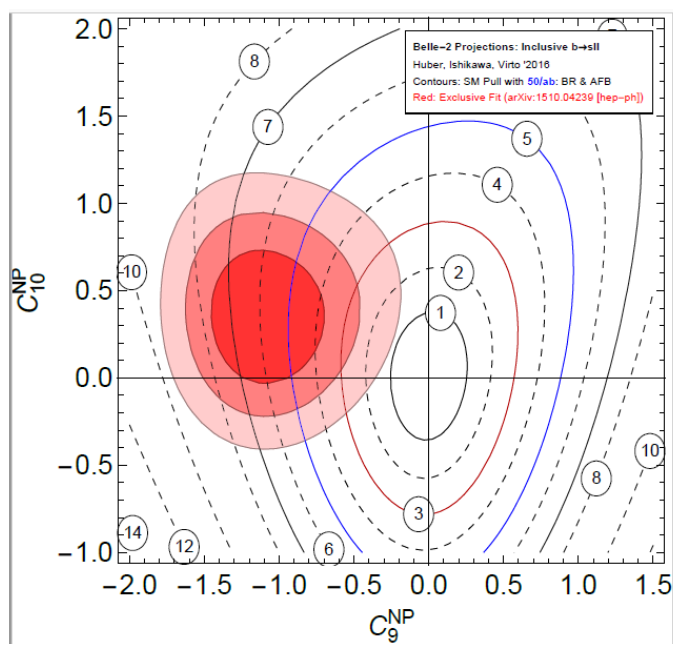
- $B(B\to X_s ll)$ w/full Belle data sample soon ?
- $B\to X_s ll$ at LHCb ?





Hurt, Mahmoudi, Neshatpour
arXiv:1410.4545

If NP then the effect of C_9 and C_9' are large enough to be checked at Belle II with theoretically clean modes



[see J.Virto's talk]

Global analysis of $b \to s\ell\ell$ anomalies (SDG, L. Hofer, J. Matias, J. Virto)

Global analysis needed

- deviations for same quark transition but different hadrons
- eff Hamiltonian adapted for a global model-independent analysis
- further tests of the computations by looking for inconsistencies

96 observables in total (LHCb for exclusive, no CP-violating obs)

- $B \to K^*\mu\mu$ ($P_{1,2}, P'_{4,5,6,8}, F_L$ in 5 large-recoil bins + 1 low-recoil bin)
- $B_s \to \phi\mu\mu$ ($P_1, P'_{4,6}, F_L$ in 3 large-recoil bins + 1 low-recoil bin)
- $B^+ \to K^+\mu\mu$, $B^0 \to K^0\mu\mu$ (BR)
- $B \to X_s\gamma$, $B \to X_s\mu\mu$, $B_s \to \mu\mu$
  (updated for the central values [Misiak et al., Huber et al., Bobeth et la.])
- $B \to K^*\gamma$ (A_I and $S_{K^*\gamma}$)

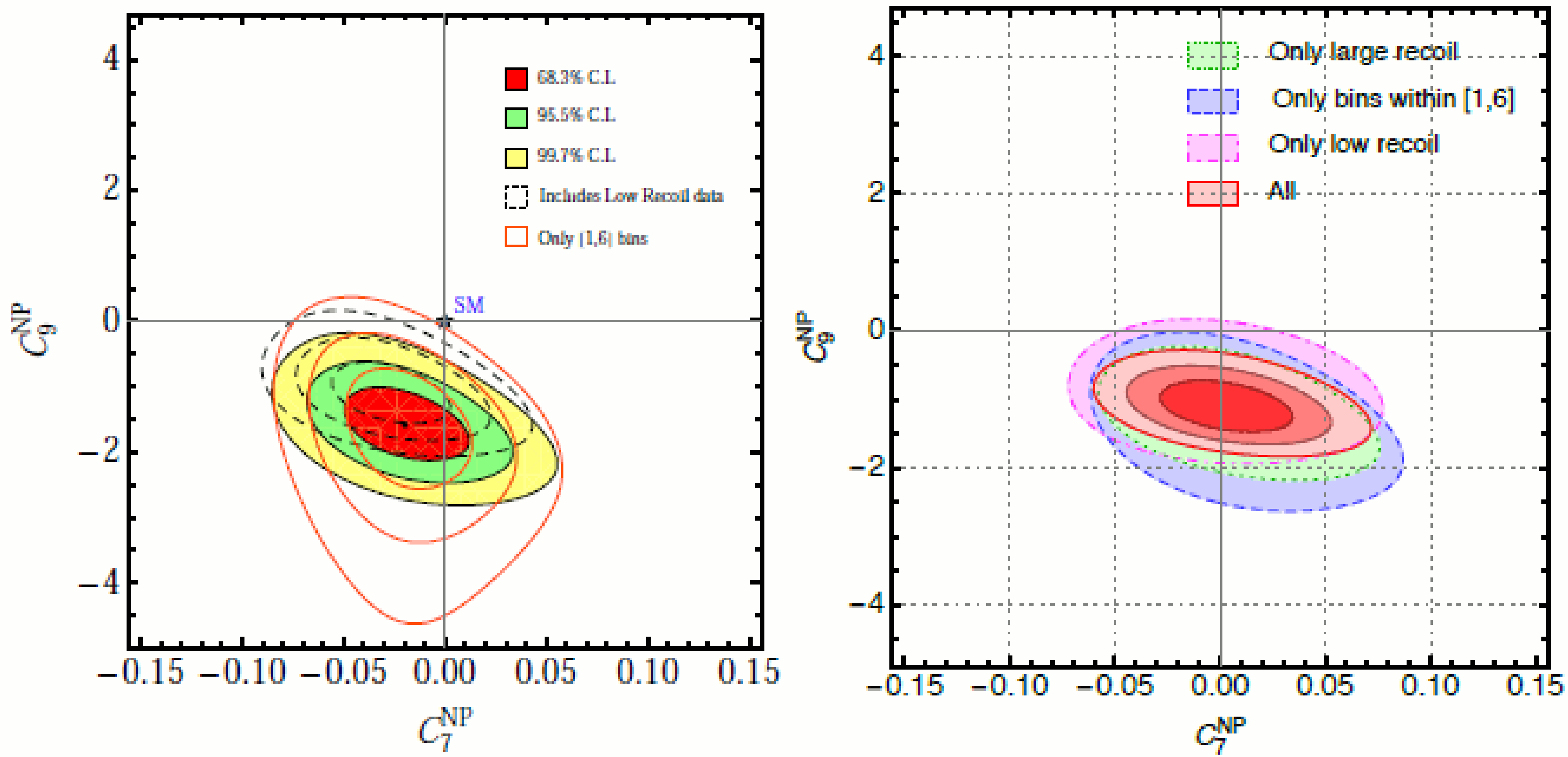
Version 2 of the analysis, essentially unchanged conclusions but

- including final results from LHCb on $B \to K^*\ell\ell$
- correcting the dictionnary between LHCb and our kinematics
  (change only for angular observables sensitive to NP phases)

[Grantrex, Hopfer, Zwicky; Becirevic, Sumensari, Zukanovic-Funchal]

Global analysis of b→sll anomalies

[S.Descotes-Genon, Q.Matias, J.Virto]

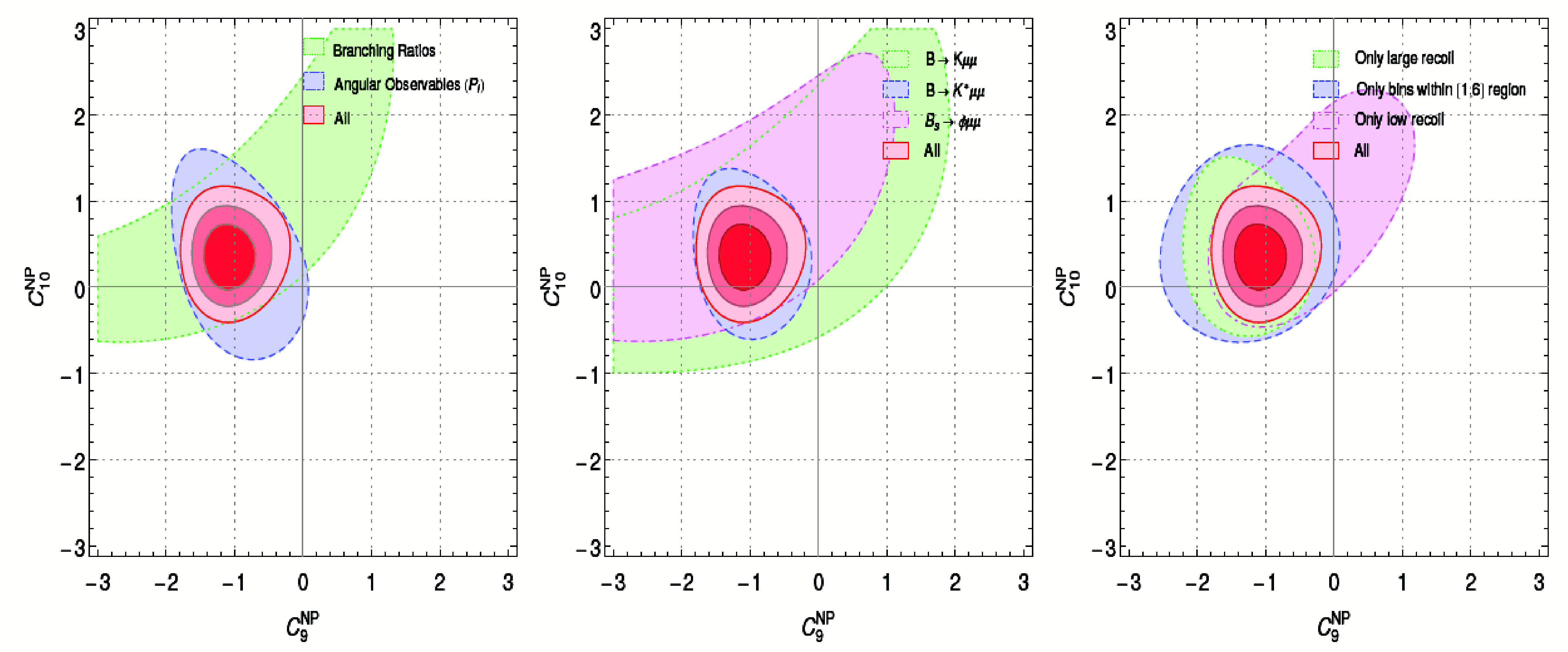


(2013) (2016)

In global fits of the WC to the data, scenarios with a large negative C_9^{NP} are preferred over the SM by typically more than 4σ

Consistency of different fits

[See J.Virto's talk]



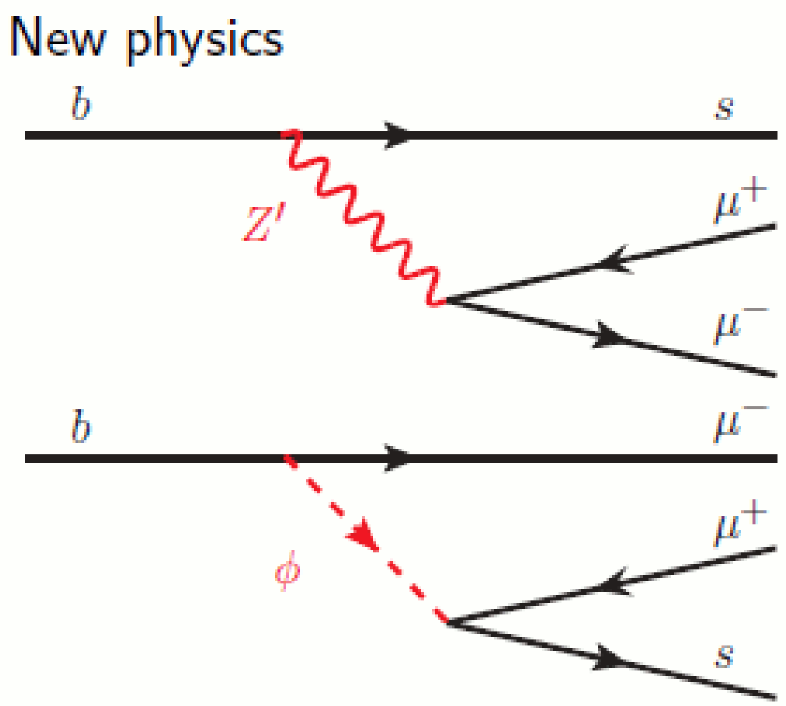
- Good consistency between BRs and Angular observables
- Good consistency between different modes
- Good consistency between different q^2 regions

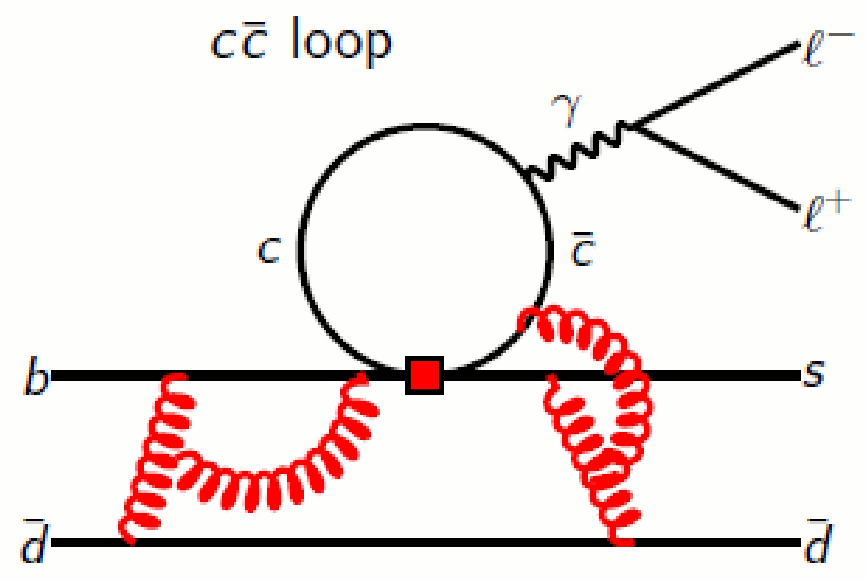
NP or hadronic effect ?

Possible explanations for shift in C_9:

a potential new physics contribution C_9^{NP} enters amplitudes always with
a charm-loop contribution $C_9^{c\bar{c}\,i}(q^2)$

⇒ **spoiling an unambiguous interpretation of the fit result in terms of NP**





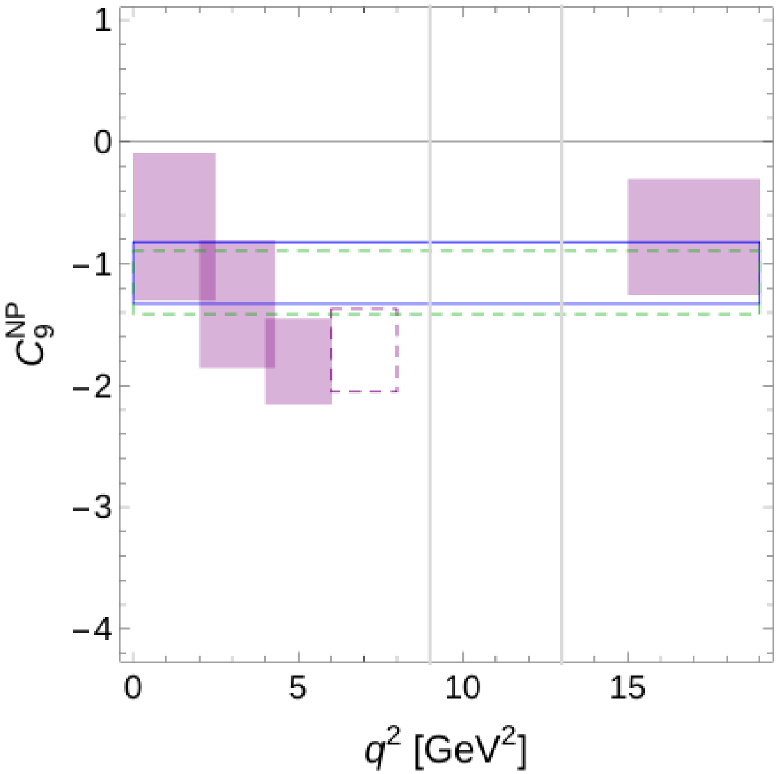
NP e.g. Z', leptoquarks

hadronic charm loop contributions

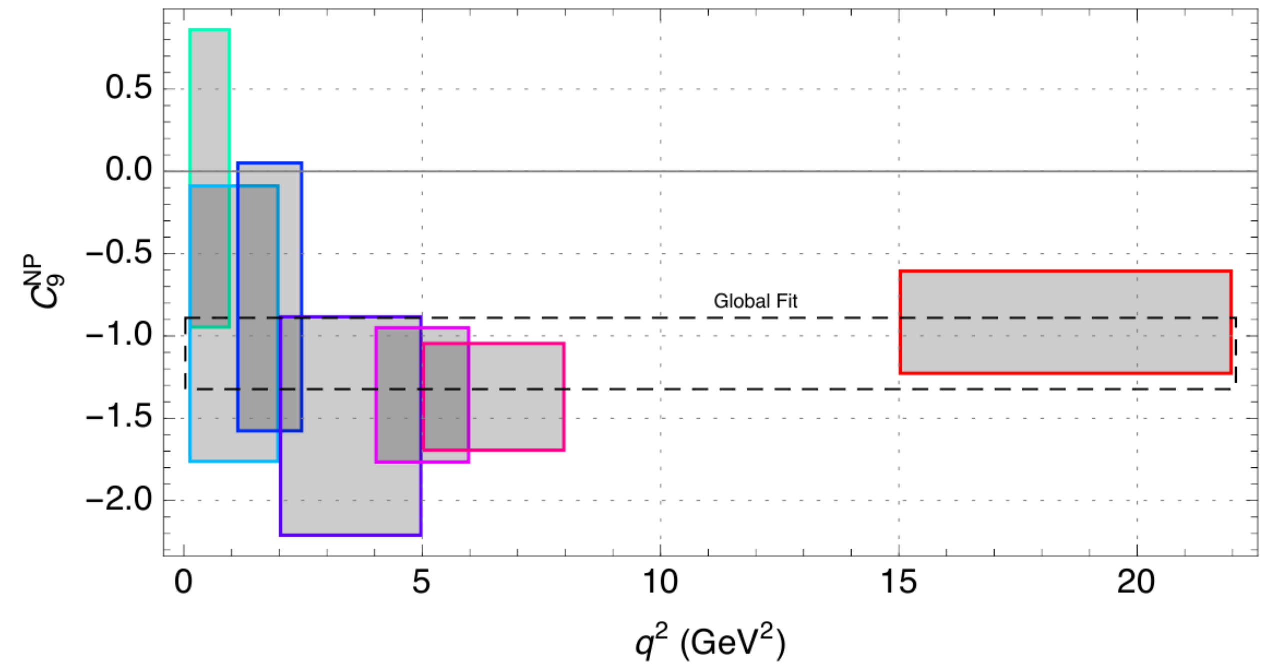
NP or hadronic effect ?

Bin-by-bin fit of the one-parameter scenario with a single coefficient $\mathbf{C_9^{NP}}$

[W.Altmannshofer et al, arXiv:1503.06199]



[S.Descotes-Genon et al, arXiv:1510.04239]



C_9^{NP} doesn't depend on q^2,

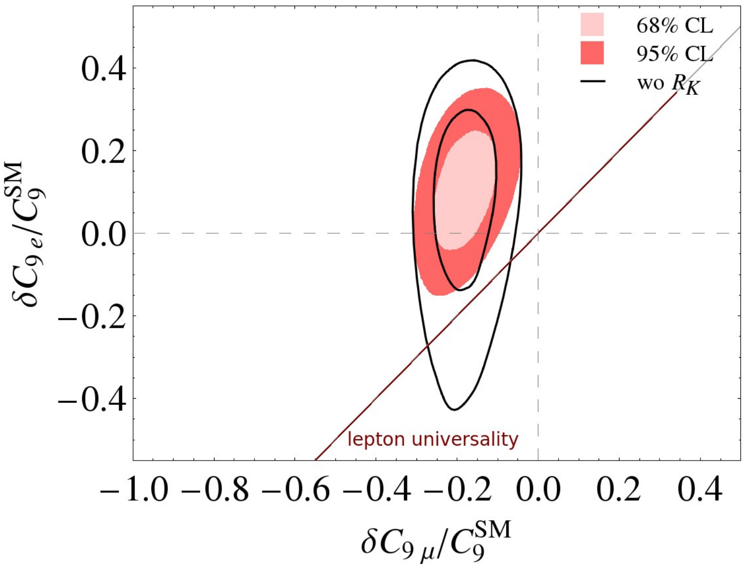
$C_9^{c\bar{c}\,i}(q^2)$ expected to exhibit a non-trivial q^2 dependence

⇒ definitely need more stat.

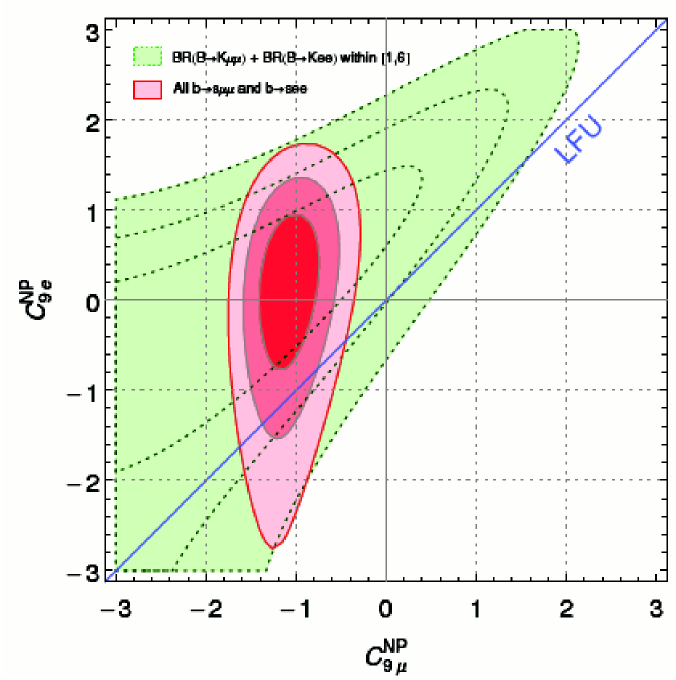
Lepton-flavour universality violation

QCD effect could not explain the tension in R_K !!

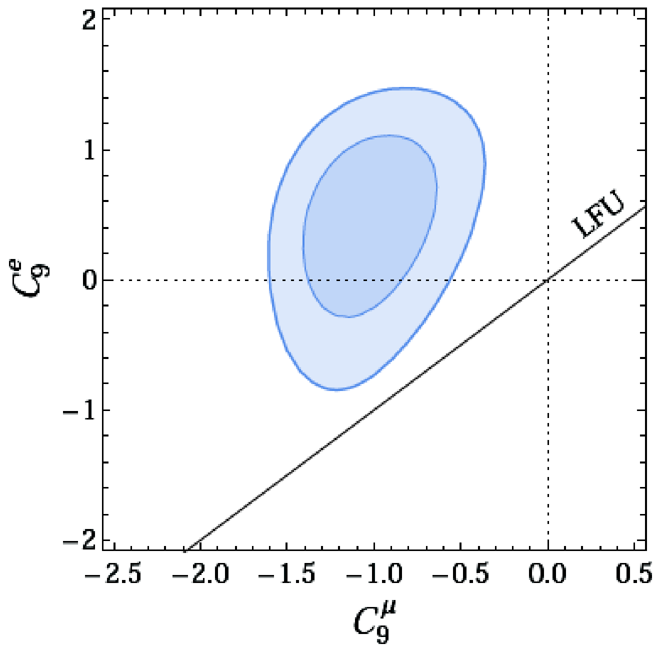
Hurt, Mahmoudi, Neshatpour
arXiv:1603.00865



S.Descotes-Genon et al,
arXiv:1510.04239



W.Altmannshofer et al,
arXiv:1411.3161



Fit prefers an electron-phobic scenario with NP coupling to $\mu^+\mu^-$

1. We find new particles at the LHC [See J.Camalich's talk]
   - Modelling their flavor structure should explain anomalies+new predictions!
2. We do not find new particles but we confirm LUV
   - Reading the shape with more sophisticated (angular) observables
     - Take LUV ratios between angular observables in $B \to K^* \ell\ell$
   - **Bottom-up model-building:** Path for discovery at LHC or beyond!
3. No new particles+No LUV
   - More data needed to confirm or rule out q^2-dependence of the effect
   - Tackling theoretical errors **systematically** will require a **theoretical** **breakthrough**
   - **New ideas:** e.g. $B_s^* \to \ell\ell$ (Grinstein&JMC, Phys.Rev.Lett. 116 (2016) no.14, 141801)

Only 2.6σ deviation for R_K... Need more information: R_{K^*}, R_φ...

Sensitive probes of LUV and allow to distinguish between different NP scenarios:

- ratio e/μ of $A_{FB}(B^0 \to K^* l^+ l^-)_{[4,\,6]\,\mathrm{GeV}^2}$ [W.Altmannshofer and D.Straub]
- $\langle A_{FB}(B^0 \to K^* \mu^+ \mu^-)\rangle / \langle A_{FB}(B^0 \to K^* e^+ e^-)\rangle$ at $q^2 \in [4, 6]\,\mathrm{GeV}^2$, $[15, 19]\,\mathrm{GeV}^2$ [F.Mahmoudi et al]
- $\langle Q_i \rangle = \langle P_i^\mu \rangle - \langle P_i^e \rangle$... [Q.Matias et al]

Conclusion

- New Physics may manifest itself in B physics in many ways
- Number of exciting tensions !!
- Expect much more data, improved analyses
- Look for new observables: CP-violation, time-dependence, involving τ, LFV observables...