CKM fitter

Overview 4 NPhys @ Belle II

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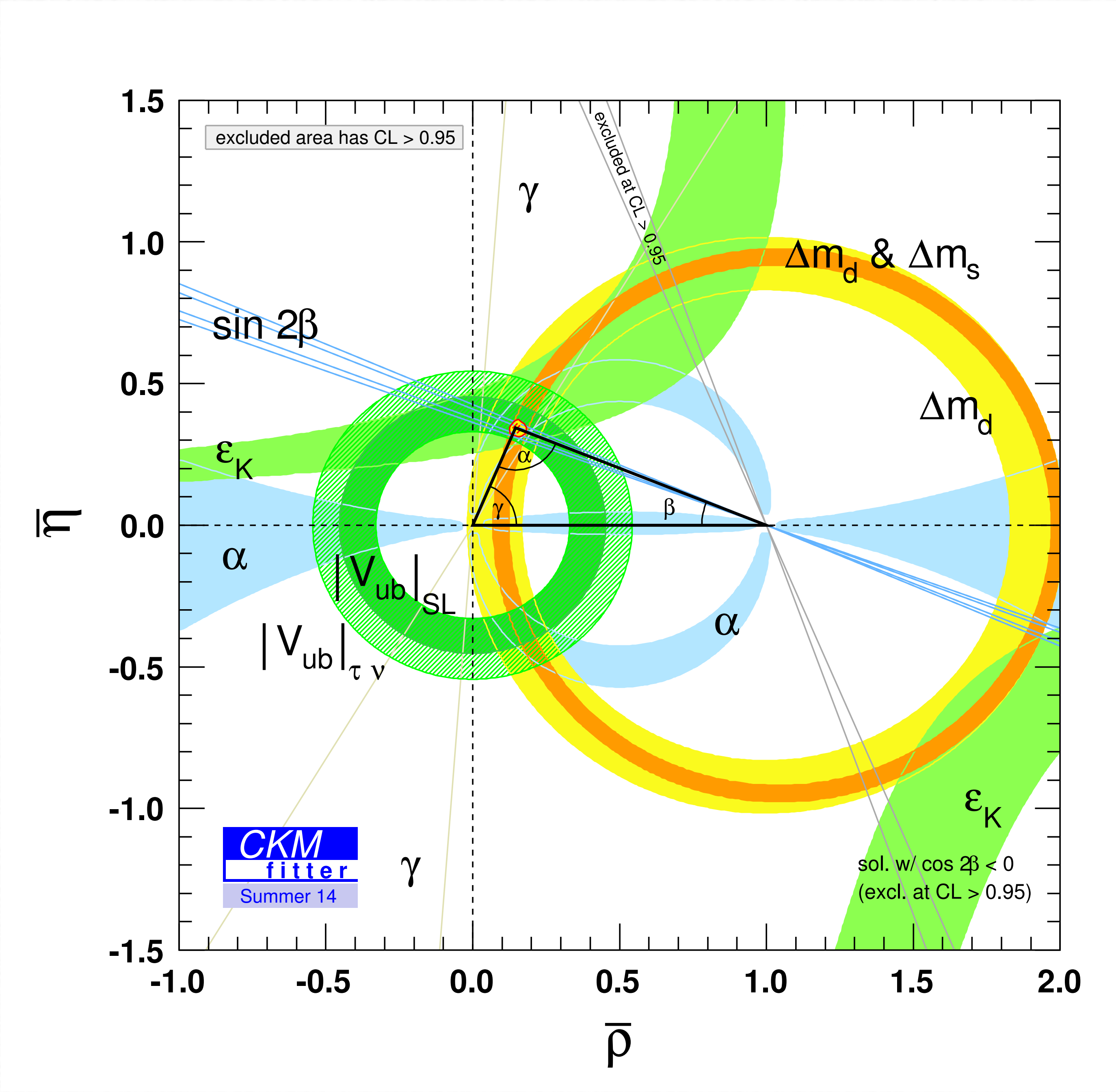
Plan

- Latest update results: SM-CKM
- Latest update results: New Physics example
- Structure of the code
- How to add NP

Latest global CKM fit

arXiv:1501.05013

- With new 2014 data and th. results, the global fit remains excellent
- Measurement of the dominant CKM paradigm definitely entered a high precision era

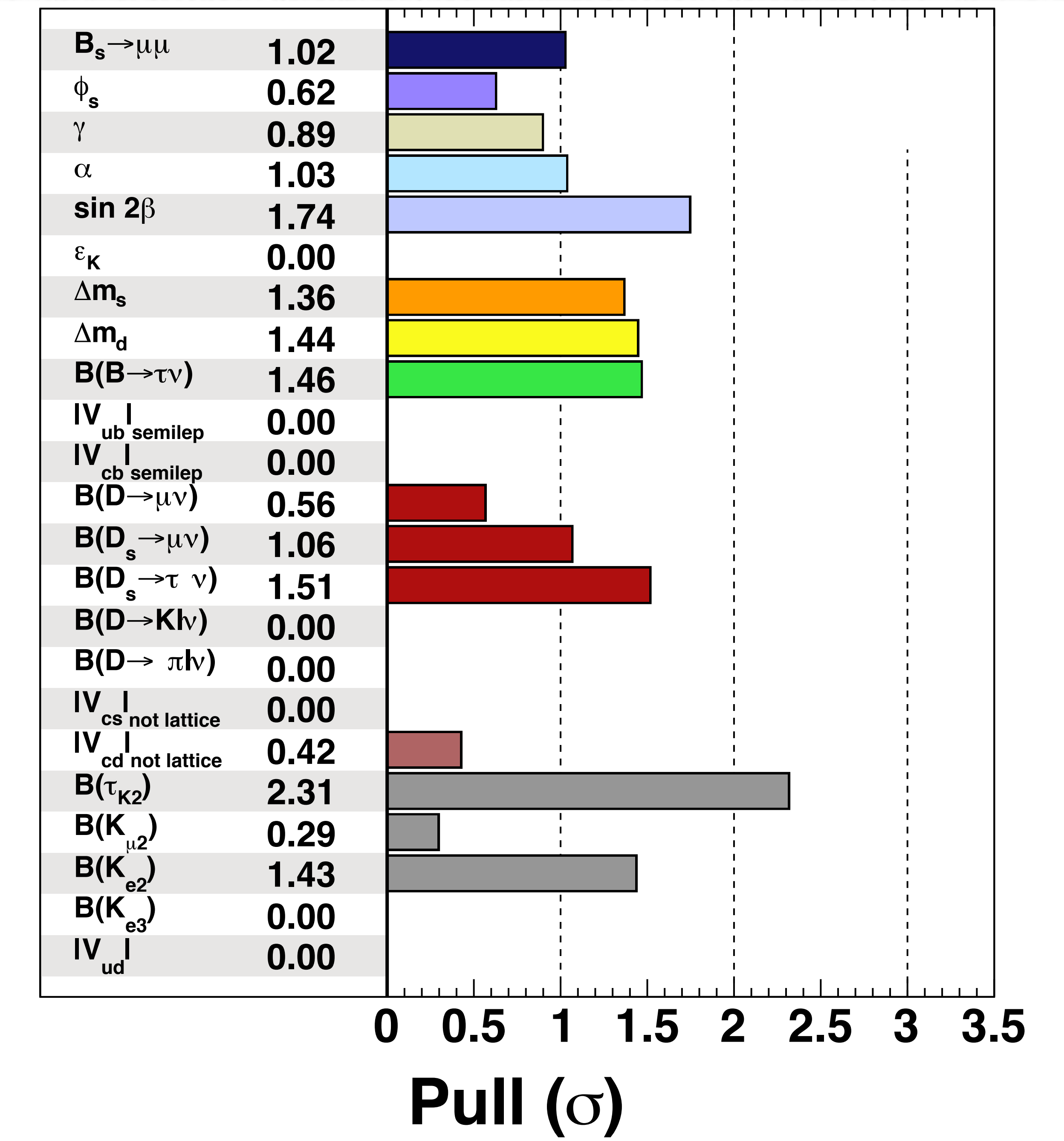


2014 observables and inputs

CKM	Process	Observables				Theoretical inputs
$\|V_{ud}\|$	$0^+ \to 0^+$ transitions	$\|V_{ud}\|_{\rm nucl}$	=	$0.97425 \pm 0 \pm 0.00022$	[6]	Nuclear matrix elements
$\|V_{us}\|$	$K \to \pi\ell\nu$	$\|V_{us}\|_{\rm SL} f_+^{K\to\pi}(0)$	=	0.21664 ± 0.00048	[7]	$f_+^{K\to\pi}(0) = 0.9641 \pm 0.0015 \pm 0.045$
	$K \to e\nu_e$	$\mathcal{B}(K \to e\nu_e)$	=	$(1.581 \pm 0.008) \cdot 10^{-5}$	[7]	$f_K = 155.2 \pm 0.2 \pm 0.6$ MeV
	$K \to \mu\nu_\mu$	$\mathcal{B}(K \to \mu\nu_\mu)$	=	0.6355 ± 0.0011	[7]	
	$\tau \to K\nu_\tau$	$\mathcal{B}(\tau \to K\nu_\tau)$	=	$(0.6955 \pm 0.0096) \cdot 10^{-2}$	[7]	
$\frac{\|V_{us}\|}{\|V_{ud}\|}$	$K \to \mu\nu / \pi \to \mu\nu$	$\frac{\mathcal{B}(K \to \mu\nu_\mu)}{\mathcal{B}(\pi \to \mu\nu_\mu)}$	=	1.3365 ± 0.0032	[7]	$f_K/f_\pi = 1.1942 \pm 0.0009 \pm 0.0030$
	$\tau \to K\nu / \tau \to \pi\nu$	$\frac{\mathcal{B}(\tau \to K\nu_\tau)}{\mathcal{B}(\tau \to \pi\nu_\tau)}$	=	$(6.43 \pm 0.09) \cdot 10^{-2}$	[7]	
$\|V_{cd}\|$	νN	$\|V_{cd}\|_{\nu N}$	=	0.230 ± 0.011	[7]	
	$D \to \mu\nu$	$\mathcal{B}(D \to \mu\nu)$	=	$(3.74 \pm 0.17) \cdot 10^{-4}$	[9]	$f_{D_s}/f_D = 1.201 \pm 0.004 \pm 0.010$
	$D \to \pi\ell\nu$	$\|V_{cd}\| f_+^{D\to\pi}(0)$	=	0.148 ± 0.004	[8]	$f_+^{D\to\pi}(0) = 0.666 \pm 0.020 \pm 0.048$
$\|V_{cs}\|$	$W \to c\bar{s}$	$\|V_{cs}\|_{W\to c\bar{s}}$	=	$0.94^{+0.32}_{-0.26} \pm 0.13$	[7]	
	$D_s \to \tau\nu$	$\mathcal{B}(D_s \to \tau\nu)$	=	$(5.55 \pm 0.24) \cdot 10^{-2}$	[9]	$f_{D_s} = 245.3 \pm 0.5 \pm 4.5$ MeV
	$D_s \to \mu\nu$	$\mathcal{B}(D_s \to \mu\nu_\mu)$	=	$(5.57 \pm 0.24) \cdot 10^{-3}$	[9]	
	$D \to K\ell\nu$	$\|V_{cs}\| f_+^{D\to K}(0)$	=	0.712 ± 0.007	[8, 10]	$f_+^{D\to K}(0) = 0.747 \pm 0.011 \pm 0.034$
$\|V_{ub}\|$	semileptonic decays	$\|V_{ub}\|_{\rm SL}$	=	$(3.70 \pm 0.12 \pm 0.26) \cdot 10^{-3}$	[9]	form factors, shape functions
	$B \to \tau\nu$	$\mathcal{B}(B \to \tau\nu)$	=	$(1.08 \pm 0.21) \cdot 10^{-4}$	[9, 11]	$f_{B_s}/f_B = 1.205 \pm 0.004 \pm 0.007$
$\|V_{cb}\|$	semileptonic decays	$\|V_{cb}\|_{\rm SL}$	=	$(41.00 \pm 0.33 \pm 0.74) \cdot 10^{-3}$	[9]	form factors, OPE matrix elements
α	$B \to \pi\pi,\ \rho\pi,\ \rho\rho$	branching ratios, CP asymmetries			[9]	isospin symmetry
β	$B \to (c\bar{c})K$	$\sin(2\beta)_{[c\bar{c}]}$	=	0.682 ± 0.019	[9]	
γ	$B \to D^{(*)}K^{(*)}$	inputs for the 3 methods			[9]	GGSZ, GLW, ADS methods
ϕ_s	$B_s \to J/\psi(KK, \pi\pi)$	ϕ_s	=	-0.015 ± 0.035	[9]	
$V_{tq}^* V_{tq'}$	Δm_d	Δm_d	=	0.510 ± 0.003 ps^{-1}	[9]	$\hat{B}_{B_s}/\hat{B}_{B_d} = 1.023 \pm 0.013 \pm 0.014$
	Δm_s	Δm_s	=	17.757 ± 0.021 ps^{-1}	[9]	$\hat{B}_{B_s} = 1.320 \pm 0.017 \pm 0.030$
	$B_s \to \mu\mu$	$\mathcal{B}(B_s \to \mu\mu)$	=	$(2.8^{+0.7}_{-0.6}) \cdot 10^{-9}$	[12]	$f_{B_s} = 225.6 \pm 1.1 \pm 5.4$ MeV
$V_{td}^* V_{ts}$	ϵ_K	$\|\epsilon_K\|$	=	$(2.228 \pm 0.011) \cdot 10^{-3}$	[7]	$\hat{B}_K = 0.7615 \pm 0.0027 \pm 0.0137$
$V_{cd}^* V_{cs}$						$\kappa_\epsilon = 0.940 \pm 0.013 \pm 0.023$

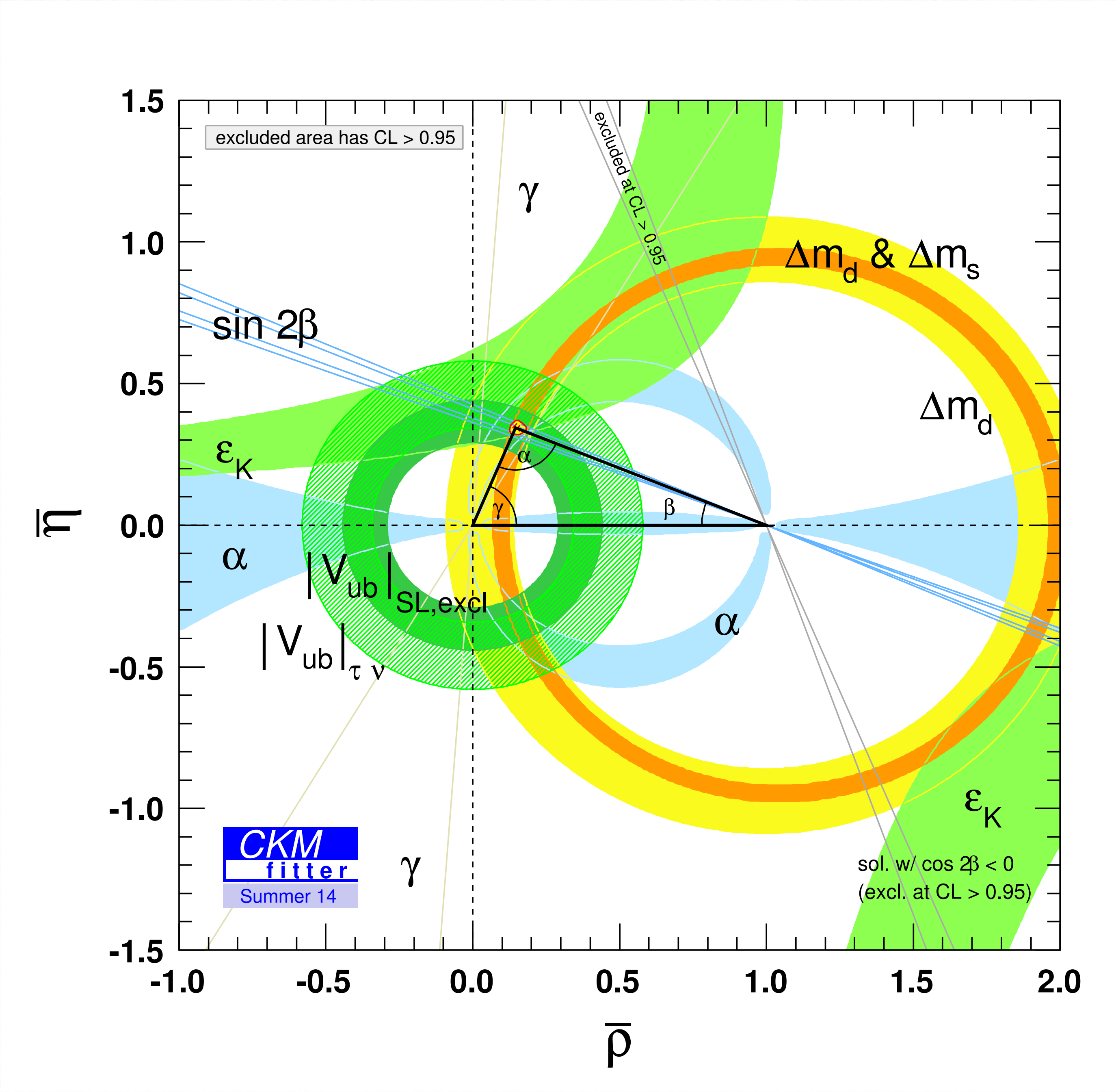
1-Dimensional Pulls

- Comparing χ^2_{min} without and with a given quantity gives a measure the « tension » it brings in the fit
- Nothing really sticks out
- Beware correlations…



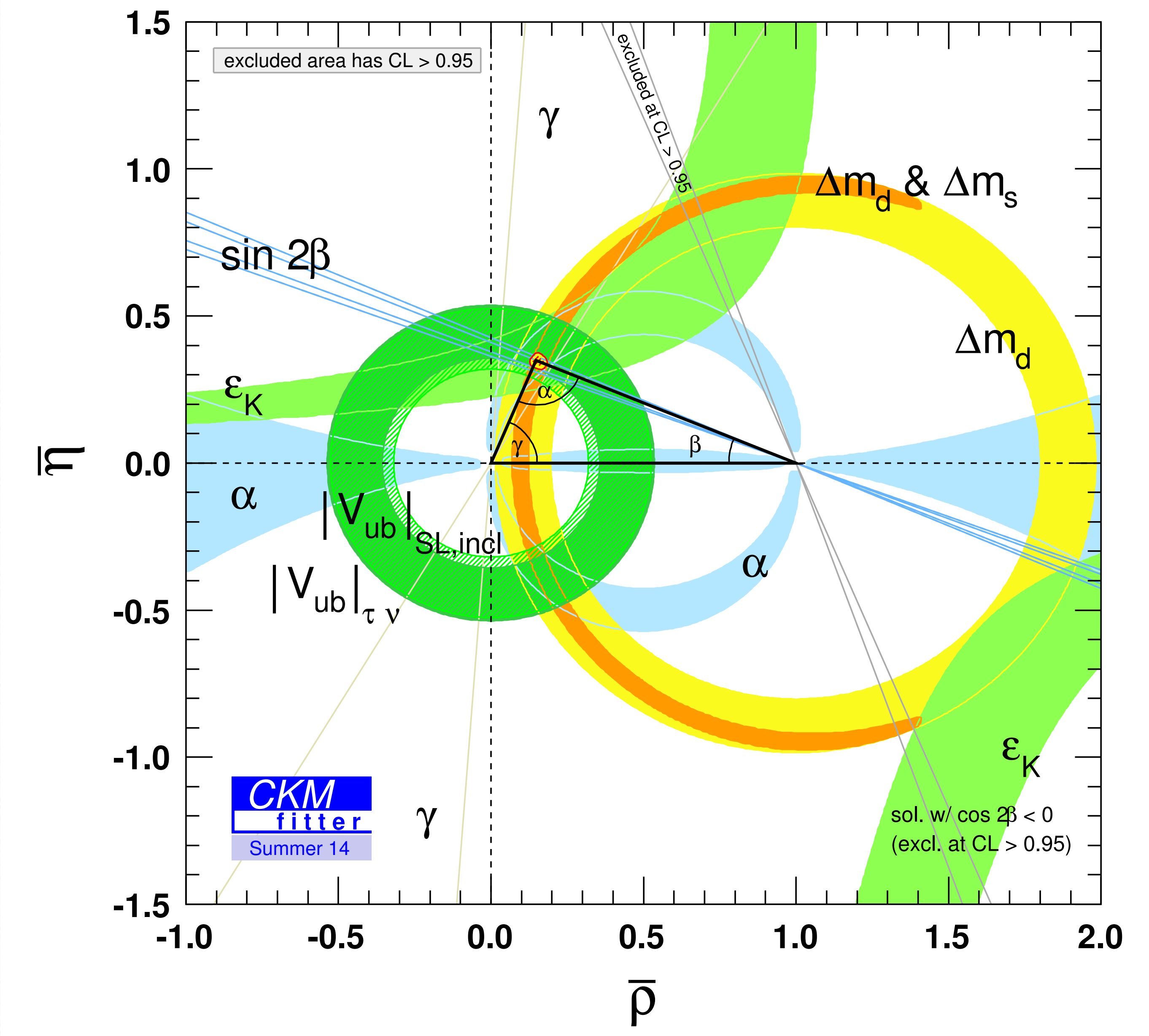
Latest global fit (V_{ub} excl.)

- Previous fit uses a particular average of exclusive and inclusive decays
- Using only exclusive semi-leptonic B decays to fix V_{ub} (and V_{ub}) changes the ε_K contour,
- But not the best fit point



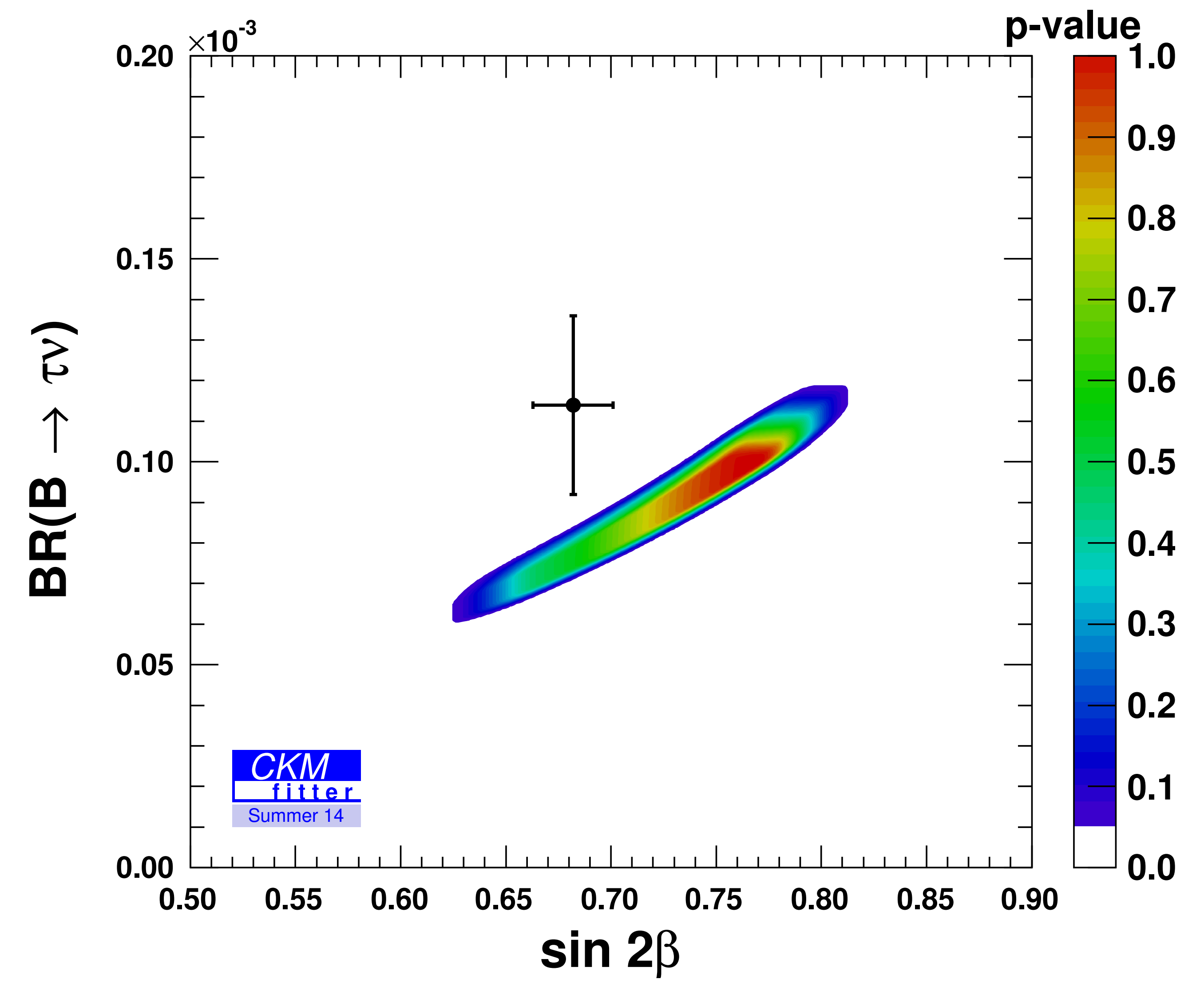
Latest global fit (V_{ub} incl.)

- Same when moving to inclusive SL decays, more in agreement with $B \to \tau\nu$
- Notice the Δm_s ring stops closing



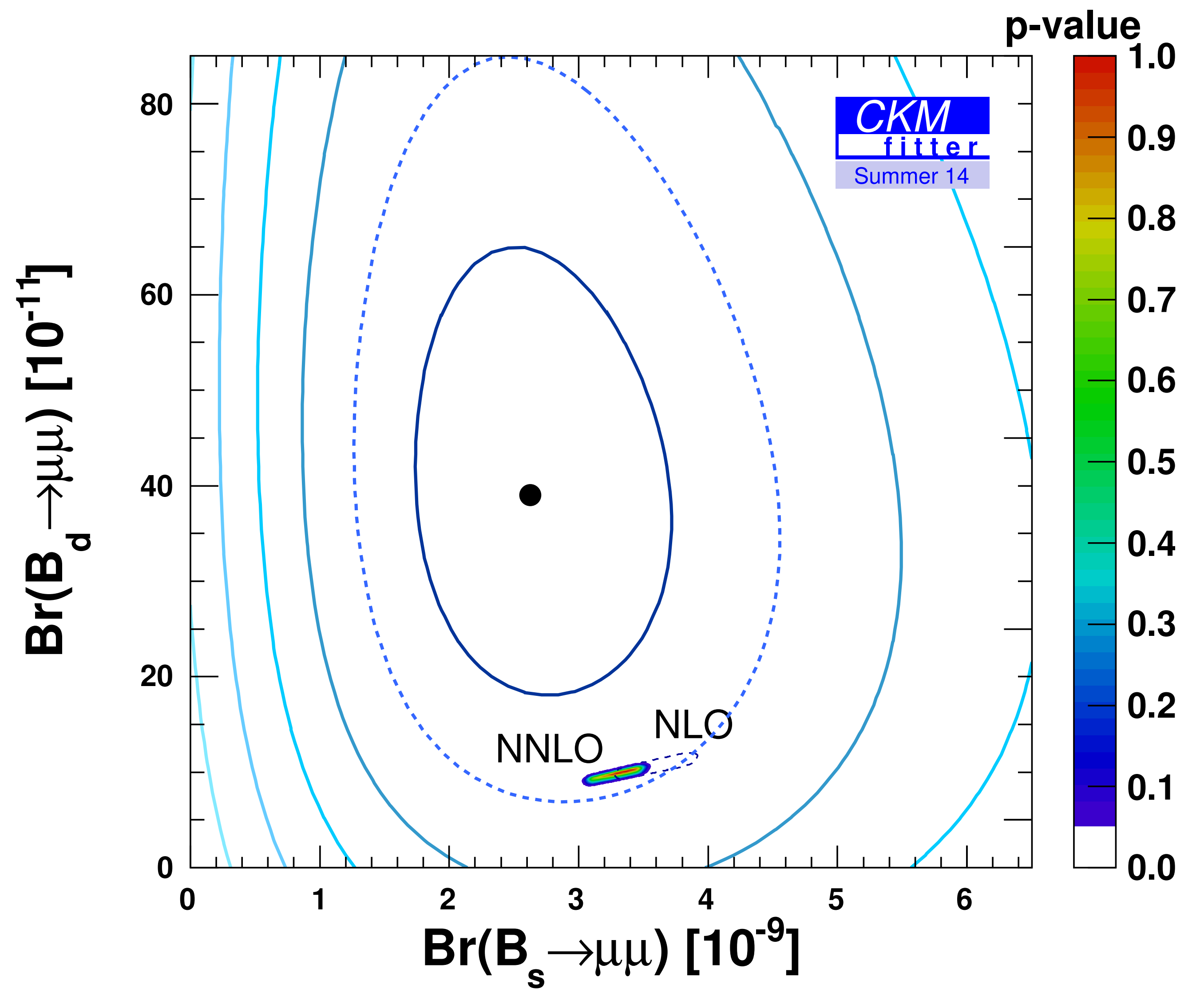
Correlations: Br(B→τν)

- There are ~1.5σ pulls in sin2β and Br(B→τν)
- These are in fact very much correlated: the fit determines very precisely a combination of both (much better than the good exp. precision on β)
- **Lesson**: global fit of both is essential to reveal a possible discrepancy



Correlations: Br($B_x \to \mu\mu$)

- Same is true for $B_x \to \mu\mu$
- Experimental progresses (Belle II) will be welcome!



New Physics Example: ΔF=2

- Assume generic and independent contributions to Bs and B_d mixing (as well as K^0: left alone)

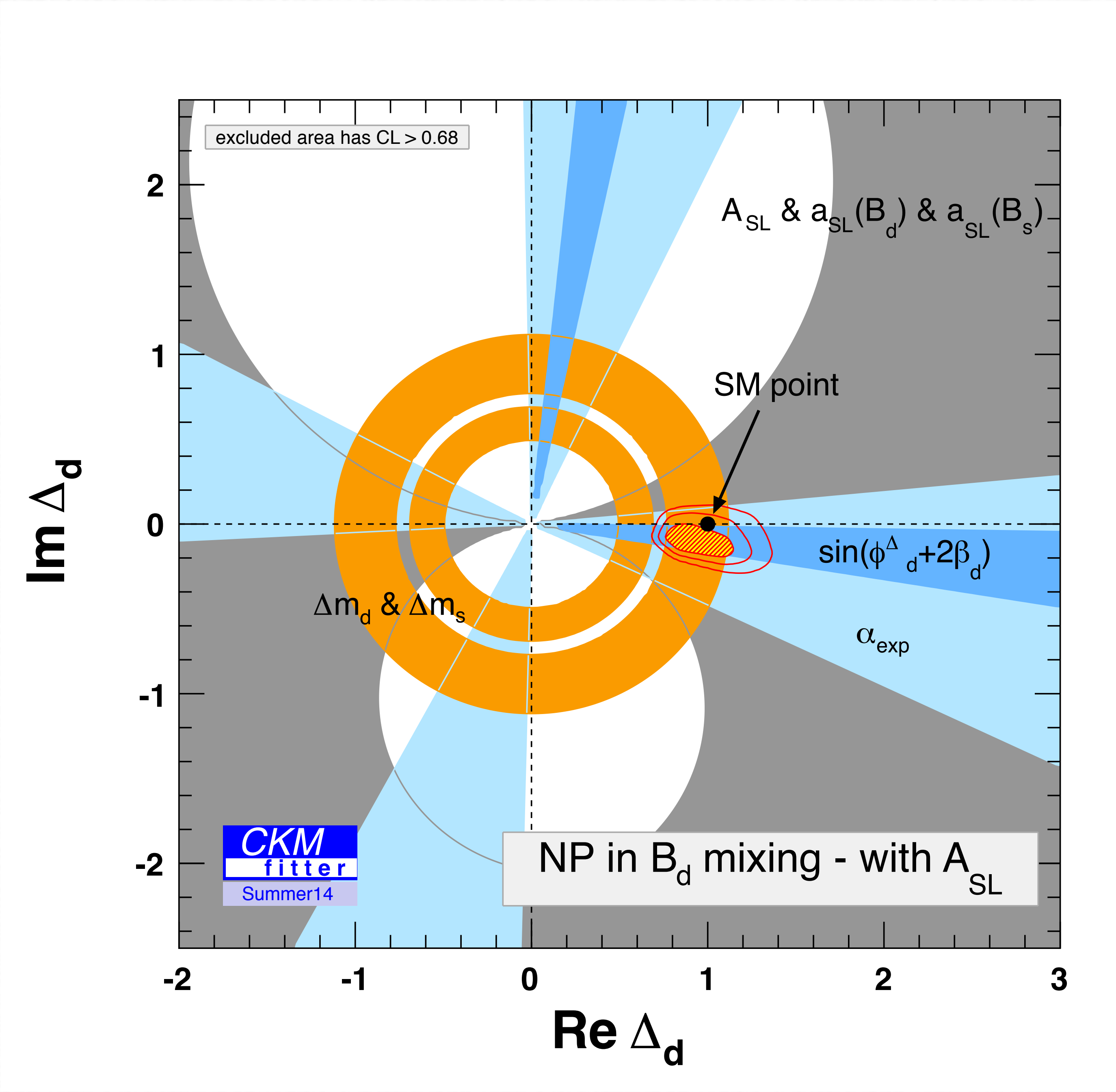
$$M_{12}^q = (M_{12}^q)_{SM} \times \Delta^q$$
$$\Delta^q = |\Delta^q| e^{i\phi_q^\Delta} = (1 + h_q e^{2i\sigma_q})$$

- Observables are

  - $\Delta m_q \leftrightarrow |\Delta^q|$
  - $a_{SL}^q \leftrightarrow \Delta^q$
  - $\Delta\Gamma_q \leftrightarrow \phi_q^\Delta$

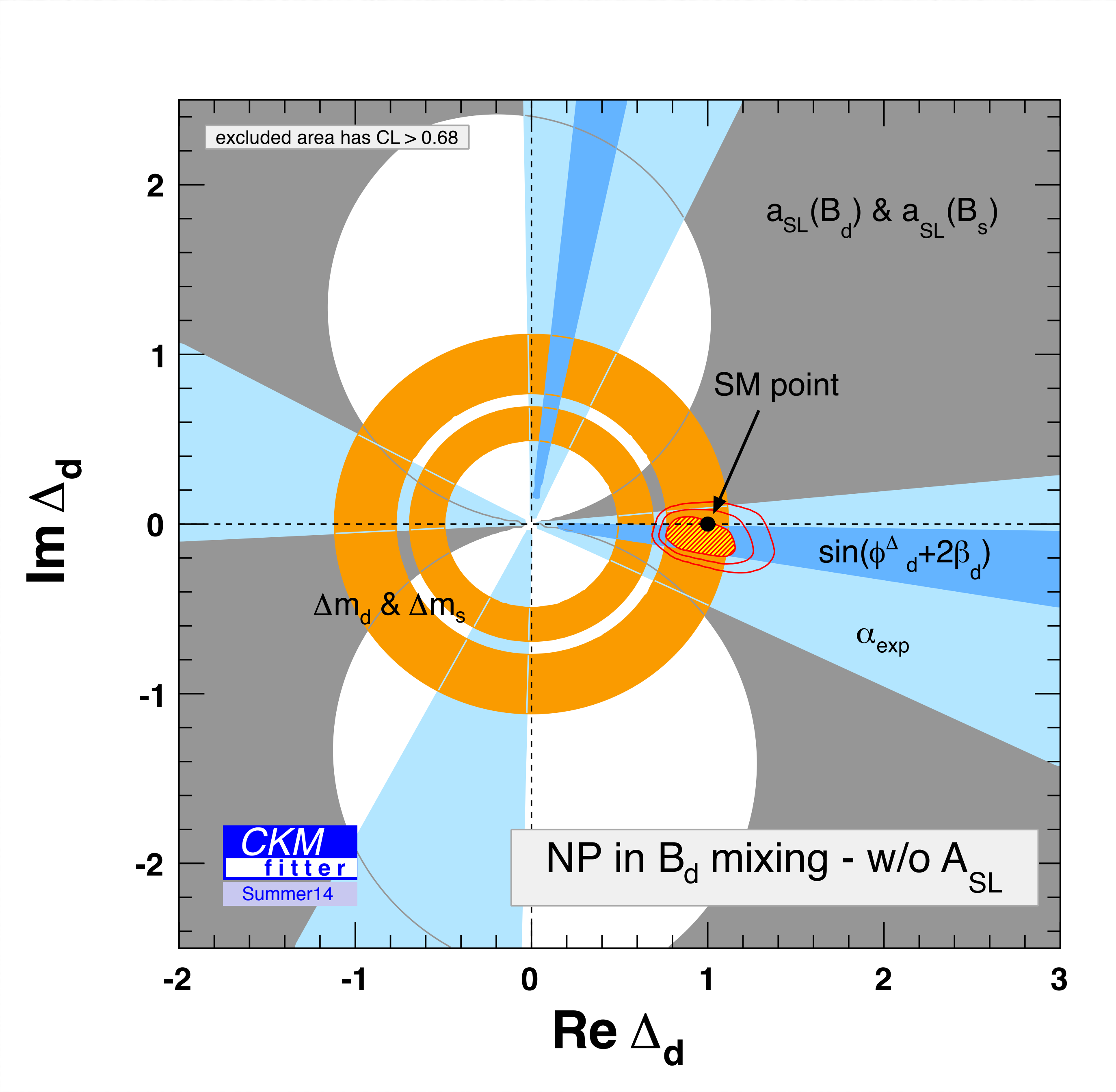
NP in B_d mixing

- Global NP fit view in B_d parameter space
- SM ($\Delta=0$) is not excluded, and nearly as good as best fit
- NP contributions up to 40% are not excluded either!



NP in B_d mixing (w/o A_{SL})

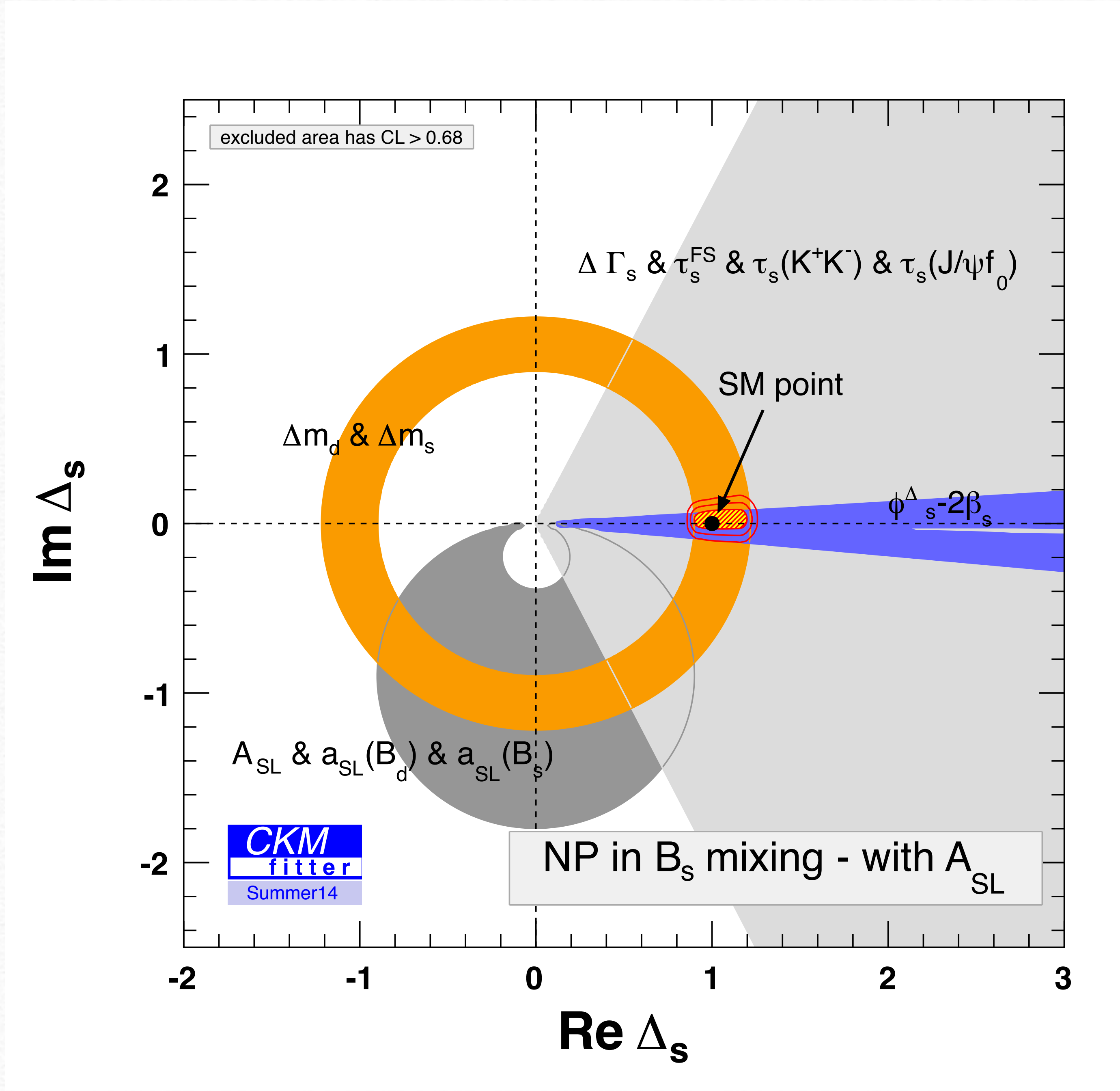
- A_{SL} (combination of a^d_{SL} and a^s_{SL}) measurement at Tevatron is in tension with others
- Discarding it doesn't change the conclusions



J. Orloff, NP@BII Karlsruhe, Feb.25 2015

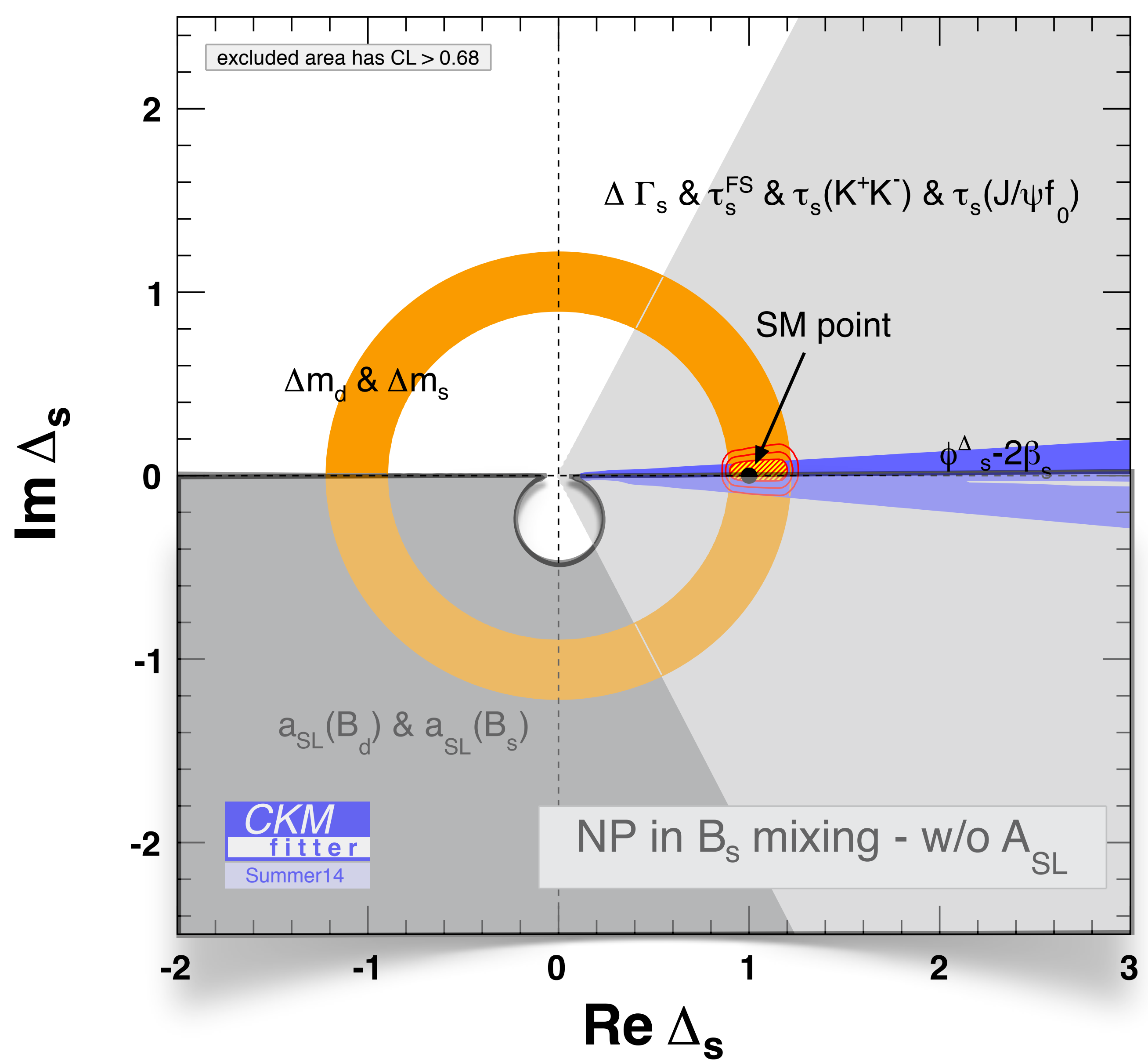
NP in B_s mixing

- Global NP fit view in B_s parameter space
- SM (Δ=0) is not excluded either, although outside of the A_{SL} contour
- NP contributions up to 30% are also allowed

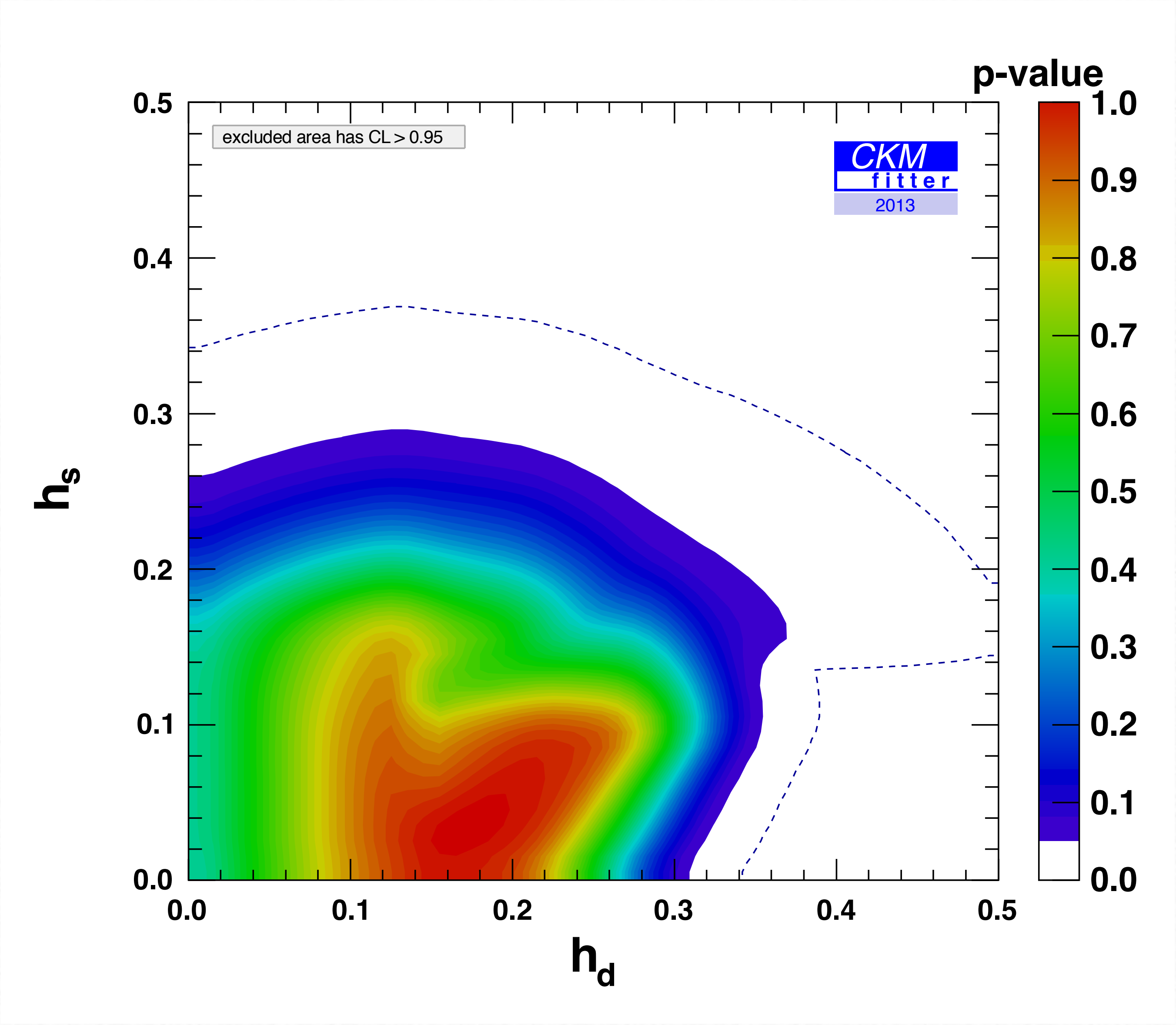


NP in B_s mixing (w/o A_{SL})

- Dropping A_{SL} releases the tension

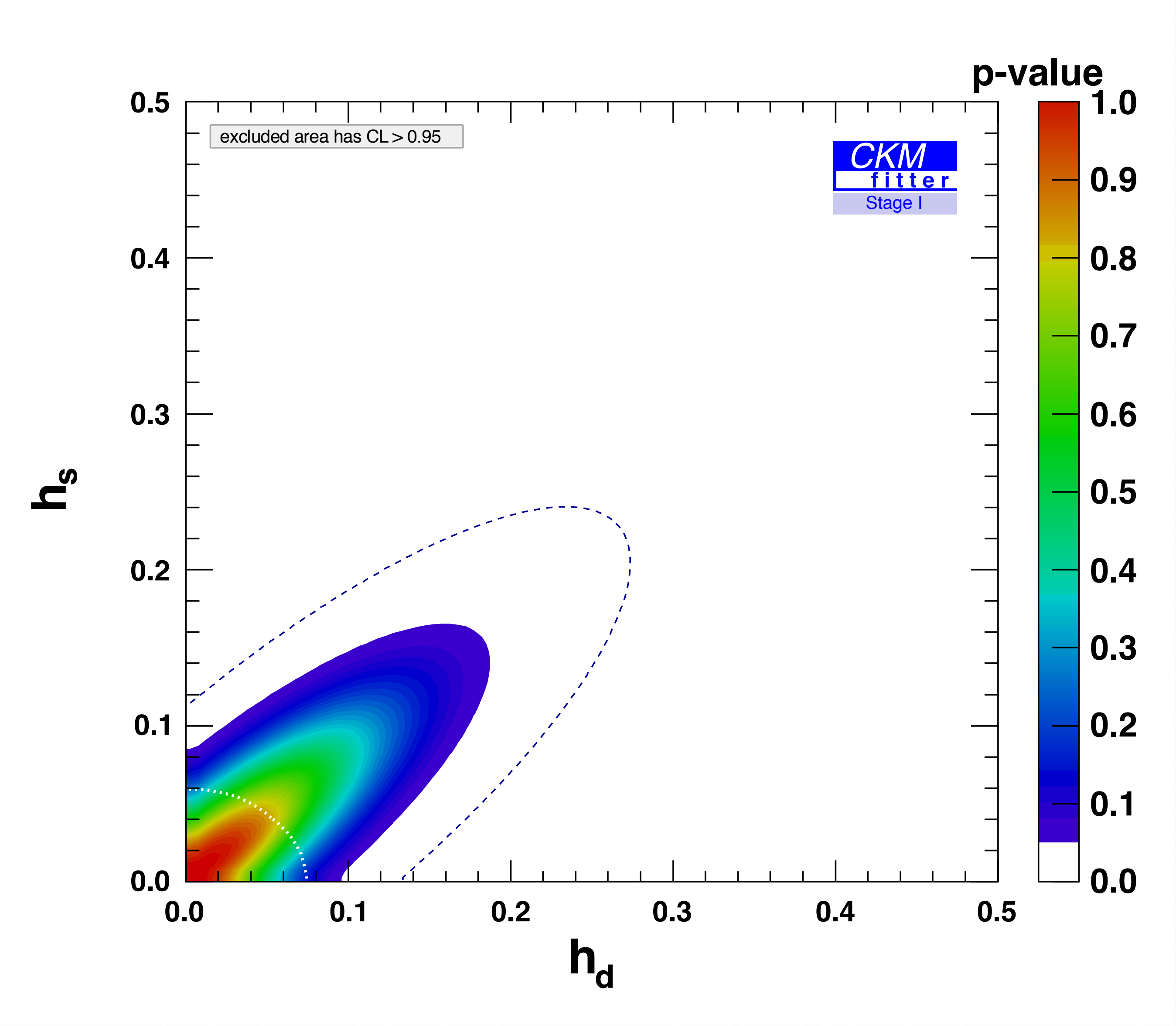


NP in B_x mixing : current



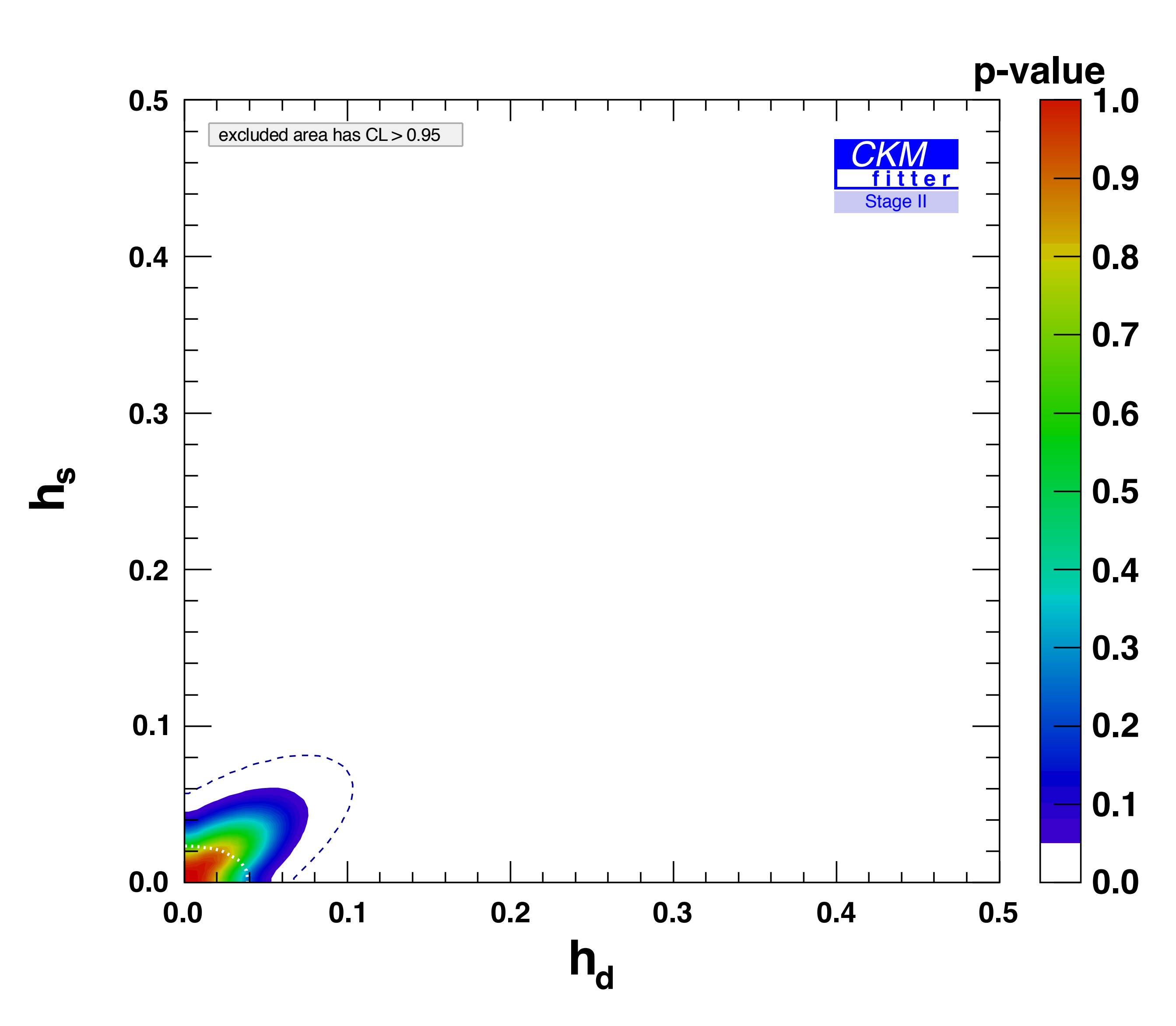
Deviations up to 30-40% (at 2 σ) are currently possible

NP in B_X mixing : future 1



Stage 1 projection: LHCb 7fb^{-1} + Belle II 7ab^{-1} (~2018?)
Excluding 20% deviations

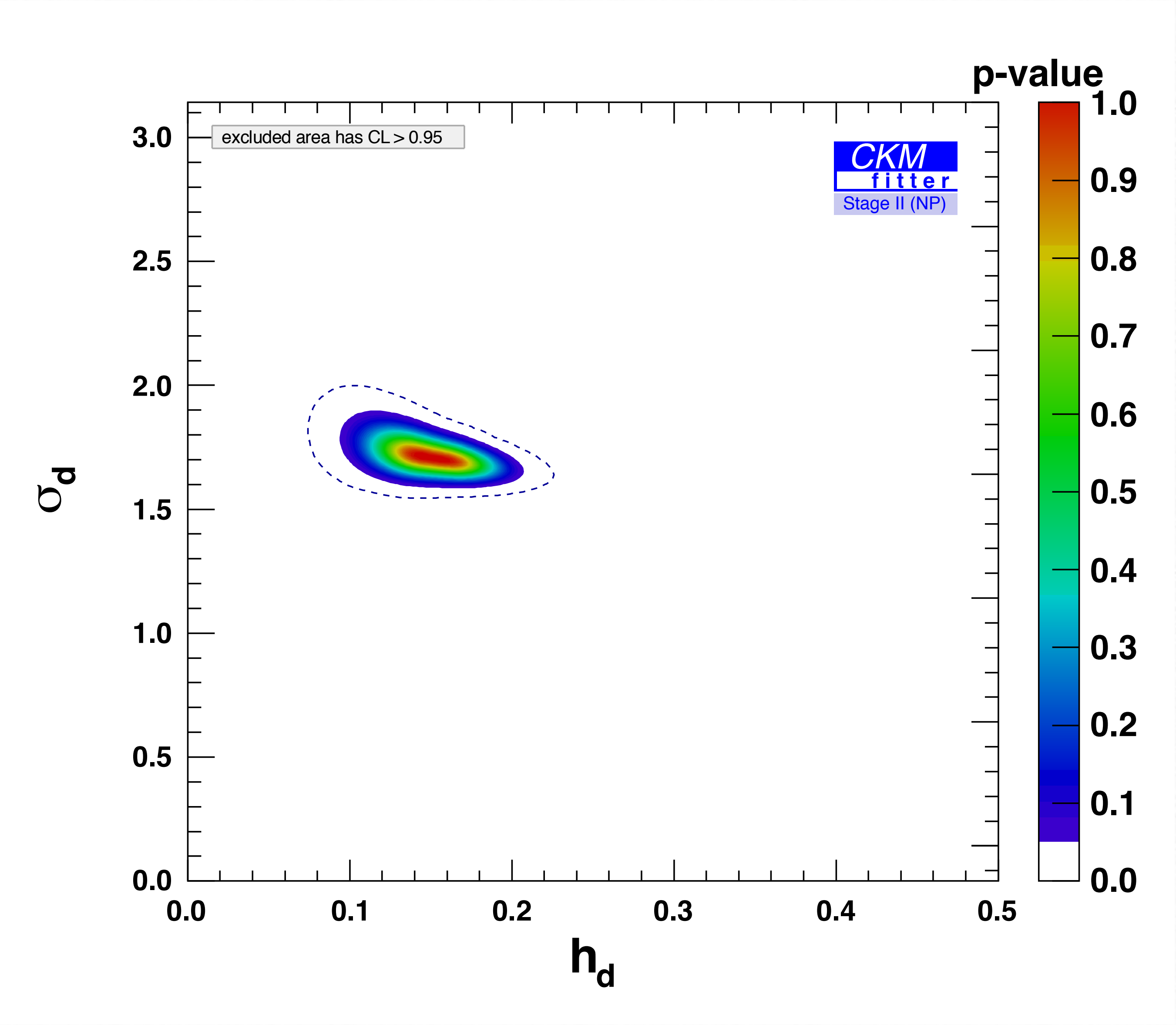
NP in B_X mixing : future 2



Stage 2 projection: LHCb 50 fb^{-1} + Belle II 50ab^{-1} (~2023?)

Excluding 8% deviations

NP in B_X mixing : future 2



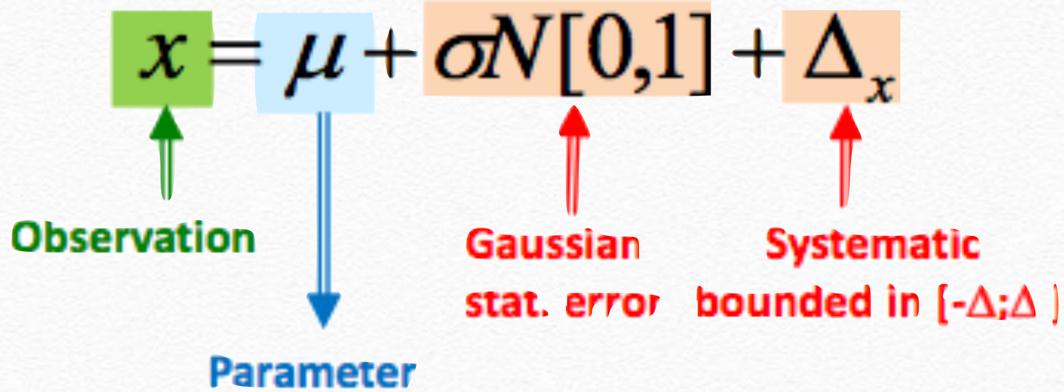
Stage 2 projection: LHCb 50 fb^{-1} + Belle II 50ab^{-1} (~2023?)

Measuring a 15% deviation to SM

Uncertainties

- CKMfitter code is designed to allow for a frequentist approach where theoretical parameters have initially NO probability distribution
- Restrictions only come from experimental input (with statistical distributions)
- **RFit :** Theoretical uncertainties are treated as nuisance parameters bounded (but undistributed) in a range

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



Structure of the code

- **Core libraries:** *(~5000 Mathematica lines)*
  - Perform minimisation, and scans of p-values
  - Taking symbolic partial derivatives $\partial O_i / \partial p_j$ is a major speedup (x100?)
  - Automatically generate and compile fortran code for speed
- « **Theories** » **packages:** *(~15000 Mathematica lines)*
  - each define analytically a set of observables O_i as functions of input parameters: $O_i(p_j)$; e.g. $Br(B_s \to \mu\mu)$ is in « DiLeptonicDecays.m »
  - Can coexist in different versions (eg. NLO or NNLO), and with different inputs (e.g. SM, NP, MFV for BBbarKKbarmixing.m)
- **Analysis Datacards:** define
  - free fit parameters (with initial search range)
  - experimental results (incl. statistical and systematic uncertainties)
  - theoretical uncertainties

How to add a NP model?

- Provide a Mathematica theory package
(or alternative version) defining affected observables
- Code is not public, but the group is flexible
(not every member signs every paper)
and open to project-oriented partnerships
(e.g. NP in mixing)
- Models benefitting most of the refined statistical analysis are over-constrained, with correlations between observables:
    - 2HDM type II
    - limited Wilson coefficients sets (C_7, C_9, C_{10}, …)
    - CMFV

CKMfitter group & page:

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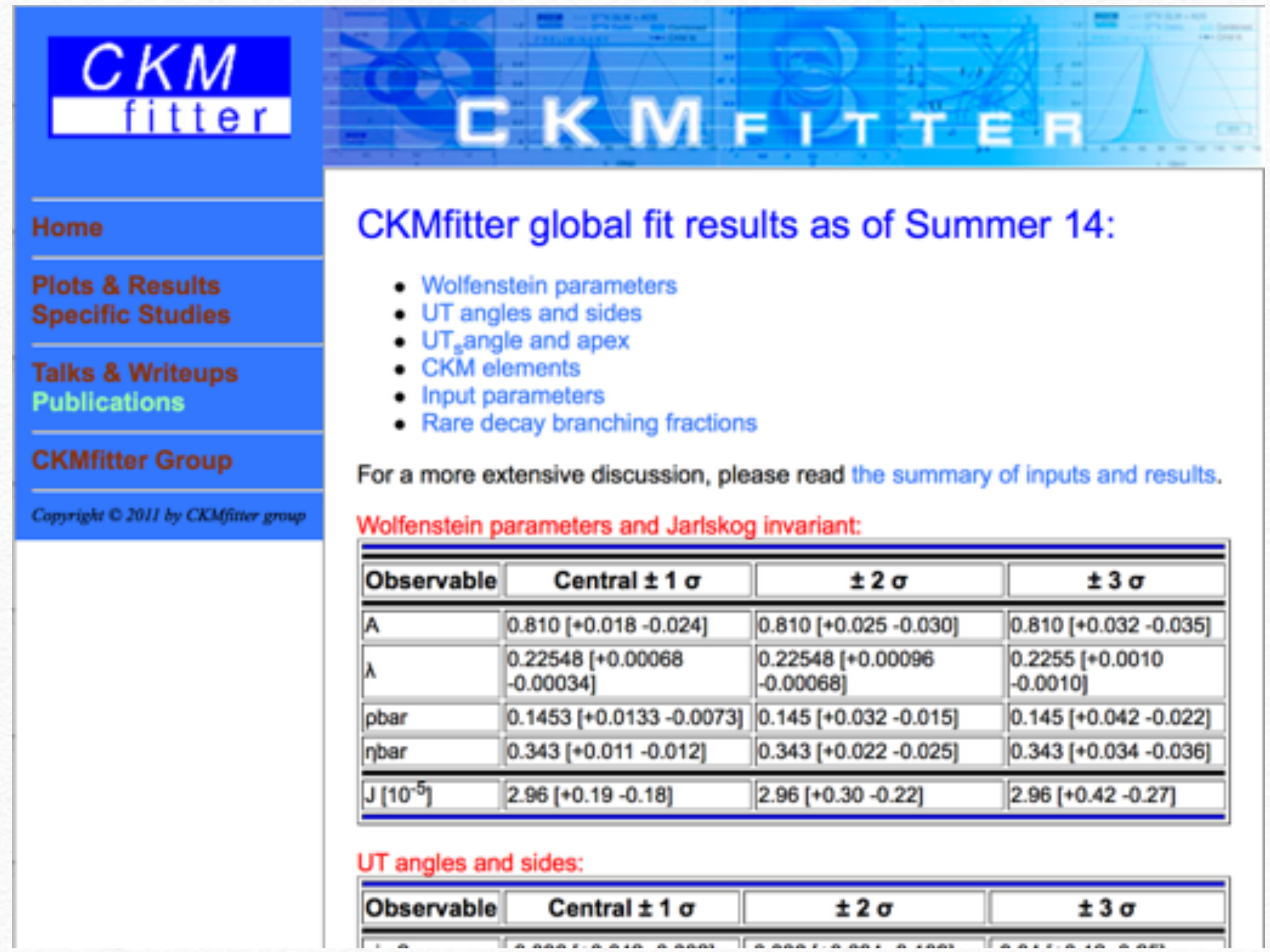
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CKMfitter global fit results as of Summer 14:

- Wolfenstein parameters
- UT angles and sides
- UT$_s$ angle and apex
- CKM elements
- Input parameters
- Rare decay branching fractions

For a more extensive discussion, please read the summary of inputs and results.

Wolfenstein parameters and Jarlskog invariant:

Observable	Central ± 1 σ	± 2 σ	± 3 σ
A	0.810 [+0.018 -0.024]	0.810 [+0.025 -0.030]	0.810 [+0.032 -0.035]
λ	0.22548 [+0.00068 -0.00034]	0.22548 [+0.00096 -0.00068]	0.2255 [+0.0010 -0.0010]
ρbar	0.1453 [+0.0133 -0.0073]	0.145 [+0.032 -0.015]	0.145 [+0.042 -0.022]
ηbar	0.343 [+0.011 -0.012]	0.343 [+0.022 -0.025]	0.343 [+0.034 -0.036]
J [10^{-5}]	2.96 [+0.19 -0.18]	2.96 [+0.30 -0.22]	2.96 [+0.42 -0.27]

UT angles and sides:

Observable	Central ± 1 σ	± 2 σ	± 3 σ

http://ckmfitter.in2p3.fr/

Coming soon: web interface ***CKMlive***