Prospettive per la fisica del Flavour per il Run 2 di LHC

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- Introduction
- SM UTA and NP in $\Delta F=2$
- Rare decays and LUV
- Conclusions

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WHY FLAVOUR?

- Because we don't understand the origin of the peculiar SM flavour structure (q vs l)
- Because flavour is the most powerful probe of physics beyond the SM
- Because flavour strongly constrains any NP within the LHC reach

INDIRECT SEARCHES FOR NP

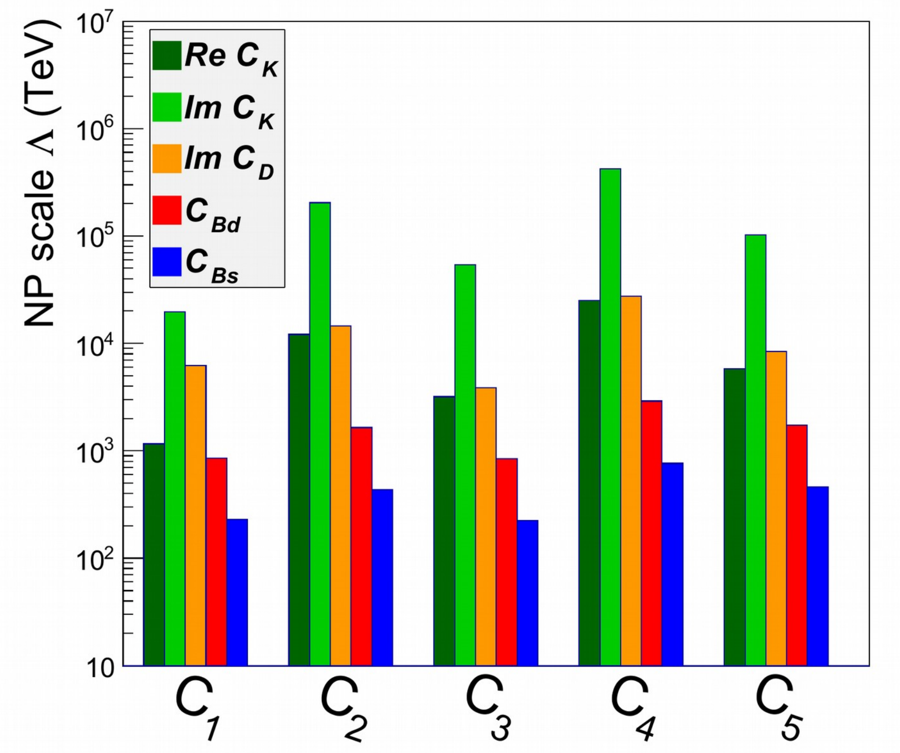
- Search for virtual contributions of new particles: sensitive to g_{NP}^2/Λ^2
- Use observables where SM contributions are either absent (BNV, LNV, LFV) or loop-suppressed (EWPO, FCNC).
- Advantage of flavour over EWPO: hierarchical structure of CKM provides very strong suppression of FCNC & CPV

INDIRECT SEARCHES FOR NP II

- For models with new sources of flavour and CP violation, flavour sensitivity orders of magnitude larger than EWPO
- For models with Minimal Flavour and CP Violation, flavour sensitivity comparable to EWPO
- Flavour physics plays a key role in indirect searches for NP

BOUNDS ON NP: GENERIC

Bounds from $\Delta F=2$ processes, generic flavour structure

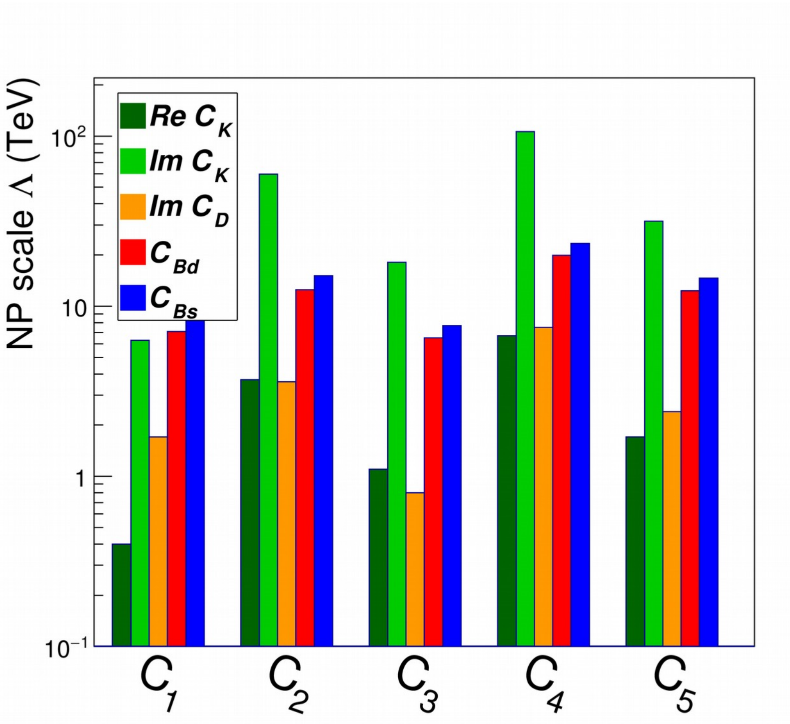


$\Delta F=2$ processes scale as $1/\Lambda^2$

- Best bound from ε_K, dominated by CKM error
- CPV in charm mixing follows, exp error dominant
- Best CP conserving from Δm_K, dominated by long distance
- B_d and B_s behind, error from both CKM and B-params

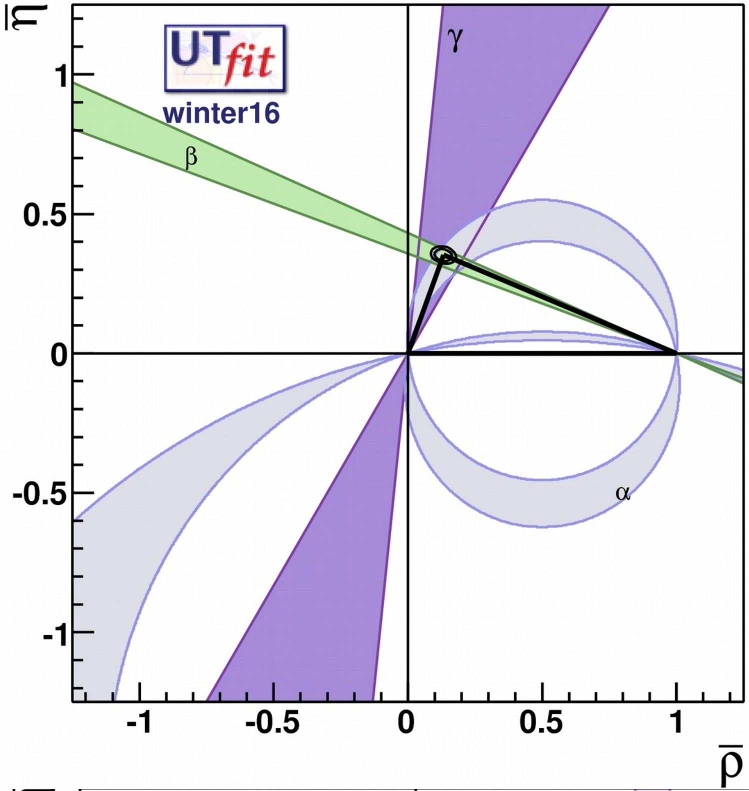
BOUNDS ON NP: CKM-LIKE

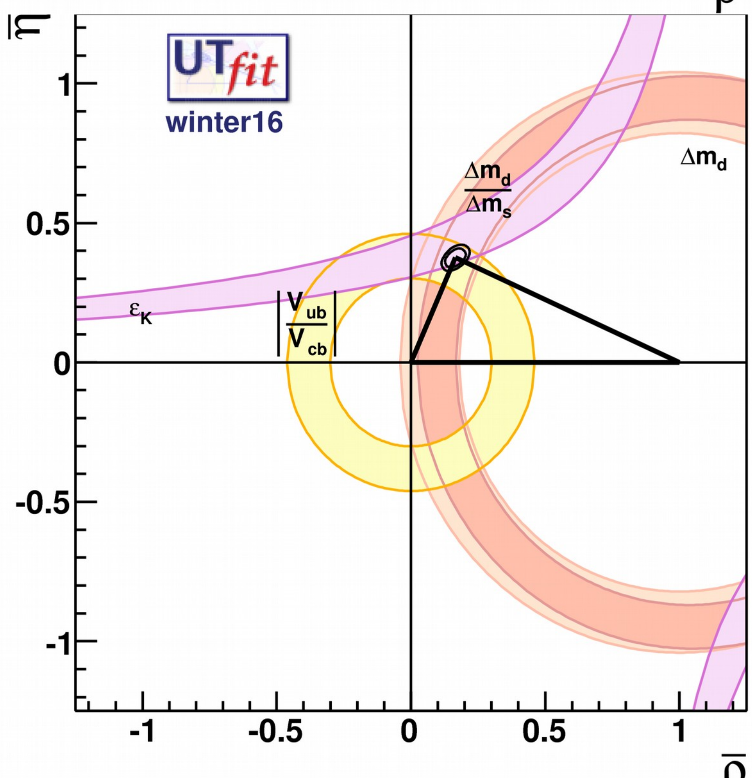
Bounds from $\Delta F=2$ processes, CKM-like flavour structure

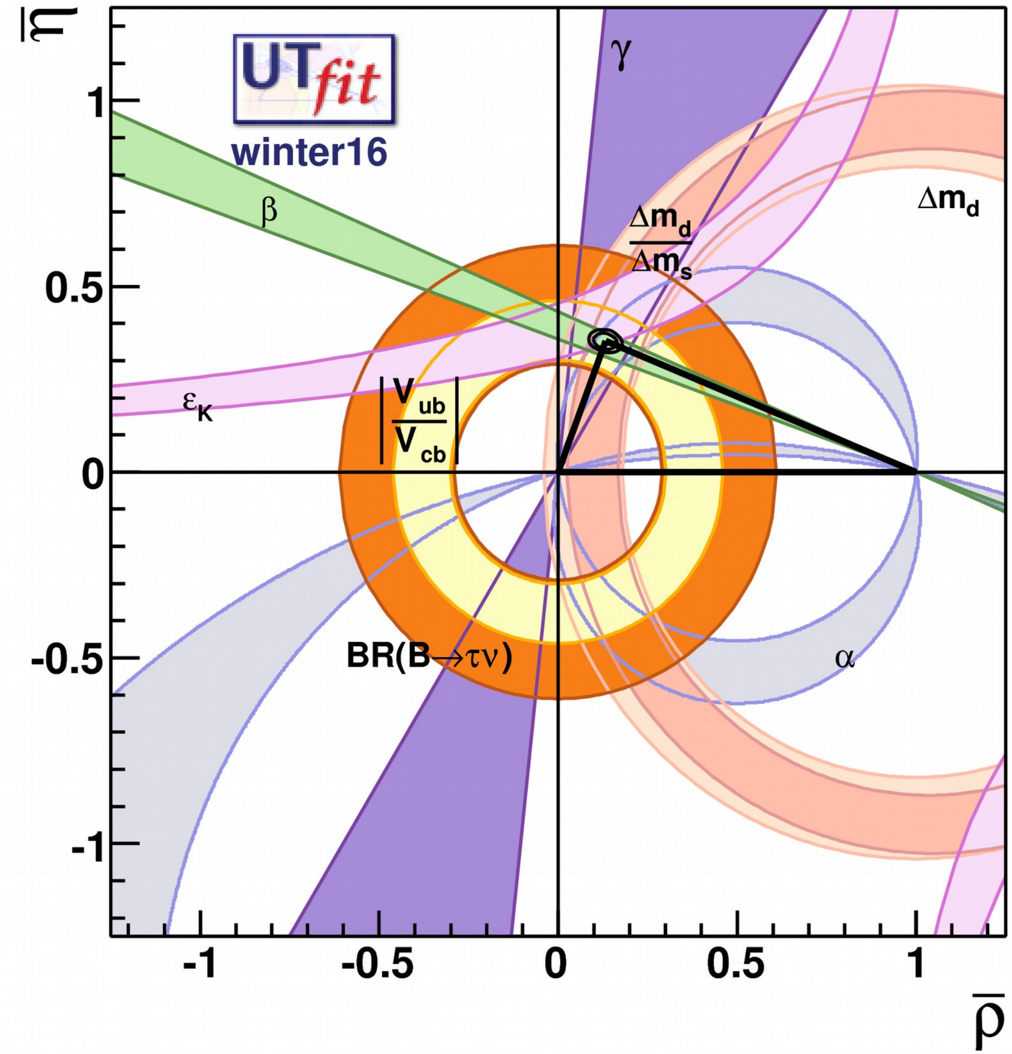


$\Delta F=2$ processes scale as $1/\Lambda^2$

- If new chiral structures present, ε_K still leading
- $B_{(s)}$ mixing provides very stringent constraints, specially if no new chiral structures are present
- Constraining power of the various sectors depends on unknown NP flavour structure: must improve all sectors!





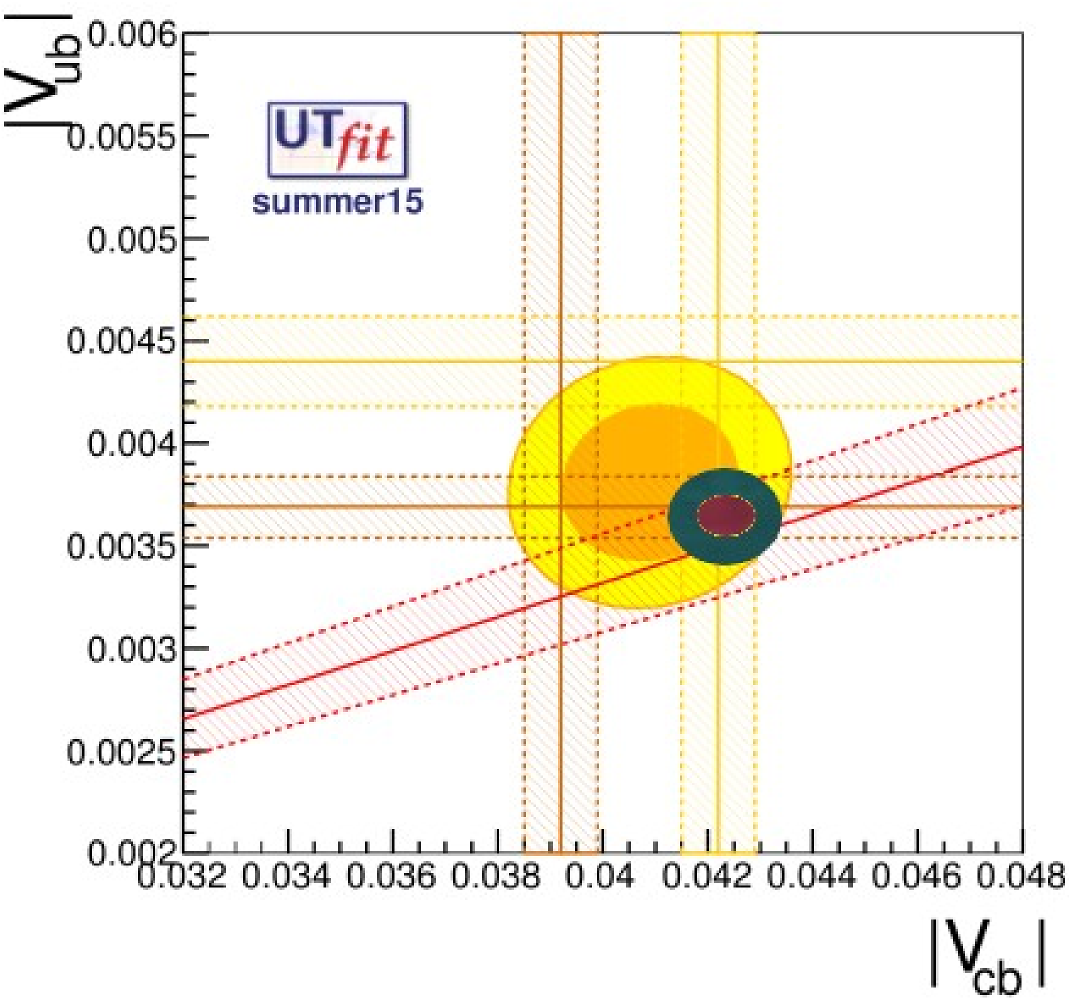


$\rho = 0.142 \pm 0.018$

$\eta = 0.348 \pm 0.012$

Parameter	Input value	Full fit	SM Prediction	Pull
$\bar\rho$	–	–	0.142 ± 0.018	–
$\bar\eta$	–	–	0.348 ± 0.012	–
A	–	–	0.829 ± 0.012	–
λ	0.22518 ± 0.00087	–	0.22504 ± 0.00064	-0.2
$\|V_{ub}\|$	0.00380 ± 0.00040	0.00365 ± 0.00011	0.00364 ± 0.00012	-0.4
$\|V_{ub}\|$ (excl.)	0.00369 ± 0.00014	–	–	-0.3
$\|V_{ub}\|$ (incl.)	0.00440 ± 0.00022	–	–	-3.1
$\|V_{cb}\|$	0.0408 ± 0.0011	0.04205 ± 0.00053	0.04237 ± 0.00062	$+1.1$
$\|V_{cb}\|$ (excl.)	0.03919 ± 0.00070	–	–	$+3.3$
$\|V_{cb}\|$ (incl.)	0.04220 ± 0.00070	–	–	$+0.1$
$\alpha[^\circ]$	92.5 ± 5.5 and 166.1 ± 0.6	90.0 ± 2.7	88.1 ± 3.4	-0.7
$\beta[^\circ]$	–	22.04 ± 0.85	24.2 ± 1.6	–
$\gamma[^\circ]$	-108.5 ± 6.5 and 71.4 ± 6.5	67.7 ± 2.8	66.9 ± 3.0	-0.7
$\sin(2\beta)$	0.679 ± 0.023	0.695 ± 0.021	0.746 ± 0.039	$+1.4$
$\beta_s[^\circ]$	0.97 ± 0.94	–	1.057 ± 0.038	0.0
$\|\epsilon_k\| \cdot 10^3$	2.228 ± 0.011	2.227 ± 0.010	2.03 ± 0.18	-1.1
$\Delta m_s [\mathrm{ps}^{-1}]$	17.761 ± 0.022	17.760 ± 0.022	17.3 ± 1.0	-0.5

INCLUSIVE VS EXCLUSIVE

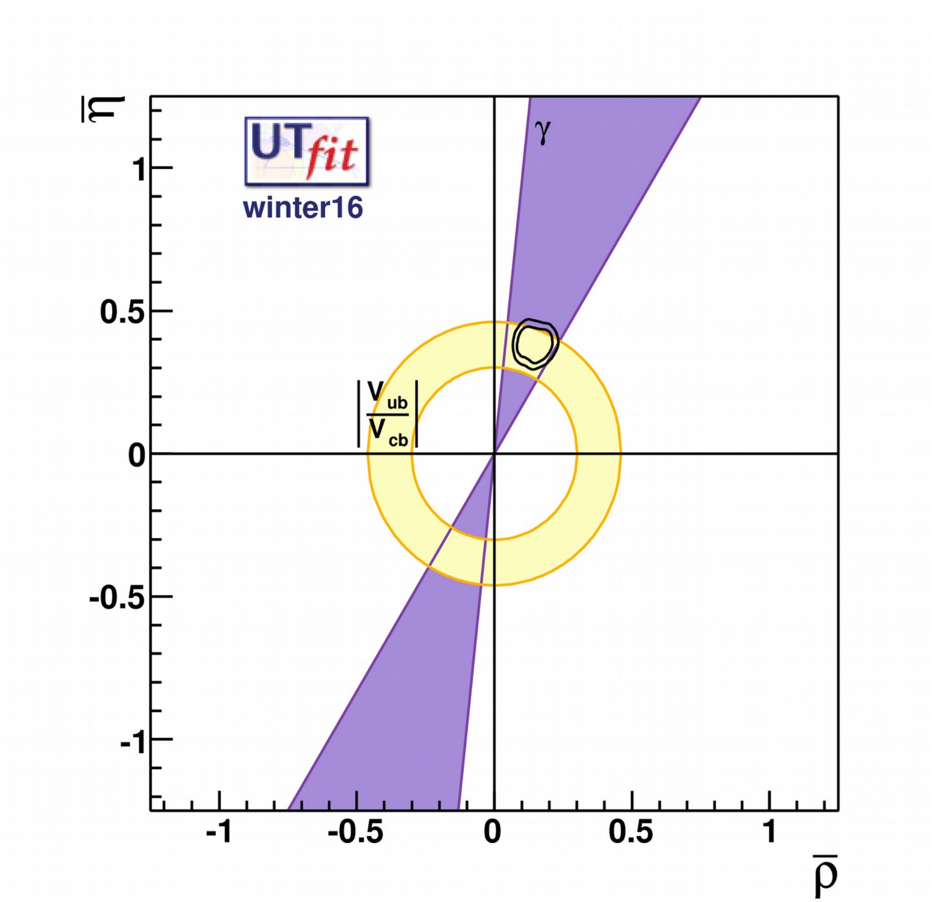


Disagreement between inclusive and exclusive

Use inflated error à la PDG

Indirect determination in agreement with excl. V_{ub} and incl. V_{cb}

NP-INDEPENDENT CKM

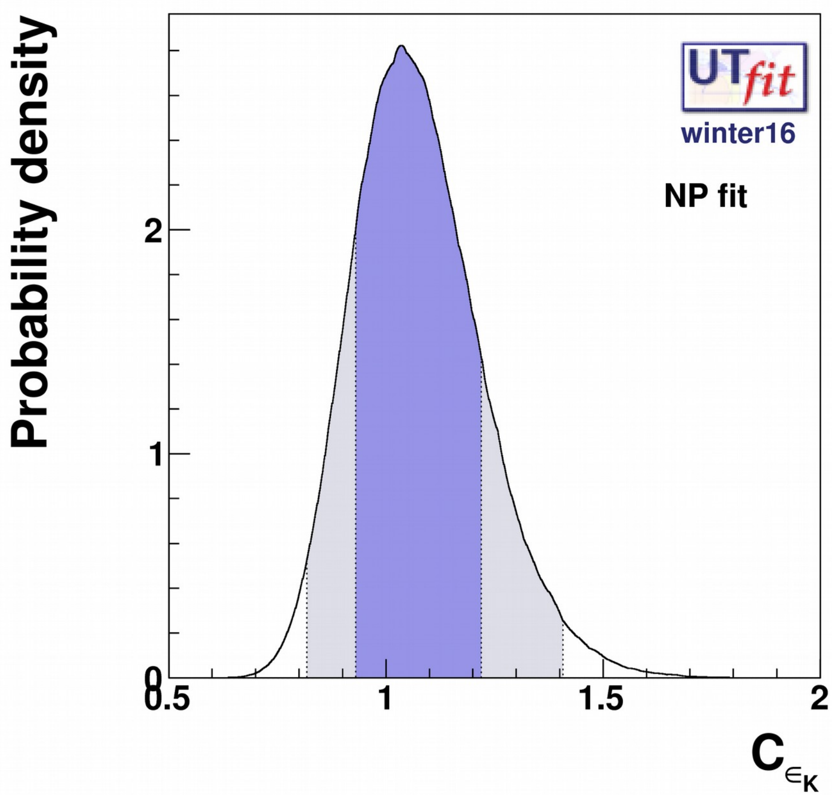


SM fit:
$\rho = 0.142 \pm 0.018$
$\eta = 0.348 \pm 0.012$

NP fit:
$\rho = 0.146 \pm 0.043$
$\eta = 0.384 \pm 0.043$

- $|V_{ub}|$ and $|V_{cb}|$ from semileptonic B dec.
- γ from tree-level decays
- A_{sl}^{d} to exclude 2nd solution model-independently

NP FIT RESULTS

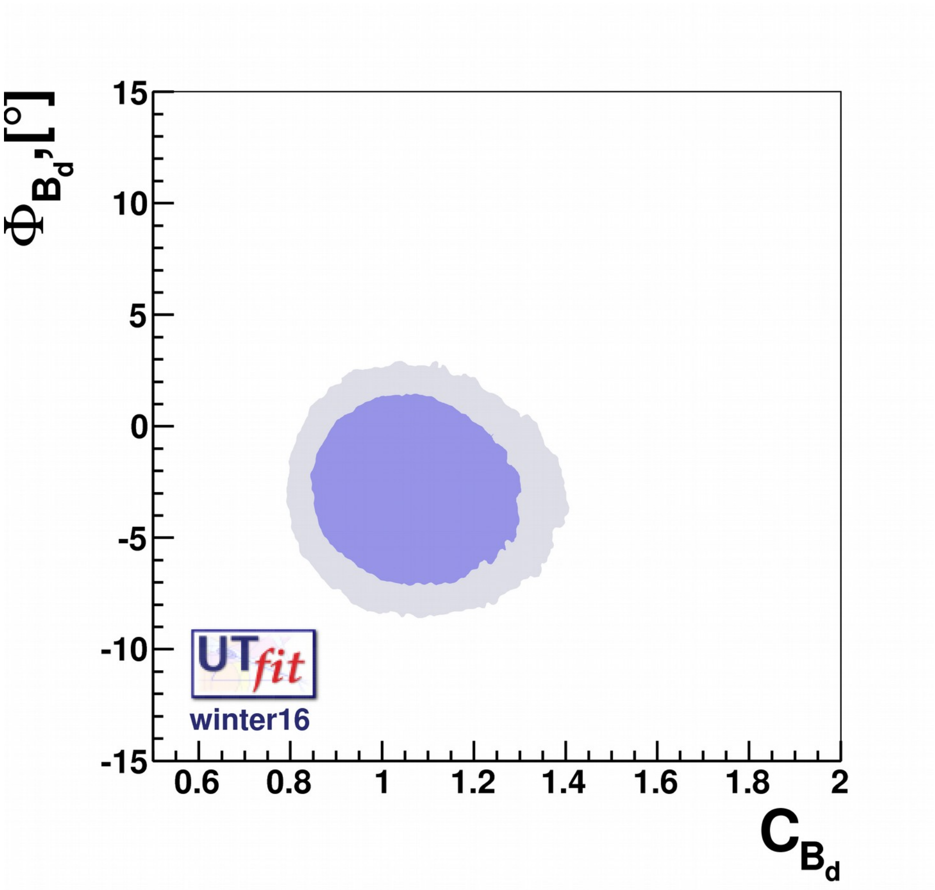


Preliminary!

- $C_{\varepsilon K} = \varepsilon_K/\varepsilon_K^{SM} = 1.07 \pm 0.14$

  ([0.80,1.38] @ 95% probability)
- Main source of error: CKM, then B_K (1.3%), LD (~%)

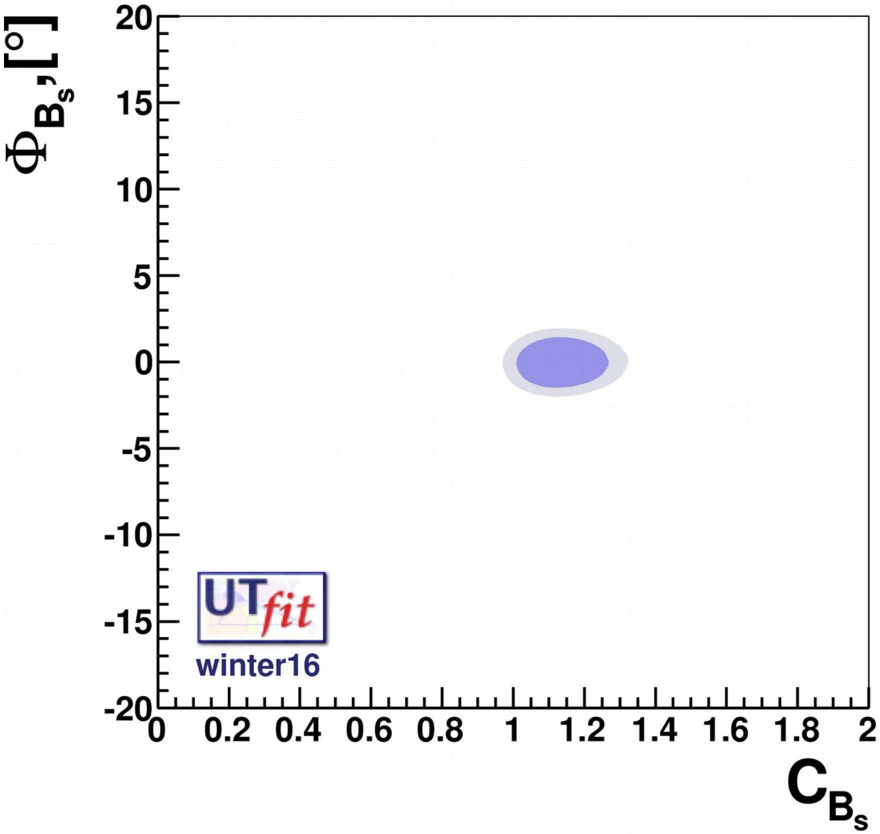
NP IN B_d MIXING



Preliminary!

- C_{Bd} = 1.08 ± 0.15 ([0.79,1.40] @ 95%)
- ϕ_{Bd} = (-2.8 ± 2.8)° ([-8.5,2.7]° @ 95%)
- Sources of error: CKM ~ M.E. ~ 10%

NP IN B_s MIXING



- $C_{Bs} = 1.141 \pm 0.087$ ([0.97,1.32] @ 95%)
- $\phi_{Bs} = (0 \pm 1)°$ ([-2,2]° @ 95%)
- sources of error: CKM ~ M.E. ~ 5%

NP contributions at the level of 30-40% of the SM still allowed in all sectors!

D MIXING

- D mixing is described by:
  - Dispersive $D \to \bar{D}$ amplitude M_{12}
    - SM: long-distance dominated, not calculable
    - NP: short distance, calculable w. lattice
  - Absorptive $D \to \bar{D}$ amplitude Γ_{12}
    - SM: long-distance, not calculable
    - NP: negligible
  - Observables: $|M_{12}|$, $|\Gamma_{12}|$, $\Phi_{12}=\arg(\Gamma_{12}/M_{12})$

"REAL SM" APPROXIMATION

- Given present experimental errors, it is perfectly adequate to assume that SM contributions to both M_{12} and Γ_{12} are real
- all decay amplitudes relevant for the mixing analysis can also be taken real
- NP could generate a nonvanishing phase for M_{12}

"REAL SM" APPROXIMATION II

- Define $|D_{S,L}| = p|D^0| \pm q|D^0|$ and $\delta = (1-|q/p|^2)/(1+|q/p|^2)$. All observables can be written in terms of $x=\Delta m/\Gamma$, $y=\Delta\Gamma/2\Gamma$ and δ, with

$$\sqrt{2}\,\Delta m = \mathrm{sign}(\cos\Phi_{12})\sqrt{4|M_{12}|^2-|\Gamma_{12}|^2+\sqrt{(4|M_{12}|^2+|\Gamma_{12}|^2)^2-16|M_{12}|^2|\Gamma_{12}|^2\sin^2\Phi_{12}}}\,,$$

$$\sqrt{2}\,\Delta\Gamma = 2\sqrt{|\Gamma_{12}|^2-4|M_{12}|^2+\sqrt{(4|M_{12}|^2+|\Gamma_{12}|^2)^2-16|M_{12}|^2|\Gamma_{12}|^2\sin^2\Phi_{12}}}\,,$$

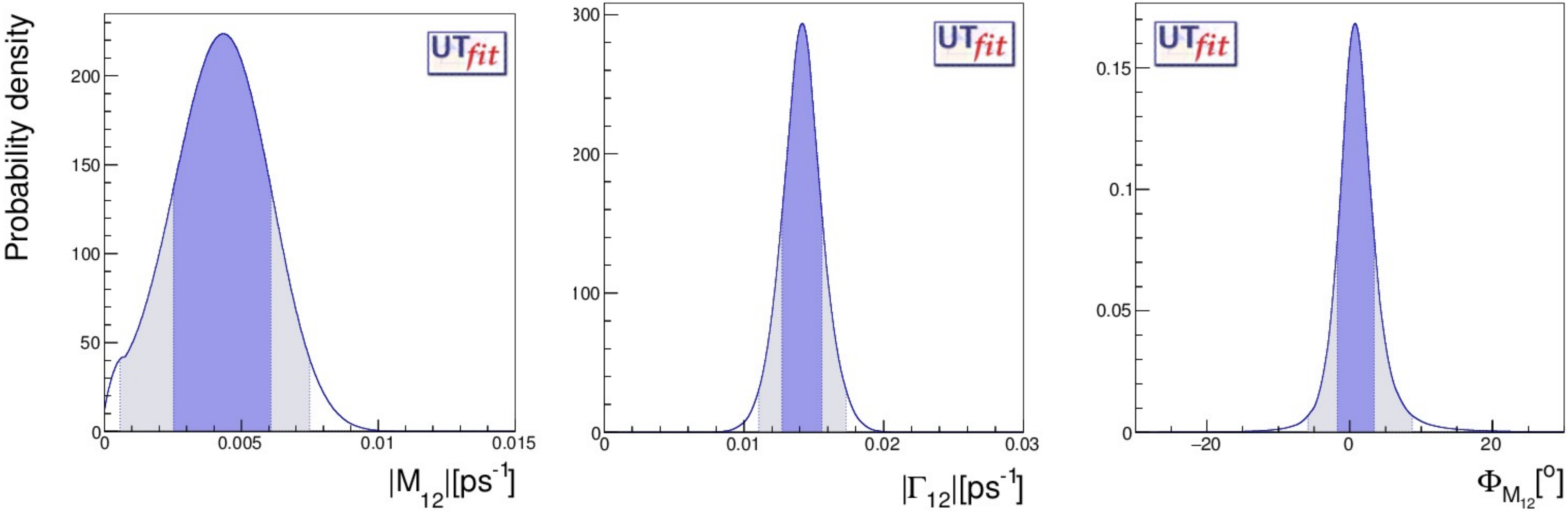
$$\delta = \frac{2|M_{12}||\Gamma_{12}|\sin\Phi_{12}}{(\Delta m)^2+|\Gamma_{12}|^2}\,, \tag{7}$$

- Notice that $\phi=\arg(q/p)=\arg(y+i\delta x)$ - ~~$\arg\Gamma_{12}$~~
- $|q/p|\neq 1 \Leftrightarrow \phi\neq 0$ clear signals of NP

Ciuchini et al; Kagan & Sokoloff

CPV IN CHARM MIXING

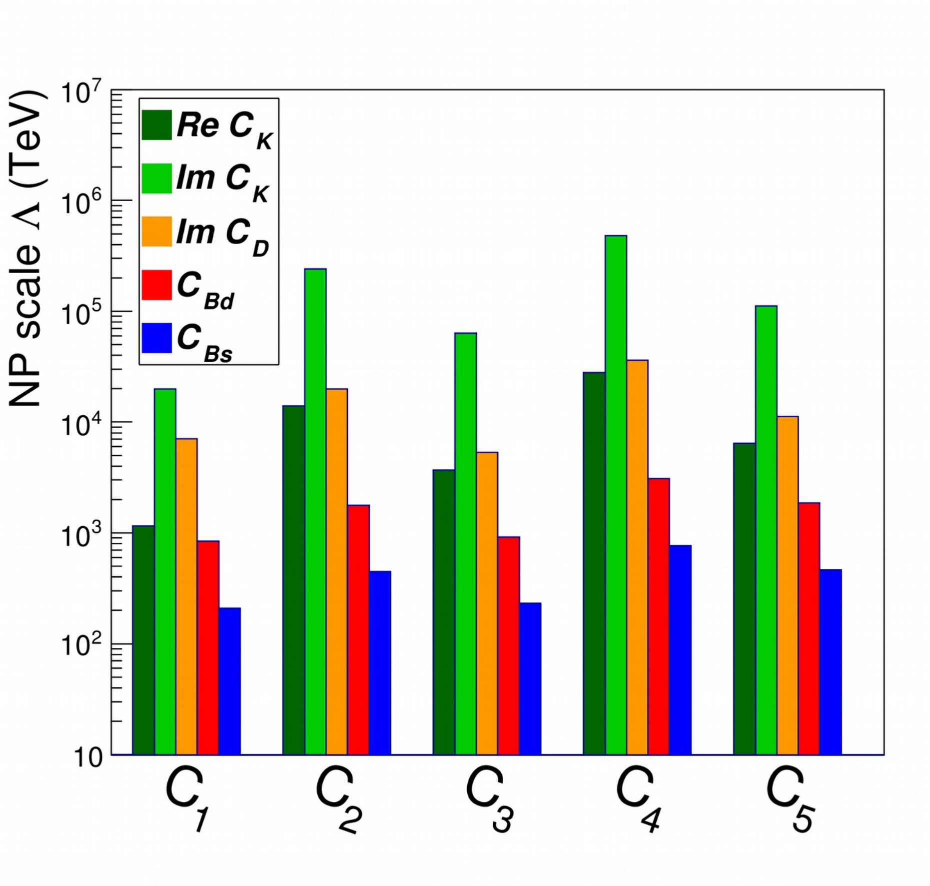
- Latest UTfit average (HFAG very similar):
  $x = (3.5 \pm 1.5)\ 10^{-3}$, $y = (5.8 \pm 0.6)\ 10^{-3}$,
  $|q/p|-1 = (0.7 \pm 1.8)\ 10^{-2}$, $\phi = \arg(q/p) = (0.20 \pm 0.56)°$
  $|M_{12}| = (4 \pm 2)/\text{fs}$, $|\Gamma_{12}| = (14 \pm 1)/\text{fs}$, $\Phi_{12} = (0 \pm 3)°$

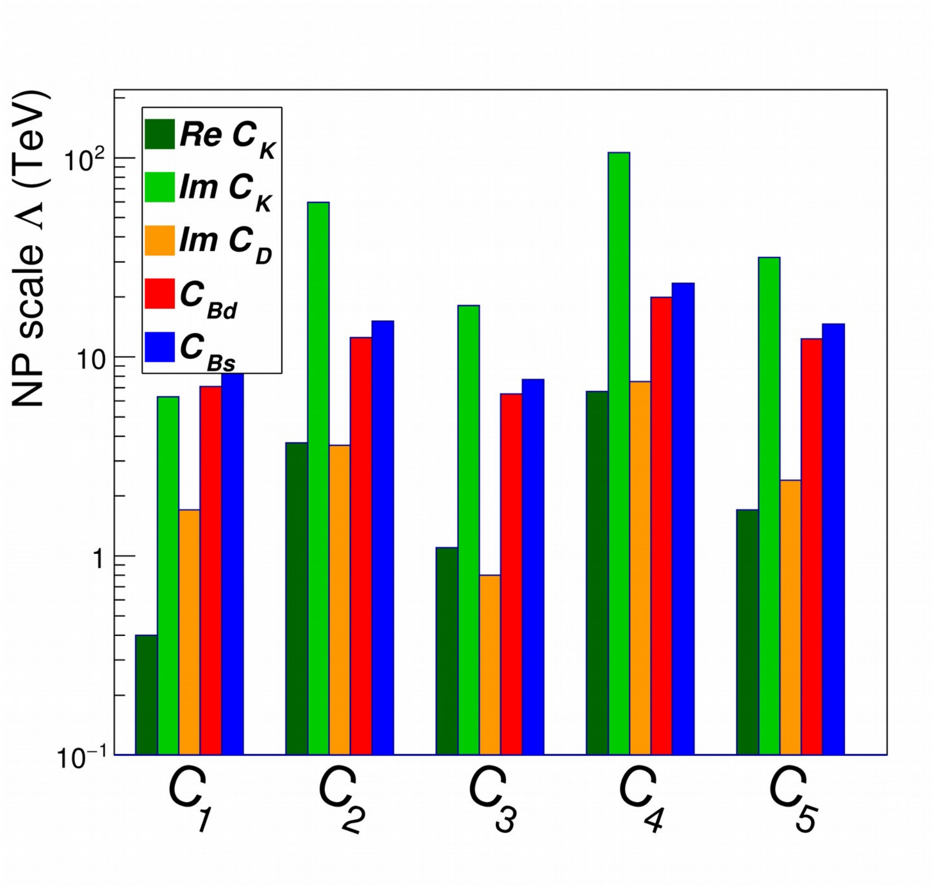


FROM A_{NP} TO Λ

- Having derived the NP amplitudes from the fit, the extraction of the NP scale Λ requires:
  - computing the hadronic matrix elements of NP-induced operators: currently all M.E. computed on the lattice, not a limitation
  - choosing a NP coupling and flavour structure

THE Λ PLOTS AGAIN



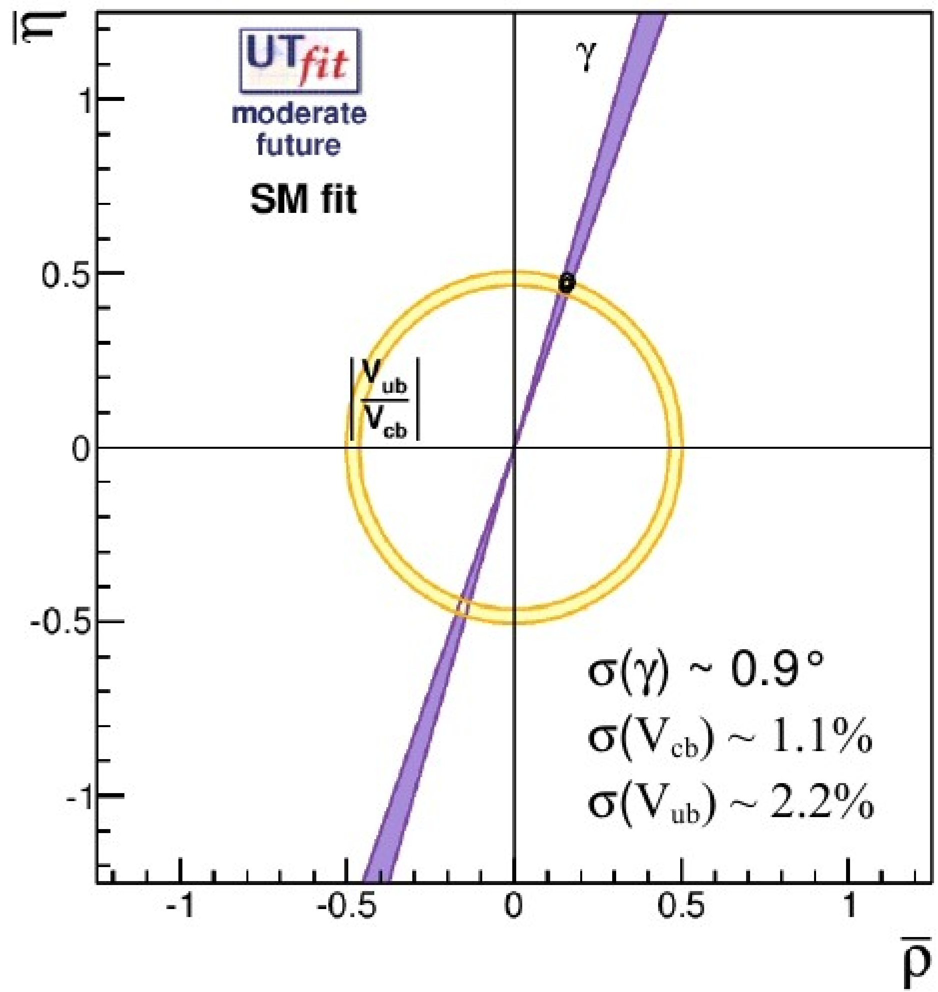


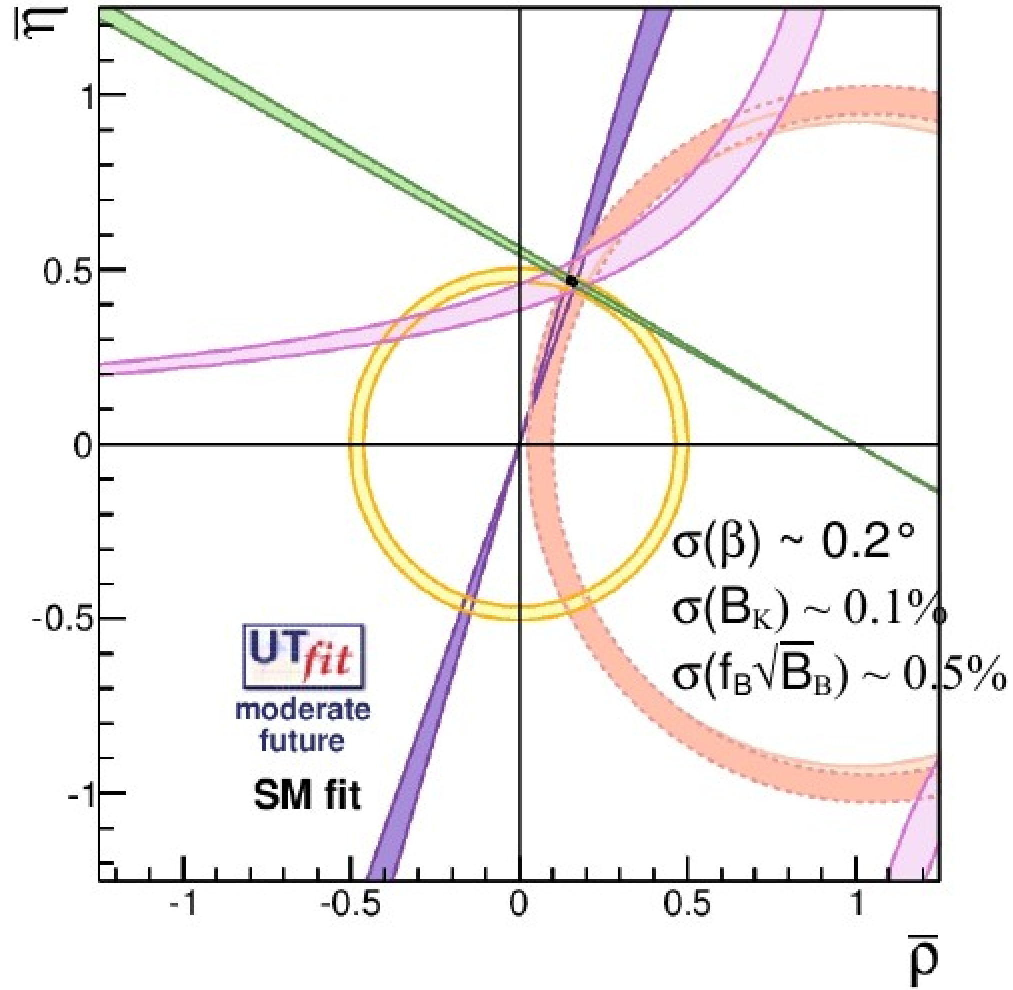
INTERPRETING THE BOUNDS

- generic case (no loop, no flavour suppression, all chiral structures): $\Lambda > 4.2\ 10^5$ TeV
- Extra-Dim case (no loop suppression, CKM suppression, all chiral structures): $\Lambda >96$ TeV
- MFV case (no loop suppression, CKM suppression, only left-handed): $\Lambda > 9$ TeV
- weakly-interacting MFV case (EW loop & CKM suppression, left-handed): $\Lambda > 300$ GeV

FUTURE OF $\Delta F=2$

- In the next decade, Belle-II and LHCb upgrade will push down the exp. error on $\sin 2\beta_{(s)}$ to less than 0.01
- Th. error can be kept below 0.01 using control channels as $S(B \to J/\psi\pi)$
- B-parameters will go below the % level, new ideas to attack long-distance in K and D
- Improving γ, α, $|V_{cb}|$ & $|V_{ub}|$ crucial!





errors from tree-only fit on ρ and η:

$\sigma(\rho) = 0.008$ *[currently 0.051]*

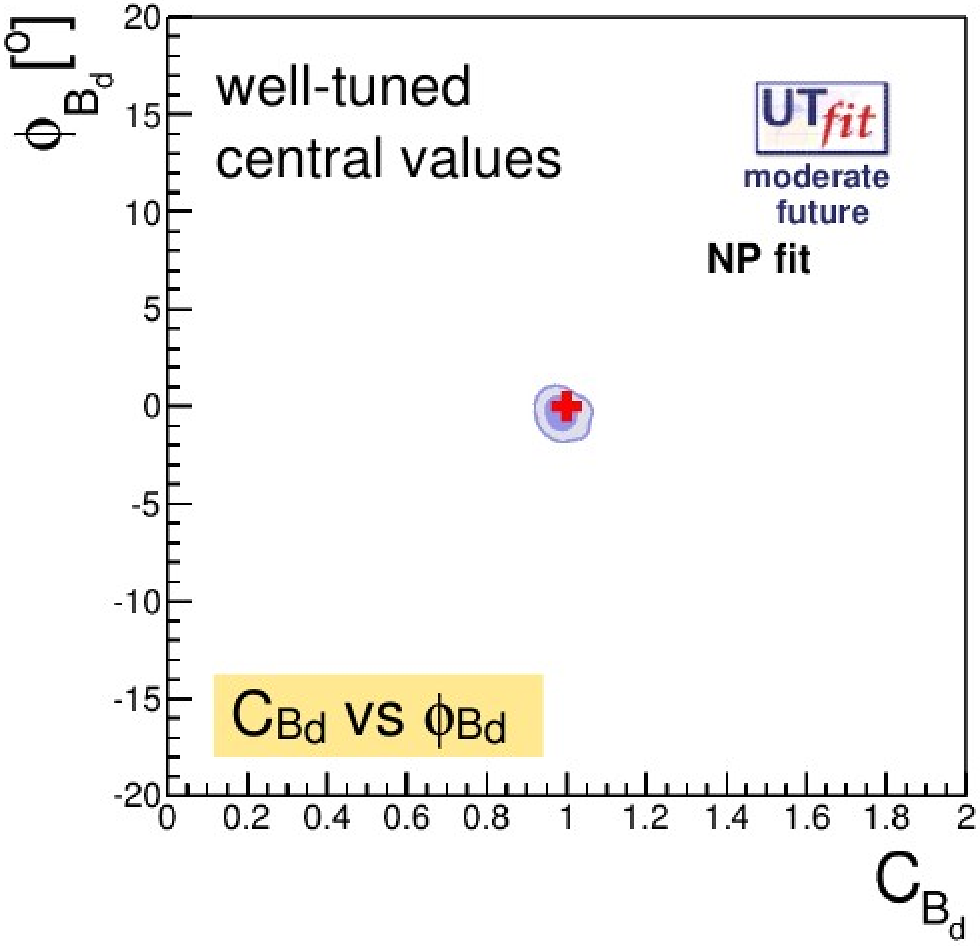
$\sigma(\eta) = 0.010$ *[currently 0.050]*

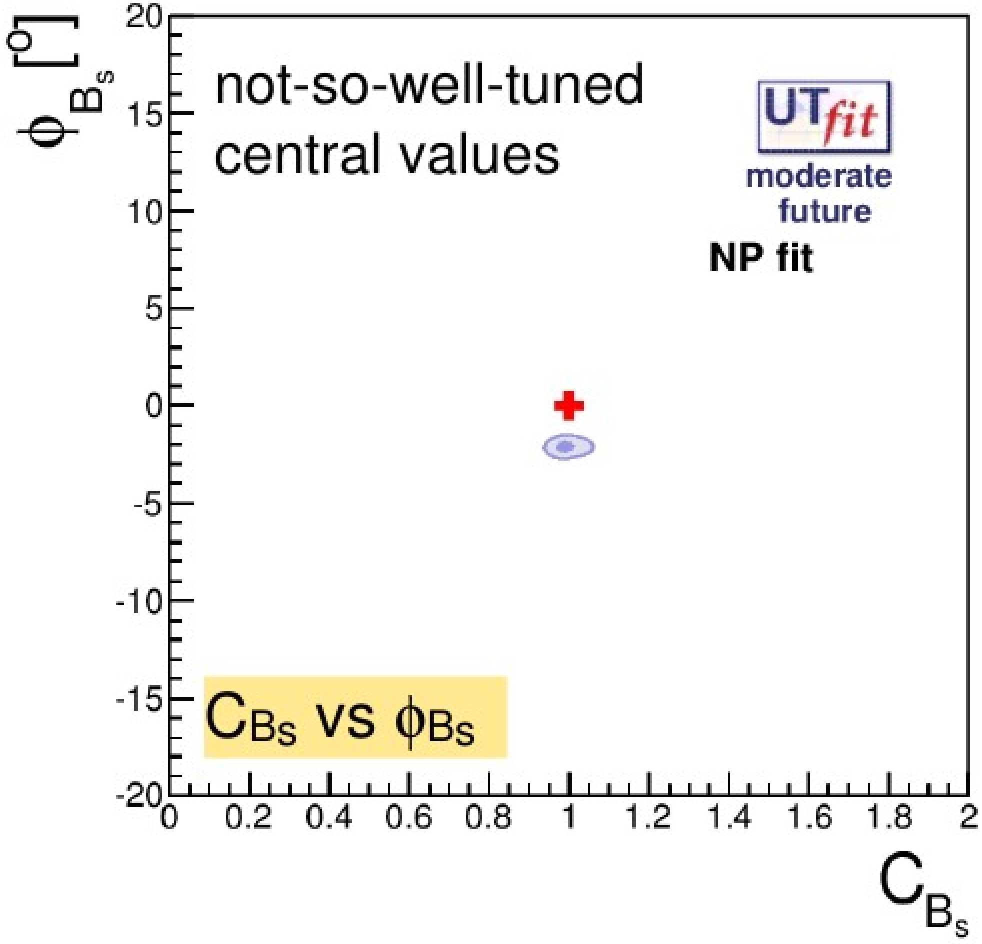
errors from 5-constraint fit on ρ and η:

$\sigma(\rho) = 0.005$ *[currently 0.034]*

$\sigma(\eta) = 0.004$ *[currently 0.015]*

M. Bona @ CKM2014





errors on general NP parameters:

$\sigma(C_{Bd}) = 0.03$ *[currently 0.16]*

$\sigma(\phi_{Bd}) = 0.7$ *[currently 3.2]*

$\sigma(C_{Bs}) = 0.03$ *[currently 0.08]*

$\sigma(\phi_{Bs}) = 0.6$ *[currently 2.0]*

M. Bona @ CKM2014

Parameter	Error				
	Now	50/fb	300/fb	1000/fb	3000/fb
$\bar{\rho}$ (SM fit)	0.002	0.0039	0.0023	0.0013	0.00064
$\bar{\eta}$ (SM fit)	0.021	0.0037	0.0019	0.0013	0.00068
γ [°] (SM fit)	6.5	0.6	0.35	0.2	0.09
α [°] (SM fit)	5.5	0.6	0.37	0.2	0.1
β [°] (SM fit)	4	0.2	0.10	0.07	0.04
β_s [°] (SM fit)	4	0.011	0.057	0.004	0.0023
$\bar{\rho}$ (NP fit)	0.002	0.006	0.0034	0.0028	0.0022
$\bar{\eta}$ (NP fit)	0.021	0.006	0.0053	0.0061	0.0052
γ [°] (NP fit)	6.5	0.9	0.4	0.2	0.09
α [°] (NP fit)	5.5	1	0.5	0.45	0.36
β [°] (NP fit)	4	0.8	0.7	0.7	0.7
β_s [°] (NP fit)	4	0.017	0.016	0.016	0.016
C_{ε_K}	0.14	0.065	0.065	0.065	0.064
C_{B_d}	0.15	0.024	0.024	0.024	0.022
Φ_{B_d}	2.8	0.48	0.36	0.36	0.35
C_{B_s}	0.087	0.02	0.02	0.02	0.02
Φ_{B_s}	0.96	0.26	0.11	0.063	0.038
$\Phi_{M_{12}}$ [°]	2.5	0.4	0.1	0.08	0.04
$\Phi_{\Gamma_{12}}$ [°]	–	1.2	0.4	0.24	0.12

Crucial to improve SM predictions of rare decays!

Need progress in $|V_{ub}|$ and $|V_{cb}|$

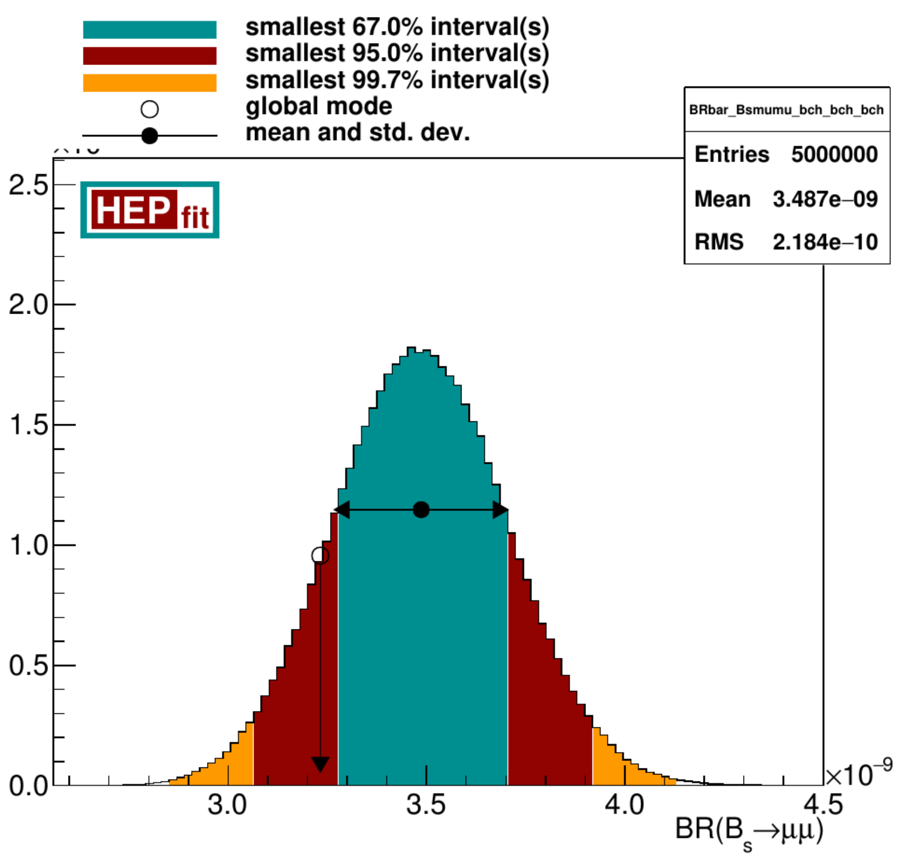
Steady improvement

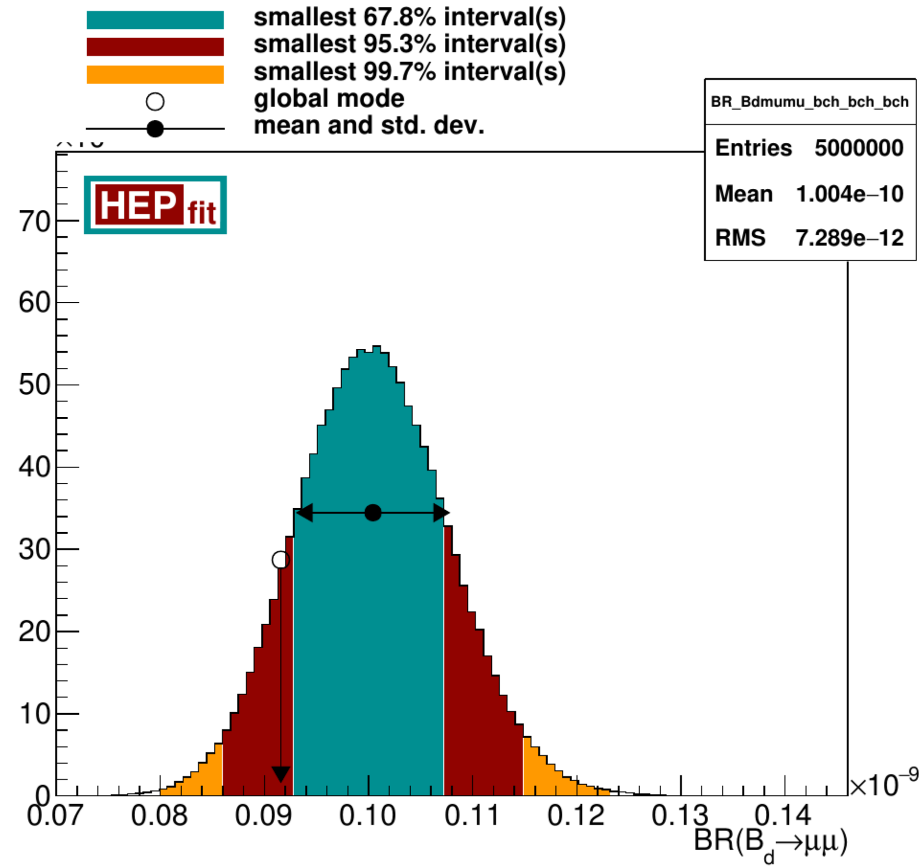
Very preliminary!!!

RARE DECAYS

- Rare and CP-violating decays are an excellent probe of NP
- Main (only) showstoppers are long-distance / infrared contributions to matrix elements
- $B_{d,s} \to \mu^+\mu^-$ extremely clean: dominated by parametric error, well below current and future exp error
- LFV/LUV also very clean and very interesting

$B_{s,d} \to \mu^+\mu^-$





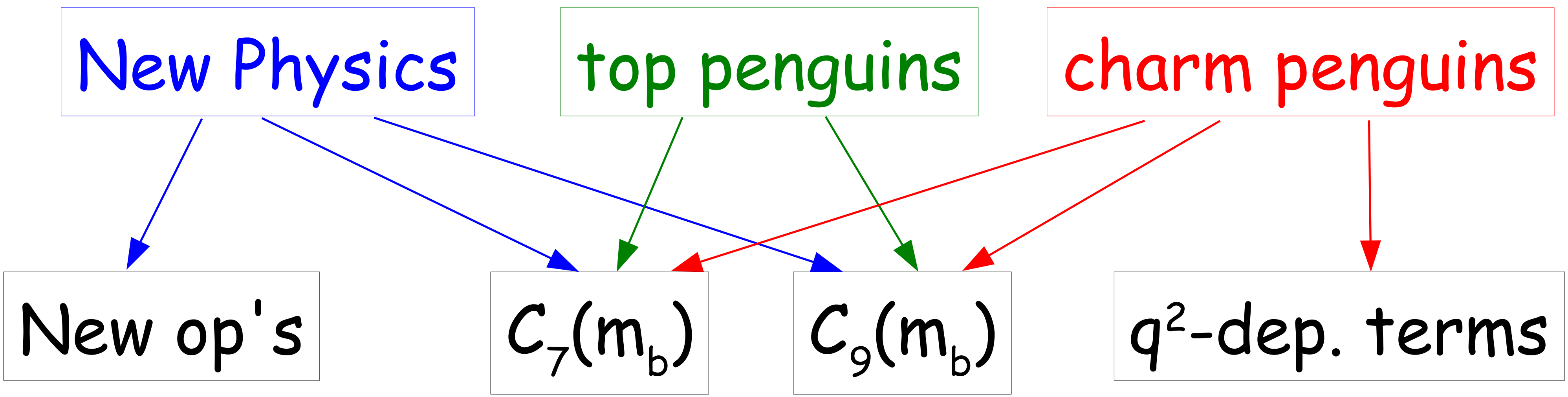
$BR(B_s \to \mu\mu)_{exp} = (2.9 \pm 0.7) 10^{-9}$, $BR(B_d \to \mu\mu)_{exp} = (0.39 \pm 0.15) 10^{-9}$

See also Bobeth et al. '14

Z-penguins/boxes vs γ-penguins

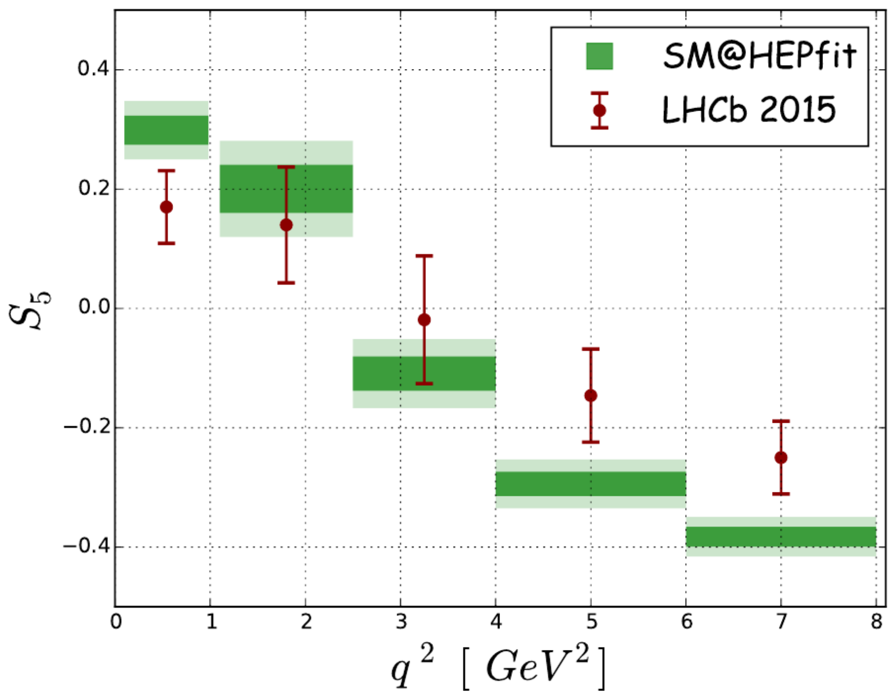
- $B_{s,d} \to \mu^+\mu^-$ not affected by photonic penguins $\Rightarrow$ no long-distance contributions

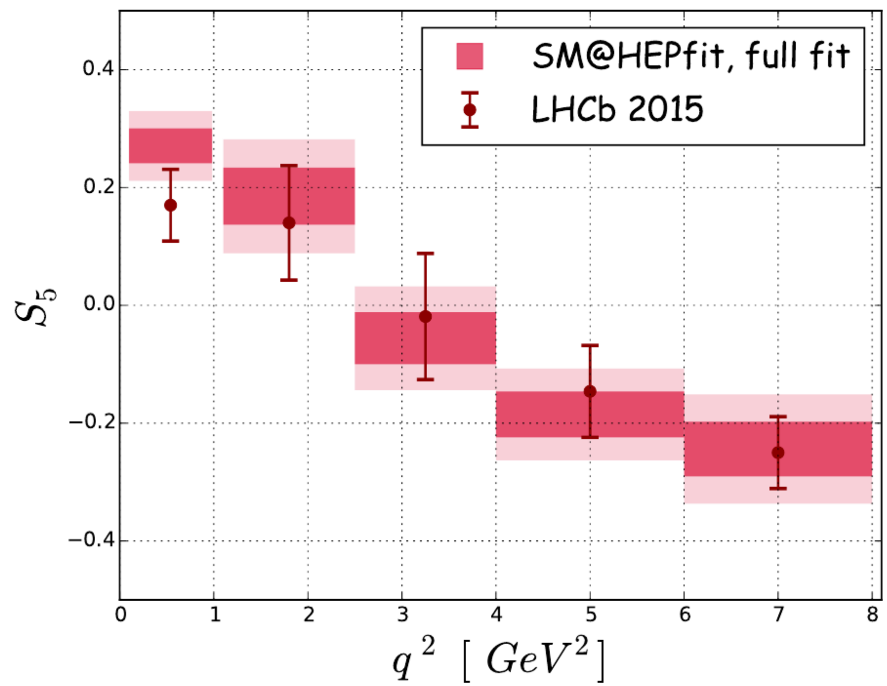
- $b \to s\mu^+\mu^-$ has photon-mediated contributions:



- Need to control the charm penguin to disentangle SM from NP in C_7^{eff} and C_9^{eff}

IMPACT OF CHARM LOOP

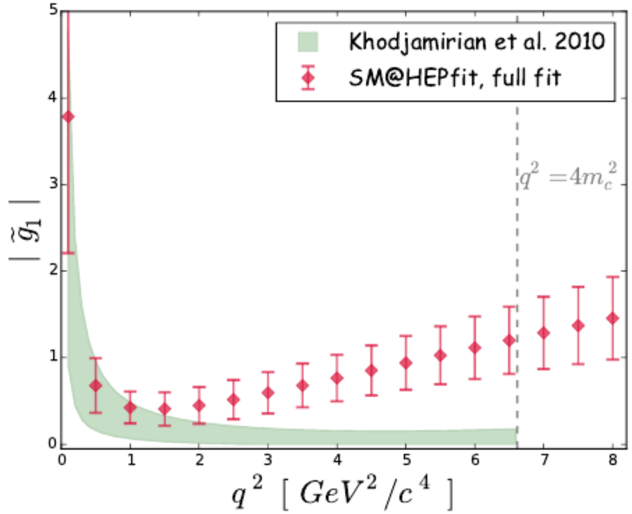


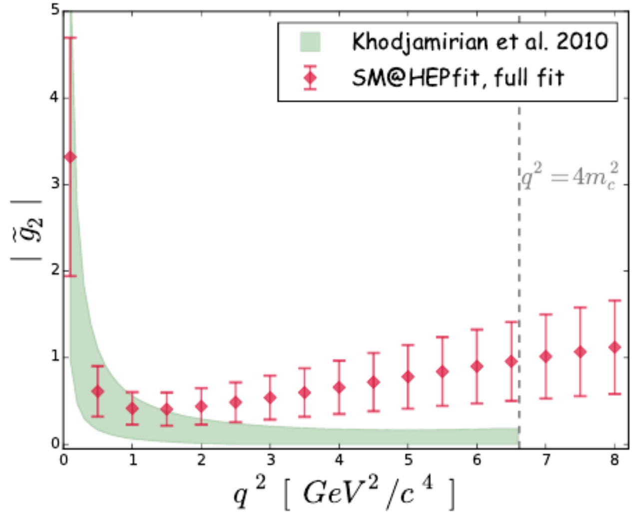


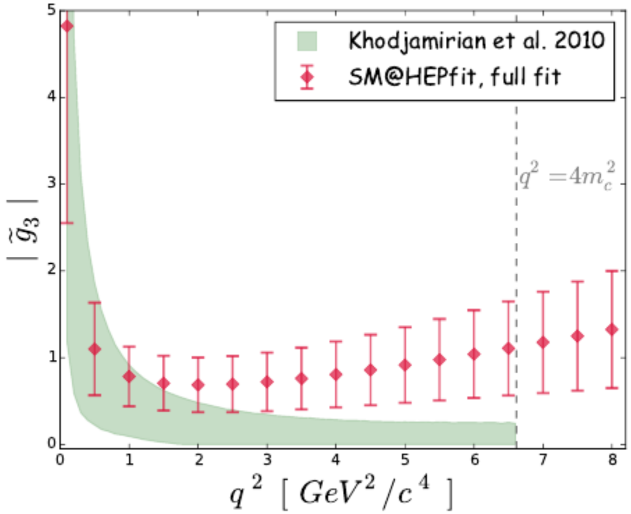
"Optimistic" evaluation of nonfactorizable contributions

Conservative evaluation of nonfactorizable contributions

SIZE OF CHARM LOOP







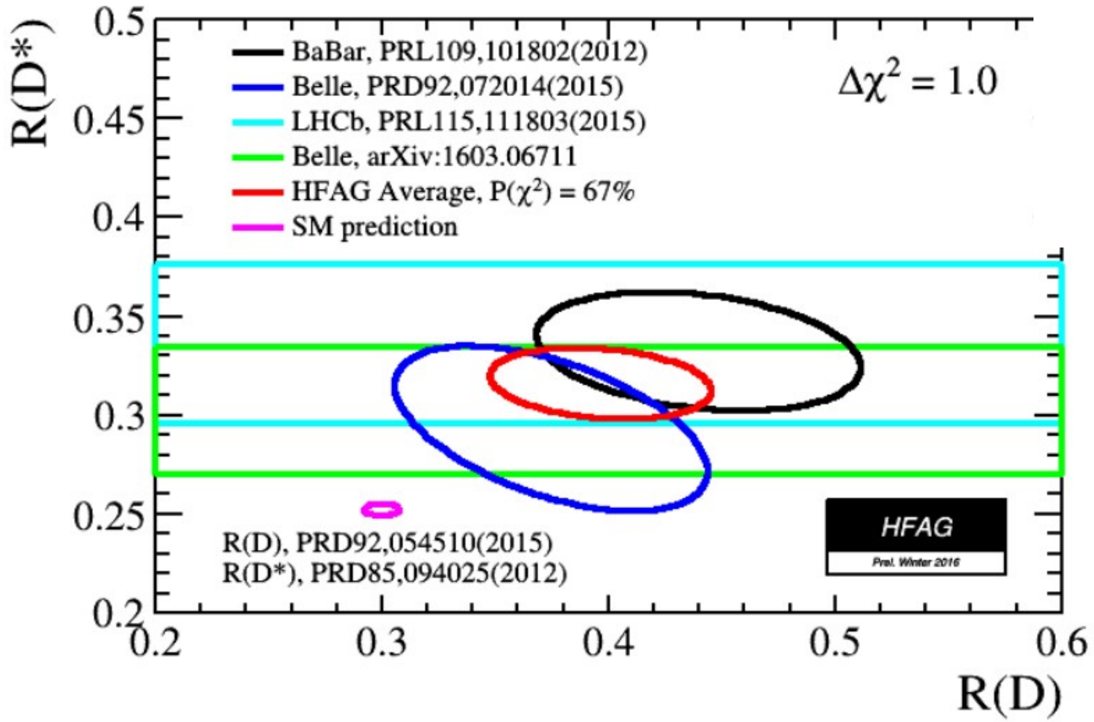
LESSONS FROM $B \to K^{*}\mu^{+}\mu^{-}$

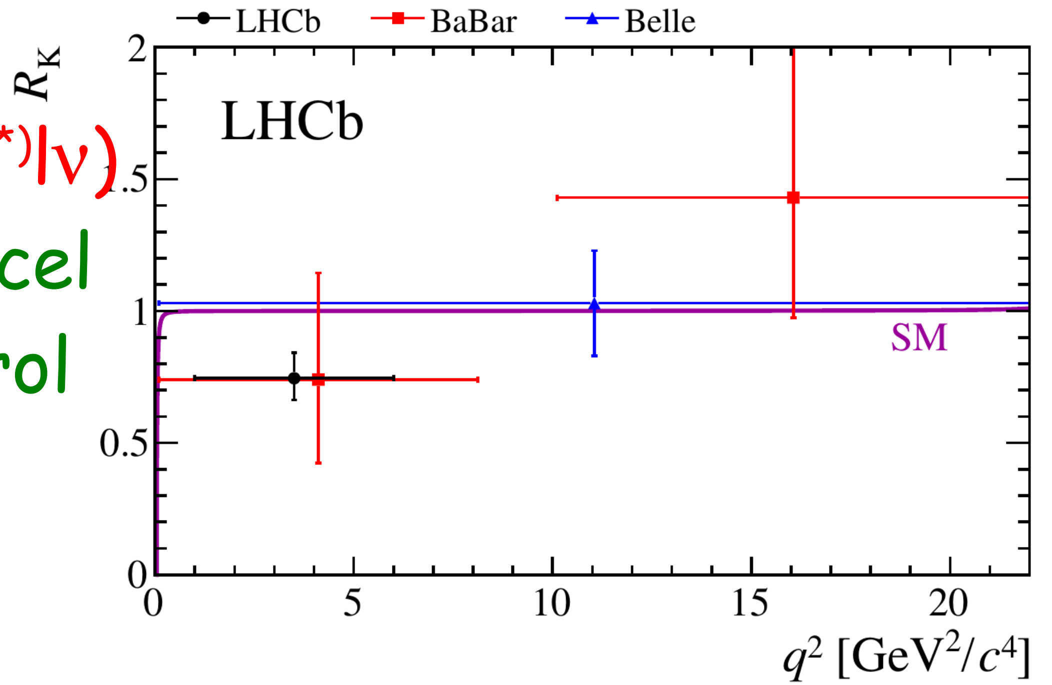
- Exp. data call for an extra contribution to the photonic penguin
- This contribution might come from hadronic effects or from NP
- With more data it may be possible to determine the q^2 dependence from data
- Need th breakthrough to disentangle NP in ΔC_9 from SM uncertainties

LEPTON UNIVERSALITY

$R(D^{(*)}) = BR(B \to D^{(*)}\tau\nu)/BR(B \to D^{(*)}l\nu)$

Form factor uncertainties cancel to a good extent – under control





$R_K = BR(B \to K\mu\mu)/BR(B \to Kee)$

$R_K = 1$ in the SM with negl. uncertainty; consistent w. possible NP in $K^*\mu\mu$

LEPTOQUARKS AND LUV

- LUV in both $b \to c l \nu$ and $b \to s l l$ mediated by semileptonic operators
- NP in $b \to c l \nu$ must compete with tree-level SM, NP in $b \to s l l$ with loop-mediated SM:
  - LQ entering $b \to c l \nu$ at tree level and $b \to s l l$ at loop level
    Bauer & Neubert '15
  - LQ entering both at tree level, but with flavour symmetry protection
    Calibbi, Crivellin & Ota '15; Barbieri et al. '15
  - heavy vectors with flavour symmetry
    Greljo, Isidori & Marzocca '15; Buttazzo et al. '16

CONCLUSIONS

- In a global strategy for NP searches, improving the accuracy on FCNC and CPV processes has a key role to ensure that:
  - we are able to determine the flavour structure of any NP directly seen, and hopefully understand its origin; roughly 2x in M_{NP} ⇔ 4x in exp & th ⇔ 16x in L
  - we increase the sensitivity of indirect searches (flavour has the lead in this field) and maybe detect an indirect NP signal

CONCLUSIONS II

- Intriguing hints of possible NP in LUV, look forward to Run II results
- Emphasis often on "golden modes", but a global experimental and theoretical effort is required to fully exploit the constraining power of flavour physics
- The complementarity of high-pT, LHCb, Belle-II and dedicated K and LFV experiments is crucial

UTfit beyond the SM

1. fit simultaneously for CKM and NP
   - add most general NP to all sectors
   - use all available experimental info
   - find out how much room is left for NP in $\Delta F=2$ transitions

Soares, Wolfenstein; Deshpande, Dutta, Oh; Silva, Wolfenstein; Cohen et al.; Grossman, Nir, Worah; Laplace et al; Ciuchini et al; Ligeti; CKMFitter; UTfit; Botella et al.; Agashe et al.; ...

2. perform an $\Delta F=2$ EFT analysis to put bounds on the NP scale
   - consider different choices of the FV and CPV couplings

UTfit; Davidson, Isidori, Uhlig; Isidori, Nir, Perez;...

1. Parameterization of generic NP contributions to the mixing amplitudes

K mixing amplitude (2 real parameters):

$$\mathrm{Re}\,A_K = C_{\Delta m_K}\,\mathrm{Re}\,A_K^{SM} \qquad \mathrm{Im}\,A_K = C_\varepsilon\,\mathrm{Im}\,A_K^{SM}$$

B_d and B_s mixing amplitudes (2+2 real parameters):

$$A_q e^{2i\phi_q} = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP}-\phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$

Observables:

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_d\to J/\psi K_s} = \sin 2(\beta + \phi_{B_d}) \qquad A_{CP}^{B_s\to J/\psi\phi} \sim \sin 2(-\beta_s + \phi_{B_s})$$

$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right) \qquad \Delta\Gamma^q/\Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

Parameter	Error				
	Now	50/fb	300/fb	1000/fb	3000/fb
ΔM_d [ps^{-1}]	0.002	0.0005	0.0002	0.0001	0.00006
ΔM_s [ps^{-1}]	0.021	0.005	0.002	0.001	0.0006
$\sin 2\beta$	0.022	0.008	0.0026	0.0018	0.001
γ [°]	6.5	0.9	0.4	0.2	0.09
α [°]	5.5	1	Belle II		
β_s [°]	4	0.26	0.11	0.06	0.034
V_{us}	$1 \cdot 10^{-4}$	$1 \cdot 10^{-4}$			
V_{cb}	2.7%	1%	Belle II		
V_{ub}	10%	1%	Belle II		
x		$1.5 \cdot 10^{-4}$	$4.5 \cdot 10^{-5}$	$3 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$
y		10^{-4}	$3 \cdot 10^{-5}$	$2 \cdot 10^{-5}$	10^{-5}
$\lvert q/p \rvert$		0.01	0.003	0.002	0.001
ϕ [°]		3	0.9	0.6	0.3
A_Γ		$4 \cdot 10^{-5}$	$12 \cdot 10^{-6}$	$8 \cdot 10^{-6}$	$4 \cdot 10^{-6}$
$\alpha_s(M_Z)$	0.0005	0.0002			
m_t	760 MeV	250 MeV	theory limited		
m_b	50 MeV	10 MeV			
B_K	1.3%	0.1%			
F_{B_s}	5 MeV	1 MeV			
F_{B_s}/F_{B_d}	1.4%	0.5%			
$F_{B_s}\sqrt{B_{B_s}}$	3.8%	3%			
ξ	2.5%	0.5%			

THE CHARM LOOP IN LCSR

- Working on the light-cone in the single-soft-gluon approximation (both conditions require $q^2 \ll 4m_c^2$), Khodjamirian et al obtain:

$$\Delta C_9^{(\bar{c}c,B\to K^*,\mathcal{M}_i)}(q^2) = (C_1 + 3C_2)\, g(m_c^2, q^2) + 2C_1 \tilde{g}^{(\bar{c}c,B\to K^*,\mathcal{M}_i)}(q^2)\,,$$

function	$\tilde{g}^{(\bar{c}c,B\to K)}$	$\tilde{g}^{(\bar{c}c,B\to K^*,M_1)}$	$\tilde{g}^{(\bar{c}c,B\to K^*,M_2)}$	$\tilde{g}^{(\bar{c}c,B\to K^*,M_3)}$
centr.value	-0.041	0.26	0.27	0.46
Δ_{m_c}	$+0.014$	-0.08	-0.09	-0.15
Δ_{M^2}	$^{+0.00}_{-0.001}$	$^{-0.04}_{+0.07}$	$^{-0.04}_{+0.08}$	$^{-0.07}_{+0.12}$
Δ_{λ_B}	$^{-0.016}_{+0.017}$	$^{+0.30}_{-0.17}$	$^{+0.36}_{-0.18}$	$^{+0.75}_{-0.33}$
Δ_{tot}	$^{+0.022}_{-0.016}$	$^{+0.31}_{-0.19}$	$^{+0.37}_{-0.21}$	$^{+0.76}_{-0.37}$

@ $q^2 = 1$ GeV^2

$$\left[\Delta C_7^{(\bar{c}c,B\to K^*\gamma)}\right]_1 \simeq \left[\Delta C_7^{(\bar{c}c,B\to K^*\gamma)}\right]_2 = (-1.2^{+0.9}_{-1.6}) \times 10^{-2}$$

@ $q^2 = 0$

- We use this result as an estimate at low q^2

THE HADRONIC ME

$$h_\lambda(q^2) = \frac{\epsilon^*_\mu(\lambda)}{m_B^2}\int d^4x e^{iqx}\langle \bar{K}^*|T\{j^\mu_{\rm em}(x)\mathcal{H}_{\rm eff}^{\rm had}(0)\}|\bar{B}\rangle$$

$$= h_\lambda^{(0)} + \frac{q^2}{1\,\mathrm{GeV}^2}h_\lambda^{(1)} + \frac{q^4}{1\,\mathrm{GeV}^4}h_\lambda^{(2)},$$

Parametrization by Jäger & Martin Camalich

Additional term to allow for breakdown of expansion @ $q^2 \sim 4m_c^2$

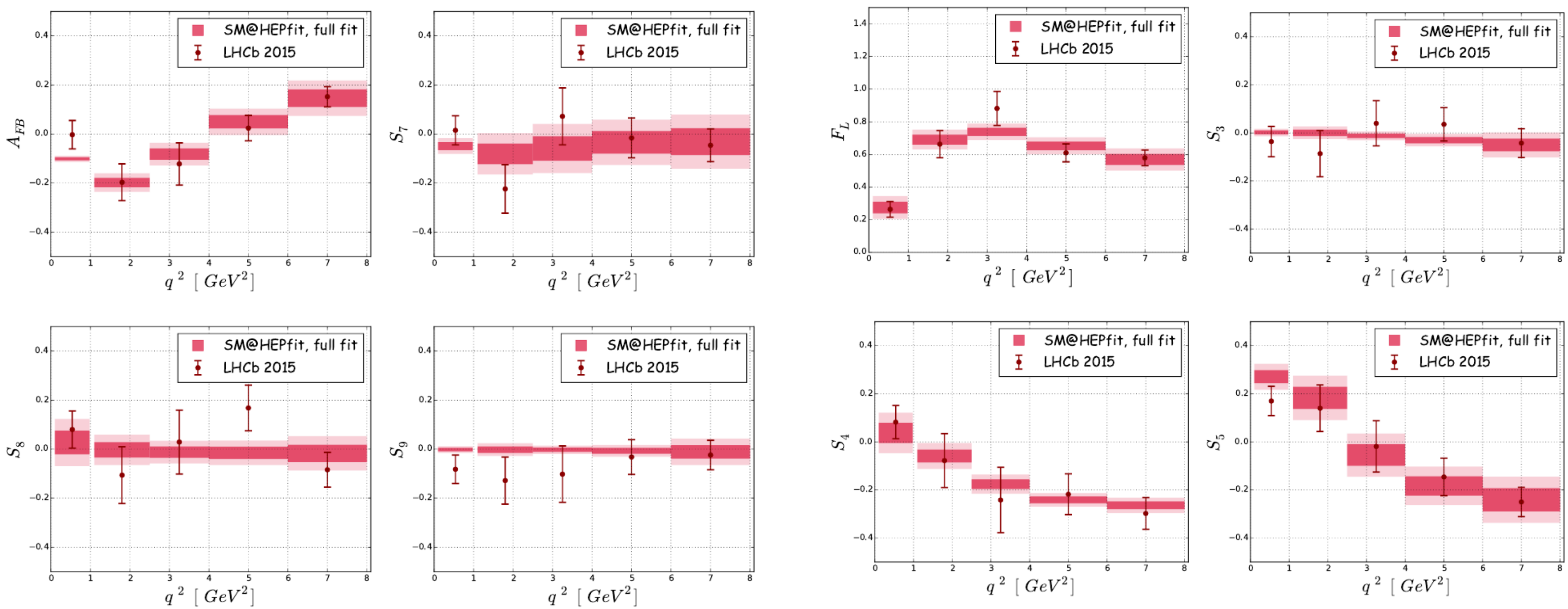
$h_\lambda^{(0)} \sim \Delta C_7$, $h_\lambda^{(1)} \sim \Delta C_9$, $h_\lambda^{(2)}$ not a shift of SM WC

Expect $h_+^{(0)}/h_-^{(0)} \sim \Lambda/m$

PHENOMENOLOGY

- Use LCSR form factors + QCDF corrections + Khodjamirian et al at $q^2=0$ and $q^2=1$
- Perform a Bayesian analysis using all available data
- Obtain posteriors for parameters and observables
- Remove data from the fit to obtain predictions and compare with data

FULL FIT



Posteriors for all observables and LHCb results.

Dark: 68% probability, light: 95% probability

q^2 bin [GeV^2]	Observable	measurement	full fit	prediction	p − value
[0.1, 0.98]	F_L	0.264 ± 0.048	0.275 ± 0.035	0.257 ± 0.035	0.13
	S_3	-0.036 ± 0.063	0.002 ± 0.008	0.002 ± 0.008	
	S_4	0.082 ± 0.069	0.037 ± 0.042	-0.025 ± 0.047	
	S_5	0.170 ± 0.061	0.271 ± 0.027	0.301 ± 0.024	
	A_{FB}	-0.003 ± 0.058	-0.102 ± 0.006	-0.104 ± 0.006	
	S_7	0.015 ± 0.059	-0.049 ± 0.016	-0.043 ± 0.017	
	S_8	0.080 ± 0.076	0.027 ± 0.048	-0.004 ± 0.046	
	S_9	-0.082 ± 0.058	-0.002 ± 0.007	-0.002 ± 0.007	
	P_5'	0.387 ± 0.142	0.774 ± 0.094	0.881 ± 0.082	0.0026
[1.1, 2.5]	F_L	0.663 ± 0.083	0.691 ± 0.030	0.688 ± 0.034	0.63
	S_3	-0.086 ± 0.096	0.000 ± 0.013	0.001 ± 0.013	
	S_4	-0.078 ± 0.112	-0.059 ± 0.027	-0.070 ± 0.032	
	S_5	0.140 ± 0.097	0.183 ± 0.046	0.208 ± 0.057	
	A_{FB}	-0.197 ± 0.075	-0.198 ± 0.019	-0.200 ± 0.022	
	S_7	-0.224 ± 0.099	-0.081 ± 0.042	-0.056 ± 0.049	
	S_8	-0.106 ± 0.116	-0.003 ± 0.031	-0.004 ± 0.033	
	S_9	-0.128 ± 0.096	-0.002 ± 0.013	0.002 ± 0.013	
	P_5'	0.298 ± 0.212	0.410 ± 0.099	0.460 ± 0.120	0.51
[2.5, 4]	F_L	0.882 ± 0.104	0.739 ± 0.025	0.729 ± 0.028	0.80
	S_3	0.040 ± 0.094	-0.012 ± 0.009	-0.014 ± 0.010	
	S_4	-0.242 ± 0.136	-0.176 ± 0.020	-0.179 ± 0.021	
	S_5	-0.019 ± 0.107	-0.055 ± 0.045	-0.055 ± 0.052	
	A_{FB}	-0.122 ± 0.086	-0.082 ± 0.023	-0.082 ± 0.025	
	S_7	0.072 ± 0.116	-0.059 ± 0.050	-0.080 ± 0.055	
	S_8	0.029 ± 0.130	-0.012 ± 0.023	-0.012 ± 0.023	
	S_9	-0.102 ± 0.115	-0.003 ± 0.009	-0.003 ± 0.009	
	P_5'	-0.077 ± 0.354	-0.130 ± 0.100	-0.130 ± 0.120	0.89
[4, 6]	F_L	0.610 ± 0.055	0.653 ± 0.026	0.661 ± 0.030	0.50
	S_3	0.036 ± 0.069	-0.030 ± 0.013	-0.030 ± 0.015	
	S_4	-0.218 ± 0.085	-0.241 ± 0.014	-0.239 ± 0.016	
	S_5	-0.146 ± 0.078	-0.183 ± 0.040	-0.205 ± 0.046	
	A_{FB}	0.024 ± 0.052	0.050 ± 0.027	0.067 ± 0.032	
	S_7	-0.016 ± 0.081	-0.034 ± 0.046	-0.037 ± 0.055	
	S_8	0.168 ± 0.093	-0.015 ± 0.025	-0.026 ± 0.026	
	S_9	-0.032 ± 0.071	-0.007 ± 0.012	-0.012 ± 0.014	
	P_5'	-0.301 ± 0.160	-0.388 ± 0.087	-0.440 ± 0.100	0.46
[6, 8]	F_L	0.579 ± 0.048	0.569 ± 0.034	0.517 ± 0.070	0.82
	S_3	-0.042 ± 0.060	-0.050 ± 0.026	-0.006 ± 0.054	
	S_4	-0.298 ± 0.066	-0.264 ± 0.016	-0.224 ± 0.037	
	S_5	-0.250 ± 0.061	-0.241 ± 0.048	-0.164 ± 0.100	
	A_{FB}	0.152 ± 0.041	0.146 ± 0.036	0.099 ± 0.077	
	S_7	-0.046 ± 0.067	-0.031 ± 0.055	0.010 ± 0.110	
	S_8	-0.084 ± 0.071	-0.017 ± 0.035	0.039 ± 0.055	
	S_9	-0.024 ± 0.060	-0.011 ± 0.027	0.018 ± 0.047	
	P_5'	-0.505 ± 0.124	-0.491 ± 0.098	-0.330 ± 0.200	0.46
[0.1, 2]	$\mathrm{BR} \cdot 10^7$	0.58 ± 0.09	0.65 ± 0.04	0.67 ± 0.04	0.36
[2, 4.3]		0.29 ± 0.05	0.33 ± 0.03	0.35 ± 0.04	0.35
[4.3, 8.68]		0.47 ± 0.07	0.45 ± 0.05	0.47 ± 0.11	1.0
	$\mathrm{BR}_{B\to K^*\gamma} \cdot 10^5$	4.33 ± 0.15	4.35 ± 0.14	4.61 ± 0.56	0.63

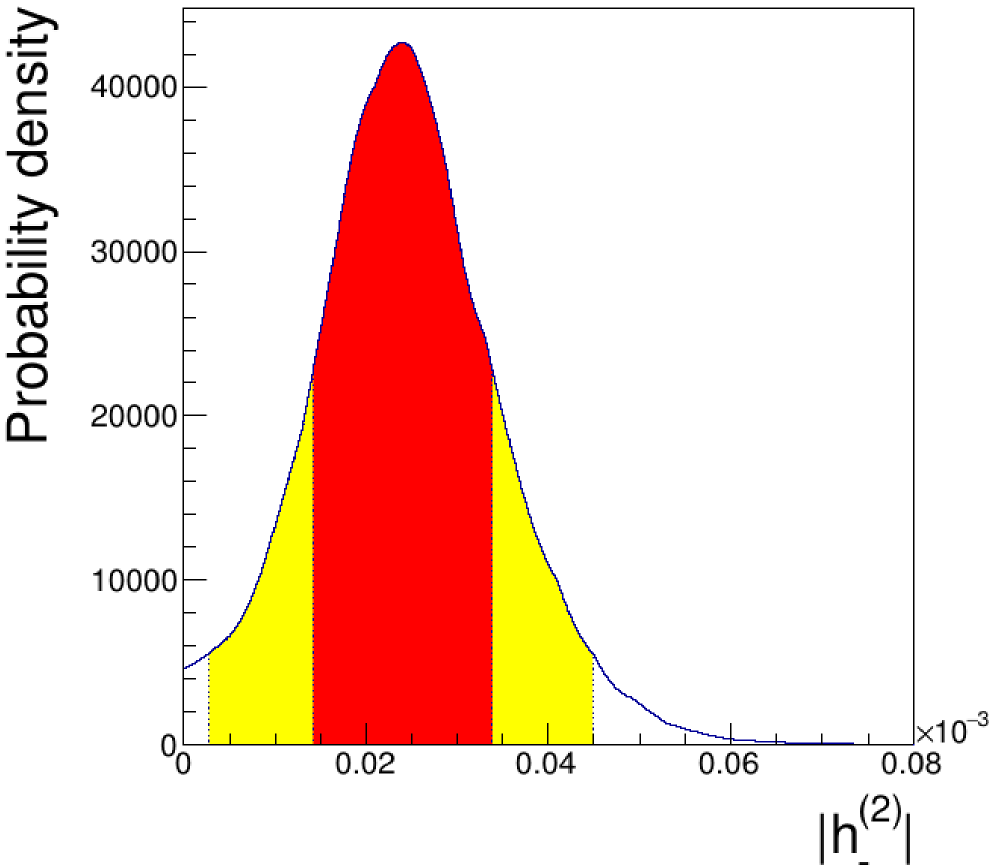
Observable	measurement	full fit	prediction	p-value
P_1	-0.23 ± 0.24	0.00 ± 0.01	0.00 ± 0.01	0.34
P_2	0.05 ± 0.09	-0.040 ± 0.00	-0.040 ± 0.00	0.32
P_3	-0.07 ± 0.11	0.00 ± 0.01	0.00 ± 0.01	0.53
F_L	0.16 ± 0.08	0.170 ± 0.04	0.18 ± 0.05	0.82
$\mathrm{BR} \cdot 10^7$	3.1 ± 1.0	1.4 ± 0.1	1.4 ± 0.1	0.06

$B \to K^* e^+ e^-$

$B \to K^* \mu^+ \mu^-$

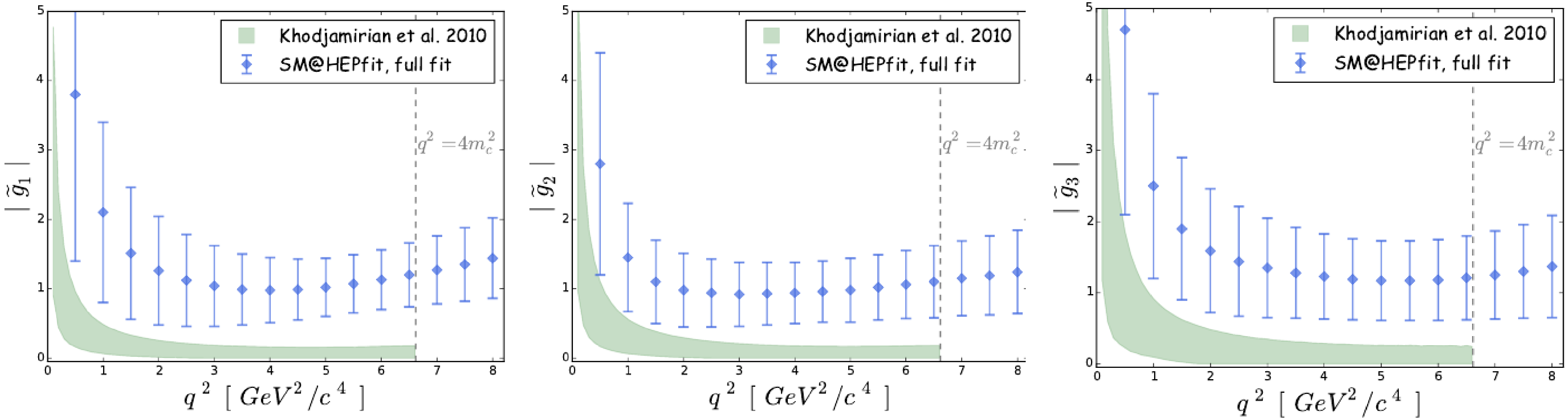
For a good model expect flatly distributed p-values

NEW PHYSICS OR SM?



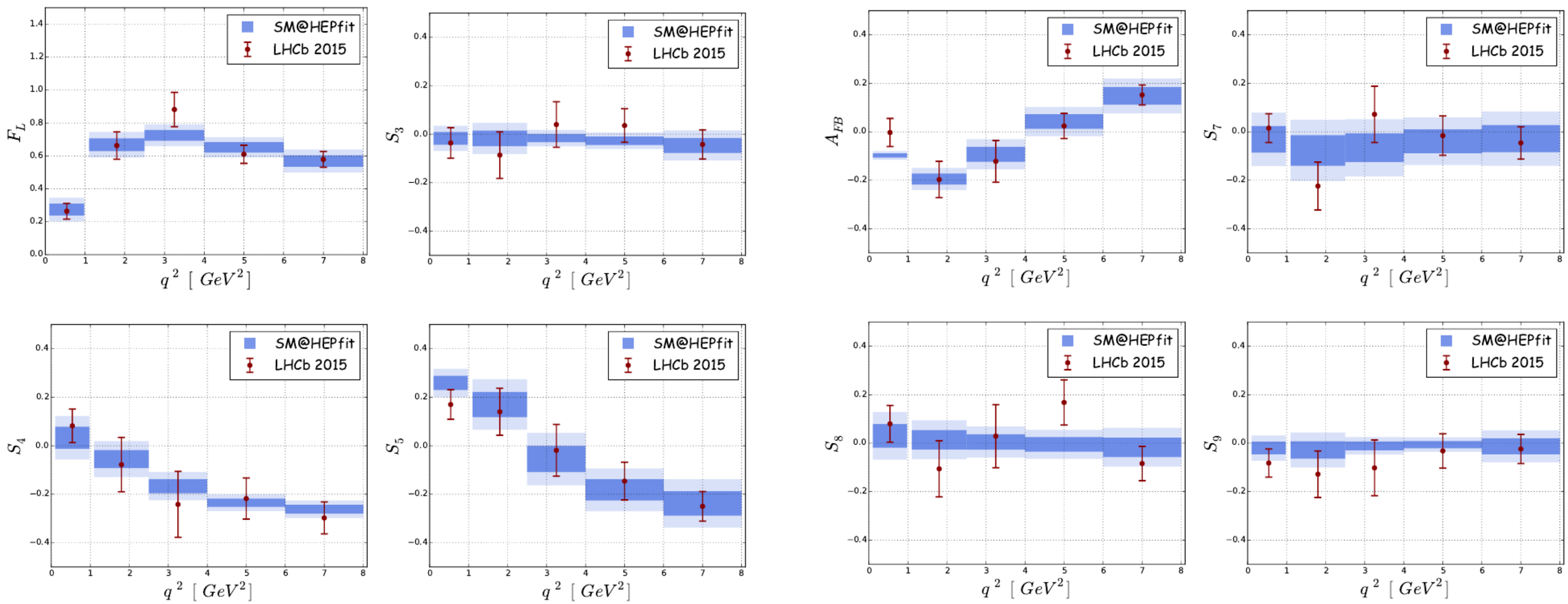
- Coefficient of q^4 term
- Cannot be reabsorbed in WC of dim-6 operators
- Distribution obtained using LCSR estimate at low q^2

GENERALIZED FIT W. NO TH INPUT ON POWER CORRS



Fitted power corrections are in the ballpark of Khodjamirian estimate. However, q^4 term now compatible with zero. Need more data and/or theory progress to clarify this issue.

GENERALIZED FIT W. NO TH INPUT ON POWER CORRS



Future projections: exp err/10

	using ref. [47] at $q^2 < 1$ GeV^2		not using ref. [47]	
Parameter	$\frac{\delta\,\text{abs}}{\text{abs}}$	δ **arg (rad)**	$\frac{\delta\,\text{abs}}{\text{abs}}$	δ **arg (rad)**
$h_0^{(0)}$	$\pm10\%$	±0.07	$\pm10\%$	±0.09
$h_0^{(1)}$	$\pm20\%$	±0.2	$\pm20\%$	±0.3
$h_0^{(2)}$	$\pm30\%$	±0.3	$\pm30\%$	±0.4
$h_+^{(0)}$	$\pm80\%$	±1.4	$\pm90\%$	±1.4
$h_+^{(1)}$	$\pm70\%$	±1.6	$\pm60\%$	±1.4
$h_+^{(2)}$	$\pm30\%$	±0.4	$\pm30\%$	±0.3
$h_-^{(0)}$	$\pm40\%$	±0.8	$\pm50\%$	±1.0
$h_-^{(1)}$	$\pm30\%$	±0.5	$\pm30\%$	±0.5
$h_-^{(2)}$	$\pm14\%$	±0.1	$\pm14\%$	±0.2