CKM 2018

Working Group IV
Sevda Esen, Alexander Lenz

Mass difference ΔM_q

Experiment.: HFLAV 2018 $\Delta m_s = 17.757 \pm 0.021\ \mathrm{ps}^{-1}$ $\Delta m_d = 0.5064 \pm 0.0019\ \mathrm{ps}^{-1}$

Talk by Manuel Schiller LHCb, most precise, so far 3fb-1, also in the analysis of $B_s \to J/\psi K^+ K^-$

Theory

$$M_{12}^s = \frac{G_F^2}{12\pi^2} \lambda_t^2 M_W^2 S_0(x_t) B f_{B_s}^2 M_{B_s} \hat{\eta}_B$$

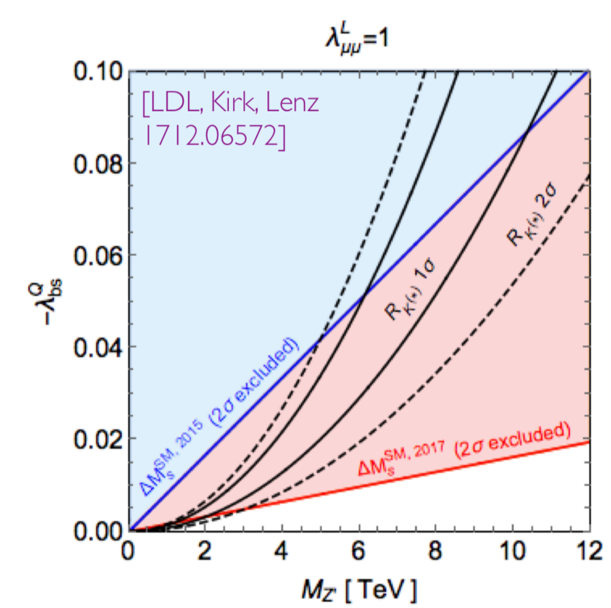
CKM

Non-Non-Perturbative theory input:

1) **Lattice: Aida El-Khadra**
2) **Sum rules: Thomas Mannel**
   Thomas Rauh

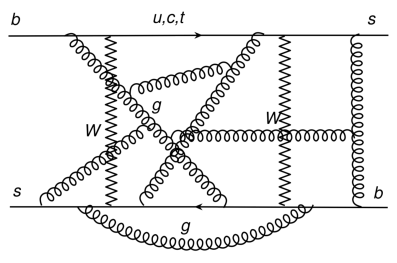
Severe consequences for BSM models: One constraint to kill them all! Luca di Luzio

Source	$f_{B_s}\sqrt{\hat{B}}$	ΔM_s^{SM}
HPQCD14 [132]	(247 ± 12) MeV	$(16.2 \pm 1.7)\ \mathrm{ps}^{-1}$
ETMC13 [133]	(262 ± 10) MeV	$(18.3 \pm 1.5)\ \mathrm{ps}^{-1}$
HPQCD09 [134] = FLAG13 [135]	(266 ± 18) MeV	$(18.9 \pm 2.6)\ \mathrm{ps}^{-1}$
FLAG17 [70]	$\mathbf{(274 \pm 8)}$ **MeV**	$\mathbf{(20.01 \pm 1.25)}$ $\mathbf{ps}^{-1}$
Fermilab16 [72]	(274.6 ± 8.8) MeV	$(20.1 \pm 1.5)\ \mathrm{ps}^{-1}$
HQET-SR [77, 136]	(278^{+28}_{-24}) MeV	$(20.6^{+4.4}_{-3.4})\ \mathrm{ps}^{-1}$
HPQCD06 [137]	(281 ± 20) MeV	$(21.0 \pm 3.0)\ \mathrm{ps}^{-1}$
RBC/UKQCD14 [138]	(290 ± 20) MeV	$(22.4 \pm 3.4)\ \mathrm{ps}^{-1}$
Fermilab11 [139]	(291 ± 18) MeV	$(22.6 \pm 2.8)\ \mathrm{ps}^{-1}$



Non-perturbative input for ΔM_q

1. **HQET-sum rules: 3-loop + NNLO matching:**
   Thomas Mannel

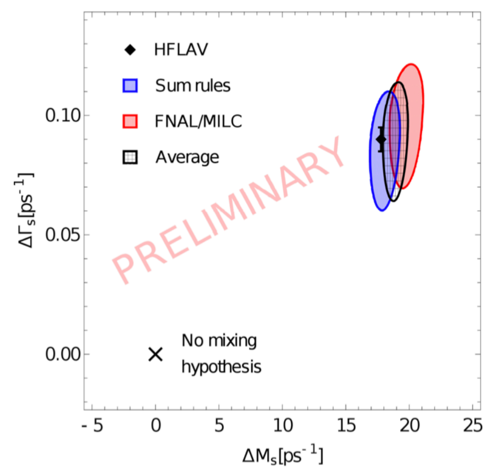


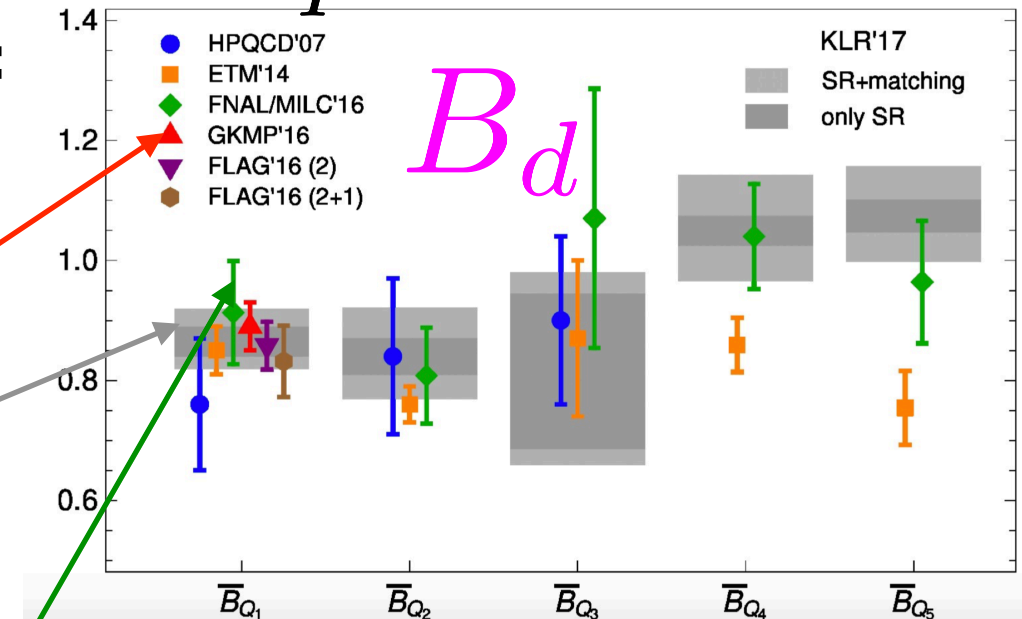
The various NLO contributions:

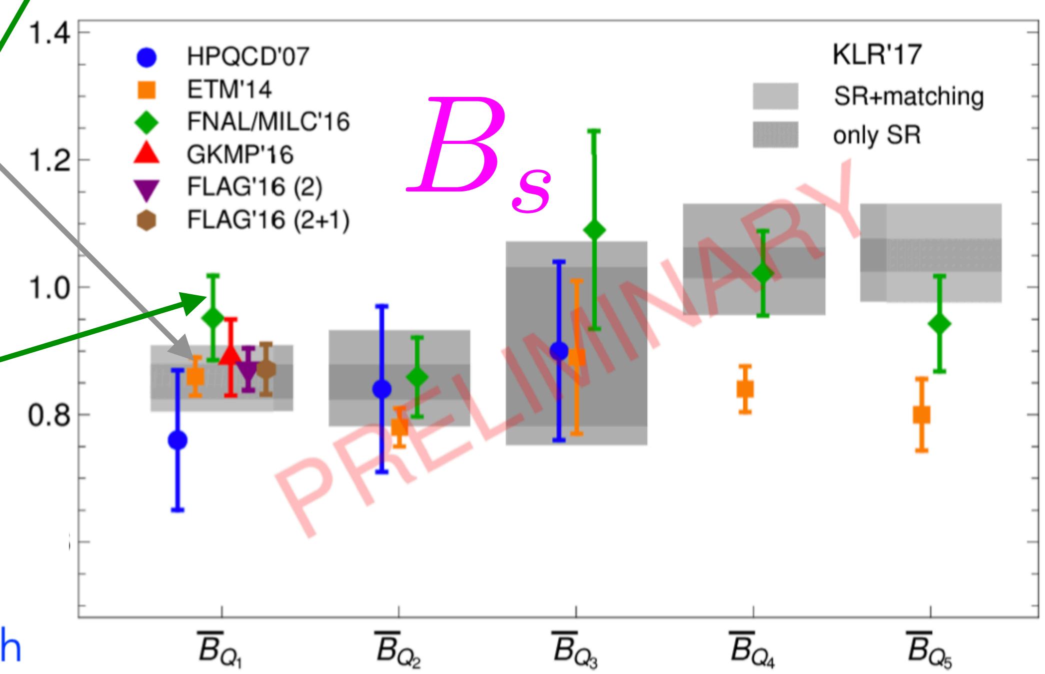
- Perturbative contribution (3-loop)
  $\Delta B_{PT} = -0.10 \pm 0.02 \pm 0.03$
  A.Grozin,R.Klein,ThM,AAP, Phys.Rev. D94, 034024 (2016)
- Quark condensate contribution (2-loop)
  $\Delta B_q = -0.002 \pm 0.001$
  A.Grozin,R.Klein,ThM,AAP, Phys.Rev. D94, 034024 (2016)
- Other condensates (tree-level+2-loop gluon cond)
  $\Delta B_{nonPT} = -0.006 \pm 0.005$
  ThM, B.D. Pecjak, AAP, Eur.Phys.J. C71 (2011) 1607

Total $\Delta B = -0.11 \pm 0.04 \pm 0.03$

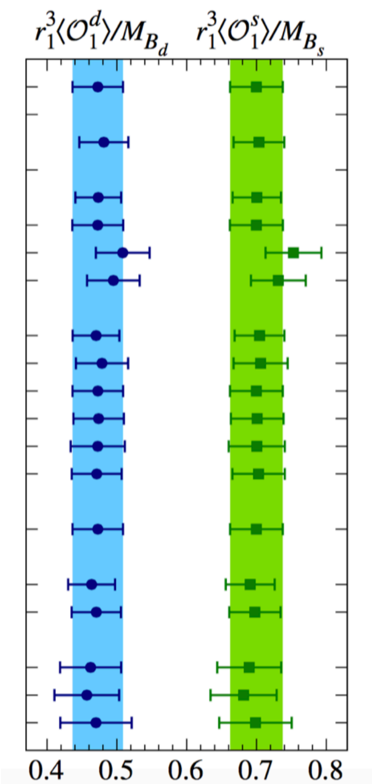
2. **HQET sum rules: ms-corrections:**
   Thomas Rauh







3. **Lattice: FNAL/MILC Aida El-Khadra**



- There are no roadblocks to increasing the precision of B mixing parameters.
- With current methods, tools, and resources, we can reach
  - 1-2% level precision for B mixing matrix elements (of local dimension 6 operators)
  - sub-percent level precision for ξ

about 2 sigma in Delta Mq

⇒ In phenomenological applications it is better to use directly the FLAG averages for the matrix elements (or $f_{B_q}\sqrt{\hat{B}_{B_q}}, \xi$), instead of reconstructing them from the bag parameters and decay constants.

Decay rate difference $\Delta\Gamma_s$

Experiment **HFLAV 2018** $\Delta\Gamma_s$ $+0.088 \pm 0.006\ \mathrm{ps}^{-1}$

Manuel Schiller LHCb

$B_s \to J/\psi K^+K^-$ K^+K^- in the $\phi(1020)$ [Phys. Rev. Lett. 114, 041801 (2015)]

higher K^+K^- invariant mass [JHEP 08 (2017) 037]

Pavel Reznicek ATLAS

Chandiprasad Kar CMS

Varavara Batozskaya LHCb

Mode	$\phi_s^{c\bar{c}s}$ [mrad]	$\Delta\Gamma_s$ [ps^{-1}]	Reference
$J/\psi K^+K^-$	-58±49±6	+0.0805±0.0091±0.0032	[PRL 114 (2015) 041801]
$J/\psi\pi^+\pi^-$	+70±68±8	-	[PLB 736 (2014) 186]
$J/\psi K^+K^{-1}$	+119±107±34	+0.066±0.018±0.010	[JHEP 08 (2017) 037]
Above 3 combined	+1±37	-	[JHEP 08 (2017) 037]
$\psi(2S)\phi$	$+230^{+290}_{-280}\pm20$	$+0.066^{+0.041}_{-0.044}\pm0.007$	[PLB 762 (2016) 253-262]
$D_s^+D_s^-$	+20±170±20	-	[PRL 113 (2014) 211801]

$s \times \Delta\Gamma_d/\Gamma_d = -0.002 \pm 0.010$

LHCb

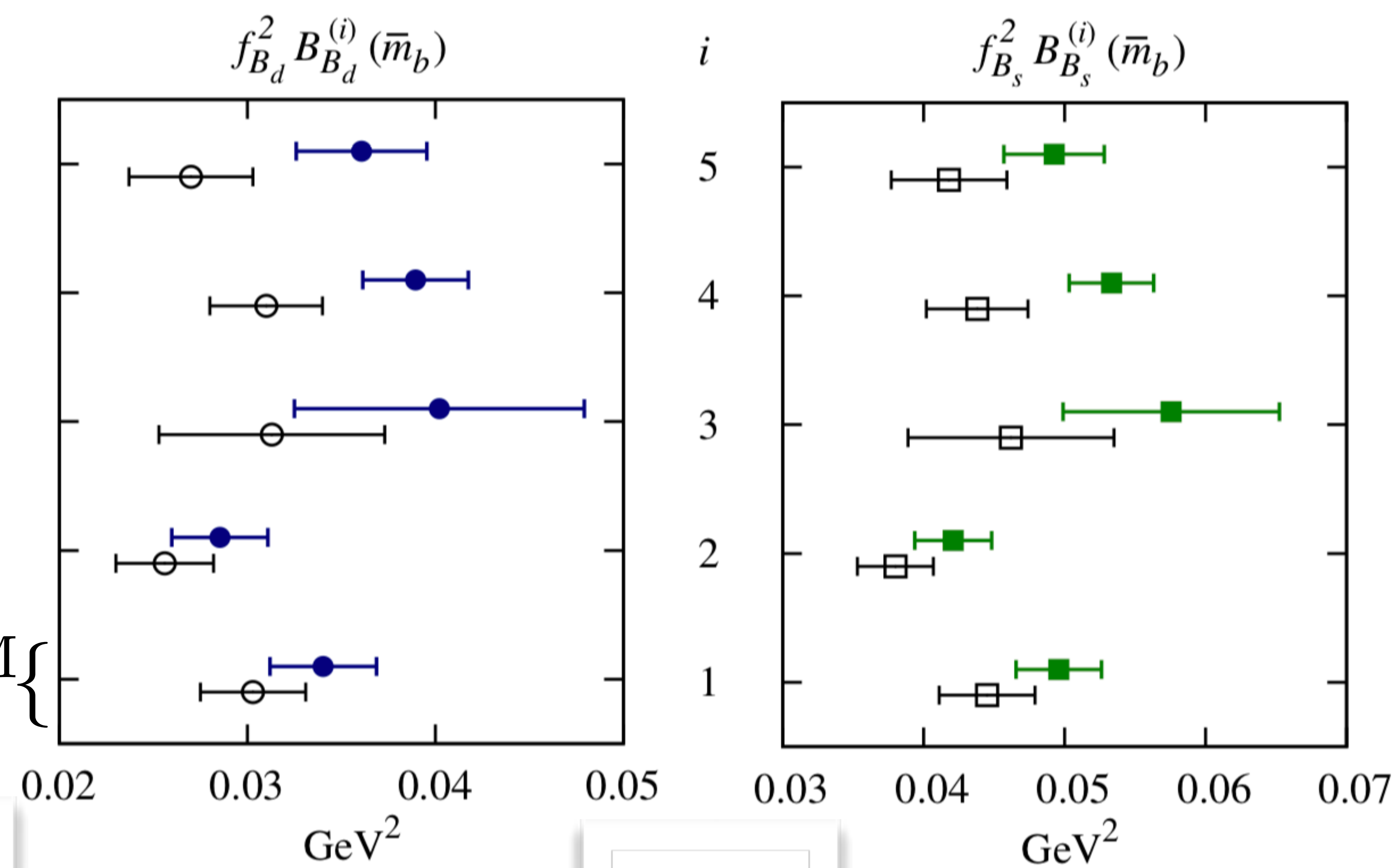
effective lifetimes $B^0 \to J/\psi K^{*0}$ $B^0 \to J/\psi K_S^0$ [JHEP04(2014)114]

ATLAS [JHEP06 (2016) 081]

Decay rate difference $\Delta\Gamma_s$

Theory:
Dim 6
Aida El Khadra
Thomas Rauh
Thomas Mannel

$\Delta M_s^{\mathrm{BSM}}$ $\Delta\Gamma_s^{\mathrm{SM}}$ ΔM_s^{SM}



$$\Delta\Gamma = \left(0.104 \pm 0.008_{\mathrm{scale}} \pm 0.007_{B,\tilde{B}_S} \pm 0.015_{\Lambda_{QCD}/m_b}\right)\ \mathrm{GeV} \qquad (\overline{\mathrm{MS}})$$

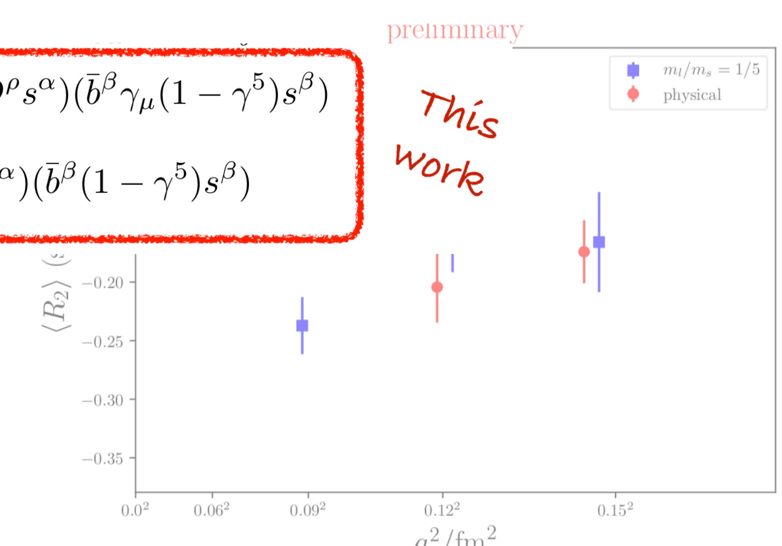
0.004?

0.007?

NNLO-QCD: Uli Nierste

Dim 7: Matthew Wingate

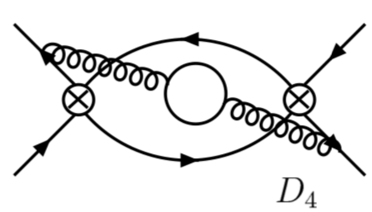
$$R_2 = \frac{1}{m_b^2}(\bar{b}^\alpha \overleftarrow{D}_\rho \gamma^\mu (1-\gamma^5) D^\rho s^\alpha)(\bar{b}^\beta \gamma_\mu (1-\gamma^5) s^\beta)$$
$$R_3 = \frac{1}{m_b^2}(\bar{b}^\alpha \overleftarrow{D}_\rho (1-\gamma^5) D^\rho s^\alpha)(\bar{b}^\beta (1-\gamma^5) s^\beta)$$



CKM 2020: α_s/m_b corrections to $\Delta\Gamma$

CKM 2022: NNLO corrections to $\Delta\Gamma$

CKM 2024: NNLO corrections to semileptonic CP asymmetry in $B_d - \bar{B}_d$ and $B_s - \bar{B}_s$ mixing



Lifetimes

b-hadron species	average lifetime	lifetime ratio
B^0	**1.520 ± 0.004 ps**	
B^+	**1.638 ± 0.004 ps**	$B^+/B^0 = 1.076 \pm 0.004$
B_s^0	**1.509 ± 0.004 ps**	$B_s^0/B^0 = 0.993 \pm 0.004$
B_{sL}	**1.415 ± 0.006 ps**	
B_{sH}	**1.615 ± 0.009 ps**	
B_c^+	**0.507 ± 0.009 ps**	
Λ_b	**1.470 ± 0.010 ps**	$\Lambda_b/B^0 = 0.967 \pm 0.007$

HFLAV 2018

Experiment

Γ_s

Manuel Schiller LHCb

$B_s \to J/\psi K^+K^-$ K^+K^- in the $\phi(1020)$ [Phys. Rev. Lett. 114, 041801 (2015)]
higher K^+K^- invariant mass [JHEP 08 (2017) 037]

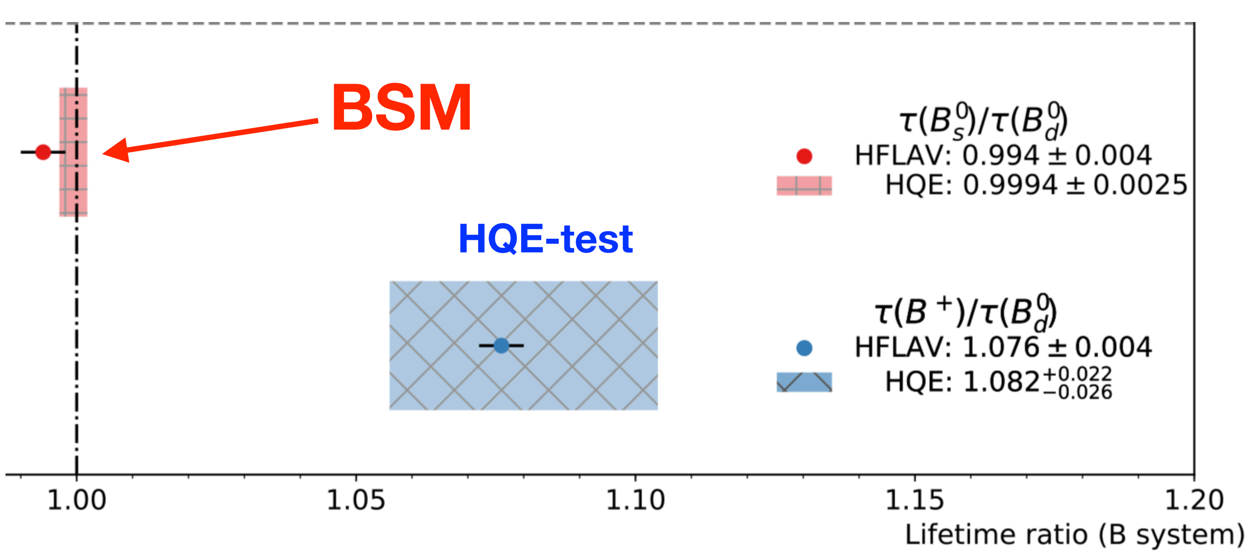
Pavel Reznicek ATLAS **Varavara Batozskaya LHCb**

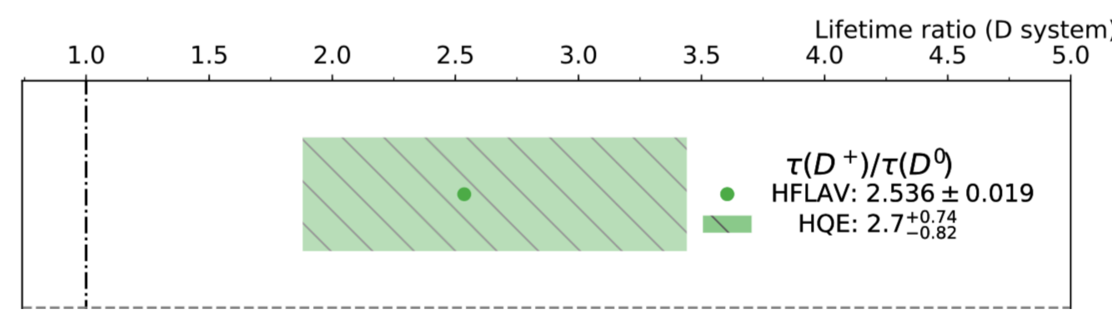
B^+, B_d, B_s, Λ_b **Chandiprasad Kar CMS: impressive list**

Theory:

non-perturbative determination of matrix elements with sum rules Thomas Rauh

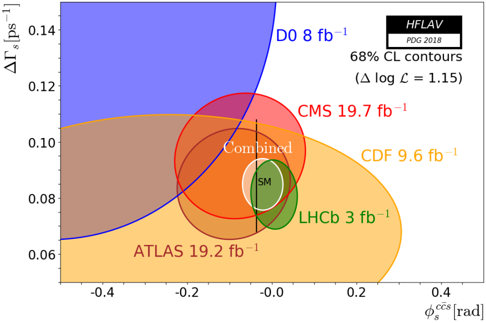
HQE-test





Andreas Jüttner to Oliver Witzel: Let's count the seconds until he asks us to do the lifetimes on the lattice....

CP violating phases



mixing phase from FCNC modes at LHCb [Maria]

- $B_s \to (K^+\pi^-)(K^-\pi^+)$ [$3fb^{-1}$]
  $\phi_{s\bar{d}d} = -0.06 \pm 0.13 \pm 0.03$ rad
- $B_s \to \phi\phi$ [$5fb^{-1}$ preliminary]
  $\phi_{ss\bar{s}} = -0.06 \pm 0.13 \pm 0.03$ rad

LHCb with $3fb^{-1}$ [Varvara]

$\mathcal{B}(B_s \to \phi f_0(980)) = (1.12 \pm 0.16^{+0.09}_{-0.08} \pm 0.2) \times 10^{-6}$
[gluonic $b \to s$]
$\mathcal{B}(B_s \to \phi\rho^0) = (2.7 \pm 0.7 \pm 0.2 \pm 0.2) \times 10^{-7}$
[isospin violating e/w penguin, surpressed $b \to u$ transition]

Resolving the ambiguity for $\sin 2\beta$ with Belle+Babar data [Bilas]

$\sin 2\beta(B^0 \to D^{(*)}h^0) = 0.80 \pm 0.14 \pm 0.06 \pm 0.03$ observation at 5.1σ
$\cos 2\beta(B^0 \to D^{(*)}h^0) = 0.91 \pm 0.09 \pm 0.07 \pm 0.03$ Evidence at 3.7σ

CP violating phases: penguin pollution

flavour octet

Martin

Smallness of NP poses new challenges to CPV interpretation

- SU(3) with breaking enables model-independent analyses
  - Corrections on top of λ^2 suppression $\rightarrow$ small
- High precision $\rightarrow$ Control penguins *and* annihilation
- QCD-mixing of mesons complicates $B \rightarrow J/\psi V$ analysis
  - Nevertheless possible (no SU(3) breakdown), w.i.p.
- Interplay with SU(3) breaking
  - careful interpretation of BR data necessary
- SU(3)-breaking in penguins difficult to include
  - presently irrelevant, ultimate numerical impact?

$b \rightarrow c\bar{c}s$ modes remain "golden"!

Simon

– **Using information from $B^0 \rightarrow J/\psi\, \pi^0$** [Belle, PRL 93, 261801] **together with inputs from $B^+ \rightarrow J/\psi\, K^+$ and $B^+ \rightarrow J/\psi\, \pi^+$** [LHCb JHEP 03 (2017) 036] [LHCb, PRD 95 (2017) 052005] **translates into penguin shift on β:**

$$\Delta\beta^{\rm peng} = (-1.10^{+0.70}_{-0.85})^\circ$$

- from Belle [preliminary] Bilas:

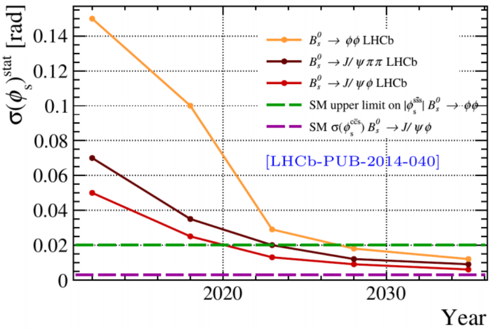
$$\mathcal{S}(B^0 \rightarrow J/\psi\pi^0) = -0.59 \pm 0.19 \pm 0.03$$

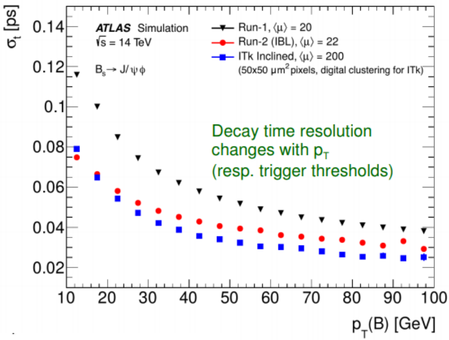
$$\mathcal{B}(B^0 \rightarrow J/\psi\pi^0) = (1.55 \pm 0.10^{+0.06}_{-0.07}) \times 10^{-5}$$

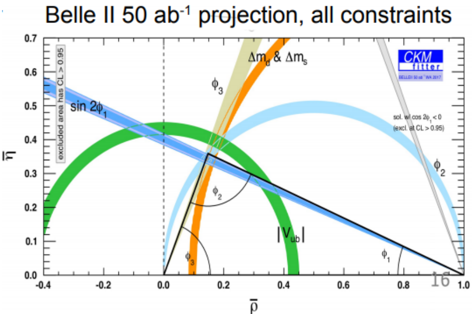
$$\sin 2\beta^{eff}(B^0 \rightarrow K_S\pi^0\pi^0) = 0.92^{+0.27}_{-0.31}{}^{+0.10}_{-0.11}$$

CP violating phases: prospects

Varvara, Pavel, Benjamin







CP violating phases: New physics

Luiz, Marcella, Gilberto