WG4 Summary:
Mixing and Mixing-induced CP Violation in the B system

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CKM Unitarity Triangle

Mumbai, India
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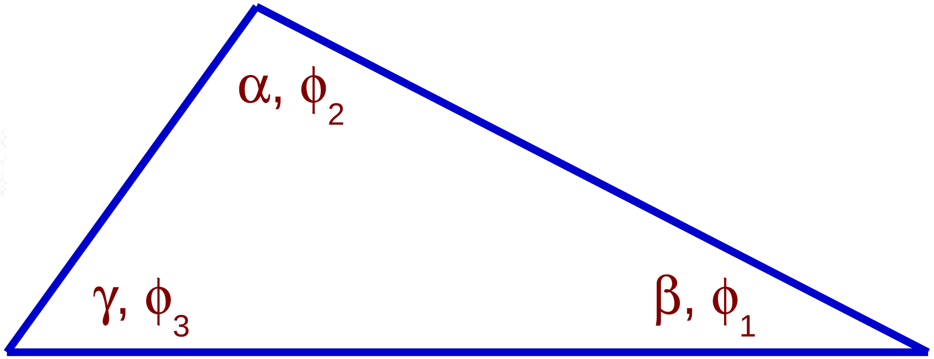
Introduction

- 3 parallel sessions + 2 joint sessions with WG5;
- Contributions including theory discussion and measurements of $\Delta m_{d,s}$, $\Delta\Gamma_{d,s}$, and the angles of the Unitarity TriangleS:

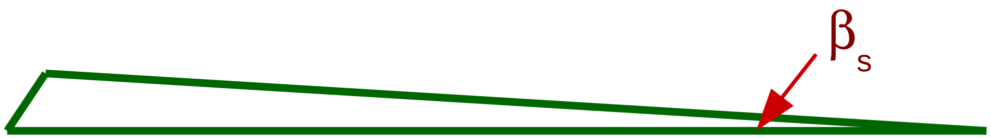
“bd triangle”

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



“bs triangle”

$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$



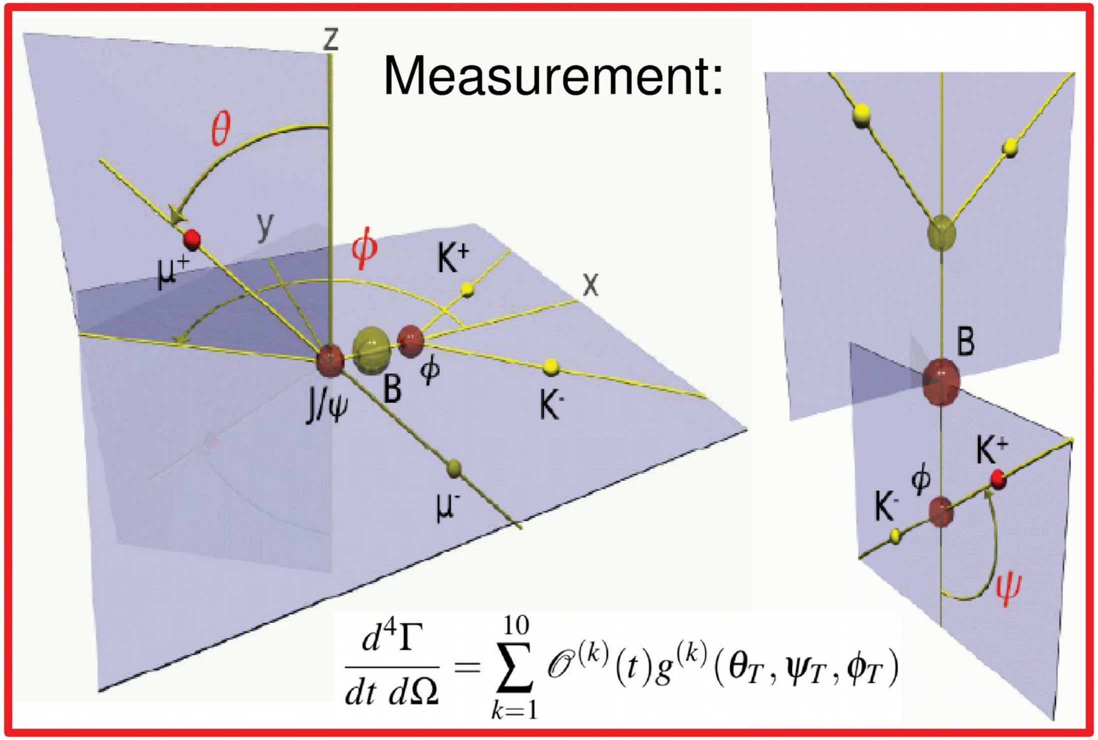
- Highlights from all talks will be presented (with apologies for skipping many important details)

ϕ_s and $\Delta\Gamma_s$ at ATLAS

Full angular analysis is needed to separate CP-odd and -even components.

Flavor tagging relying on electrons, muons, and charge of b-jet recoiling against B_s candidate

Tagging power ~1.5%



Measurement:

$$\frac{d^4\Gamma}{dt\,d\Omega} = \sum_{k=1}^{10} \mathcal{O}^{(k)}(t)\,g^{(k)}(\theta_T, \psi_T, \phi_T)$$

Muon tagger:

- muon $p_T > 2.5$ GeV
- $\Delta z(\mu)$ w.r.t. PV < 5 mm
- ΔR (cone) = 0.5
- $\kappa = 1.1$
- tracks $p_{Ti} > 0.5$ GeV

Electron tagger:

- electron $p_T > 0.5$ GeV
- $\Delta z(e)$ w.r.t. PV < 5 mm
- $\Delta R(e^\pm, B_s) > 0.4$
- ΔR (cone) = 0.5
- $\kappa = 1.0$
- tracks $p_{Ti} > 0.5$ GeV

b-jet tagger:

- b-tag weight 0.7 maximizing the tagging power on $B^\pm$ sample
- anti-k_T (R = 0.8)
- $\kappa = 1.1$
- using all tracks associated to the jet

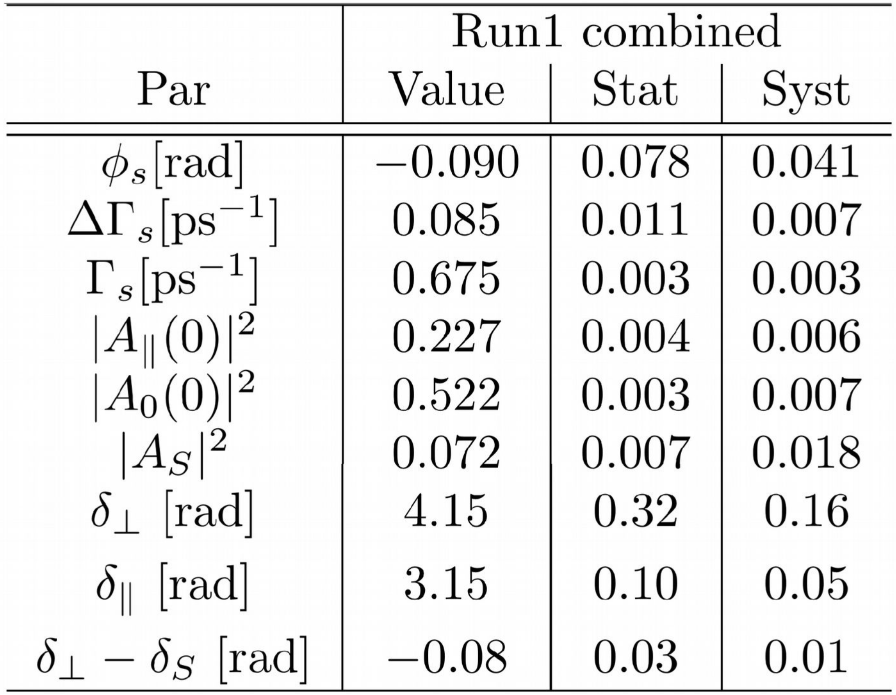
$$Q_{\text{jet}} = \frac{\sum_i^{N\text{ tracks}} q_i \cdot (p_{\text{T}i})^\kappa}{\sum_i^{N\text{ tracks}} (p_{\text{T}i})^\kappa}$$

P. Řezníček

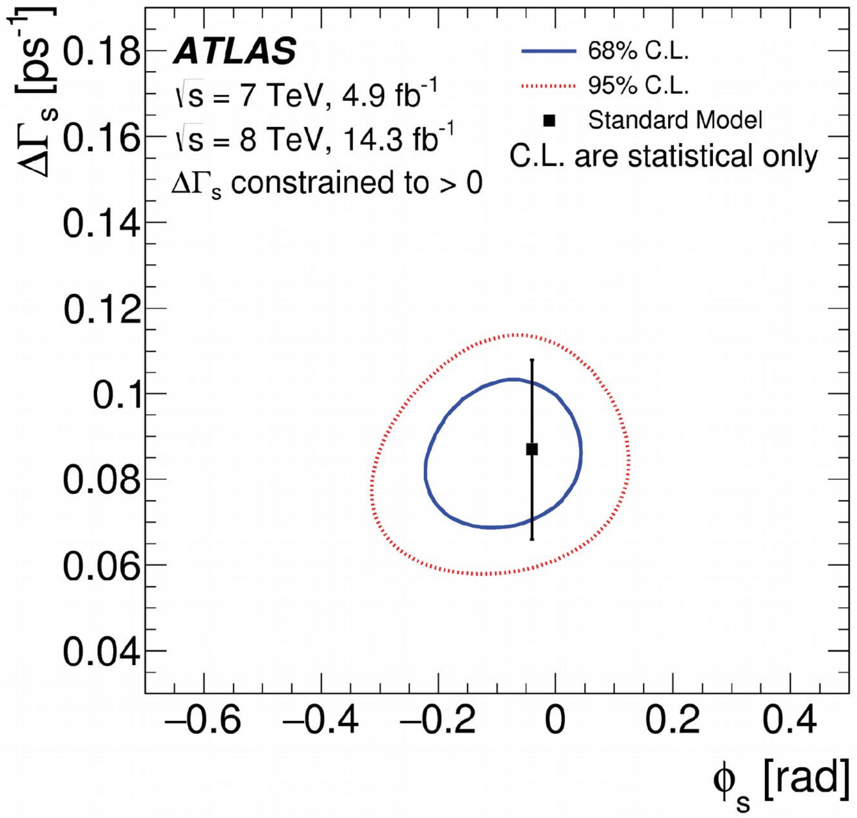
ϕ_s and $\Delta\Gamma_s$ at ATLAS

Combination of 7 and 8 TeV datasets:

ϕ_s and $\Delta\Gamma_s$ very well compatible with SM expectations



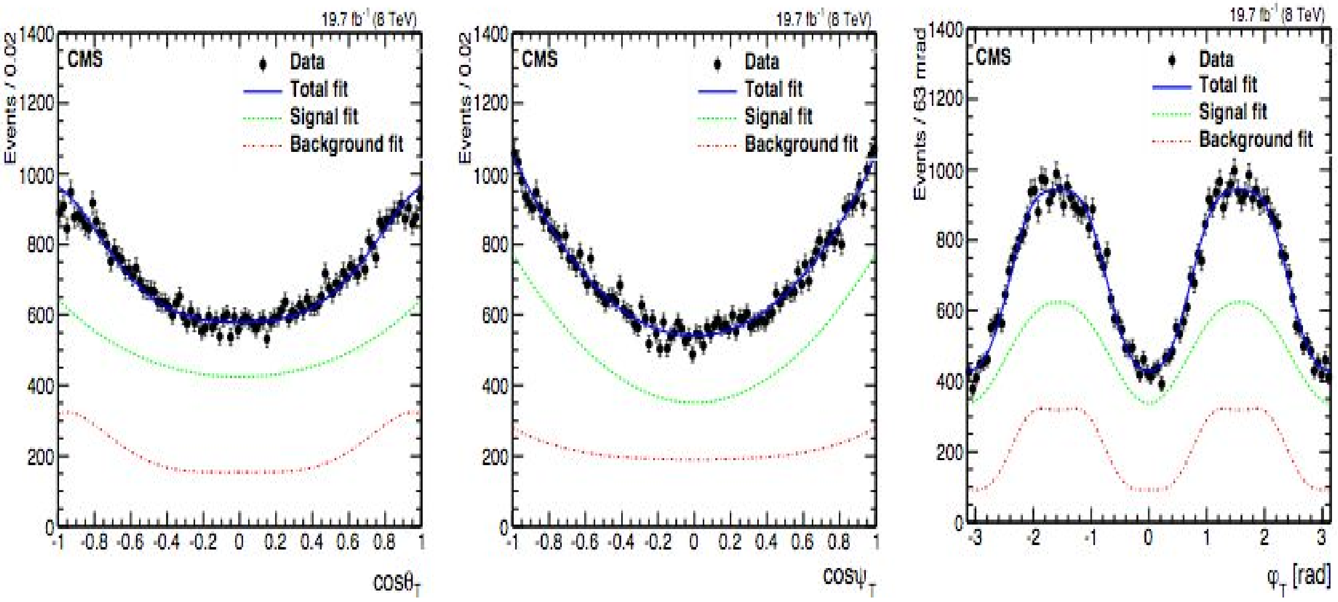
Par	Run1 combined Value	Stat	Syst
ϕ_s[rad]	-0.090	0.078	0.041
$\Delta\Gamma_s$[ps^{-1}]	0.085	0.011	0.007
Γ_s[ps^{-1}]	0.675	0.003	0.003
$\lvert A_{\parallel}(0)\rvert^2$	0.227	0.004	0.006
$\lvert A_0(0)\rvert^2$	0.522	0.003	0.007
$\lvert A_S\rvert^2$	0.072	0.007	0.018
$\delta_\perp$ [rad]	4.15	0.32	0.16
$\delta_\parallel$ [rad]	3.15	0.10	0.05
$\delta_\perp - \delta_S$ [rad]	-0.08	0.03	0.01



Large improvement expected with Run2 data (and upgraded detector and trigger strategies)

P. Řezníček

ϕ_s and $\Delta\Gamma_s$ at CMS



CMS performs a similar full angular analysis

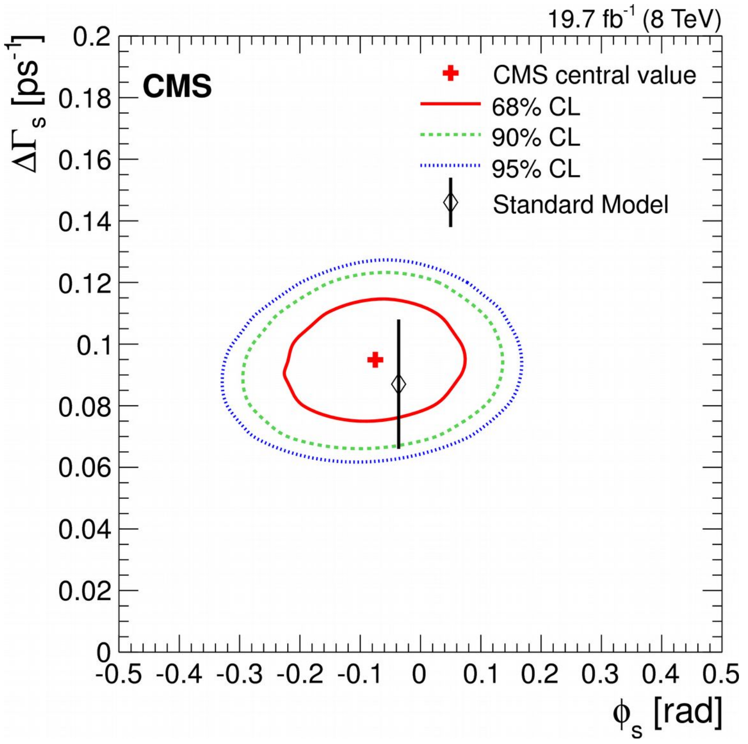
Flavor tagging based on high p_T leptons from the decay of the other b hadron.

Tagging power ~1.3%

8 TeV dataset results:

$$\phi_s = -0.075 \pm 0.097\,(\text{stat}) \pm 0.031\,(\text{syst})\,\text{rad}$$

$$\Delta\Gamma_s = 0.095 \pm 0.013\,(\text{stat}) \pm 0.007\,(\text{syst})\,\text{ps}^{-1}$$

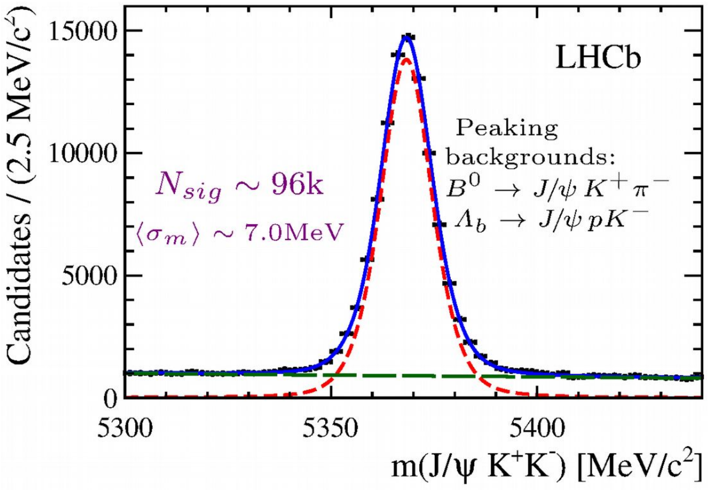


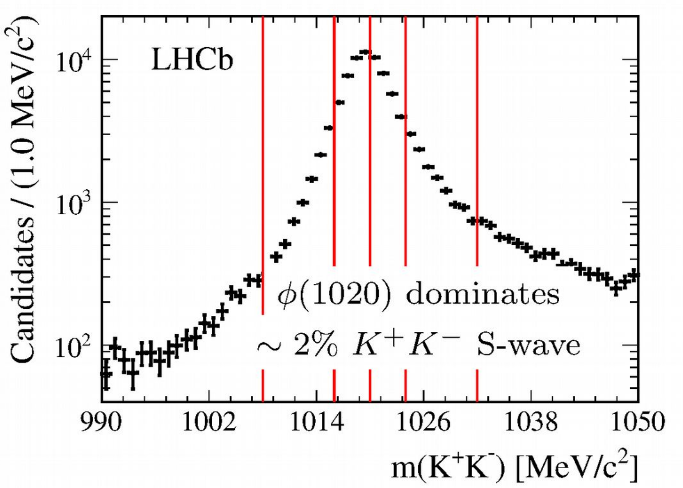
P. Behera

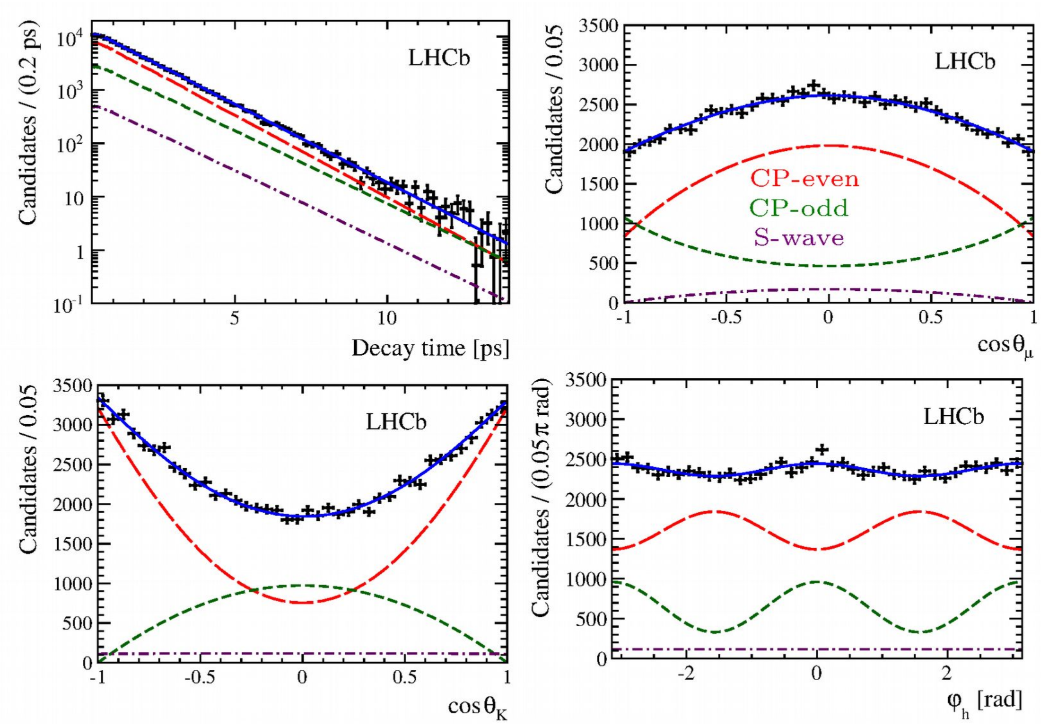
ϕ_s and $\Delta\Gamma_s$ at LHCb

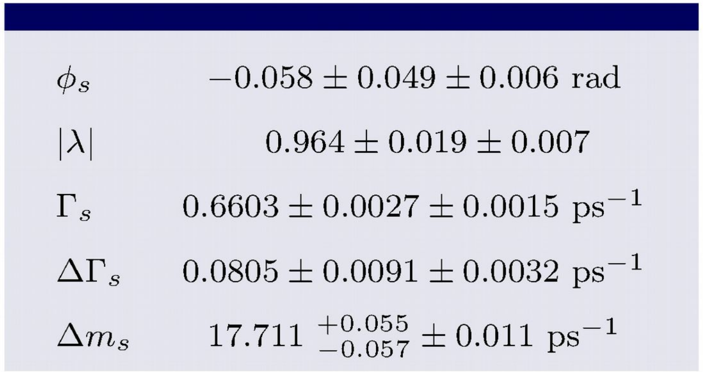
$B_s \rightarrow J/\psi\ \phi$ full angular analysis

A small S-wave component is taken into account









ϕ_s	$-0.058 \pm 0.049 \pm 0.006$ rad
$\lvert\lambda\rvert$	$0.964 \pm 0.019 \pm 0.007$
Γ_s	$0.6603 \pm 0.0027 \pm 0.0015$ ps^{-1}
$\Delta\Gamma_s$	$0.0805 \pm 0.0091 \pm 0.0032$ ps^{-1}
Δm_s	$17.711\ ^{+0.055}_{-0.057} \pm 0.011$ ps^{-1}

G. Cowan

ϕ_s and $\Delta\Gamma_s$ at LHCb

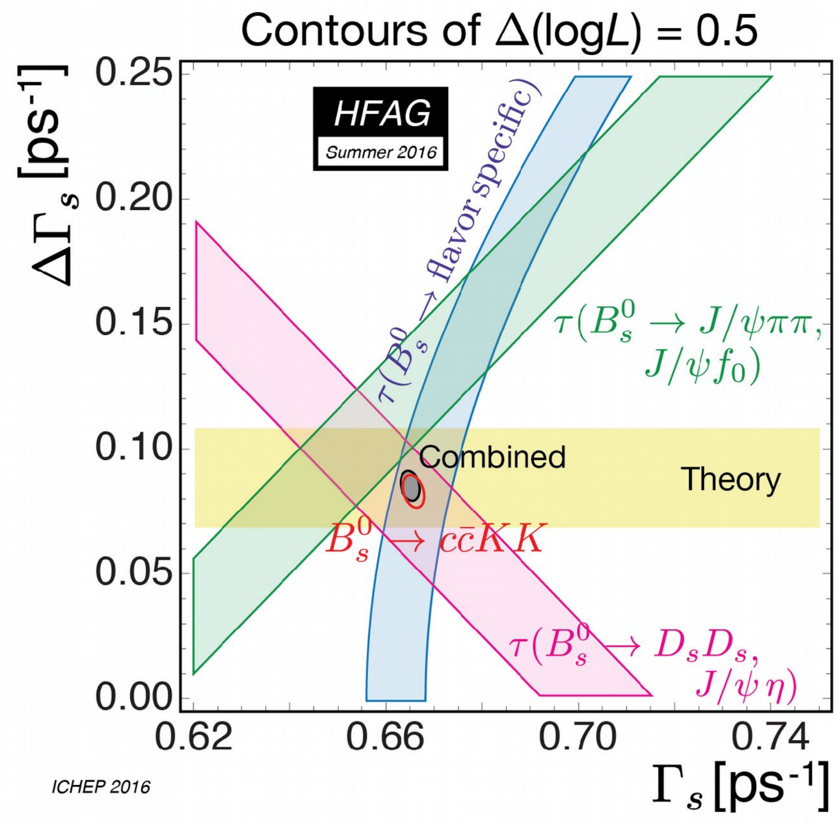
More channels sensitive to ϕ_s are considered or will be added using Run2 data:

- ➔ $B_s \rightarrow \eta_c\,\phi$ (first observation reported)

Gluonic penguin dominated modes:

- ➔ $B_s \rightarrow \phi\,\phi$,
- ➔ $B_s \rightarrow \phi\,\pi^+\,\pi^-$,
- ➔ $B_s \rightarrow \phi\,K^+\,K^-$,
- ➔ ...

Constraints on $(\Delta)\Gamma_s$ can be obtained by measuring the lifetimes of CP-odd, CP-even, and flavor specific final states:



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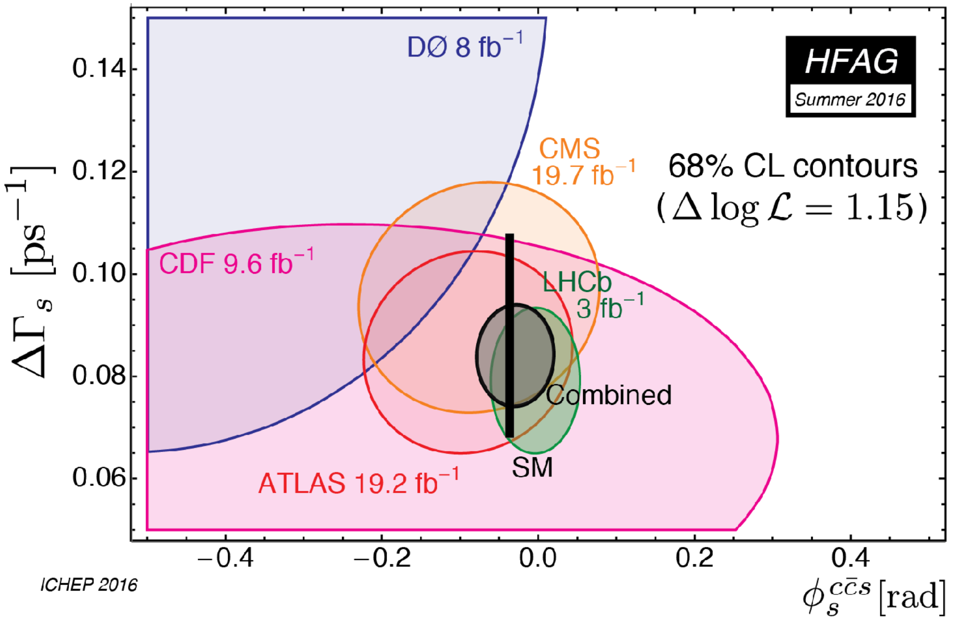
ϕ_s and $\Delta\Gamma_s$ - Summary



$$\Delta\Gamma_s = 0.085 \pm 0.006\,\mathrm{ps}^{-1}$$

$$\phi_s = -0.030 \pm 0.033\ \mathrm{rad}$$

$$\Delta\Gamma_s^{\mathrm{SM}} = 0.088 \pm 0.020\,\mathrm{ps}^{-1}$$

assumes no NP in B_s^0 mixing

[Artuso et al. arXiv:1511.09466]

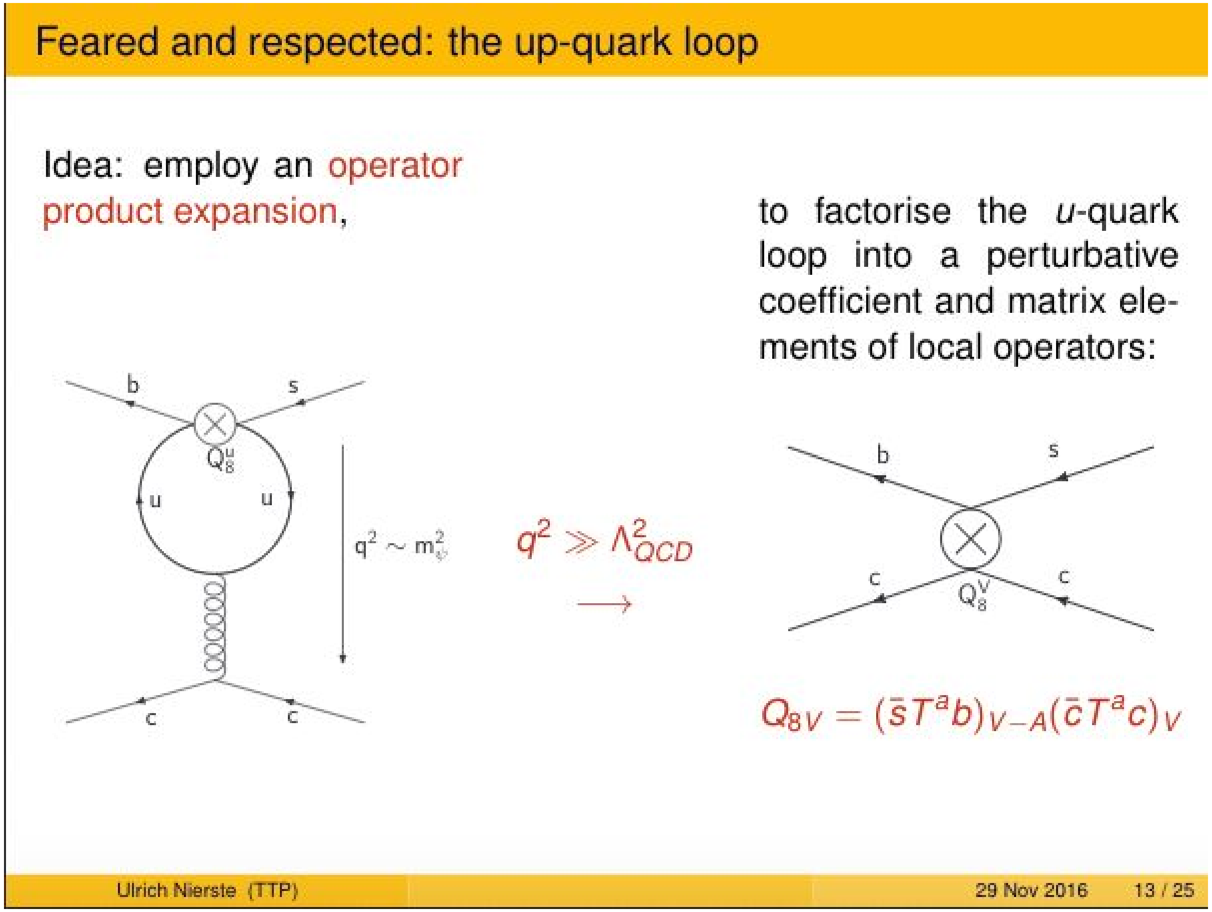
- Still room for NP at ~ 20% [see Zoltan's talk].
- As precision improves, need to control penguin pollution (see next talk).

Mode	$\phi_s^{c\bar{c}s}$ [rad]	$\Delta\Gamma_s$ [ps^{-1}]	Ref.	Exp
$B_s^0 \to J/\psi\,\phi$	$[-0.60, +0.12]$, 68%CL	$+0.068 \pm 0.026 \pm 0.009$	PRL 109 (2012) 171802	CDF (9.6 fb^{-1})
$B_s^0 \to J/\psi\,\phi$	-0.55 ± 0.37	$+0.163 \pm 0.065$	PRD 85 (2012) 032006	D0 (8.0 fb^{-1})
$B_s^0 \to J/\psi\,\phi$	$-0.090 \pm 0.078 \pm 0.041$	$+0.085 \pm 0.011 \pm 0.007$	JHEP 1608 (2016) 147	ATLAS (19.2 fb^{-1})
$B_s^0 \to J/\psi\,\phi$	$-0.075 \pm 0.097 \pm 0.031$	$+0.095 \pm 0.013 \pm 0.007$	PLB 757 (2016) 97	CMS (19.7 fb^{-1})
$B_s^0 \to J/\psi\,\phi$	$-0.058 \pm 0.049 \pm 0.006$	$+0.0805 \pm 0.0091 \pm 0.0033$	PRL 114 (2015) 041801	LHCb (3.0 fb^{-1})
$B_s^0 \to J/\psi\,\pi^+\pi^-$	$+0.070 \pm 0.068 \pm 0.008$	–	PLB 736 (2014)	LHCb (3.0 fb^{-1})
$B_s^0 \to \psi(2S)\phi$	$+0.23 \pm 0.29 \pm 0.02$	$+0.066 \pm 0.042 \pm 0.007$	PLB 762 (2016) 253-262	LHCb (3.0 fb^{-1})
$B_s^0 \to D_s^+ D_s^-$	$+0.02 \pm 0.17 \pm 0.02$	–	PRL 113 (2014) 211801	LHCb (3.0 fb^{-1})

G. Cowan

Constraining “penguin” pollution - theory

- Attempts to control th. uncertainty based on either flavor SU(3) or direct calculation approaches;
- Most recent developments are flavor SU(3) approaches including 1st order breaking effects, or OPE style calculations;
- For ϕ_s, the latter avoids issues with ϕ-ω mixing.



Feared and respected: the up-quark loop

Idea: employ an operator product expansion,

to factorise the *u*-quark loop into a perturbative coefficient and matrix elements of local operators:

$q^2 \gg \Lambda^2_{QCD}$ $\longrightarrow$

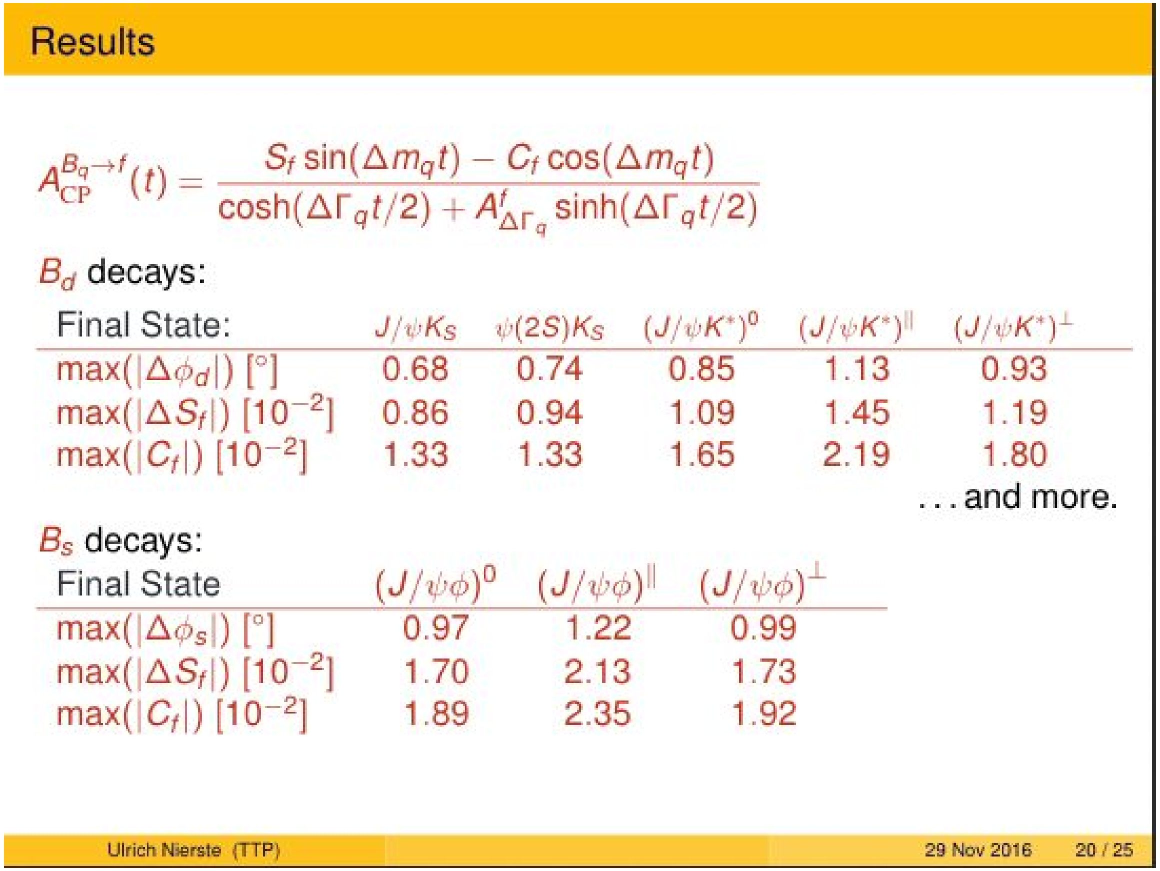
$Q_{8V} = (\bar{s}T^a b)_{V-A}(\bar{c}T^a c)_V$

Ulrich Nierste (TTP) 29 Nov 2016 13 / 25

U. Nierste

Constraining “penguin” pollution - theory

- Integrate out the u-quark loop, on the basis that the typical momentum flow is large ~m(J/ψ) (cf Bander Soni Silverman);
- Produces a factorization formula for the penguin contributions, relying on the observation that soft and collinear divergences formally cancel or factorize at leading order;
- The current corresponding estimate is $|\Delta\phi_s| < 1^o$ degree, using $B_s \to J/\psi\ \phi$;



Results

$$A_{\rm CP}^{B_q\to f}(t) = \frac{S_f \sin(\Delta m_q t) - C_f \cos(\Delta m_q t)}{\cosh(\Delta\Gamma_q t/2) + A^f_{\Delta\Gamma_q}\sinh(\Delta\Gamma_q t/2)}$$

B_d decays:

Final State:	$J/\psi K_S$	$\psi(2S)K_S$	$(J/\psi K^*)^0$	$(J/\psi K^*)^{\parallel}$	$(J/\psi K^*)^{\perp}$
$\max(\lvert\Delta\phi_d\rvert)$ [°]	0.68	0.74	0.85	1.13	0.93
$\max(\lvert\Delta S_f\rvert)$ $[10^{-2}]$	0.86	0.94	1.09	1.45	1.19
$\max(\lvert C_f\rvert)$ $[10^{-2}]$	1.33	1.33	1.65	2.19	1.80

. . . and more.

B_s decays:

Final State	$(J/\psi\phi)^0$	$(J/\psi\phi)^{\parallel}$	$(J/\psi\phi)^{\perp}$
$\max(\lvert\Delta\phi_s\rvert)$ [°]	0.97	1.22	0.99
$\max(\lvert\Delta S_f\rvert)$ $[10^{-2}]$	1.70	2.13	1.73
$\max(\lvert C_f\rvert)$ $[10^{-2}]$	1.89	2.35	1.92

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U. Nierste

Constraining “penguin” pollution - experiment

- We are well into the precision era for sin(2β) and ϕ_s: it is crucial to be able to control “penguin” pollution effects;
- LHCb is pioneering this effort: simultaneous fit of golden modes $B_d \to J/\psi\ K_S$ and $B_s \to J/\psi\ \phi$ and other channels related to them via SU(3);
- Target: control effects from penguin amplitudes;

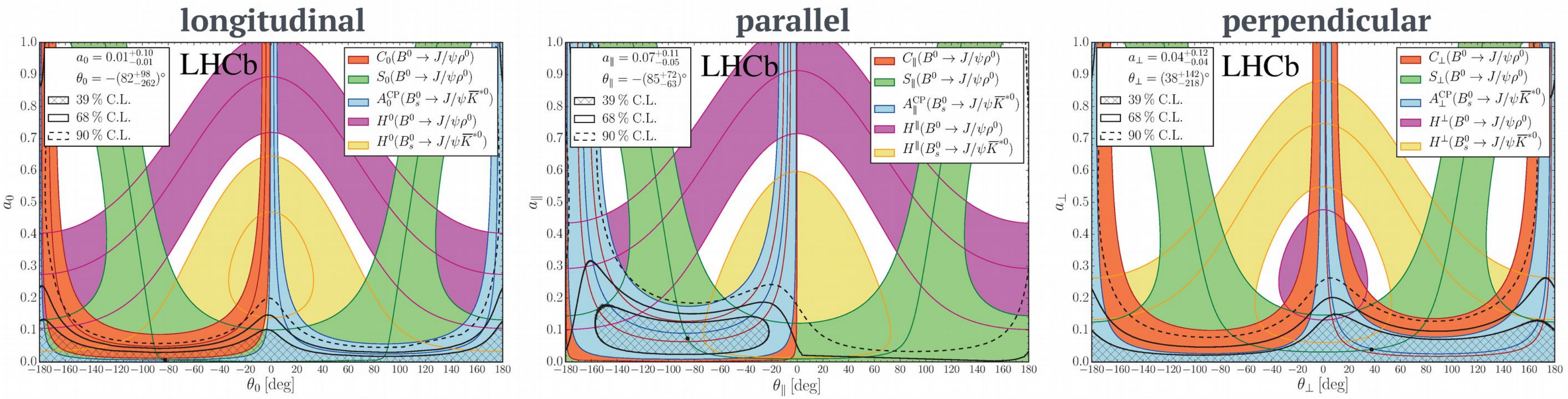
- Control modes for $B_s \to J/\psi\ \phi$:
  - $B_d \to J/\psi\ \rho^0$(and $B_d \to J/\psi\ \omega$), $B_s \to J/\psi\ K^{*0}$, search for $B_d \to J/\psi\ \rho^0$ and $B_d \to J/\psi\ \phi$;

- Control modes for $B_d \to J/\psi\ K_S$:
  - $B_s \to J/\psi\ K_S$, $B_d \to J/\psi\ \pi^0$ and $B_s \to J/\psi\ \pi^0$.

S. Akar

Constraining “penguin” pollution - experiment

- **Using the extended fit method proposed in:** [JHEP 1503 (2015) 145]
  - Assuming: $\left|\frac{\mathcal{A}_i'(B_s^0 \to J/\psi\phi)}{\mathcal{A}_i(B_s^0 \to J/\psi \bar{K}^{*0})}\right| = \left|\frac{\mathcal{A}_i'(B_s^0 \to J/\psi\phi)}{\mathcal{A}_i(B^0 \to J/\psi\rho^0)}\right|$



$$a_0 = 0.01^{+0.10}_{-0.01} \qquad \theta_0 = -\left(82^{+98}_{-262}\right)^\circ$$
$$a_\parallel = 0.07^{+0.11}_{-0.05} \qquad \theta_\parallel = -\left(85^{+71}_{-63}\right)^\circ$$
$$a_\perp = 0.04^{+0.12}_{-0.04} \qquad \theta_\perp = \left(38^{+142}_{-218}\right)^\circ$$

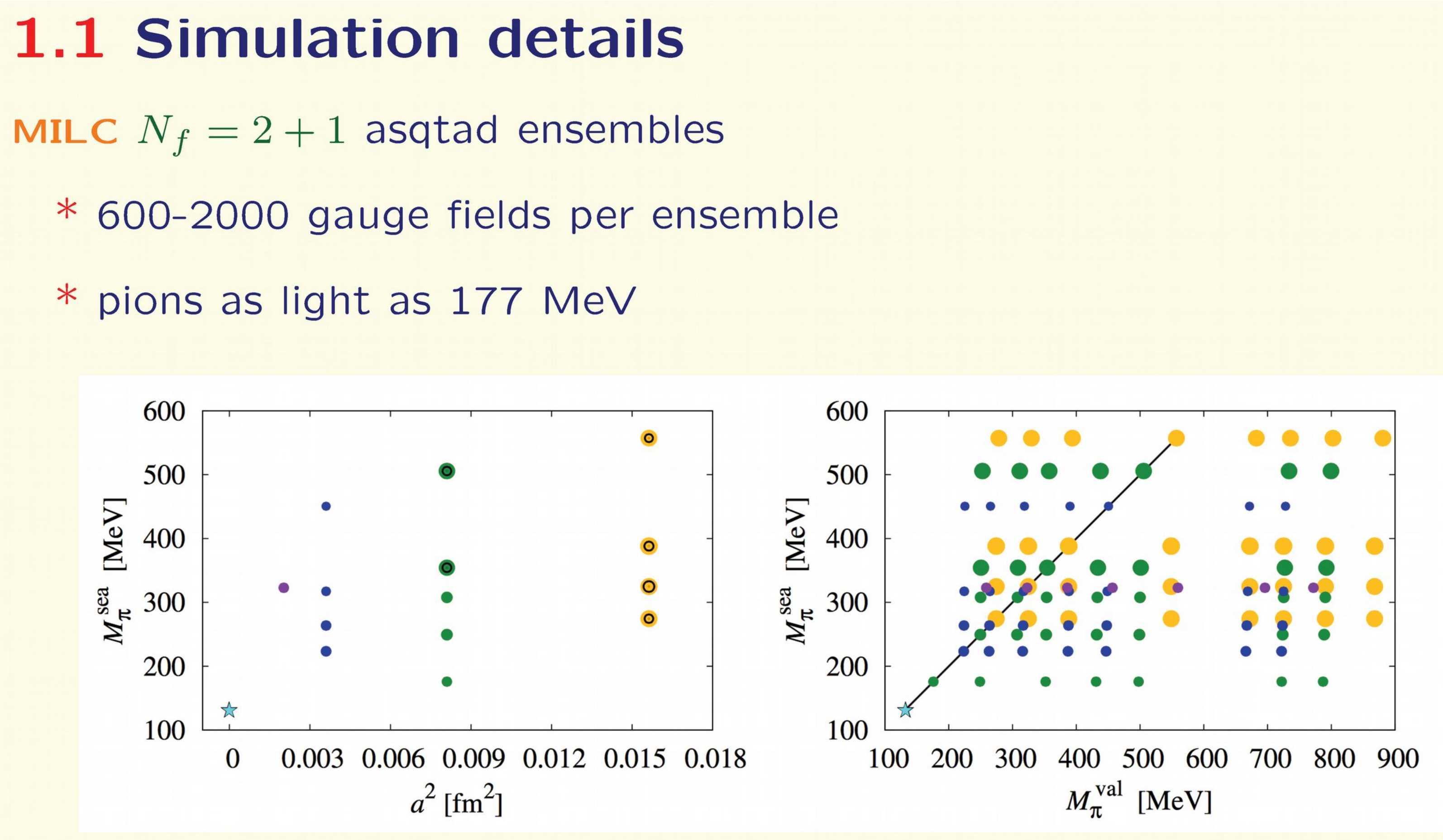
$$\Delta\phi_{s,0}^{J/\psi\phi} = 0.000^{+0.009}_{-0.011}\,(\text{stat})^{+0.004}_{-0.009}\,(\text{syst})$$
$$\Delta\phi_{s,\parallel}^{J/\psi\phi} = 0.001^{+0.010}_{-0.014}\,(\text{stat})^{+0.007}_{-0.008}\,(\text{syst})$$
$$\Delta\phi_{s,\perp}^{J/\psi\phi} = 0.003^{+0.010}_{-0.014}\,(\text{stat})^{+0.007}_{-0.008}\,(\text{syst})$$

Penguin effects in B_s^0 mixing are under control!

S. Akar

Lattice developments for $\Delta m_{d,s}$

- Update from the MILC Collaboration;
- Calculation of the hadronic matrix elements with three flavor Lattice QCD:



1.1 Simulation details

MILC $N_f = 2+1$ asqtad ensembles

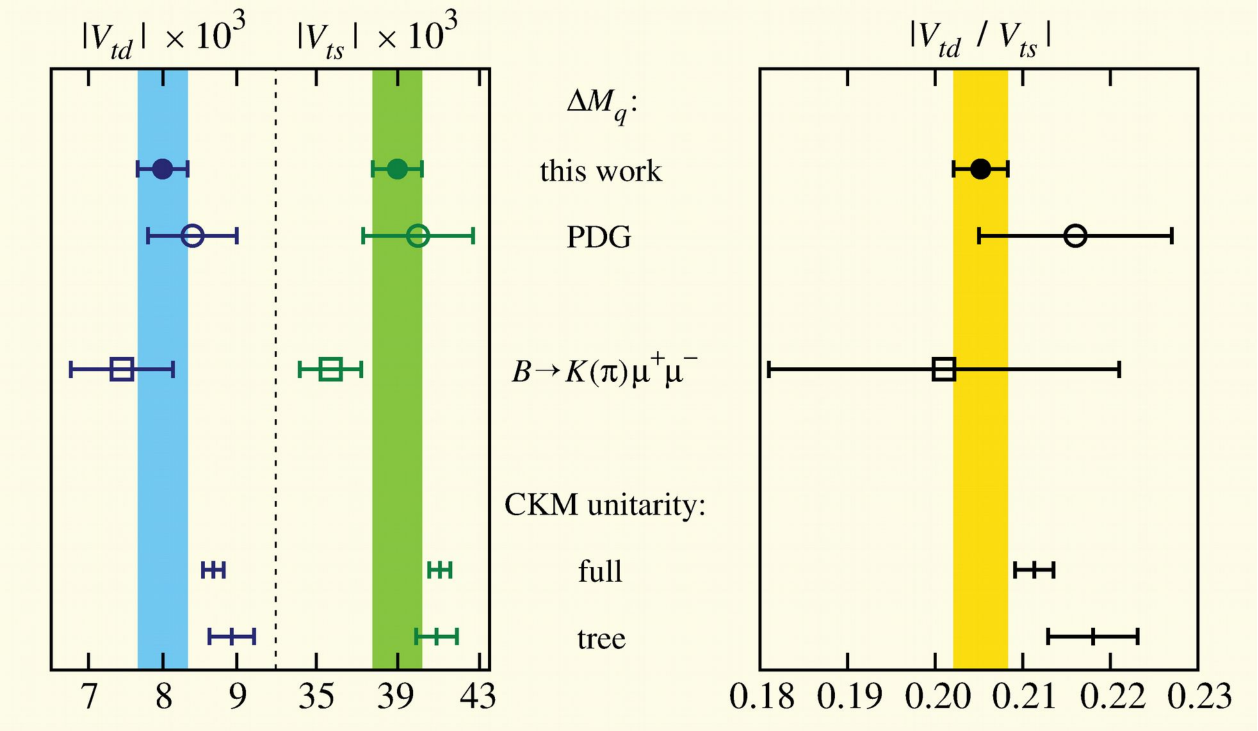
* 600-2000 gauge fields per ensemble

* pions as light as 177 MeV

E. Gamiz

Lattice developments for $\Delta m_{d,s}$

- Results on $|V_{td}|$, $|V_{ts}|$:

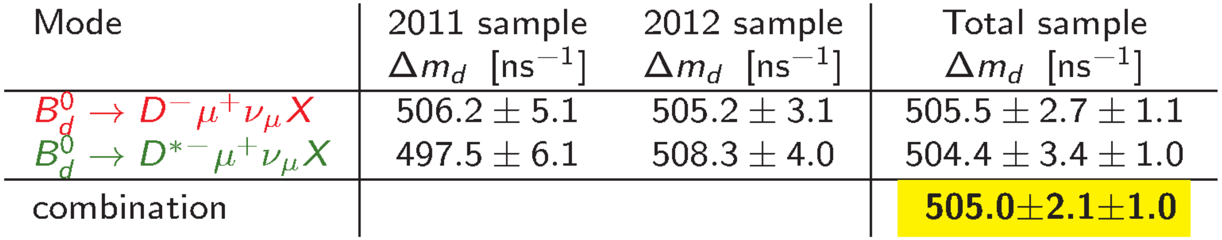


- Some tension with the values preferred by CKM fit;
- Plenty of space for New Physics contributions in $B_{d,s}$ oscillations!

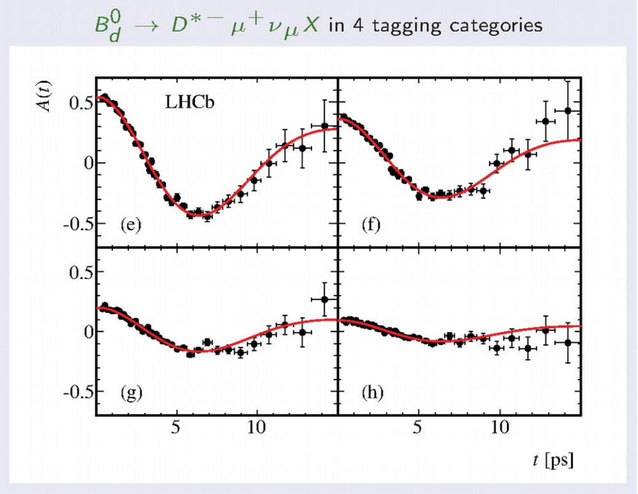
E. Gamiz

Measurements of $\Delta m_{d,s}$ and $\Delta\Gamma_d$

- New measurement of Δm_d and Δm_s from LHCb, exploiting the channels $B_d \rightarrow D^{(*)-} \mu^+ \nu X$ and $B_s \rightarrow D_s^- \pi^+$;



Mode	2011 sample Δm_d [ns^{-1}]	2012 sample Δm_d [ns^{-1}]	Total sample Δm_d [ns^{-1}]
$B_d^0 \to D^- \mu^+ \nu_\mu X$	506.2 ± 5.1	505.2 ± 3.1	$505.5 \pm 2.7 \pm 1.1$
$B_d^0 \to D^{*-} \mu^+ \nu_\mu X$	497.5 ± 6.1	508.3 ± 4.0	$504.4 \pm 3.4 \pm 1.0$
combination			**$505.0 \pm 2.1 \pm 1.0$**

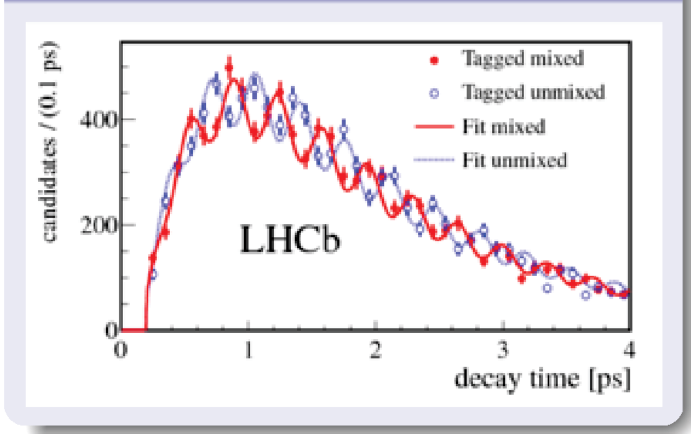


Most precise measurement, dominating WA!

$$\Delta m_s = 17.768 \pm 0.023 \pm 0.006 \text{ ps}^{-1}$$

Most precise measurement to date

[LHCb: New J. Phys. 15 (2013) 053021]



S. Vecchi

Measurements of $\Delta m_{d,s}$ and $\Delta\Gamma_d$

$\Delta\Gamma_d$ is measured at LHCb by comparing the effective lifetime of B_d decaying to flavor specific final states and to CP eigenstates;

$$\tau^{\mathrm{eff}}_{B^0_q \to f} = \frac{1}{\Gamma_q} \frac{1}{1-y_q^2} \left[\frac{1 + 2A^f_{\Delta\Gamma} y_q + y_q^2}{1 + A^f_{\Delta\Gamma} y_q} \right]$$

- $A^f_{\Delta\Gamma} = 0$ for *flavour specific* decays
- $A^f_{\Delta\Gamma} = \cos 2\beta$ for $B_d \to J/\psi K^0_S$

Effective lifetime results:

$\tau^{\mathrm{eff}}_{B^0_d \to J/\psi K^{*0}} = 1.524 \pm 0.006 \pm 0.004$ ps

$\tau^{\mathrm{eff}}_{B^0_d \to J/\psi K^0_s} = 1.499 \pm 0.013 \pm 0.005$ ps

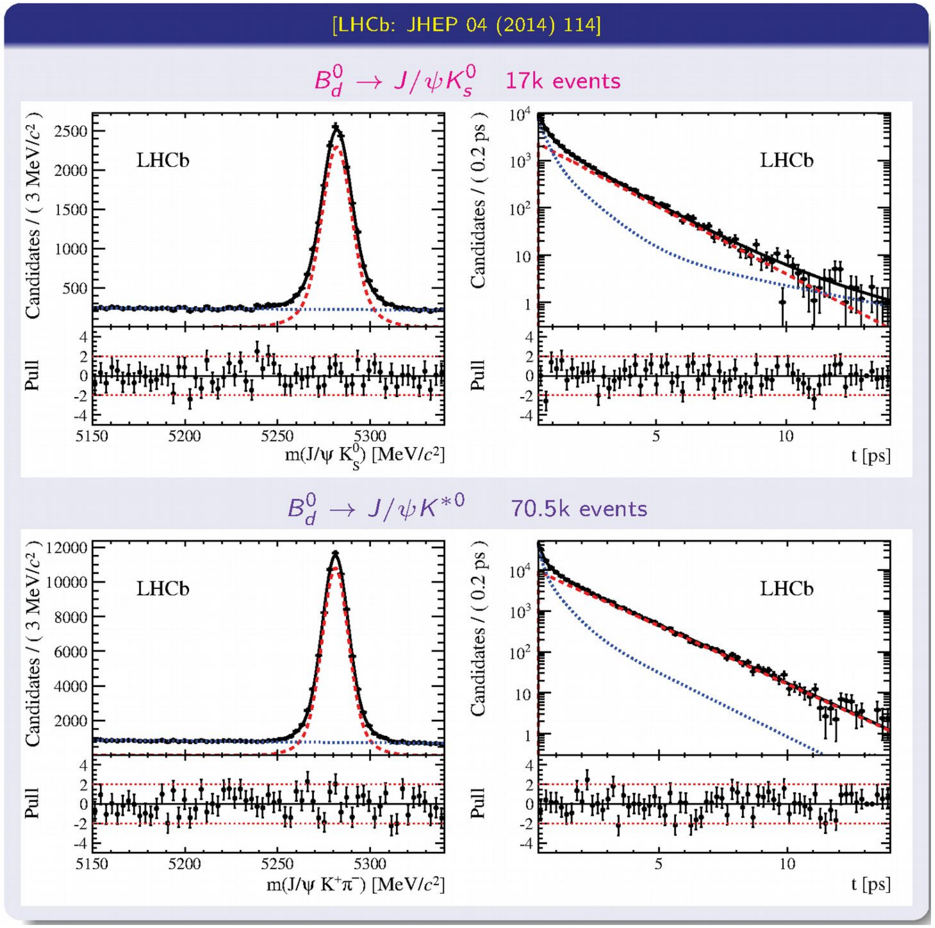
we measure:

$\Gamma_d = 0.656 \pm 0.003 \pm 0.002 \ \mathrm{ps}^{-1}$

$\Delta\Gamma_d = -0.029 \pm 0.016 \pm 0.007 \ \mathrm{ps}^{-1}$

$\Delta\Gamma_d / \Gamma_d = (-4.4 \pm 2.5 \pm 1.1) \times 10^{-2}$

[LHCb: JHEP 04 (2014) 114]



$B^0_d \to J/\psi K^0_s$ 17k events

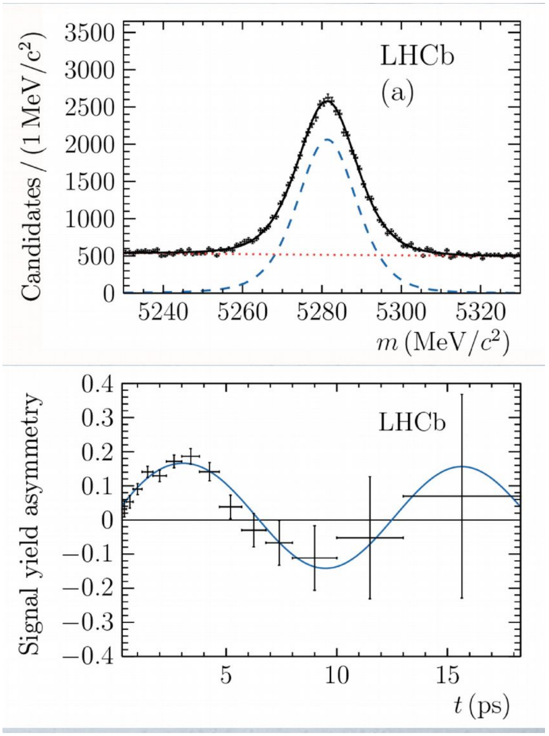
$B^0_d \to J/\psi K^{*0}$ 70.5k events

(the best measurement is currently from ATLAS)

S. Vecchi

Mixing induced CPV in B_d decays

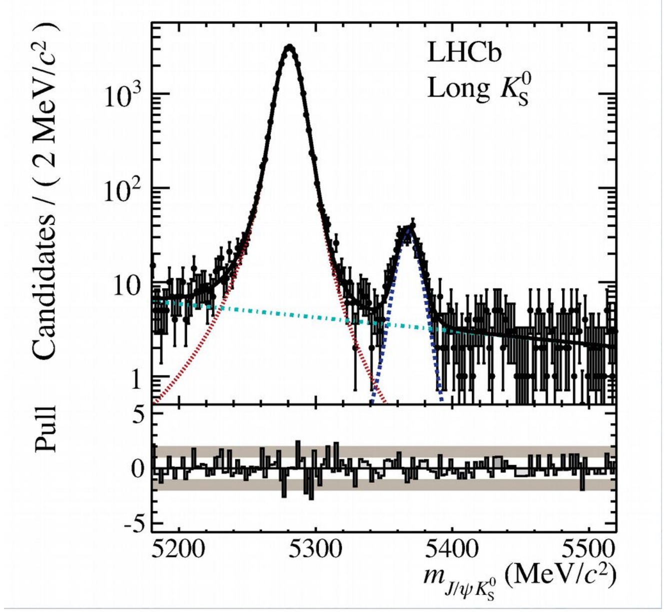
$B_d \to J/\psi K_S$



$$S = 0.731 \pm 0.035(\text{stat}) \pm 0.020(\text{syst}),$$
$$C = -0.038 \pm 0.032(\text{stat}) \pm 0.005(\text{syst})$$

Very close in precision to the B-factories

$B_s \to J/\psi K_S$



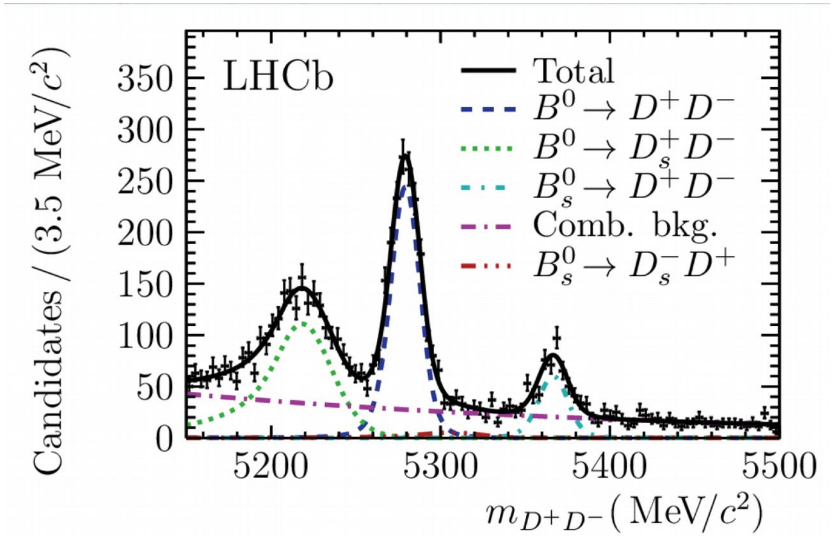
$$C_{\text{dir}} = -0.28 \pm 0.41\ (\text{stat}) \pm 0.08\ (\text{syst})$$
$$S_{\text{mix}} = -0.08 \pm 0.40\ (\text{stat}) \pm 0.08\ (\text{syst})$$

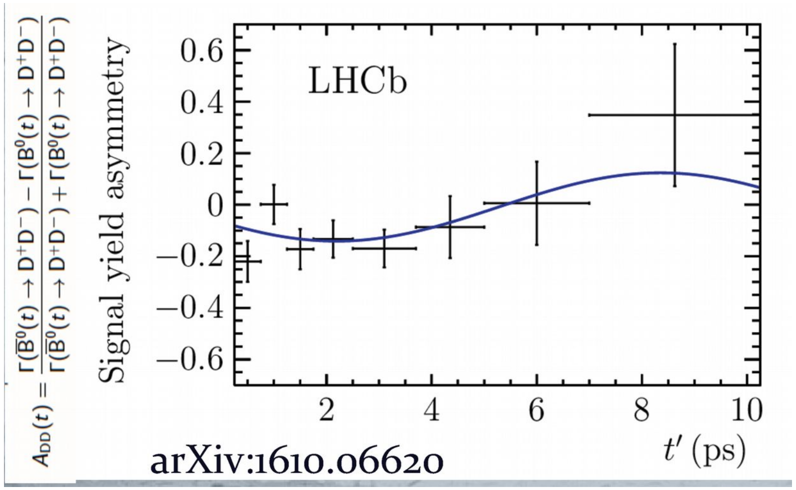
With more statistic, can provide very useful constraints for the penguin pollution

M. Calvi

Mixing induced CPV in B_d decays

Measuring sin2β using a different class of decays: $B \rightarrow D^+D^-$:





arXiv:1610.06620

$$S = -0.54\,^{+0.17}_{-0.16}\,(\text{stat}) \pm 0.05\,(\text{syst})$$
$$C = 0.26\,^{+0.18}_{-0.17}\,(\text{stat}) \pm 0.02\,(\text{syst})$$

Constraint on the phase shift due to higher order SM corrections:

$$\Delta\phi = -0.16\,^{+0.19}_{-0.21}\ \text{rad}$$

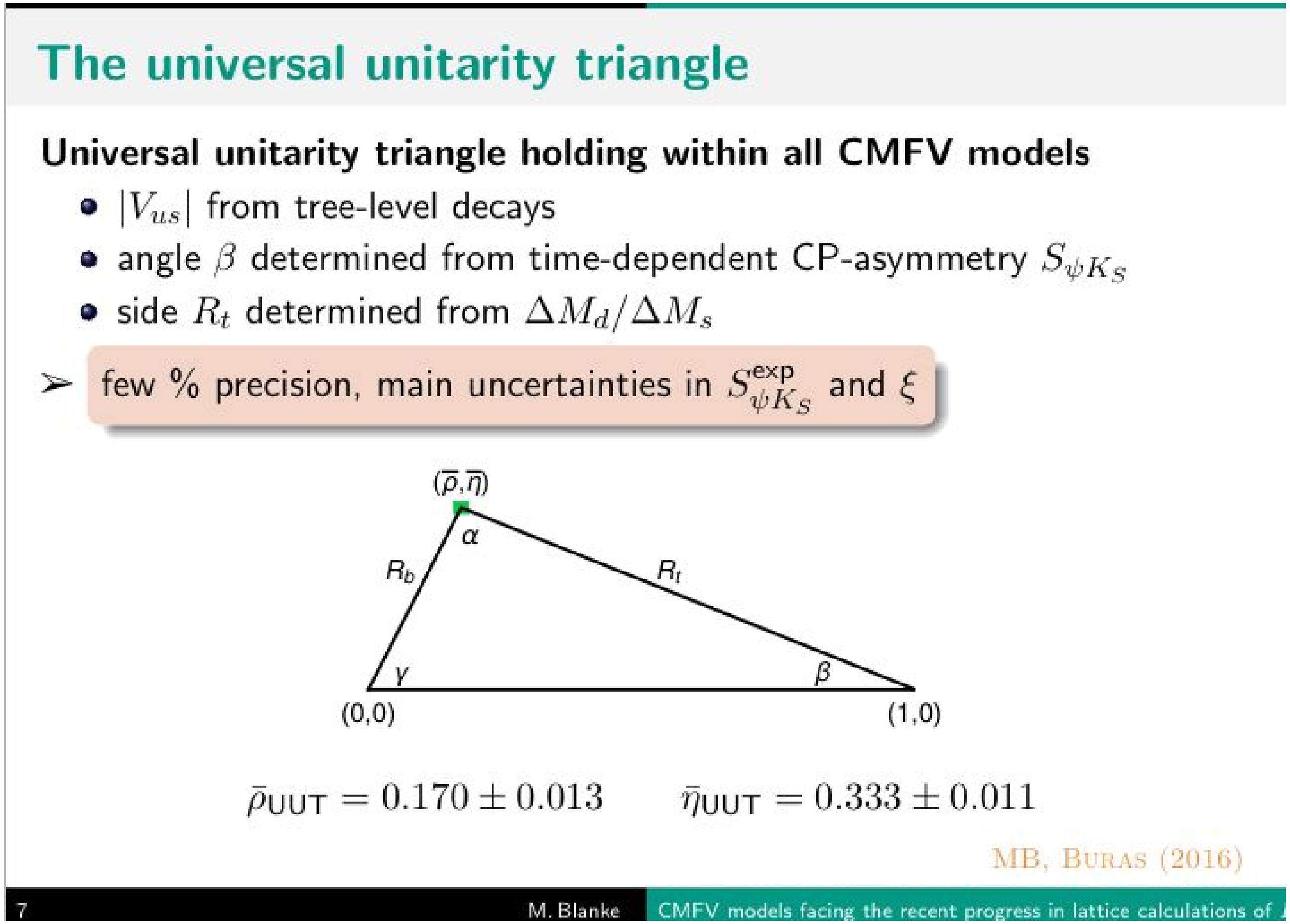
No observed deviation from SM expectations (at order zero $\phi_d = 2\beta$)

Impressing improvement in tagging power, now $\varepsilon(1 - 2\omega)^2 = (8.1 \pm 0.6)\%$

M. Calvi

Pheno. Implications of mixing measurements

- Constrained minimal flavor violation models (CMFV):
- $Y_{u,d}$ only sources of quark flavor breaking, no extra CPV, only SM effective operators.
- $\Delta F = 2$ operators manifest this NP in terms of single flavor universal function.
- Feature a universal unitarity triangle dependent on $\Delta M_s/\Delta M_d$ and sin2β, but not on V_{ub}/V_{cb} or γ.



The universal unitarity triangle

Universal unitarity triangle holding within all CMFV models

- $|V_{us}|$ from tree-level decays
- angle β determined from time-dependent CP-asymmetry $S_{\psi K_S}$
- side R_t determined from $\Delta M_d/\Delta M_s$

➢ few % precision, main uncertainties in $S^{\text{exp}}_{\psi K_S}$ and ξ

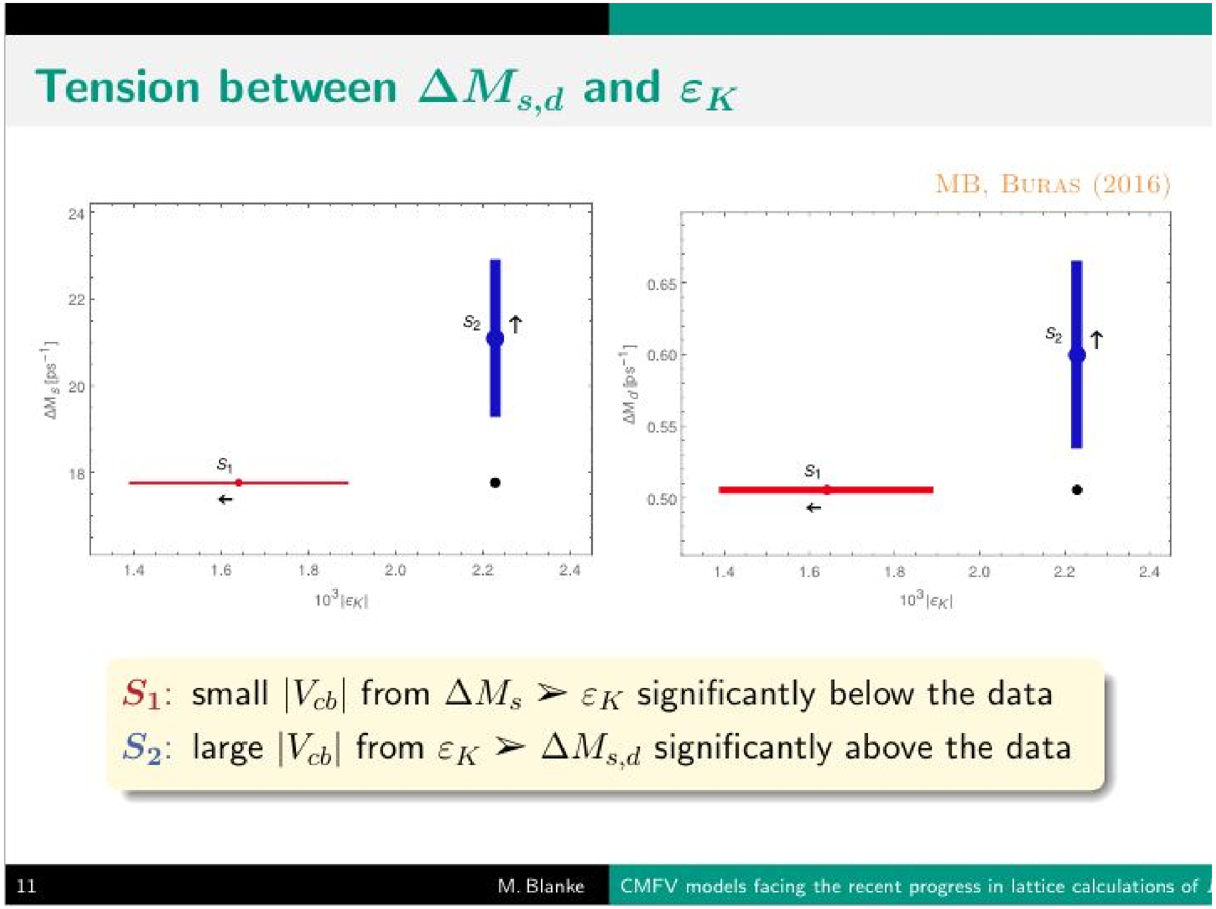
$\bar\rho_{\text{UUT}} = 0.170 \pm 0.013$ $\quad$ $\bar\eta_{\text{UUT}} = 0.333 \pm 0.011$

MB, Buras (2016)

M. Blanke

Pheno. Implications of mixing measurements

- Can this class of theories explain possible lattice tension between $\Delta M_{s,d}$ and ε_K?
- CMFV models have difficulty explaining this tension; under pressure from lattice results.
- We may need to think about new sources of flavor violation in $\Delta F = 2$ processes, beyond CMFV models.



Tension between $\Delta M_{s,d}$ and ε_K

MB, Buras (2016)

S_1: small $|V_{cb}|$ from ΔM_s ➢ ε_K significantly below the data

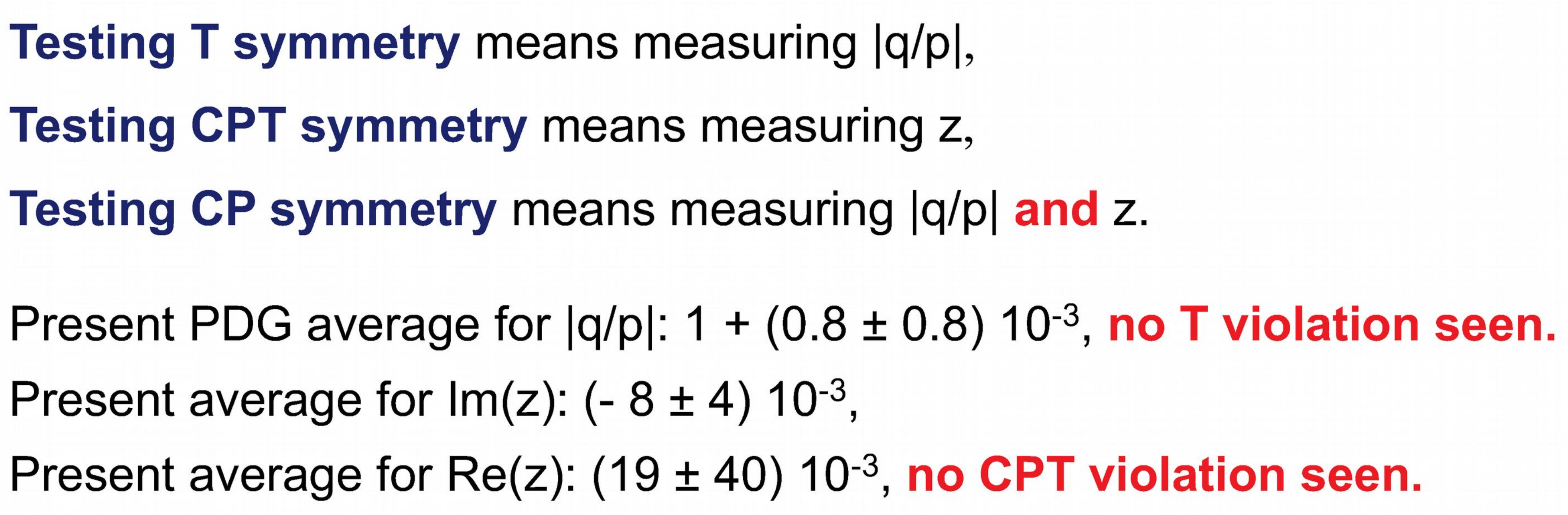
S_2: large $|V_{cb}|$ from ε_K ➢ $\Delta M_{s,d}$ significantly above the data

M. Blanke

Tests of CPT at BaBar

- BaBar uses $B^0 \to J/\psi\, K^0$ decays to test the conservation of the CPT symmetry;
- Recalling the definitions:

$$\left|\frac{q}{p}\right| = 1 - \frac{2\,\mathrm{Im}\left(\Gamma_{12}/m_{12}\right)}{4 + \left|\Gamma_{12}/m_{12}\right|^2}, \qquad z = \frac{\left(m_{11} - m_{22}\right) - \mathrm{i}\left(\Gamma_{11} - \Gamma_{22}\right)/2}{\Delta m - \mathrm{i}\Delta\Gamma/2}$$



Testing T symmetry means measuring |q/p|,

Testing CPT symmetry means measuring z,

Testing CP symmetry means measuring |q/p| **and** z.

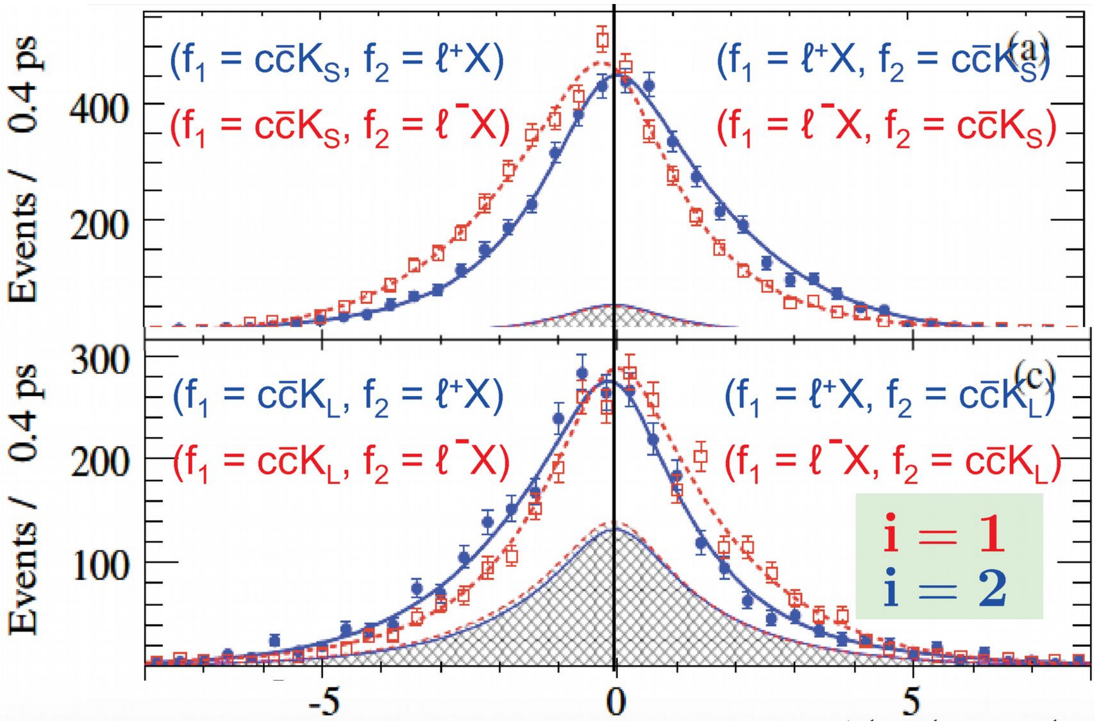
Present PDG average for |q/p|: 1 + (0.8 ± 0.8) 10^{-3}, **no T violation seen.**

Present average for Im(z): (- 8 ± 4) 10^{-3},

Present average for Re(z): (19 ± 40) 10^{-3}, **no CPT violation seen.**

M. Sokoloff

Tests of CPT at BaBar



$\mathrm{Im}(z) = 0.010 \pm 0.030 \pm 0.013$,

$\mathrm{Re}(z) = -0.065 \pm 0.028 \pm 0.014$,

$|\bar{A}/A| = 0.999 \pm 0.023 \pm 0.017$,

No CPT violation seen

To our knowledge, the $|\bar{A}/A|$ result is the first one obtained without requiring z = 0. (*)

in the B_d system

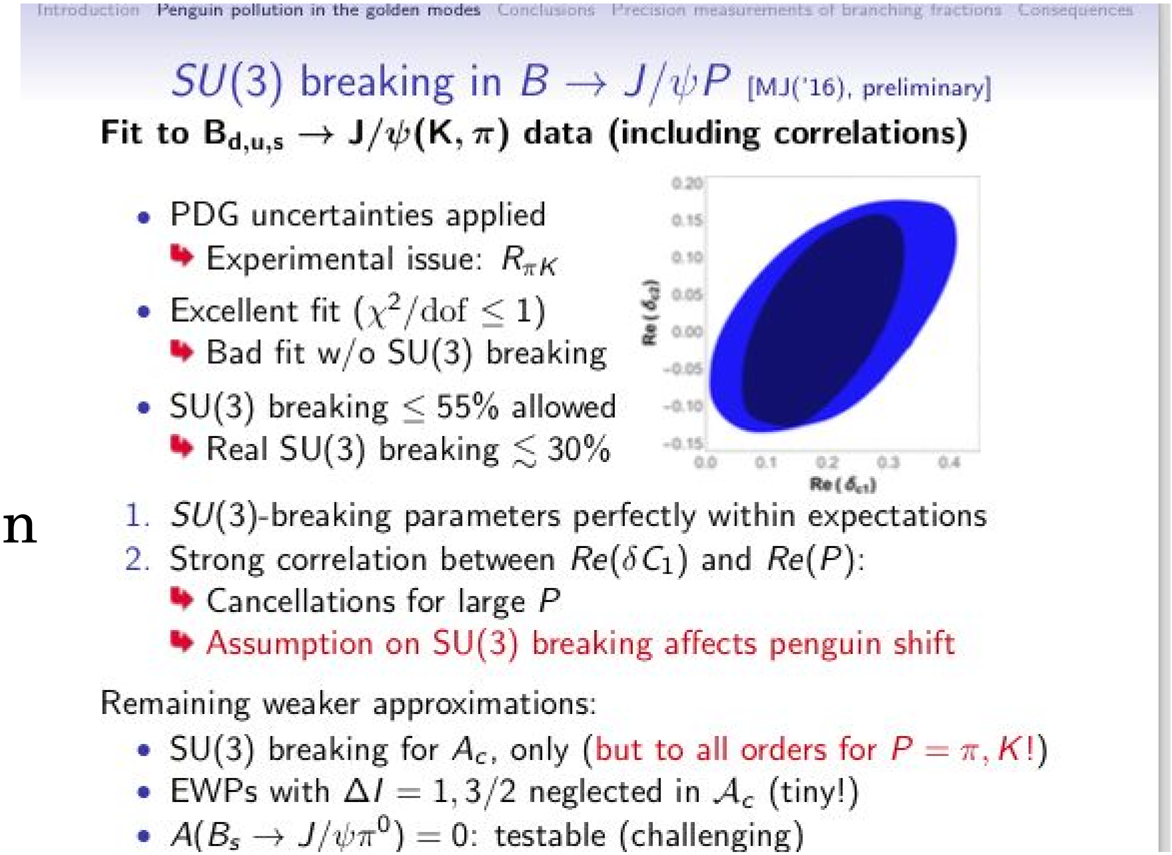
M. Sokoloff

sin2β from $c\bar{c}K^0$

- Control $\Delta\phi_d$ with flavor SU(3): include fits from multiple decay modes, using a combination of CP asymmetries and CP-averaged rates to account for first order flavor SU(3) breaking.
- Two different approaches:

1) consider only factorizable breaking as a starting point, while an additional non-factorizable part is assumed to be smaller.

2) model-independent expansion to first order in the breaking. Some assumptions on certain diagrammatic topologies, e.g. neglect $B_s \to J/\psi\,\pi$



$SU(3)$ breaking in $B \to J/\psi P$ [MJ('16), preliminary]

Fit to $B_{d,u,s} \to J/\psi(K,\pi)$ data (including correlations)

- PDG uncertainties applied
  - Experimental issue: $R_{\pi K}$
- Excellent fit ($\chi^2/\mathrm{dof} \leq 1$)
  - Bad fit w/o SU(3) breaking
- SU(3) breaking $\leq 55\%$ allowed
  - Real SU(3) breaking $\lesssim 30\%$

1. $SU(3)$-breaking parameters perfectly within expectations
2. Strong correlation between $Re(\delta C_1)$ and $Re(P)$:
   - Cancellations for large P
   - Assumption on SU(3) breaking affects penguin shift

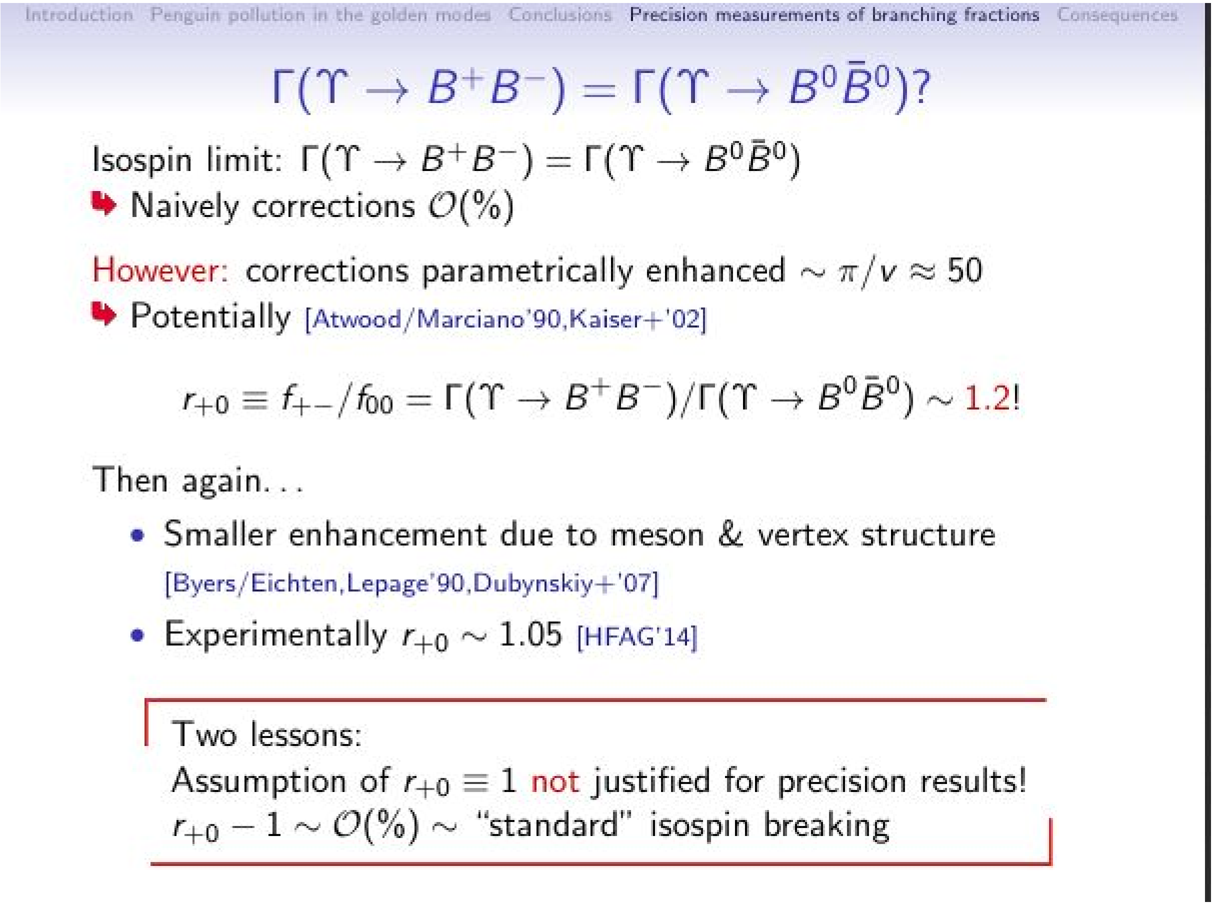
Remaining weaker approximations:

- SU(3) breaking for A_c, only (but to all orders for $P = \pi, K$!)
- EWPs with $\Delta I = 1, 3/2$ neglected in $\mathcal{A}_c$ (tiny!)
- $A(B_s \to J/\psi\pi^0) = 0$: testable (challenging)

M. Jung

sin2β from $c\bar{c}K^0$

- High precision: $\Delta\phi_d < 0.6^\circ$ from fit.
- Using branching ratios requires care wrt charged/neutral B production ratio: an isospin violating effect!
- $r_{+0} = 1$ not justified.
- Can try to control with either single vs double semileptonic tag or inclusive decays.
- $r_{+0} = 1.027 \pm 0.037$



$\Gamma(\Upsilon \to B^+B^-) = \Gamma(\Upsilon \to B^0\bar{B}^0)$?

Isospin limit: $\Gamma(\Upsilon \to B^+B^-) = \Gamma(\Upsilon \to B^0\bar{B}^0)$

➥ Naively corrections $\mathcal{O}(\%)$

However: corrections parametrically enhanced $\sim \pi/v \approx 50$

➥ Potentially [Atwood/Marciano'90,Kaiser+'02]

$$r_{+0} \equiv f_{+-}/f_{00} = \Gamma(\Upsilon \to B^+B^-)/\Gamma(\Upsilon \to B^0\bar{B}^0) \sim 1.2!$$

Then again. . .

- Smaller enhancement due to meson & vertex structure [Byers/Eichten,Lepage'90,Dubynskiy+'07]
- Experimentally $r_{+0} \sim 1.05$ [HFAG'14]

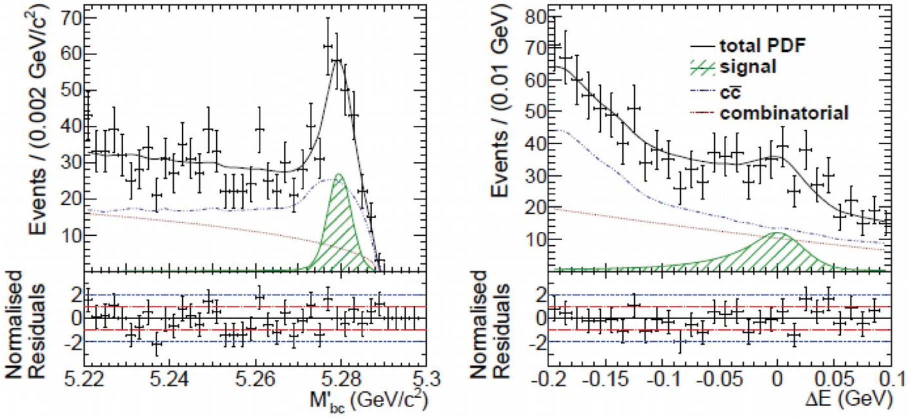
Two lessons:
Assumption of $r_{+0} \equiv 1$ not justified for precision results!
$r_{+0} - 1 \sim \mathcal{O}(\%) \sim$ "standard" isospin breaking

M. Jung

New results from Belle(+BaBar)

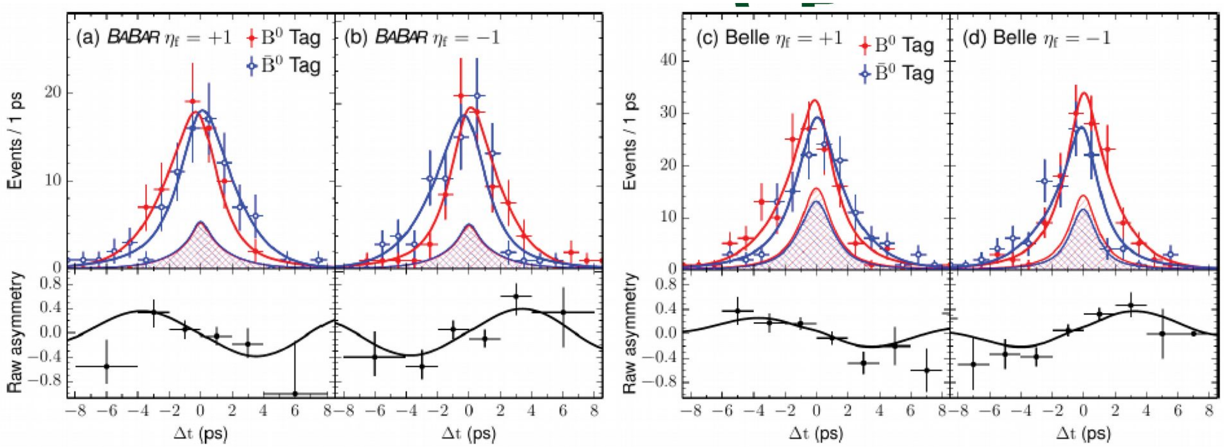
- Observation of $B^0 \rightarrow \psi(2s)\, \pi^0$:

85 signal events found, need more statistics for CP measurement;



- Joint Belle+BaBar analysis on $B^0 \rightarrow D^0_{CP}\, h^0$:

penguin free modes, first observation (5.4σ) of CPV on these modes;

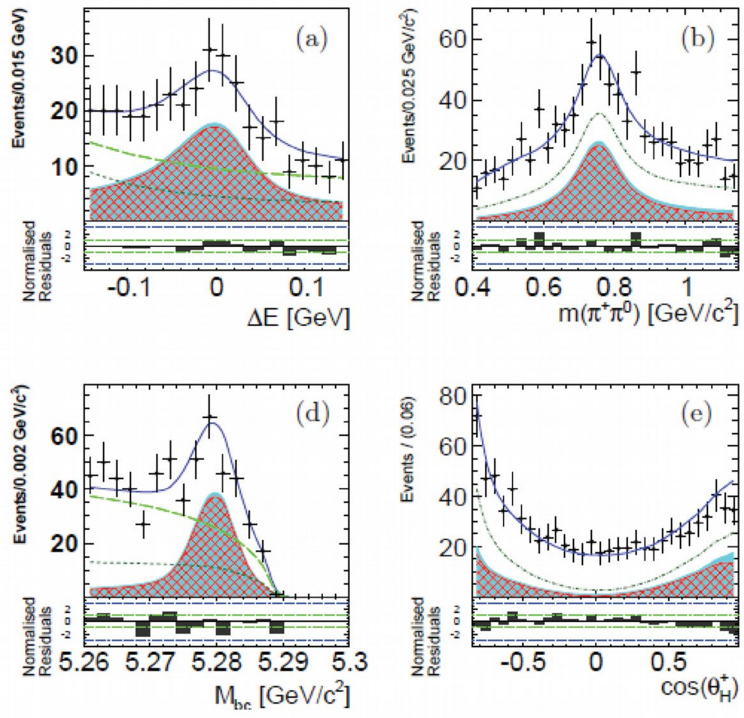


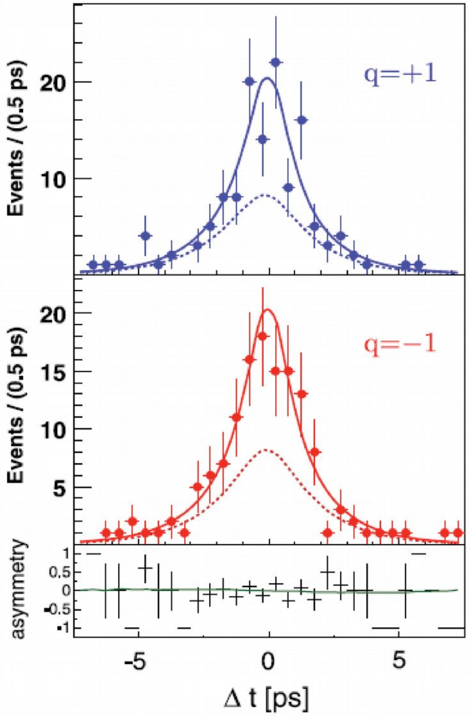
- Binned Dalitz plot analysis of $B^0 \rightarrow D^{(*)0}\, h^0$ favors the $\beta/\phi_1 = 21.9^o$ solution from the current value of sin2β.

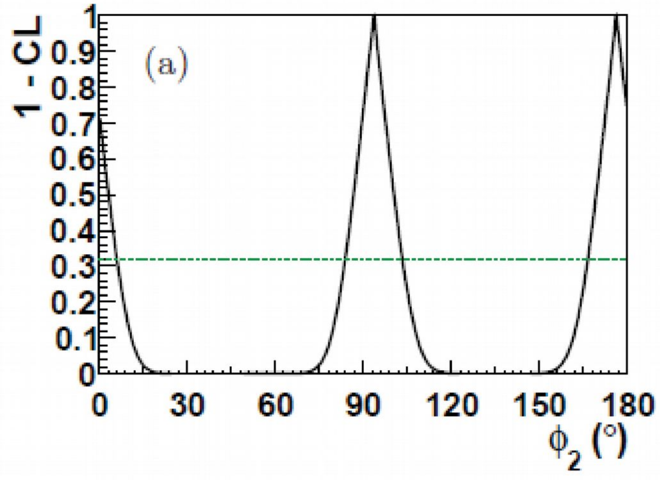
B. Pal

New results from Belle

- New result on TD CPV on $B^0 \rightarrow \rho^+\rho^-$:







This is used in an isospin analysis together with inputs from $\rho^0\rho^0$ and $\rho^+\rho^0$ to determine the allowed values for α/ϕ^2

B. Pal

$B_s \to \phi\,\gamma$ TDCPV

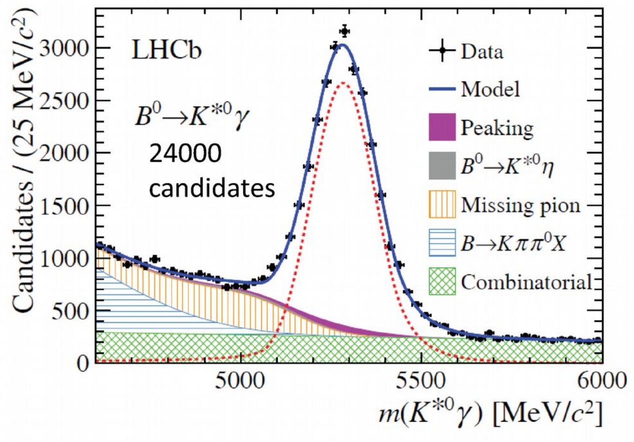
In the SM, photons from the b ($\bar{b}$) quark decay are mostly left (right) polarized

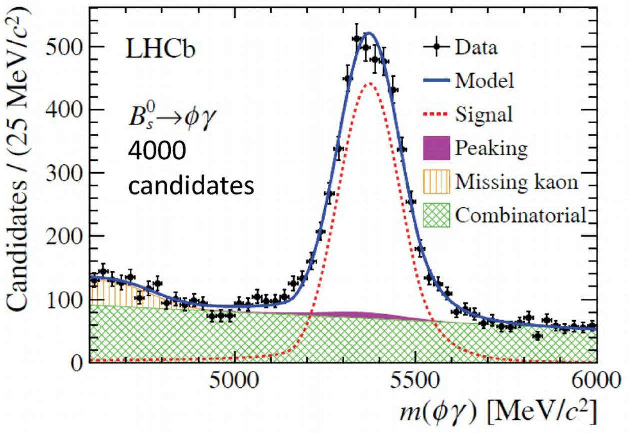
$$\Gamma_{B,\bar{B}}(t) = \mathcal{B}_0 e^{-\Gamma t}[\cosh(\frac{\Delta\Gamma}{2}t) - A^{\Delta} \sinh(\frac{\Delta\Gamma}{2}t) \pm C \cos(\Delta m\ t) \mp S \sin(\Delta m\ t)]$$

→ For the $B_s \to \phi\gamma$ decay channel the SM predictions are:

[Muheim, Xie, Zwicky, PLB664(2008)174]

$$A^{\Delta}_{\mathrm{SM}} = 0.047 \pm 0.025 + 0.015_{O(\alpha_s)} \qquad S_{\mathrm{SM}} = 0 \pm 0.002$$

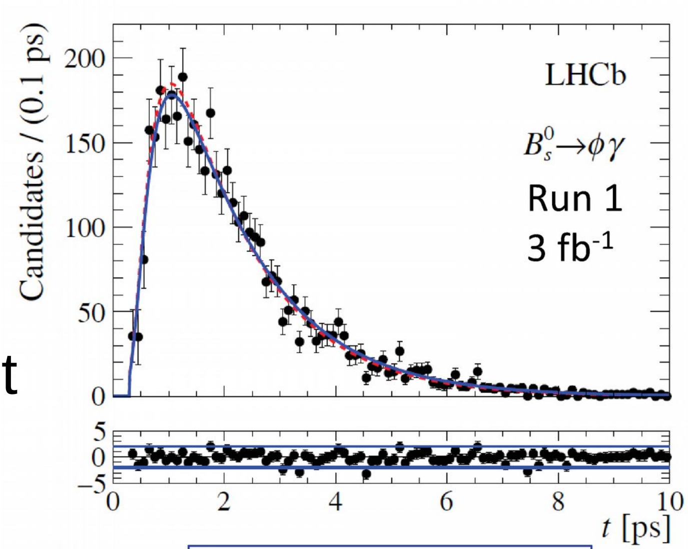




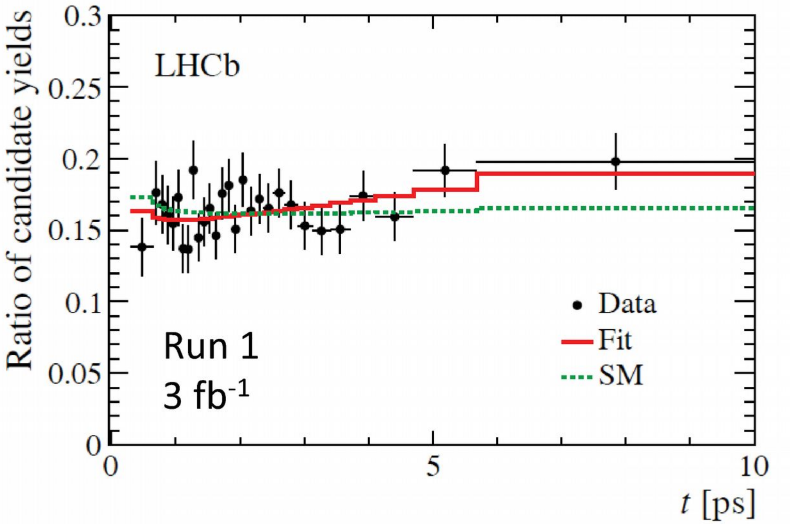
A. Oyanguren

$B_s \to \phi\,\gamma$ TDCPV

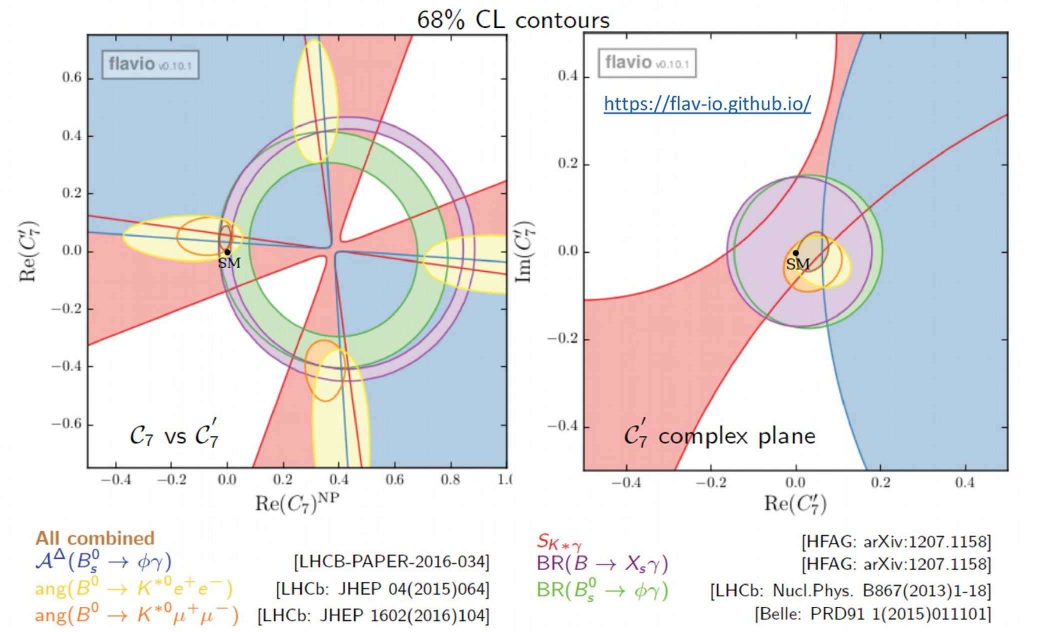
Two alternative fit strategies are employed to extract the relevant parameter A^Δ



$$\mathcal{A}^\Delta = -0.98\,^{+0.46}_{-0.52}$$



$$\mathcal{A}^\Delta = -0.85\,^{+0.43}_{-0.46}$$



γ from TD $B_s \to D_s K$

$$\frac{\Gamma(B_s^0(t)\to D_s^- K^+)-\Gamma(\overline{B_s^0}(t)\to D_s^- K^+)}{\Gamma(B_s^0(t)\to D_s^- K^+)+\Gamma(\overline{B_s^0}(t)\to D_s^- K^+)} =$$

$$\frac{-C(B_s^0(t)\to D_s^- K^+)cos(\Delta m_s t)+S(B_s^0(t)\to D_s^- K^+)sin(\Delta m_s t)}{cosh(\Delta\Gamma_s t/2)+A^{\Delta\Gamma}(B_s^0(t)\to D_s^- K^+)sinh(\Delta\Gamma_s t/2)}$$

[arXiv:hep-ph/0304027v2]

Numerator:

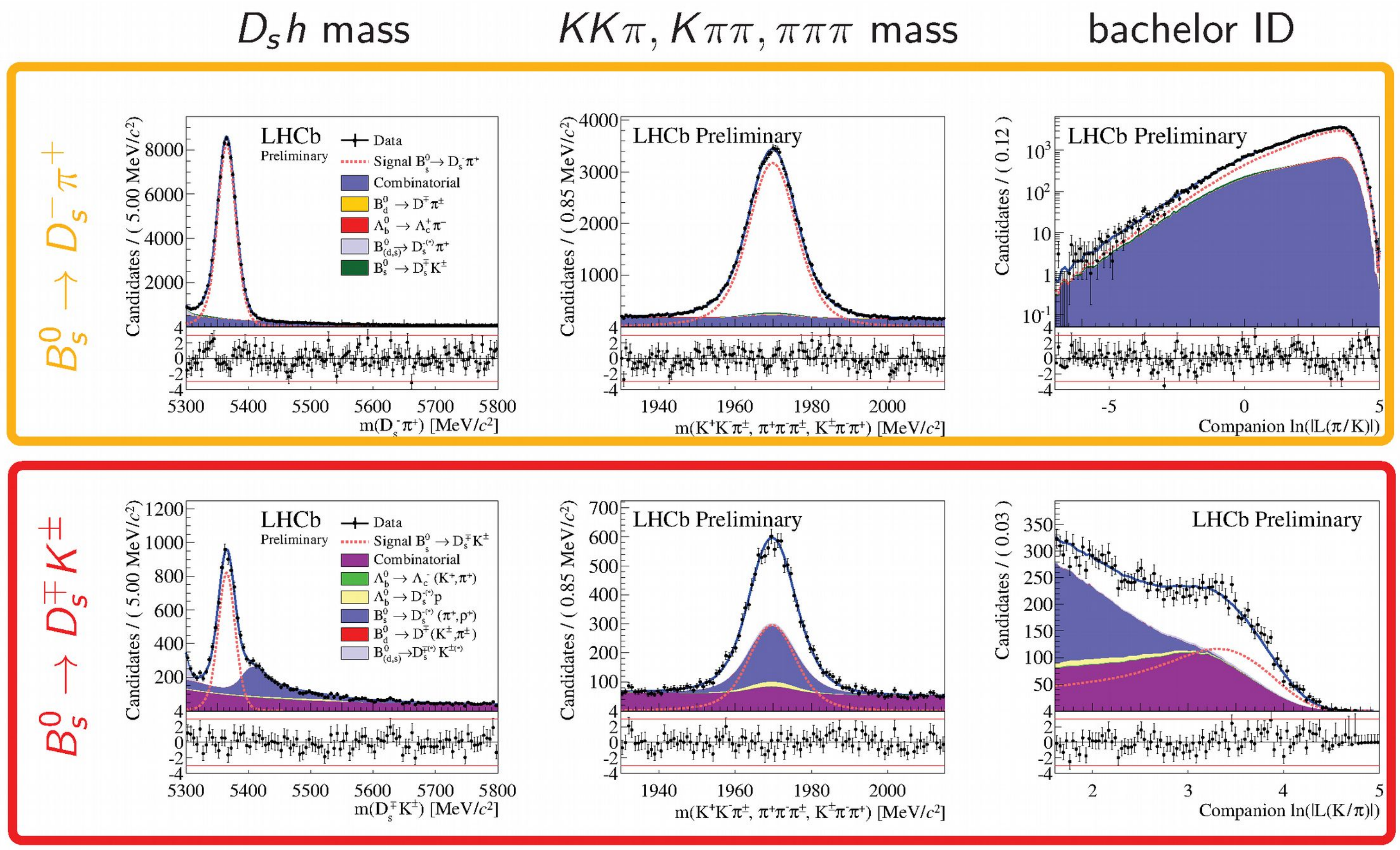
- oscillation terms
- sensitivity comes only from events with known initial flavour
- flavour tagging detects, if B_s^0 or $\overline{B_s^0}$ was produced
- requires knowledge about Δm_s (oscillation in B_s system)

Denominator:

- hyperbolics terms
- sensitivity comes from all events
- requires knowledge about $\Delta\Gamma_s$ (width difference in B_s system)

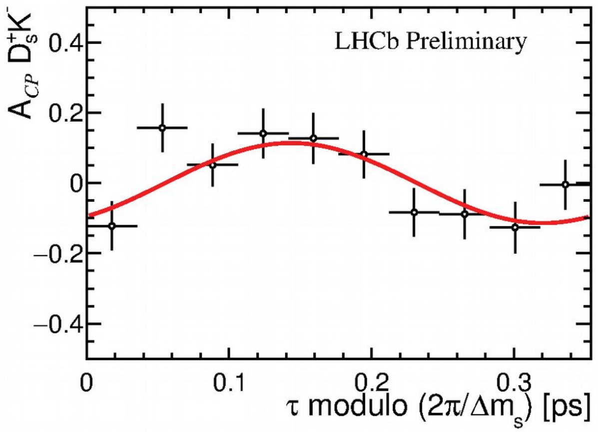
A. Dziurda

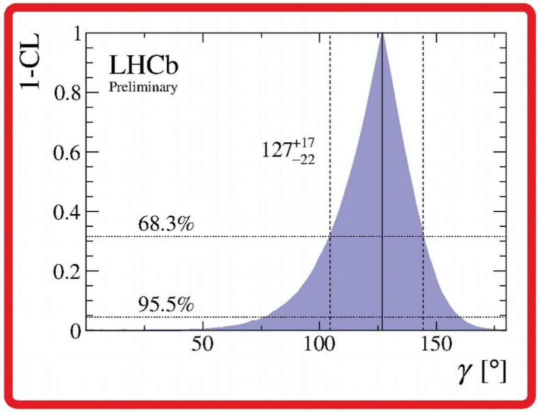
γ from TD $B_s \rightarrow D_s K$



Signal $B_s^0 \rightarrow D_s^- \pi^+ = 96942 \pm 345$

Signal $B_s^0 \rightarrow D_s^\mp K^\pm = 5955 \pm 90$



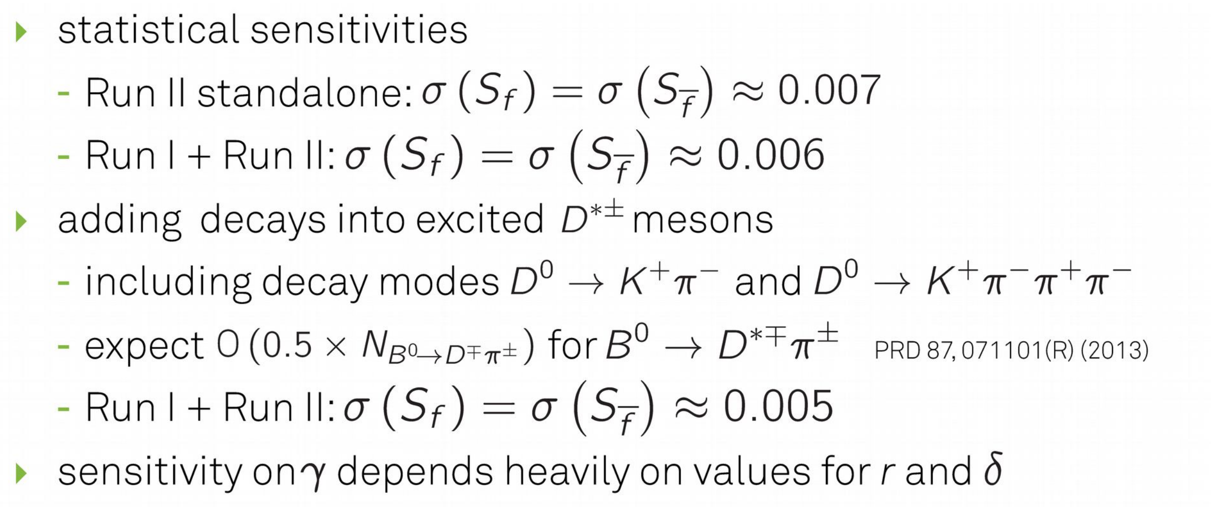


A. Dziurda

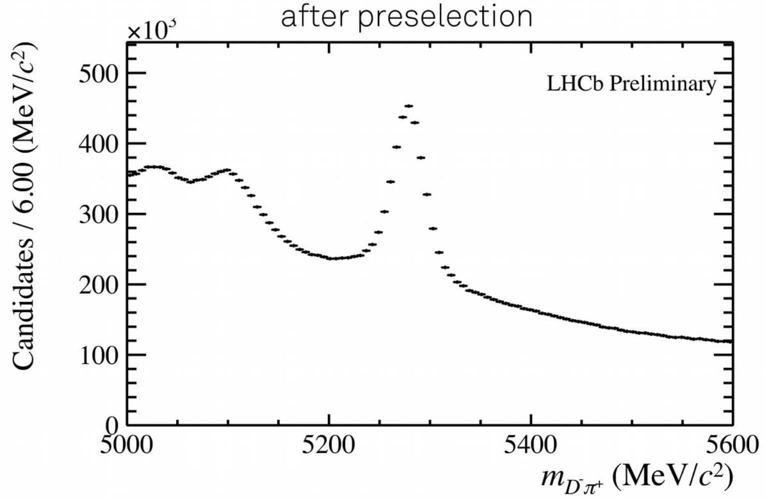
γ from TD $B \to D^{\pm}\pi^{\mp}$

Sensitivity study on γ from TD B → Dπ.

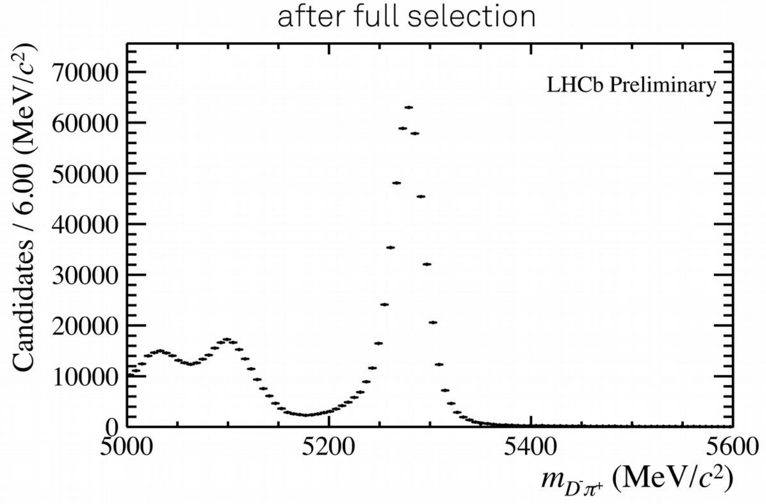
Despite small interference (% level), a very large sample with high purity can be selected.



- statistical sensitivities
  - Run II standalone: $\sigma(S_f) = \sigma(S_{\bar{f}}) \approx 0.007$
  - Run I + Run II: $\sigma(S_f) = \sigma(S_{\bar{f}}) \approx 0.006$
- adding decays into excited $D^{*\pm}$ mesons
  - including decay modes $D^0 \to K^+\pi^-$ and $D^0 \to K^+\pi^-\pi^+\pi^-$
  - expect $\mathcal{O}(0.5 \times N_{B^0 \to D^{\mp}\pi^{\pm}})$ for $B^0 \to D^{*\mp}\pi^{\pm}$ PRD 87, 071101(R) (2013)
  - Run I + Run II: $\sigma(S_f) = \sigma(S_{\bar{f}}) \approx 0.005$
- sensitivity on γ depends heavily on values for r and δ



after preselection

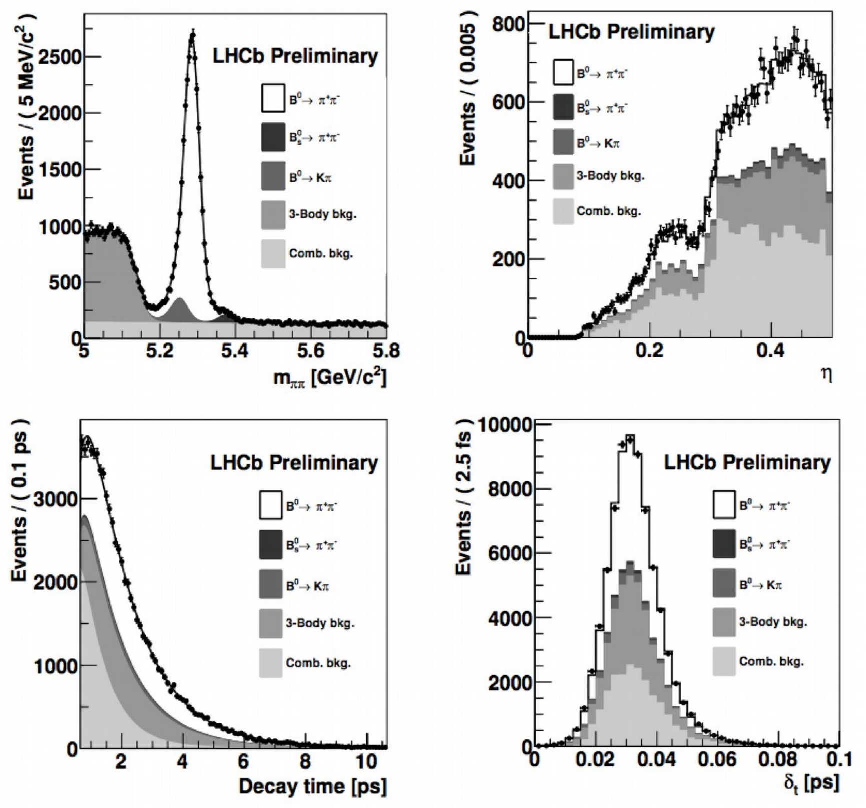


after full selection

A. Birnkraut

TD $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$

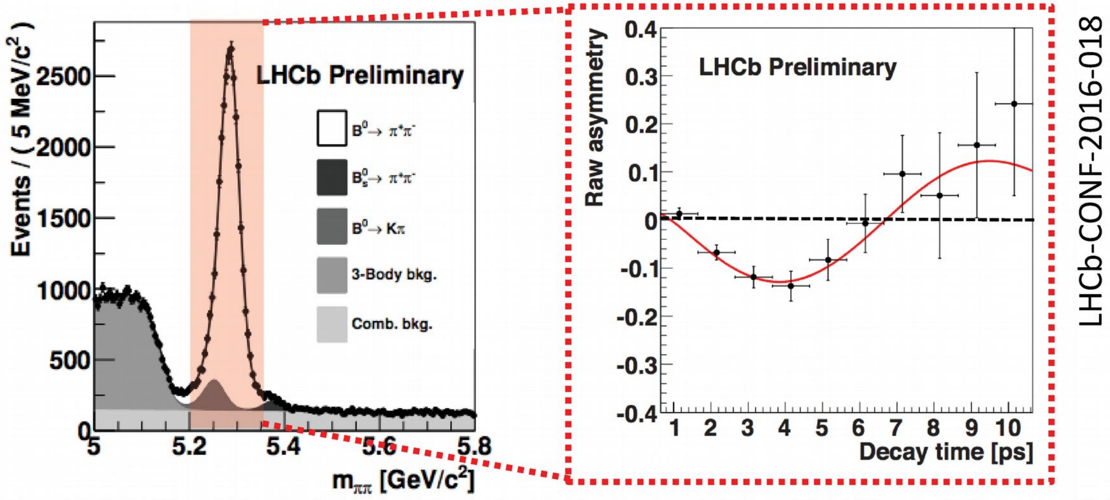
LHCb-CONF-2016-018



$\pi^+\pi^-$ spectrum

(LHCb Preliminary)

$$\begin{aligned} C_{\pi^+\pi^-} &= -0.243 \pm 0.069, \\ S_{\pi^+\pi^-} &= -0.681 \pm 0.060, \end{aligned}$$



Most precise measurement of $S_{\pi\pi}$ and $C_{\pi\pi}$

S. Perazzini

TD $B_d \to \pi^+\pi^-$ and $B_s \to K^+K^-$

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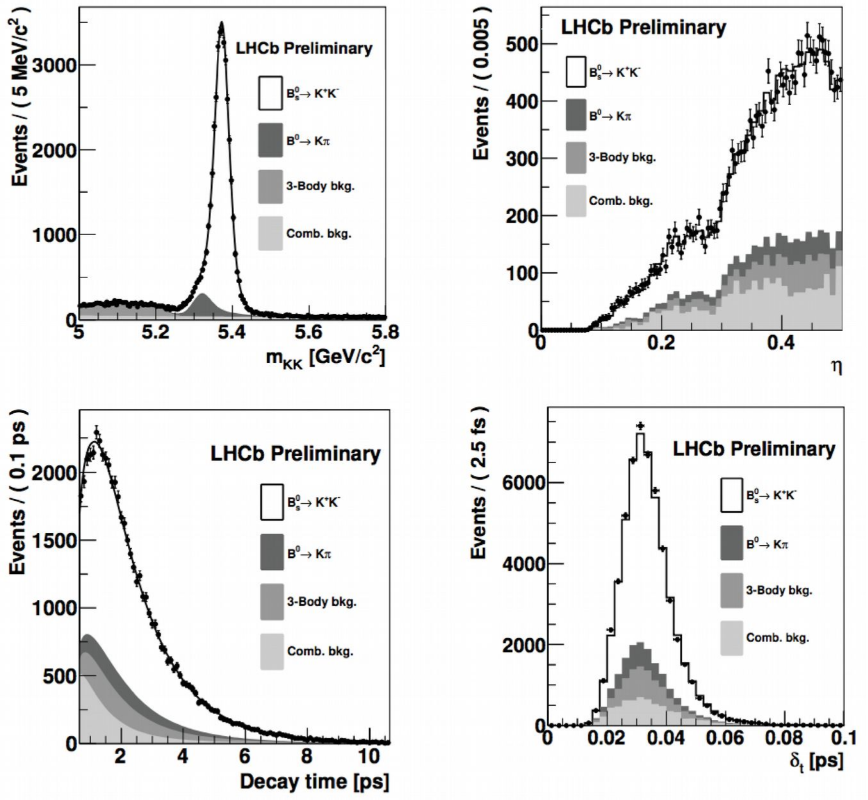
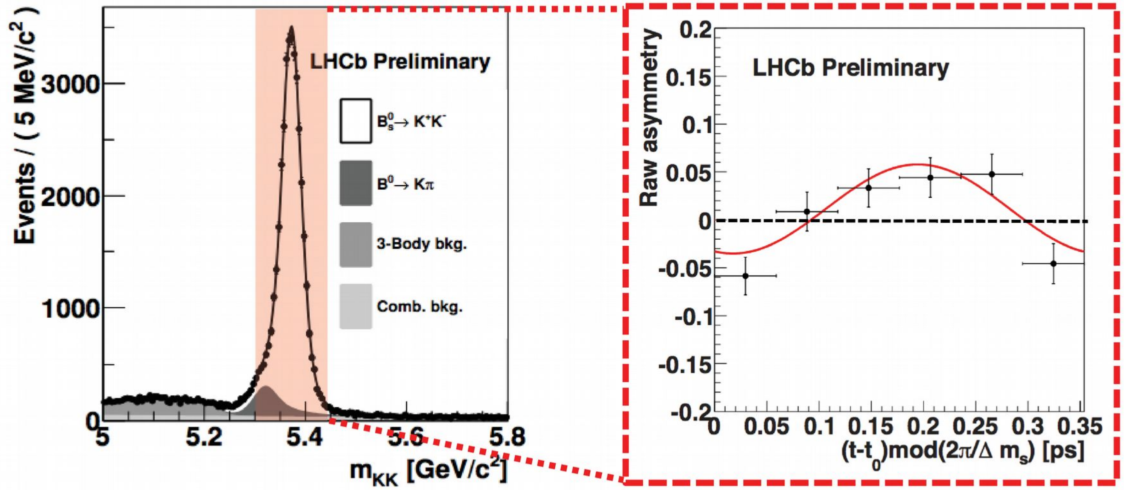


K^+K^- spectrum

(LHCb Preliminary)

$$
\begin{aligned}
C_{K^+K^-} &= 0.236 \pm 0.062, \\
S_{K^+K^-} &= 0.216 \pm 0.062, \\
A^{\Delta\Gamma}_{K^+K^-} &= -0.751 \pm 0.075.
\end{aligned}
$$



LHCb-CONF-2016-018

First observation of CPV in $B_s \to KK$

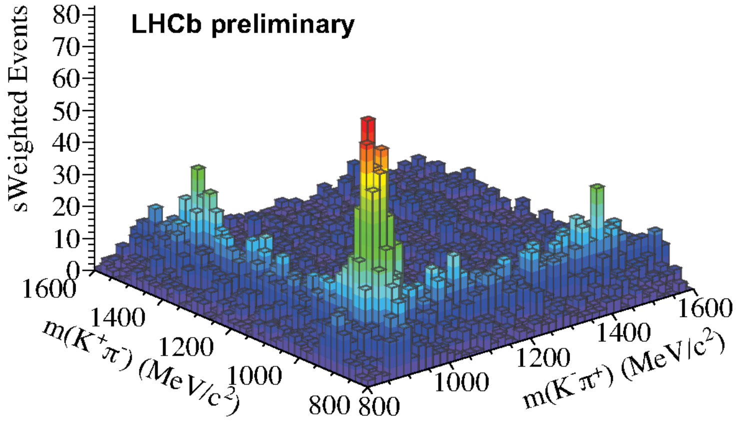
S. Perazzini

ϕ_s^{dd} from $B_s \to (K^-\pi^+)(K^+\pi^-)$

- Gluonic penguin dominated decay, potentially sensitive to New Physics contribution:

Dominant $K\pi$ components:

- **Scalar comp.**: $K_0^*(1430)^0$ + Non Res.
- **Vector comp.**: $K^*(892)^0$
- **Tensor comp.**: $K_2^*(1430)^0$



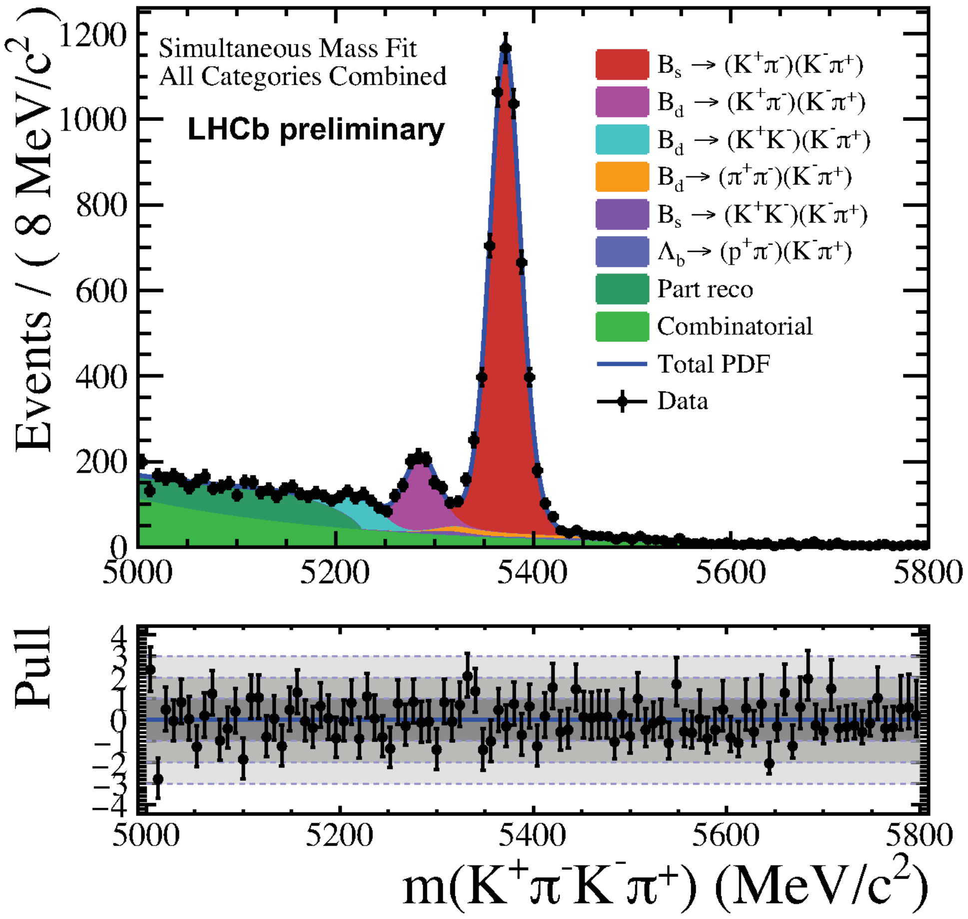
This leads to 3×3 = **9 decay channels** with **19 polarisation amplitudes**.

Channel	Decay	Polarisation states
Channel #1	$B_s^0 \to (K^+\pi^-)_0^*(K^-\pi^+)_0^*$	SS
Channel #2	$B_s^0 \to (K^+\pi^-)_0^*\bar{K}^*(892)^0$	SV
Channel #3	$B_s^0 \to K^*(892)^0(K^-\pi^+)_0^*$	VS
Channel #4	$B_s^0 \to (K^+\pi^-)_0^*\bar{K}_2^*(1430)^0$	ST
Channel #5	$B_s^0 \to K_2^*(1430)^0(K^-\pi^+)_0^*$	TS
Channel #6	$B_s^0 \to K^*(892)^0\bar{K}^*(892)^0$	VV0, VV$\parallel$, VV$\perp$
Channel #7	$B_s^0 \to K^*(892)^0\bar{K}_2^*(1430)^0$	VT0, VT$\parallel$, VT$\perp$
Channel #8	$B_s^0 \to K_2^*(1430)^0\bar{K}^*(892)^0$	TV0, TV$\parallel$, TV$\perp$
Channel #9	$B_s^0 \to K_2^*(1430)^0\bar{K}_2^*(1430)^0$	TT0, TT$\parallel$1, TT$\perp$1, TT$\parallel$2, TT$\perp$2

J. Garcia Pardiñas

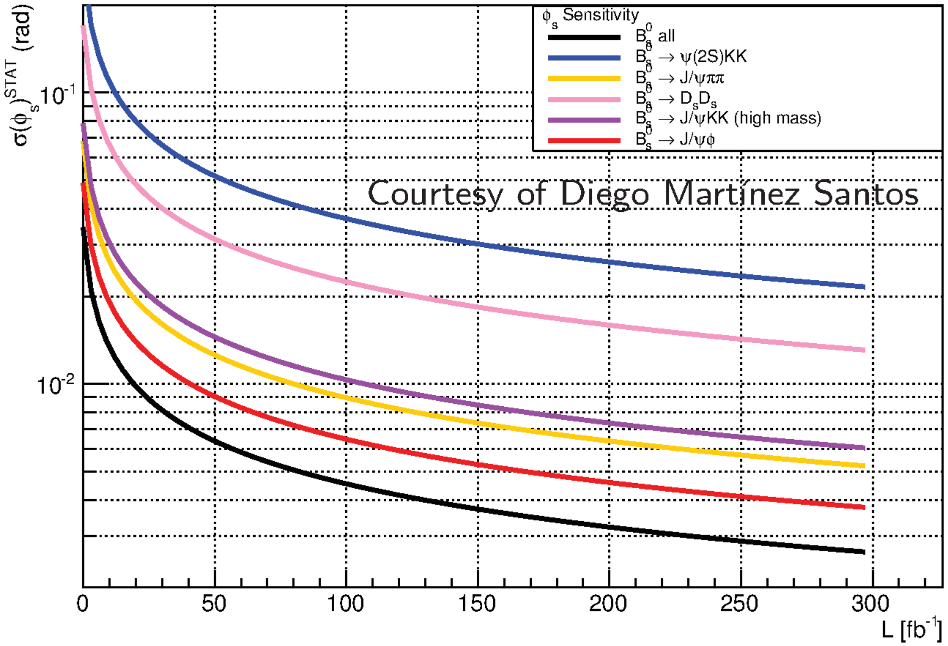
ϕ_s^{dd} from $B_s \to (K^-\pi^+)(K^+\pi^-)$

- Nice signal sample already selected;
- CP phase still blind;
- Expected statistical uncertainty on ϕ_s^{dd} less than 0.2 rad.



J. Garcia Pardiñas

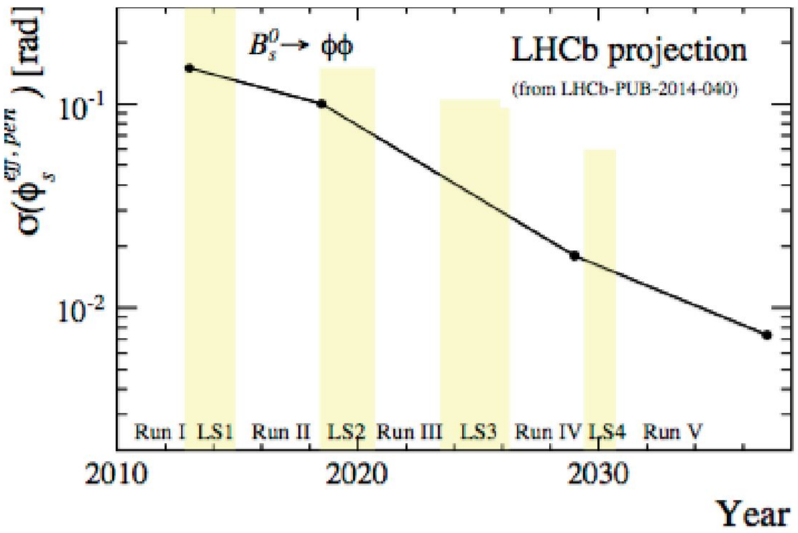
Mid- and long-term prospects at LHCb

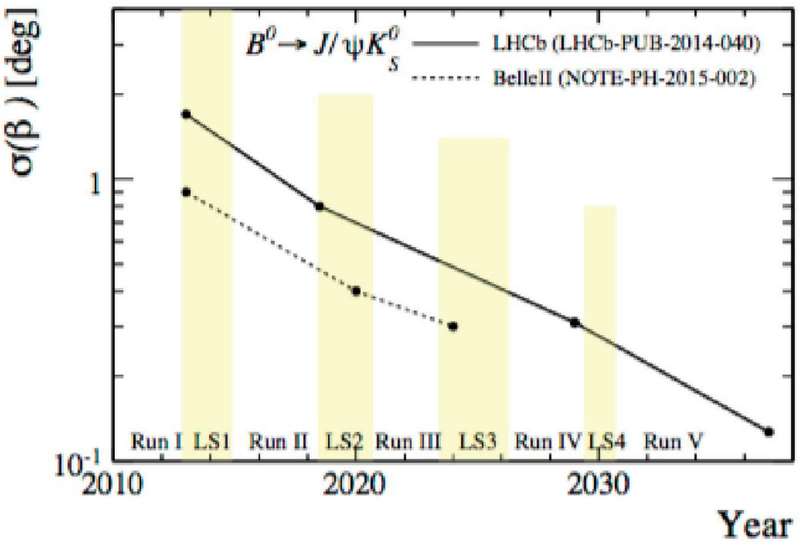


Courtesy of Diego Martínez Santos

← ϕ_s combined precision to reach < 5 mrad at 300 fb^{-1}

Mandatory to study also “low sensitivity” channels, that might evidence specific patterns if New Physics shows up.



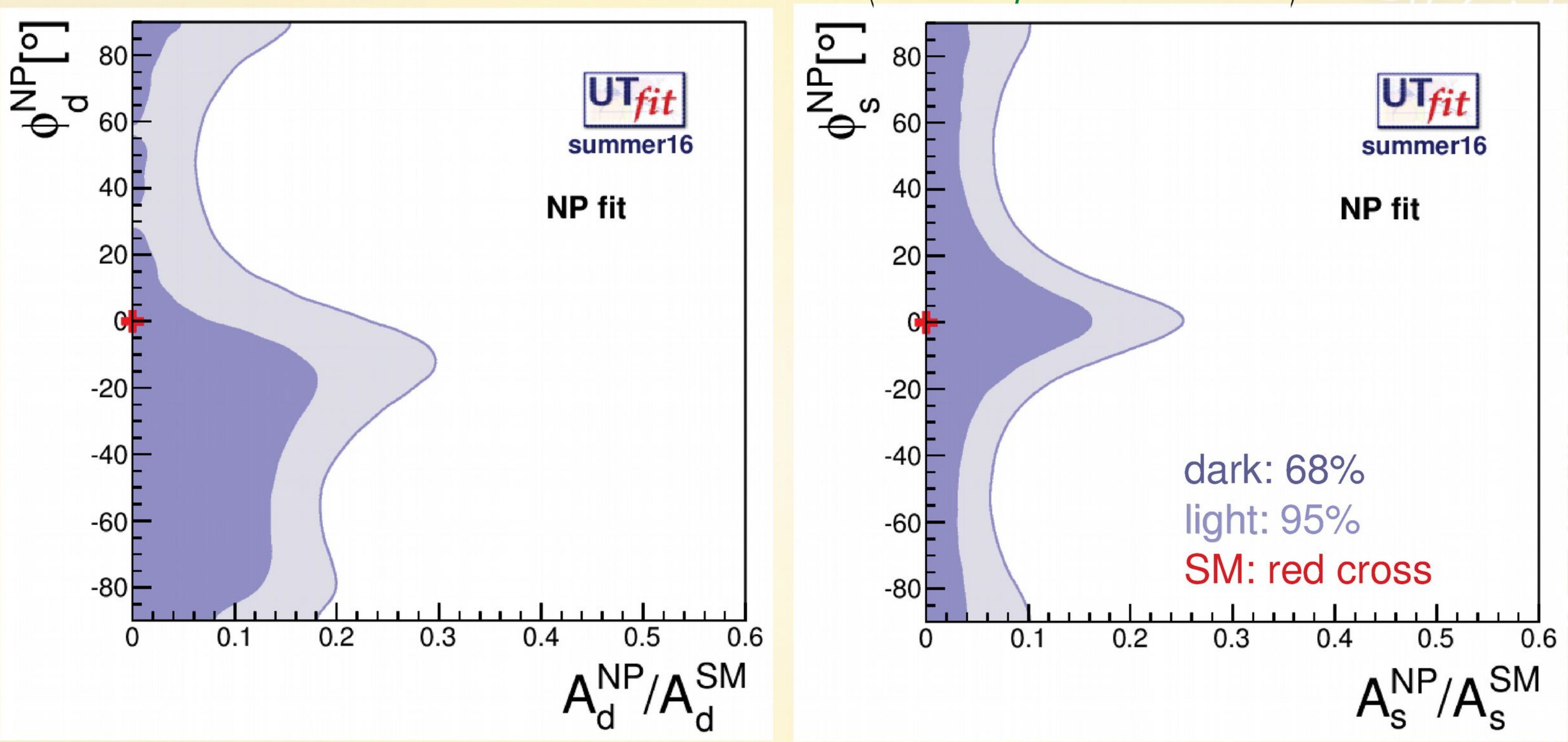


V. Chobanova

Update from UTfit

NP parameter results

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



The ratio of NP/SM amplitudes is:

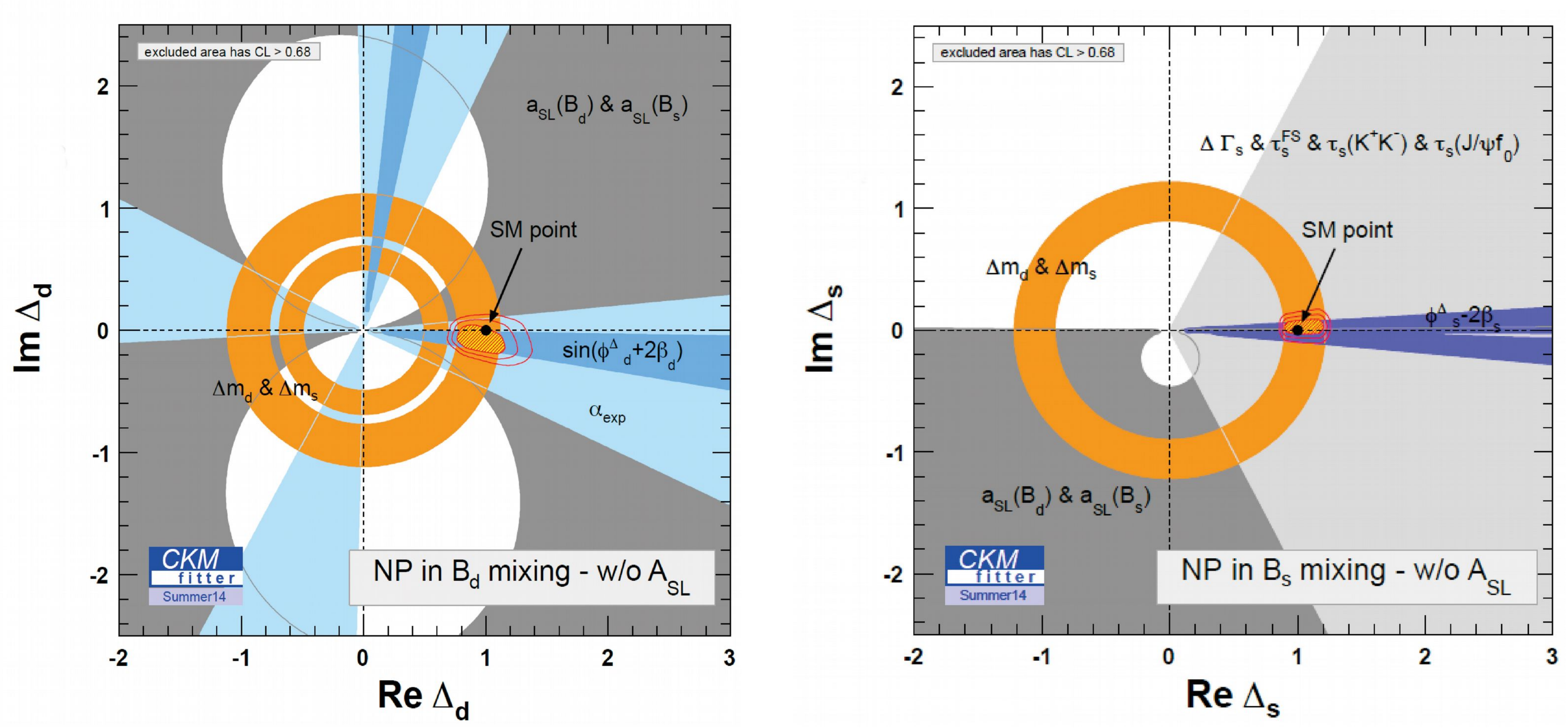
< 15% @68% prob. (30% @95%) in B_d mixing

< 15% @68% prob. (25% @95%) in B_s mixing

see also Lunghi & Soni, Buras et al., Ligeti et al.

M. Bona

Update from CKMfitter



The message is the same: still plenty of room for New Physics in B_d and B_s oscillations!

A. Perez

Conclusions

- Many new exciting results have been presented, many more will come with the datasets already available;
- The increase in luminosity, the upgrade of the LHCb detector, and the start of Belle II will greatly extend the sensitivity of these searches;

- Many thanks to all the presenters for excellent contributions:

Simon Akar, Prafulla Behera, Alex Birnkraut, Monika Blanke,
Marcella Bona, Marta Calvi, Veronika Chobanova,
Agnieszka Dziurda, Greig Cowan, Elvira Gamiz,
Julian Garcia Pardinas, Martin Jung, Ulrich Nierste,
Arantza Oyanguren, Bilas Pal, Stefano Perazzini, Alejandro Perez,
Pavel Reznicek, Mike Sokoloff, Stefania Vecchi