Measurements of CP violating phases in B decays at LHCb

Sevda Esen [Heidelberg University]
on behalf of the LHCb collaboration

UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

Les Rencontres de Physique de la Vallée d'Aoste, 1-7 March 2015

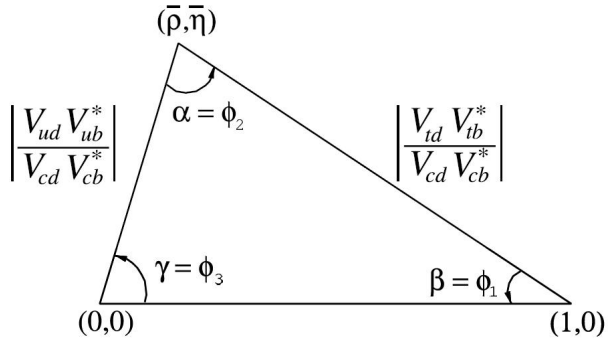
CP Violation in the SM

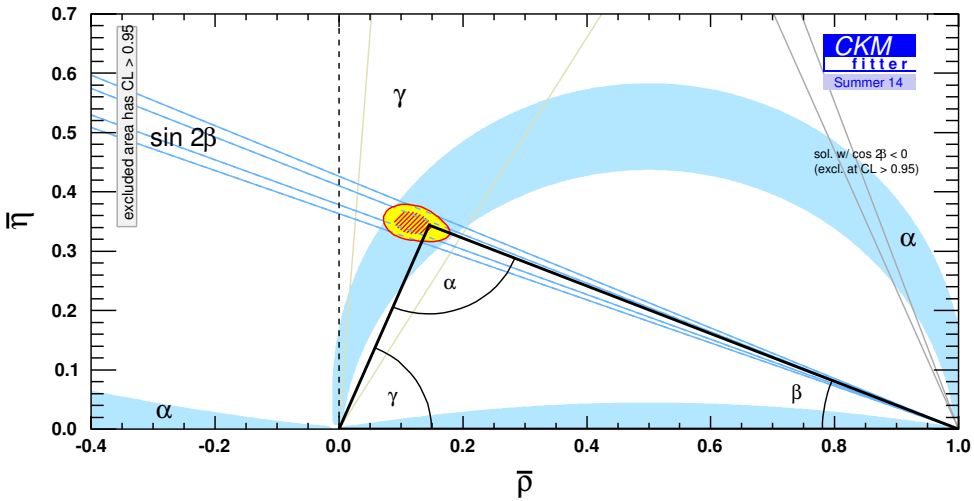
- Source of CPV: the complex phase in the CKM matrix

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

Wolfenstein, PRL 51, 1945 (1983)

- Unitarity requirements: $\Sigma_i V_{ij} V_{ik}^* = \delta_{jk}$
  - $V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$
  - $V_{us} V_{ub}^* + V_{cs} V_{cb}^* + V_{ts} V_{tb}^* = 0$

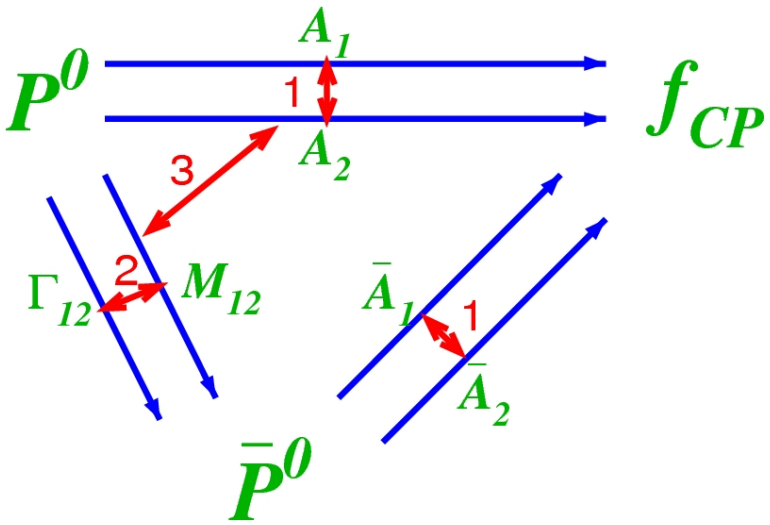




- Check consistency of the CKM framework:
  - measure three angles and two sides of the UT
  - search for potential new physics contributions

(1) CPV in decay:

$$P(B \to f) \neq P(\bar{B} \to \bar{f})$$



(2) CPV in mixing

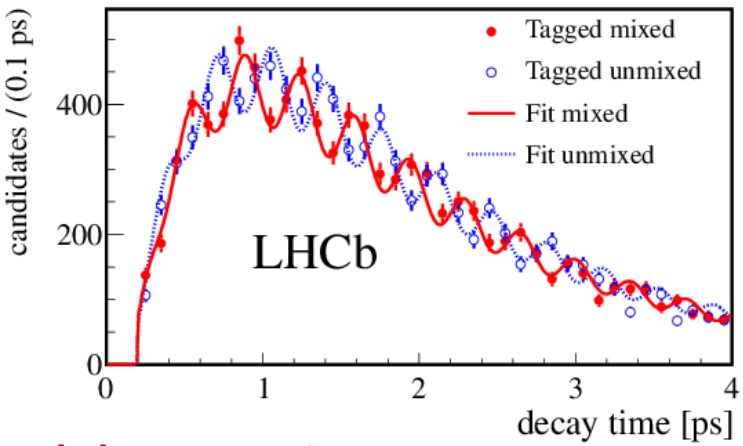
$$P(B \to \bar{B}) \neq P(\bar{B} \to B)$$

Mass eigenstates:

$$\left|B_H^0\right\rangle = p\left|B^0\right\rangle - q\left|\bar{B}^0\right\rangle$$
$$\left|B_L^0\right\rangle = p\left|B^0\right\rangle + q\left|\bar{B}^0\right\rangle$$

$|p/q| \neq 1 \Rightarrow$ CPV

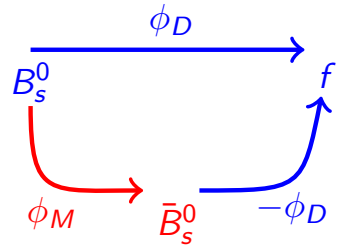
New J. Phys. 15 (2013) 053021



(3) CPV in the interference of decay and mixing

$$P(B \to f_{CP}) \neq P(B \to \bar{B} \to f_{CP})$$

$$\lambda = \frac{q}{p}\frac{\bar{A}(\bar{B}\to f_{CP})}{A(B\to f_{CP})} \qquad \phi_q^f = -arg(\eta_f \lambda_f) = \phi_M - 2\phi_D$$



- Theoretical time dependent CP asymmetry

$$A_{CP}(t) = \frac{\Gamma(\bar{B}^0_q \to f) - \Gamma(B^0_q \to f)}{\Gamma(\bar{B}^0_q \to f) + \Gamma(B^0_q \to f)} = \frac{A^{dir}_{CP}\cos(\Delta M_q t) + A^{mix}_{CP} sin(\Delta M_q t)}{\cosh(\Delta\Gamma_q t/2) + A_{\Delta\Gamma}\sinh(\Delta\Gamma_q t/2)}$$

- Experimentally

$$A_{CP} \approx (1-2w)e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2} A^{theory}_{CP}$$

  - w Probability of getting the initial flavor wrong
  - σ_t Decay time resolution
  - η_f CP eigenvalue $\rightarrow$ angular analysis

for negligible penguin contr.

$A^{dir}_{CP} \approx 0 \Rightarrow$ C

$A^{mix}_{CP} \approx \eta_f \sin\phi_q \Rightarrow$ S

for B^0_s: ϕ_s and λ

for B^0: C and S

- Minimum requirements:
  - excellent decay time resolution

LHCb $40 - 50$ fs

  - good flavor tagging

LHCb Effective tagging power: $3 - 4\%$

  - large statistics

LHCb trigger efficiencies: ~ 90 % for dimuon channels

track reconstruction efficiency: > 96 % for long tracks

$B_s^0 \to J/\psi K^+K^-$

PRL 114, 041801

- SM prediction:

  $\phi_s = (-0.036 \pm 0.002) rad$ and $|\lambda| \approx 1$

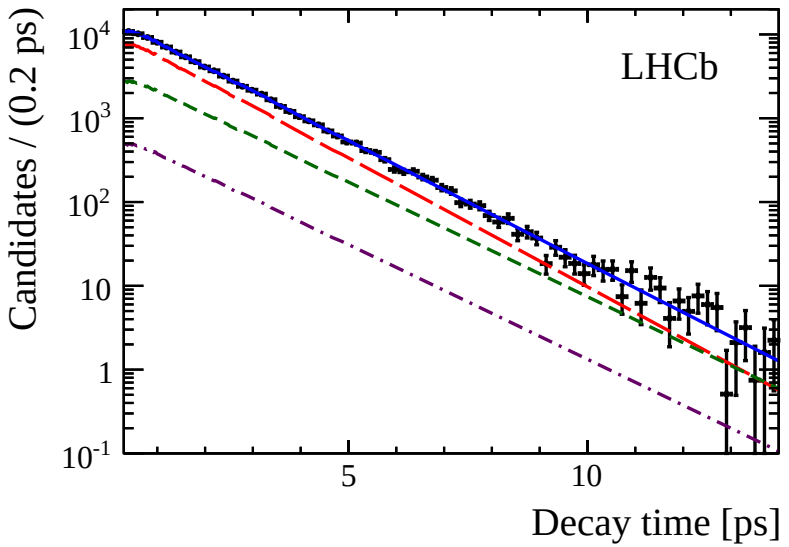
- Signal: 95690±350 events

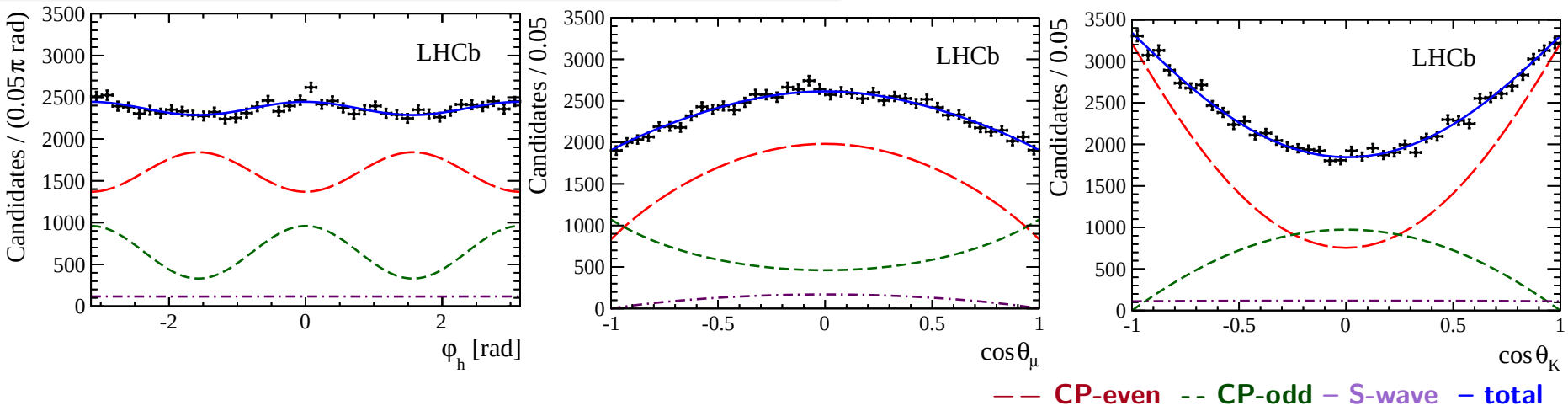
- 4d fit in bins of m_{KK}:

  decay time and angles in helicity frame

Results

ϕ_s [rad]	$-0.058 \pm 0.049 \pm 0.006$
$\lvert\lambda\rvert$	$0.964 \pm 0.019 \pm 0.007$





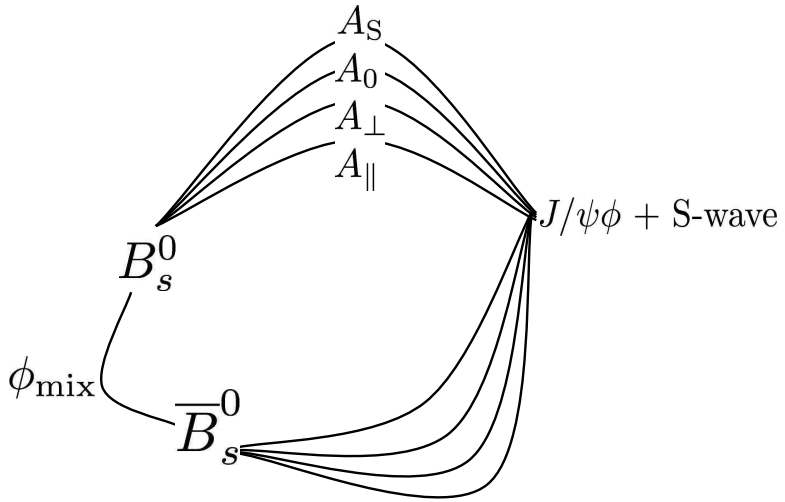
$B_s^0 \to J/\psi K^+K^-$: Polarization dependence

PRL 114, 041801

For non-negligible penguin contributions

- size of pollution could be different for 3 P-wave and the S-wave states
- CPV might be polarization dependent
- complicates the search for NP effects

e.g.,Bhattacharya, Datta, Int. J. Mod, Phys. **A28**(2013) 1350063



We measure:

$$\lambda_f = \frac{q}{p}\frac{\bar{A}_f}{A_f} = |\lambda_f| e^{-i\phi_s^f}$$

for each $f = 0, \parallel, \perp, S$

assume zero CPV in mixing

PLB 728, (2014) 607

ϕ_s^0 [rad]	$-0.045 \pm 0.053 \pm 0.007$
$\phi_s^\parallel - \phi_s^0$ [rad]	$-0.018 \pm 0.043 \pm 0.009$
$\phi_s^\perp - \phi_s^0$ [rad]	$-0.014 \pm 0.035 \pm 0.006$
$\phi_s^S - \phi_s^0$ [rad]	$0.015 \pm 0.061 \pm 0.021$
$\lvert\lambda^0\rvert$	$1.012 \pm 0.058 \pm 0.013$
$\lvert\lambda^\parallel/\lambda^0\rvert$	$1.02 \pm 0.12 \pm 0.05$
$\lvert\lambda^\perp/\lambda^0\rvert$	$0.97 \pm 0.16 \pm 0.01$
$\lvert\lambda^S/\lambda^0\rvert$	$0.86 \pm 0.12 \pm 0.04$

$B_s^0 \to J/\psi\pi^+\pi^-$

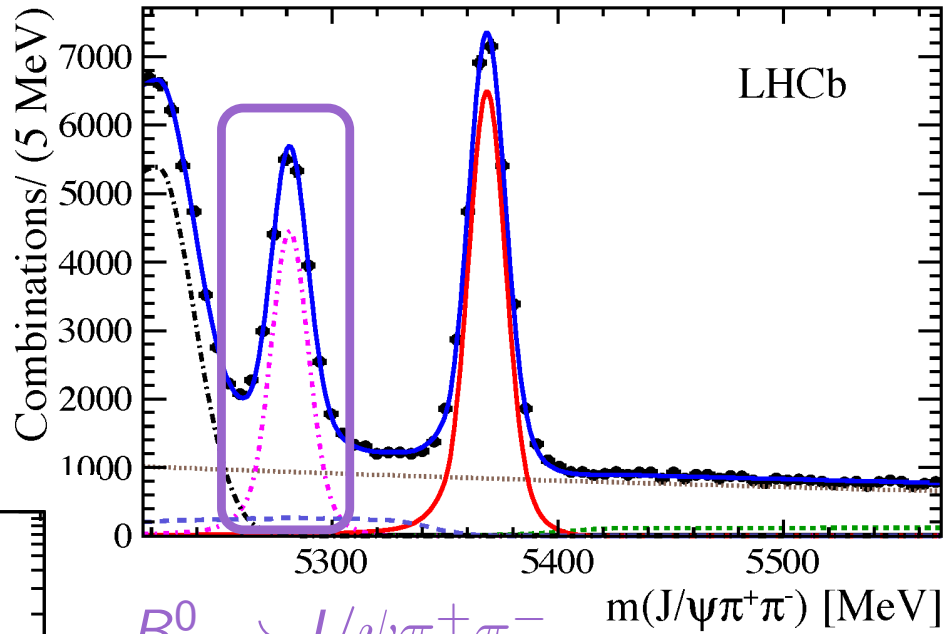
Phys. Lett. B 736 (2014) 186

- 27100 ± 200 signal events
- 6 dimensional fit:

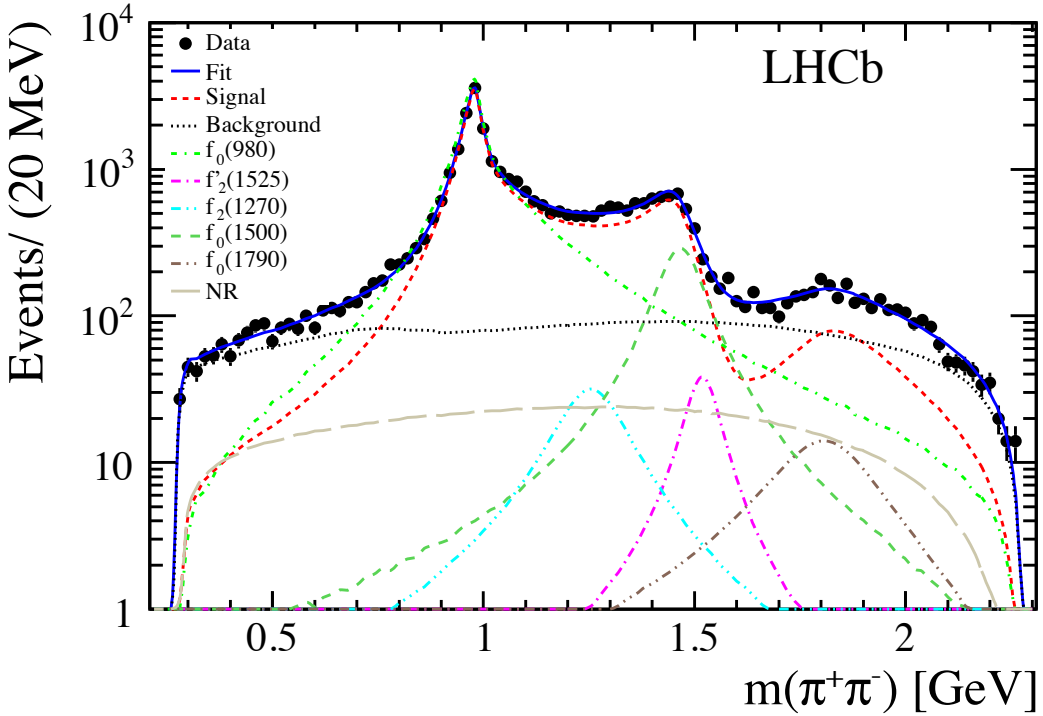
  $m_{\pi\pi}$, $m_{J/\psi\pi\pi}$,

  decay time

  decay angles in helicity frame



$B^0 \to J/\psi\pi^+\pi^-$



- from the amplitude analysis

  2.3% CP even @ 95% CL

- largest component $f_0(980)$

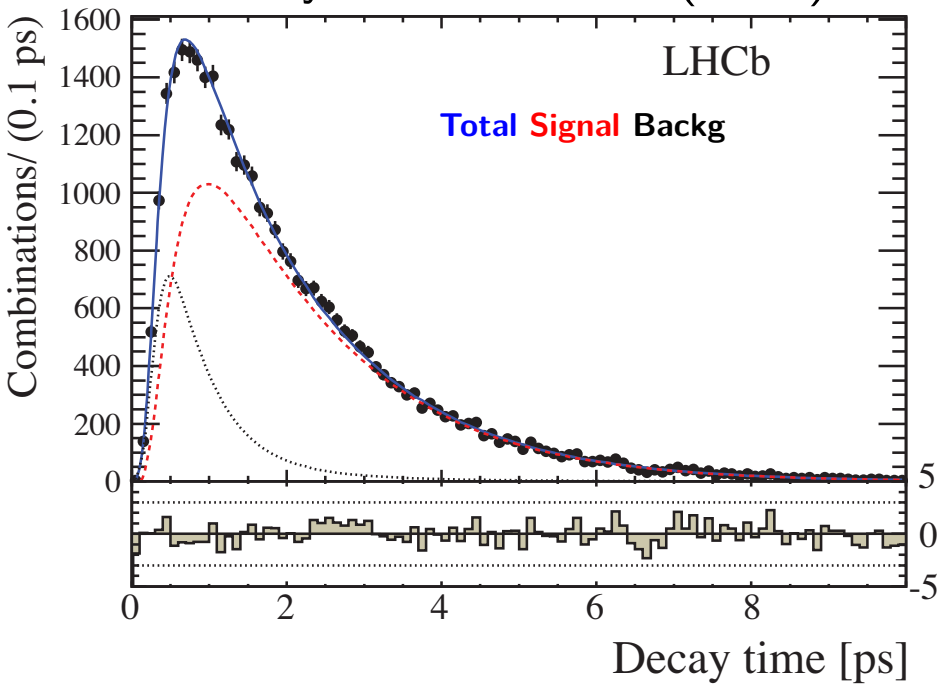
$B_s^0 \to J/\psi\pi^+\pi^-$

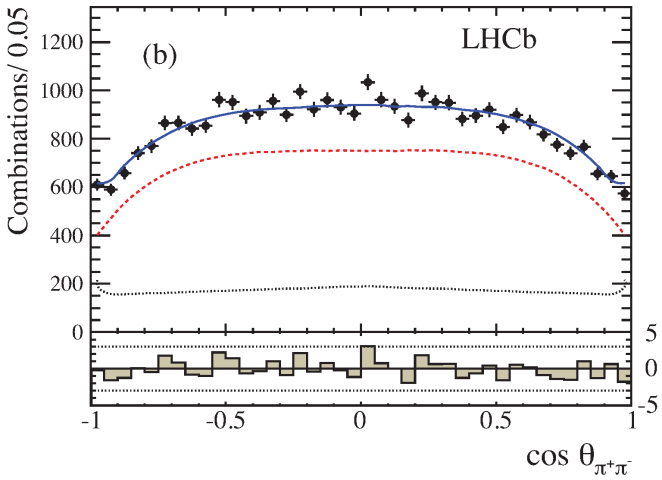
- SM prediction:
  $\phi_s = (-0.036 \pm 0.002)rad$ and $|\lambda| \approx 1$
- 27100 ± 200 signal events

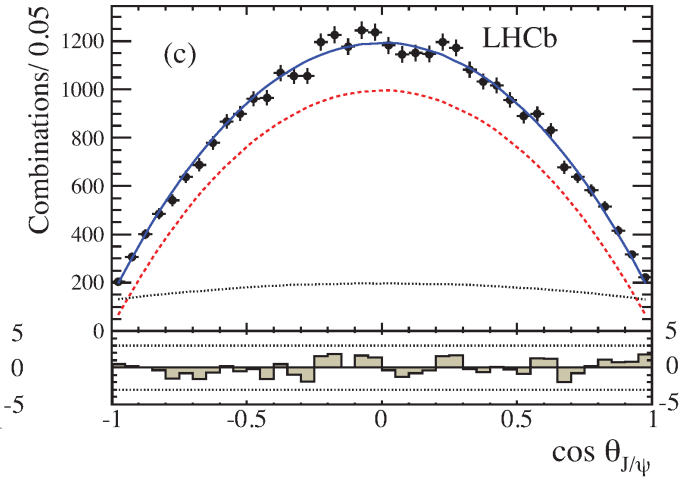
Results

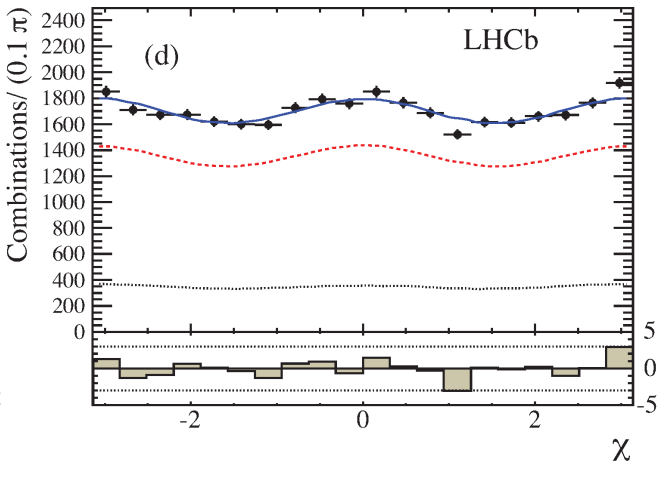
ϕ_s [rad]	$0.070 \pm 0.068 \pm 0.008$
$\lvert\lambda\rvert$	$0.89 \pm 0.05 \pm 0.01$

Phys. Lett. B 736 (2014) 186

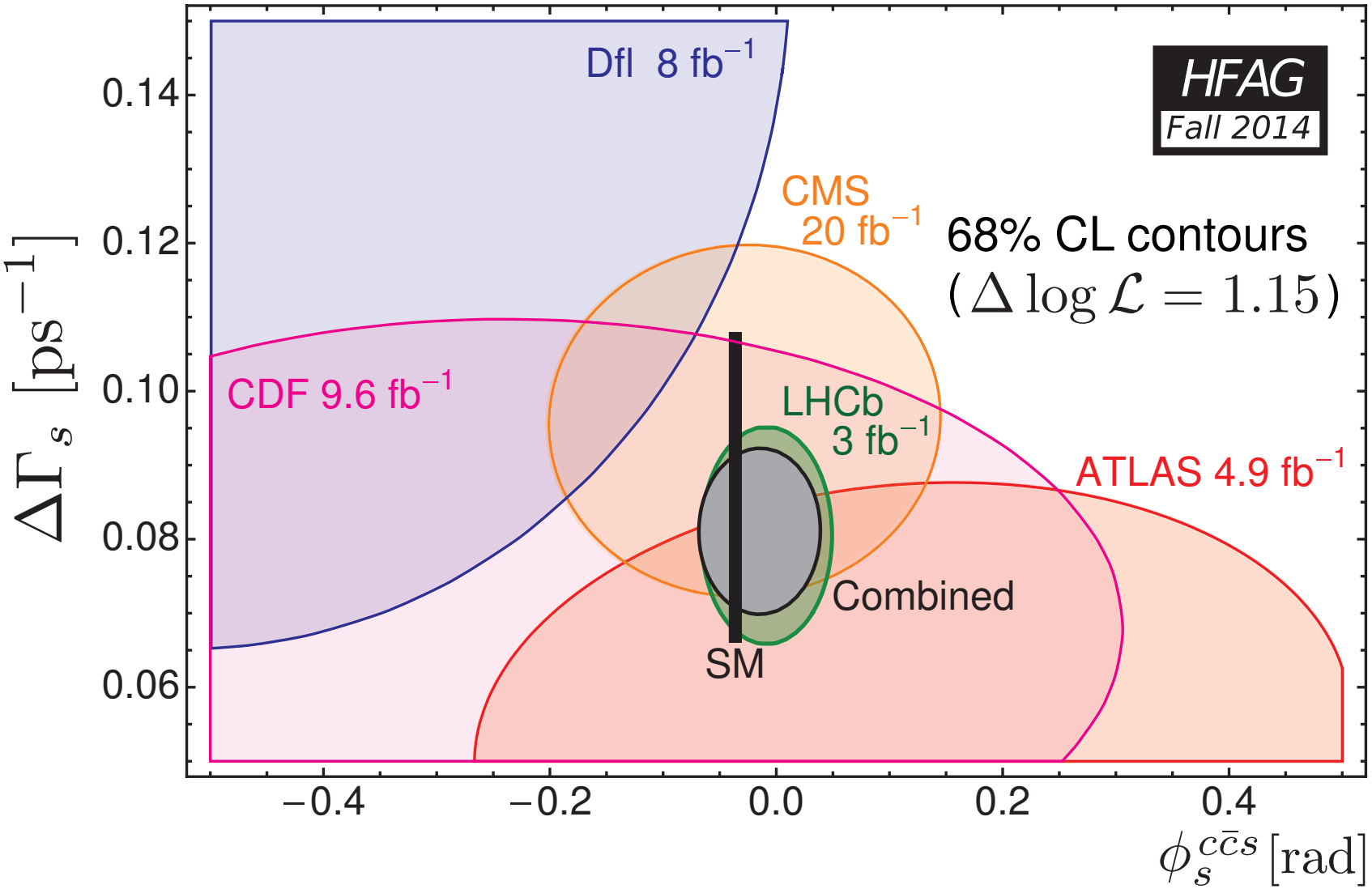






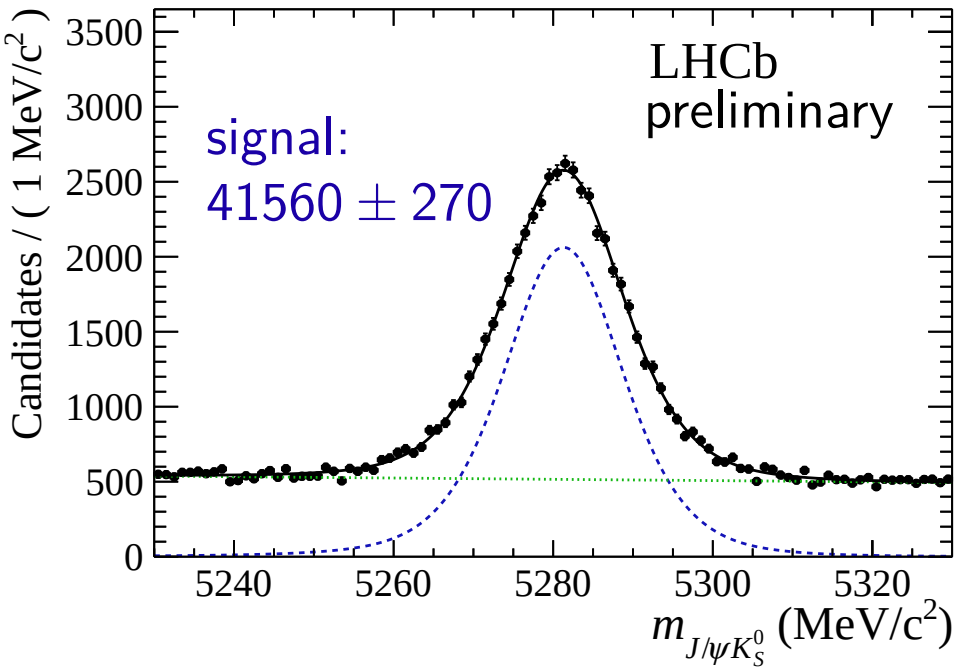


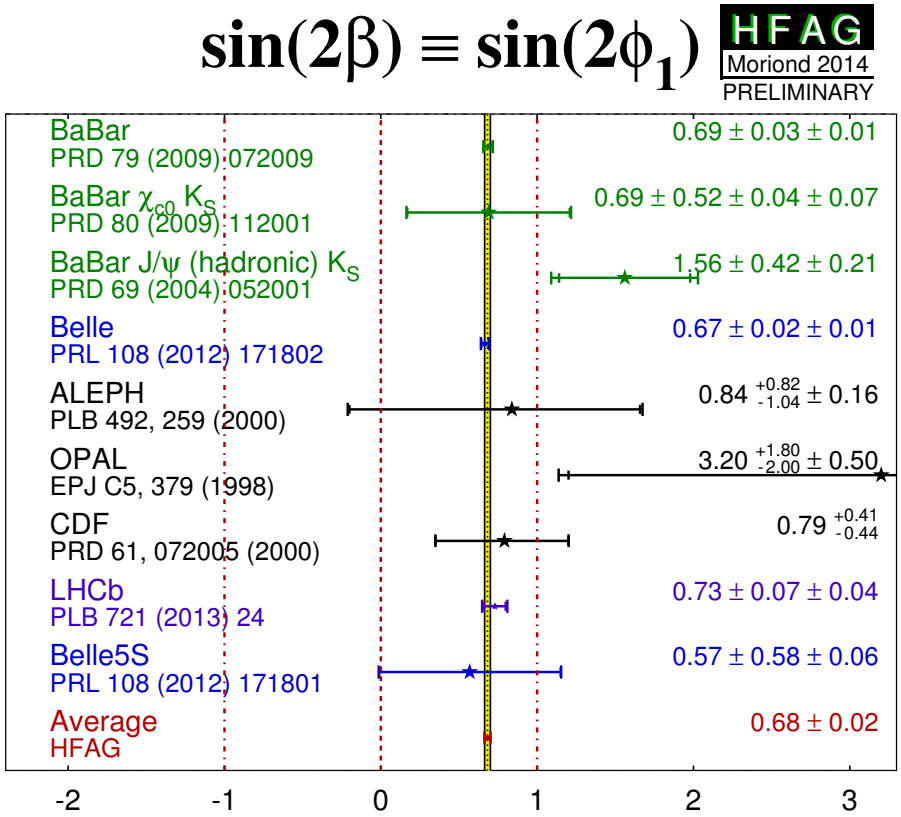
ϕ_s-$\Delta\Gamma_s$ world average



$B^0 \to J/\psi K_S$ NEW

- precise measurement of sin(2β)
  $\Rightarrow$ mostly by B-factories so far
- LHCb update with 3fb^{-1}
  - increased data set
  - improved flavor tagging





$B^0 \to J/\psi K_S$ NEW

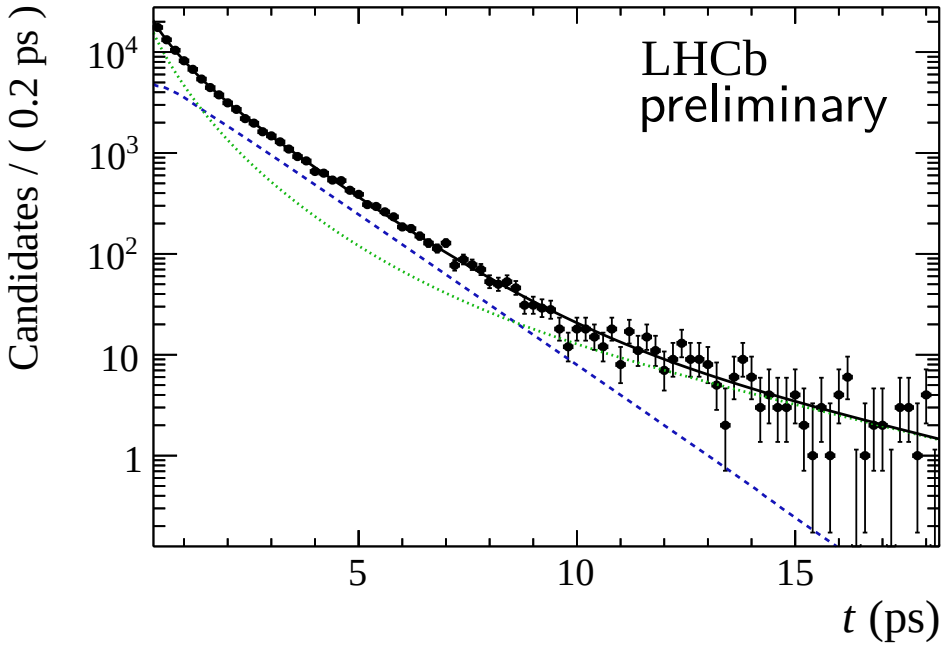
Preliminary

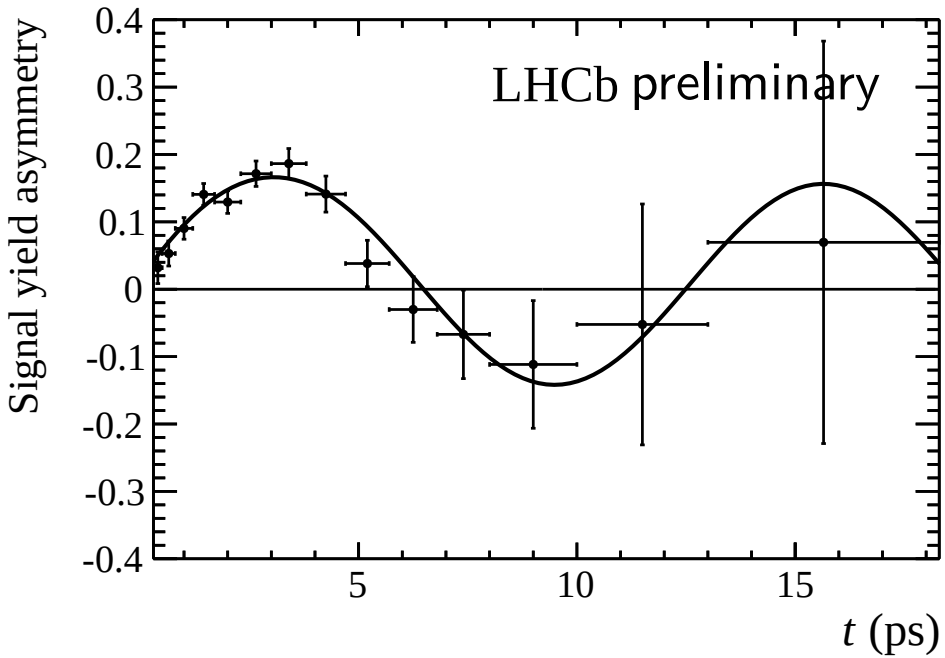
$C = -0.038 \pm 0.032 \pm 0.005$

$S = 0.731 \pm 0.035 \pm 0.020$

- consistent with current WA and the SM
- precision similar to B factories

more details by Frank Meier on Wednesday at YSF

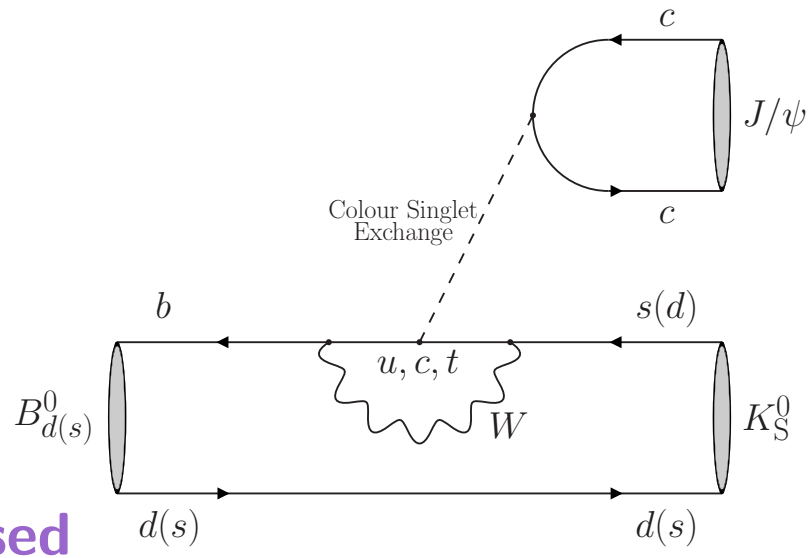




Penguin Pollution in ϕ_q

What we really measure:

$\phi_q = \phi_{SM} + \delta\phi_{NP} + \delta\phi_{pen}$

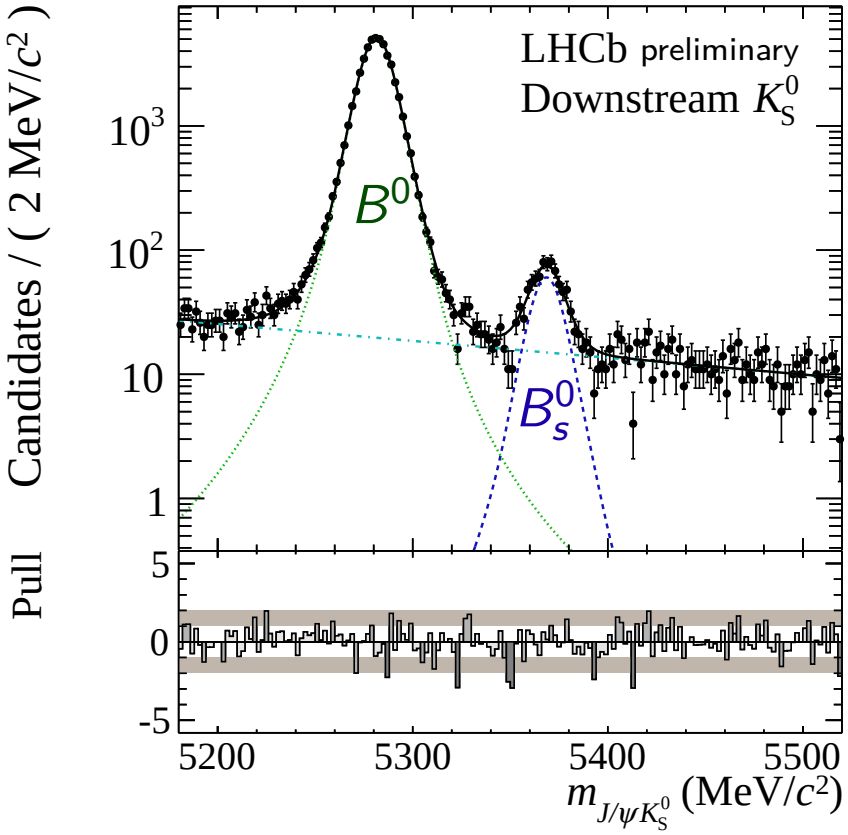


- **doubly Cabibbo suppressed**
- **non-perturbative hadronic enhancements?**

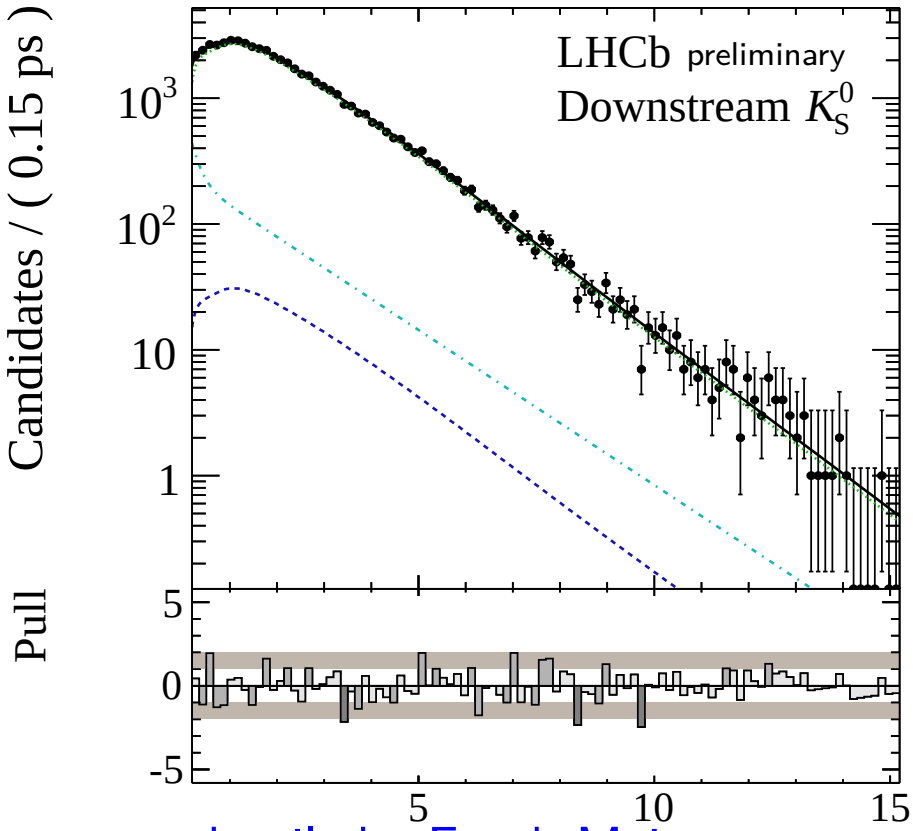
Control penguins via flavor symmetry: R. Fleischer, Eur. Phys. J. C 10, 299 (1999)

- use U-spin-related modes
  $\Rightarrow$ with increased relative penguin influence
  ex: $B^0_s \to J/\psi K_S$, $B^0_s \to J/\psi K^\star$, $B^0 \to J/\psi \rho$, $B^0 \to J/\psi \pi^0$
  to be published soon — ongoing analysis — Phys.Lett. B742 (2015) 38-49.
- can extract $\delta\phi_{pen}$
  $\Rightarrow$ need to take into account SU(3) breaking

$B_s^0 \to J/\psi K_S^0$



- K_S^0 split into two categories: Long and Downstream
- Signal B_s^0 Yield: 307 ± 20 Long and 601 ± 30 Downstream



more details by Frank Meier on Wednesday at YSF

Preliminary

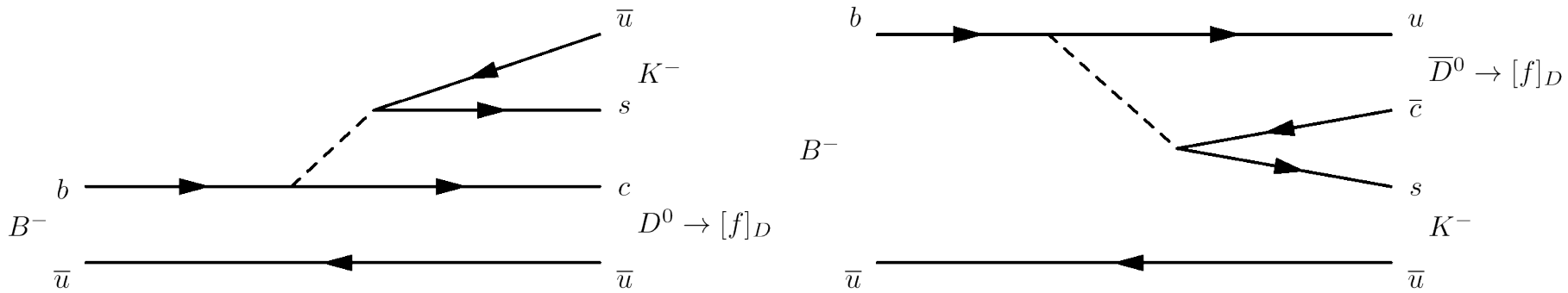
$A_{\Delta\Gamma} = 0.49^{+0.77}_{-0.65} \pm 0.06$

$C = -0.28 \pm 0.41 \pm 0.08$

$S = -0.08 \pm 0.40 \pm 0.08$

γ from B Decays

- Can be determined entirely from tree decays
  - typical decays are $B \to Dh$: interference between D and $\bar{D}$ contributions
  - small theoretical uncertainty ($\Delta\gamma/\gamma \sim 10^{-6}$)



$$A_{B^-} \quad \alpha \quad A_f \qquad + \qquad r_B e^{i(\delta_B - \gamma)} \bar{A}_f$$

Amplitude ratio: $r_B = |A(B \to \bar{D}K)|/|A(B \to DK)|$

Strong phase difference: δ_B

- Several methods: GSW, ADS, GSGZ...

LHCb Combination

- Measurements considered in combination:

Decay	Method	Data
$B^+ \to D(\to hh)h^+$	GLW/ADS	1 fb^{-1}
$B^+ \to D(\to K\pi\pi\pi)h^+$	ADS	1 fb^{-1}
$B^+ \to D(\to K^0_S hh)K^+$	GGSZ	3 fb^{-1}
$B^+ \to D(\to K^0_S K\pi)K^+$	GLS	3 fb^{-1}
$B^0 \to D(\to hh)K^{*0}$	GLW/ADS	3 fb^{-1}
$B^0_s \to D^\pm_s K^\mp$	time-dependent	1 fb^{-1}

- **robust combination:**

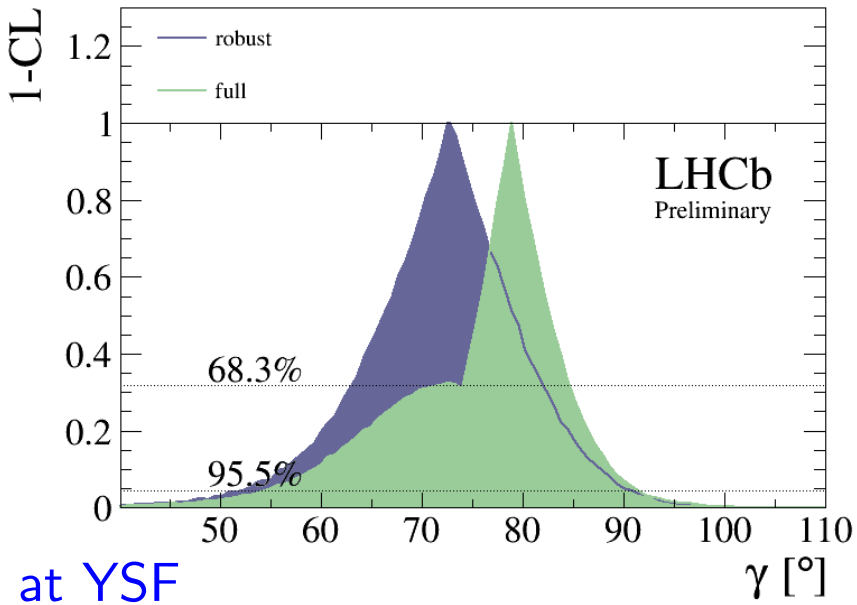
  only $B \to DK$-like channels

  $\gamma = 73^{+9}_{-10}{}^\circ$

- **full combination:**

  + $B \to D\pi$-like channels

  $\gamma = 79^{+6}_{-7}{}^\circ$



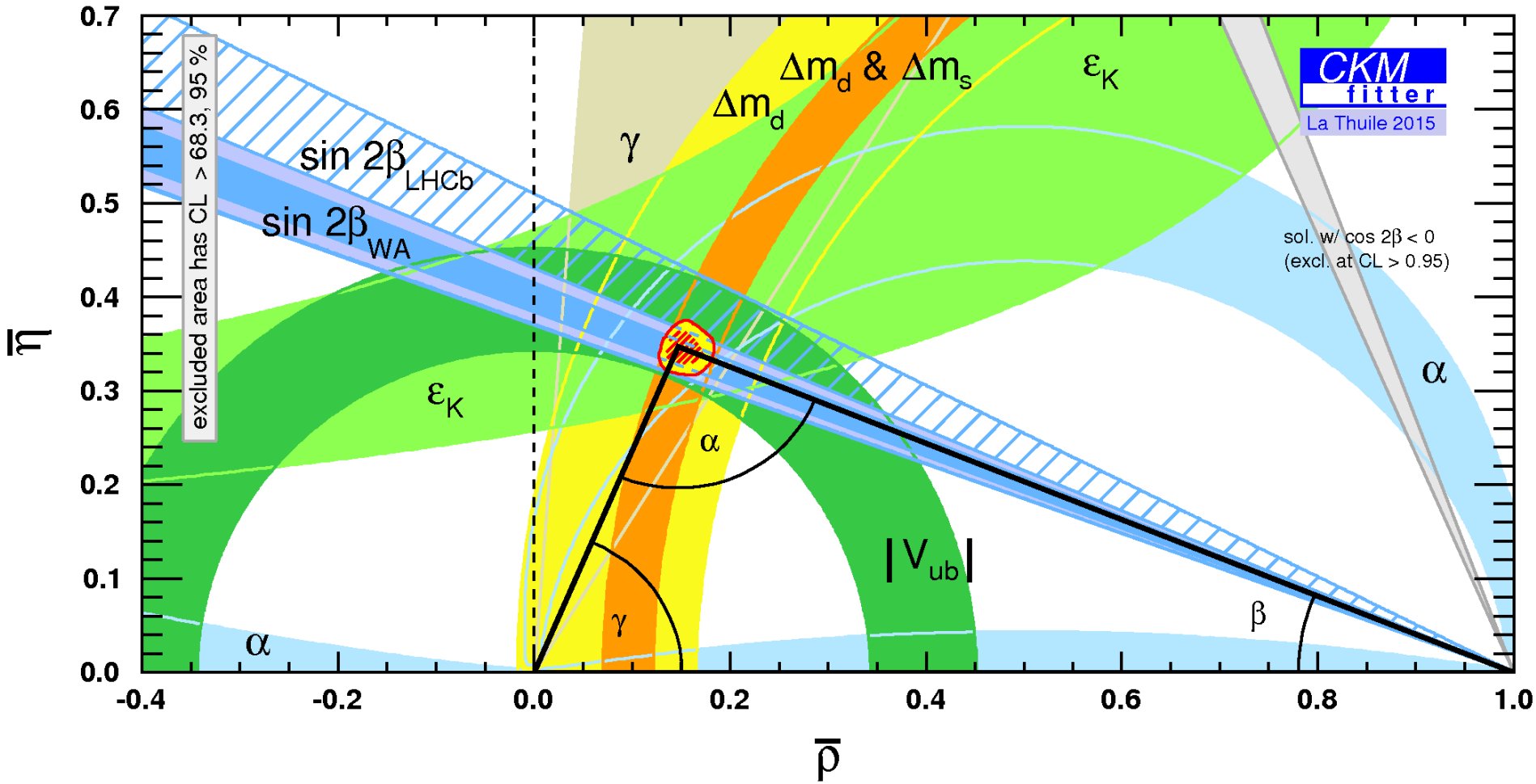
more details by Rose Koopman on Tuesday at YSF

Summary I

- Precision measurements of CP violating phases at LHCb
- Updated measurements of $B - \bar{B}$ mixing phases [3 fb^{-1}]
  - experimental sensitivity $\sigma(\phi_s) < 0.038$
  - first polarization dependent ϕ_s measurements
  - $\sin(2\beta)$ competitive precision with Belle and Babar
    $\Rightarrow$ good prospects for run II
  - limits on penguin contributions
- precise measurement of γ through combination

Summary II

- good agreement with the SM overall, but not the end of the story...



BACKUP