Mixing and mixing-related CP violation in the B system

Martin Jung Tagir Aushev
Yasmine Amhis

CKM 2014 - Wien

WG4 - 21 contributions !

B mixing in and beyond the SM *Alexander LENZ*
EI 10 lecture hall, Vienna University of Technology

Lifetime measurements in B decays at LHCb *Francesca DORDEI*
EI 10 lecture hall, Vienna University of Technology

Measurement of CP observables in semi-leptonic decays at LHCb *Lucia GRILLO*

CP violation in B0-B0bar mixing with dilepton events at BaBar *Chih-hsiang CHENG*
EI 10 lecture hall, Vienna University of Technology

The like-sign dimuon asymmetry and new physics *Miguel NEBOT*

Effect of Delta Gamma on the dimuon asymmetry in B decays *Ulrich NIERSTE*

Tevatron results in CP Violation *Iain BERTRAM*

Measurement of CP observables using Bs-> DsK at LHCb

CP violation in B0-->pi+pi-, rho0rho0, omega Ks, Ks e... *Pit VANHOEFER*

Fits of the Unitarity Triangle *Dr. Marcella BONA*

Penguin pollution in Bs->J/Psi Phi *Rob KNEGJENS*

Penguin pollution in Bd -> J/Psi K_S and Bs -> J/Psi Phi *Philipp FRINGS*

Phi_s and penguin pollution at LHCb *Walaa KANSO*
EI 8 lecture hall, Vienna University of Technology

CP violation measurements and prospects for the upgrade at ATLAS

CP violation measurements at CMS *Jacopo PAZZINI*

Testing the SM with B->DD decays *Stefan SCHACHT*

Measurement of CP observables using Bs-> DsDs at LHCb *Conor FITZPATRICK*

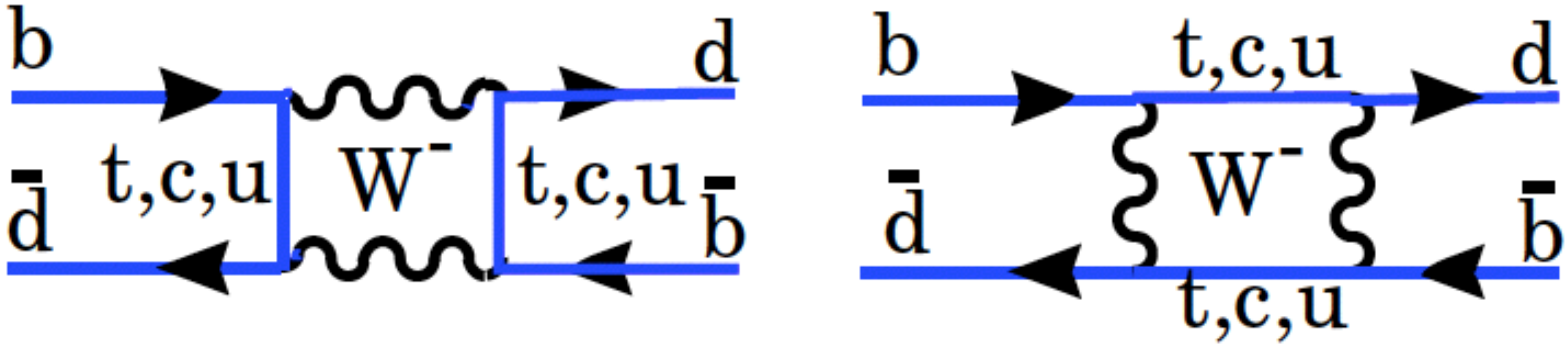
Analysis of B -> rho pi Dalitz plot and measurement of B0->D*+D*- with partial reconstruction at BaBar *Tomonary MIYASHITA*

CP violation in B0-->eta' K0 at Belle *Martin RITTER*
EI 10 lecture hall, Vienna University of Technology

Fits of the Unitarity Triangle
EI 10 lecture hall, Vienna University of Technology

Prospects of time dependent CP Violation with the LHCb Upgrade *Eduardo RODRIGUES*

WG4 - 21 contributions !



$|M_{12}|$, $|\Gamma_{12}|$ and $\phi = \arg(-M_{12}/\Gamma_{12})$ can be related to three observables:

Alex

- **Mass difference:** $\Delta M := M_H - M_L \approx 2|M_{12}|$ **(off-shell)**
  $|M_{12}|$: heavy internal particles: t, SUSY, ...
- **Decay rate difference:** $\Delta\Gamma := \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\phi$ **(on-shell)**
  $|\Gamma_{12}|$: light internal particles: u, c, ... (almost) no NP!!!
- **Flavor specific/semi-leptonic CP asymmetries:** e.g. $B_q \to Xl\nu$ (*semi-leptonic*)

$$a_{sl} \equiv a_{fs} = \frac{\Gamma(\overline{B}_q(t) \to f) - \Gamma(B_q(t) \to \overline{f})}{\Gamma(\overline{B}_q(t) \to f) + \Gamma(B_q(t) \to \overline{f})} = \left|\frac{\Gamma_{12}}{M_{12}}\right| \sin\phi$$

- New physics

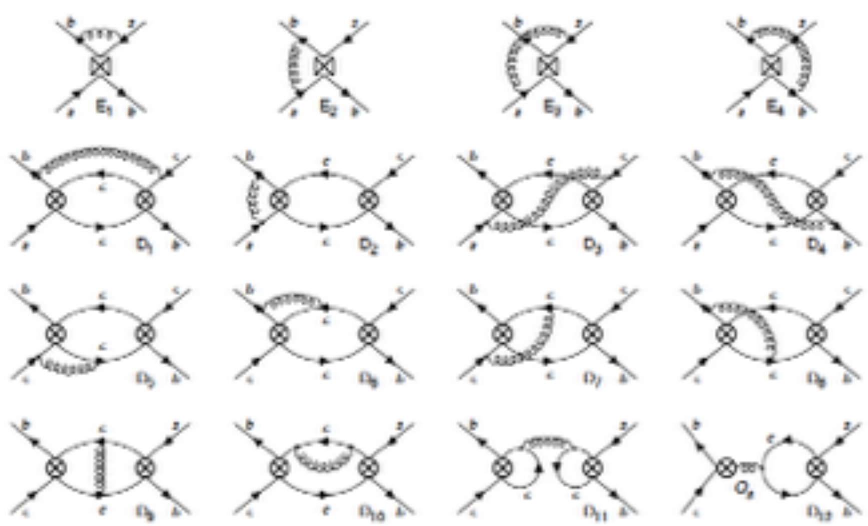
$$\begin{aligned} M_{12}^s &= M_{12}^{s,\mathrm{SM}} |\Delta_s| e^{i\phi_s^\Delta} \\ \Gamma_{12}^s &= \Gamma_{12}^{s,\mathrm{SM}} |\tilde{\Delta}_s| e^{i\phi_s^{\tilde{\Delta}}} \\ -2\beta_s + \delta_s^{\mathrm{peng,SM}} &\to \phi_s^{c\bar{c}s} = -2\beta_s + \delta_s^{\mathrm{peng,SM}} + \delta_s^{\mathrm{peng,NP}} + \phi_s^\Delta \end{aligned}$$

Decay rate difference: Second OPE = Heavy Quark Expansion (HQE)

$$\Gamma_{12} = \left(\frac{\Lambda}{m_b}\right)^3 \left(\Gamma_3^{(0)} + \frac{\alpha_s}{4\pi}\Gamma_3^{(1)} + \ldots\right) + \left(\frac{\Lambda}{m_b}\right)^4 \left(\Gamma_4^{(0)} + \ldots\right) + \left(\frac{\Lambda}{m_b}\right)^5 \left(\Gamma_5^{(0)} + \ldots\right) + \ldots$$

'96: Beneke, Buchalla; '98: Beneke, Buchalla, Greub, A.L., Nierste;
'03: Beneke, Buchalla, A.L., Nierste; '03: Ciuchini, Franco, Lubicz, Mescia, Tarantino;
'06; '11: A.L., Nierste; '07 Badin, Gabianni,Petrov

Calculating the following diagrams



Alex

Finally $\Delta\Gamma_s$ is measured! E.g. from $B_s \to J/\psi\phi$
LHCb Moriond 2012, 2013; ATLAS; CDF; DO; CMS

$$\Delta\Gamma_s^{\rm Exp} = (0.091 \pm 0.008)\,\text{ps}^{-1}$$
$$\Delta\Gamma_s^{\rm SM} = (0.087 \pm 0.021)\,\text{ps}^{-1}$$

HFAG 2014
A.L.,Nierste 1102.4274

(Almost) all discrepancies disappeared:

- '12: $n_c^{2011PDG} = 1.20 \pm 0.06$ vs. $n_c^{SM} = 1.23 \pm 0.08$ **Krinner, A.L., Rauh 1305.5390**
- HFAG '03 $\tau_{\Lambda_b} = 1.229 \pm 0.080$ ps^{-1} $\longrightarrow$ HFAG '14 $\tau_{\Lambda_b} = 1.451 \pm 0.013$ ps^{-1}

Shift by 2.8σ!

- **HFAG 2014:** $\tau_{B_s}/\tau_{B_d} = 0.995 \pm 0.006$
- 2010/2011: dimuon asymmetry too large — Test Γ_{12} with $\Delta\Gamma_s$!

Alex

Theory arguments for HQE

$\Rightarrow$ calculate corrections in all possible "directions", to test convergence

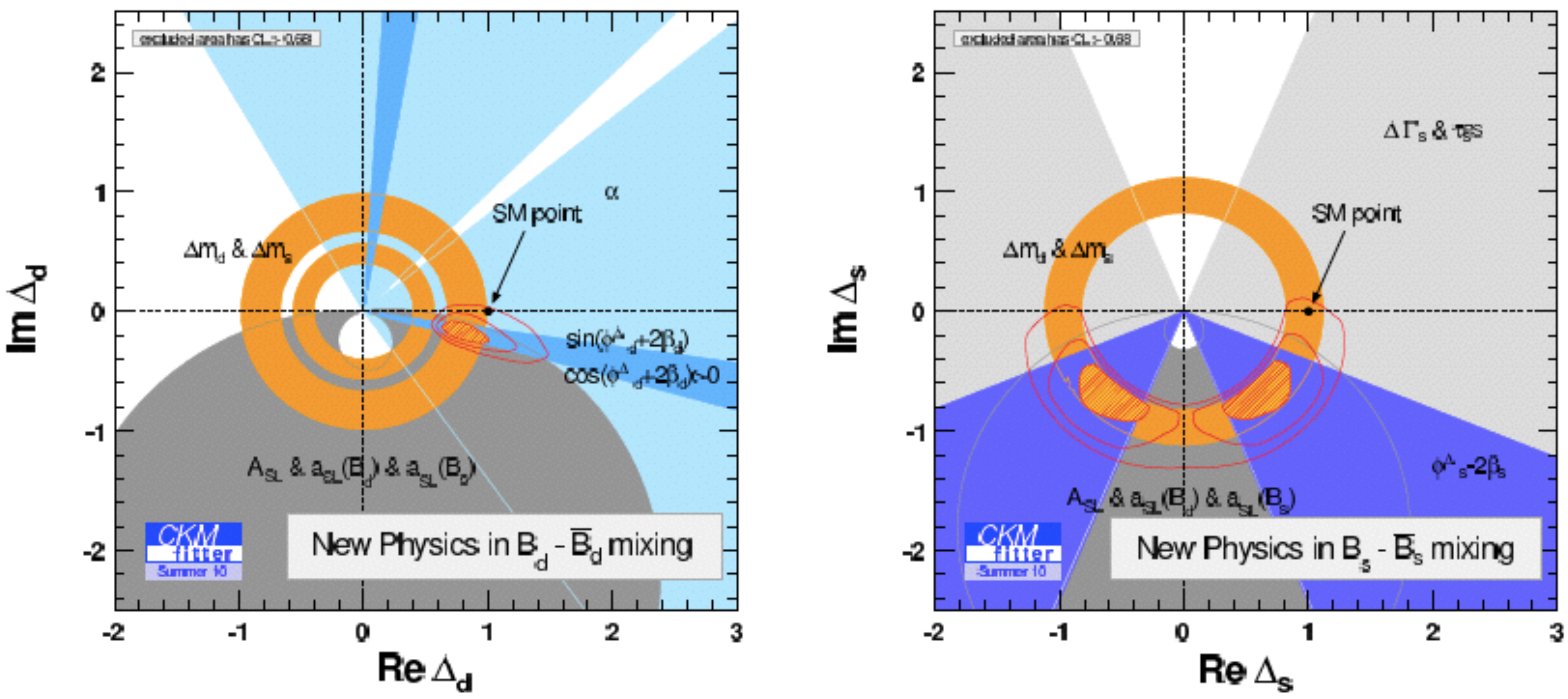
$$\begin{aligned} \Delta\Gamma_s &= \Delta\Gamma_s^0 \left(1 + \delta^{\mathrm{Lattice}} + \delta^{\mathrm{QCD}} + \delta^{\mathrm{HQE}}\right) \\ &= 0.142\ \mathrm{ps}^{-1} \left(1 - 0.14 - 0.06 - 0.19\right) \end{aligned}$$

$\Rightarrow$ looks ok!

$\Rightarrow$ test reliability of HQE via lifetimes (no NP effects expected)

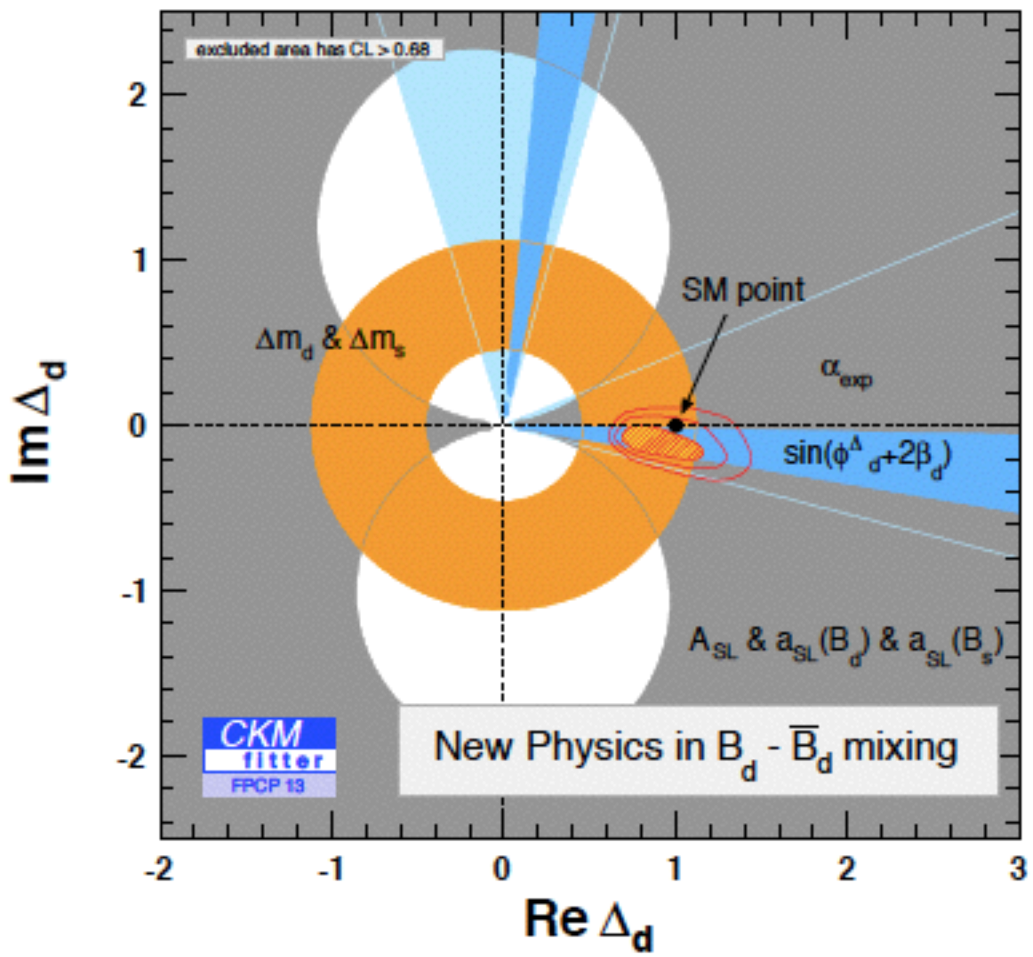
$\Rightarrow$ $\tau(B^+)/\tau(B_d)$ experiment and theory agree within hadronic uncertainties

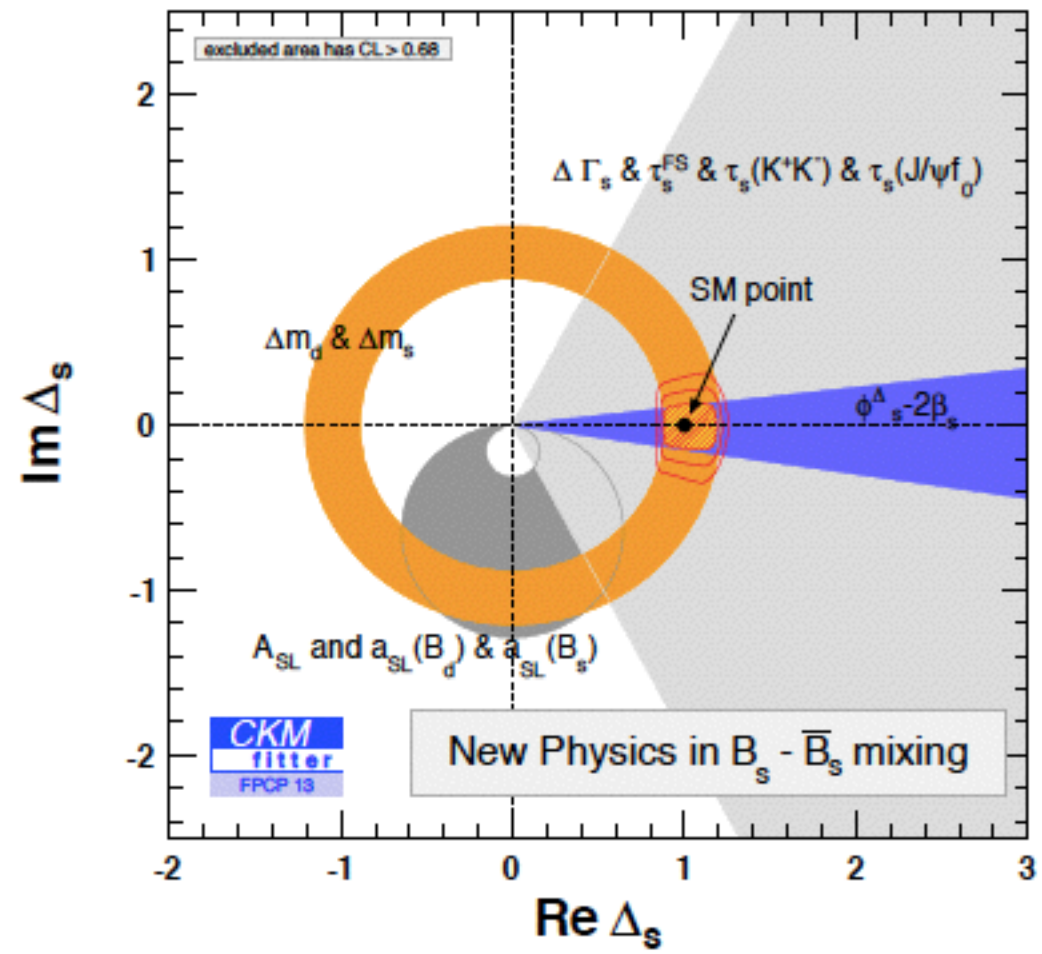
Search for New Physics in B-Mixing



Alex

Search for New Physics in B-Mixing





Alex

(Almost) all discrepancies disappeared:

- '12: $n_c^{2011\mathrm{PDG}} = 1.20 \pm 0.06$ vs. $n_c^{\mathrm{SM}} = 1.23 \pm 0.08$ **Krinner, A.L., Rauh 1305.5390**
- HFAG '03 $\tau_{\Lambda_b} = 1.22$ … $= 1.451 \pm 0.013$ ps^{-1}
- **HFAG 2014:** $\tau_{B_s}/\tau_{B_d} =$ …
- 2010/2011: dimuon a… th $\Delta\Gamma_s$!

Alex

$\Rightarrow$ calculate corrections … convergence

$\Delta\Gamma_s$ … HQE$)$ … $0.19)$ $\Rightarrow$ looks ok!

$\Rightarrow$ test reliability of HQE … ted)

$\Rightarrow \tau(B^+)/\tau(B_d)$ expe… dronic uncertainties

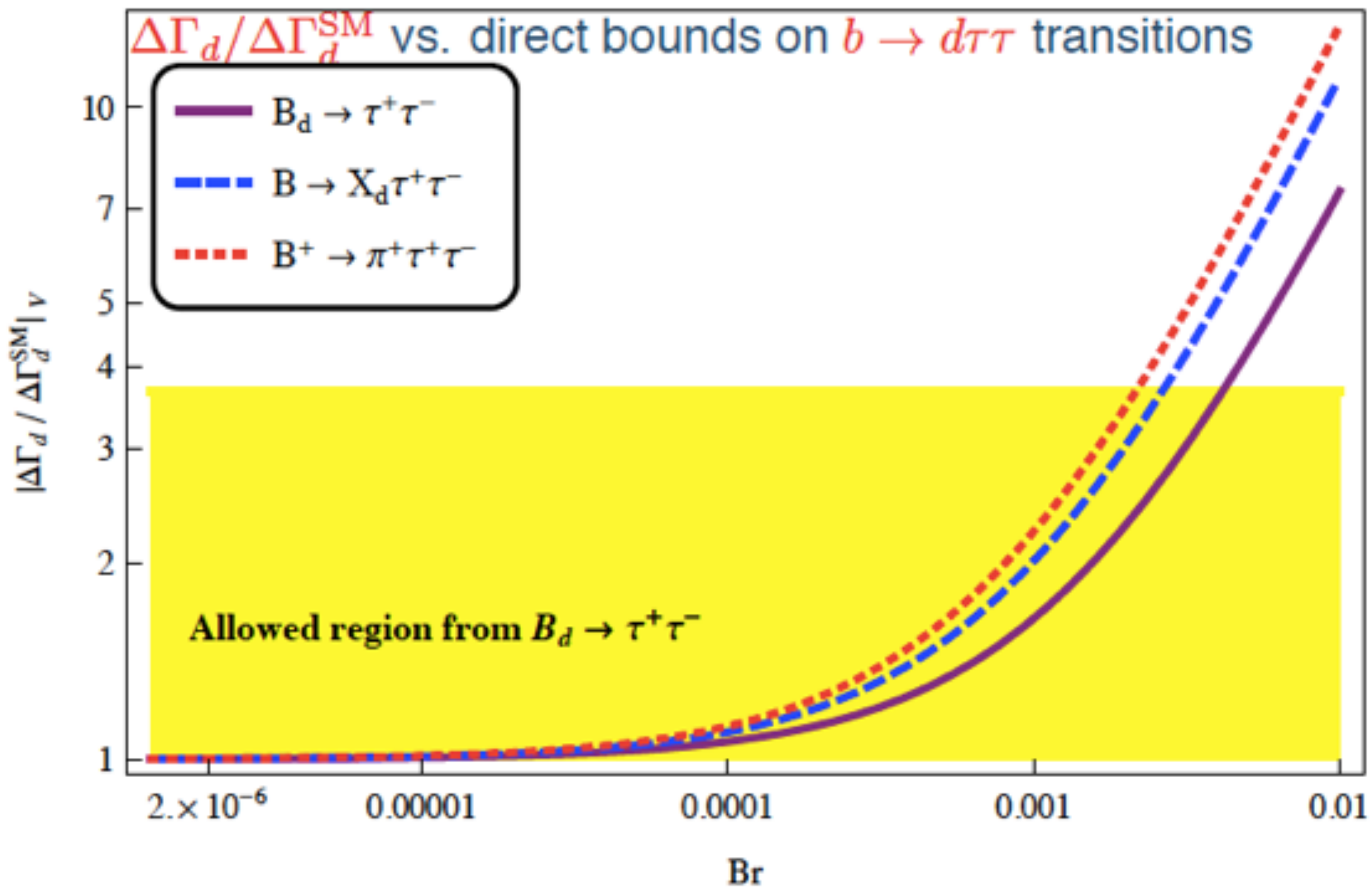
New physics in $\Delta\Gamma_d$?

A class of (almost) invisible decays

$b \to d\tau\tau$ can enhance $\Delta\Gamma_d$

Enhancement via

- Violations of CKM duality
- New **(almost unconstrained)** $bd\tau\tau$ operators
- New physics in current-current operators Q_1 and Q_2



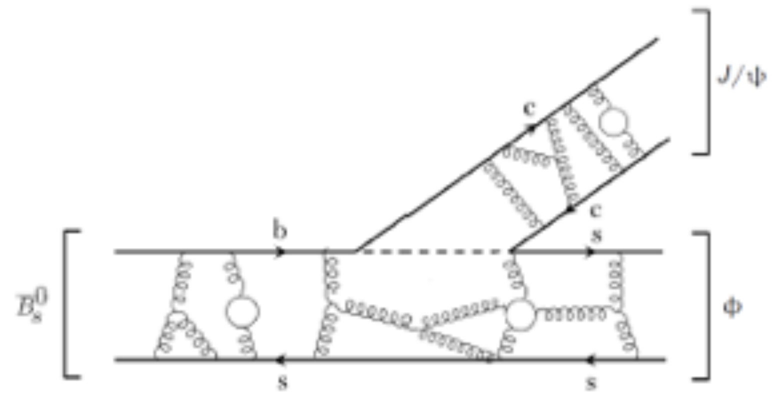
Alex

- Search for NP
  - No huge effects seen, but still some sizable space left
    Test: $\Delta\Gamma_d, B \to X\tau\tau, \tau(B_s)/\tau(B_d), a_{sl}, R, C_{1,2}$...

Lifetime measurements in B decays at LHCb

Francesca

Different b species have distinct lifetimes $\Longrightarrow$ light quark(s) cannot be ignored.
Difficult interplay between weak and strong forces!

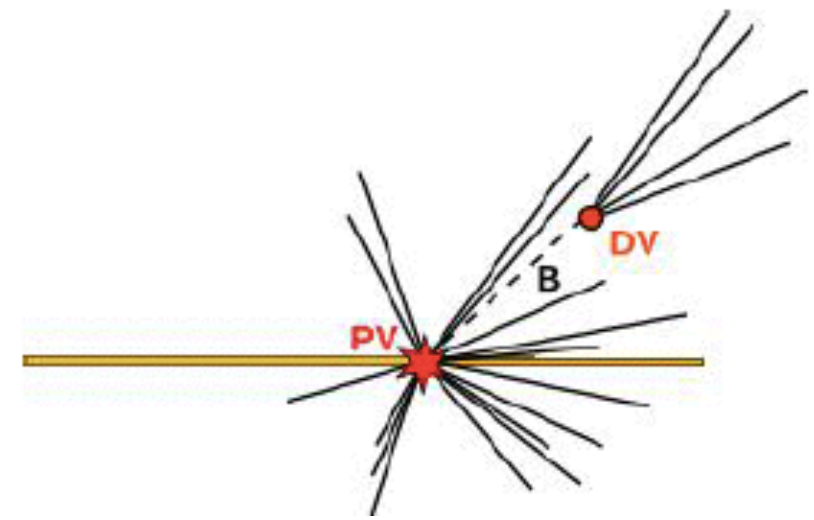


Predictions made from series expansion

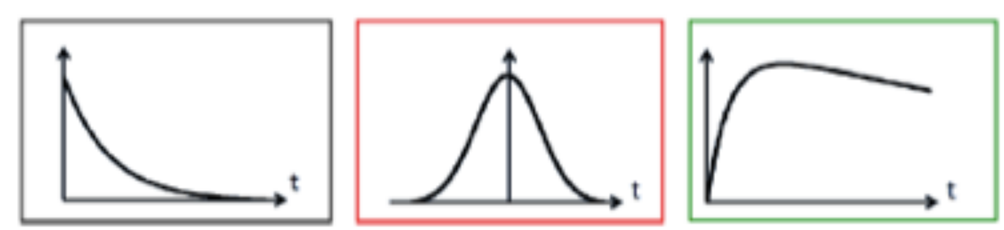
$\hookrightarrow$ Heavy Quark Expansion (HQE)

$$\Gamma = \Gamma_0 + \frac{\Lambda^2}{m_b^2}\Gamma_2 + \frac{\Lambda^3}{m_b^3}\Gamma_3 + \ldots$$

- decay of a free heavy b-quark: $\tau_{B_d^0} \sim \tau_{B^+} \sim \tau_{B_s^0} \sim \tau_{\Lambda_b^0}$
- separation between mesons and baryons: $\tau_{B^+} \sim \tau_{B_d^0} \sim \tau_{B_s^0} > \tau_{\Lambda_b^0}$
- spectator quark/s involved: $\tau_{B^+} > \tau_{B_d^0} \sim \tau_{B_s^0} > \tau_{\Lambda_b^0}$

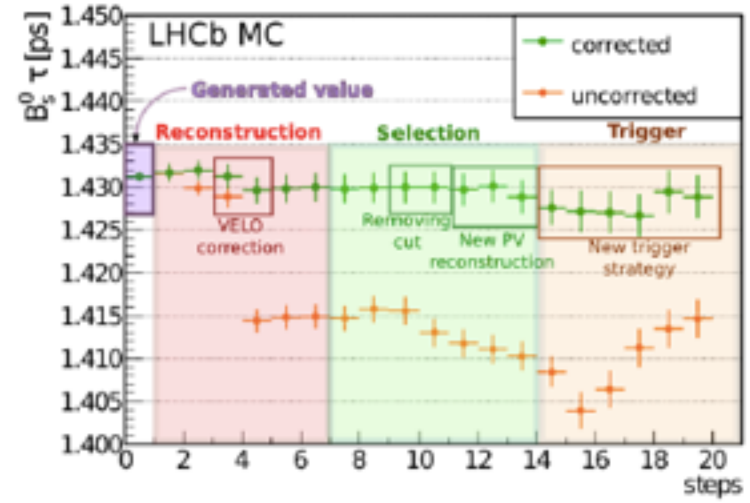


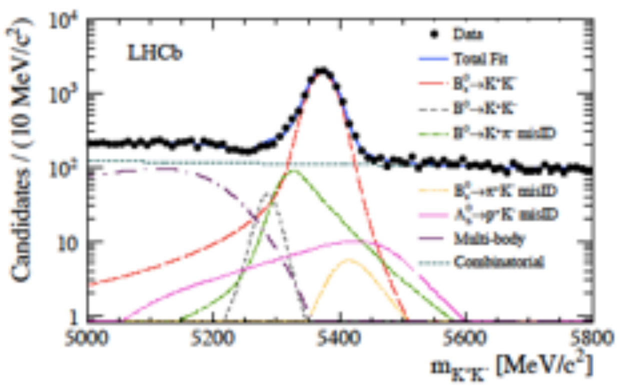
Decay time Resolution Acceptance

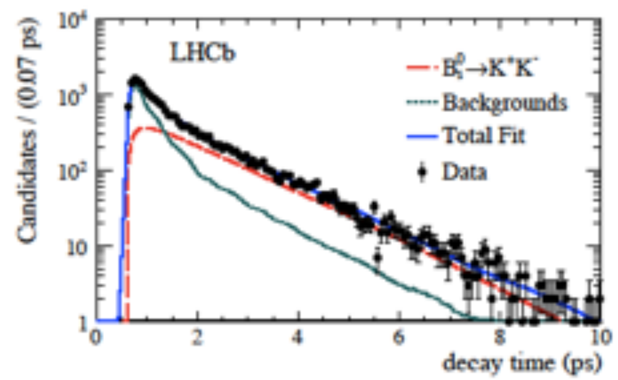


$$\text{Distribution} = \left[e^{\frac{-t}{\tau}} \otimes \text{Res}(t, t')\right] \cdot \text{Acc}(t')$$

Lifetime	Value [ps]	World average 2013 [ps]
$\tau_{B^+ \to J/\psi K^+}$	$1.637 \pm 0.004 \pm 0.003$	1.641 ± 0.008
$\tau_{B^0 \to J/\psi K^*(892)^0}$	$1.524 \pm 0.006 \pm 0.004$	1.519 ± 0.007
$\tau_{B^0 \to J/\psi K^0_S}$	$1.499 \pm 0.013 \pm 0.005$	1.519 ± 0.007
$\tau_{\Lambda^0_b \to J/\psi \Lambda}$	$1.415 \pm 0.027 \pm 0.006$	1.429 ± 0.024
$\tau_{B^0_s \to J/\psi \phi}$	$1.480 \pm 0.011 \pm 0.005$	1.429 ± 0.088

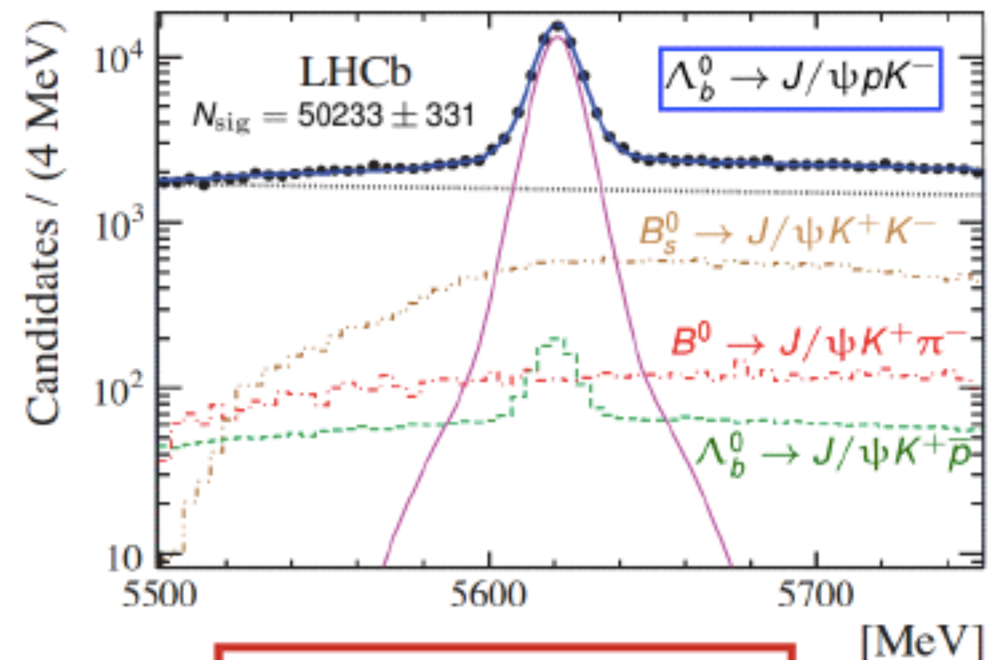




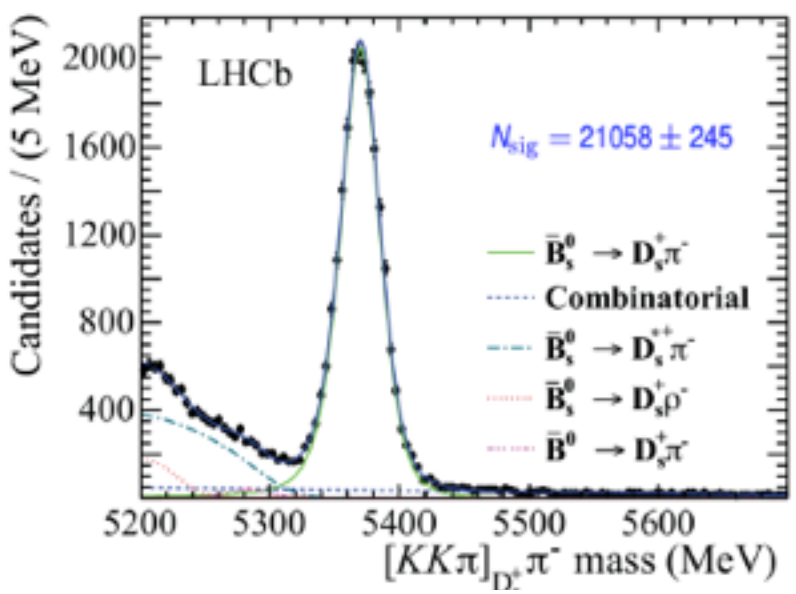


Francesca

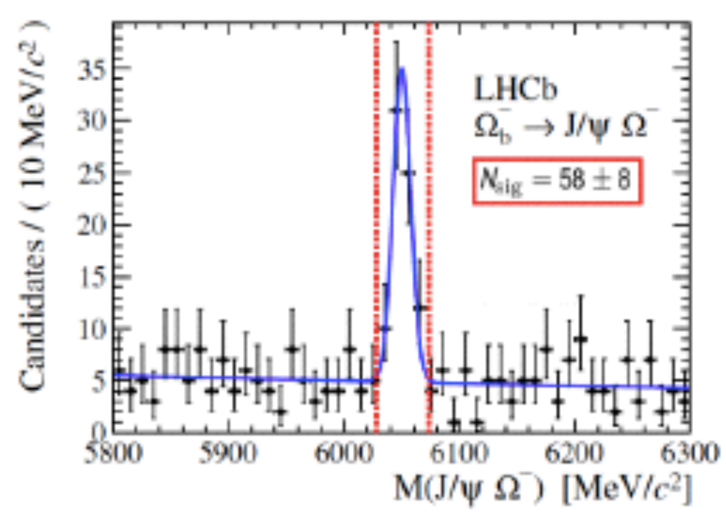
$\tau_{KK} = 1.407 \pm 0.016\ (\text{stat}) \pm 0.007\ (\text{syst})$ ps



$\frac{\tau_{\Lambda^0_b}}{\tau_{B^0}} = 0.974 \pm 0.006 \pm 0.004$



$\tau_{fs}(\overline{B}^0_s) = 1.535 \pm 0.015 \pm 0.012 \pm 0.007$ps



$\tau_{\Xi_b^-} = 1.55^{+0.10}_{-0.09} \pm 0.03$ ps

$\tau_{\Omega_b^-} = 1.54^{+0.26}_{-0.21} \pm 0.05$ ps

Walaa

CP violating phase ϕ_s

Mixing induced CPV phase:

$$\phi_s = \phi_M - 2\phi_D$$

Theoretical uncertainty on ϕ_s is mainly due to unknown penguin contributions $\Delta\phi_s^{\text{peng}}$:

$$\phi_s^{\text{SM}} = -2\beta_s + \Delta\phi_s^{\text{peng}}$$

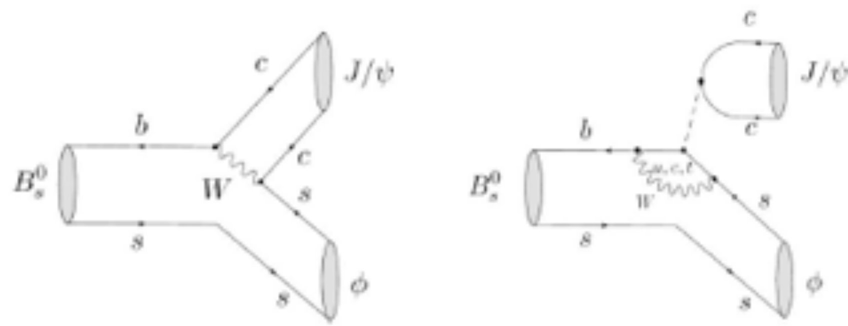
$$-2\beta_s = 2\arg\left(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) = -0.0363 \pm 0.0013$$

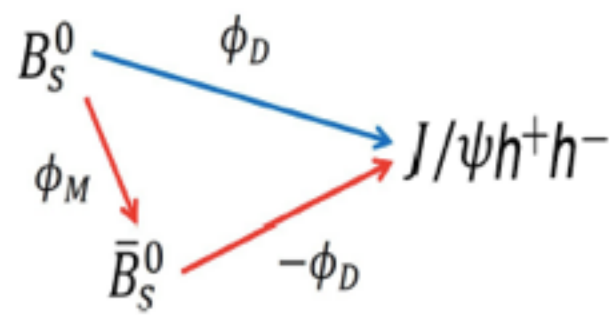
J. Charles et al. (CKMfitter group), LHCb, P. R. D 84, 033005 (2011)

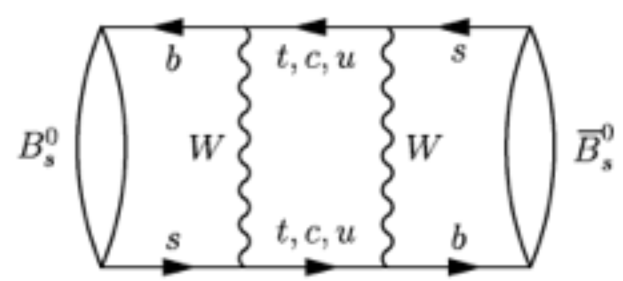
New Physics (NP) processes can modify the value of ϕ_s if new particles contribute to box diagrams:

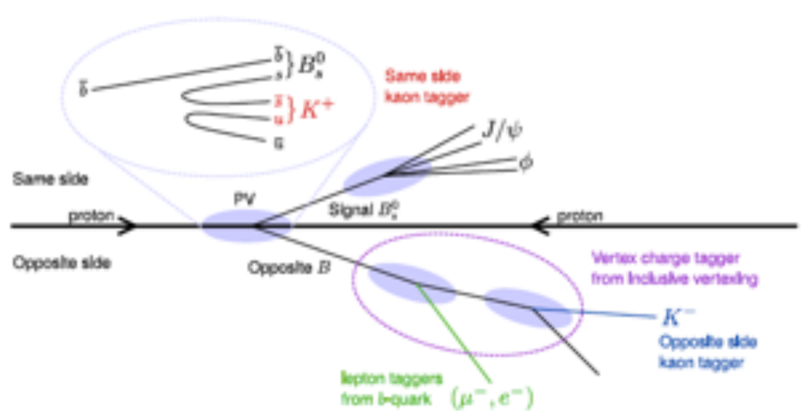
$$\phi_s^{\text{meas}} = -2\beta_s + \Delta\phi_s^{\text{peng}} + \delta^{\text{NP}}$$

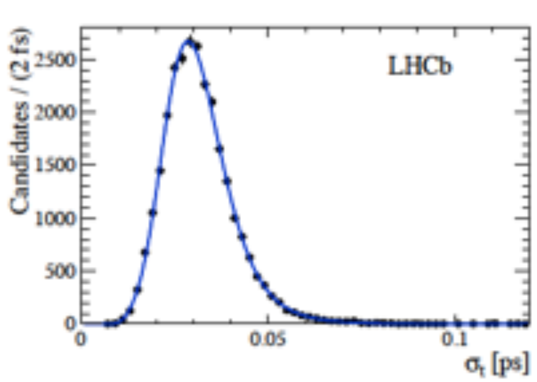
$\Rightarrow$we should estimate $\Delta\phi_s^{\text{peng}}$

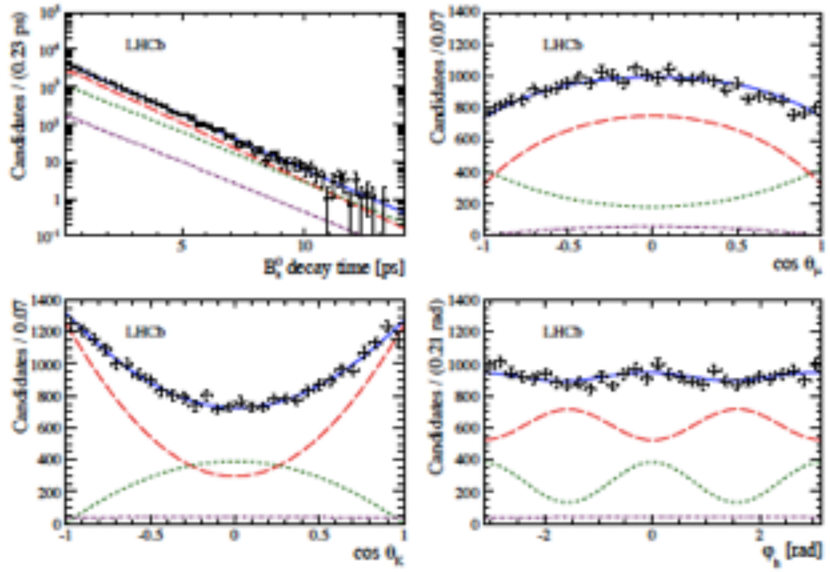








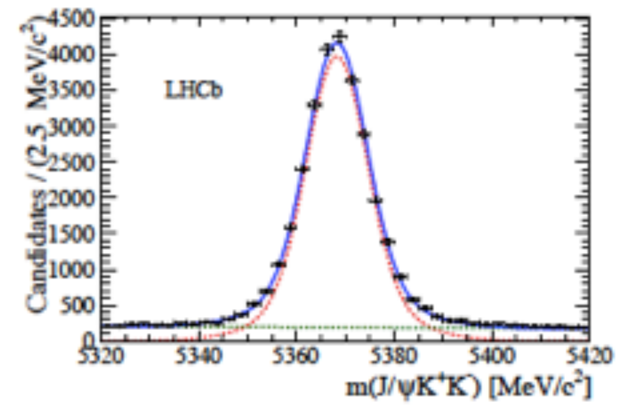




Decay time and decay angles. Red: CP-even, green: CP-odd, purple: S-wave

$$\phi_s = 0.07 \pm 0.09 \text{ (stat)} \pm 0.01 \text{ (syst)}$$
$$\Gamma_s = 0.663 \pm 0.005 \text{ (stat)} \pm 0.006 \text{ (syst)}$$
$$\Delta\Gamma_s = 0.100 \pm 0.016 \text{ (stat)} \pm 0.003 \text{ (syst)}$$

27 617 $B_s^0 \to J/\psi\phi$ candidates

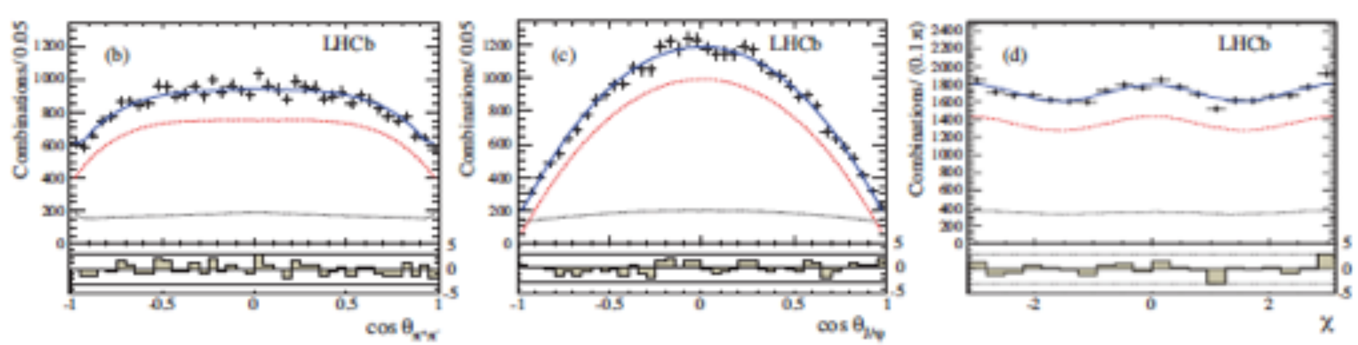


Walaa

update with 3 fb^{-1} is ongoing!

- $B_s^0 \to J/\psi\pi^-\pi^+$ only. No direct CP-violation ($|\lambda| = 1$)

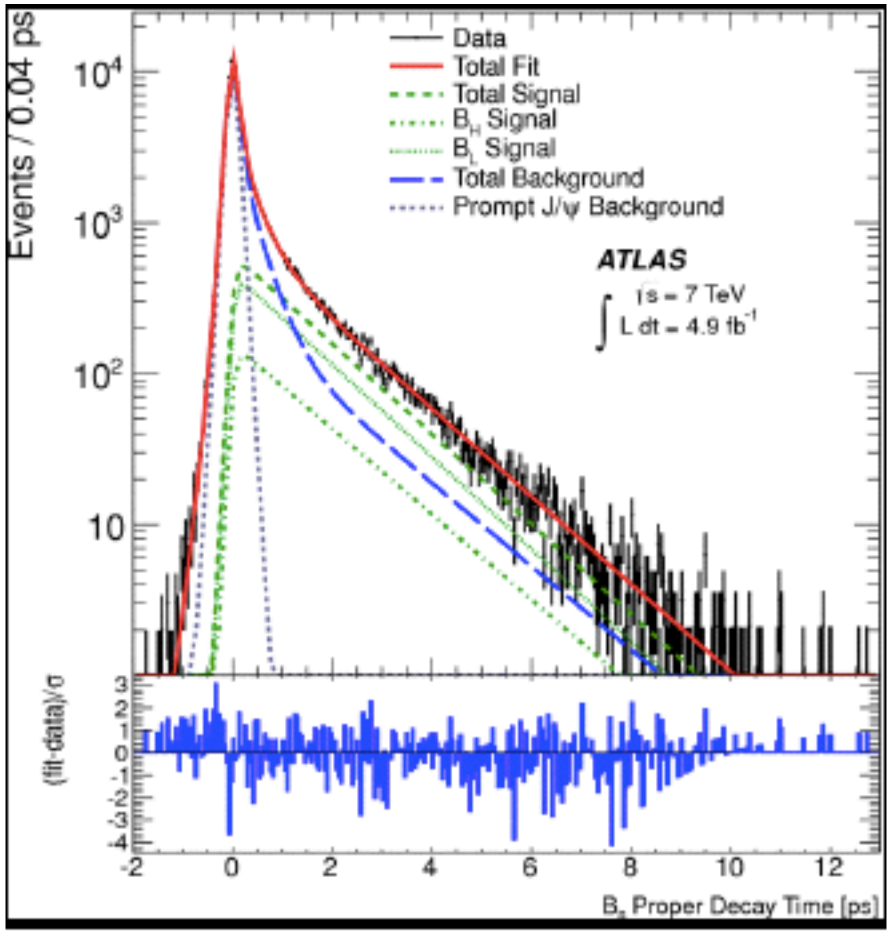
$$\phi_s = \mathbf{0.075} \pm \mathbf{0.067} \text{ (stat)} \pm \mathbf{0.008} \text{ (syst)}$$

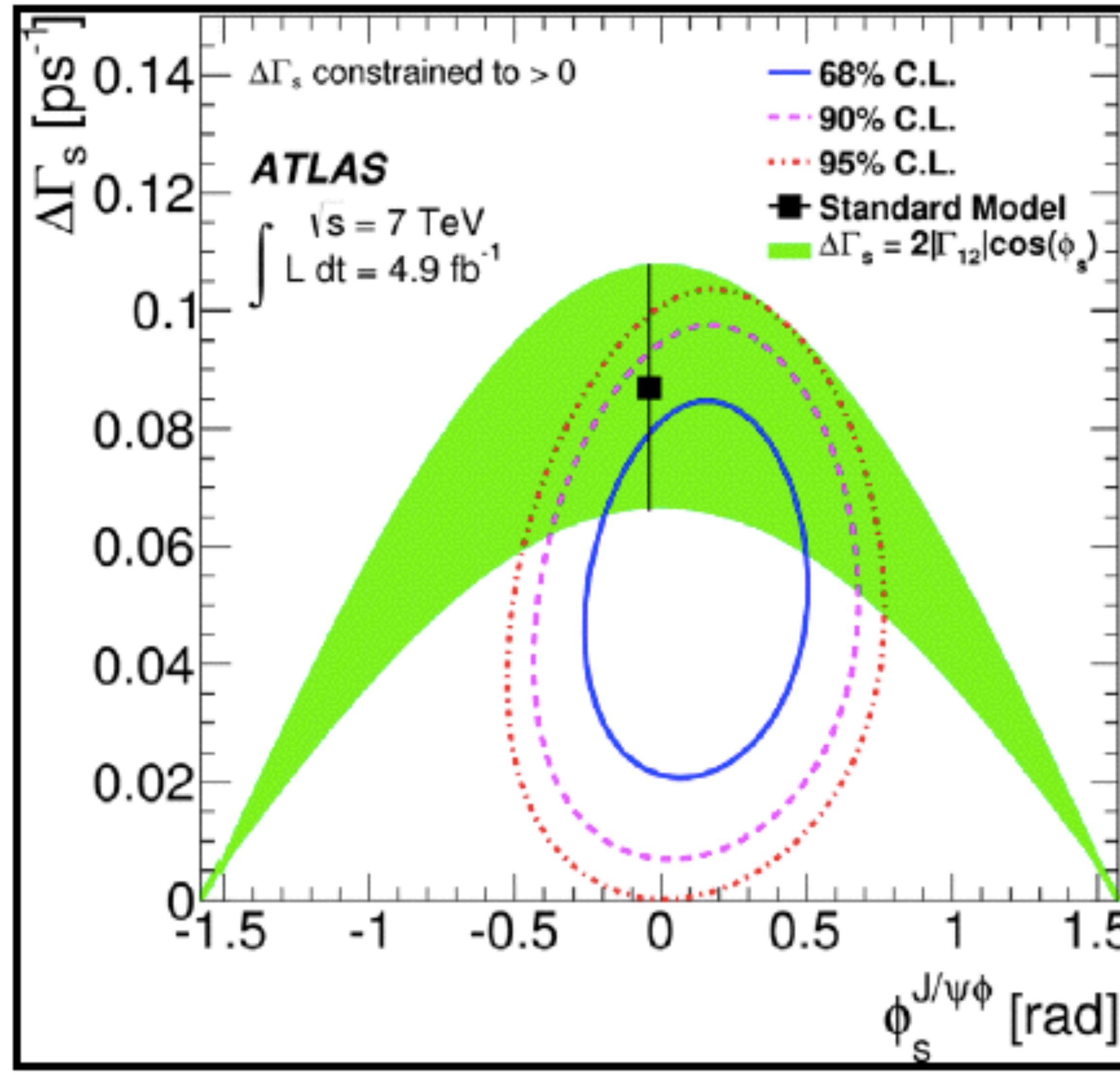


- Preliminary combination of 3 fb^{-1} $B_s^0 \to J/\psi\pi^-\pi^+$ with 1 fb^{-1} $B_s^0 \to J/\psi K^- K^+$

$$\phi_s = \mathbf{0.070} \pm \mathbf{0.054} \pm \mathbf{0.011}$$

Borissov





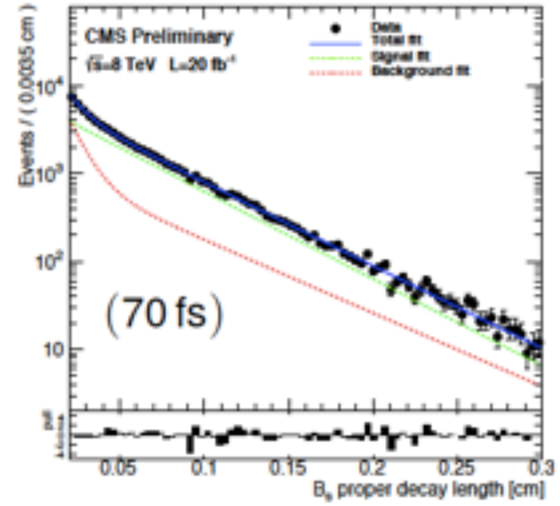
$$\phi^{J/\psi\varphi} = 0.12 \pm 0.25\,(\text{stat}) \pm 0.11\,(\text{syst})$$

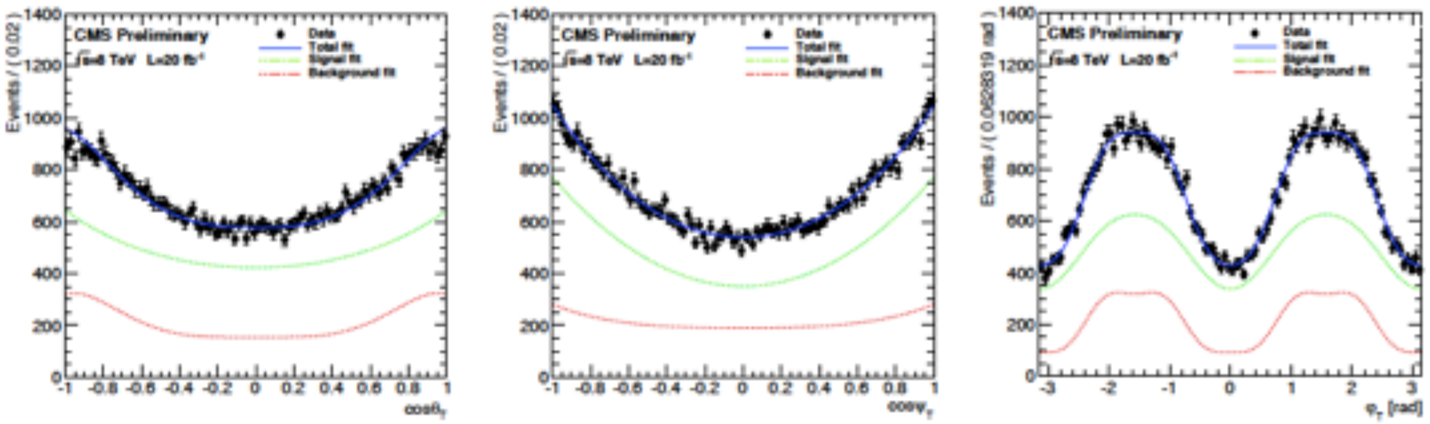
$$\Delta\Gamma_s = 0.053 \pm 0.021\,(\text{stat}) \pm 0.009\,(\text{syst})$$

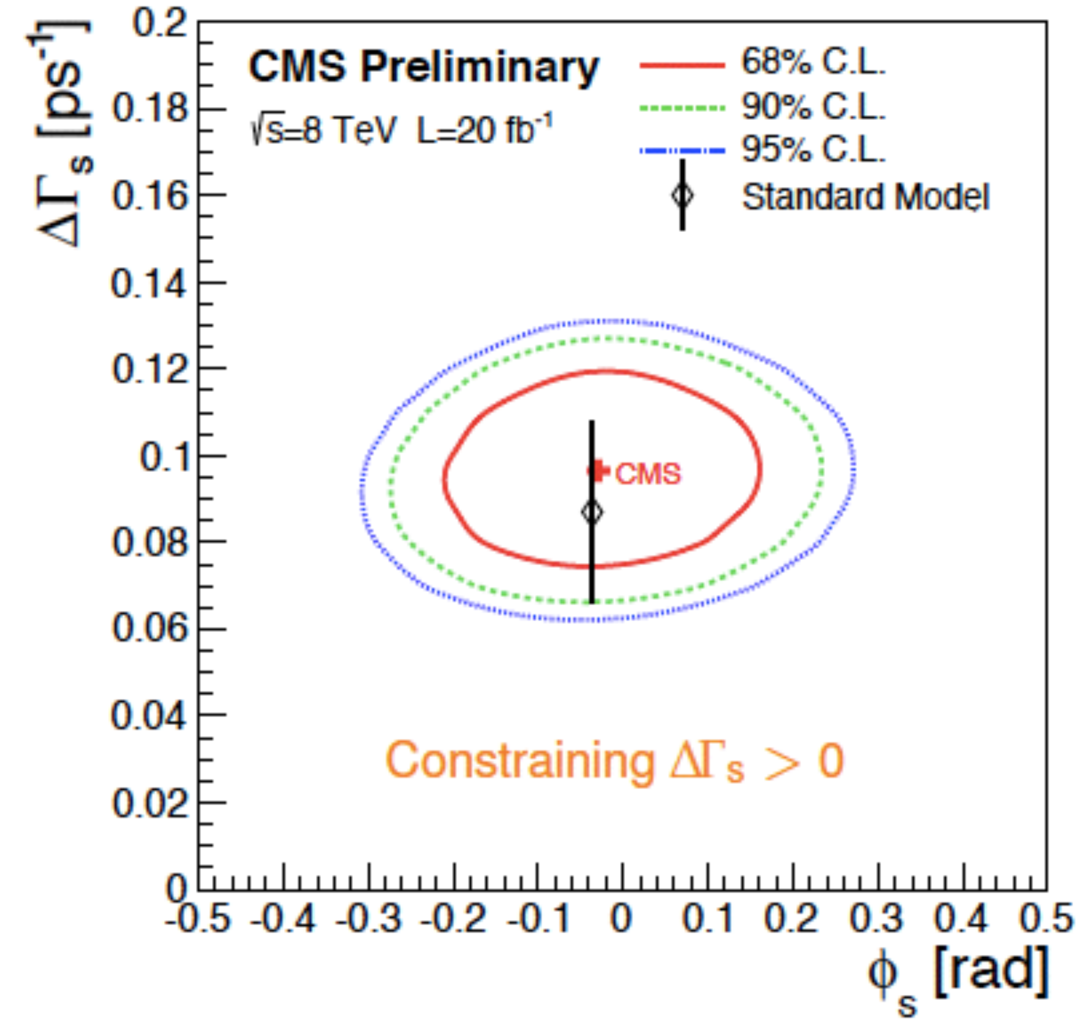
- 40% improvement of the $\phi^{J/\psi\varphi}$ precision compared to our previous result
  - Because of adding flavour tagging in the analysis

Projections

Jacopo







CMS 2012 data (20 fb^{-1}) results:

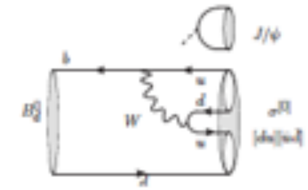
$$\phi_s = -0.03 \pm 0.11 \pm 0.03 \text{ rad}$$
$$\Delta\Gamma_s = 0.096 \pm 0.014 \pm 0.007 \text{ ps}^{-1}$$

$\Delta\Gamma_s$ confirmed to be non-zero

Measurement precision still dominated by statistical uncertainty

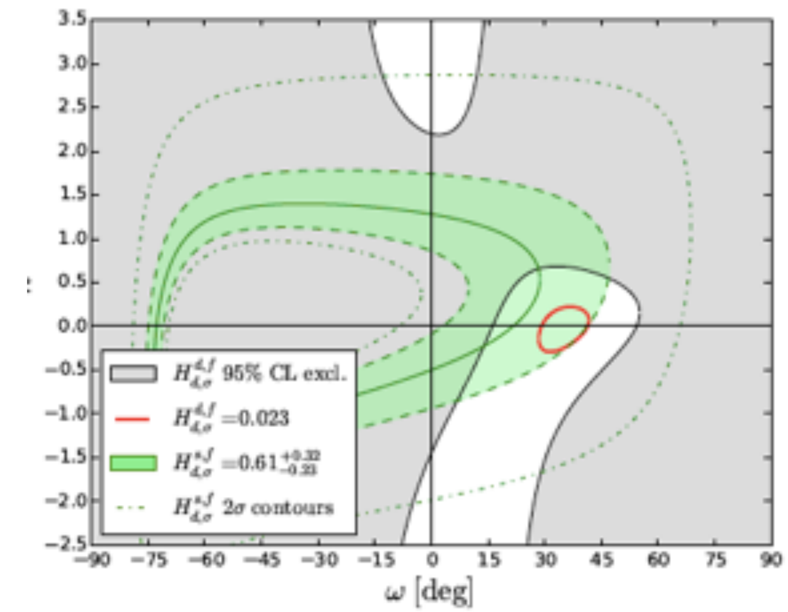
Rob

$$\lambda_h \equiv \frac{q}{p}\frac{\overline{A}_h}{A_h} = -e^{-i\phi_s} \underbrace{\eta_h}_{\text{CP eval}} \sqrt{\frac{1-C_h}{1+C_h}}\, e^{-i\Delta\phi_h}$$



Relative size special topology:

$$\kappa' \equiv R_b \frac{\tilde{A}'_{4q}}{\tilde{A}_{\mathrm{T}}^{(c)} + \tilde{A}_{\mathrm{P}}^{(c)}}$$

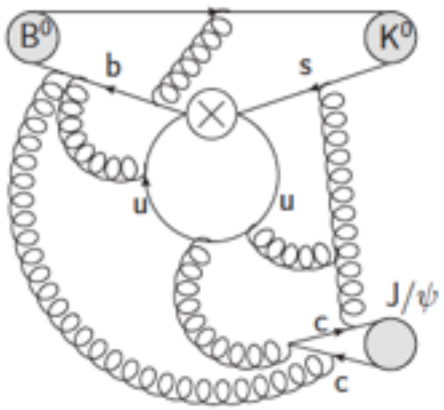


$$S_h = \frac{2\mathrm{Im}(\lambda_h)}{1+|\lambda_h|^2} = \eta_h \sqrt{1-C_h}\sin(\phi_s + \Delta\phi_h) \quad \text{for each h} \in \{\|, \perp, 0, S\}$$

- Treat uncertainties in $B_s \to (J/\psi\, s\bar{s})_{\|,\perp,0,S}$ **separately**
  $\to$ can control with flavour symmetry related modes
  $\to$ eventually full $SU(3)$ fit including breaking corrections
- Suitability of $f_0(980)$ for precision ϕ_s extractions **debatable**
  $\to$ tetraquark picture still compatable with data
  $\to$ unique tetraquark dynamics give sizable uncertainty
- **Average** $\phi_s + \Delta\phi_f$ results **carefully**

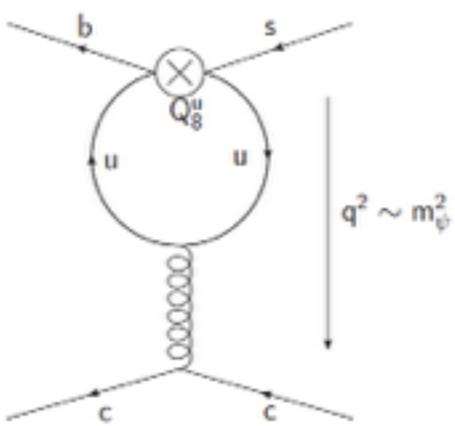
$$S(B \to f) = \sin(\phi + \Delta\phi)$$

Philipp



	ϕ	
$B^0 \to J/\psi K^0$	$\phi_d =$	2β
$B^0_s \to J/\psi\phi$	$\phi_s =$	$-2\beta_s$

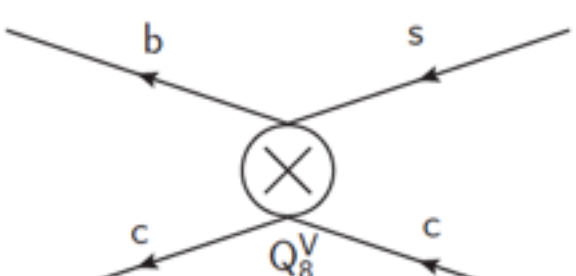
- Exploit the heaviness of the J/ψ mass $m_\psi = 3.1$ GeV $\gg \Lambda_{QCD}$
- Factorization of hard and soft scales
- $1/N_c$ expansion



Our preliminary results:

$$|\Delta\phi_d| \leq 0.56^\circ \pm 0.02^\circ$$
$$|\Delta\phi_s^{\parallel}| \leq 0.75^\circ \pm 0.09^\circ \quad \text{for} \quad A_{\parallel}$$

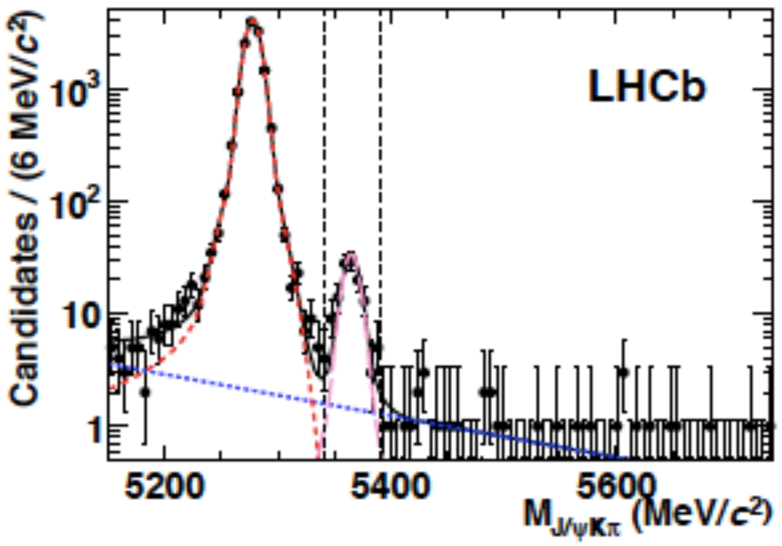
- OPE gives a limit for the size of the penguin pollution.
- No long-distance enhanced up quark penguins



Upper bound of the
penguin pollution can be **calculated !**

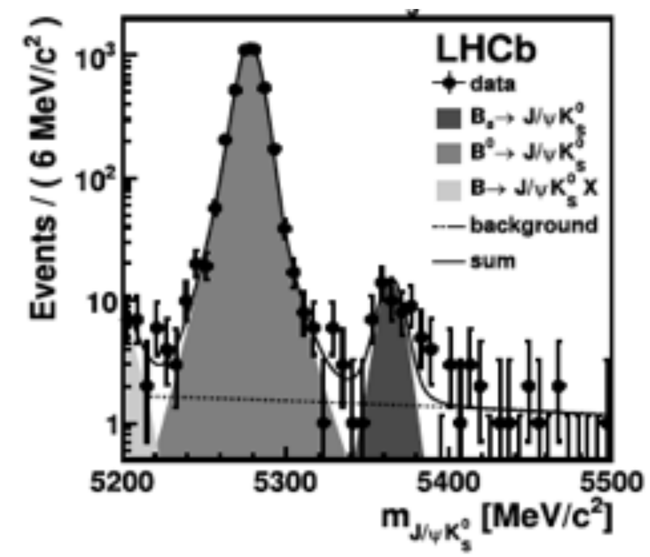
Never forget about the penguins

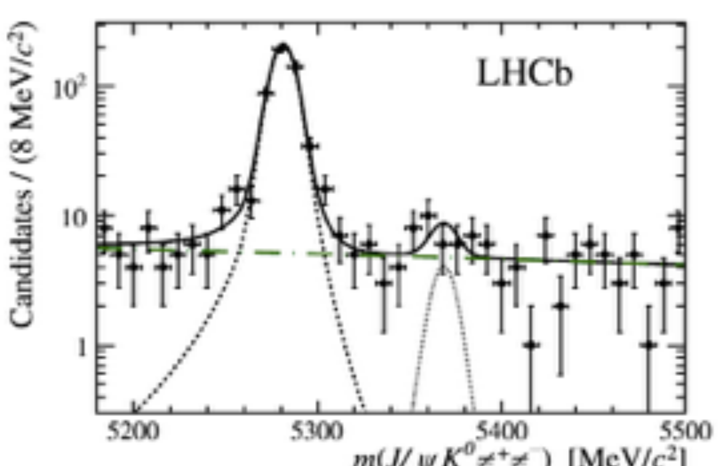
Walaa



$$BR(B_s^0 \to J/\psi \overline{K}^{*0}) = (4.4^{+0.5}_{-0.4} \pm 0.8) \times 10^{-5}$$
$$f_L = 0.50 \pm 0.08 \pm 0.02$$
$$f_{\parallel} = 0.19^{+0.10}_{-0.08} \pm 0.02$$

$$BR(B_s^0 \to J/\psi K_s^0) = (1.97 \pm 0.23) \times 10^{-5}$$
$$\tau^{eff} = 1.75 \pm 0.12(\text{stat}) \pm 0.07(\text{syst})\ \text{ps}$$





$$\begin{aligned}
\mathcal{B}(B^0 \to J/\psi \overset{(-)}{K}{}^0 K^\pm\pi^\mp) &= (11 \pm 5\,(\text{stat}) \pm 3\,(\text{syst}) \pm 1\,(\text{PDG})) \times 10^{-6}\,, \\
&< 21 \times 10^{-6} \text{ at 90\% CL}\,, \\
&< 24 \times 10^{-6} \text{ at 95\% CL}\,, \\
\mathcal{B}(B^0 \to J/\psi K^0 K^+K^-) &= (20.2 \pm 4.3\,(\text{stat}) \pm 1.7\,(\text{syst}) \pm 0.8\,(\text{PDG})) \times 10^{-6}\,, \\
\mathcal{B}(B_s^0 \to J/\psi \overline{K}{}^0 \pi^+\pi^-) &= (2.4 \pm 1.4\,(\text{stat}) \pm 0.8\,(\text{syst}) \pm 0.1\,(f_s/f_d) \pm 0.1\,(\text{PDG})) \times 10^{-5}\,, \\
&< 4.4 \times 10^{-5} \text{ at 90\% CL}\,, \\
&< 5.0 \times 10^{-5} \text{ at 95\% CL}\,, \\
\mathcal{B}(B_s^0 \to J/\psi \overset{(-)}{K}{}^0 K^\pm\pi^\mp) &= (91 \pm 6\,(\text{stat}) \pm 6\,(\text{syst}) \pm 3\,(f_s/f_d) \pm 3\,(\text{PDG})) \times 10^{-5}\,, \\
\mathcal{B}(B_s^0 \to J/\psi \overline{K}{}^0 K^+K^-) &= (5 \pm 9\,(\text{stat}) \pm 2\,(\text{syst}) \pm 1\,(f_s/f_d)) \times 10^{-6}\,, \\
&< 12 \times 10^{-6} \text{ at 90\% CL}\,, \\
&< 14 \times 10^{-6} \text{ at 95\% CL}\,,
\end{aligned}$$

Symmetry analysis ⇒ Data-driven approach: Fit $SU(3)_F$ matrix elements to the data

Stefan

1st Rule: 2σ Tension

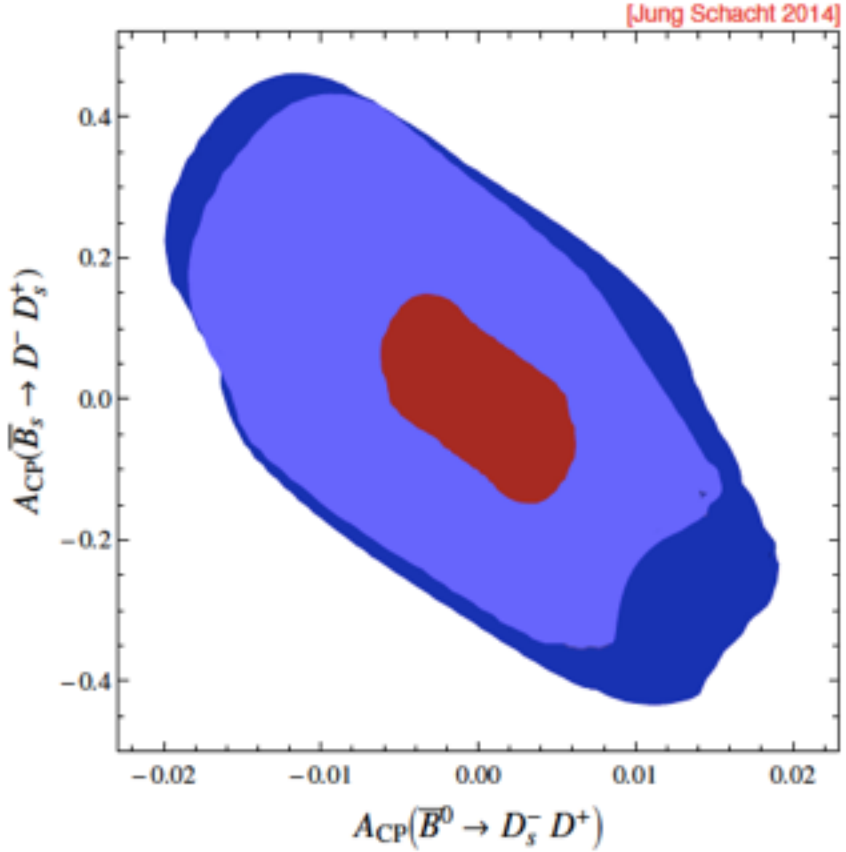
$$\Gamma(\bar{B}^0 \to D_s^- D^+) = \Gamma(B^- \to D_s^- D^0)\left(1 + \mathcal{O}(\delta^5)\right)$$

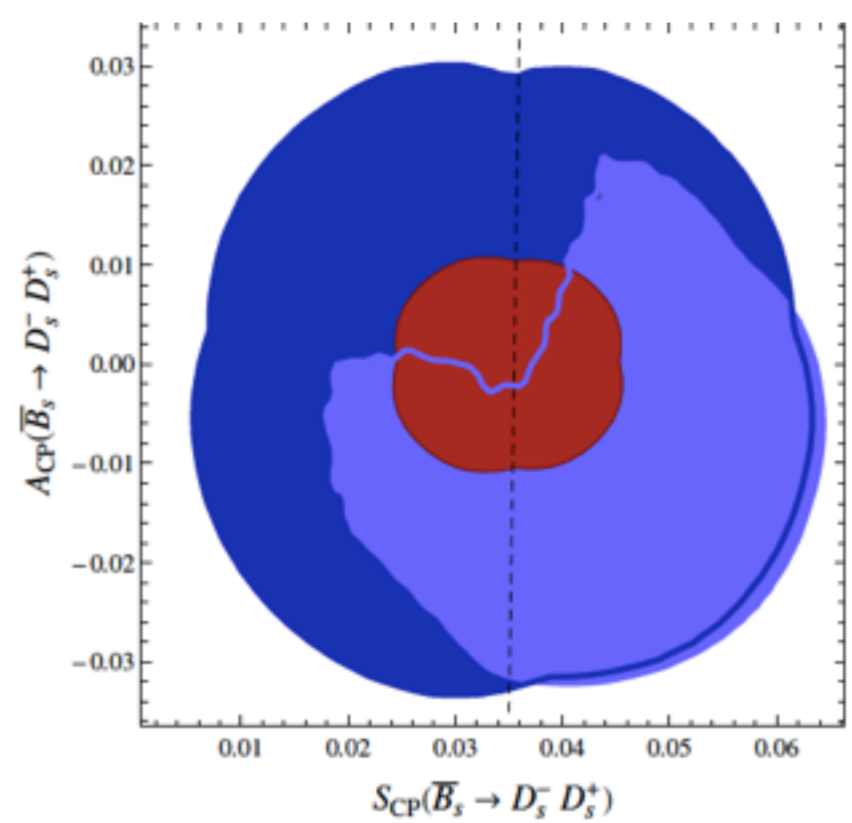
Theory: $BR(B^- \to D_s^- D^0)/BR(\bar{B}^0 \to D_s^- D^+) \sim 1.08$ (including $\tau_{B^-,\bar{B}^0}$)

Experiment: $BR(B^- \to D_s^- D^0)/BR(\bar{B}^0 \to D_s^- D^+) = 1.22 \pm 0.07$ [LHCb 2013]

Predictions (not post-dictions) of CP asymmetries using global Fit

[Jung Schacht 2014]

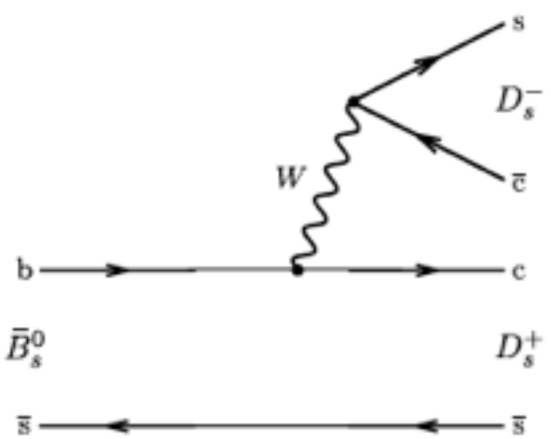


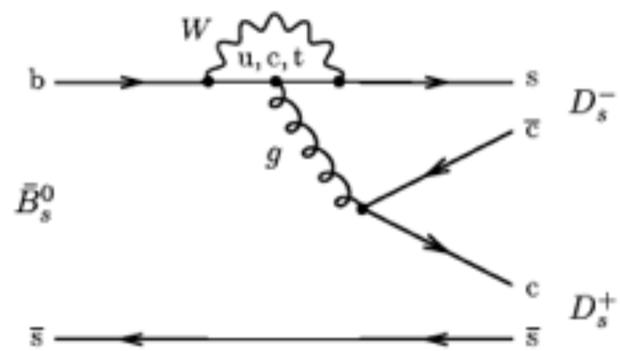


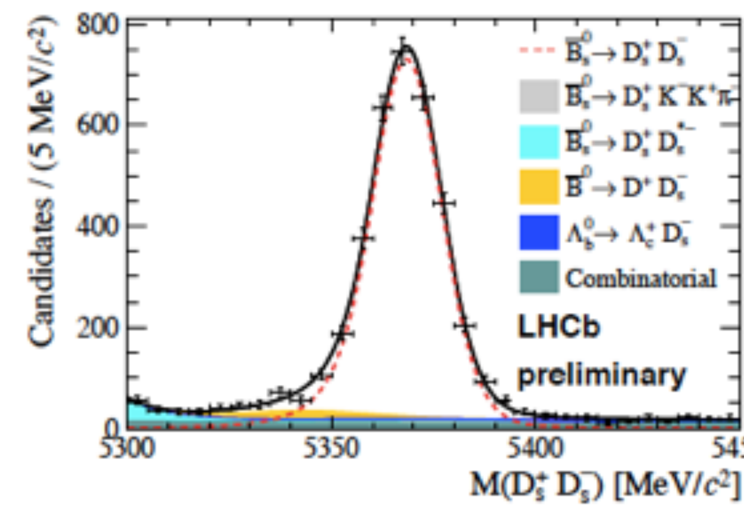
- ϕ_s fixed to SM value.
- Line: $S_{CP} = \sin\phi_s$.
- Red: Standard counting.
- Blue: Enhanced penguins.
- Light: HFAG input.
- Dark: BaBar input.
- Outside of blue (red): NP.

ϕ_s from $D_s^+ D_s^-$

Conor



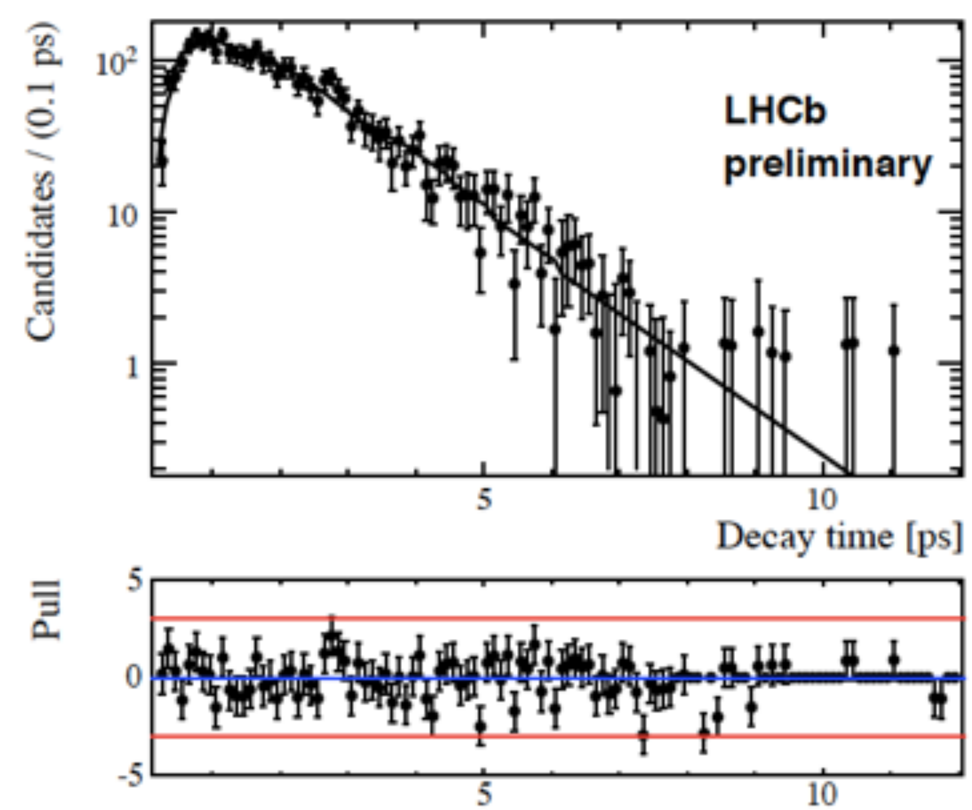




3345 ± 62 $\bar{B}_s^0 \to D_s^+ D_s^-$

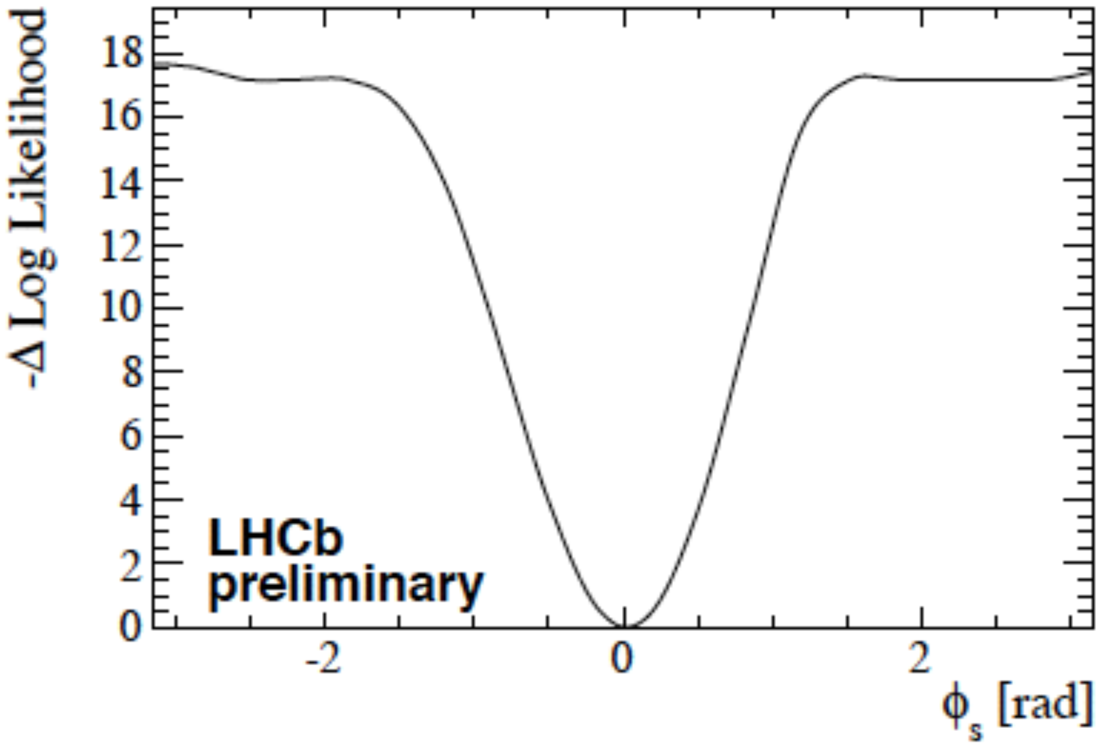
$$\Gamma(\hat{t}) = \mathcal{N} e^{-\Gamma_s \hat{t}} \left[\cosh\left(\frac{\Delta\Gamma_s}{2}\hat{t}\right) - \frac{2|\lambda|\cos\phi_s}{1+|\lambda|^2} \sinh\left(\frac{\Delta\Gamma_s}{2}\hat{t}\right) + \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos(\Delta m_s \hat{t}) - \frac{2|\lambda|\sin\phi_s}{1+|\lambda|^2}\sin(\Delta m_s \hat{t}) \right],$$

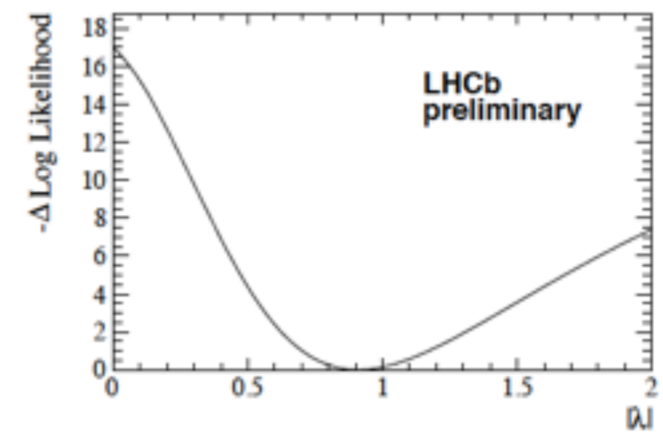
$$\bar{\Gamma}(\hat{t}) = \left|\frac{p}{q}\right|^2 \mathcal{N} e^{-\Gamma_s \hat{t}} \left[\cosh\left(\frac{\Delta\Gamma_s}{2}\hat{t}\right) - \frac{2|\lambda|\cos\phi_s}{1+|\lambda|^2} \sinh\left(\frac{\Delta\Gamma_s}{2}\hat{t}\right) - \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos(\Delta m_s \hat{t}) + \frac{2|\lambda|\sin\phi_s}{1+|\lambda|^2}\sin(\Delta m_s \hat{t}) \right],$$



Conor

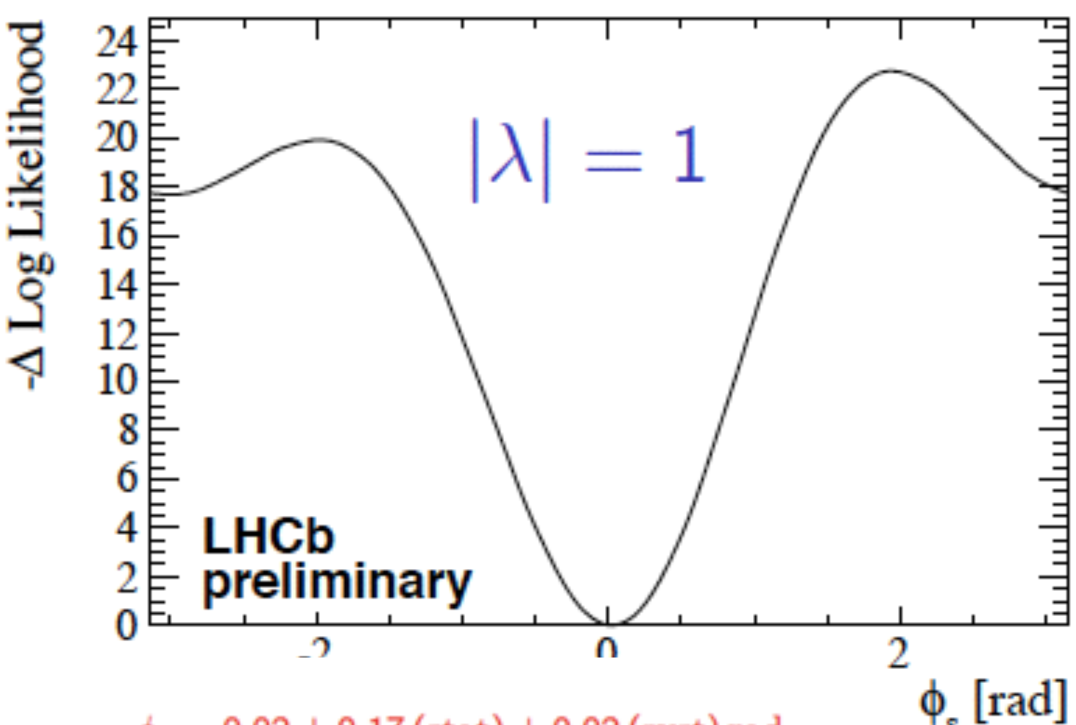
ϕ_s from $D_s^+ D_s^-$



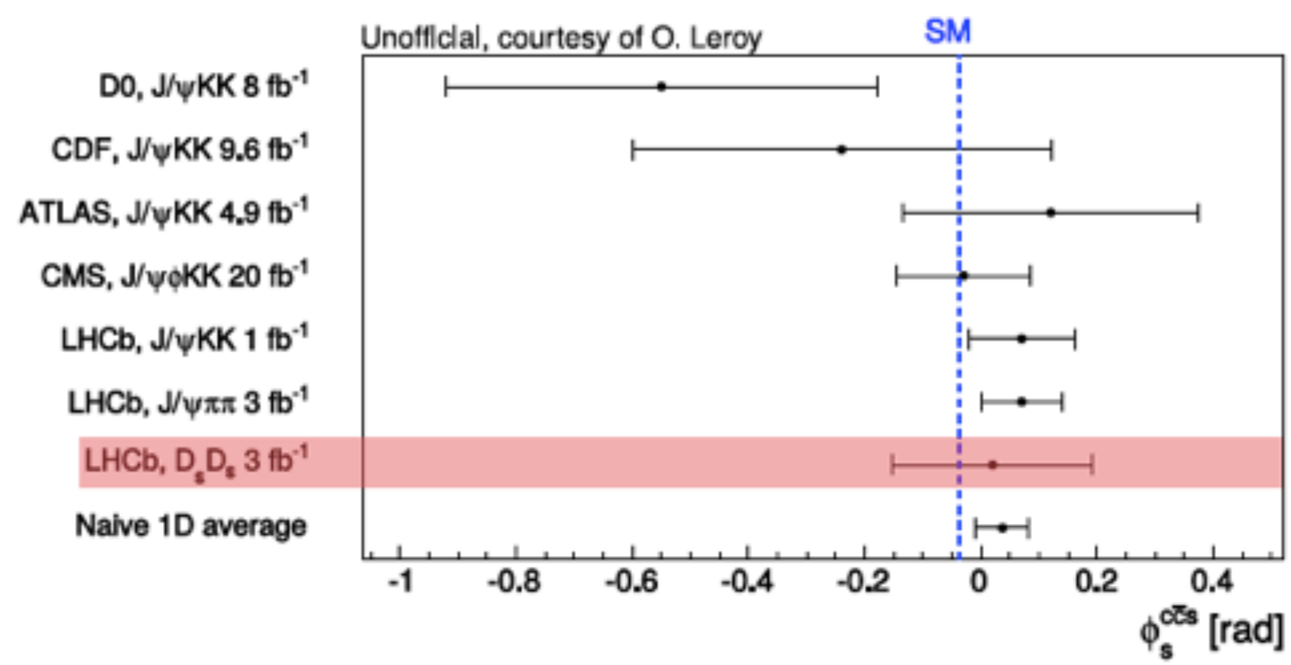


$$|\lambda| = 0.91\ ^{+0.18}_{-0.15}\,(\text{stat}) \pm 0.02\,(\text{syst})$$

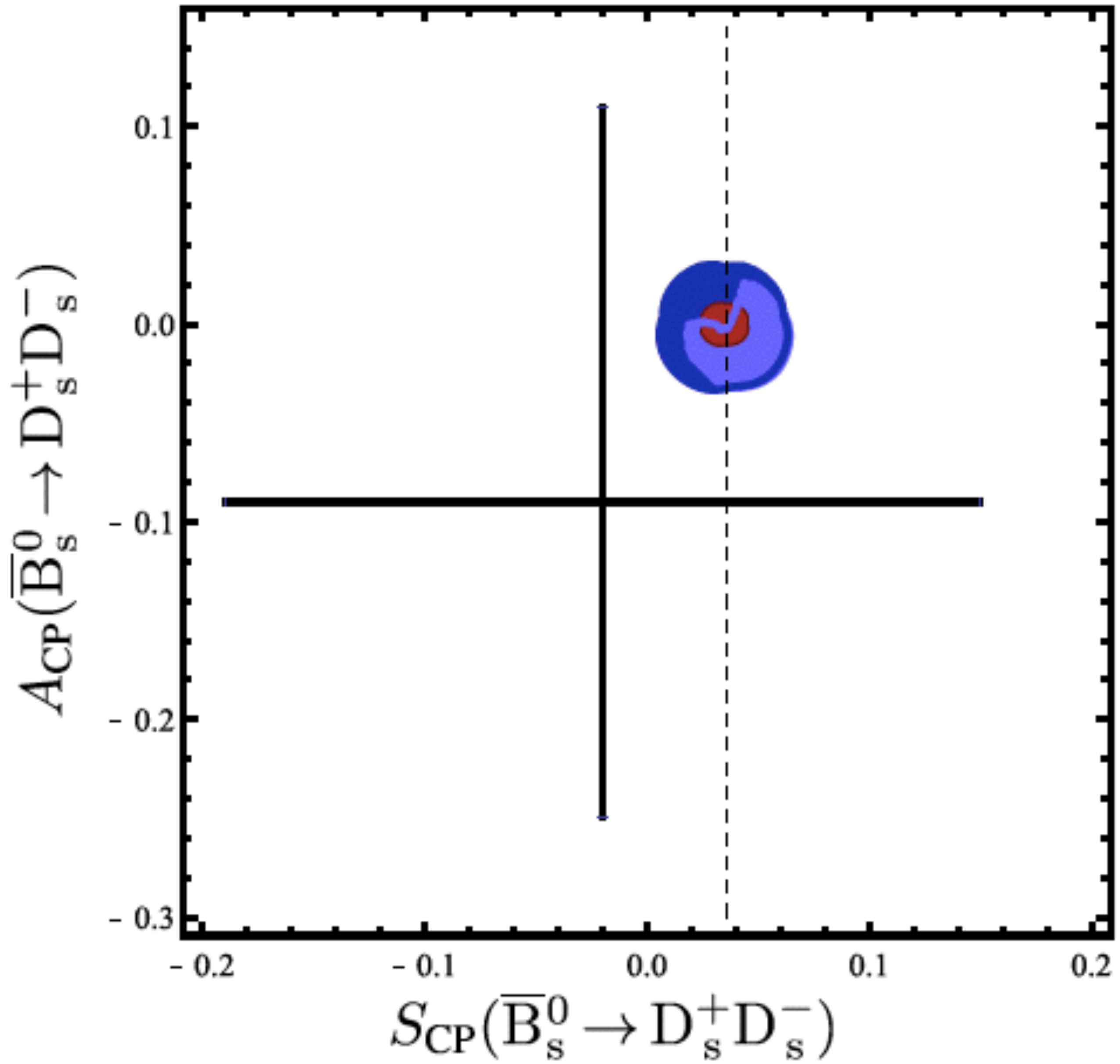
$$\phi_s = 0.02 \pm 0.17\,(\text{stat}) \pm 0.02\,(\text{syst})\ \text{rad},$$



$\phi_s = 0.02 \pm 0.17\,(\text{stat}) \pm 0.02\,(\text{syst})\ \text{rad}$

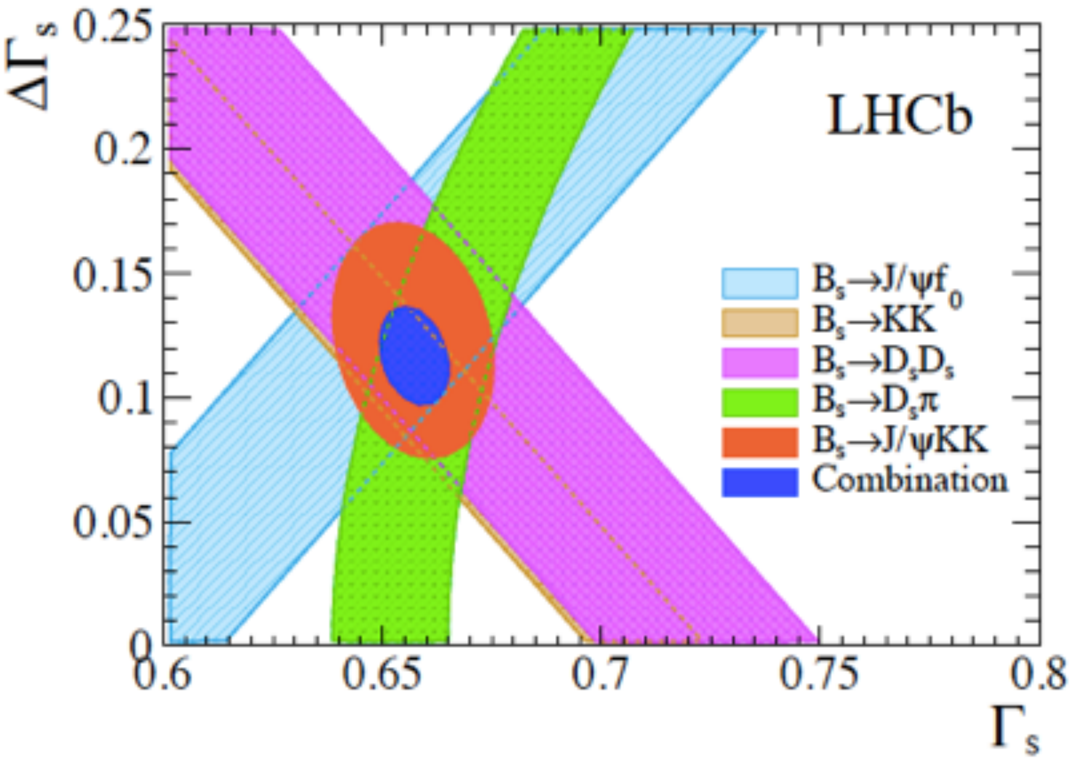


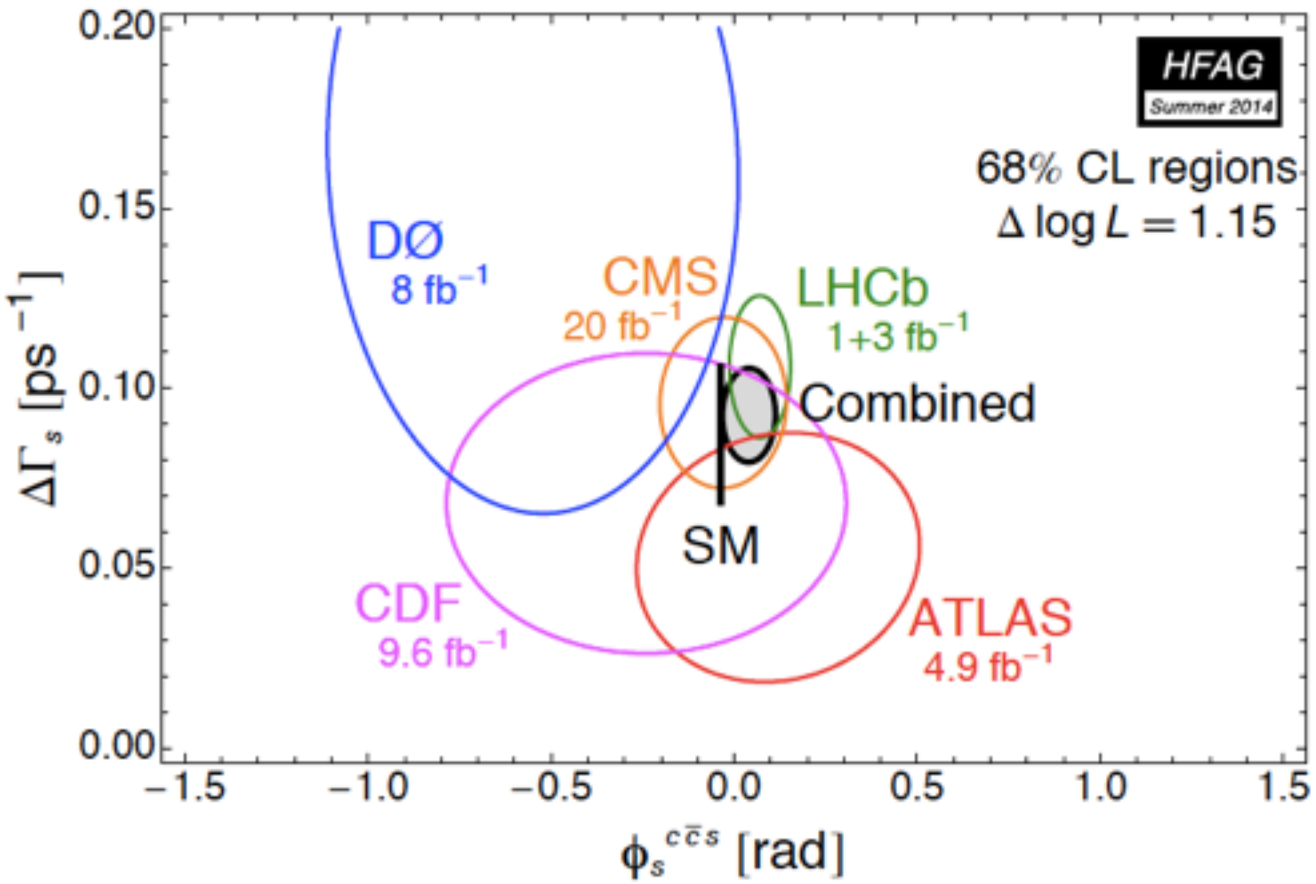
Stefan
Conor



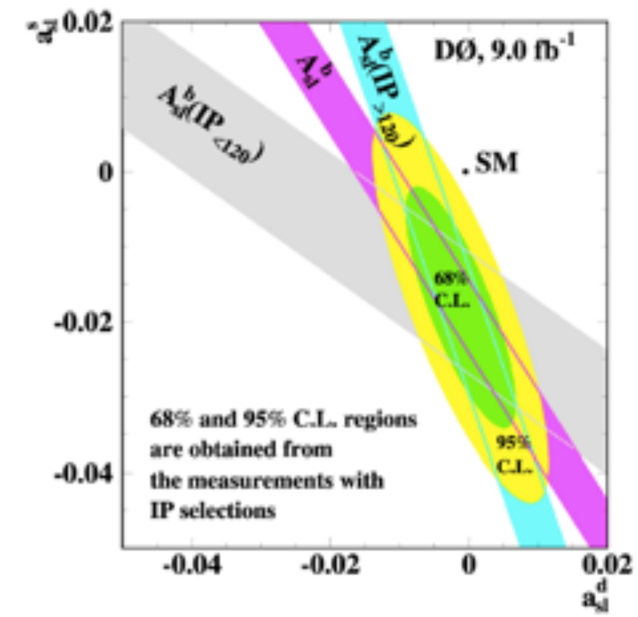
Motivation for the Upgrade…

Looking at the whole picture



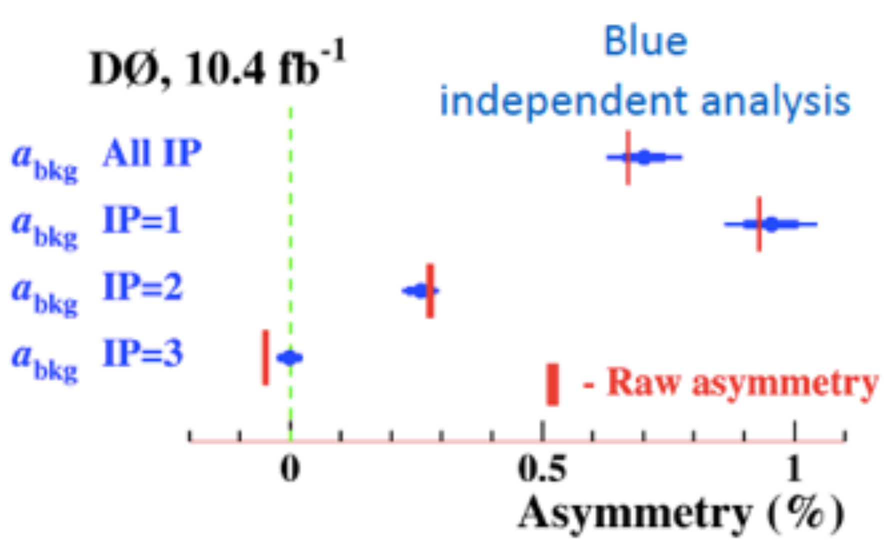


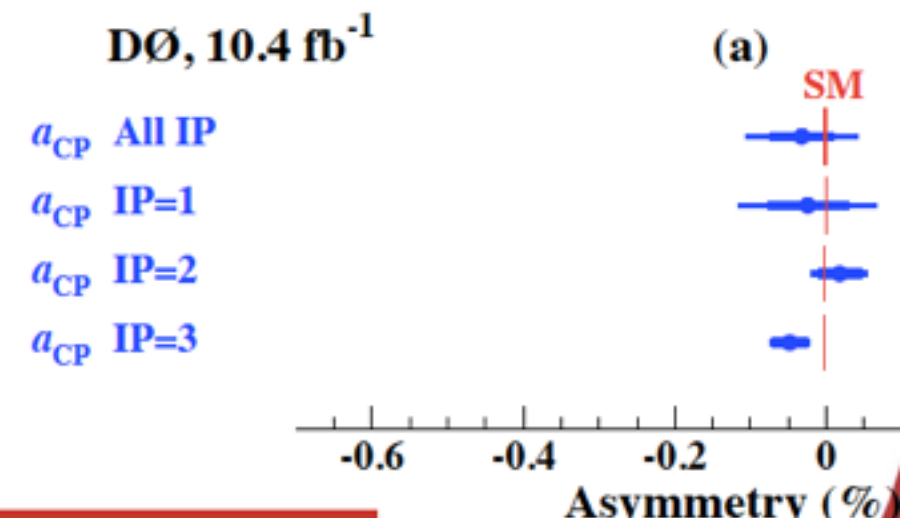
$$\Gamma(B^0_{(s)} \to \bar{B}^0_{(s)} \to \mu^- X) \neq \Gamma(\bar{B}^0_{(s)} \to B^0_{(s)} \to \mu^- X)$$



$$A^b_{sl} = \frac{N_b(\mu^+\mu^+) - N_b(\mu^-\mu^-)}{N_b(\mu^+\mu^+) + N_b(\mu^-\mu^-)}$$

$$A^b_{sl} = (-0.787 \pm 0.172(\text{stat}) \pm 0.093(\text{syst}))\,\%$$

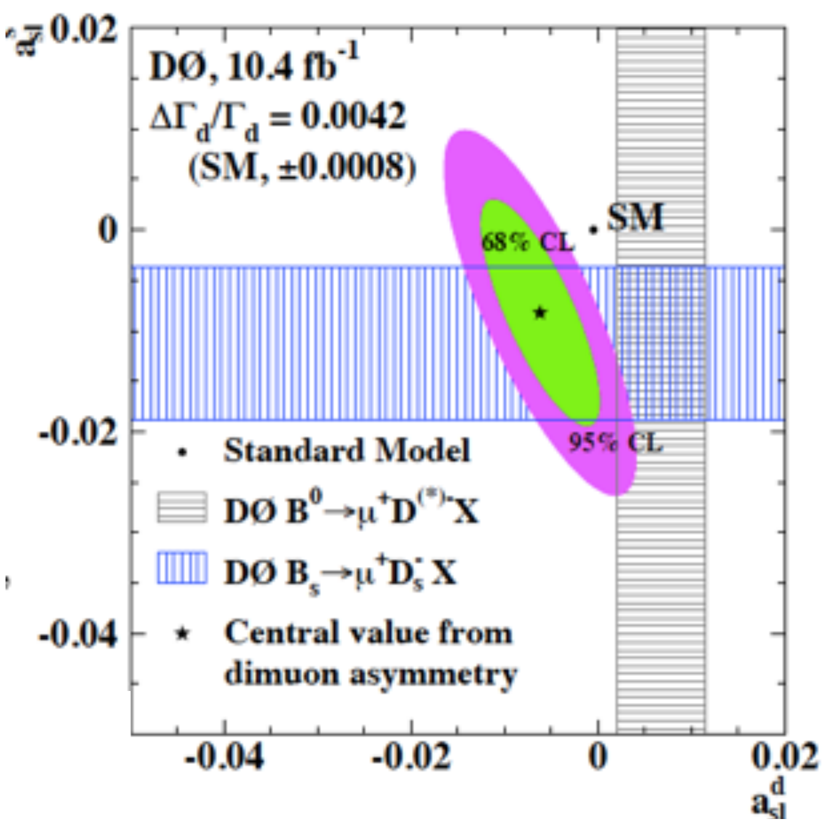


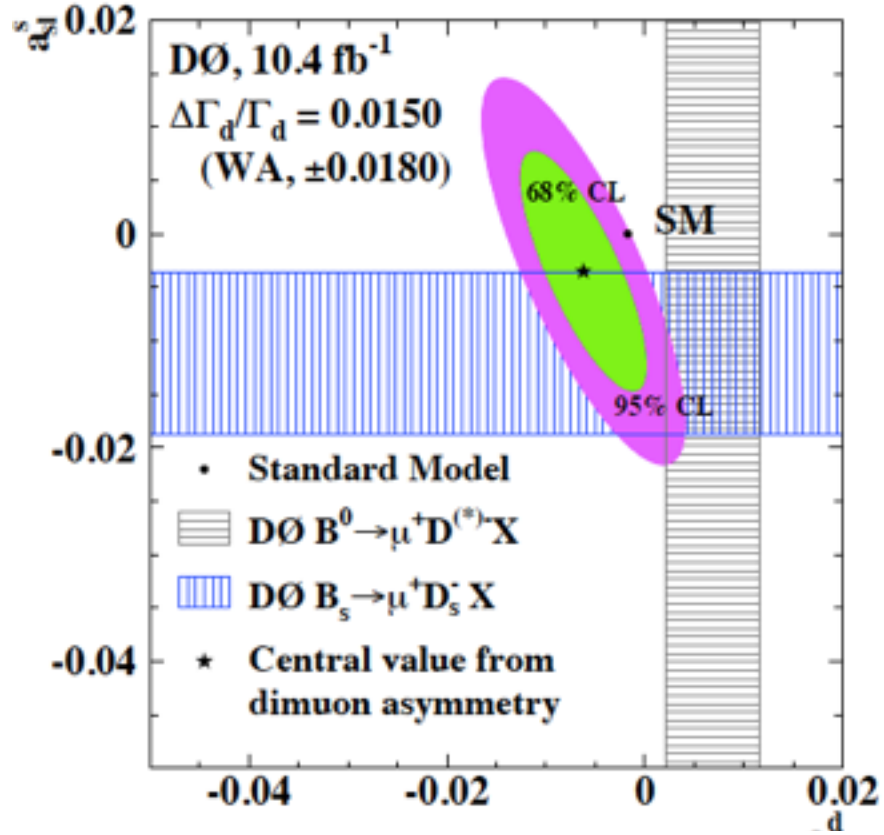


A_{CP} = (-0.235 ± 0.064 ± 0.055)%

3.6σ deviation from SM

Iain

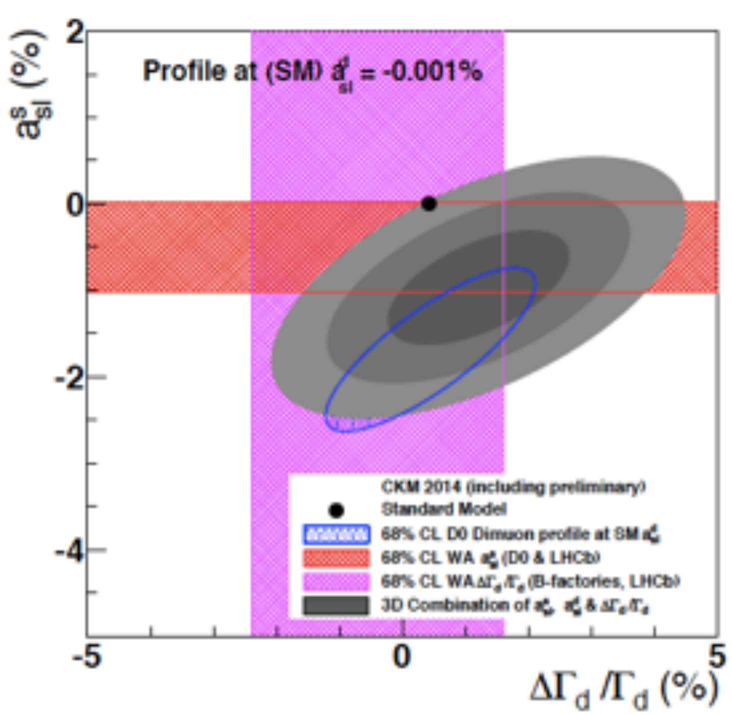


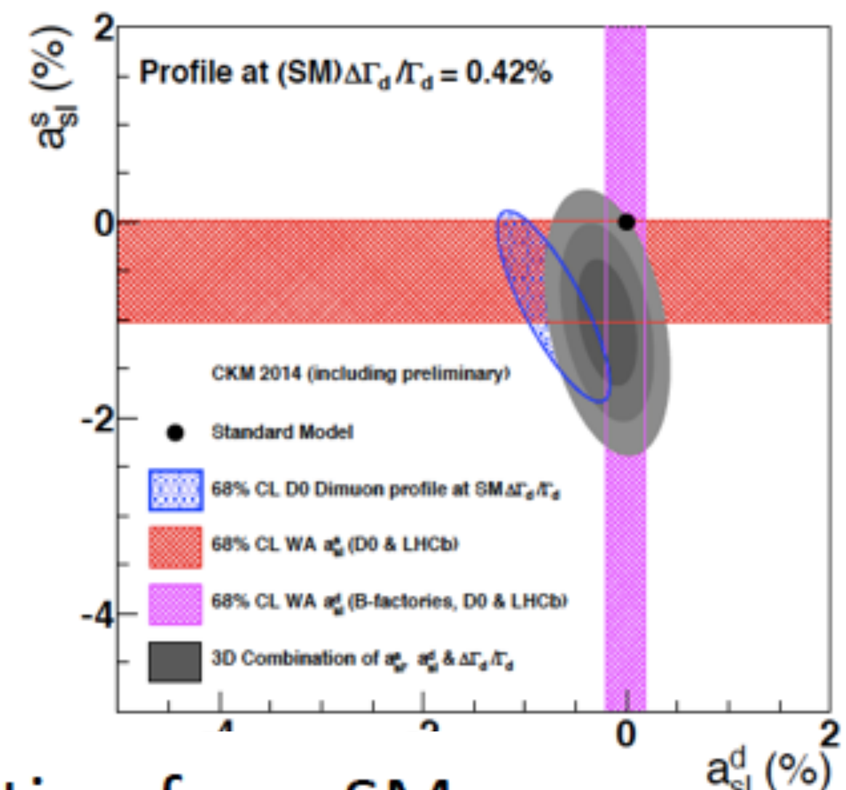


3.0σ deviation from SM of three values

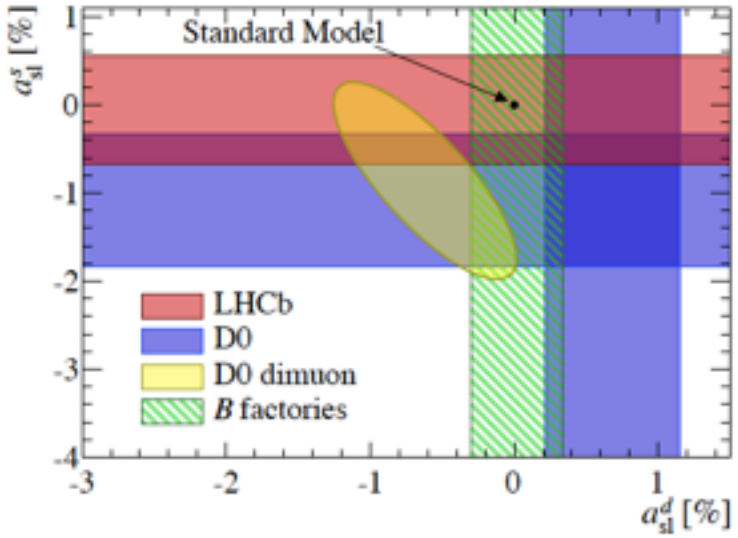
– Deviation now only 1.9σ

Iain





2.9σ deviation from SM



$$A_{\text{meas}} = \frac{\Gamma(D_s^-\mu^+) - \Gamma(D_s^+\mu^-)}{\Gamma(D_s^-\mu^+) + \Gamma(D_s^+\mu^-)} = \frac{a_{sl}^s}{2} + A_D - \underbrace{\left(A_P + \frac{a_{sl}^s}{2}\right) \frac{\int e^{\Gamma_s t}\cos(\Delta m_s t)\epsilon(t)dt}{\int e^{\Gamma_s t}\cosh(\Delta\Gamma_s t/2)\epsilon(t)dt}}_{\sim 10^{-4}}$$

$$A_{\text{meas}}(t) = \frac{\Gamma(f,t) - \Gamma(\bar{f},t)}{\Gamma(f,t) + \Gamma(\bar{f},t)} = \frac{a_{sl}^d}{2} + A_D - \left(A_P + \frac{a_{sl}^d}{2}\right) \frac{\cos(\Delta m_d t)}{\cosh(\Delta\Gamma_d t/2)}$$

$$a_{sl}^s = (-0.06 \pm 0.50(\text{stat}) \pm 0.36(\text{syst}))\%$$

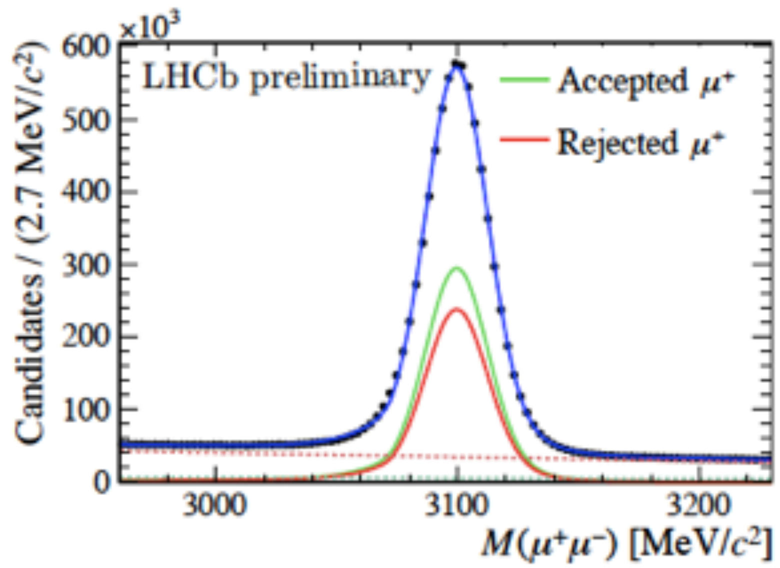
SM!

Phys. Lett. B 728 (2014) 607-615

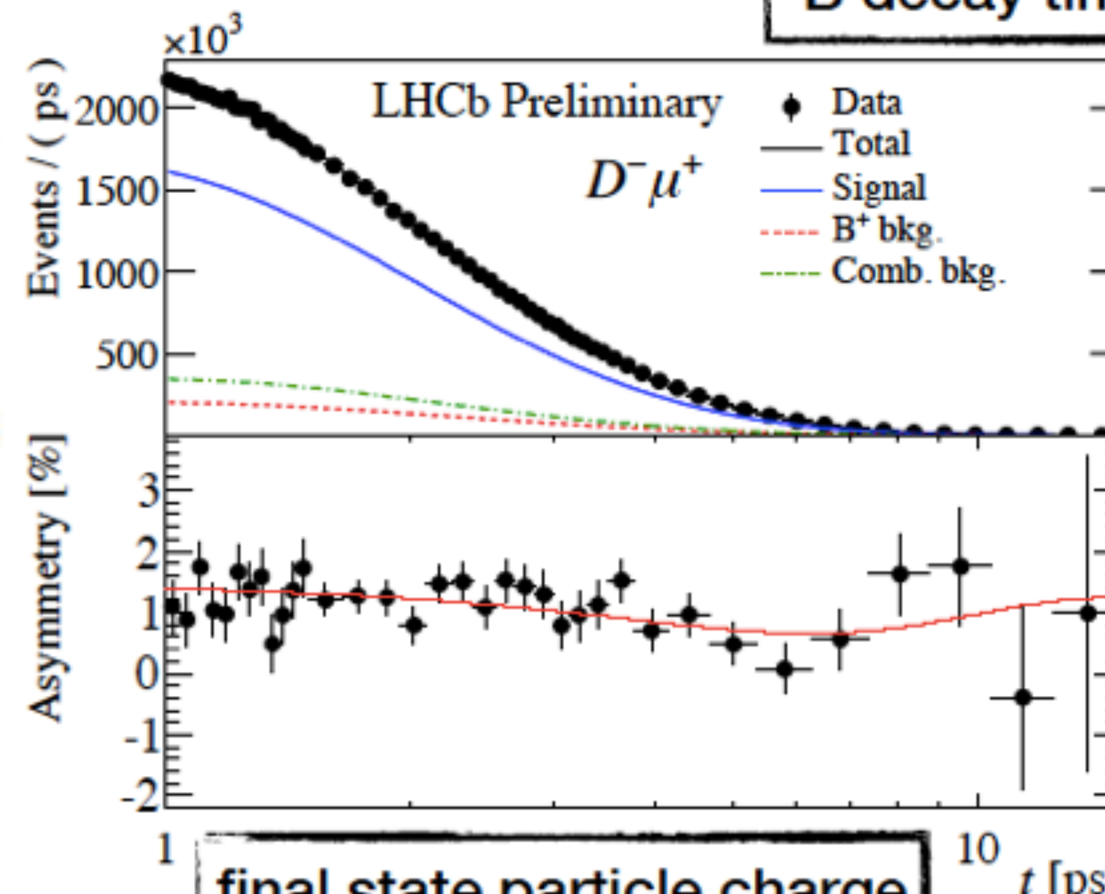
$3\ \text{fb}^{-1}$ MEASUREMENT COMING SOON...

Lucia

Ex of detection asymmetry

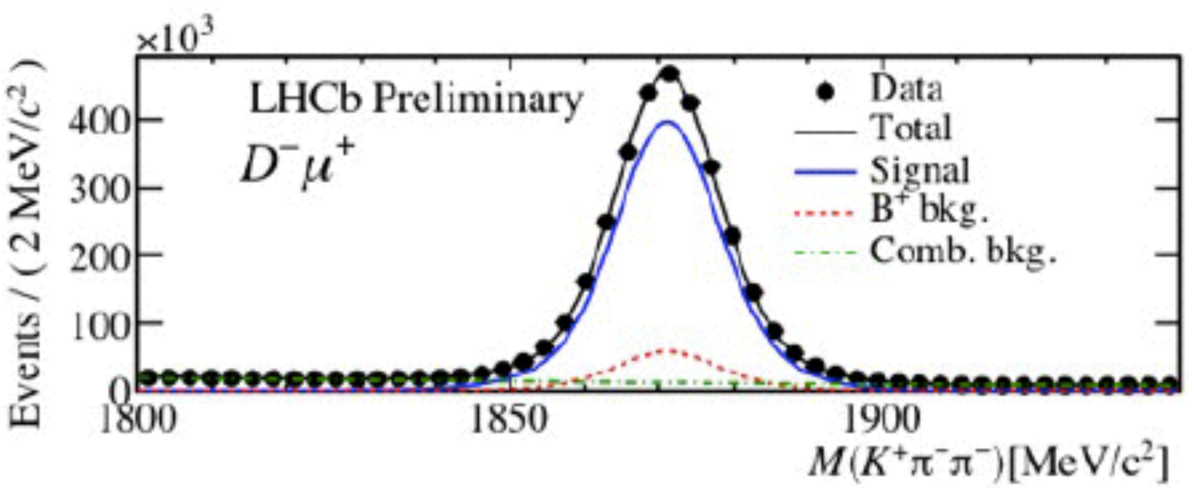


B decay time

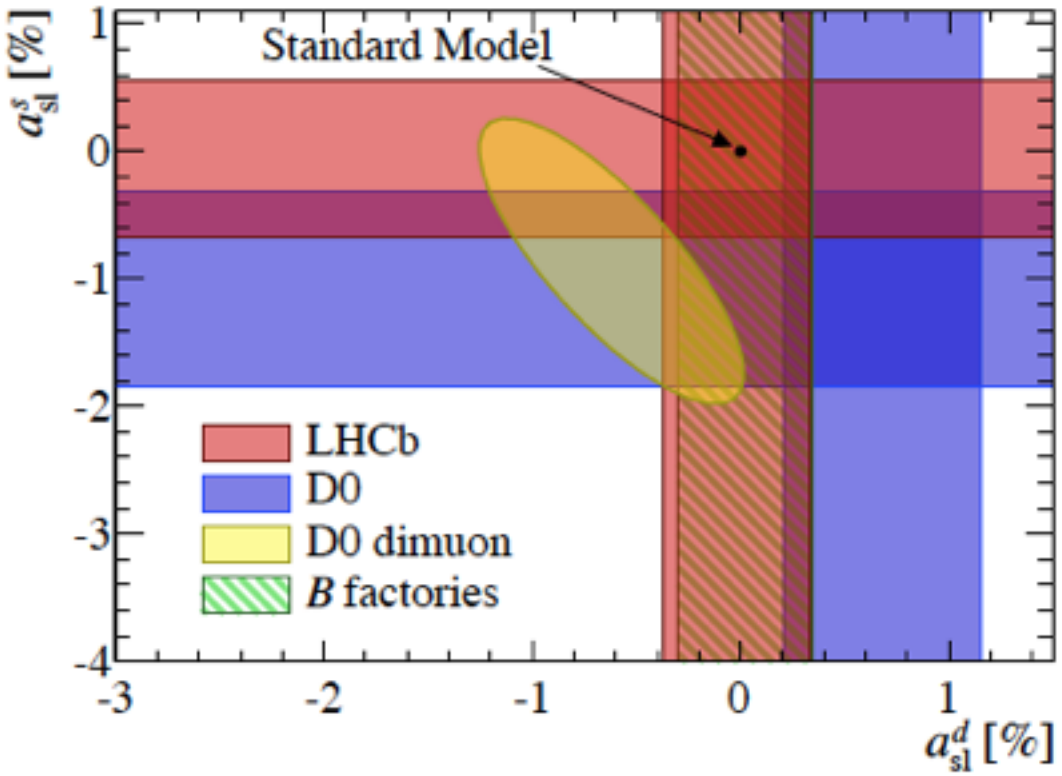


final state particle charge

example of projections (for D+ mode)



Lucia



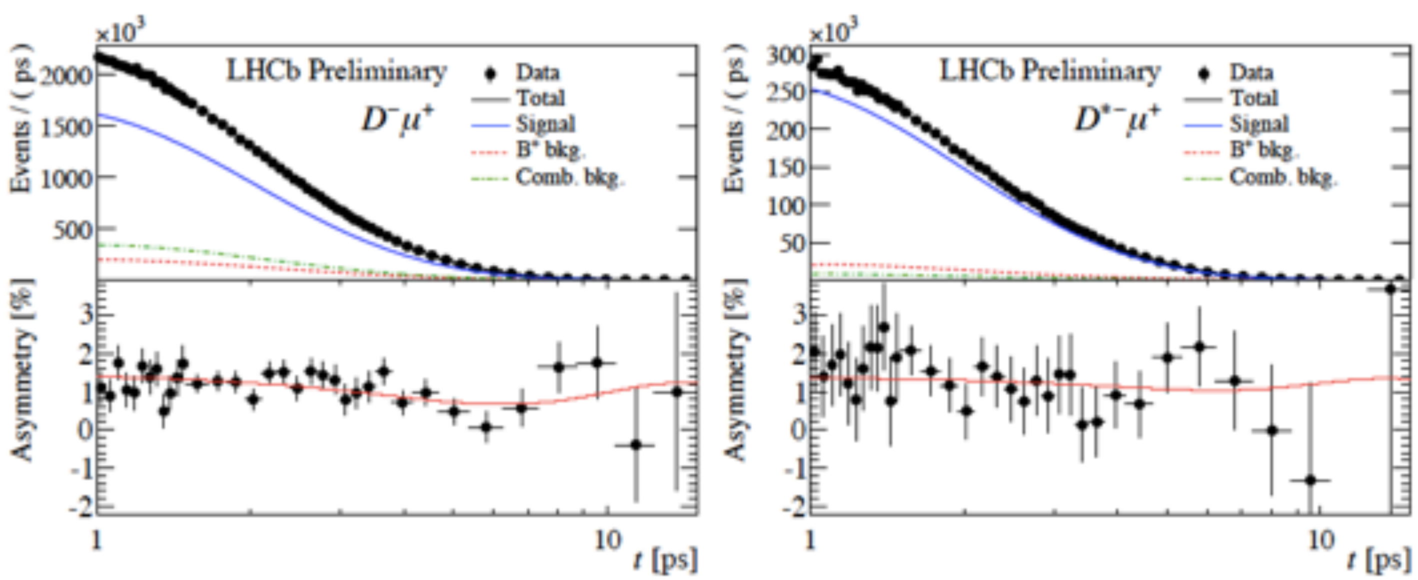
$$a^s_{sl} = (-0.06 \pm 0.50(\text{stat}) \pm 0.36(\text{syst}))\%$$

NEW preliminary

$$a^d_{sl} = (-0.02 \pm 0.19(\text{stat}) \pm 0.30(\text{syst}))\%$$

SM!!

MOST PRECISE VALUE FROM A SINGLE MEASUREMENT



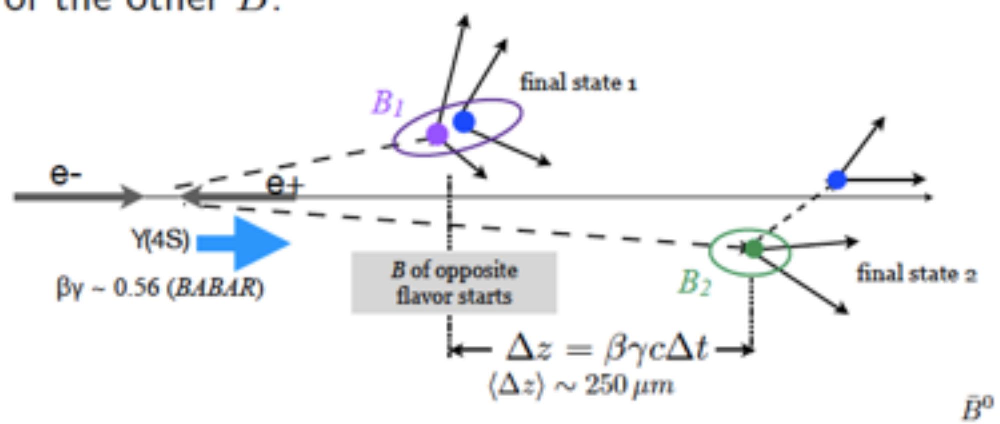
Useful for other CP measurement

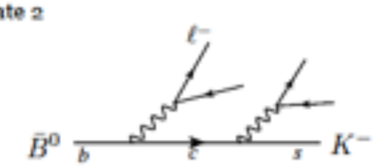
$$A_P(7\ TeV) = (-0.66 \pm 0.26(\text{stat}) \pm 0.22(\text{syst}))\%$$
$$A_P(8\ TeV) = (-0.48 \pm 0.15(\text{stat}) \pm 0.17(\text{syst}))\%$$

Chih-hsiang

We measure A_{CP} in B^0-$\overline{B}^0$ mixing using dilepton events from the full *BABAR* dataset 471×10^6 $B\overline{B}$ pairs.

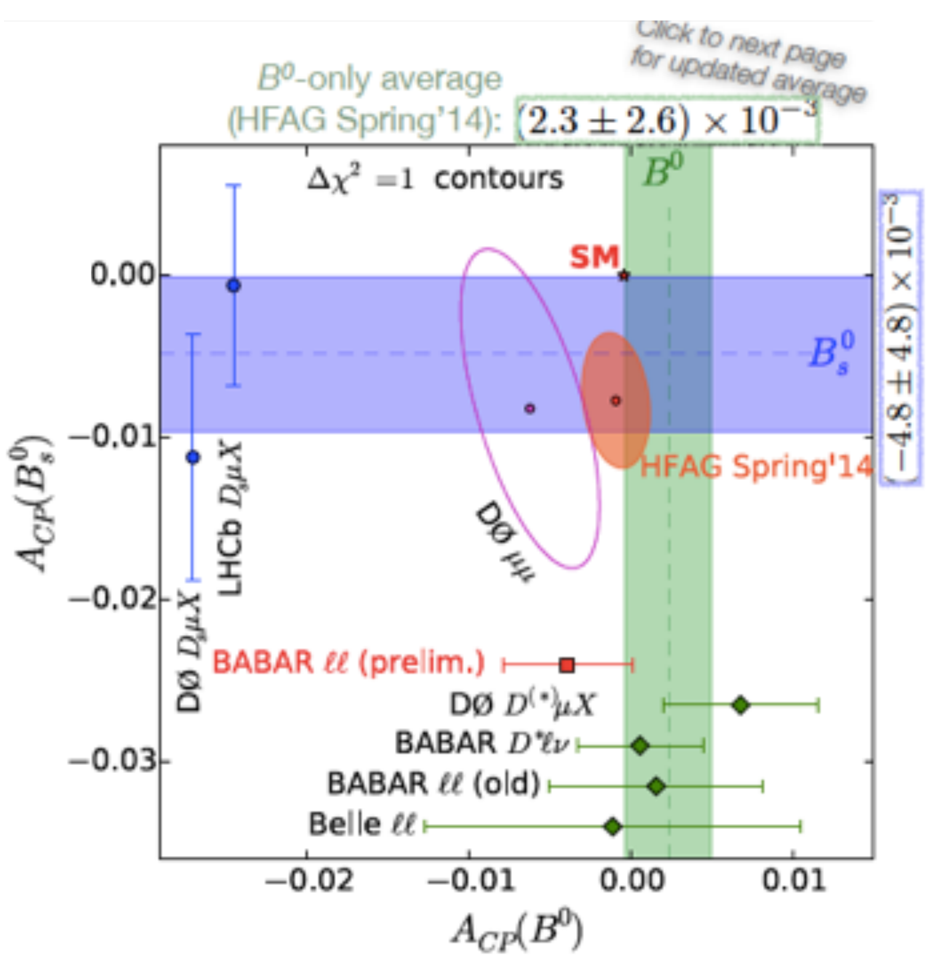
- Look for two flavor-specific final states; one would tag the initial state of the other B.

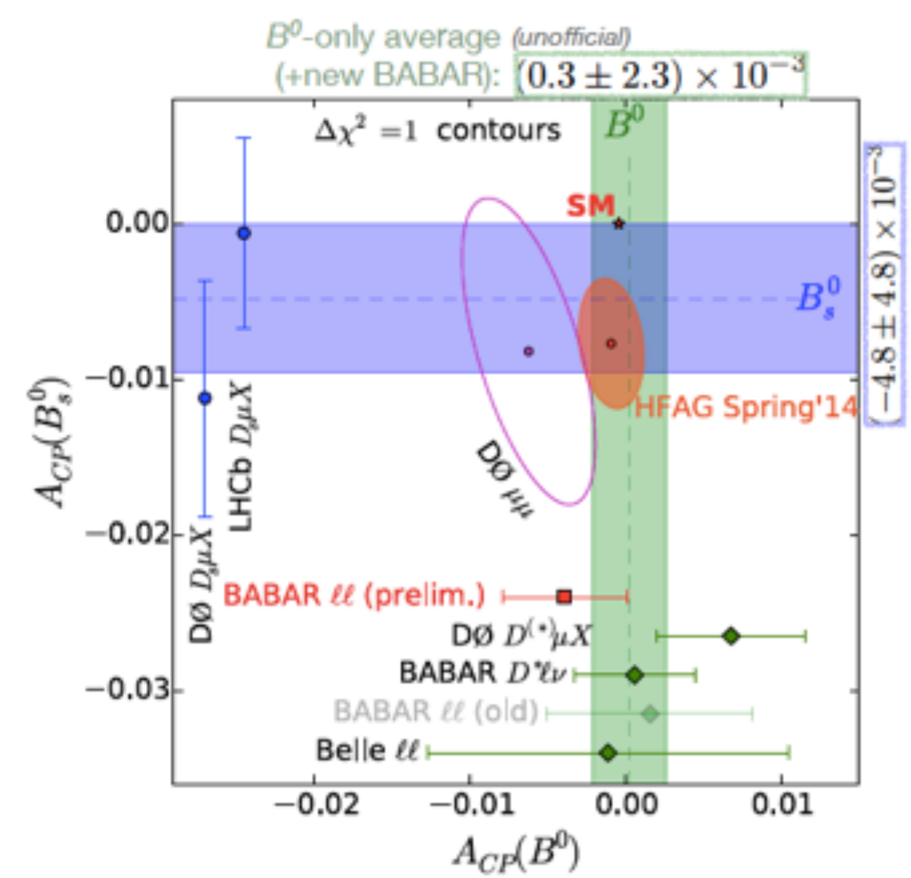




$$A_{CP} = (-3.9 \pm 3.5 \pm 1.9) \times 10^{-3}$$

BABAR preliminary





Miguel

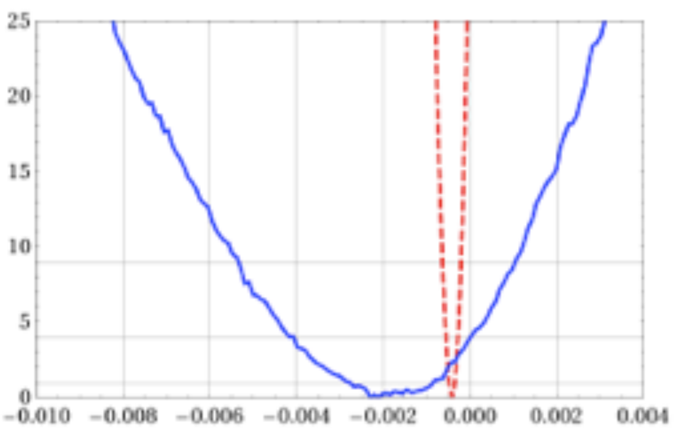
Scenarios in which the CKM matrix is no longer 3×3 unitary,
it is, on the contrary, part of a larger unitary matrix

Modified $M_{12}^{(q)}$

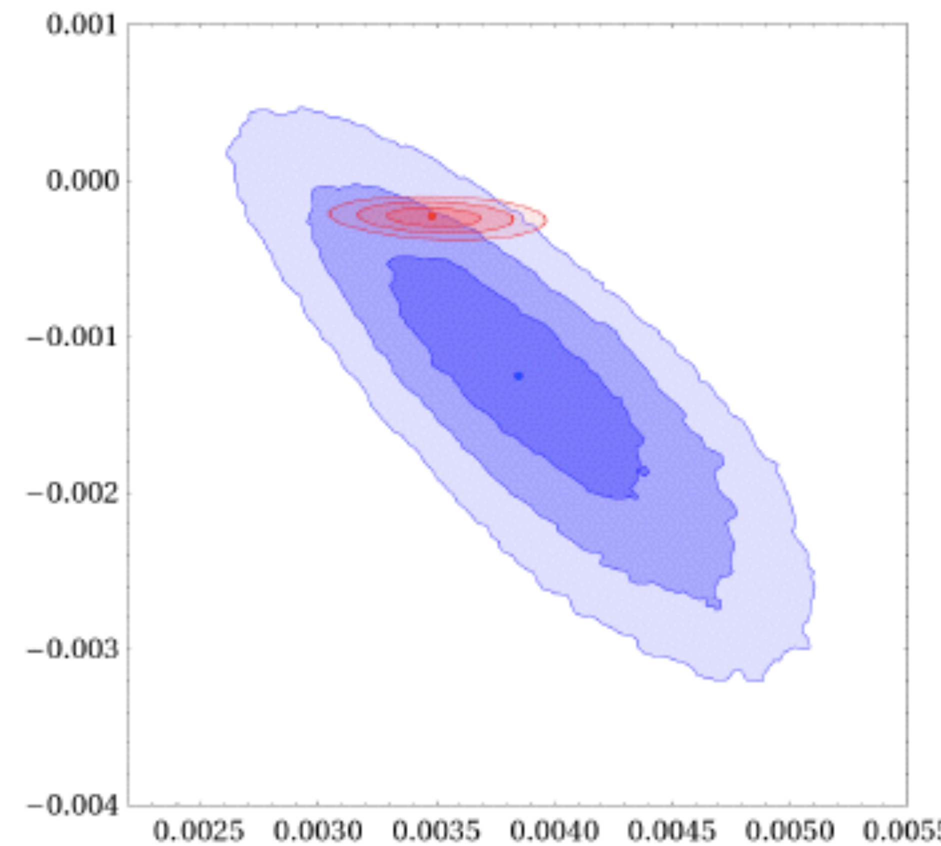
Controlled removal of SM ingredients

1. $M_{12}^{(q)}$ dominated by a single weak amplitude
2. use of 3×3 unitarity of CKM

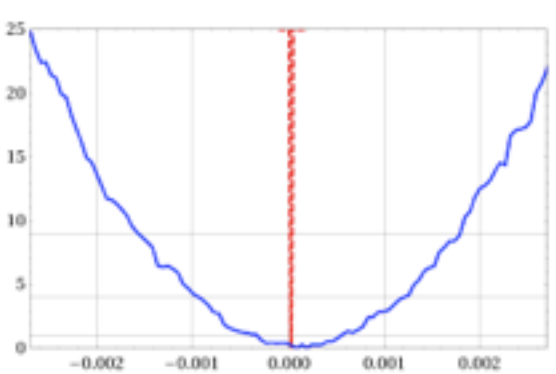
– NP – SM



(a) $\Delta\chi^2$ vs. A_{SL}^d



(f) $\Delta\chi^2$ contours, A_{SL}^b vs. $|V_{ub}|$



(b) $\Delta\chi^2$ vs. A_{SL}^s

- Enhancement of A_{SL}^b up to $-2 \cdot 10^{-3}$ (N.B. SM fit $-2.3 \cdot 10^{-4}$)
- . . . requires $|V_{ub}| \uparrow$ and/or $A_{J/\Psi\Phi} \uparrow$
- Closer to the D0 measurement $(-4.96 \pm 1.69) \times 10^{-3}$, but insufficient

Effect of $\Delta\Gamma$ on the dimuon asymmetry in B decays

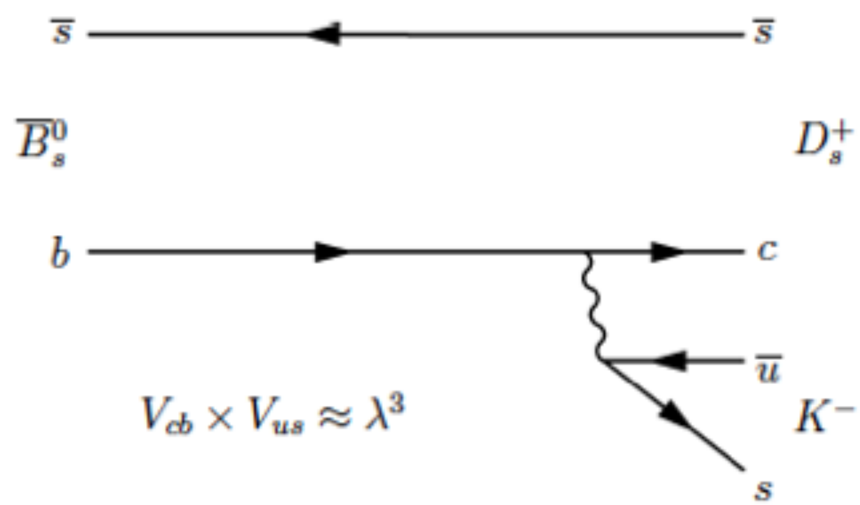
Nierste

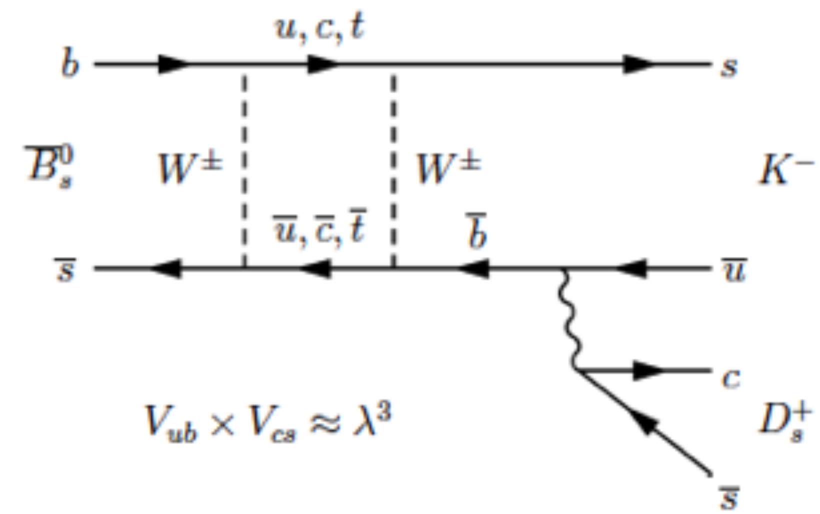
- I agree with Borissov and Hoeneisen that the DØ dimuon asymmetry receives a contribution $A_S^{\rm int}$ from mixing-induced CP violation in decays $B \to X \to X'\mu$.
- Final states with all combinations $(c,\overline{c})$, $(c,\overline{u})$, $(u,\overline{c})$, and $(u,\overline{u})$ must be considered.
- $$A_S^{\rm int} = -(P_{c\to\mu} - P_{u\to\mu})\frac{|\Delta\Gamma|}{\Gamma}\frac{|\lambda_t|}{|\lambda_c|}\sin(\beta)\frac{x_d}{1+x_d^2}$$

  is smaller in magnitude by at least a factor of 0.49 compared to the formulae used in the DØ analysis, so that the discrepancy with the SM is larger than the quoted 3.6σ.
- $A_S^{\rm int}$ depends differently on new physics than $a_{\rm fs}^d$.

The physics of $B_s \to D_s K$

Vava





Time dependent asymmetry

$$\frac{\Gamma(B^0_q(t) \to D_q\overline{u}_q) - \Gamma(\overline{B^0_q}(t) \to D_q\overline{u}_q)}{\Gamma(B^0_q(t) \to D_q\overline{u}_q) + \Gamma(\overline{B^0_q}(t) \to D_q\overline{u}_q)} = \left[\frac{C(B_q \to D_q\overline{u}_q)\cos(\Delta M_q t) - S(B_q \to D_q\overline{u}_q)\sin(\Delta M_q t)}{\cosh(\Delta\Gamma_q t/2) + \mathcal{A}_{\Delta\Gamma}(B_q \to D_q\overline{u}_q)\sinh(\Delta\Gamma_q t/2)}\right]$$

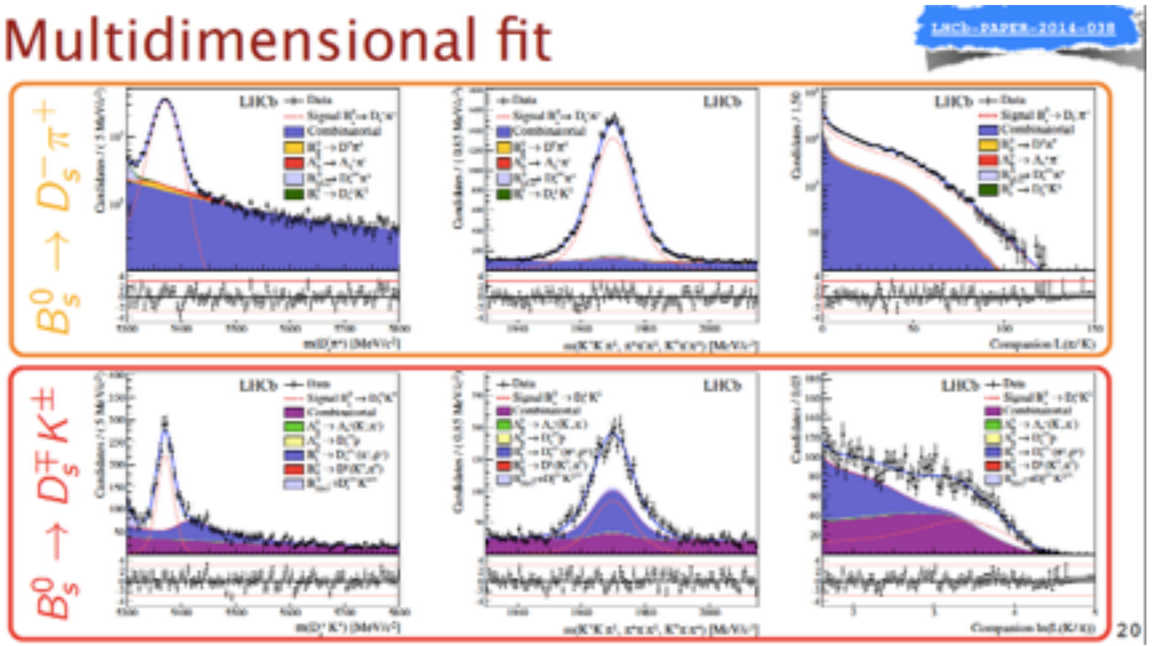
The observables

$$C_f = \frac{1 - r^2_{D_sK}}{1 + r^2_{D_sK}},$$

$$A_f^{\Delta\Gamma} = \frac{2r_{D_sK}\cos(\delta - (\gamma - 2\beta_s))}{1 + r^2_{D_sK}}, \quad A_{\overline{f}}^{\Delta\Gamma} = \frac{2r_{D_sK}\cos(\delta + (\gamma - 2\beta_s))}{1 + r^2_{D_sK}},$$

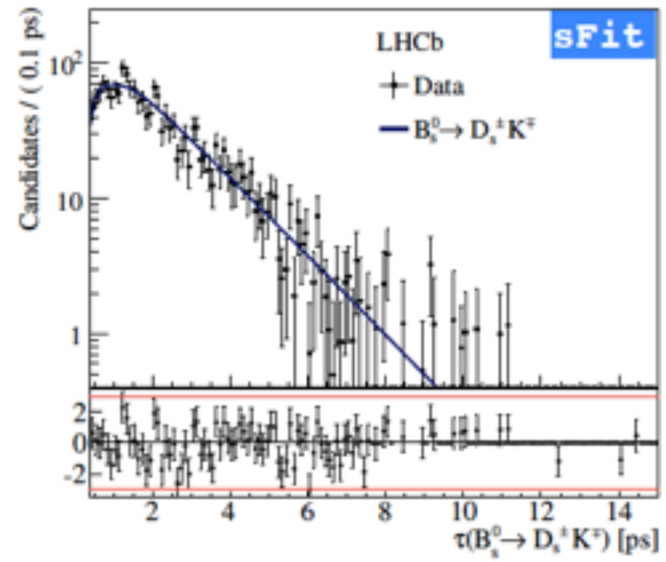
$$S_f = \frac{2r_{D_sK}\sin(\delta - (\gamma - 2\beta_s))}{1 + r^2_{D_sK}}, \quad S_{\overline{f}} = \frac{2r_{D_sK}\sin(\delta + (\gamma - 2\beta_s))}{1 + r^2_{D_sK}}.$$

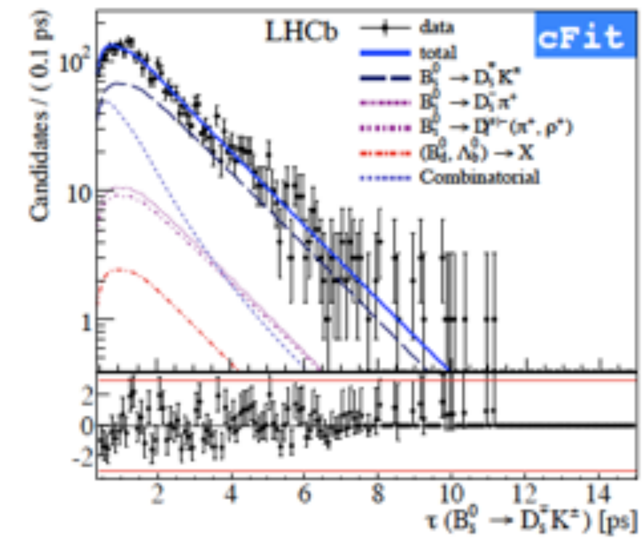
Multidimensional fit

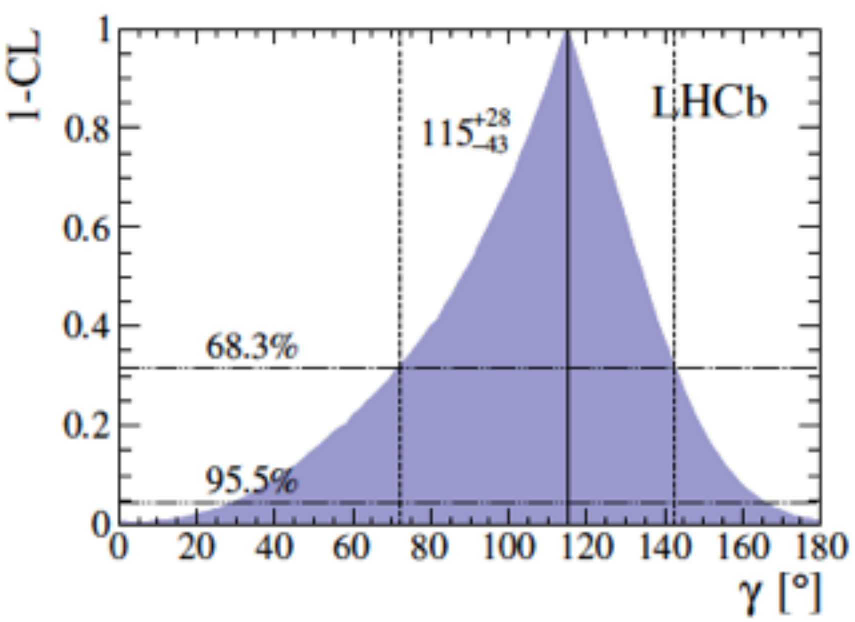


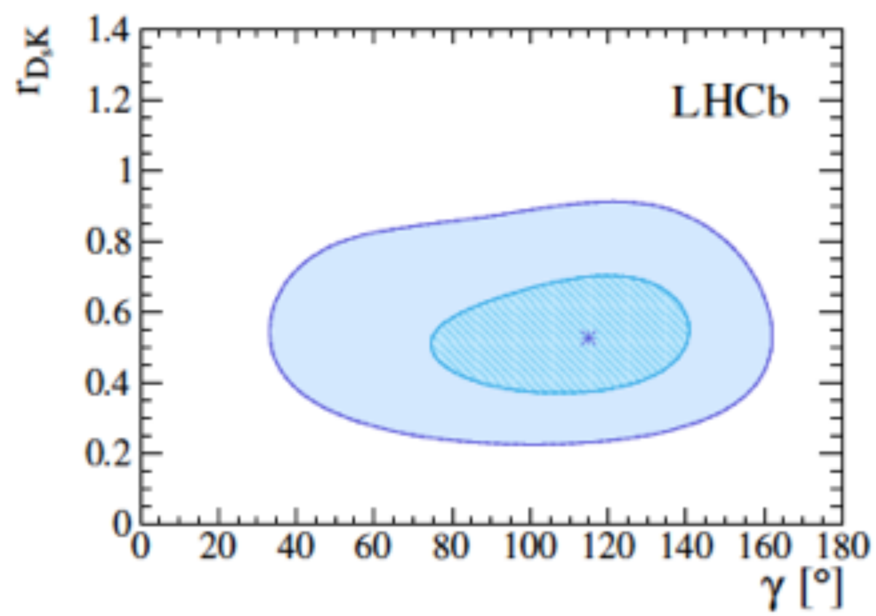
$28\,260 \pm 180 \; B_s^0 \to D_s^- \pi^+$ (85%)

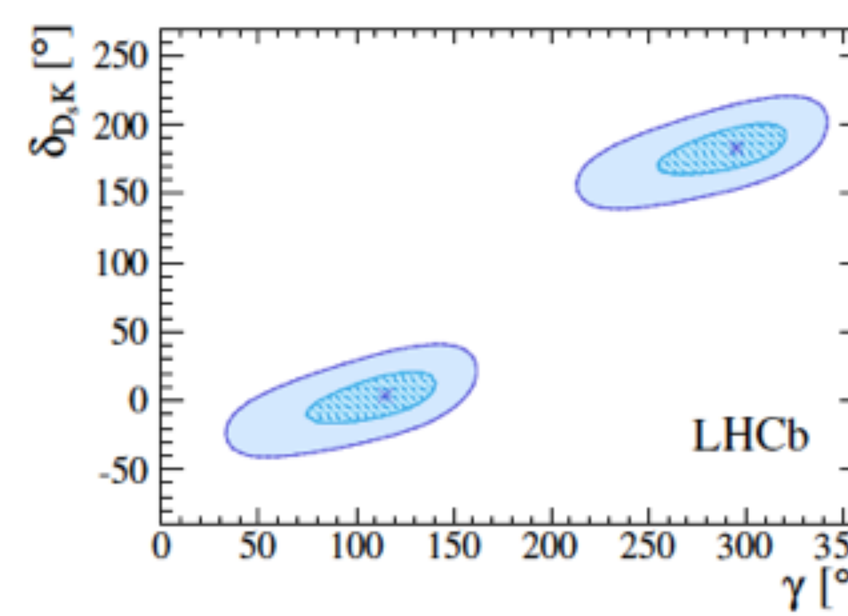
$1770 \pm 50 \; B_s^0 \to D_s^\mp K^\pm$ (74%)







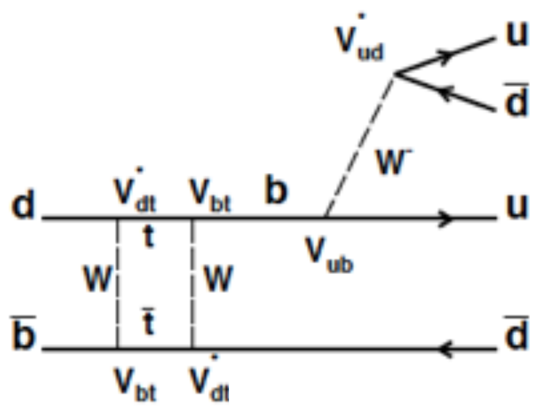




$$\gamma = (115^{+28}_{-43})^\circ ,$$
$$\delta = (3^{+19}_{-20})^\circ ,$$
$$r_{D_sK} = 0.53^{+0.17}_{-0.16} ,$$

Vava

At tree level: $\mathcal{S}_{CP} = \sin(2\phi_2)$ and $\mathcal{A}_{CP} = 0$.



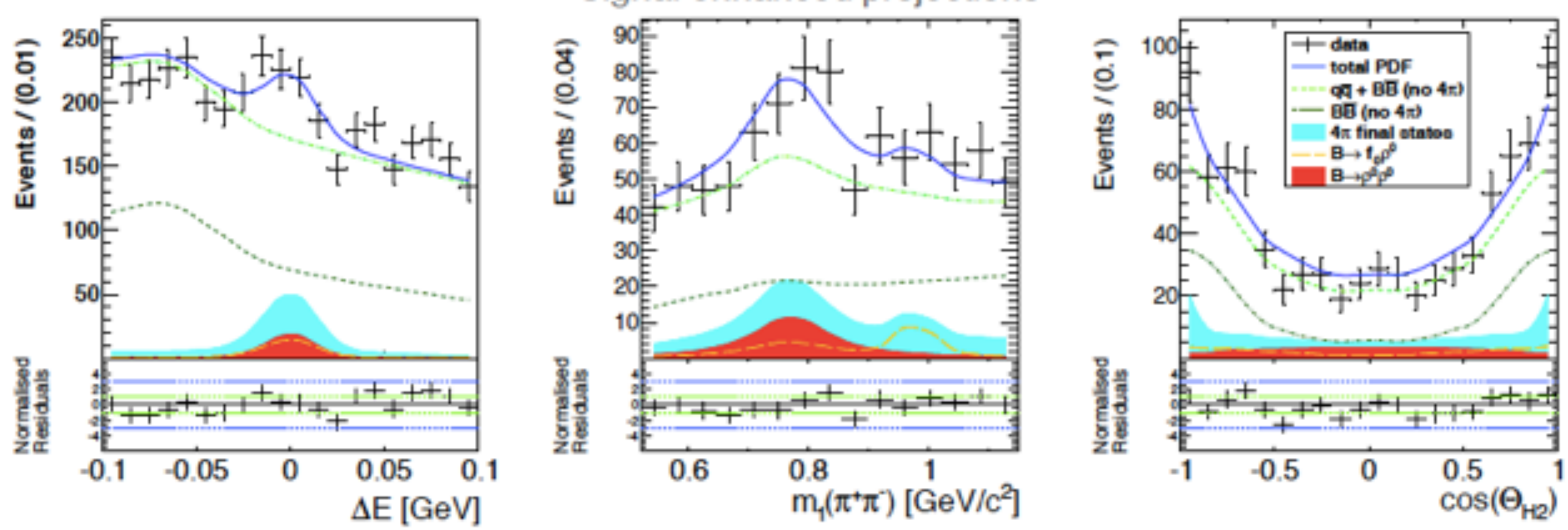
penguin pollution $\Rightarrow \Delta\phi_2, \mathcal{A}_{CP}$

$\Rightarrow$ measured observable $\phi_2^{eff} = \phi_2 + \Delta\phi_2$

and $\mathcal{A}_{CP} \neq 0$ possible

extraction of $\Delta\phi_2$ with isospin analysis (remove penguin pollution)

Signal enhanced projections

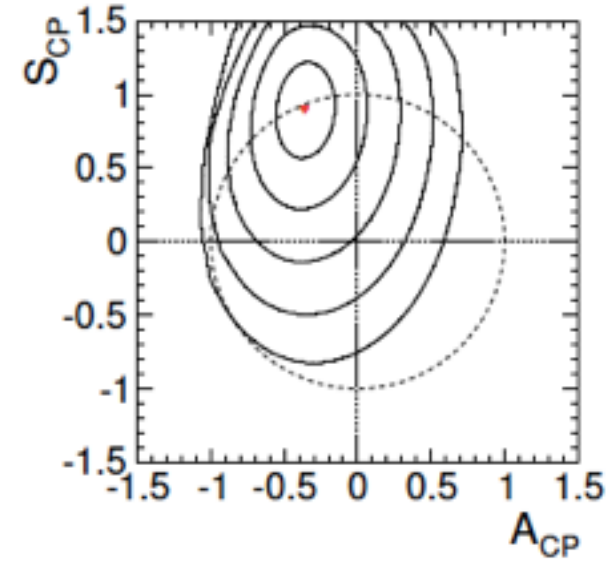


$$\mathcal{B}(B^0 \to \rho^0\rho^0) = (1.02 \pm 0.30 \pm 0.15) \times 10^{-6}$$

$$f_L = 0.21^{+0.18}_{-0.22} \pm 0.15$$

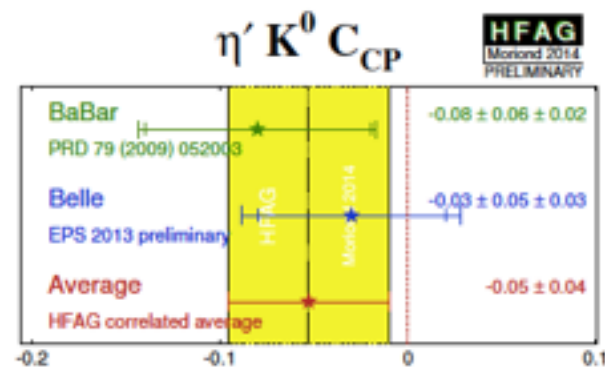
[prospect for Belle2 $\phi_2^{\rho\rho} = (X \pm 3)^\circ$]

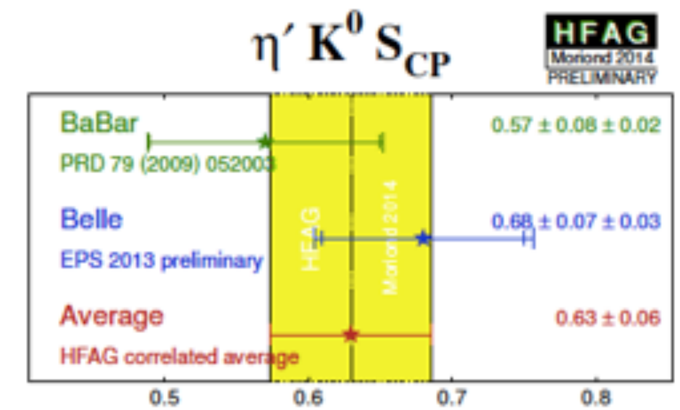
Pit



$B^0 \to \omega K^0_S$: BR and time dependent CPV

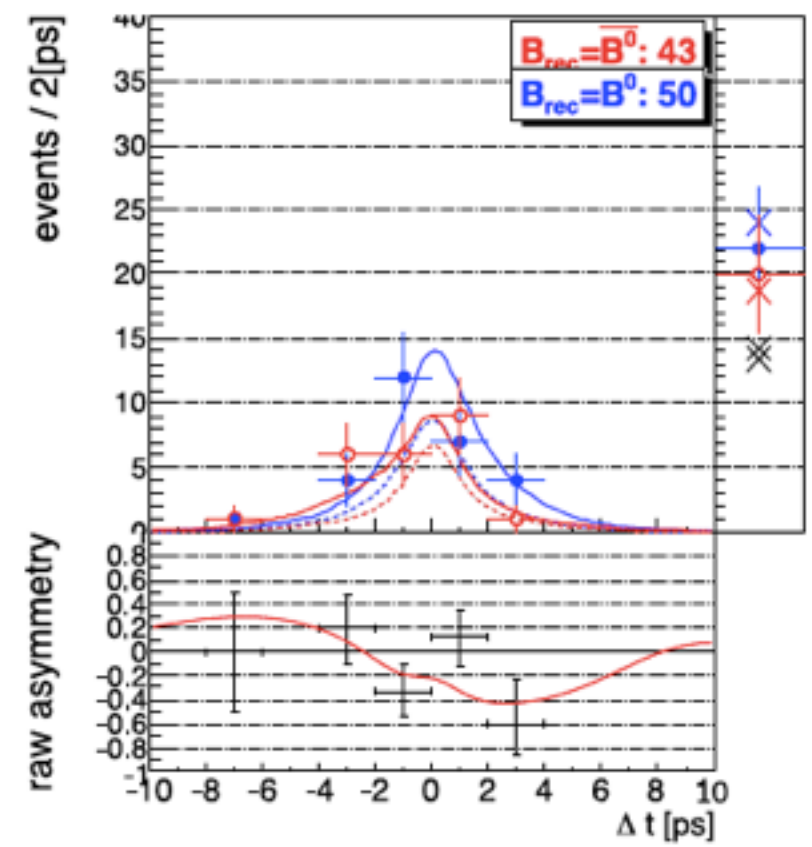
- $\mathcal{S}_{\omega K^0_S} = +0.91 \pm 0.32 \pm 0.05$
- first evidence (3.1σ) for CPV
- four out of five parameters world's most precise results





$B^0 \to \eta' K^0$: time dependent CPV

- $\mathcal{S}_{\eta' K^0} = +0.68 \pm 0.07 \pm 0.03$
- Most precise determination of CPV parameters



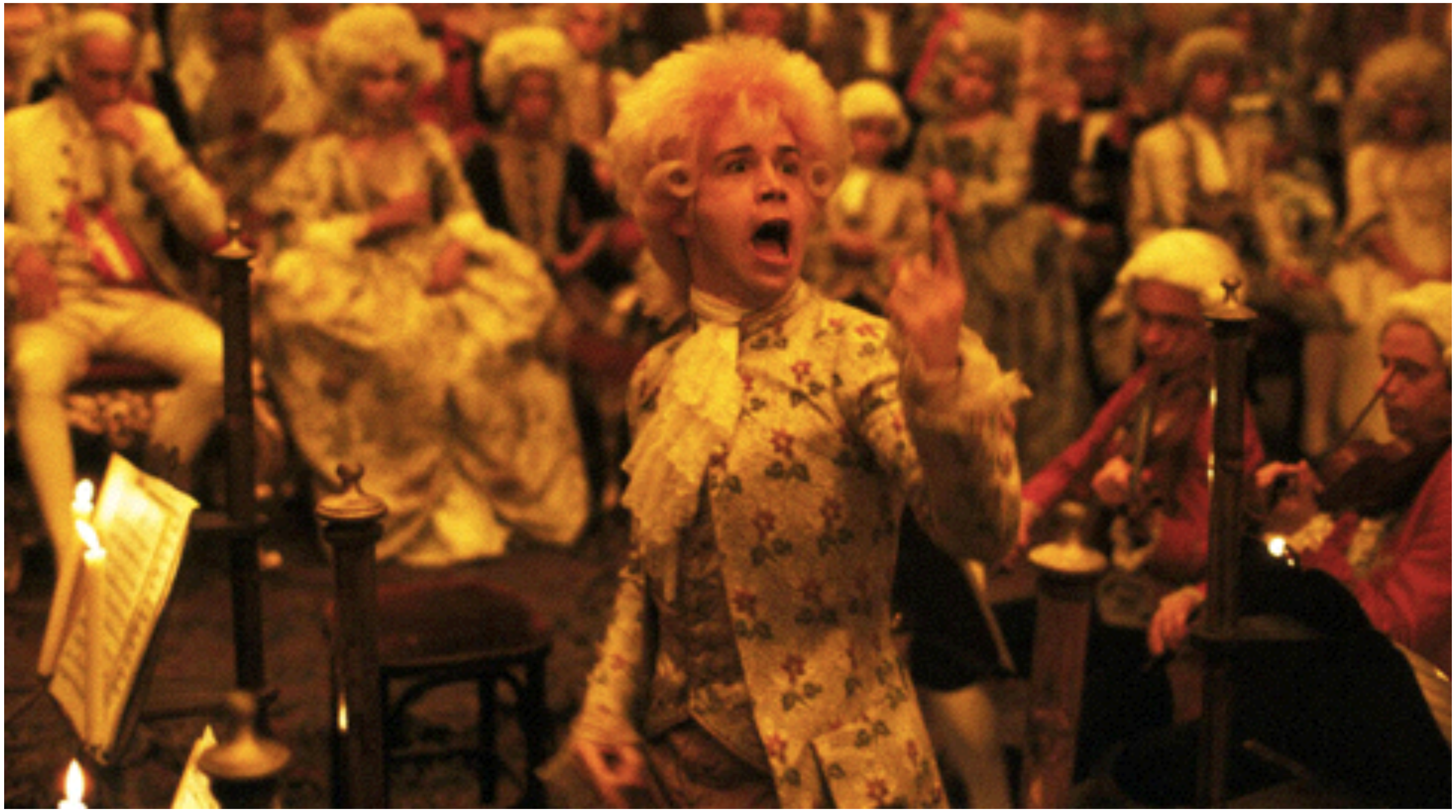
$B^0 \to K^0_S \eta\gamma$: time dependent CPV

- no significant CPV observed

So far, everything is consistent with SM

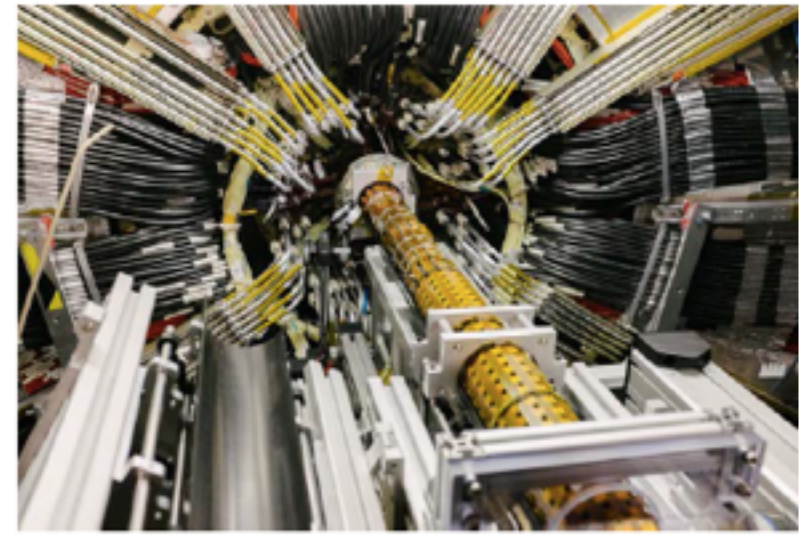
Martin

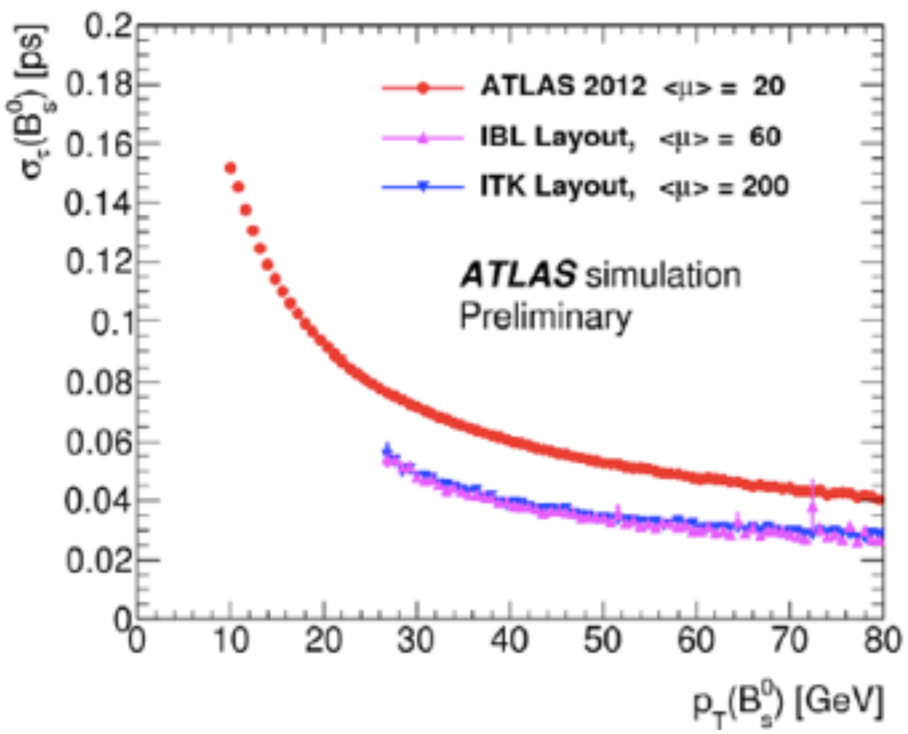
This is not the end of the story

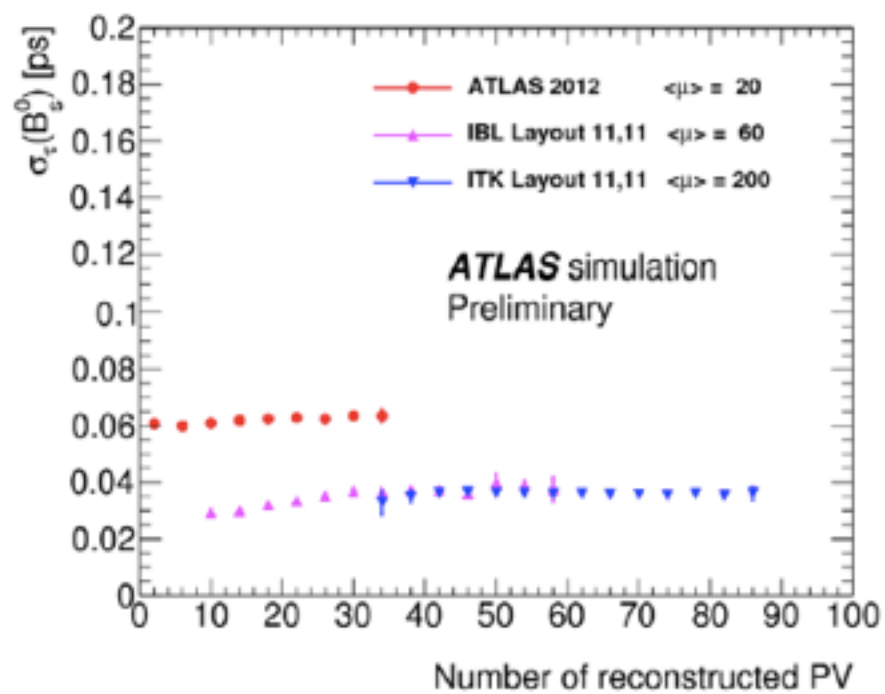


Borissov

Upgrade of ATLAS detector will significantly improve its ability to work at high luminosity with better tracking precision







This year our precision is expected to be $\sigma(\phi^{J/\psi\varphi}) \approx 0.12$

Our final precision $\sigma(\phi^{J/\psi\varphi}) = 0.022$ is expect to be at the level of the SM value ($\phi^{J/\psi\varphi,\,SM} = -0.038 \pm 0.002$)

LHC run I	LHCb 2018	LHCb upgrade
$\int L dt \approx 3\ fb^{-1}$	$\int L dt \approx 8\ fb^{-1}$	$\int L dt \approx 50\ fb^{-1}$

Eduardo

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

LHC Run I
pp runs with
- 50ns bunch spacing
- E_{CM} 7TeV and 8 TeV
LHCb $\mathcal{L}$~4x10³²/cm²/s
LHCb $\int\mathcal{L}$ ~3/fb

LS1
LHC splice consoli-dation

LHC Run II
pp runs with
- 25ns bunch spacing,
- E_{CM} 13 TeV
LHCb $\mathcal{L}$>4x10³²/cm²/s
LHCb $\int\mathcal{L}$ >5/fb

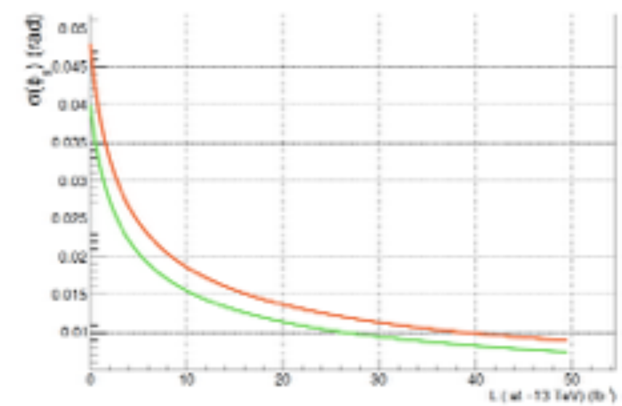
LS 2
LHC injector upgrade
LHCb upgrade

LHC Run III
pp runs with
- 25ns b.spacing
- E_{CM} 14 TeV
$\mathcal{L}$ > 1x10³³/cm²/s
LHCb $\int\mathcal{L}$ > 15/fb

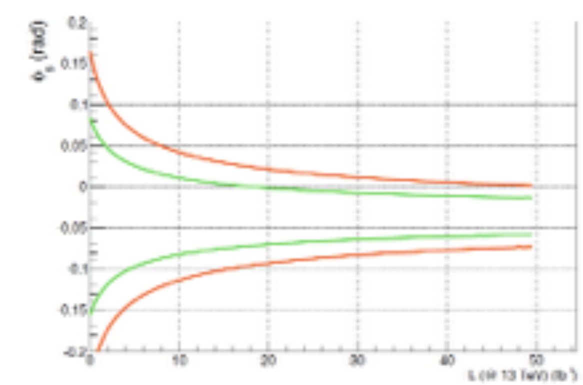
LS3
HL-LHC prep
GPD phase 2 upgrades

LHC Run IV
$\mathcal{L}$=2x10³³/cm²/s
$\int\mathcal{L}$ > 23/fb

Observable	LHC run I	LHCb 2018	LHCb upgrade	Theory
$\gamma\ (B_s^0 \to D_s^{\pm} K^{\mp})$	17°	11°	2.4°	negligible

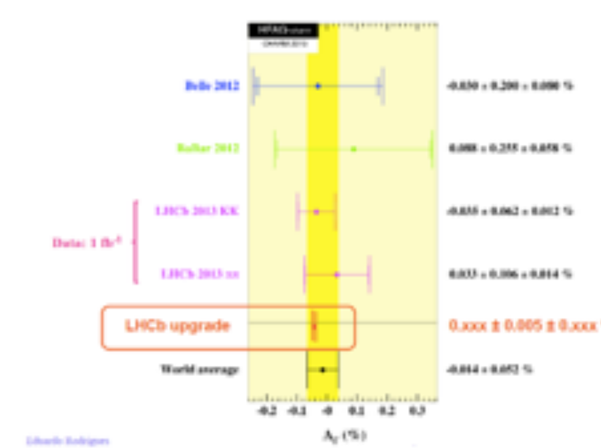


Observable	LHC run I	LHCb 2018	LHCb upgrade	Theory
$\phi_s^{eff}\ (B_s^0 \to \phi\ \phi)$ (rad)	0.15	0.10	**0.023**	0.02
$\phi_s^{eff}\ (B_s^0 \to K^{*0}\ \overline{K}^{*0})$ (rad)	0.19	0.13	**0.029**	< 0.02
$2\beta^{eff}\ (B^0 \to \phi\ K_S^0)$ (rad)	0.30	0.20	**0.04**	0.02



Observable	LHC run I	LHCb 2018	LHCb upgrade	Theory
$\phi_s\ (B_s^0 \to J/\psi\ \phi)$ (rad)	0.050	0.025	0.009	~ 0.003
$\phi_s\ (B_s^0 \to J/\psi\ f_0(980))$ (rad)	0.068	0.035	0.012	~ 0.01
$\beta\ (B^0 \to J/\psi\ K_S^0)$	1.7°	0.8°	0.31°	negligible

Observable	LHC run I	LHCb 2018	LHCb upgrade	Theory
$A_\Gamma\ (D \to K^+ K^-)$ (10^{-4})	3.4	2.2	0.5	-

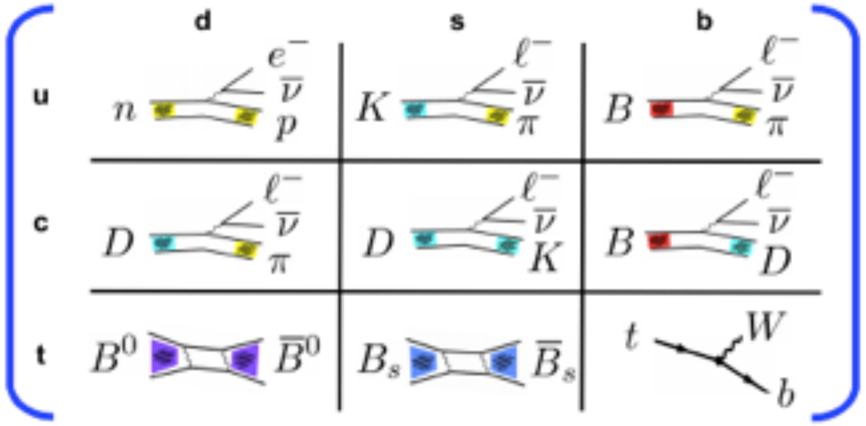


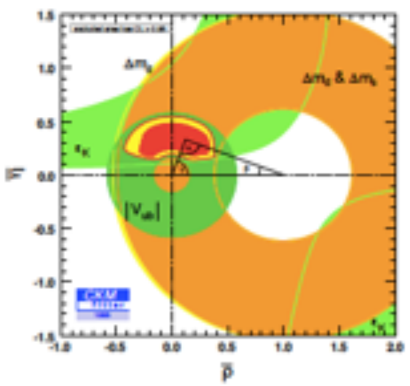
Fitters

Extracting the CKM parameters

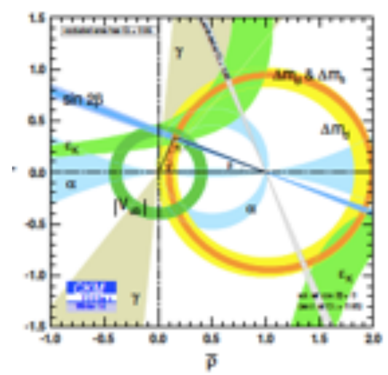
Sebastien

V =

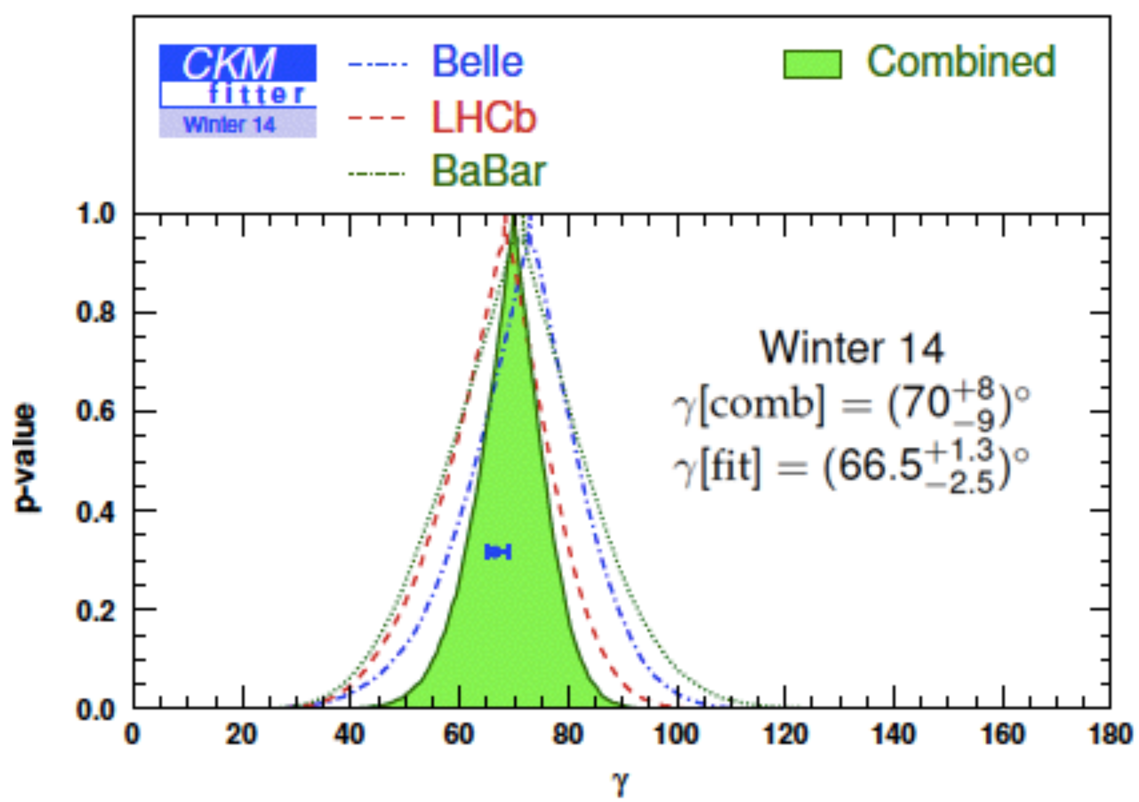


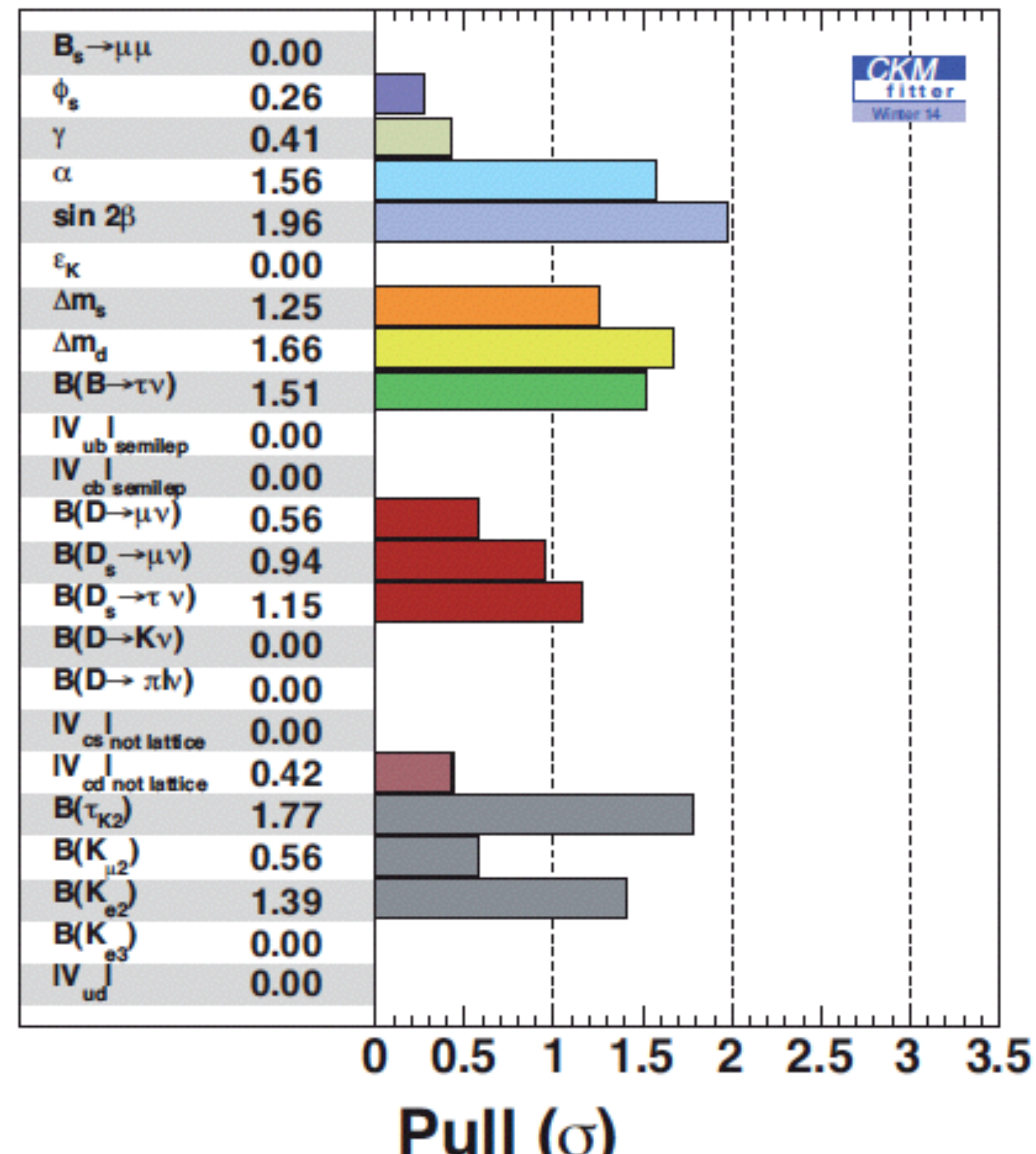


1995



2014





Marcella

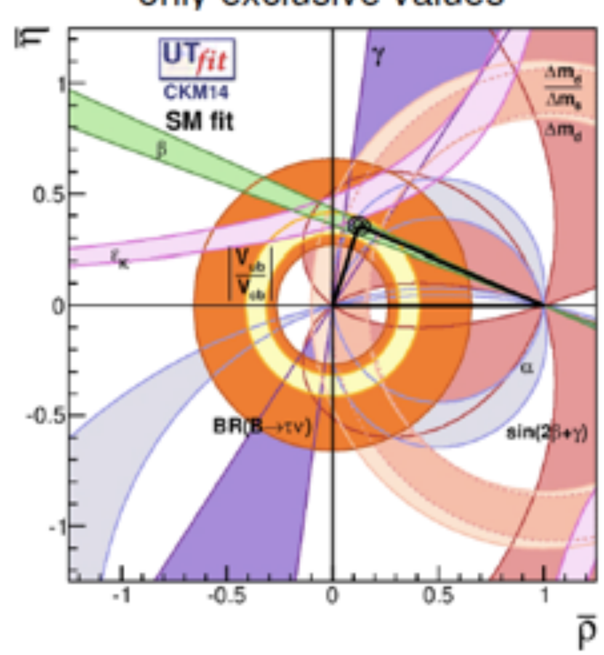
Unitarity Triangle analysis in the SM:

obtained excluding the given constraint from the fit

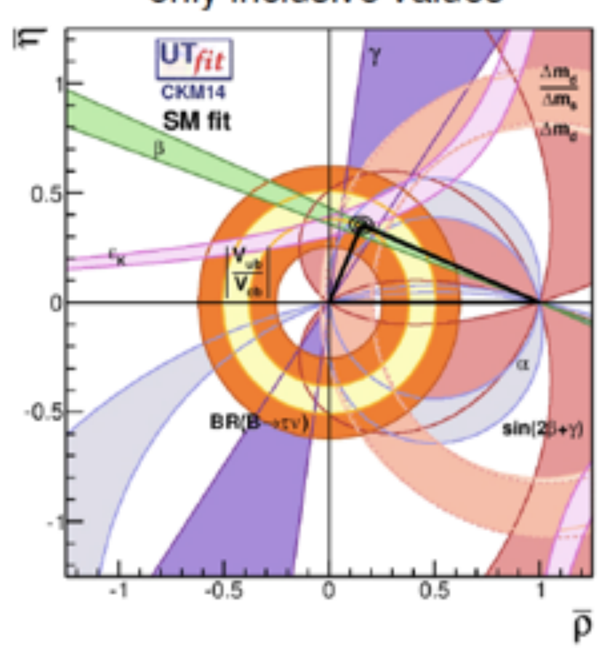
Observables	Measurement	Prediction	Pull (#σ)
$\sin 2\beta$	0.679 ± 0.024	0.752 ± 0.041	~ 1.5
γ	68.3 ± 7.5	68.6 ± 3.7	< 1
α	92.2 ± 6.2	87.3 ± 3.9	< 1
$\lvert V_{ub}\rvert \cdot 10^3$	3.75 ± 0.46	3.63 ± 0.13	< 1
$\lvert V_{ub}\rvert \cdot 10^3$ (incl)	4.40 ± 0.31	–	~ 2.3
$\lvert V_{ub}\rvert \cdot 10^3$ (excl)	3.42 ± 0.22	–	< 1
$\lvert V_{cb}\rvert \cdot 10^3$	40.9 ± 1.0	*42.1 ± 0.7*	< 1
B_K	0.766 ± 0.010	*0.841 ± 0.078*	< 1
$BR(B \to \tau\nu)[10^{-4}]$	1.14 ± 0.22	0.82 ± 0.07	~ 1.3
$BR(B_s \to ll)[10^{-9}]$	2.8 ± 0.7	3.88 ± 0.15	~ 1.4
$BR(B_d \to ll)[10^{-9}]$	0.39 ± 0.16	0.113 ± 0.007	~ 1.7
$A_{SL}^s \cdot 10^3$	-4.8 ± 5.2	0.013 ± 0.001	< 1
$A_{\mu\mu} \cdot 10^3$	-7.9 ± 2.0	-0.13 ± 0.02	~ 3.9

14

only exclusive values



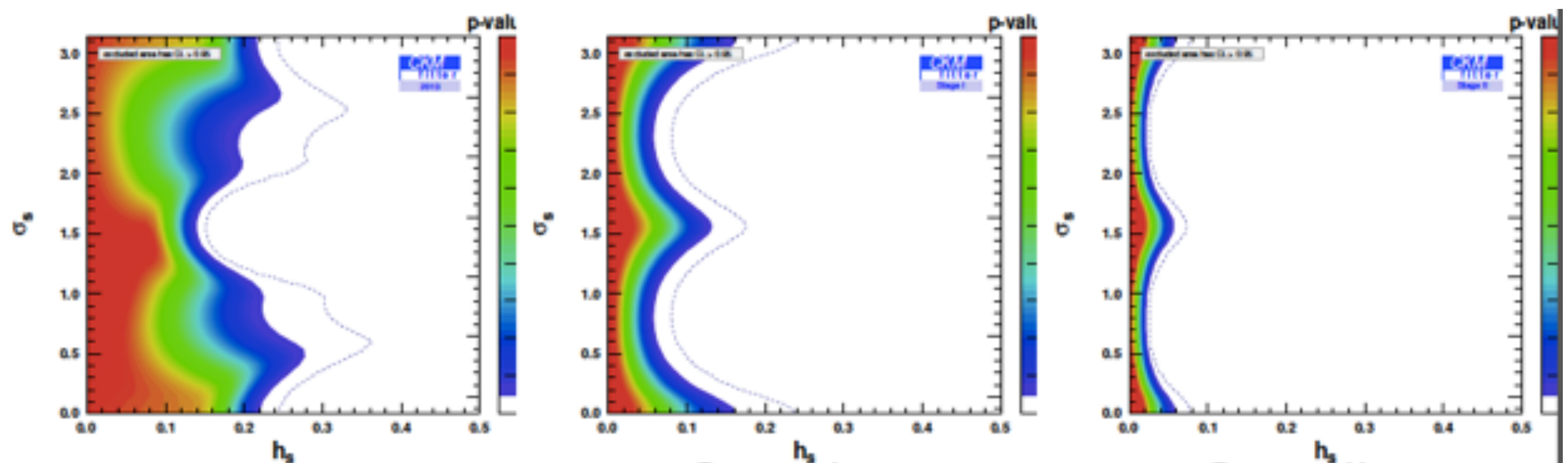
only inclusive values



$\Delta F = 2$: New Physics

Sebastien

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



2013 Stage I Stage II

From $C_{ij}^2/\Lambda^2 \times (\bar{b}_L \gamma^\mu q_{j,L})^2$

$$h \simeq 1.5 \frac{|C_{ij}|^2}{|V_{ti} V_{tj}|^2} \frac{(4\pi)^2}{G_F \Lambda^2}$$

Couplings	NP loop order	Scales (in TeV) probed by B_d mixing	Scales (in TeV) probed by B_s mixing
$\lvert C_{ij}\rvert = \lvert V_{ti} V_{tj}^*\rvert$ (CKM-like)	tree level	17	19
	one loop	1.4	1.5
$\lvert C_{ij}\rvert = 1$ (no hierarchy)	tree level	2×10^3	5×10^2
	one loop	2×10^2	40

CKM fitter

Bounds/prospects for New Physics at

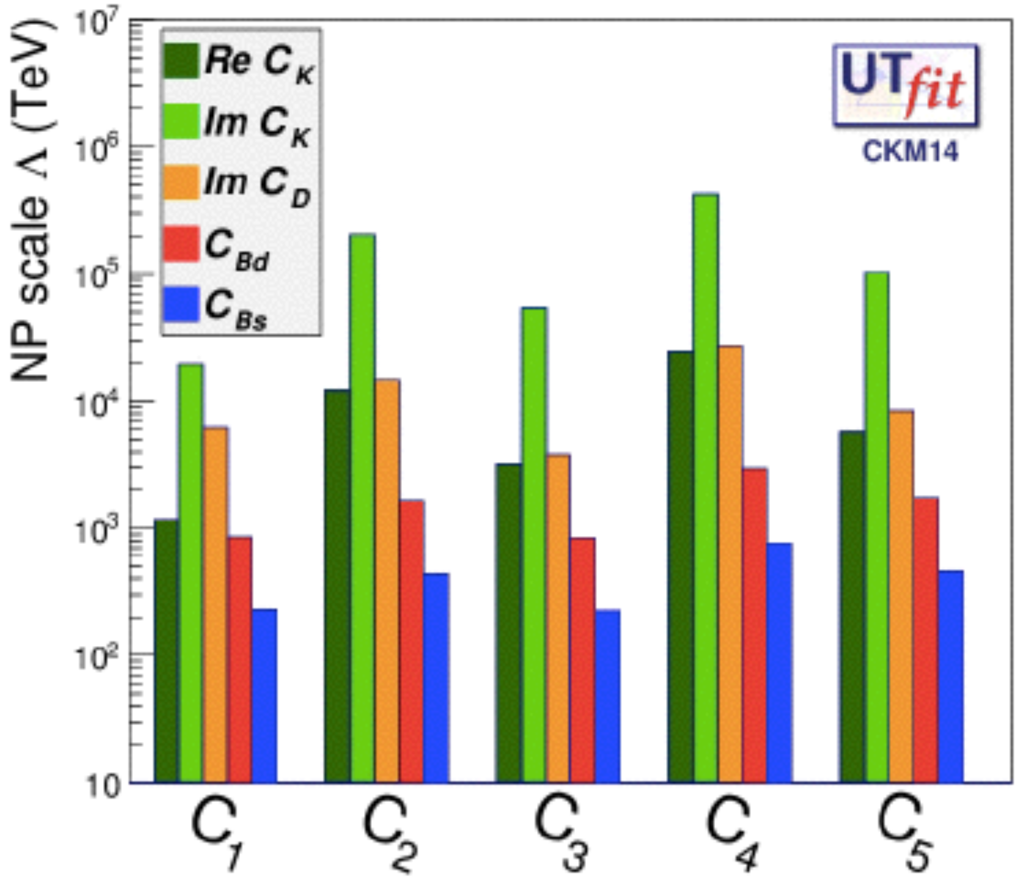
- Stage I: 7 fb^{-1} LHCb data + 5 ab^{-1} Belle II
- Stage II: 50 fb^{-1} LHCb data + 50 ab^{-1} Belle II

Marcella

results from the Wilson coefficients

Generic: $C(\Lambda) = \alpha/\Lambda^2$, $F_i \sim 1$, arbitrary phase

$\alpha \sim 1$ for strongly coupled NP



Lower bounds on NP scale
(in TeV at 95% prob.)

To obtain the lower bound for loop-mediated contributions, one simply multiplies the bounds by α_s ($\sim$ 0.1) or by α_W ($\sim$ 0.03).

$\alpha \sim \alpha_W$ in case of loop coupling through weak interactions

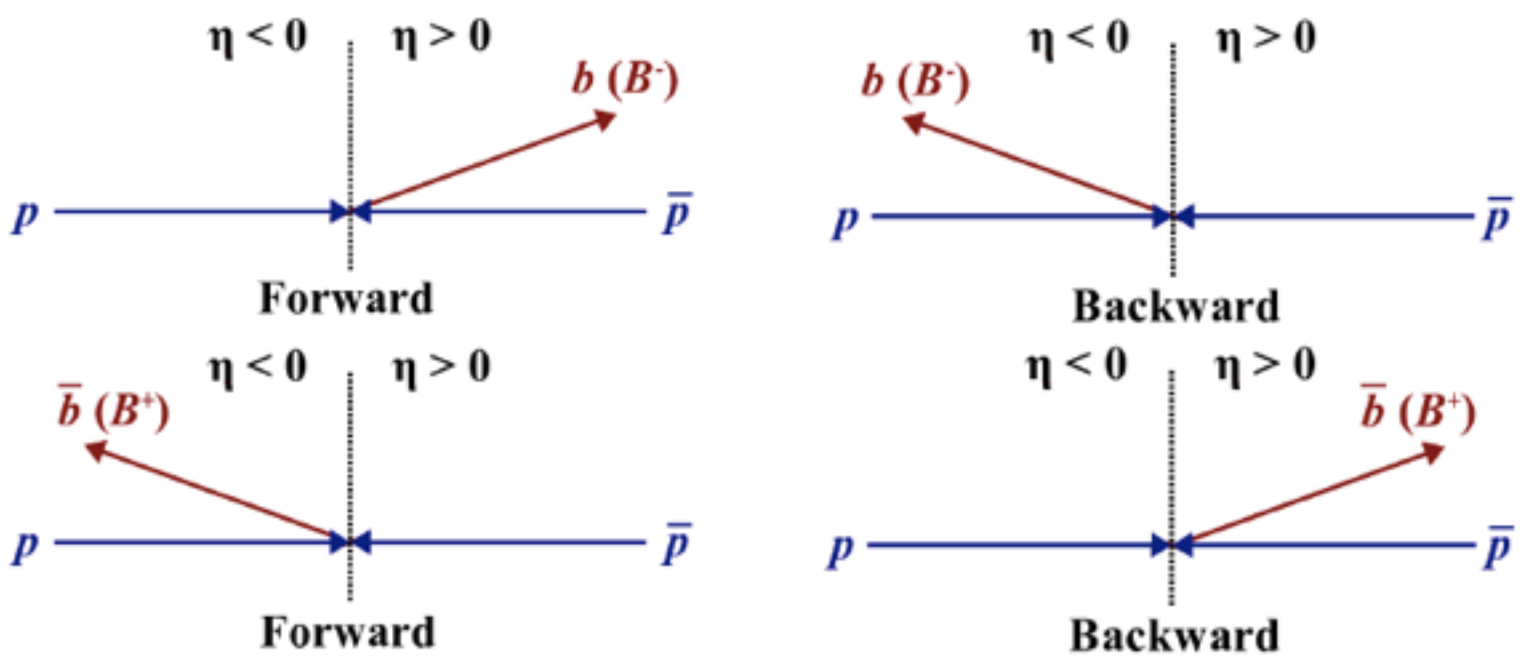
NP in α_W loops
$\Lambda > 1.3 \; 10^4$ TeV

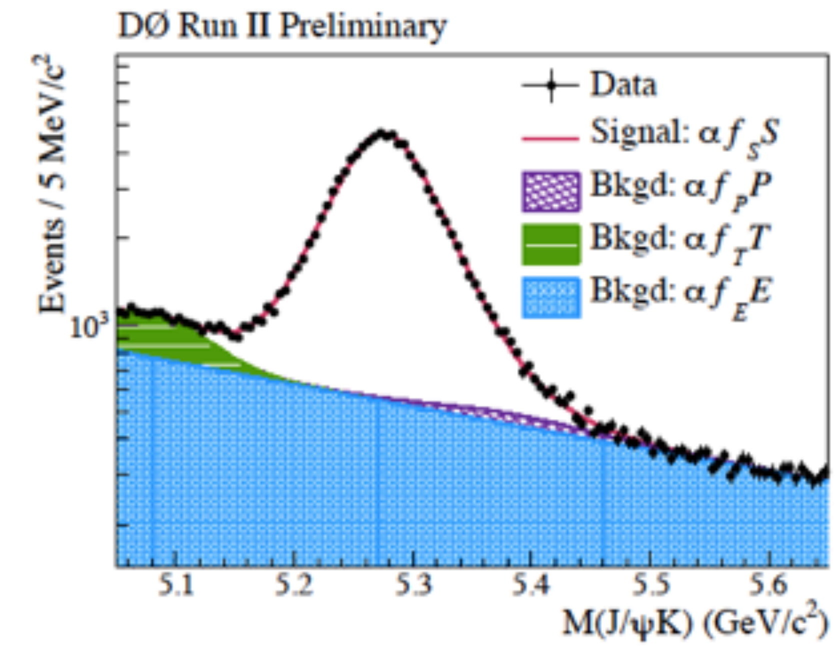
Non-perturbative NP
$\Lambda > 4.2 \; 10^5$ TeV

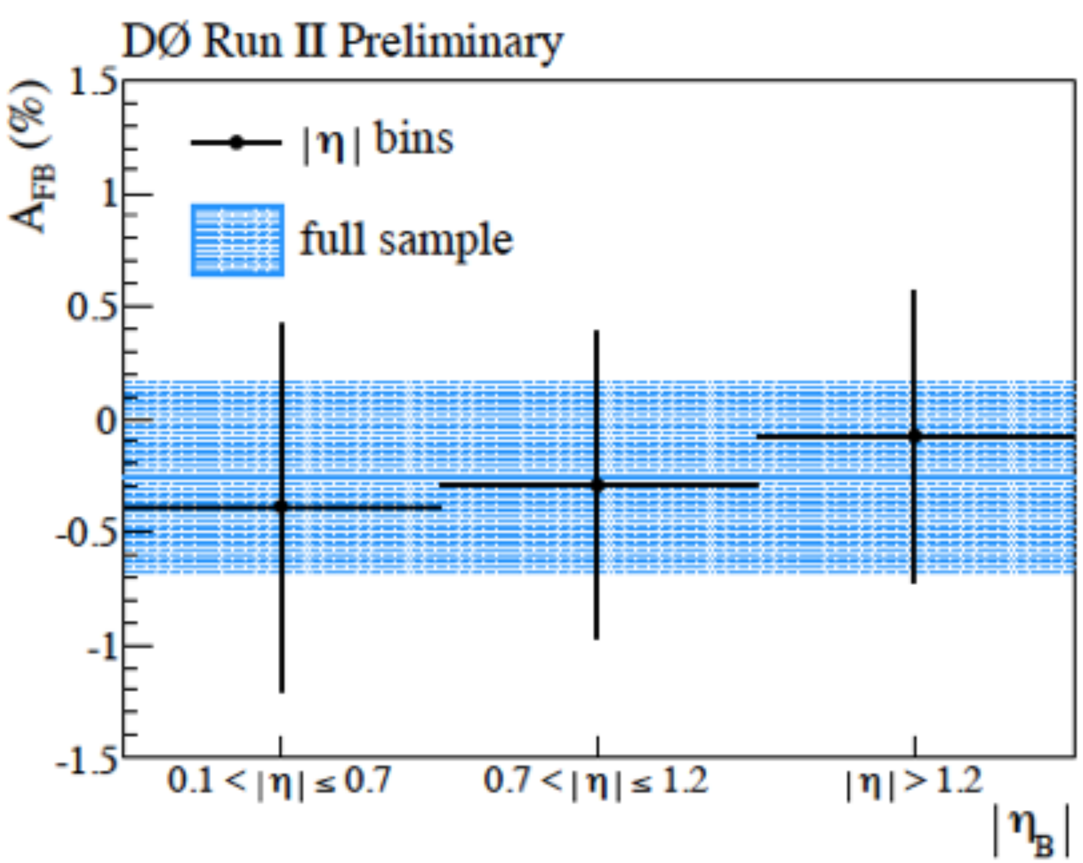
Four busy and rich sessions !
Progress was shown on both experimental and theoretical sides
Unfortunately…
…No clear sign of New Physics…
We can go back home full of Viennese Schnitzel and continue to think about what’s next.

Backup slides

B± F-B Asymmetry   a New Physics probe







$$A_{FB} = [-0.26 \pm 0.41 \pm 0.17]\,\%$$

Comparison with MC@NLO

$$A_{\mathrm{MC@NLO}} = [1.63 \pm 0.43 \pm X.XX]\,\%$$

Iain