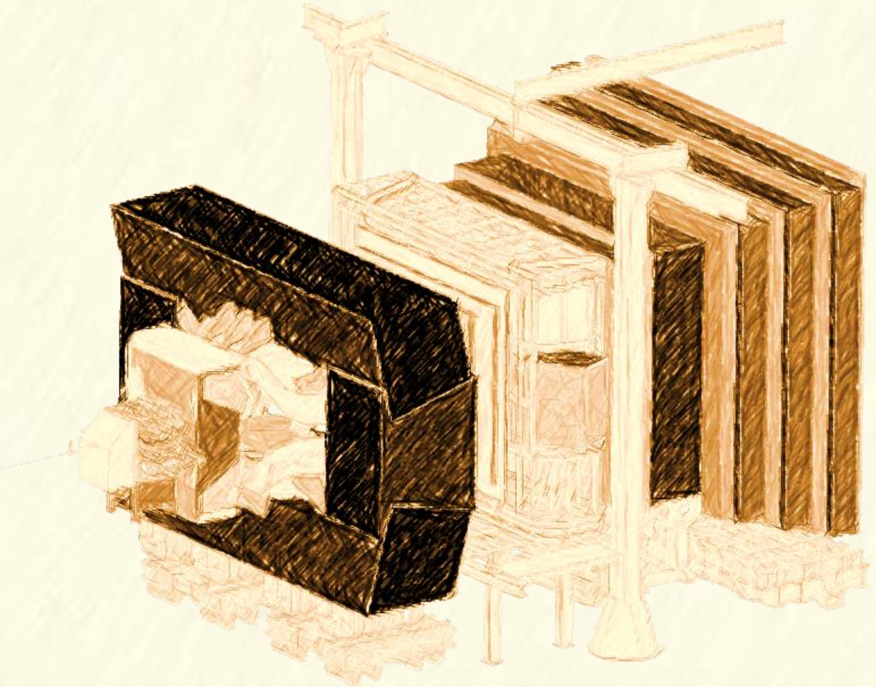
Latest results on ϕ_s

Diego Martínez Santos
(on behalf of LHCb collaboration)

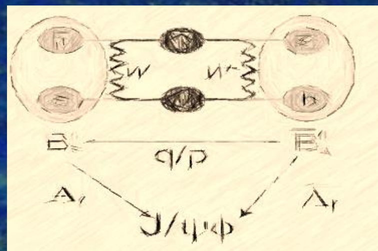
LHCb Implications workshop.
October 15th, 2014

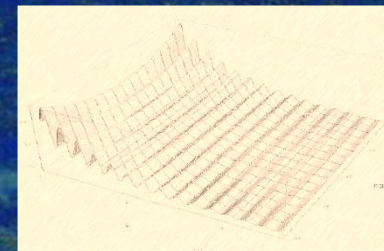
Introduction

- ϕ_s results from LHCb

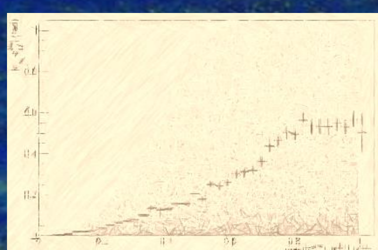


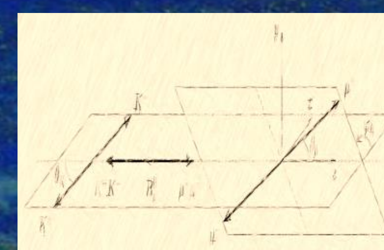
  - Introduction
  - Analysis overview
  - Results
  - Prospects
  - Results on penguin pollution



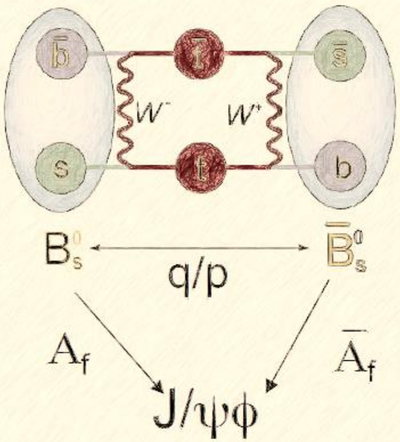


What (and why) Φ_s





Φ_s from $B_s \rightarrow J/\psi$ ($\rightarrow\mu\mu$) KK



B_s mass eigenstates:

$$|B_L^s\rangle = p|B_s\rangle + q|\bar{B}_s\rangle$$
$$|B_H^s\rangle = p|B_s\rangle - q|\bar{B}_s\rangle$$

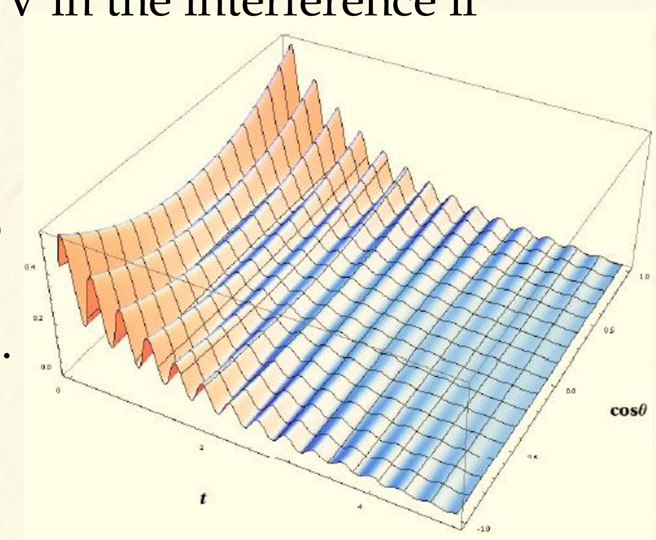
Weak eigenstates (mix via box diagram)

- q/p: complex number. |q/p| ≠ 1 → CPV in mixing
- $A_f, \overline{A_f}$ complex amplitudes. $|A_f/\overline{A_f}| \neq 1$ → CPV in decay

Even if not CPV in mixing or decay, you can generate CPV in the interference if

$$\sin(\phi_s) \equiv \sin\left(-arg\left(\frac{q}{p}\frac{A_f}{\overline{A_f}}\right)\right) \neq 0$$

Main (but not only) experimental signature of a non-zero ϕ_s: it generates **wiggles** in the time-dependent angular distribution of the $B_s \rightarrow J/\psi\ \phi \rightarrow \mu\mu KK$ final state particles. The frequency of the (potential) wiggles is known: Δm_s.



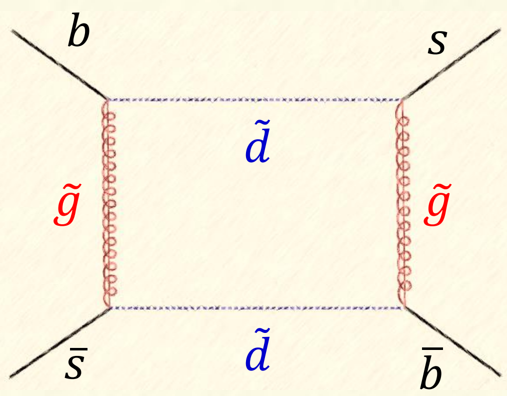
$$|\lambda| \equiv \left|\frac{q}{p}\frac{A_f}{\overline{A_f}}\right| \sim 1$$

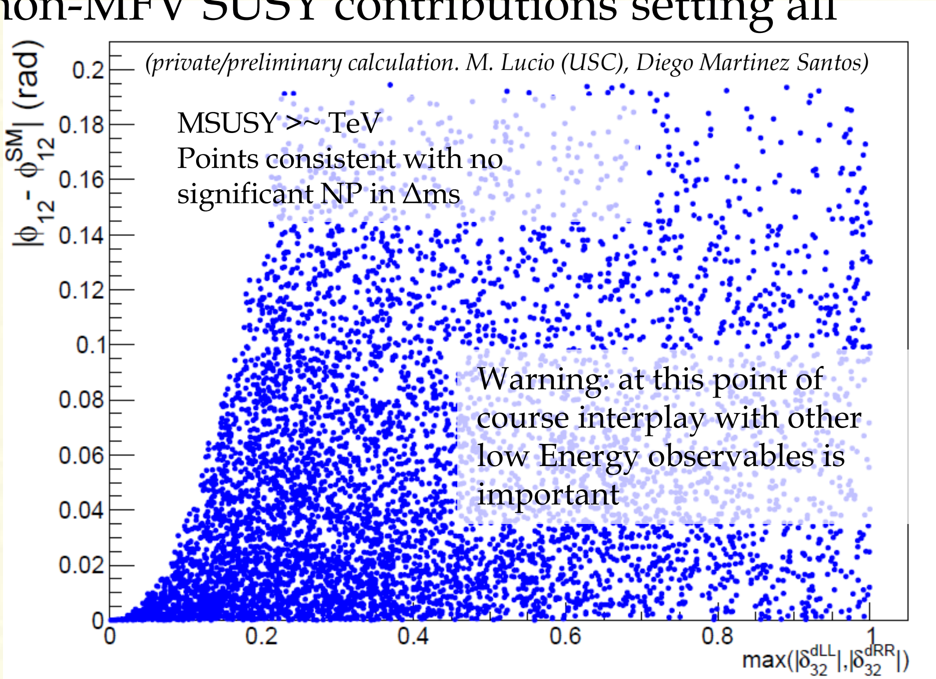
Φ_s : Standard Model and New Physics sensitivity

SM prediction: $\Phi s = -2\arg\left(-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right)$ = -0.0363±0.0013(*) (*)Neglecting penguin contributions.

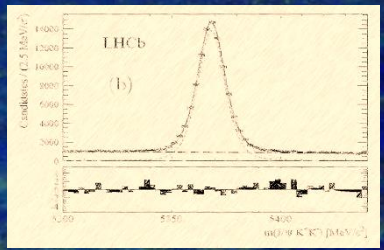
It is very precise, and sensitive to Physics Beyond the SM, specially to non–MFV New physics …. which is accessible even if the NP is at a high scales

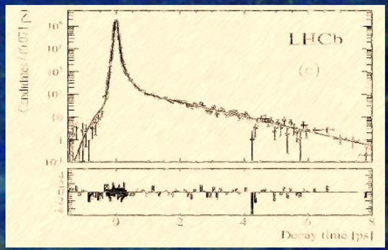
→ Illustrative (brute force) test: calculate non-MFV SUSY contributions setting all particle masses ~10 TeV



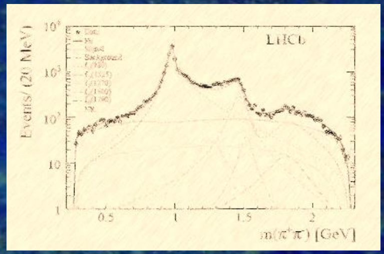


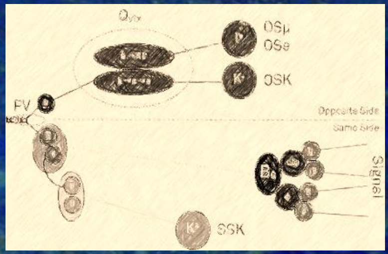
Those potential effects are within reach of current experimental precision!


LHCb
(b)


LHCb
(c)
Decay time [ps]

Analysis

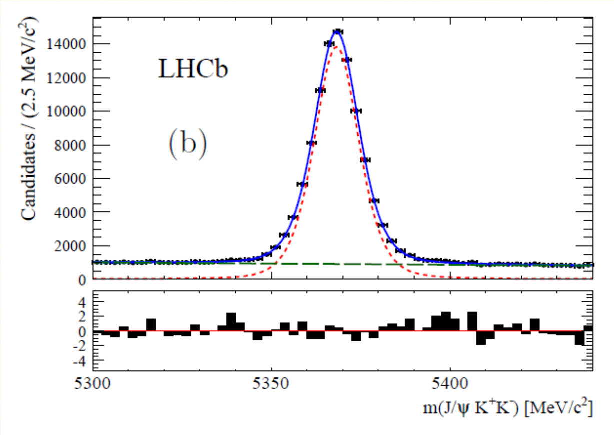

LHCb
Events/ (20 MeV)
m(π⁺π⁻) [GeV]


OSμ
OSe
OSK
PV
Opposite Side
Same Side
Signal
SSK

Φ_s from $B_s \rightarrow J/\psi\ (\rightarrow\mu\mu)\ KK$

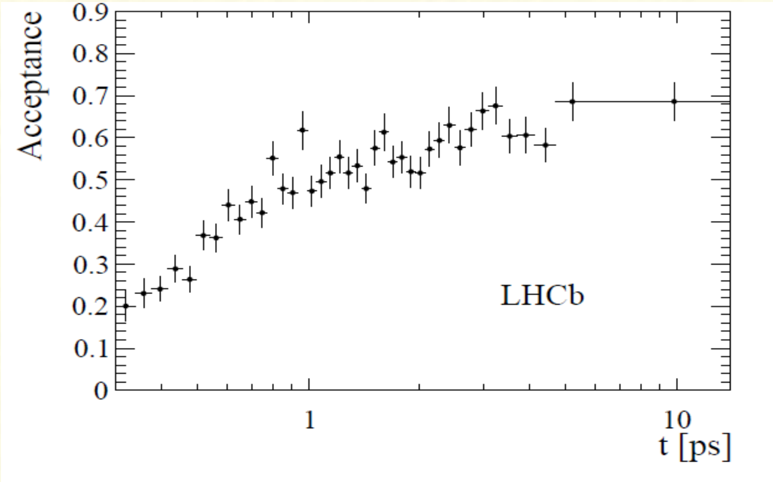
Analysis strategy: Fit the time dependent angular distribution, considering experimental effects:

- **Background**: Events are weighted according to position in J/ψKK mass spectrum



- Angular distributions are distorted on data because of **non-flat angular acceptance**. Simulation (weighted according to kinematics seen on data) is used to correct for this

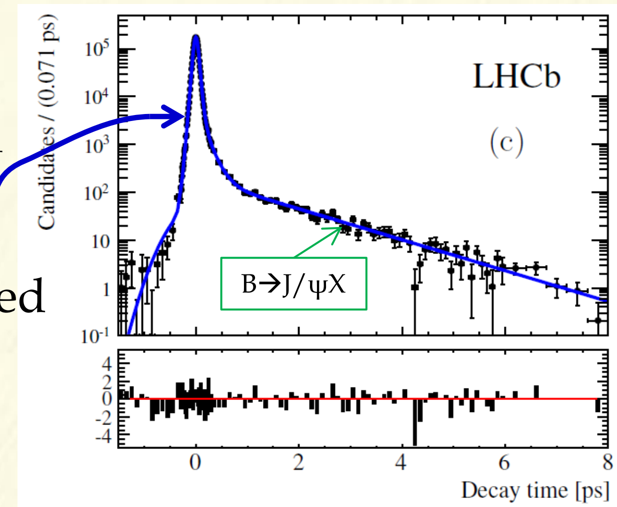
- **Lifetime acceptance**. Samples from different trigger lines are used to unfold trigger biases. Per event weights are used to correct for track reconstruction biases

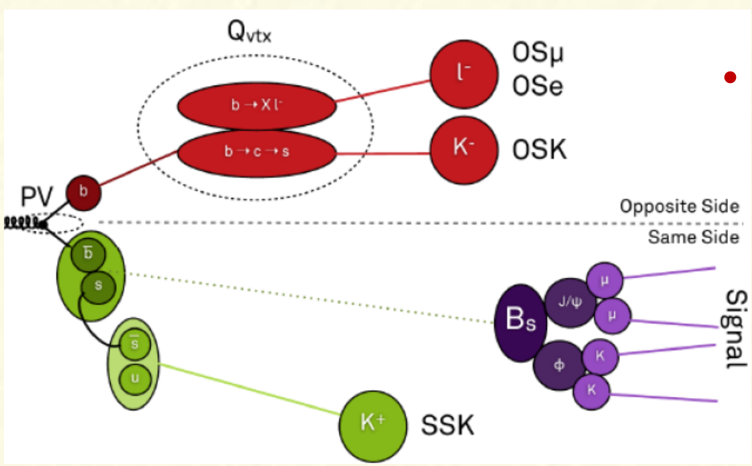


Φ_s from $B_s \to J/\psi\ (\rightarrow \mu\mu)\ KK$

Analysis strategy: Fit the time dependent angular distribution, considering experimental effects:

- **Lifetime resolution**: Non-perfect time resolution (46 fs, still much smaller than oscillation period, 350 fs) convolved with the pdf. Main effect is a ~25% dilution of the amplitude of the wiggles. Measured on data using prompt J/ψ events



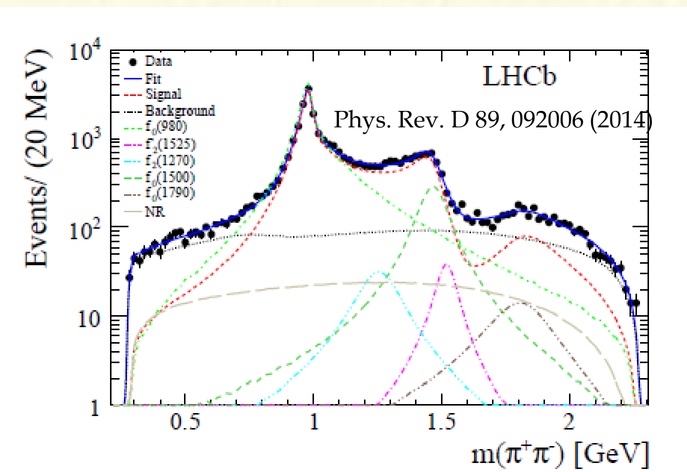


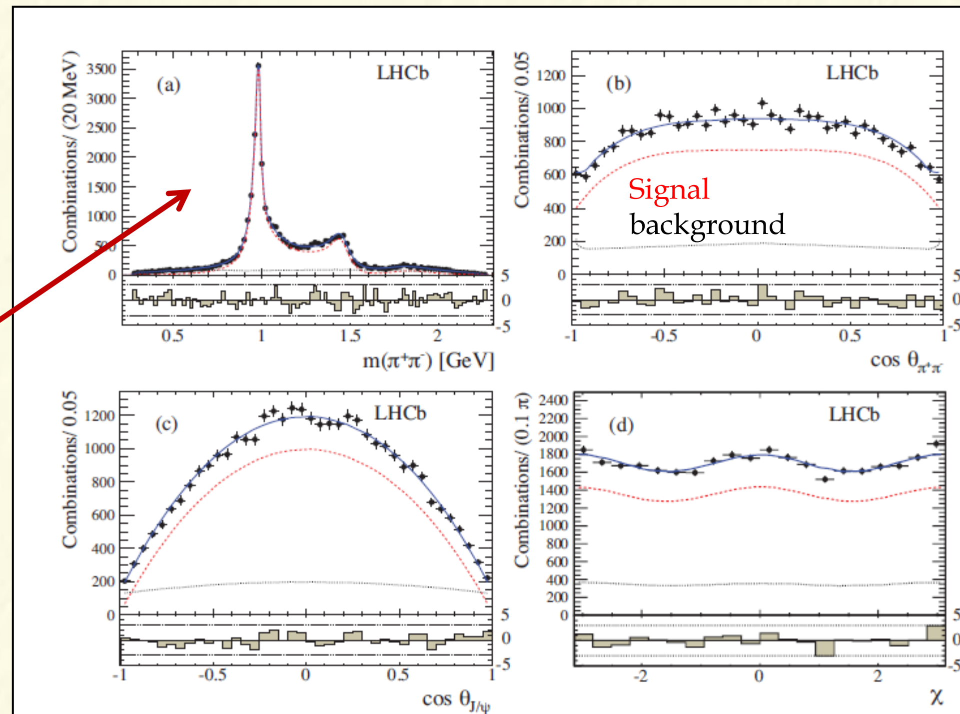
- **Flavour tagging**: The initial flavour of the B_s is determined either by a lepton/kaon from the other B, and/or by a kaon from the fragmentation. The performance of these taggers is calibrated with control samples such as $B^+ \to J/\psi K^+$, $B_d \to D^{*+}\mu\upsilon$ and $B_s \to D_s^- \pi^+$

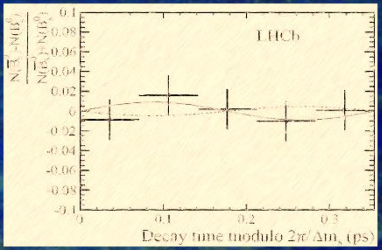
Φ_s from $B_s \to J/\psi\ (\rightarrow \mu\mu)\ \pi\pi$

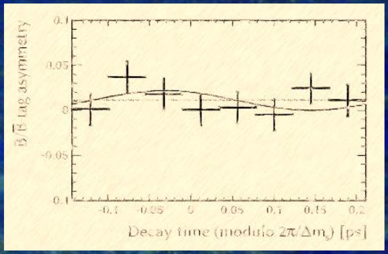
arXiv:1405.4140
Physics Letters B, 736, (2014) 186

- Similar analysis methodology than $B_s \to J/\psi KK$. Some differences:
  - Deal with several $\pi^+\pi^-$ resonances (implies a time dependent Dalitz analysis)
  - Almost no sensitivity to $\Delta\Gamma_s$ → less sensitive to decaytime acceptance

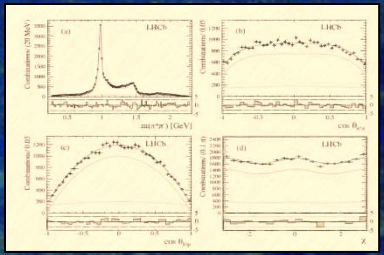


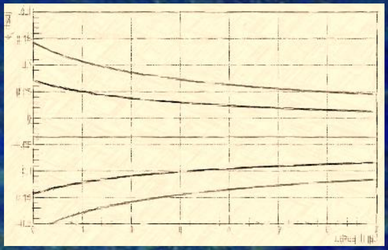






Results and prospects





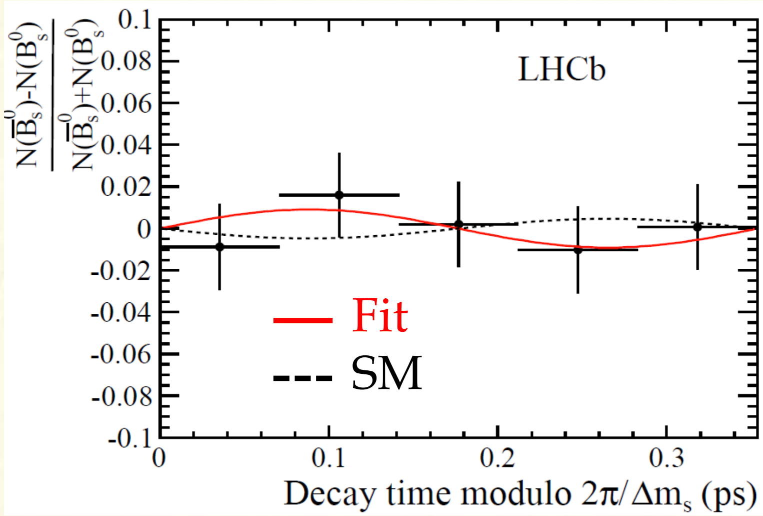
Φ_s from $B_s \to J/\psi$ (→μμ) hh

arXiv:1405.4140
Physics Letters B, 736, (2014) 186

ϕ_s ($B_s \to J/\psi\pi\pi$), $3fb^{-1}$

0.070±0.068±0.008 rad

SM prediction: $\Phi s = -2\arg\left(-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right)$ = -0.0363±0.0013(*)



NIKHEF

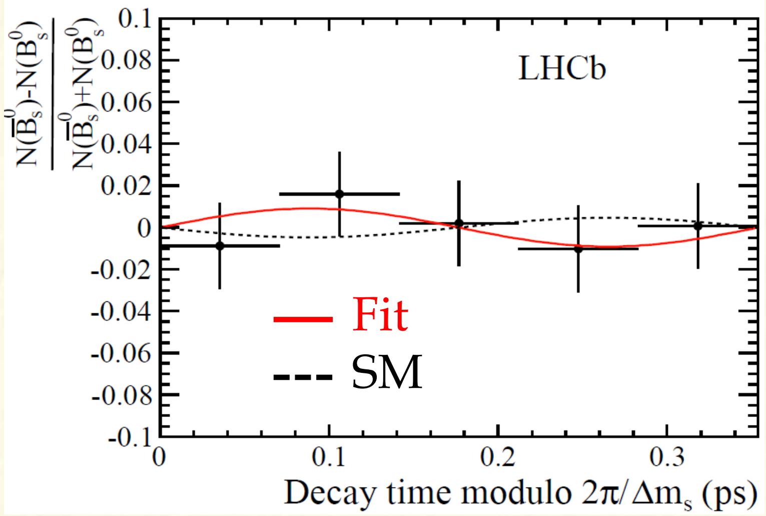
Φ_s from $B_s \rightarrow J/\psi$ ($\rightarrow\mu\mu$) hh

arXiv:1405.4140
Physics Letters B, 736, (2014) 186

ϕ_s ($B_s \rightarrow J/\psi\pi\pi$), 3fb^{-1}

0.070±0.068±0.008 rad

SM prediction: $\Phi s = -2\arg\left(-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right)$ = -0.0363±0.0013(*)

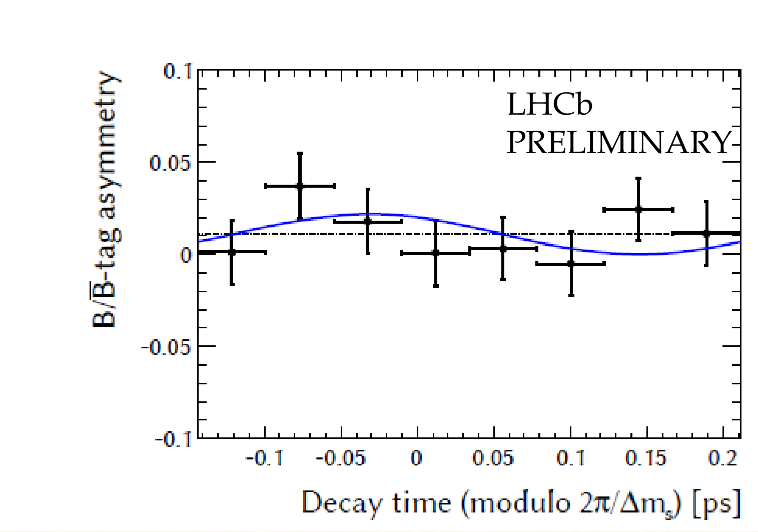


ϕ_s ($B_s \rightarrow J/\psi KK$), 3fb^{-1}

-0.058±0.049±0.006 rad

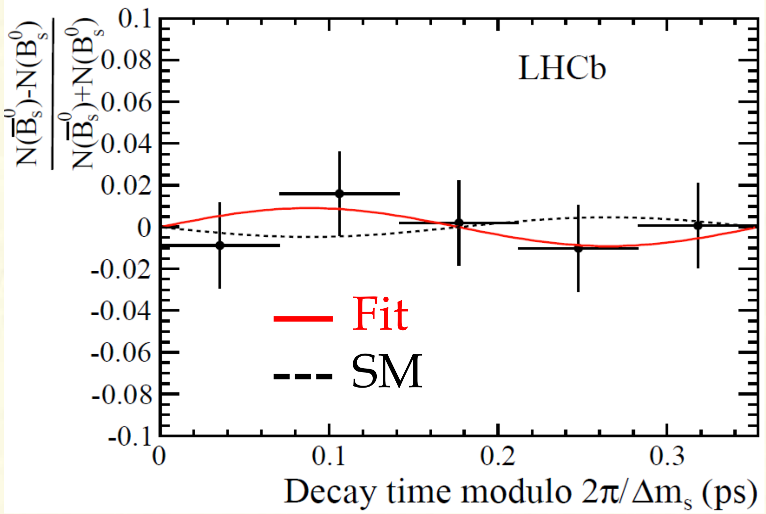
NEW

LHCB-PAPER-2014-059
In preparation



Φ_s from $B_s \to J/\psi$ (→μμ) hh

arXiv:1405.4140
Physics Letters B, 736, (2014) 186



ϕ_s ($B_s \to J/\psi\pi\pi$), $3fb^{-1}$

0.070±0.068±0.008 rad

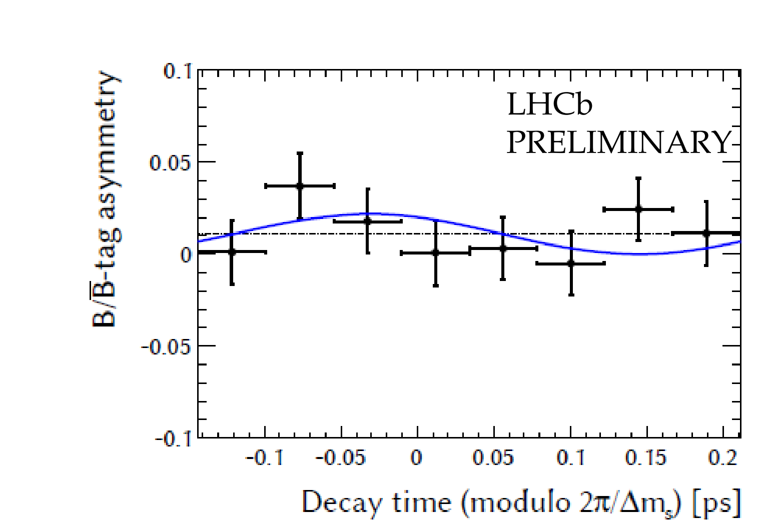
SM prediction: $\Phi s = -2\arg\left(-\frac{V_{cb}V_{cs}^*}{V_{tb}V_{ts}^*}\right) = -0.0363 \pm 0.0013^{(*)}$

ϕ_s ($B_s \to J/\psi KK$), $3fb^{-1}$

-0.058±0.049±0.006 rad

NEW

LHCB-PAPER-2014-059
In preparation



Combined, $3fb^{-1}$

$$\phi_s = -0.010 \pm 0.040 \text{ rad}$$

Other observables from $B_s \to J/\psi\ KK$

LHCB-PAPER-2014-059
In preparation

Observable	value
Γ_s [ps^{-1}]	$0.6603 \pm 0.0027 \pm 0.0015$
$\Delta\Gamma_s$ [ps^{-1}]	$0.0805 \pm 0.0091 \pm 0.0033$
$\|\lambda\|$	$0.964 \pm 0.019 \pm 0.007$
$\|\lambda\|$ (*combined w/ ππ*)	0.957 ± 0.017

NEW

(world's most precise measurements of basic B_s physics observables)

Other observables from $B_s \to J/\psi KK$

LHCB-PAPER-2014-059
In preparation

Observable	value
Γ_s [ps^{-1}]	0.6603 ± 0.0027 ± 0.0015
$\Delta\Gamma_s$ [ps^{-1}]	0.0805 ± 0.0091 ± 0.0033
$\lvert\lambda\rvert$	0.964 ± 0.019 ± 0.007
$\lvert\lambda\rvert$ (*combined w/ ππ*)	0.957±0.017

NEW

(world's most precise measurements of basic B_s physics observables)

First polarization dependent results (to study penguin pollutions)

NEW

Observable	value	Observable	value
$\lvert\lambda_0\rvert$	1.012 ± 0.058 ± 0.013	Φ_0	-0.045 ± 0.053 ± 0.006
$\lvert\lambda_{\parallel}/\lambda_0\rvert$	0.97 ± 0.16 ± 0.01	$\Phi_{\parallel}-\Phi_0$	-0.018 ± 0.043 ± 0.009
$\lvert\lambda_{\perp}/\lambda_0\rvert$	1.02 ± 0.12 ± 0.05	$\Phi_{\perp}-\Phi_0$	-0.014 ± 0.035 ± 0.006
$\lvert\lambda_S/\lambda_0\rvert$	0.86 ± 0.12 ± 0.03	$\Phi_S-\Phi_0$	0.015 ± 0.061 ± 0.021

Everything compatible with no polarization dependence

Φ_s in other channels

In addition to $B_s \to J/\psi KK$ and $B_s \to J/\psi\pi\pi$ LHCb measured Φs in $B_s \to D_s D_s$:

$$\phi_s = 0.02 \pm 0.17\,(\text{stat}) \pm 0.02\,(\text{syst})\,\text{rad}, \qquad |\lambda| = 0.91\,^{+0.18}_{-0.15}\,(\text{stat}) \pm 0.02\,(\text{syst})$$

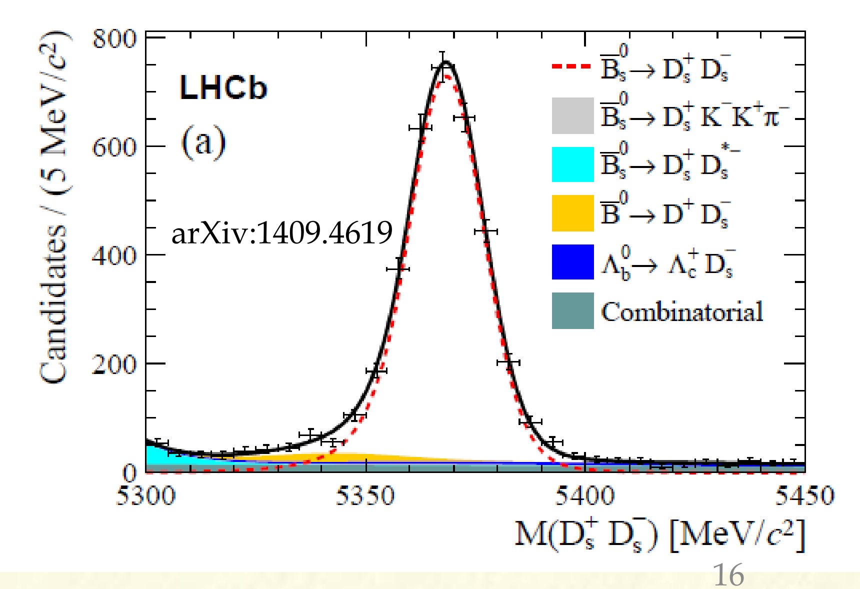
arXiv:1409.4619

See M.Jung's talk at 12.05: https://indico.cern.ch/event/324660/session/4/contribution/43

And also plans to:

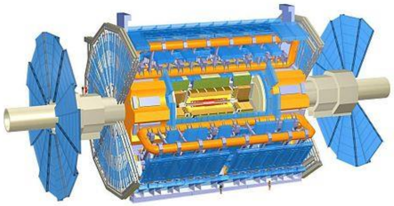
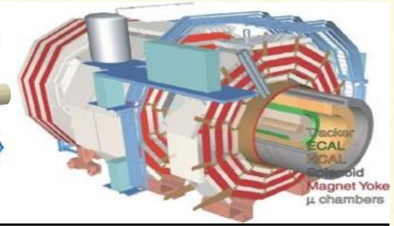
- $B_s \to \psi(2S)KK$ (~10% of the statistics power of $B_s \to J/\psi KK$)
- $B_s \to J/\psi KK$ (high KK mass)
- $B_s \to J/\psi KK$ with the J/ψ going to electrons

Altogether could give an extra ~25 % reduction of the uncertainty in Φ_s



Φ_s (ATLAS/CMS)

ATLAS and CMS also study
$B_s \rightarrow J/\psi\ \phi \rightarrow \mu\mu KK$

Experiment		
Lumi. (fb^{-1})	4.9	20.0
$\Delta\Gamma_s$ (ps^{-1})	0.053±0.021±0.010	0.096±0.014±0.007
Φ_s (rad)	0.12±0.25±0.05 arxiv.org/abs/1407.1796	-0.03±0.11±0.03 CMS-PAS-BPH-13-012

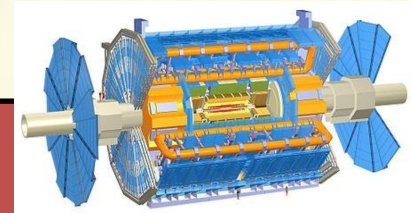
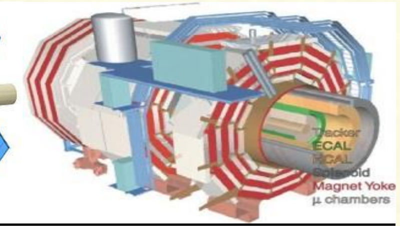
Φ_s (world average)

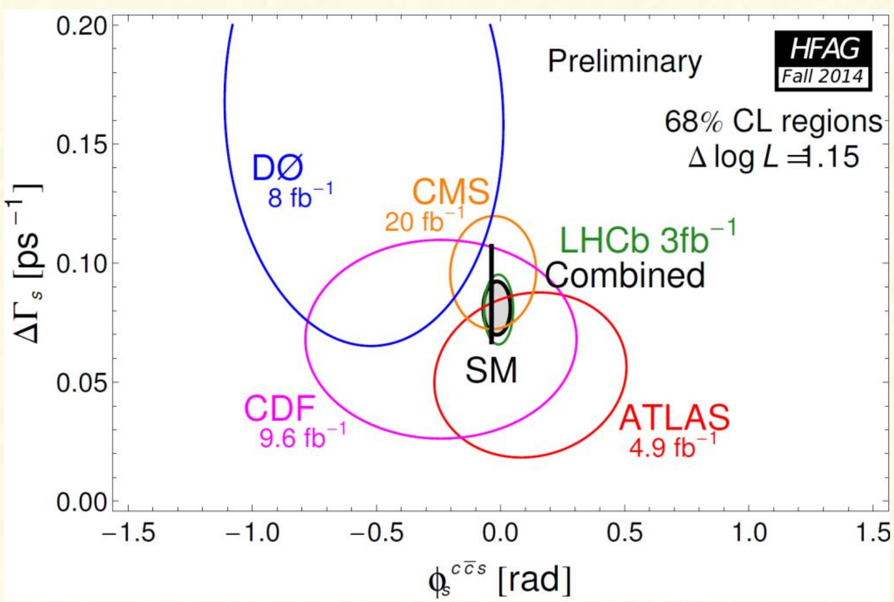
ATLAS and CMS also study $B_s \rightarrow J/\psi\ \phi \rightarrow \mu\mu KK$

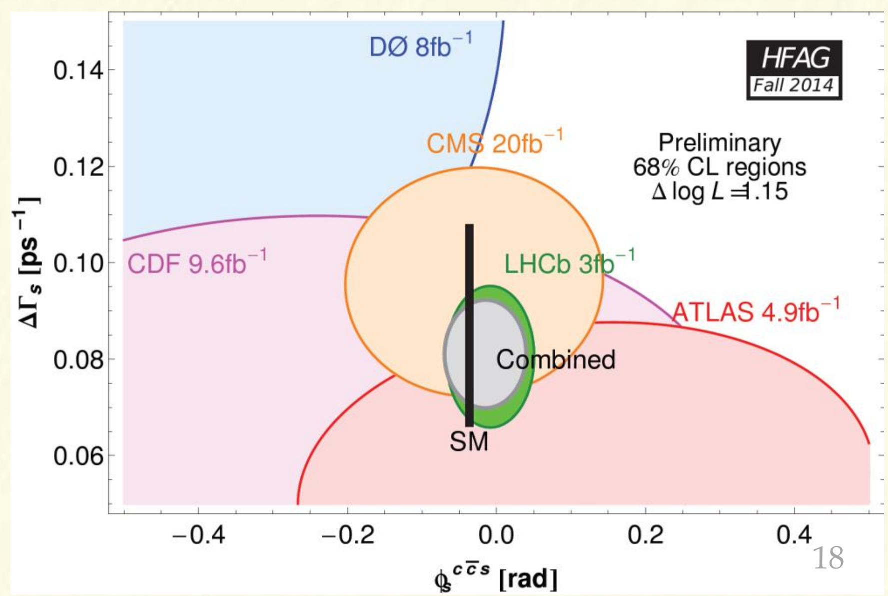
HFAG private/unofficial world average yields

HFAG world average, unofficial

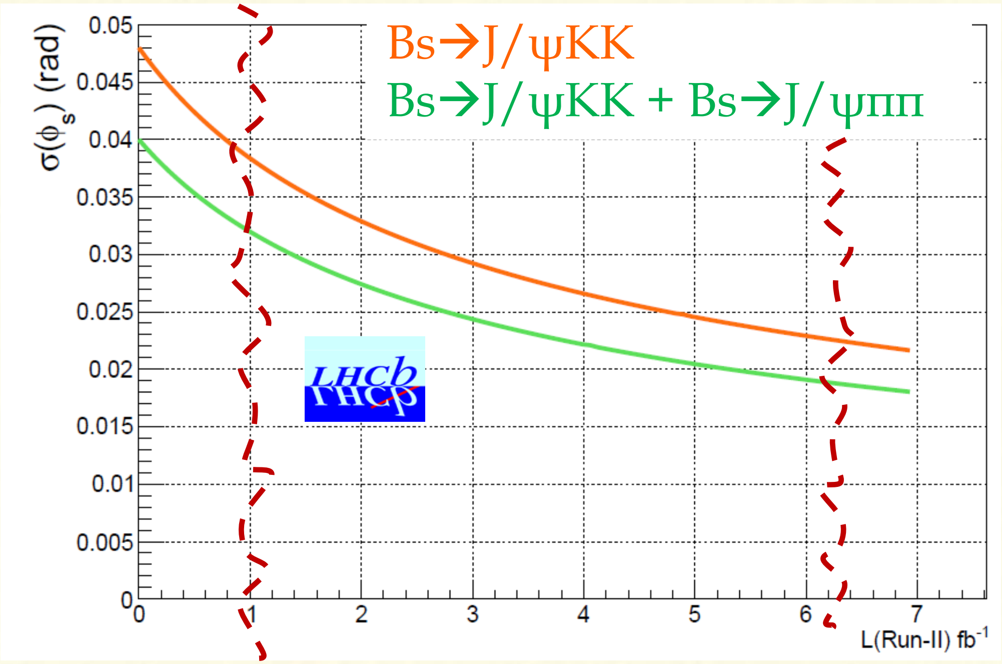
$\phi_s = -0.015 \pm 0.036$ rad

Experiment		
Lumi. (fb^{-1})	4.9	20.0
$\Delta\Gamma_s$ (ps^{-1})	0.053±0.021±0.010	0.096±0.014±0.007
Φ_s (rad)	0.12±0.25±0.05 arxiv.org/abs/1407.1796	-0.03±0.11±0.03 CMS-PAS-BPH-13-012





Prospects

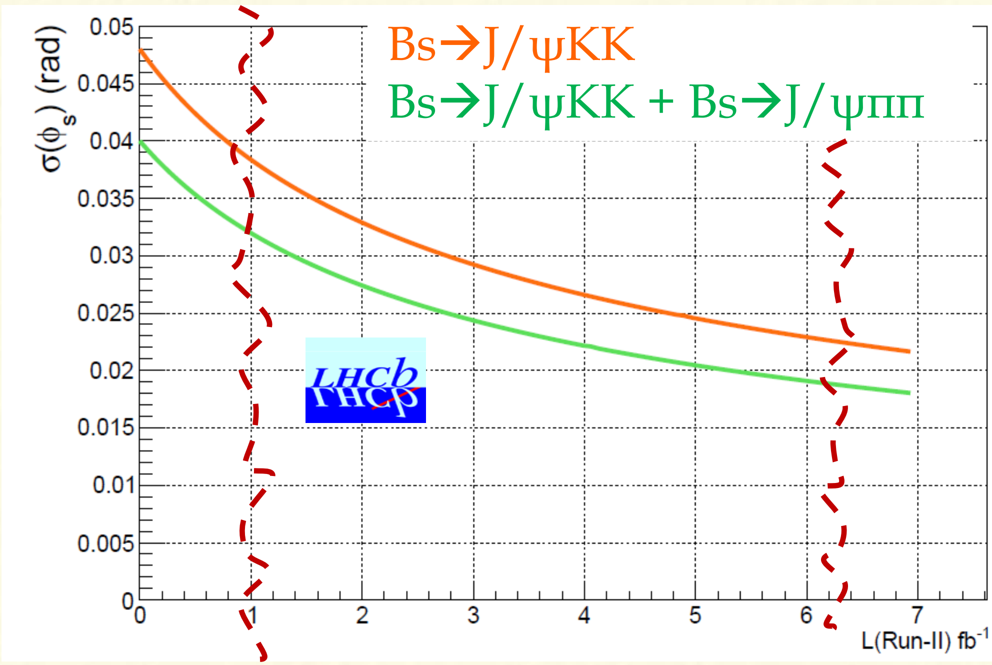


~2016

~ end of Run-II

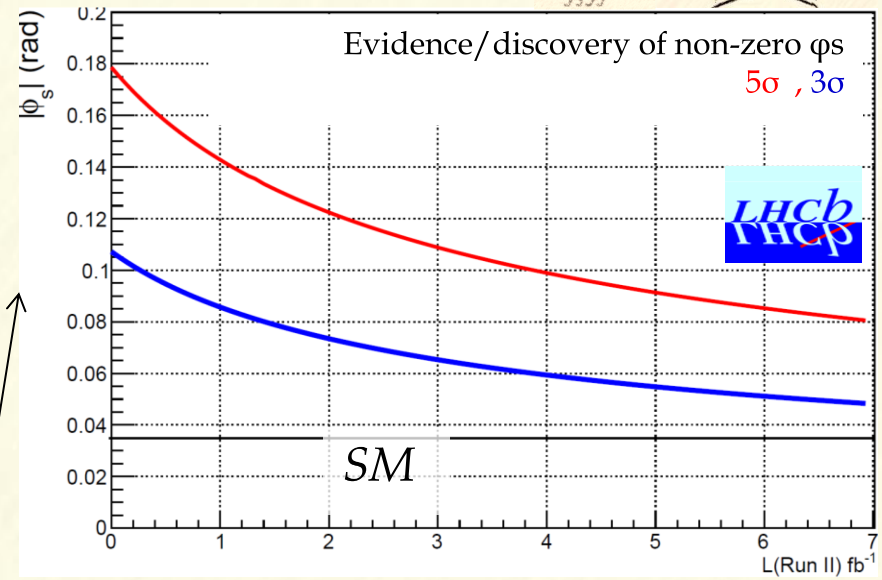
… and with LHCb upgrade the sensitivity can go below 0.01 rad

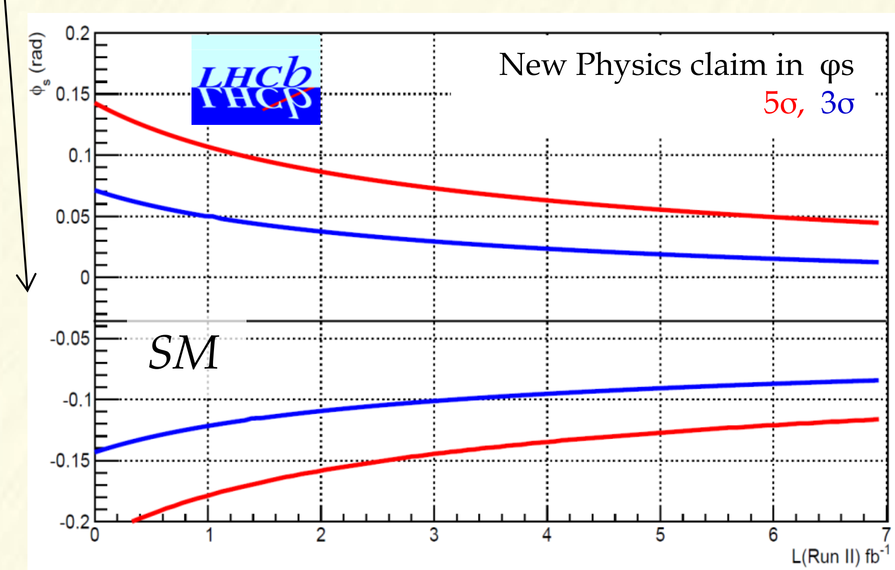
Prospects



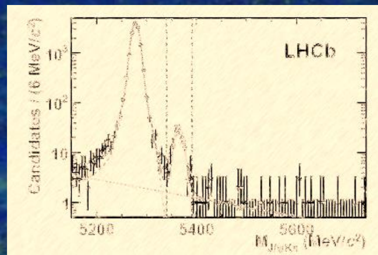
~2016

~ end of Run-II

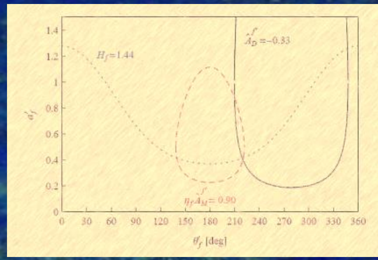


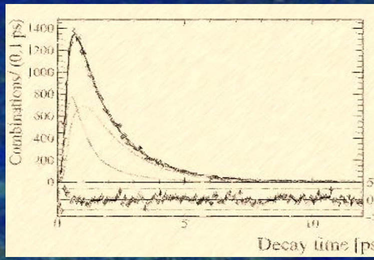


… and with LHCb upgrade the sensitivity can go below 0.01 rad



Penguin Pollutions

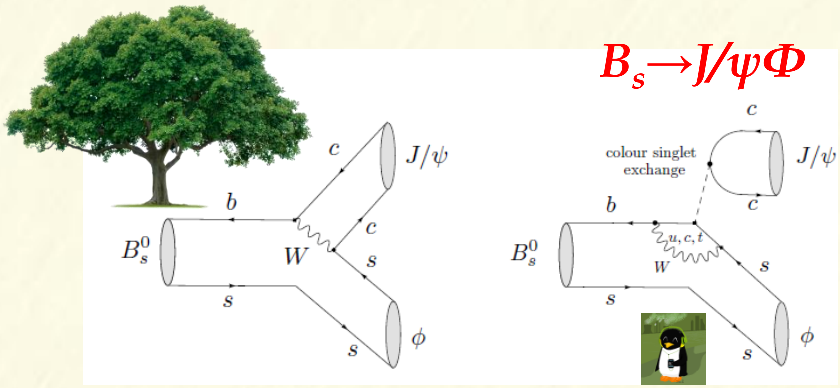


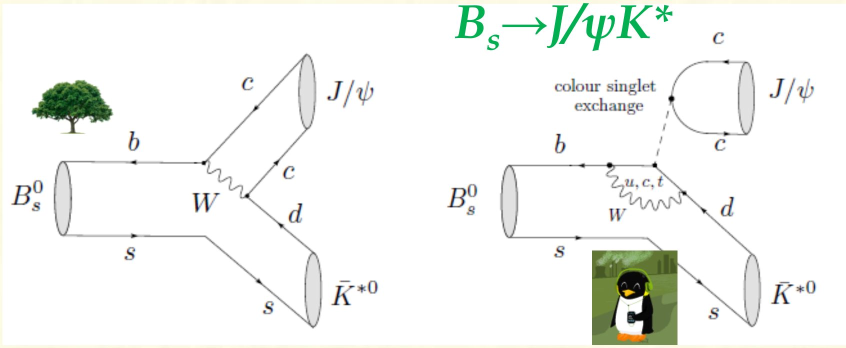


Penguin pollution

Source: google penguin pollution

- Penguin contributions to Φ_s , are usually neglected because they are doubly Cabibbo supressed.
- However, these contributions cannot be calculated reliably from QCD
- S. Faller, R. Fleischer, T. Mannel arXiv:0810.4248 [hep-ph] propose a method to calculate the penguin pollution to Φ_s by analysing $B \rightarrow J/\psi\rho$ and/or $B_s \rightarrow J/\psi K^*$ data





Penguin pollution

LHCb-PAPER-2014-058
In preparation

$B \to J/\psi\rho$ analysed full dataset

$$\Gamma(t) = \mathcal{N} e^{-\Gamma_d t}\left\{\frac{|\mathcal{A}|^2+|\overline{\mathcal{A}}|^2}{2}+\frac{|\mathcal{A}|^2-|\overline{\mathcal{A}}|^2}{2}\cos(\Delta m_d t)-\mathcal{I}m(\mathcal{A}^*\overline{\mathcal{A}})\sin(\Delta m_d t)\right\}$$

$$\overline{\Gamma}(t) = \mathcal{N} e^{-\Gamma_d t}\left\{\frac{|\mathcal{A}|^2+|\overline{\mathcal{A}}|^2}{2}-\frac{|\mathcal{A}|^2-|\overline{\mathcal{A}}|^2}{2}\cos(\Delta m_d t)+\mathcal{I}m(\mathcal{A}^*\overline{\mathcal{A}})\sin(\Delta m_d t)\right\}$$

- CPV in time dependent Dalitz analysis, measure an effective 2β, $2\beta^{eff}$

$\mathcal{A} \equiv \sum_i A_i$ (sum over $\pi^+\pi^-$ resonant transversity amplitudes)

Using formalism PLB, 719, 383 (2013)

$$\lambda_i \equiv \frac{q}{p}\frac{\overline{A}_i}{A_i} \qquad 2\beta_i^{\rm eff} \equiv -\arg(\eta_i\lambda_i)$$

Penguin info

$$|\lambda_f|e^{-i2\beta_f^{\rm eff}} = \frac{1-a'_f e^{i\theta'_f}e^{-i\gamma}}{1-a'_f e^{i\theta'_f}e^{i\gamma}}e^{-i2\beta}$$

$$\beta \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right)$$

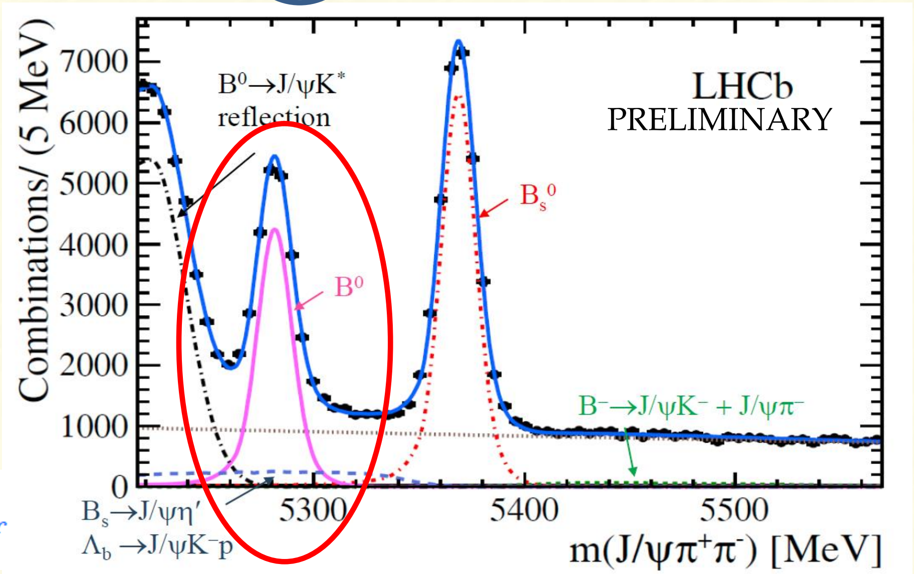
$$\Delta 2\beta_f \equiv 2\beta_f^{\rm eff} - 2\beta$$

- Apply SU(3) symmetry ($\theta' \to \theta$, $a' \to -\epsilon a$) to convert result into estimate of penguin pollution in Φ_s or $2\beta^{\psi K_s}$

$$\delta_P = -\arg\left(\frac{1+\epsilon a_f e^{i\theta_f}e^{-i\gamma}}{1+\epsilon a_f e^{i\theta_f}e^{i\gamma}}\right)$$

$\epsilon = |V_{us}|^2/(1-|V_{us}|^2) = 0.0534$

$$\delta_P \approx -\epsilon\,\Delta 2\beta_f$$



Penguin pollution

LHCb-PAPER-2014-058
In preparation

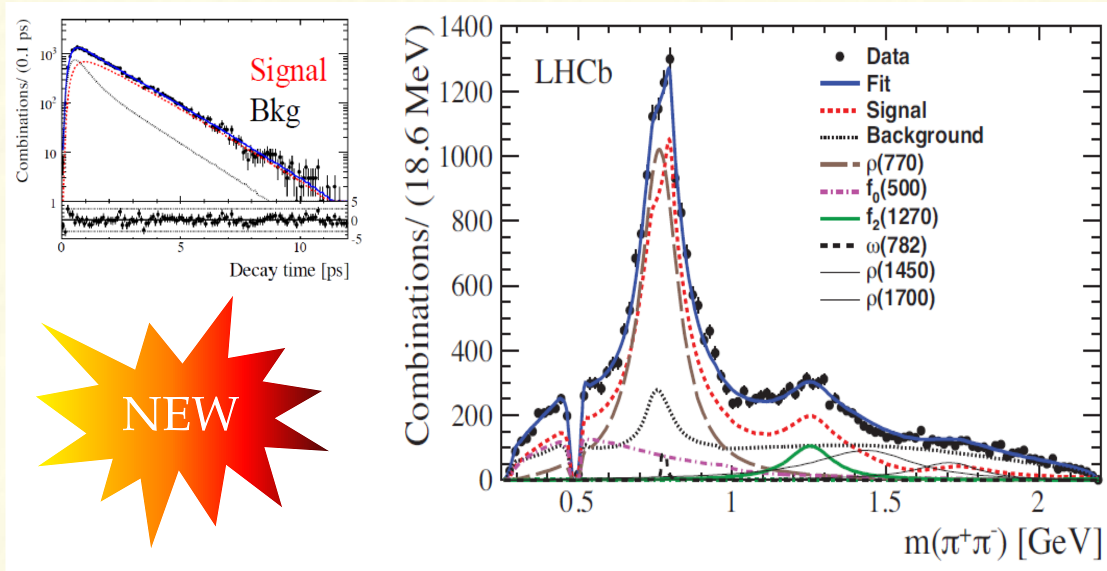
$B \rightarrow J/\psi\rho$ analysed full dataset

Obtained:

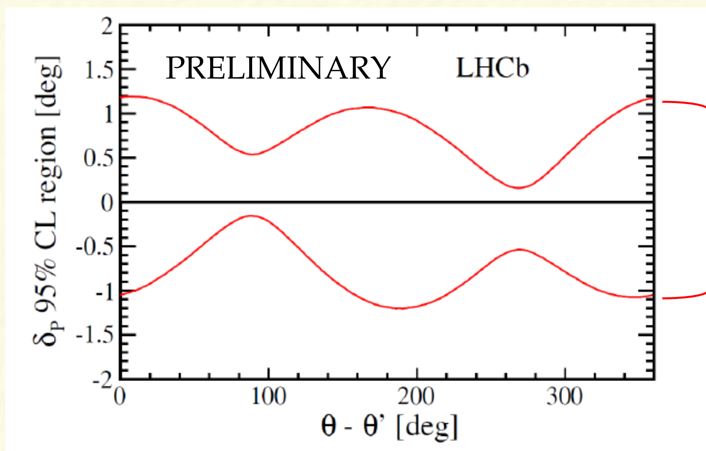
$|\delta_P| < 0.02$ rad @ 95% CL

(half of the uncertainty on Φ_s)

- The above limit depends linearly on SU(3) breaking factor a/a’
- Consistent with theory estimations



PRELIMINARY

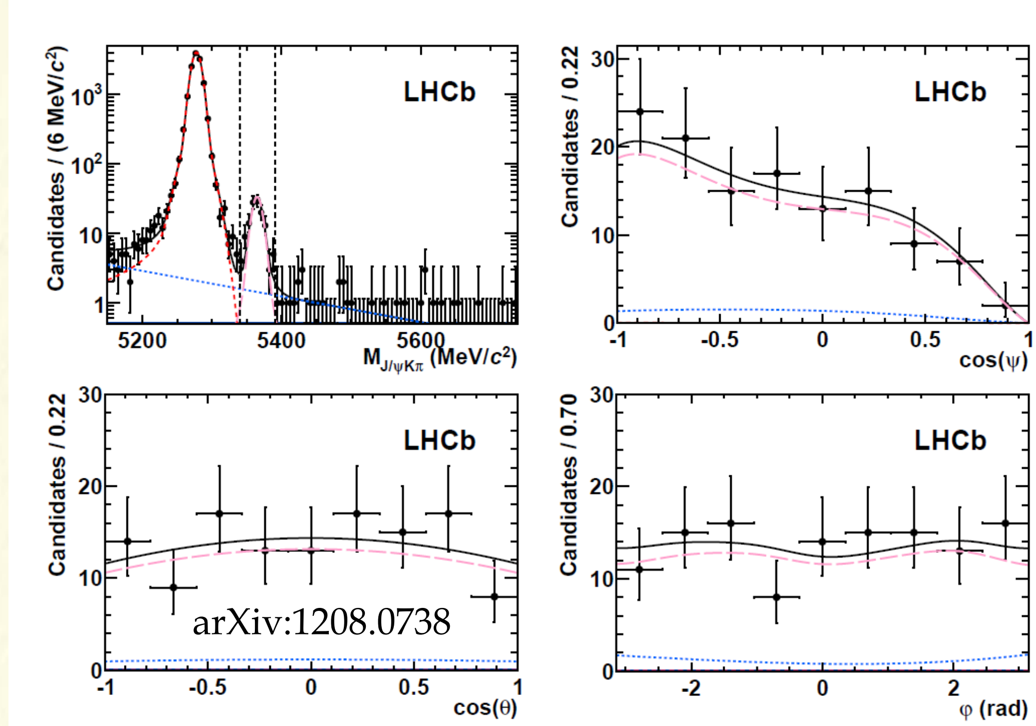


Scales linearly with SU(3) breaking factor a/a’

Penguin pollution

$B_s \rightarrow J/\psi K^*$ experimental status

- Analysed with 370pb^{-1}
- Branching fraction
- Polarization amplitudes



$$f_L = 0.50 \pm 0.08 \pm 0.02$$

$$f_{\parallel} = 0.19^{+0.10}_{-0.08} \pm 0.02$$

$$\frac{BR(B_s \to J/\psi \bar{K}^{*0})}{BR(B_d \to J/\psi K^{*0})} = (3.43^{+0.34}_{-0.36} \pm 0.50)\%$$

$$\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0}) = (4.4^{+0.5}_{-0.4} \pm 0.8) \times 10^{-5}$$

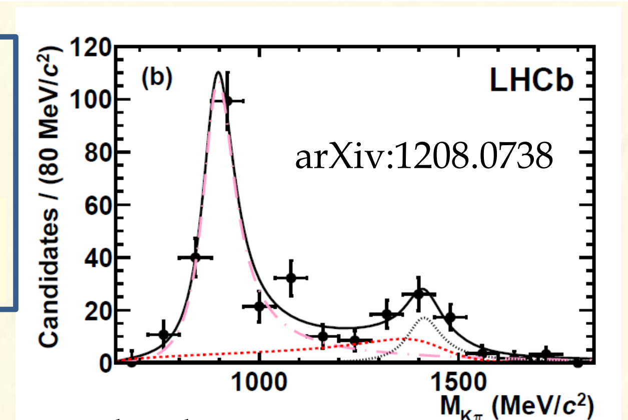
SM expectations

arXiv:1309.0313 [hep-ph]

$$\left[50.9^{+4.2}_{-4.5}\right]\%$$

$$\left[29.1^{+2.4}_{-2.6}\right]\%$$

$$\frac{BR(B_s \to J/\psi \bar{K}^{*0})}{BR(B_d \to J/\psi K^{*0})} \approx 0.0333$$



Expected similar penguin sensitivity than J/ψππ, but depends on central values

Conclusions

- New Φ_s result presented, in excellent agreement with the Standard Model

$$\phi_s = -0.010 \pm 0.040 \text{ rad}$$ *(preliminary)*

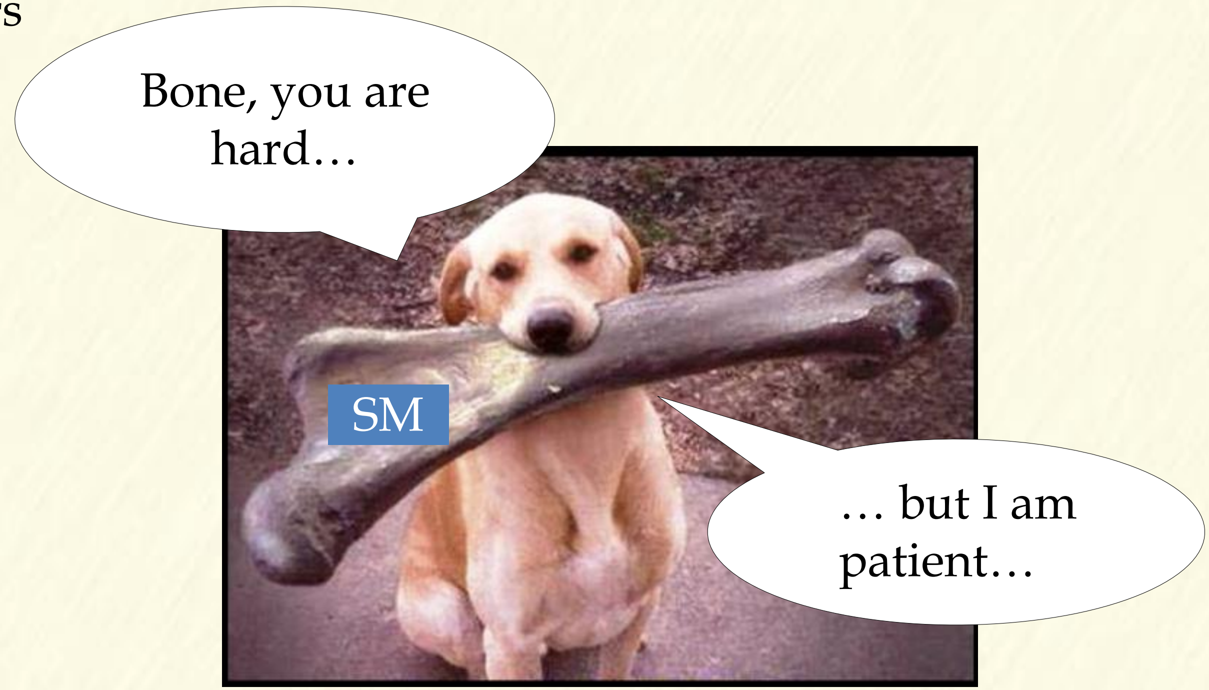
Conclusions

- New Φ_s result presented, in excellent agreement with the Standard Model

$$\phi_s = -0.010 \pm 0.040 \text{ rad}$$ *(preliminary)*

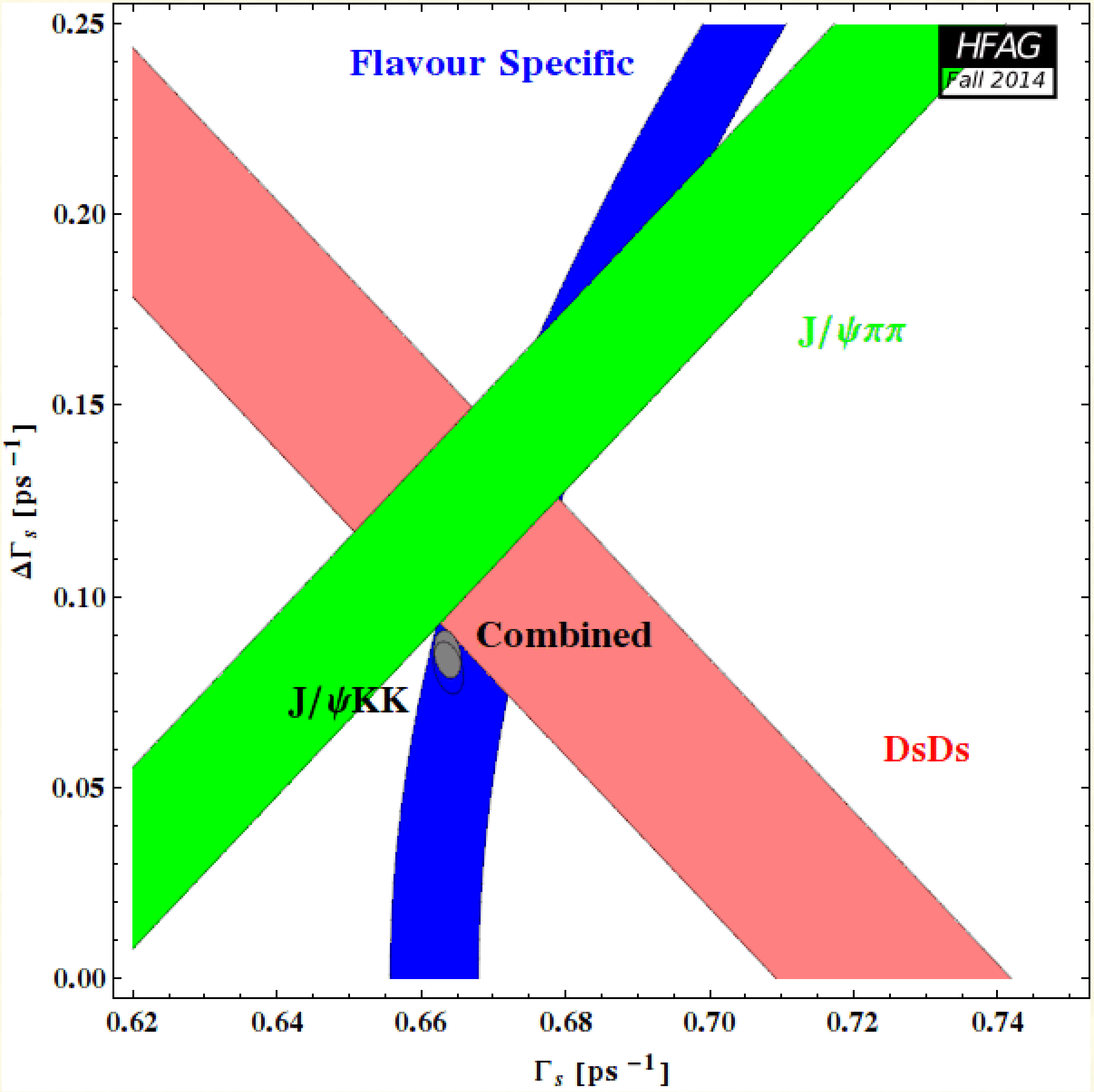
- Precision can improve to <0.02 rad in Run-II, and <0.01 rad with LHCb upgrade

- Excellent experimental sensitivity to penguin contamination, need theory input for SU(3) factors



source: google osso duro

Component	Fit fraction (%)	Transversity fractions (%)		
		0	$\parallel$	$\perp$
$\rho(770)$	65.6 ± 1.9	56.7 ± 1.8	23.5 ± 1.5	19.8 ± 1.7
$f_0(500)$	20.1 ± 0.7	1	0	0
$f_2(1270)$	7.8 ± 0.6	64 ± 4	9 ± 5	27 ± 5
$\omega(782)$	$0.64^{+0.19}_{-0.13}$	44 ± 14	53 ± 14	3^{+10}_{-3}
$\rho(1450)$	9.0 ± 1.8	47 ± 11	39 ± 12	14 ± 8
$\rho(1700)$	3.1 ± 0.7	29 ± 12	42 ± 15	29 ± 15



Flavour Specific
HFAG
Fall 2014
J/ψππ
Combined
J/ψKK
DsDs
ΔΓs [ps −1]
Γs [ps −1]
0.00
0.05
0.10
0.15
0.20
0.25
0.62
0.64
0.66
0.68
0.70
0.72
0.74

$\phi_s^{\phi\phi}$ from $B_s \to \phi\phi$

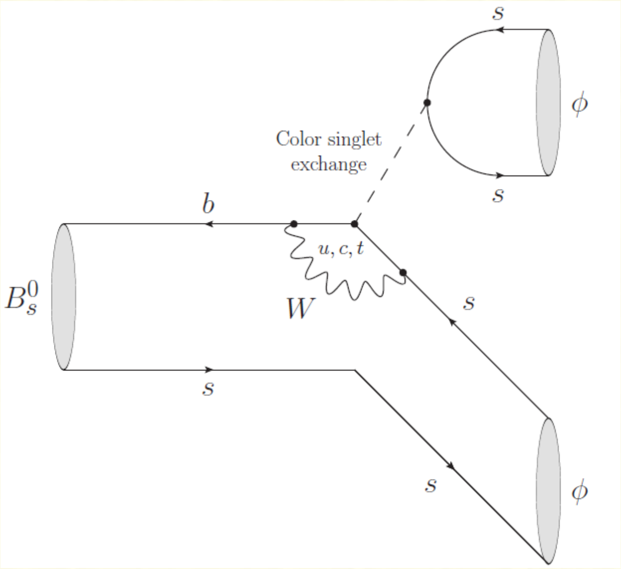
arxiv:1407.2222

$$\phi_s^{\phi\phi} \equiv arg\left(\frac{q}{p}\frac{A(\overline{B_s} \to \phi\phi)}{A(B_s \to \phi\phi)}\right)$$

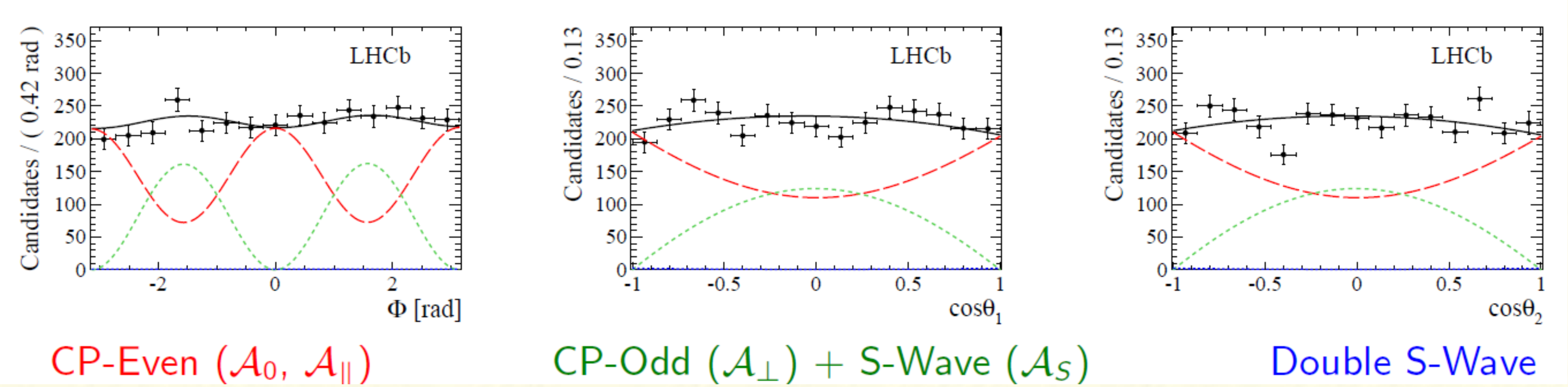
different quantity than the Φs I presented at the beginning of my talk

SM expectation is $\phi_s^{\phi\phi} < 0.02$

arXiv:0810.0249
arXiv:hep-ph/0612290
arXiv:0910.5237



Also measured through time dependent angular analysis. We have analysed the full 3 fb^{-1} dataset:



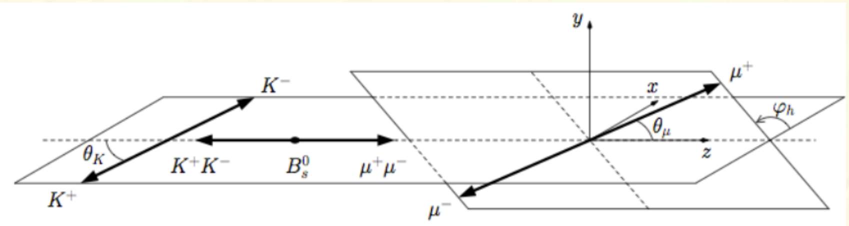
$$\phi_s^{\phi\phi} = -0.17 \pm 0.15 \pm 0.03$$

In very good agreement with SM

Φ_s from $B_s \to J/\psi\ (\rightarrow \mu\mu)\ \pi\pi$

Sources	ϕ_s(mrad)
Decay time acceptance	±0.6
Mass acceptance	±0.3
Background time PDF	±0.2
Background mass distribution PDF	±0.6
Resonance model	±6.0
Resonance parameters	±0.7
Other fixed parameters	±0.4
Production asymmetry	±5.8
Total	±8.4

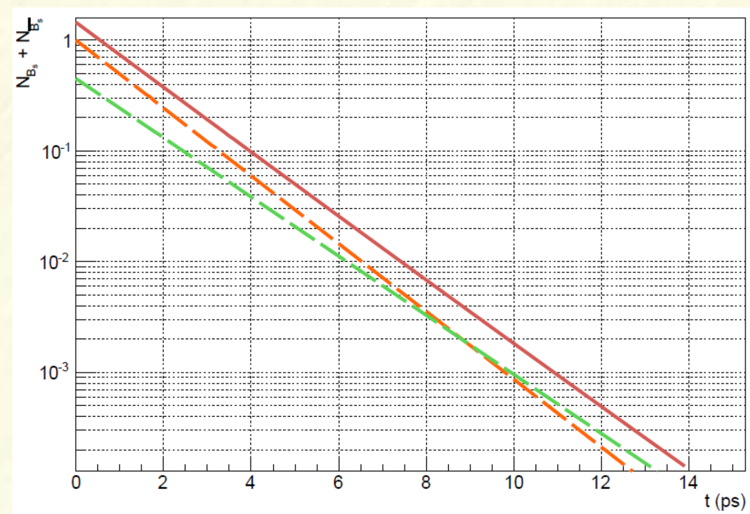
Φ_s from $B_s \rightarrow J/\psi\ (\rightarrow\mu\mu)\ KK$



wiggles

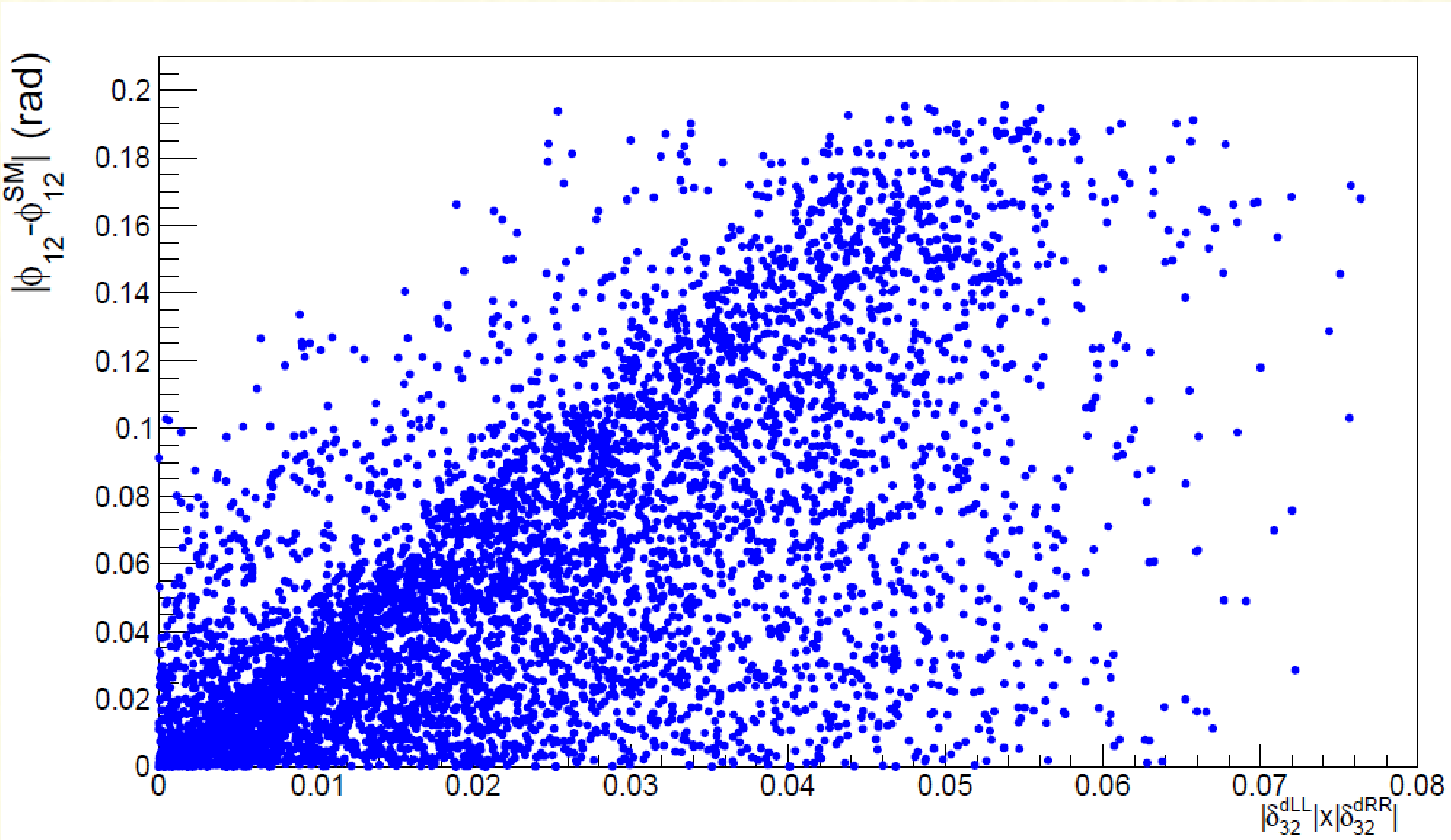
$$
\begin{aligned}
|A_0|^2(t) &= |A_0|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right],\\
|A_\parallel(t)|^2 &= |A_\parallel|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) + \sin\phi_s \sin(\Delta m t)\right],\\
|A_\perp(t)|^2 &= |A_\perp|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t)\right],\\
\Im(A_\parallel(t)\,A_\perp(t)) &= |A_\parallel||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_\parallel)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.\\
&\quad \left. -\cos(\delta_\perp - \delta_\parallel)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_\parallel)\cos(\Delta m t)\right],\\
\Re(A_0(t)\,A_\parallel(t)) &= |A_0||A_\parallel| e^{-\Gamma_s t}\cos(\delta_\parallel - \delta_0)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) - \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.\\
&\quad \left. + \sin\phi_s \sin(\Delta m t)\right],\\
\Im(A_0(t)\,A_\perp(t)) &= |A_0||A_\perp| e^{-\Gamma_s t}\left[-\cos(\delta_\perp - \delta_0)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.\\
&\quad \left. -\cos(\delta_\perp - \delta_0)\cos\phi_s \sin(\Delta m t) + \sin(\delta_\perp - \delta_0)\cos(\Delta m t)\right],\\
|A_s(t)|^2 &= |A_s|^2 e^{-\Gamma_s t}\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin\phi_s \sin(\Delta m t\right],\\
\Re(A_s^*(t)A_\parallel(t)) &= |A_s||A_\parallel| e^{-\Gamma_s t}\left[-\sin(\delta_\parallel - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right) - \sin(\delta_\parallel - \delta_s)\cos\phi_s \sin(\Delta m t)\right.\\
&\quad \left. + \cos(\delta_\parallel - \delta_s)\cos(\Delta m t)\right],\\
\Im(A_s^*(t)A_\perp(t)) &= |A_s||A_\perp| e^{-\Gamma_s t}\sin(\delta_\perp - \delta_s)\left[\cosh\left(\frac{\Delta\Gamma}{2}t\right) + \cos\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.\\
&\quad \left. - \sin\phi_s \sin(\Delta m t)\right],\\
\Re(A_s^*(t)A_0(t)) &= |A_s||A_0| e^{-\Gamma_s t}\left[-\sin(\delta_0 - \delta_s)\sin\phi_s \sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.\\
&\quad \left. - \sin(\delta_0 - \delta_s)\cos\phi_s \sin(\Delta m t) + \cos(\delta_0 - \delta_s)\cos(\Delta m t)\right].
\end{aligned}
$$

Apart from the wiggles, there are other terms in the pdf that have some sensitivity to Φs:



Φ_s from $B_s \to J/\psi$ ($\to\mu\mu$) KK

Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	$\lvert A_\perp\rvert^2$	$\lvert A_0\rvert^2$	$\delta_\parallel$ [rad]	$\delta_\perp$ [rad]	ϕ_s [rad]	$\lvert\lambda\rvert$	Δm_s [ps^{-1}]
Total stat. uncertainty	0.0027	0.0091	0.0049	0.0034	$^{+0.10}_{-0.17}$	$^{+0.14}_{-0.15}$	0.049	0.019	$^{+0.055}_{-0.057}$
Mass factorisation	–	0.0007	0.0031	0.0064	0.05	0.05	0.002	0.001	0.004
Signal weights (stat.)	0.0001	0.0008	–	0.0001	–	–	–	–	–
Resonant background	0.0001	0.0004	0.0004	0.0002	0.02	0.02	0.002	0.003	0.001
B_c^+ background	0.0005	–	–	–	–	–	–	–	–
Angular resolution bias	–	–	0.0006	0.0001	$^{+0.02}_{-0.03}$	0.01	–	–	–
Ang. efficiency (reweighting)	0.0001	–	0.0011	0.0020	0.01	–	0.001	0.005	0.002
Ang. efficiency (stat.)	0.0001	0.0002	0.0011	0.0004	0.02	0.01	0.004	0.002	0.001
Decay time resolution	–	–	–	–	–	0.01	0.002	0.001	0.005
Trigger efficiency (stat.)	0.0011	0.0009	–	–	–	–	–	–	–
Track reconstruction (simul.)	0.0007	0.0029	0.0005	0.0006	$^{+0.01}_{-0.02}$	0.002	0.001	0.001	0.006
Track reconstruction (stat.)	0.0005	0.0002	–	–	–	–	–	–	0.001
Length and momentum scales	0.0002	–	–	–	–	–	–	–	0.005
S-P coupling factors	–	–	–	–	0.01	0.01	–	0.001	0.002
Fit bias	–	–	0.0005	–	–	0.01	–	0.001	–
Quadratic sum of syst.	0.0015	0.0033	0.0036	0.0067	$^{+0.06}_{-0.07}$	0.06	0.006	0.007	0.011


$|\phi_{12}-\phi_{12}^{SM}|$ (rad)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
$|\delta_{32}^{dLL}|x|\delta_{32}^{dRR}|$

Penguin pollution

arXiv:0810.4248

Mainly two observables:

$$H_f = \frac{1}{\epsilon}\left|\frac{\mathcal{A}_f}{\mathcal{A}'_f}\right|^2 \frac{\Gamma[f,t=0]'}{\Gamma[f,t=0]} = \frac{1-2a'_f\cos\theta'_f\cos\gamma + a'^2_f}{1+2\epsilon a_f\cos\theta_f\cos\gamma+\epsilon^2 a_f^2}$$

F(|V_{us}|)

CKM angle

penguin stuff

f = polarization state

Experimental input. Basically $\frac{(BR\cdot f_f)_{J/\psi K^*}}{(BR\cdot f_f)_{J/\psi\varphi}}$

(modulo lifetimes)

$$\hat{A}_{\mathrm{D}}^{f'} = \frac{2a'_f\sin\theta'_f\sin\gamma}{1-2a'_f\cos\theta'_f\cos\gamma+a'^2_f},$$

Direct CP asymmetry (difference of yields)

Penguin pollution

arXiv:0810.4248

Mainly two observables:

$$H_f = \frac{1}{\epsilon}\left|\frac{\mathcal{A}_f}{\mathcal{A}'_f}\right|^2 \frac{\Gamma[f,t=0]'}{\Gamma[f,t=0]} = \frac{1-2a'_f\cos\theta'_f\cos\gamma+a'^2_f}{1+2\epsilon a_f\cos\theta_f\cos\gamma+\epsilon^2 a_f^2}$$

$F(|V_{us}|)$

CKM angle

penguin stuff

f = polarization state

Experimental input. Basically $\frac{(BR\cdot f_f)_{J/\psi K^*}}{(BR\cdot f_f)_{J/\psi\varphi}}$

(modulo lifetimes)

$$\hat{A}_D^{f'} = \frac{2a'_f\sin\theta'_f\sin\gamma}{1-2a'_f\cos\theta'_f\cos\gamma+a'^2_f},$$

SU(3) → a′ = a, θ′ = θ

Direct CP asymmetry (difference of yields)

…and plug here

$$\tan\Delta\phi_s^f = \frac{2\epsilon a_f\cos\theta_f\sin\gamma+\epsilon^2 a_f^2\sin 2\gamma}{1+2\epsilon a_f\cos\theta_f\cos\gamma+\epsilon^2 a_f^2\cos 2\gamma}$$

Penguin pollution

arXiv:0810.4248

Mainly two observables:

$$H_f \equiv \frac{1}{\epsilon}\left|\frac{\mathcal{A}_f}{\mathcal{A}'_f}\right|^2 \frac{\Gamma[f,t=0]'}{\Gamma[f,t=0]} = \frac{1-2a'_f\cos\theta'_f\cos\gamma+a'^2_f}{1+2\epsilon a_f\cos\theta_f\cos\gamma+\epsilon^2 a^2_f}$$

penguin stuff

This other stuff are SU(3) breaking effects which are currently poorly known

$$\left|\frac{\mathcal{A}'_0}{\mathcal{A}_0}\right|^2 = 0.42 \pm 0.27 \,,$$

$$\left|\frac{\mathcal{A}'_\parallel}{\mathcal{A}_\parallel}\right|^2 = 0.70 \pm 0.29 \,,$$

$$\left|\frac{\mathcal{A}'_\perp}{\mathcal{A}_\perp}\right|^2 = 0.38 \pm 0.16 \,.$$

Penguin pollution

arXiv:0810.4248

Mainly two observables:

$$H_f \equiv \frac{1}{\epsilon}\left|\frac{\mathcal{A}_f}{\mathcal{A}'_f}\right|^2 \frac{\Gamma[f,t=0]'}{\Gamma[f,t=0]} = \frac{1-2a'_f\cos\theta'_f\cos\gamma + a'^2_f}{1+2\epsilon a_f\cos\theta_f\cos\gamma+\epsilon^2 a_f^2}$$

penguin stuff

This other stuff are SU(3) breaking effects which are currently poorly known

Or maybe not so poorly?

arXiv:1309.0313 [hep-ph]

arXiv:0810.4248

$$\left|\frac{\mathcal{A}'_0}{\mathcal{A}_0}\right|^2 = 0.42 \pm 0.27\,, \quad \rightarrow \quad = 0.858^{+0.206}_{-0.196}$$

$$\left|\frac{\mathcal{A}'_\parallel}{\mathcal{A}_\parallel}\right|^2 = 0.70 \pm 0.29\,, \quad \rightarrow \quad = 0.845^{+0.210}_{-0.188}$$

$$\left|\frac{\mathcal{A}'_\perp}{\mathcal{A}_\perp}\right|^2 = 0.38 \pm 0.16\,. \quad \rightarrow \quad = 0.869^{+0.234}_{-0.204}$$

$$-\sqrt{2}A(B^0 \to (J/\psi\,\rho)_f) = \lambda \mathcal{A}'_f \left[1 - a'_f e^{i\theta'_f} e^{i\gamma}\right] \frac{V_{cd}V_{cb}^*}{|V_{cd}V_{cb}^*|},$$

where the CP-conserving hadronic parameters are

$$\mathcal{A}'_f \equiv \lambda^2 A \left[A_{\mathrm{T}}^{(c)f} + A_{\mathrm{P}}^{(c)f} - A_{\mathrm{P}}^{(t)f}\right]$$

and

$$a'_f e^{i\theta'_f} \equiv R_b \left[\frac{A_{\mathrm{P}}^{(u)f} - A_{\mathrm{P}}^{(t)f}}{A_{\mathrm{T}}^{(c)f} + A_{\mathrm{P}}^{(c)f} - A_{\mathrm{P}}^{(t)f}}\right].$$