CP Violation in Other B_s Decays

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On behalf of LHCb Collaboration
including results by Belle CDF and D0

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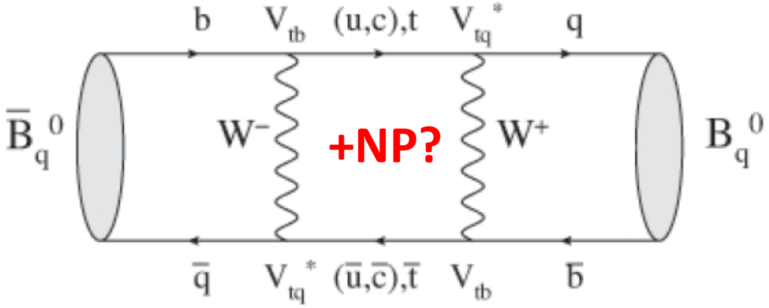
- Analysis of the resonant components and ϕ_s determination in $B_s \to J/\psi\pi\pi$
- Other possible modes for ϕ_s
- *CP* asymmetries in $B_s \to K^+K^-$
- Effective lifetimes in *CP*-even state $B_s \to K^+K^-$ and *CP*-odd state $B_s \to J/\psi f_0(980)$
- Do no cover
  - B_s semileptonic *CP* asymmetry, see talk by R. Van Kooten
  - ϕ_s from $J/\psi\phi$, see Yuehong Xie's talk
  - $B_s \to K^-\pi^+$ *CP* asymmetry, talked by I. Nasteva

Introduction

- The B_q-$\overline{B}_q$ mixing can be described by 3 numbers, after diagonalizing the mixing matrix: $|M_{12}|$, $|\Gamma_{12}|$ and
$$\phi = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right).$$
- ϕ is determined from semileptonic asymmetry, and $\arg(M_{12}) \equiv \phi_M$ is determined from mixing-induced *CP* Violation (*CPV*) phase.
- New Physics (NP) in mixing could add two new phases to M_{12} and Γ_{12}.



$B_q \to f_{CP}$

Time dependent decay rates (using $|p/q|=1$) in terms of $\lambda \equiv \left(\frac{q}{p}\right)\frac{\overline{A}_f}{A_f}$

$$\Gamma(B(t)\to f_{CP}) = \mathcal{N}e^{-\Gamma t}\left\{\frac{1+|\lambda|^2}{2}\cosh\frac{\Delta\Gamma t}{2} + \frac{1-|\lambda|^2}{2}\cos(\Delta m t) - \mathrm{Re}(\lambda)\sinh\frac{\Delta\Gamma t}{2} - \mathrm{Im}(\lambda)\sin(\Delta m t)\right\}$$

$$\Gamma(\overline{B}(t)\to f_{CP}) = \mathcal{N}e^{-\Gamma t}\left\{\frac{1+|\lambda|^2}{2}\cosh\frac{\Delta\Gamma t}{2} - \frac{1-|\lambda|^2}{2}\cos(\Delta m t) - \mathrm{Re}(\lambda)\sinh\frac{\Delta\Gamma t}{2} + \mathrm{Im}(\lambda)\sin(\Delta m t)\right\}$$

CP asymmetry:

$$A_{f_{CP}}(t) \equiv \frac{\Gamma(\overline{B}(t)\to f_{CP}) - \Gamma(B(t)\to f_{CP})}{\Gamma(\overline{B}(t)\to f_{CP}) + \Gamma(B(t)\to f_{CP})} = \frac{A^{\mathrm{dir}}\cos(\Delta m t) + A^{\mathrm{mix}}\sin(\Delta m t)}{\cosh\frac{\Delta\Gamma t}{2} + A^{\Delta\Gamma}\sinh\frac{\Delta\Gamma t}{2}}$$

Two independent *CP* observables:

direct mixing-induced

$$A^{\mathrm{dir}} = \frac{|\lambda|^2-1}{|\lambda|^2+1} \qquad A^{\mathrm{mix}} = \frac{2\mathrm{Im}\lambda}{|\lambda|^2+1} \qquad A^{\Delta\Gamma} = -\frac{2\mathrm{Re}\lambda}{|\lambda|^2+1}$$

$$\text{and} \quad (A^{\mathrm{dir}})^2 + (A^{\mathrm{mix}})^2 + (A^{\Delta\Gamma})^2 = 1$$

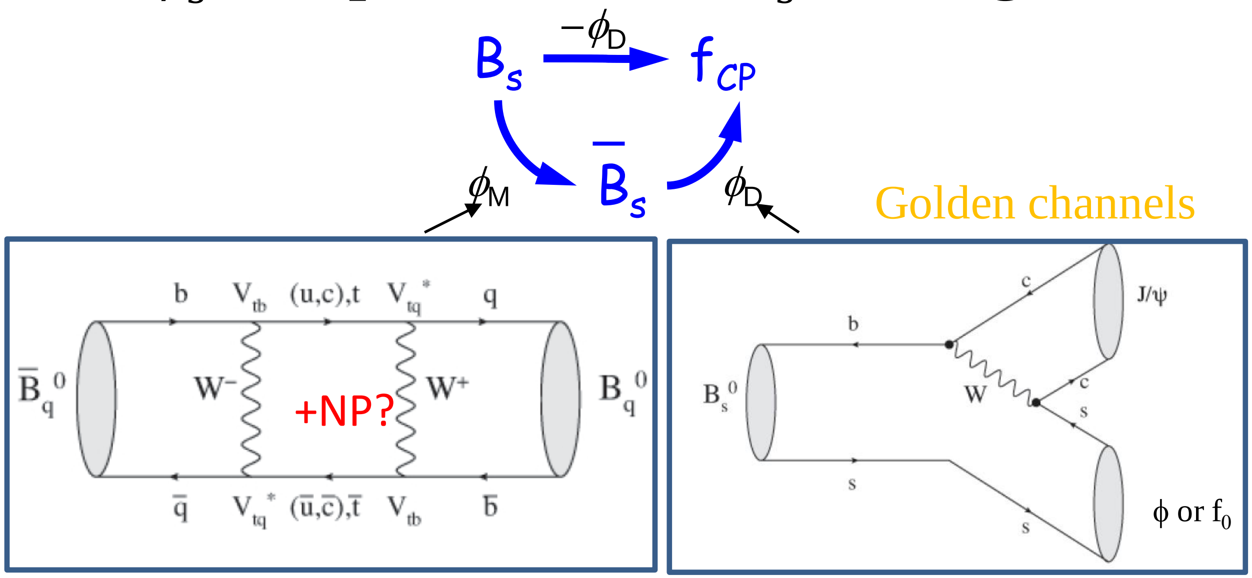
ϕ_s from $B_s \to J/\psi\phi$ or $J/\psi f_0$

- B_s mixing-induced *CPV* phase $\phi_s = \phi_M - 2\phi_D$
- Ignoring penguins, $\phi_D \approx 0$, thus $\phi_s \approx \phi_M$
- In SM, ϕ_s is small and accurately predicted $\lambda = \eta_{CP} e^{-i\phi_s^{SM}}$

$$\phi_s^{SM} \simeq -2\beta_s = -0.036 \pm 0.002$$

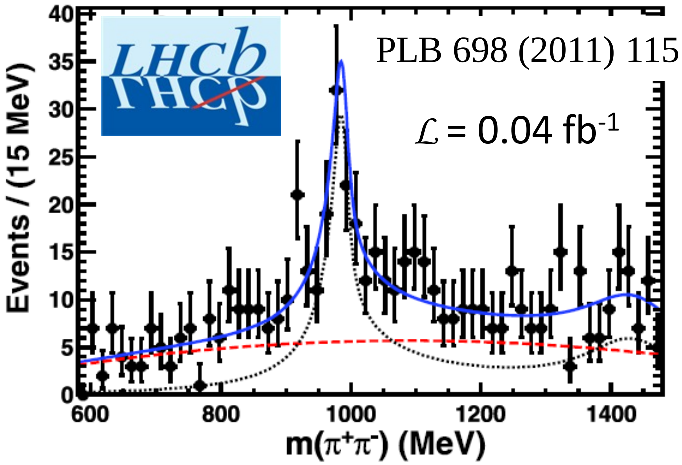
[Charles et al. PRD 84 (2011) 033005]

- Measure ϕ_s can probe NP in B_s mixing



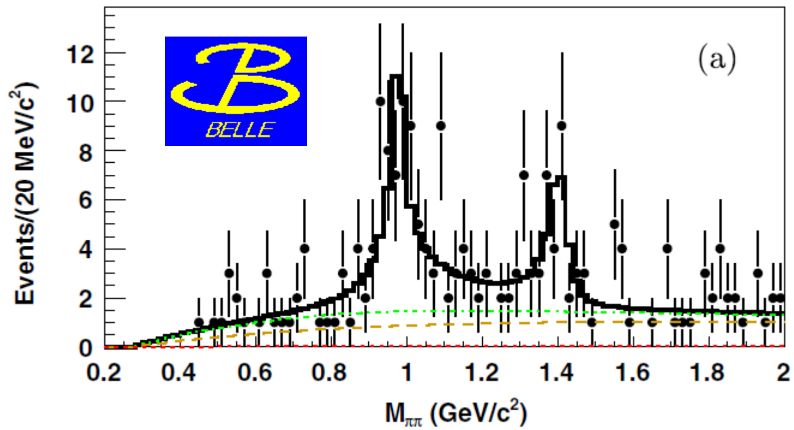
Observation of $B_s \to J/\psi f_0(980)$

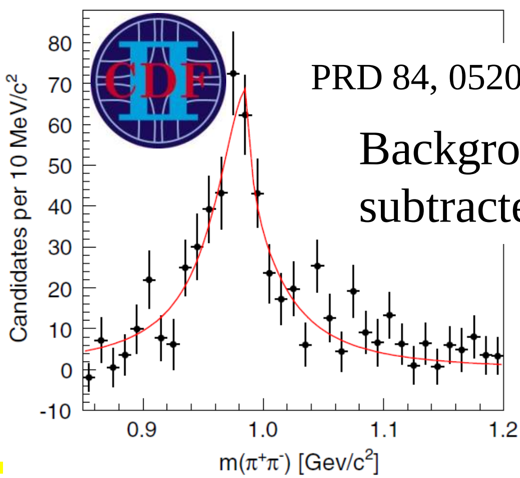
- Stone & Zhang PRD 79, 074024 (2009) predicted this mode.
- First observed by LHCb in 2011.



PLB 698 (2011) 115

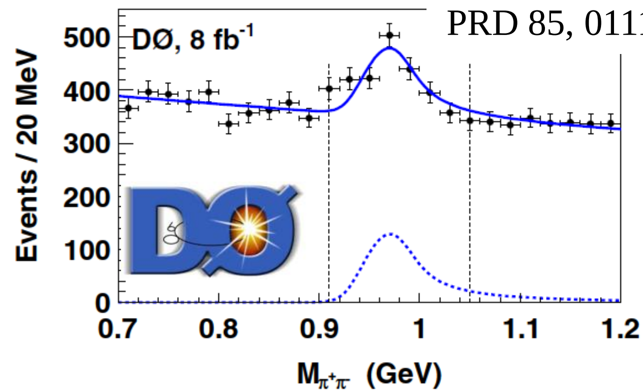
PRL 106, 121802 (2011)





PRD 84, 052012 (2011)

Background subtracted



PRD 85, 011103 (2012)

ϕ_s from CP-odd Eigenstate

- Differential decay rates for CP-odd eigenstate:

$$\Gamma\left(\overset{(-)}{B}{}^0_s \to f_-\right) = \mathcal{N} e^{-\Gamma_s t}\left\{\frac{e^{\Delta\Gamma_s t/2}}{2}(1+\cos\phi_s) + \frac{e^{-\Delta\Gamma_s t/2}}{2}(1-\cos\phi_s) \pm \sin\phi_s \sin(\Delta m_s t)\right\}$$

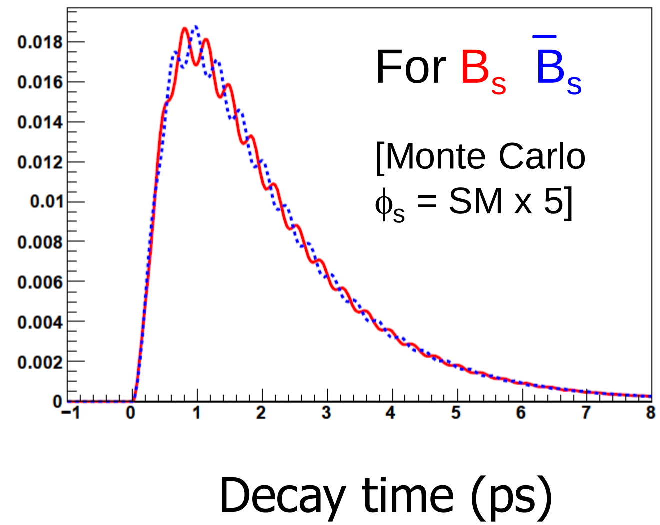
Opposite sign for B_s and $\overline{B}_s$ → must tag

– for B_s
+ for $\overline{B}_s$

- Signal PDF needs to take into account experimental effects

$$P(t;\phi_s) \propto \varepsilon(t) \times \left(\frac{1+qD}{2}\Gamma(t;\phi_s) + \frac{1-qD}{2}\overline{\Gamma}(t;\phi_s)\right) \otimes R_t$$

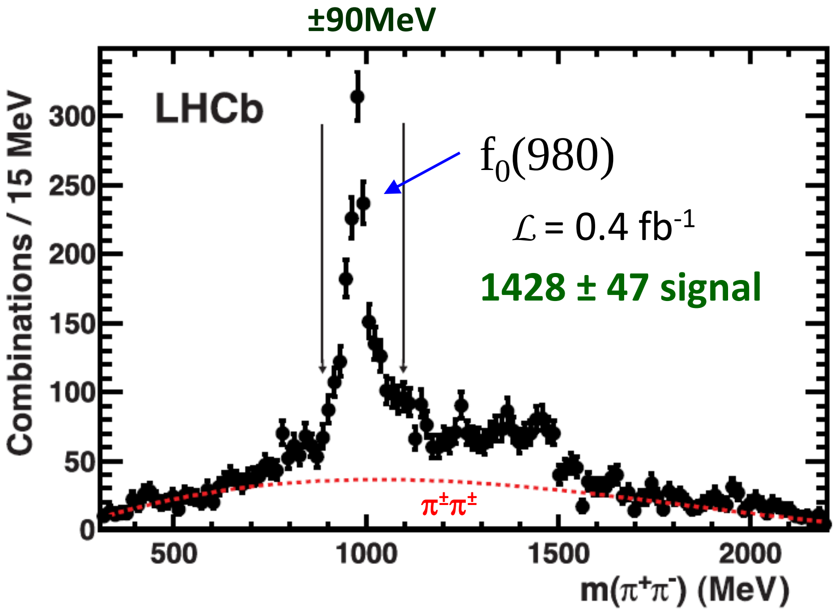
- $\varepsilon(t)$: efficiency in decay time t using control channel $B^0 \to J/\psi K^*$
- q: tag decision
- D≡1-2ω: Dilution due to mistag probability ω
- R_t: time resolution function with $\sigma_t \approx 40$ fs, w.r.t. sinusoid period ~ 350 fs. The resolution is measured using prompt J/ψ+2tracks.

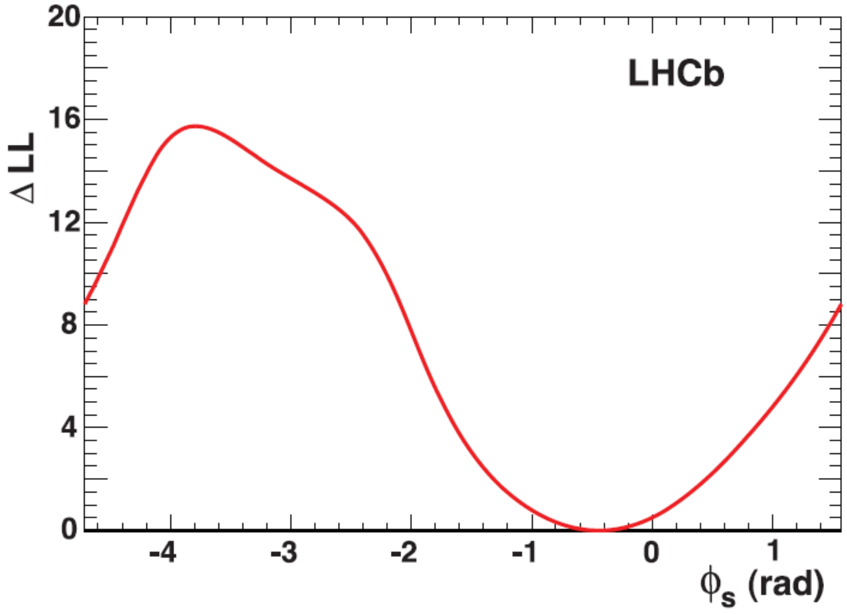


ϕ_s from $B_s \to J/\psi f_0(980)$

Previous LHCb result $\mathcal{L}$ = 0.4 fb^{-1}

LHCb first used events in $f_0(980)$ peak region and measured $\phi_s = -0.44 \pm 0.44 \pm 0.02$ rad [PLB 707 (2012) 497]

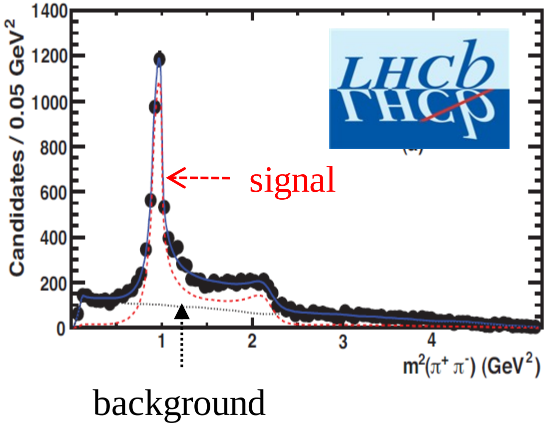


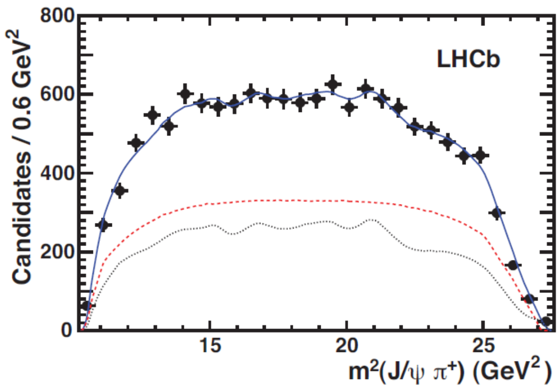


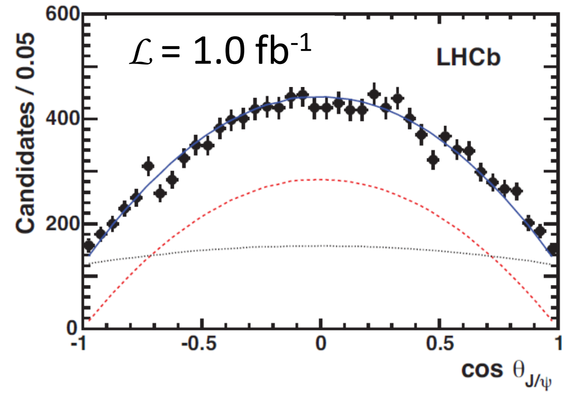
Resonant Components in $B_s \to J/\psi\pi\pi$

- $f_0(980)$ peak ($\pm$90 MeV) is only half of $J/\psi\pi\pi$ event yield.
- To optimize $J/\psi\pi\pi$ usefulness, it's needed to understand the *CP* content.
- A modified Dalitz-plot analysis is performed by fitting $m^2(\pi^+\pi^-)$, $m^2(J/\psi\pi^+)$, and $J/\psi\to\mu^+\mu^-$ helicity angle ($\theta_{J/\psi}$).
- Complication: Vector J/ψ has 3 helicity amplitudes.
- Considered all possible states decay to $\pi^+\pi^-$ including $\rho(770)$. ρ only can be present in higher order processes.

arXiv:1204.5643, submitted to PRD







CP content in $B_s \to J/\psi\pi\pi$

Best Fit Model

Resonance	Normalized fraction (%)	
$f_0(980)$	69.7 ± 2.3	CP odd
$f_0(1370)$	21.2 ± 2.7	CP odd
non-resonant $\pi^+\pi^-$	8.4 ± 1.5	CP odd
$f_2(1270)$, $\Lambda = 0$	0.49 ± 0.16	CP odd
$f_2(1270)$, $\lvert\Lambda\rvert = 1$	0.21 ± 0.65	← Mixed CP

arXiv:1204.5643, submitted to PRD

Fraction of $\rho(770)$ <1.6% at 95% CL.

Fraction of *CP*-even states <2.3% at 95% CL. The whole mode can be used for ϕ_s measurement without angular analysis.

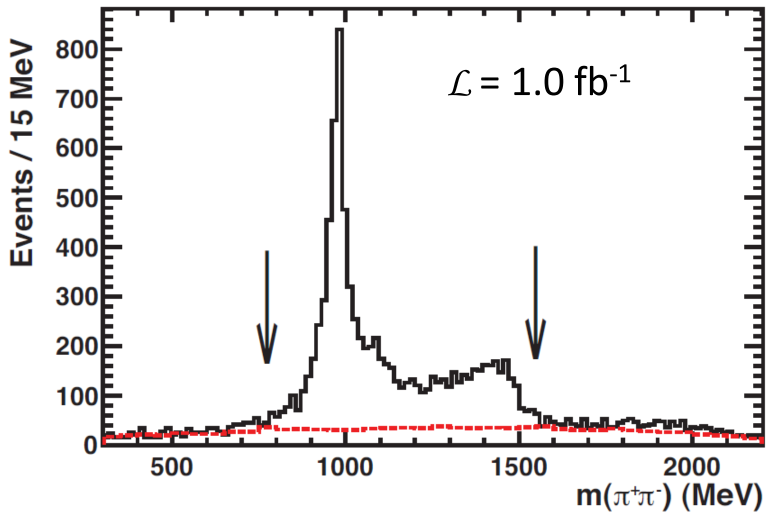
$$\frac{\mathcal{B}(B_s^0 \to J/\psi\pi^+\pi^-)}{\mathcal{B}(B_s^0 \to J/\psi\phi)} = (21.28 \pm 0.51(\text{stat}) \pm 0.56(\text{syst}))\%$$

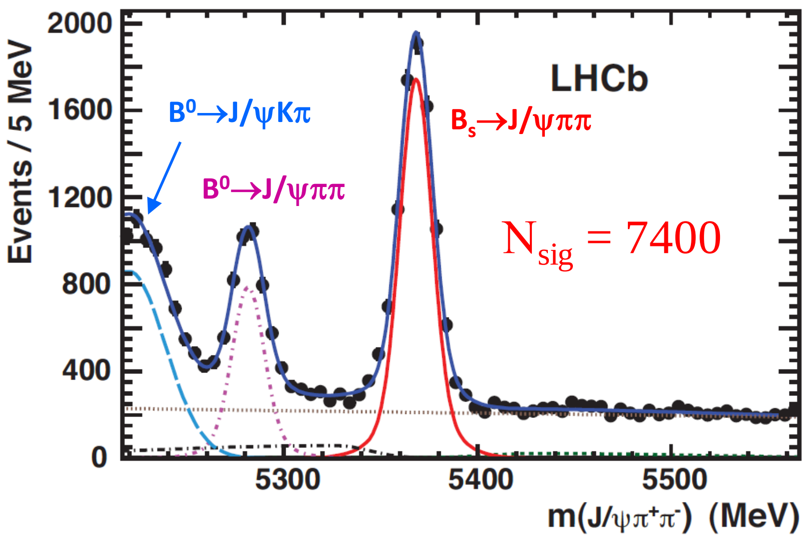
$B_s \to J/\psi\pi\pi$ is (43.5±1.5)% of $J/\psi\phi(\to K^+K^-)$

$B_s \rightarrow J/\psi\pi^+\pi^-$

- LHCb updated ϕ_s measurement with $1.0 fb^{-1}$.
- $m(\pi\pi)$ extents to [775,1550] MeV. The statistics is doubled with respect to the events only in $f_0(980)$ peak region.
- Boosted Decision Tree selection is used.

Events in B_s signal region

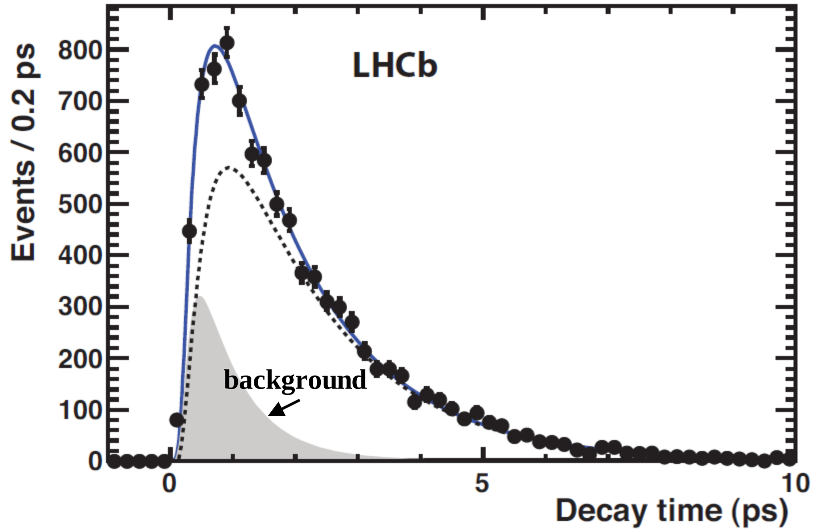




arXiv: 1204.5675, submitted to PLB

ϕ_s from $B_s \to J/\psi\pi^+\pi^-$

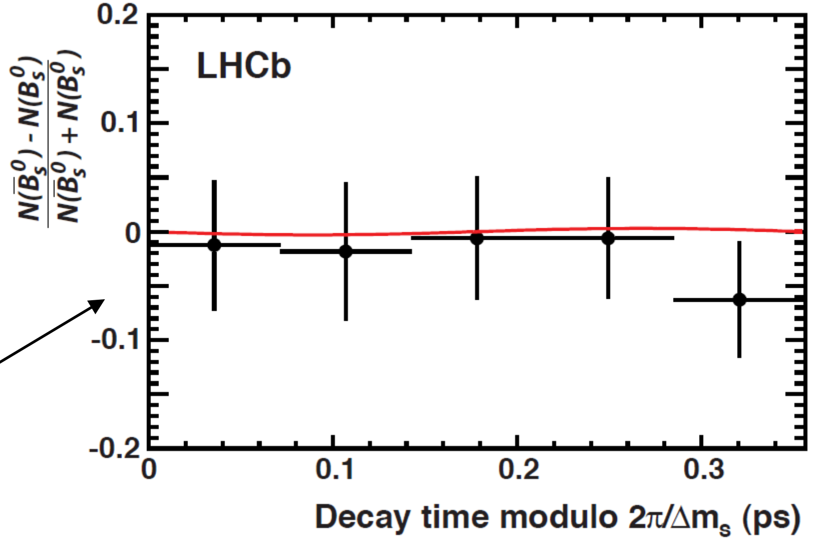
- Simultaneously fit tagged and untagged events
  - $\Delta\Gamma_s$ and Γ_s constrained to LHCb's measurements in $J/\psi\phi$
  - $\Delta m_s = 17.63 \pm 0.11 \pm 0.02\ \mathrm{ps}^{-1}$ constrained to LHCb's measurements in $B_s \to D_s(3)\pi$, PLB 709 (2012) 177



arXiv: 1204.5675, submitted to PLB

$$\boxed{\phi_s^{J/\psi\pi\pi} = -0.019^{+0.173}_{-0.174}(\mathrm{stat})^{+0.004}_{-0.003}(\mathrm{syst})\ \mathrm{rad}}$$

$$A_{CP}(t) \approx D \cdot \sin\phi_s \sin(\Delta m_s t)$$



Combination of ϕ_s

- Simultaneously fit $B_s \to J/\psi\phi$ and $J/\psi\pi\pi$

LHCb Preliminary LHCb-CONF-2012-004

$$\boxed{\phi_s^{\text{combined}} = -0.002 \pm 0.083(\text{stat}) \pm 0.027(\text{syst})\ \text{rad}}$$

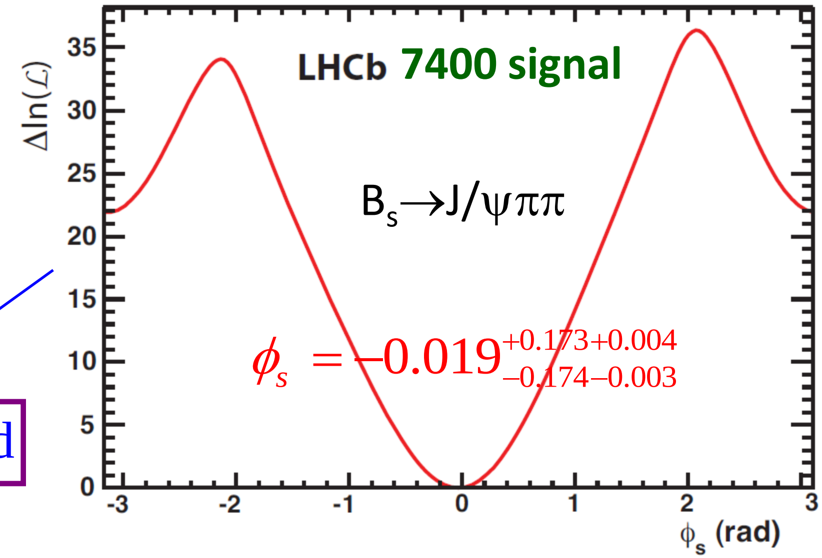
SM

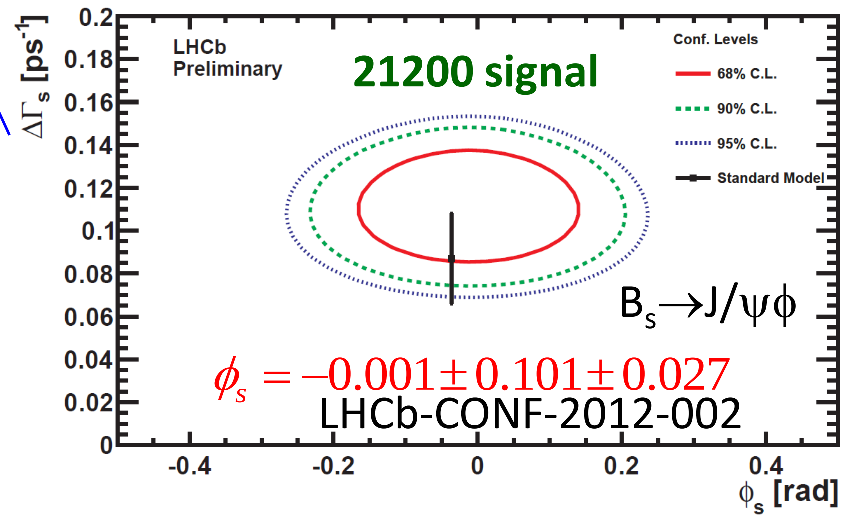
$$\phi_s = -0.036 \pm 0.002\ \text{rad}$$

[Charles et al. PRD 84 (2011) 033005]

➢ **Combination neglects additional small diagrams in $J/\psi\pi\pi$, arXiv:1109.1112**

➢ **Theoretical bound of the effect is [–0.05, 0.05] rad, arXiv: 1109.5115**





Check for Direct CPV in $B_s \to J/\psi\pi^+\pi^-$

Can also fit $|\lambda|$ without assuming $|\lambda|=1$, $|\lambda|\neq 1$ means direct *CPV*.

$$\Gamma(\overset{(-)}{B}_s \to f_-) \propto e^{-\Gamma_s t}\left\{\cosh\frac{\Delta\Gamma_s t}{2} + \frac{2|\lambda|}{1+|\lambda|^2}\cos\phi_s \sinh\frac{\Delta\Gamma_s t}{2} \pm\left[\frac{2|\lambda|}{1+|\lambda|^2}\sin\phi_s \sin(\Delta m_s t) - \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos(\Delta m_s t)\right]\right\}$$

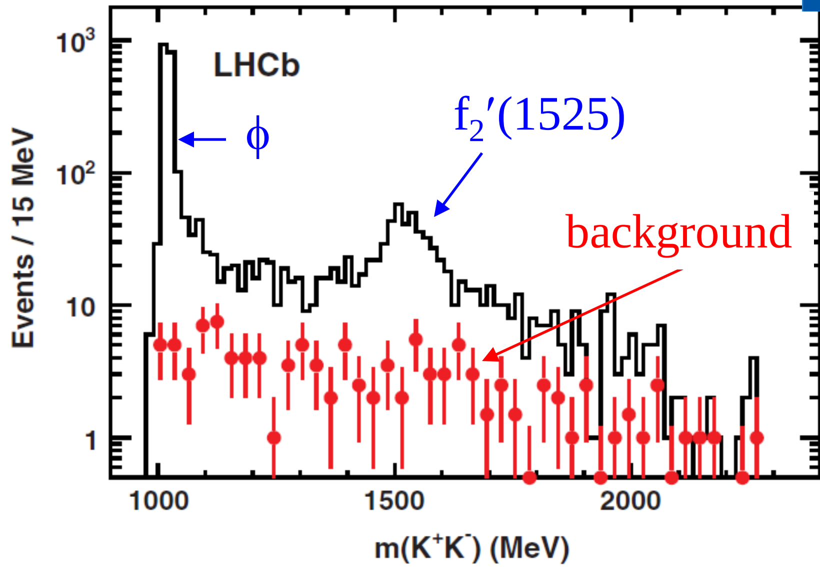
– for B_s
+ for $\overline{B}_s$

arXiv: 1204.5675

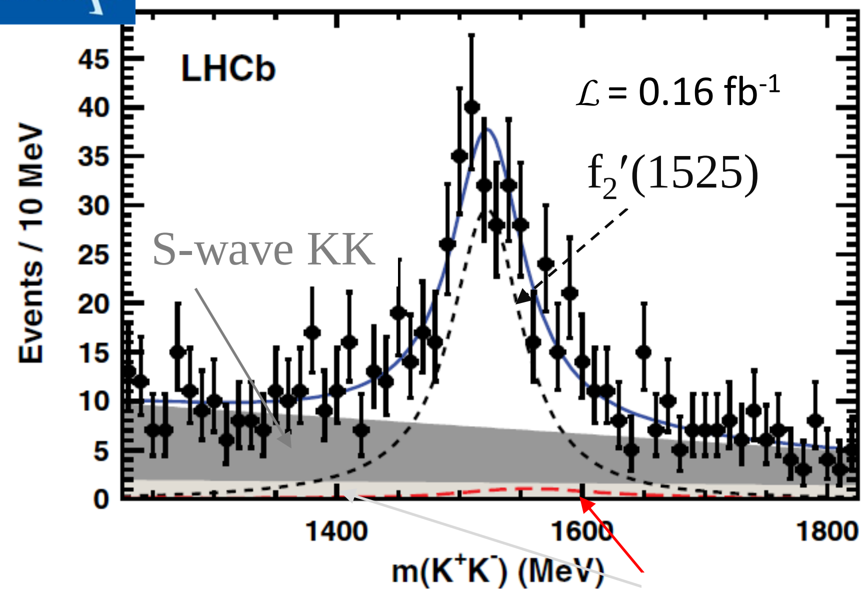
- $|\lambda| = 0.89\pm0.13$ consistent with no direct *CPV*
- ϕ_s changes only by -0.002 rad, statistical error on ϕ_s doesn't change.

Other Possible Modes for ϕ_s

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



Zoom in on $f_2'(1525)$ region



First observation by LHCb

PRL 108, 151801 (2012)

background

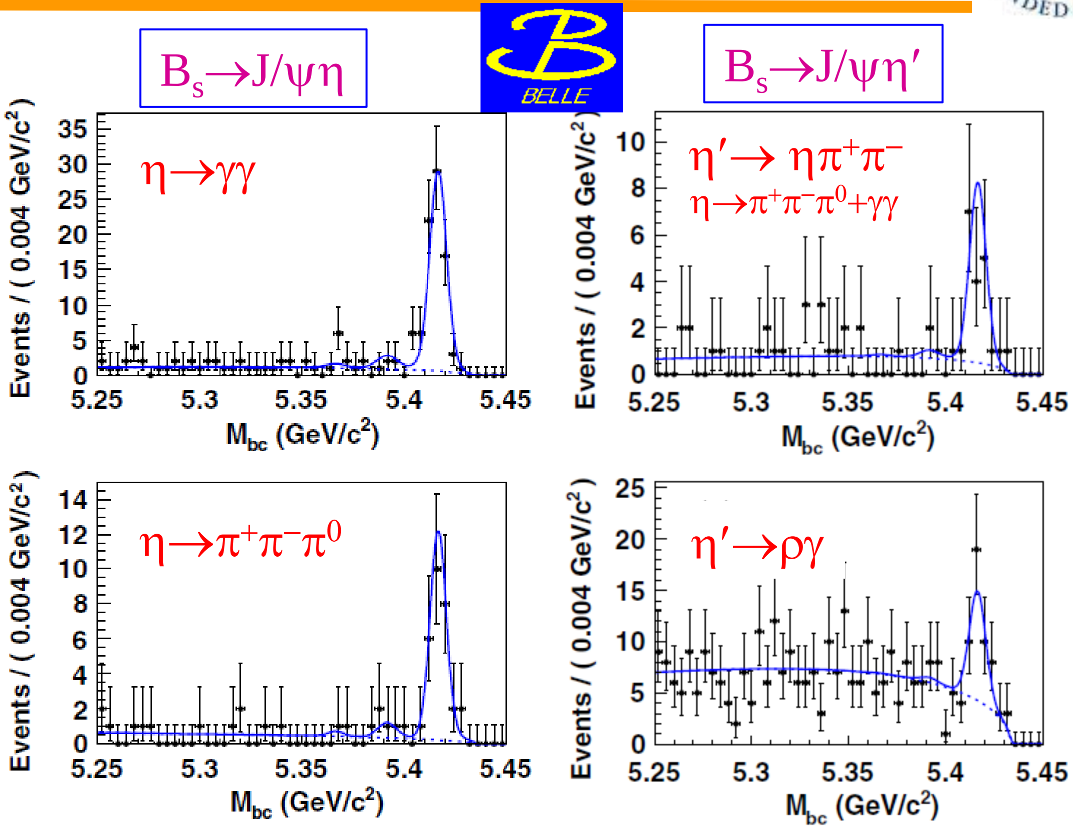
$$\frac{\mathcal{B}(B_s^0 \to J/\psi\, f_2^{'}(1525),\, f_2^{'}(1525) \to K^+K^-)}{\mathcal{B}(B_s^0 \to J/\psi\phi, \phi \to K^+K^-)} = (24.0 \pm 2.5(\text{stat}) \pm 2.2(\text{syst}))\%$$

- Another larger mode with all charged final states
- Sizable S-wave over entire m(KK) region
- Could be useful but need to include additional D-wave in transversity amplitudes

Other Possible Modes for ϕ_s

$J/\psi \to e^+e^-$ & $\mu^+\mu^-$ used

- *CP*-even states
- $\mathcal{B}$ are large, but neutral is hard for hadron collider



First observations by Belle

PRL 108, 181808 (2012)

$$\mathcal{B}(B_s^0 \to J/\psi\,\eta) = [5.10 \pm 0.50(\text{stat}) \pm 0.25(\text{syst})^{+1.14}_{-0.79}(N_{B_s^{(*)}\bar{B}_s^{(*)}})] \times 10^{-4}$$

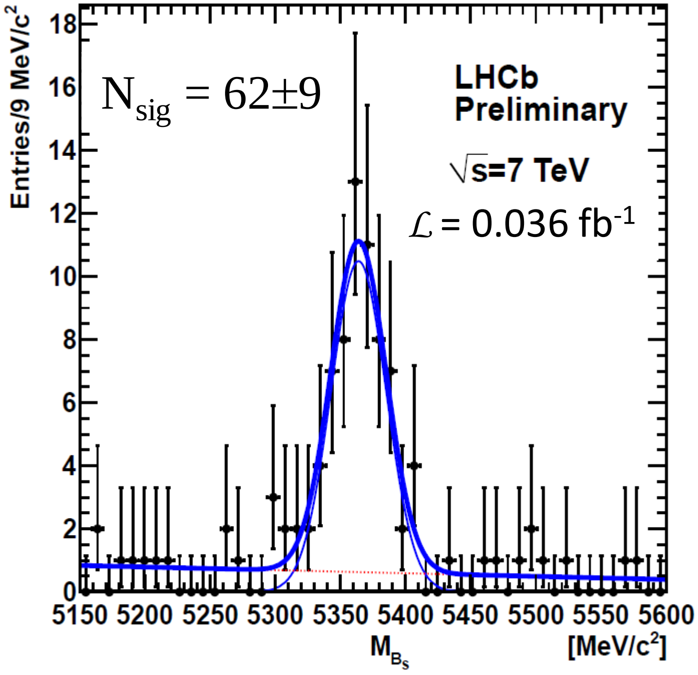
$$\mathcal{B}(B_s^0 \to J/\psi\,\eta') = [3.71 \pm 0.61(\text{stat}) \pm 0.18(\text{syst})^{+0.83}_{-0.57}(N_{B_s^{(*)}\bar{B}_s^{(*)}})] \times 10^{-4}$$

Other Possible Modes for ϕ_s

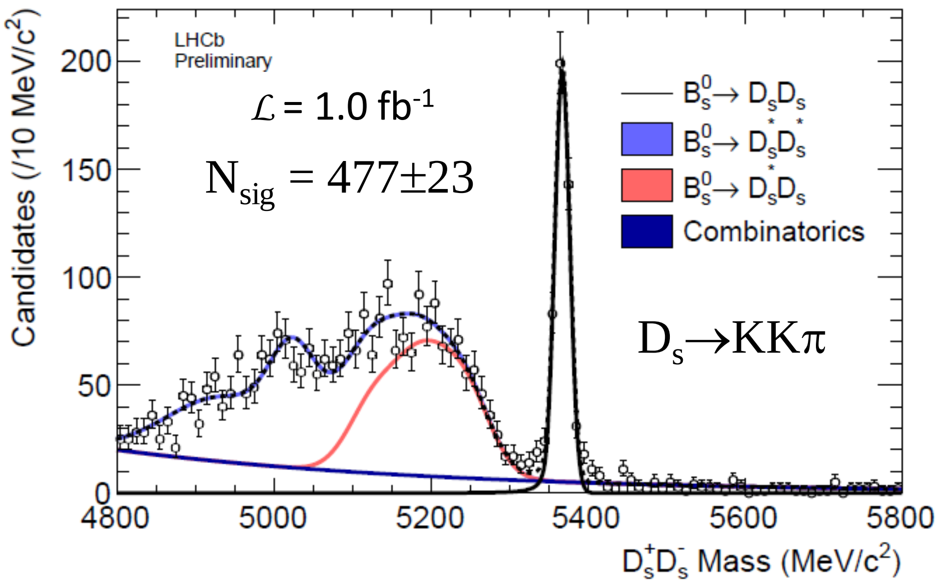
$B_s \to \psi(2S)\phi$, $\psi(2S) \to \mu\mu$

$B_s \to D_s^+ D_s^-$

LHCb-CONF-2011-014



LHCb-CONF-2012-009



Sizes are of order of 5–10% of $J/\psi(\mu\mu)\phi(K^+K^-)$

$B_s \to h^+ h'^-$

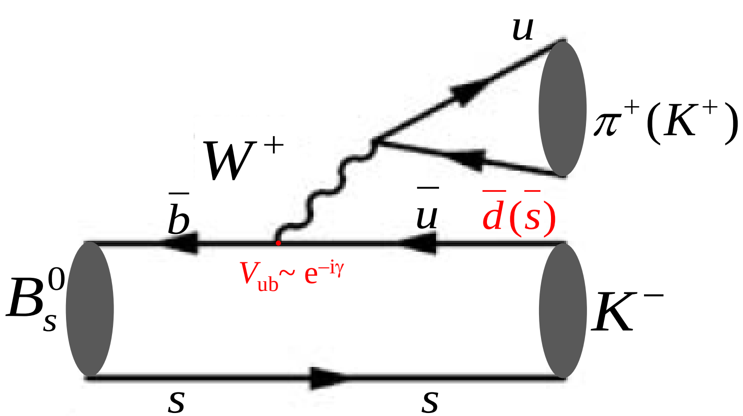
Two-body charmless B_s decays have significant contribution of Penguin diagrams, providing entry point for NP. Also could be useful to extract β and γ [R. Fleischer, PLB 459 (1999) 306].

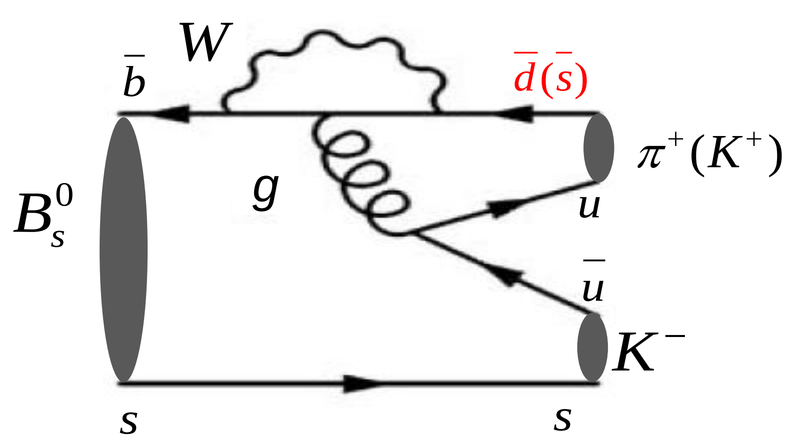
$\boxed{B_s^0 \to K^+ K^-}$ *is dominated by penguin, analogous to* $B^0 \to K^+ \pi^-$

$\boxed{B_s^0 \to K^- \pi^+}$ *has comparable tree and penguin contributions, analogous to* $B^0 \to \pi^+ \pi^-$

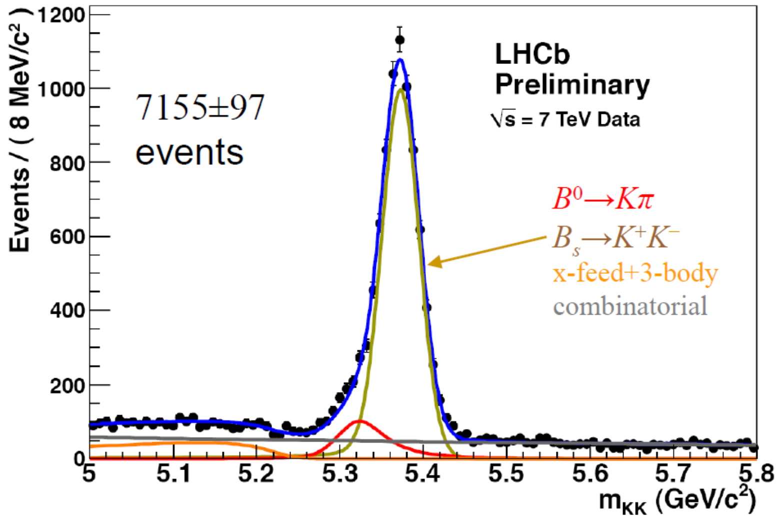
Under U-spin symmetry (s ↔ d exchange), neglecting small penguin annihilation one expects

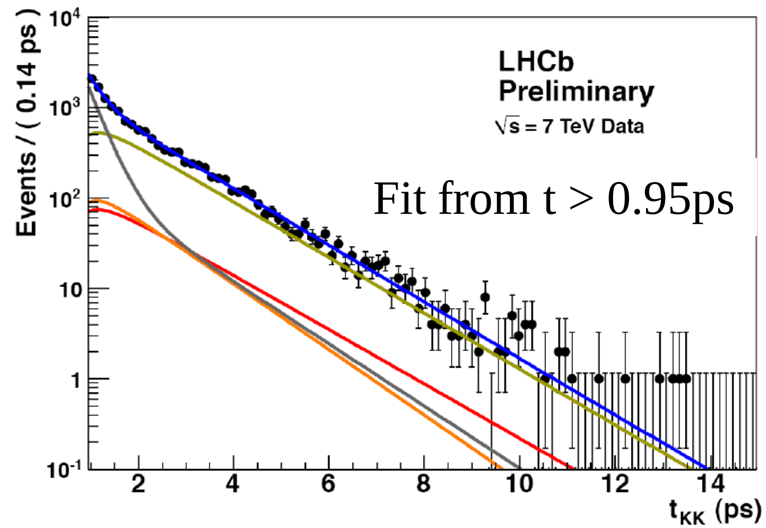
$$A_{CP}^{\text{dir}}(B_s^0 \to K^+ K^-) \approx A_{CP}(B^0 \to K^+ \pi^-)$$
$$A_{CP}(B_s^0 \to K^- \pi^+) \approx A_{CP}^{\text{dir}}(B^0 \to \pi^+ \pi^-)$$

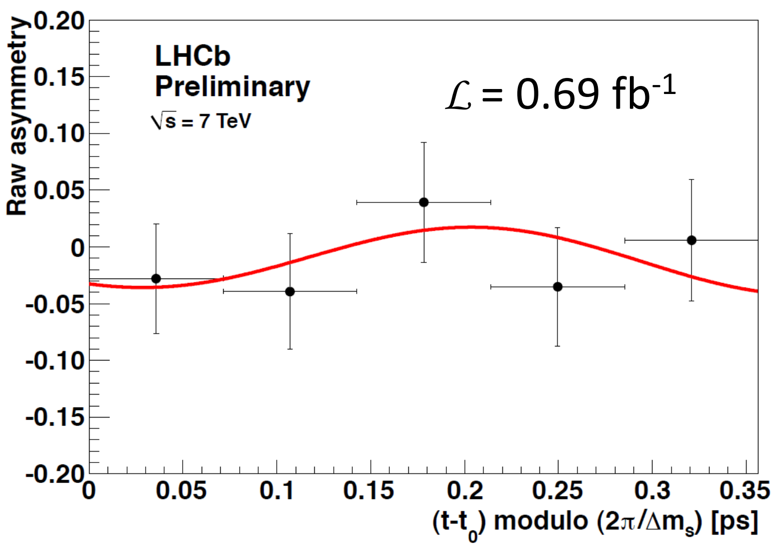




$B_s \to K^+K^-$







LHCb-CONF-2012-007

Preliminary

$$A_{KK}^{\mathrm{dir}} = 0.02 \pm 0.18 \pm 0.04$$

$$A_{KK}^{\mathrm{mix}} = 0.17 \pm 0.18 \pm 0.05$$

$$\rho(A_{KK}^{\mathrm{dir}}, A_{KK}^{\mathrm{mix}}) = -0.10$$

World first measurement

Expect:

$$A_{KK}^{\mathrm{dir}} \approx A_{CP}(B^0 \to K^+\pi^-) = -0.087 \pm 0.008$$

World average

Effective lifetime in CP eigenstates

Untagged decay time distribution:

$$\Gamma(t) = \Gamma(B_s^0) + \Gamma(\overline{B}_s^0) \propto (1 - A^{\Delta\Gamma_s}) e^{-\Gamma_L t} + (1 + A^{\Delta\Gamma_s}) e^{-\Gamma_H t}$$

$$A^{\Delta\Gamma_s} \equiv -\frac{2\mathrm{Re}\lambda}{|\lambda|^2 + 1}$$

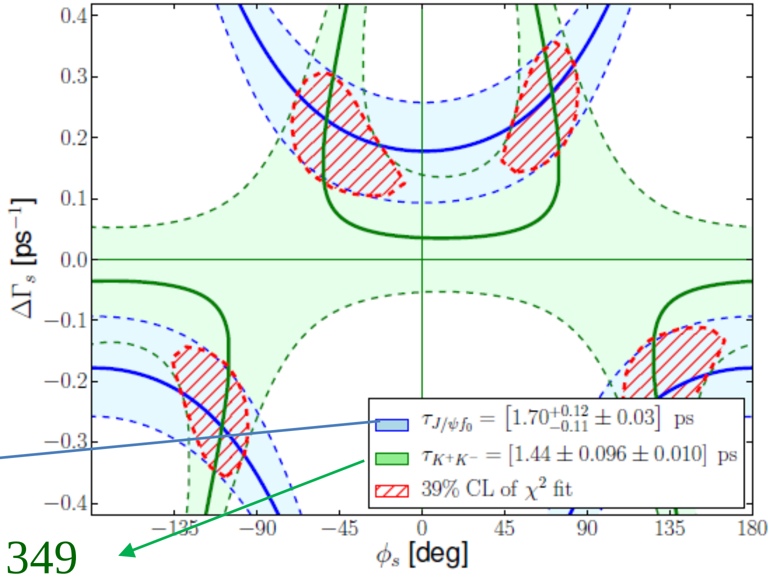
Effective lifetime

Expand in $y_s \equiv \Delta\Gamma_s / 2\Gamma_s$

$$\tau_{\text{eff}} = \tau_{B_s^0} \frac{1}{1 - y_s^2} \frac{1 + 2A^{\Delta\Gamma_s} y_s + y_s^2}{1 + A^{\Delta\Gamma_s} y_s}$$

- Provide information about $\Delta\Gamma_s$ and ϕ_s
- No flavour tagging needed

R. Fleischer & R. Knegjens
arXiv: 1109.5115



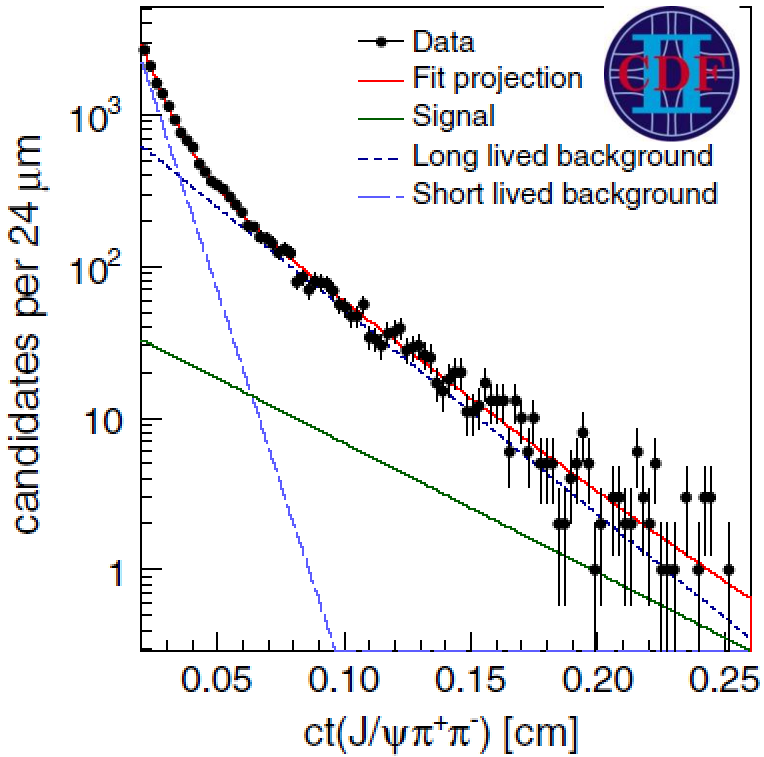
CDF measurement (see next slide)

LHCb 0.04fb^{-1}, PLB 707 (2012) 349

Effective Lifetime in $B_s \to J/\psi f_0(980)$

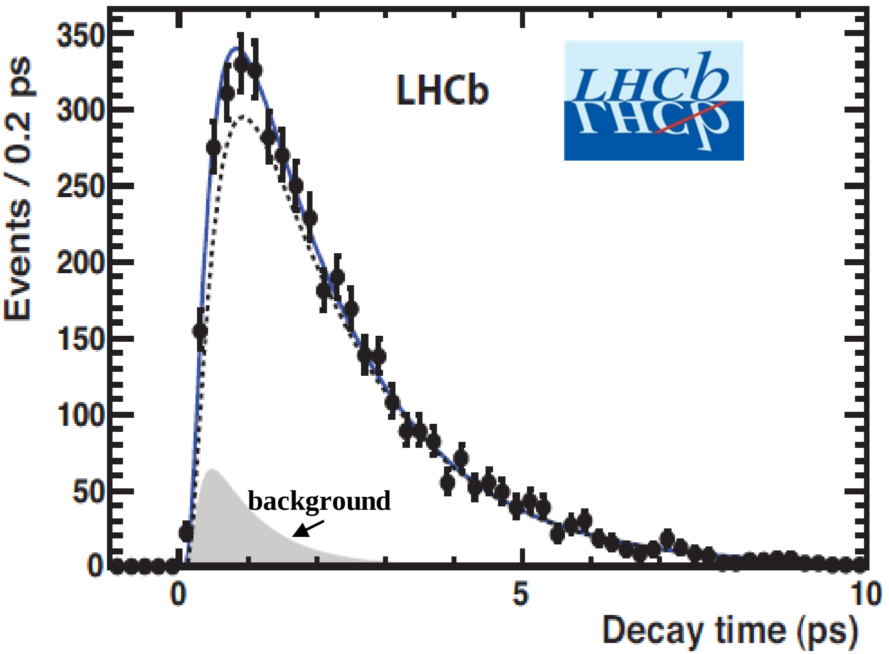
- For *CP*-odd state with $\phi_s \approx 0$, $\tau_{eff} \approx \tau_H$

PRD 84, 052012 (2011)



$$\tau_{J/\psi f_0} = 1.70^{+0.12}_{-0.11}(\text{stat}) \pm 0.03(\text{syst})\ \text{ps}$$

arXiv: 1204.5675



$$\tau_{J/\psi f_0} = 1.71 \pm 0.03(\text{stat})\ \text{ps}$$

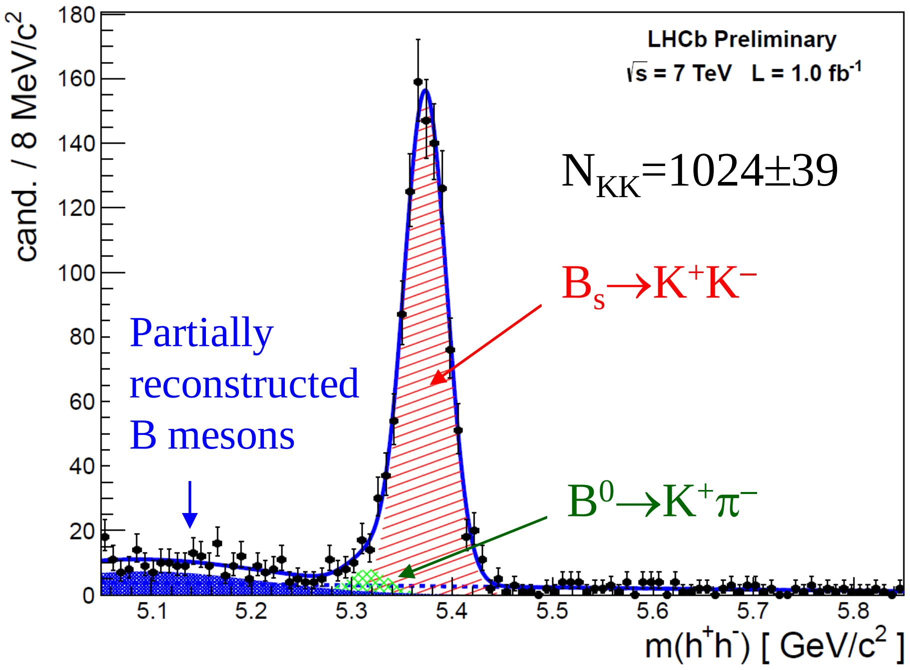
Statistical uncertainty only.
Detailed analysis is underway.

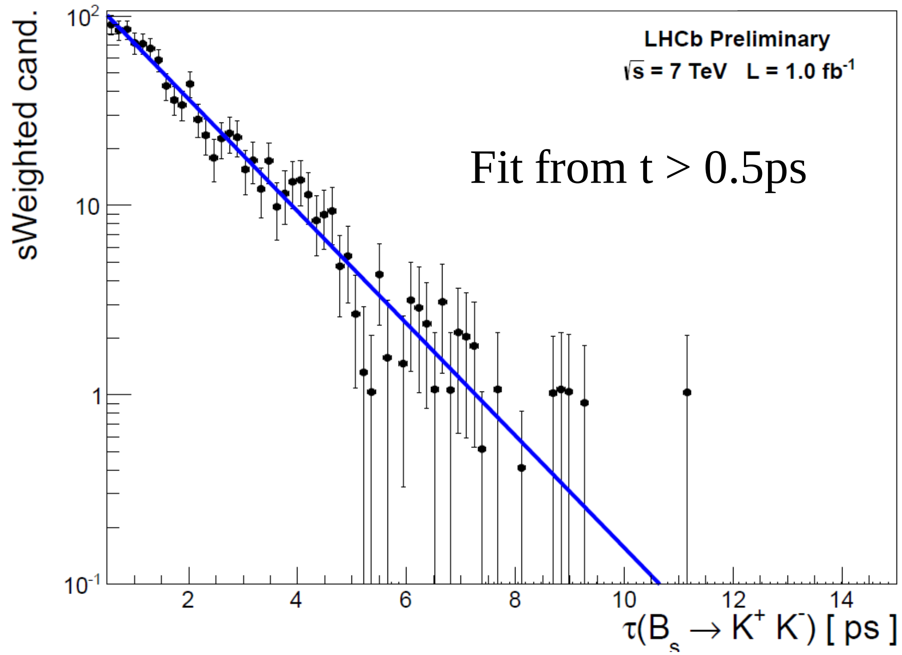
Effective lifetime in $B_s \to K^+K^-$

- Dedicated lifetime unbiased trigger and selection

CP-even state

LHCb-CONF-2012-001





Preliminary

$$\tau_{KK} = 1.468 \pm 0.046(\text{stat}) \pm 0.006(\text{syst})\ \text{ps}$$

Summary

- First use of $B_s \to J/\psi\pi\pi$ for ϕ_s (LHCb)
  - The mode is dominated by *CP*-odd states, *CP*-even fraction $< 2.3\%$ at 95 C.L.
- First observation of $B_s \to J/\psi f_2'(1525)$ (LHCb)
- First observations of $B_s \to J/\psi\eta$ and $J/\psi\eta'$ (Belle)
- First *CPV* measurement in $B_s \to K^+K^-$ (LHCb)
- World's best $B_s \to K^+K^-$ lifetime (LHCb)
- Effective lifetime in $B_s \to J/\psi f_0(980)$ (CDF)
- Outlook: in 2012, LHCb is running at 8TeV, expects to have more than double statistics.

Backup

- *Production asymmetry*
  LHC is a proton-proton collider $N(\bar{I}) \neq N(I)$

$$\boxed{\delta_p = \frac{N(\bar{I}_0)}{N(I_0)} - 1}$$

- *Detection asymmetry*
  LHCb is a matter detector $\varepsilon(\bar{f}) \neq \varepsilon(f)$

$$\boxed{\delta_c = \frac{\varepsilon(\bar{f}_i)}{\varepsilon(f_i)} - 1}$$

Initial B_q decaying to flavour-specific f

CPV: $(1+a) = \left|\frac{p}{q}\right|^2$

$$\Gamma(B_q(t) \to f) \propto e^{-\Gamma t}\{\cosh\frac{\Delta\Gamma t}{2} + \cos(\Delta m t)\}$$

$$\Gamma(\bar{B}_q(t) \to f) \propto e^{-\Gamma t}(1+a)\{\cosh\frac{\Delta\Gamma t}{2} - \cos(\Delta m t)\}\boxed{(1+\delta_p)}$$

$$\Gamma(\bar{B}_q(t) \to \bar{f}) \propto e^{-\Gamma t}\{\cosh\frac{\Delta\Gamma t}{2} + \cos(\Delta m t)\}\boxed{(1+\delta_p)}$$

$$\Gamma(B_q(t) \to \bar{f}) \propto e^{-\Gamma t}(1-a)\{\cosh\frac{\Delta\Gamma t}{2} - \cos(\Delta m t)\}$$

Untagged decay rate $\quad \Gamma[f,t] = \Gamma(B_q(t) \to f) + \Gamma(\bar{B}_q(t) \to f)$

$$x = \Delta m / \Gamma ; y = \Delta\Gamma / (2\Gamma)$$

$$A^q_{SL,unt} = \frac{\int_0^\infty dt \{\Gamma[f,t] - \boxed{(1+\delta_c)}\Gamma[\overline{f},t]\}}{\int_0^\infty dt \{\Gamma[f,t] + \boxed{(1+\delta_c)}\Gamma[\overline{f},t]\}} = \frac{a}{2}\frac{x_q^2 + y_q^2}{1+x_q^2} - \left(\boxed{\frac{\delta_c}{2}} + \boxed{\frac{\delta_p}{2}\frac{1-y_q^2}{1+x_q^2}}\right)$$

- δ_p O(10^{-2})??, $\delta_c \geq \delta_p$ **??**
- B_s: x_s=26.2±0.5, *Production asymmetry effect* O(10^{-5})
- B_d: x_d=0.774±0.008, *Production asymmetry effect* O(10^{-2})

Semileptonic CP Asymmetry

- The charge asymmetry for "wrong-charge" semileptonic B decay induced by oscillations

$$
\begin{aligned}
a_{\rm sl} &= \frac{\Gamma(\overline{B}(t)\to\mu^+X)-\Gamma(B(t)\to\mu^-X)}{\Gamma(\overline{B}(t)\to\mu^+X)-\Gamma(B(t)\to\mu^-X)} \\
&= \frac{|p/q|^2-|q/p|^2}{|p/q|^2+|q/p|^2} \\
&\approx 1-\left|\frac{q}{p}\right|^2 = \frac{\Delta\Gamma}{\Delta m}\tan\phi
\end{aligned}
$$

$$\phi = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

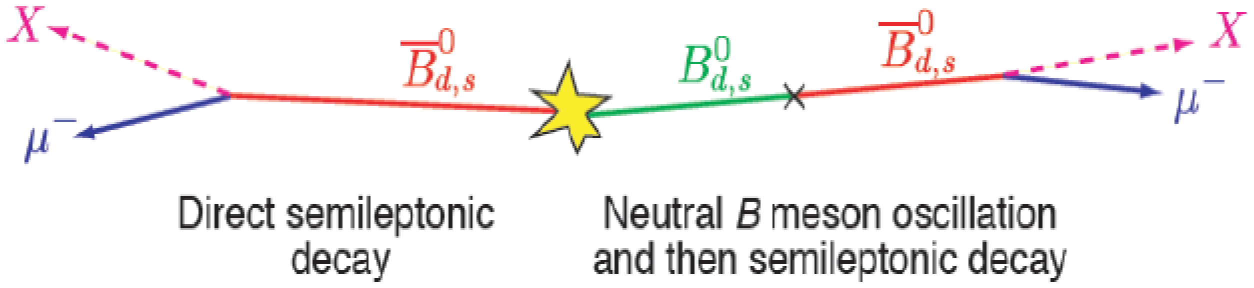
$$a^s_{\rm sl}({\rm SM}) = (2.06\pm0.57)\times10^{-5} \qquad a^d_{\rm sl}({\rm SM}) = (-4.8^{+1.0}_{-1.2})\times10^{-4}$$

$$\phi^{B_s}({\rm SM}) = 0.0042\pm0.0014$$

A. Lenz & U. Nierste JHEP06 (2007) 072

- It tests *CP* violation in mixing ($|q/p|\neq 1$)
- New Physics can introduce additional phase to $\phi = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$

Like-sign Dimuon Charge Asymmetry



Like-sign dimuon charge asymmetry equal to "wrong charge" asymmetry a_{sl} [Y. Grossman etc PRL 97, 151801 (2006)]

$$A^b_{\mathrm{sl}} \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}} = C_d a^d_{\mathrm{sl}} + C_s a^s_{\mathrm{sl}}$$

$$C_d = 0.594 \pm 0.022$$
$$C_s = 0.406 \pm 0.022$$

Experimental Procedure

- Correct the charge asymmetry due to fake muons, the fake rates and charge asymmetry in the like-sign dimuon sample are measured in data.
- Correct muon PID asymmetry, which is also measure in data.
- Use MC to predict how much the like-sign dimuon is from b decays.
- Single muon charge asymmetry is measured and combined with dimuon. The total systematic error is significantly reduced.

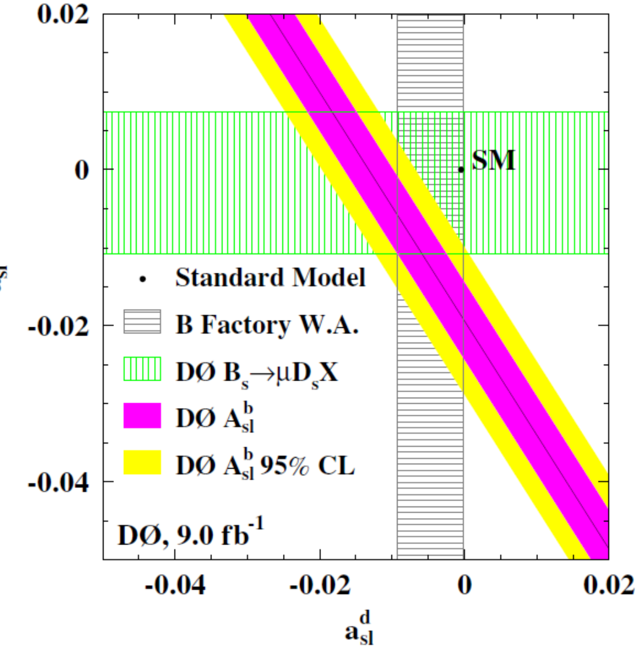
Like-sign Dimuon Charge Asymmetry

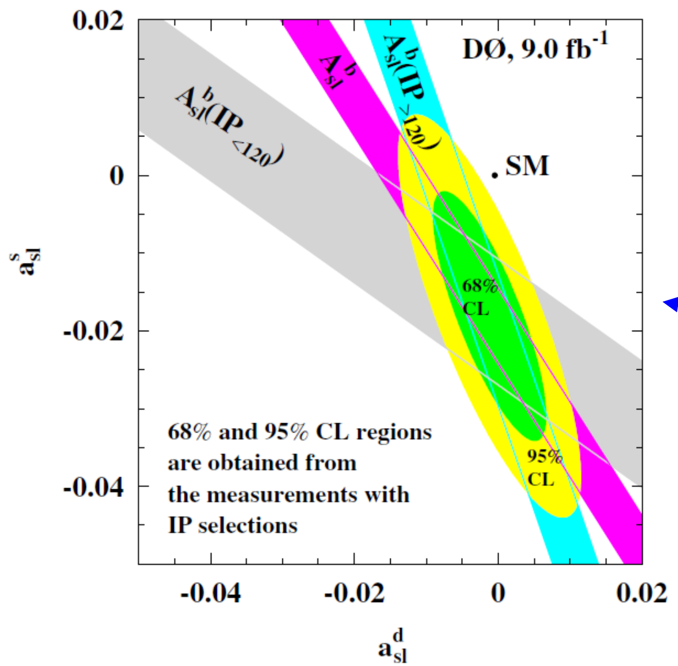
PRD, 82, 032001 (2011)

$$A_{sl}^{b} = (-0.787 \pm 0.172(\text{stat}) \pm 0.093(\text{syst}))\%$$

$$A_{sl}^{b}(\text{SM}) = (-0.028^{+0.005}_{-0.006})\%$$

- 3.9 σ discrepancy
- large new phase in B_s mixing (Γ_{12})?





The separated values of a^{d}_{sl} and a^{s}_{sl} are obtained from the study of the muon impact parameter dependence of A^{b}_{sl}

$$a_{sl}^{d} = (-0.12 \pm 0.52)\%$$

$$a_{sl}^{s} = (-1.81 \pm 1.06)\%$$

$$a_{sl}^{d} = (-0.47 \pm 0.46)\%$$

(B factories' measurements)

Other Experimental Approach (I)

- It's crucial to have an independent and uncertainty comparable measurement.
- Clearly, independent measurements of $a_{\rm sl}^{d}$, $a_{\rm sl}^{s}$ and/or $a_{\rm sl}^{s} - a_{\rm sl}^{d}$ are necessary to determine whether NP contributes to Γ_{12}^{d} and/or Γ_{12}^{s} [arXiv:1203.0238v1]
- Large statistics in LHCb allows to use exclusive semileptonic decay.
- Method 1: Time-depend $B_s \to D_s\, \mu\nu$, $D_s \to \phi\pi$
  - Measure four time-depend rates
  - Flavour tagging needed to improves sensitivity

$$a_{sl}^{s} = (-1.7 \pm 9.1(\text{stat})^{+1.4}_{-1.5}(\text{syst})) \times 10^{-3}$$

PRD 82, 012003 (2010), 5 fb^{-1}

Other Experimental Approach (II)

- Method 2: Time-integrated untagged $B_s \to D_s\, \mu\nu$, $D_s \to \phi\pi$: only have to measure yields
  - Untagged rate $\Gamma(f) = \int_0^\infty dt\, \{\Gamma(B(t) \to f) + \Gamma(\overline{B}(t) \to f)\}$

$f = D_s^- \mu^+ \nu$

$\overline{f} = D_s^+ \mu^- \overline{\nu}$

$$\boxed{A_{\rm sl}^{\rm s,unt} = \frac{\Gamma(f) - \Gamma(\bar{f})}{\Gamma(f) + \Gamma(\bar{f})} = \frac{1}{2}\frac{x_s^2 + y_s^2}{1 + x_s^2} a_{\rm sl} \approx \frac{a_{\rm sl}}{2}}$$

$x_s = \Delta m_s / \Gamma_s$

$y_s = \Delta\Gamma_s / (2\Gamma_s)$

Only feasible for B_s due to x_s>>1

Also feasible for LHCb with B_s & $\overline{B}_s$ not equally produced, because fast oscillate dilutes the production asymmetry by $\frac{1 - y_s^2}{1 + x_s^2} = O(10^{-3})$

- LHCb's precision from 1fb^{-1} is ~0.3% on $A_{\rm sl}^{\rm s,unt}$ i.e. ~0.6% on $a_{\rm sl}$

$$\Gamma(B(t)\to f) \propto |A_f|^2 e^{-\Gamma t}\left\{\frac{1+|\lambda|^2}{2}\cosh\frac{\Delta\Gamma t}{2}+\frac{1-|\lambda|^2}{2}\cos(\Delta m t)-\mathrm{Re}(\lambda)\sinh\frac{\Delta\Gamma t}{2}-\mathrm{Im}(\lambda)\sin(\Delta m t)\right\}$$

$$\Gamma(\overline{B}(t)\to f) \propto \left|\frac{p}{q}\right|^2 |A_f|^2 e^{-\Gamma t}\left\{\frac{1+|\lambda|^2}{2}\cosh\frac{\Delta\Gamma t}{2}-\frac{1-|\lambda|^2}{2}\cos(\Delta m t)-\mathrm{Re}(\lambda)\sinh\frac{\Delta\Gamma t}{2}+\mathrm{Im}(\lambda)\sin(\Delta m t)\right\}$$

$$\Gamma(\overline{B}(t)\to \bar{f}) \propto |\overline{A}_{\bar{f}}|^2 e^{-\Gamma t}\left\{\frac{1+|\bar{\lambda}|^2}{2}\cosh\frac{\Delta\Gamma t}{2}+\frac{1-|\bar{\lambda}|^2}{2}\cos(\Delta m t)-\mathrm{Re}(\bar{\lambda})\sinh\frac{\Delta\Gamma t}{2}-\mathrm{Im}(\bar{\lambda})\sin(\Delta m t)\right\}$$

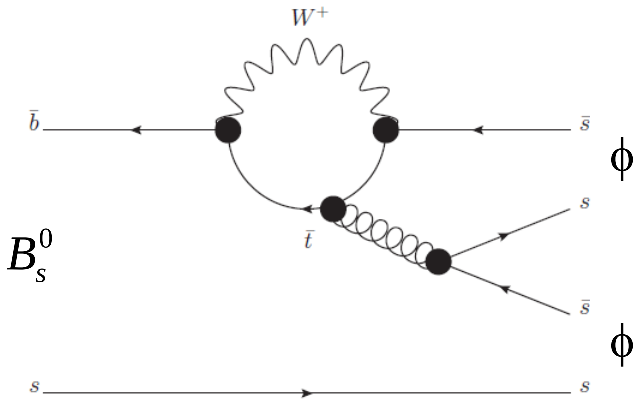
$$\Gamma(B(t)\to \bar{f}) \propto \left|\frac{q}{p}\right|^2 |\overline{A}_{\bar{f}}|^2 e^{-\Gamma t}\left\{\frac{1+|\bar{\lambda}|^2}{2}\cosh\frac{\Delta\Gamma t}{2}-\frac{1-|\bar{\lambda}|^2}{2}\cos(\Delta m t)-\mathrm{Re}(\bar{\lambda})\sinh\frac{\Delta\Gamma t}{2}+\mathrm{Im}(\bar{\lambda})\sin(\Delta m t)\right\}$$

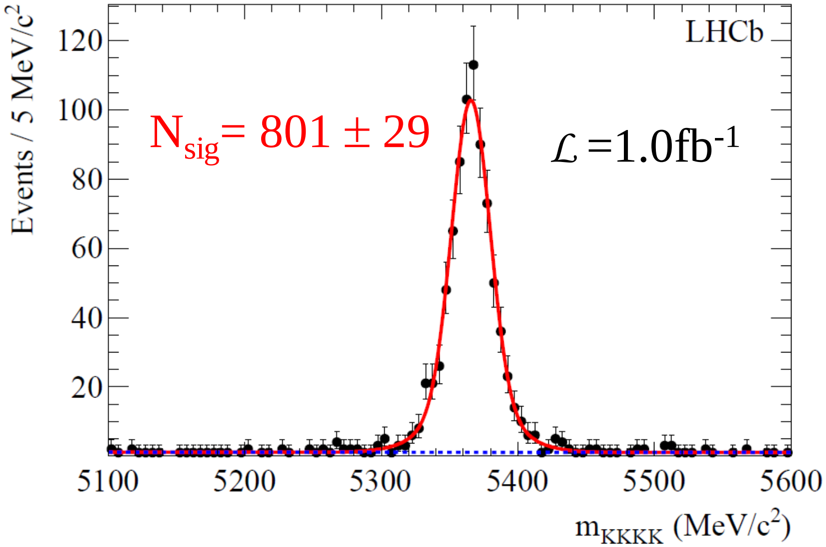
$$\lambda \equiv \left(\frac{q}{p}\right)\frac{\overline{A}_f}{A_f} \qquad \bar{\lambda} \equiv \left(\frac{p}{q}\right)\frac{A_{\bar{f}}}{\overline{A}_{\bar{f}}} \qquad \begin{aligned}\Delta m &= m_H - m_L\\ \Delta\Gamma &= \Gamma_L - \Gamma_H\end{aligned} \qquad \Gamma = \frac{\Gamma_L+\Gamma_H}{2}$$

Ulrich Nierste, arXiv:0904.1869

$B_s \to \phi\phi$

- Like $B^0 \to \phi K_S$, the decay only proceeds via penguin diagram.
- In SM, cancellation between decay and mixing phases → prediction for $\phi_s^{\phi\phi}$ is close to zero.
- Sensitive to NP in mixing or penguin.
- It needs more statistics for $\phi_s^{\phi\phi}$ measurement and will be a key channel for LHCb upgrade.





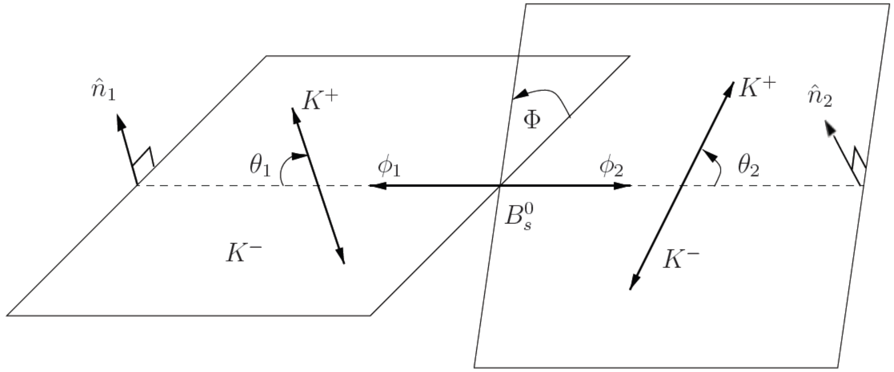
LHCb-PAPAR-2012-004, arXiv 1204.2813, submitted to PLB

$B_s \to \phi\phi$ Triple Product Asymmetries

- Triple Product Asymmetries

$$A_u \equiv \frac{\Gamma(U>0)-\Gamma(U<0)}{\Gamma(U>0)+\Gamma(U<0)}$$

$$A_v \equiv \frac{\Gamma(V>0)-\Gamma(V<0)}{\Gamma(V>0)+\Gamma(V<0)}$$



No tagging needed

$$U \equiv \sin(2\Phi)/2$$
$$V \equiv \sin\Phi \cdot \mathrm{sign}(\cos\theta_1 \cos\theta_2)$$

$$\sin\Phi = (\hat{n}_1 \times \hat{n}_2)\cdot\hat{p}_1,$$
$$\sin(2\Phi)/2 = (\hat{n}_1 \cdot \hat{n}_2)(\hat{n}_1 \times \hat{n}_2)\cdot\hat{p}_1$$

- Non-zero triple-product asymmetries imply different $\phi_s^{\phi\phi}$ in three polarization amplitudes and NP. [M. Gronau & J. Rosner PRD 84, 096013 (2011)]

LHCb-PAPER-2012-004, arXiv 1204.2813, submitted to PLB

$$A_U = -0.055 \pm 0.036\,(\mathrm{stat}) \pm 0.018\,(\mathrm{syst})$$
$$A_V = 0.010 \pm 0.036\,(\mathrm{stat}) \pm 0.018\,(\mathrm{syst})$$

Consistent with zero

Improved precision w.r.t CDF measurement [PRL 107, 261802 (2011)]

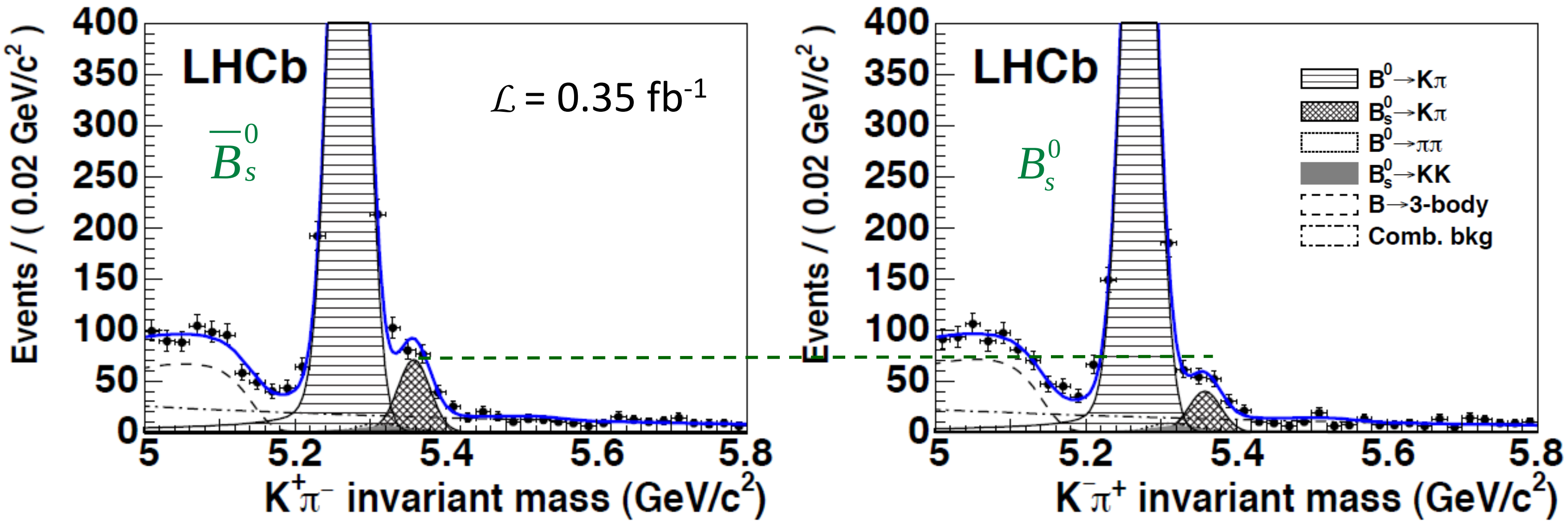
$B_s \rightarrow J/\psi\pi\pi$ Systematics

Quantity (Q)	$\pm\Delta$Q	+Change in ϕ_s (rad)	−Change in ϕ_s (rad)
β	4.4×10^{-3}	0.0008	−0.0007
$\tau_1^{\rm bkg}$ (ps)	0.046	−0.0006	0.0014
$\tau_2^{\rm bkg}$ (ps)	0.8	−0.0014	0.0014
$f_2^{\rm bkg}$	0.02	−0.0006	0.0012
$N_{\rm bkg}$	38	0.0009	−0.0001
$N_{\eta'}$	9	0.0006	0.0001
$N_{\rm sig}$	105	0.0021	0.0006
m_0 (MeV)	0.12	0.0012	−0.0004
σ_1^m (MeV)	0.1	−0.0002	0.0008
α	1.1×10^{-4}	0.0003	0.0003
T function	5%	0.0005	0.0005
CP-even	multiply dilution by 0.954	−0.0008	0
Direct CP	free in fit	−0.0020	0
Total systematic uncertainty on ϕ_s		$^{+0.004}_{-0.003}$	

Direct A_{CP} in $B_s \to K^{\mp}\pi^{\pm}$

Untagged time-integrated Asymmetry

$$A_{CP} = \frac{|\bar{A}_{\bar{f}}|^2 - |A_f|^2}{|\bar{A}_{\bar{f}}|^2 + |A_f|^2} + \mathcal{O}(a_{SL})$$



$$\boxed{A_{CP}(B_s^0 \to K\pi) = (27 \pm 8(\text{stat}) \pm 2(\text{syst}))\%}$$

PRL 108, 201601 (2012)

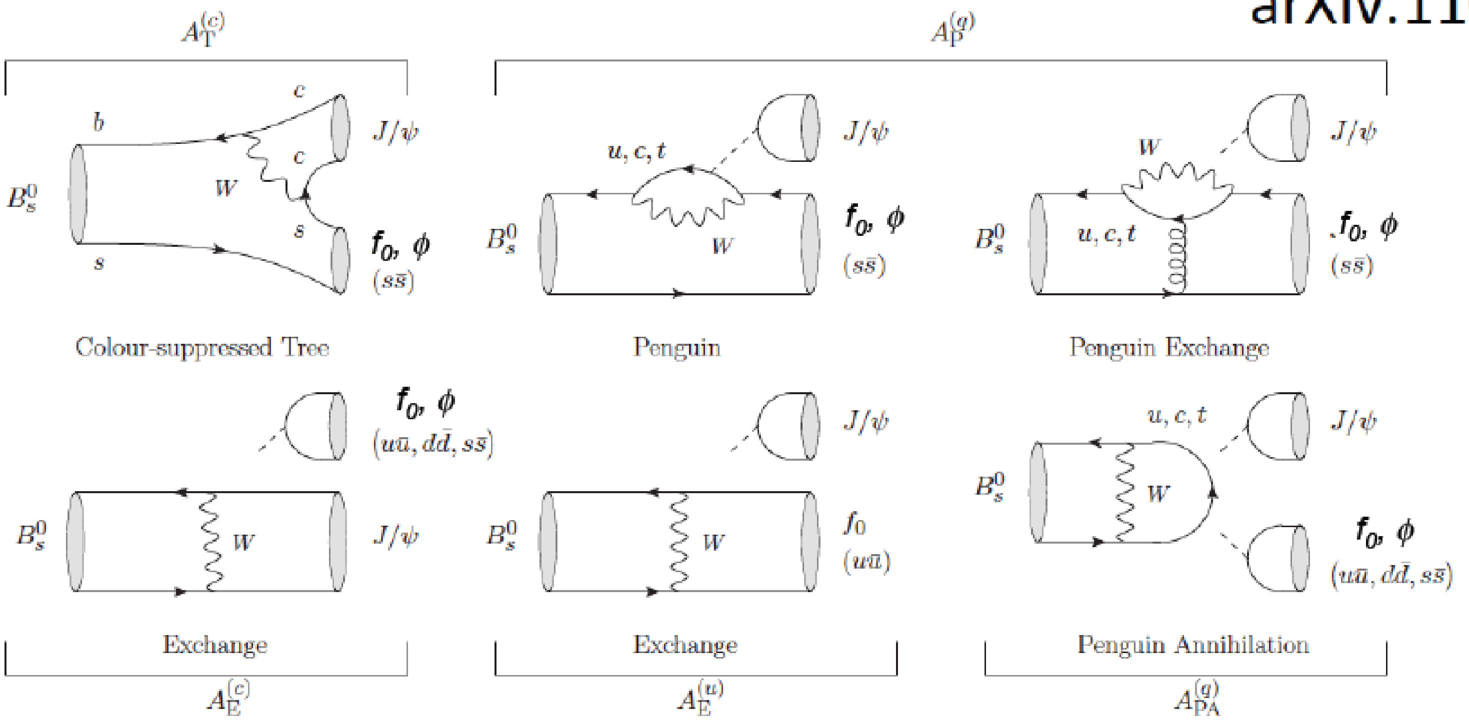
First evidence of direct *CPV* in $B_s \to K^-\pi^+$

CDF: (39 ± 15(stat) ± 8(syst))% PRL 106, 181802 (2011)

Penguin etc.

- Something to be learned by comparing the CPV in the ϕ & $\pi\pi$ modes ala' Fleischer

arXiv:1109.1112



- Not clear any diff f_0-ϕ, depends on $s\bar{s}$ content

Tetraquarks