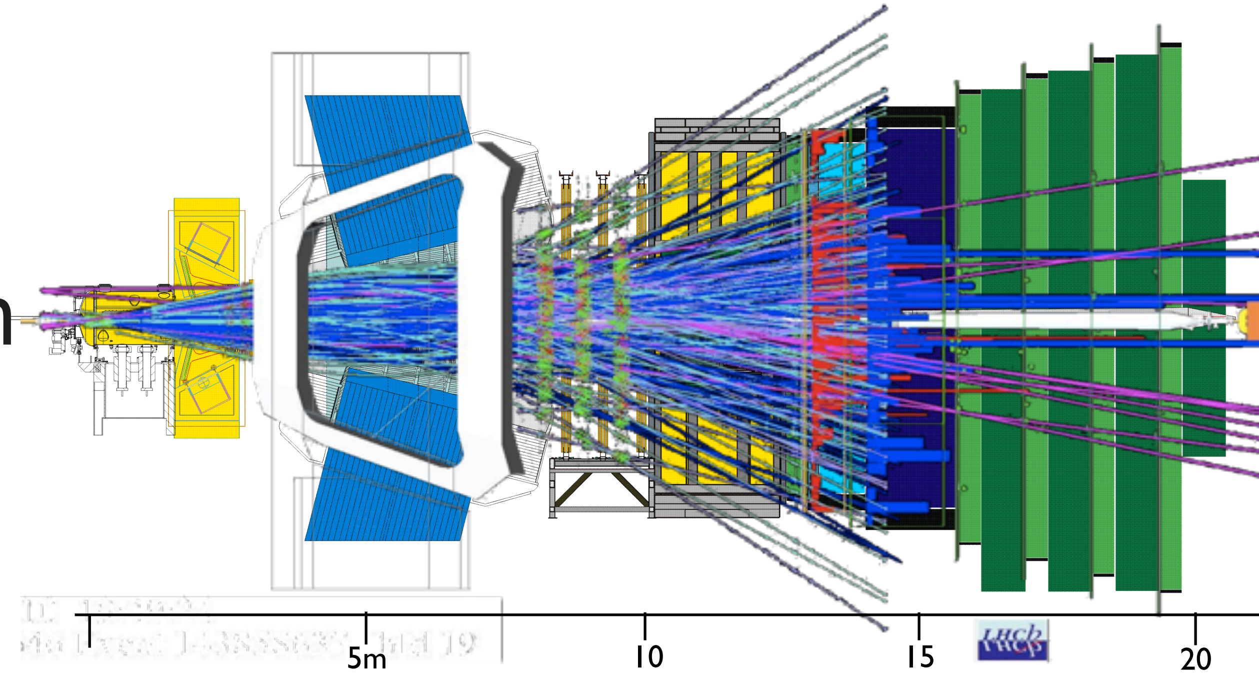
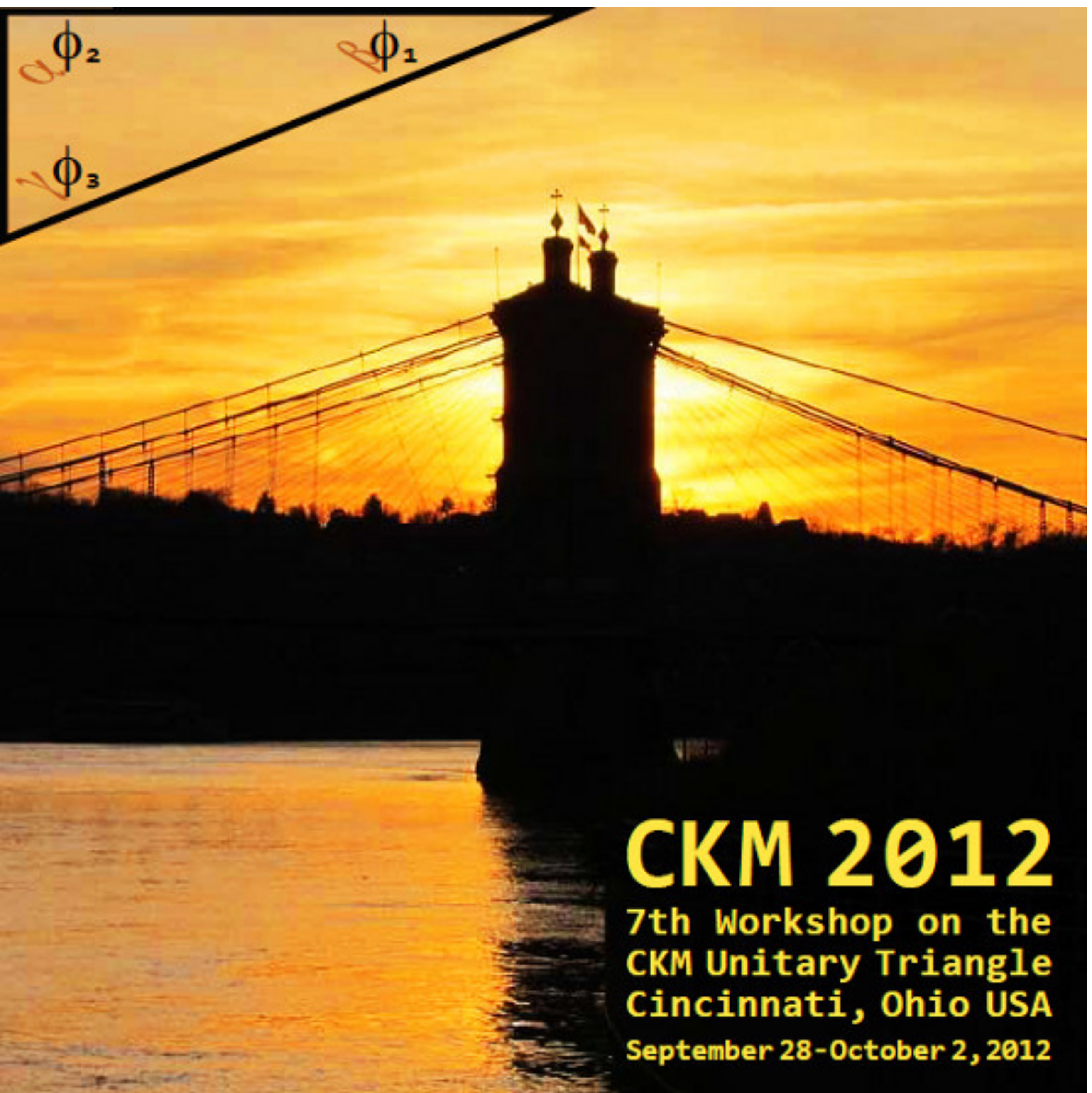
Measurement of ~~Mixing and~~ (*) the CPV Phase φ_s in the B_s System at LHCb

Gerhard Raven
on behalf of the LHCb collaboration





Outline:

- $B_s \to J/\psi\ \varphi(KK)$ — LHCb-CONF-2012-002, LHCb-PAPER-2011-028
- $B_s \to J/\psi\ \pi\pi$ — LHCb-PAPER-2012-005, LHCb-PAPER-2012-006
- $B_s \to J/\psi\ \underline{K}^{*0}(K\pi)$ — LHCb-PAPER-2012-014

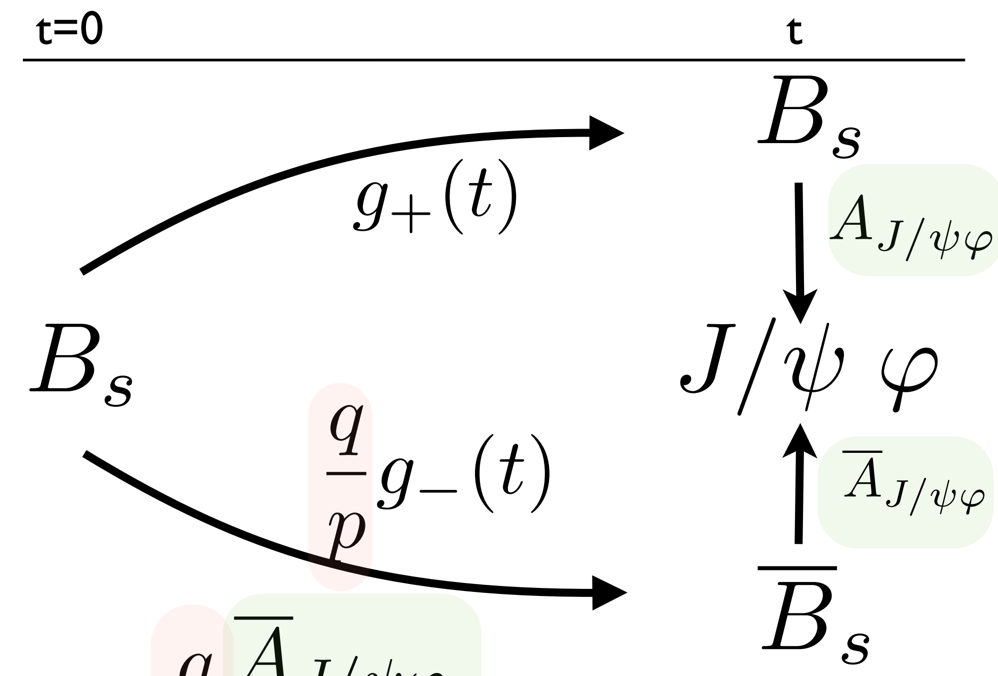
(*) see talk (previous session) by Julian Wishahi: "Measurement of Δm_d, Δm_s, and sin2β from LHCb"

vrije Universiteit amsterdam
NIKHEF

CP violation in $\overset{(-)}{B}_s \to J/\psi\varphi$

Interference between decay with/without mixing gives rise to CP-violating phase difference:

$$\phi_s = \arg(\lambda) = \phi_M - 2\phi_{c\bar{c}s}$$



$$\lambda \equiv \frac{q}{p}\frac{\overline{A}_{J/\psi\varphi}}{A_{J/\psi\varphi}}$$

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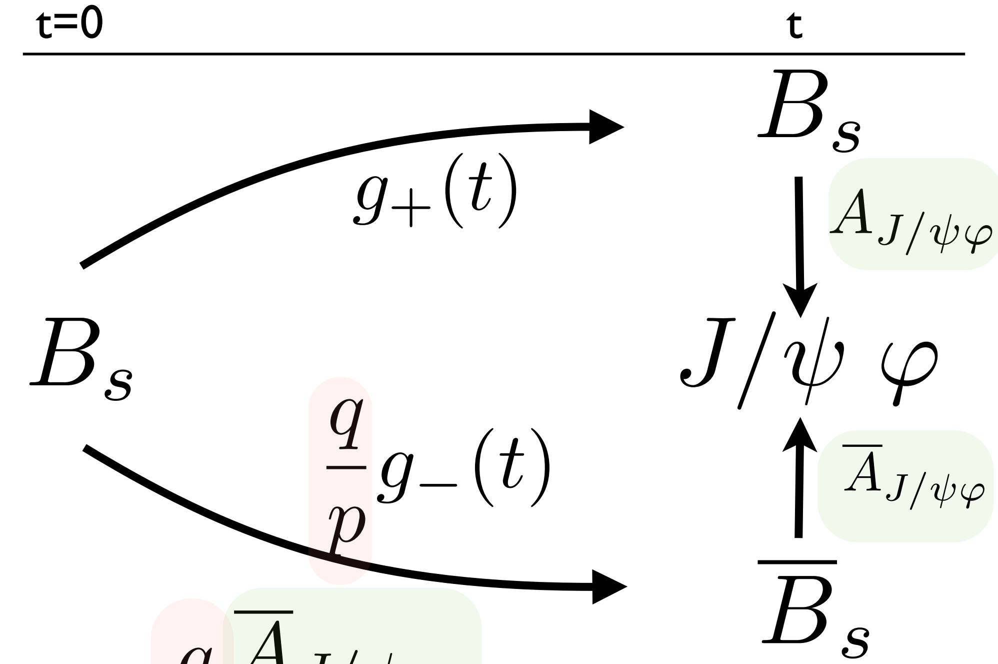

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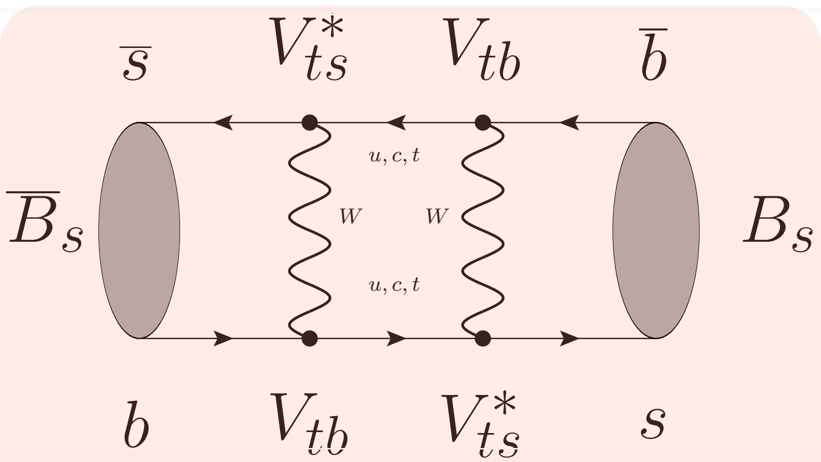
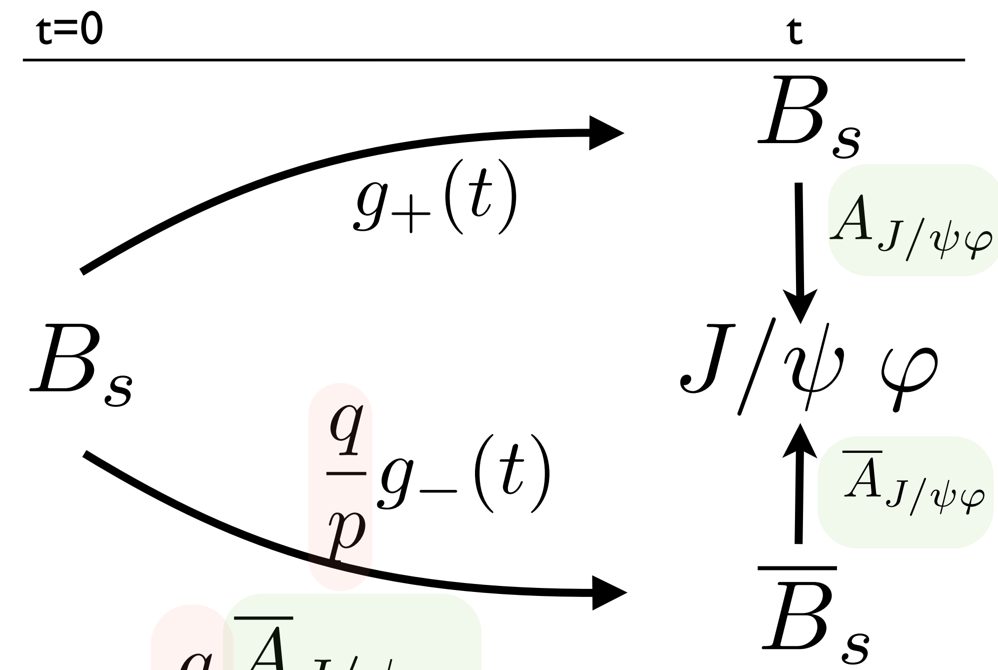


$$\phi_M^{SM} = \arg\left(V_{tb}V_{ts}^*\right)^2$$

CP violation in $\overset{(-)}{B}_s \to J/\psi\varphi$



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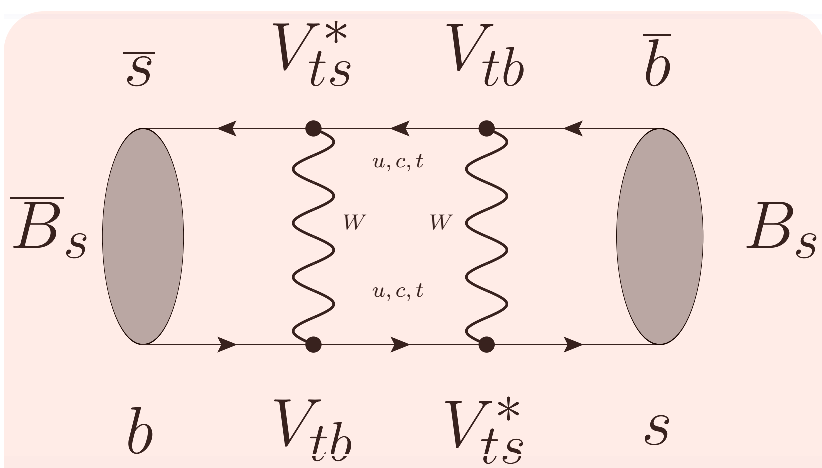

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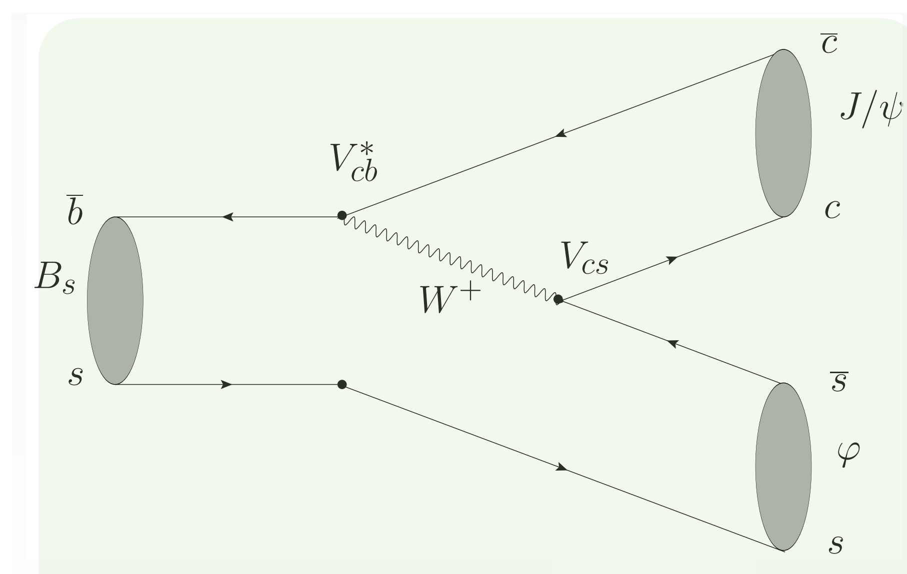
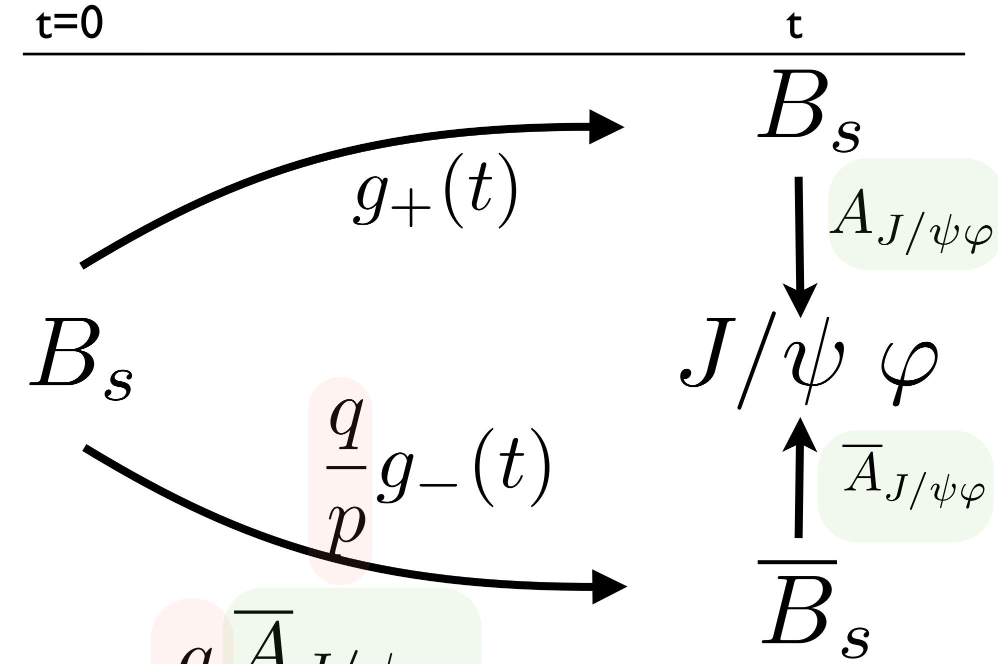


$\phi_{c\bar{c}s}^{SM} = \arg(V_{cb}V_{cs}^*)$
+ small penguin contribution

CP violation in $\overset{(-)}{B}_s \to J/\psi\varphi$

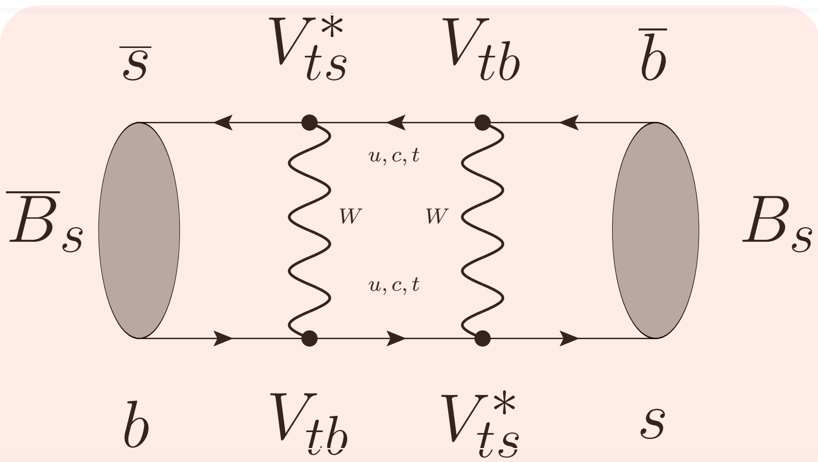


$$\lambda \equiv \frac{q}{p}\frac{\overline{A}_{J/\psi\varphi}}{A_{J/\psi\varphi}}$$

Interference between decay with/without mixing gives rise to CP-violating phase difference:

$$\phi_s = \arg(\lambda) = \phi_M - 2\phi_{c\bar{c}s}$$
$$= -2\arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) \equiv -2\beta_s \approx -0.04$$

(arXiv:1102.4274)



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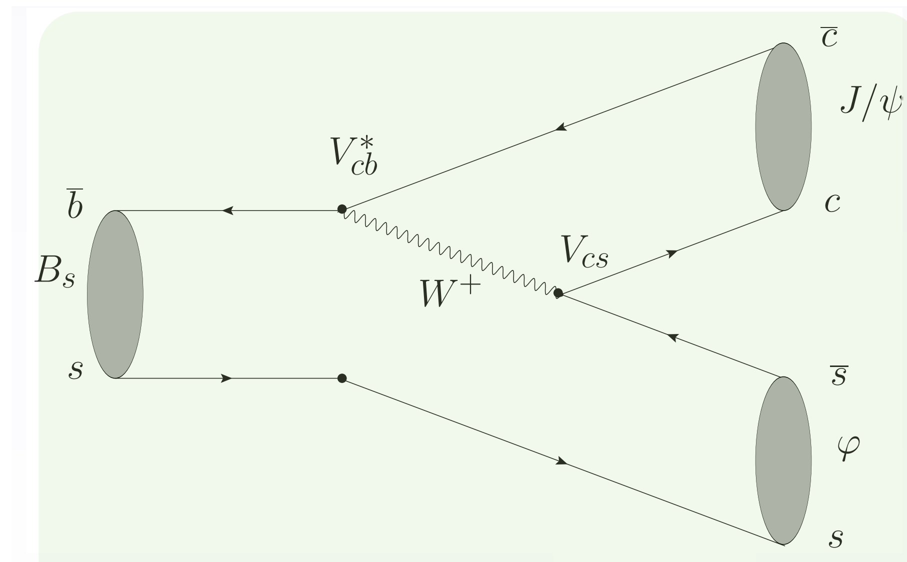

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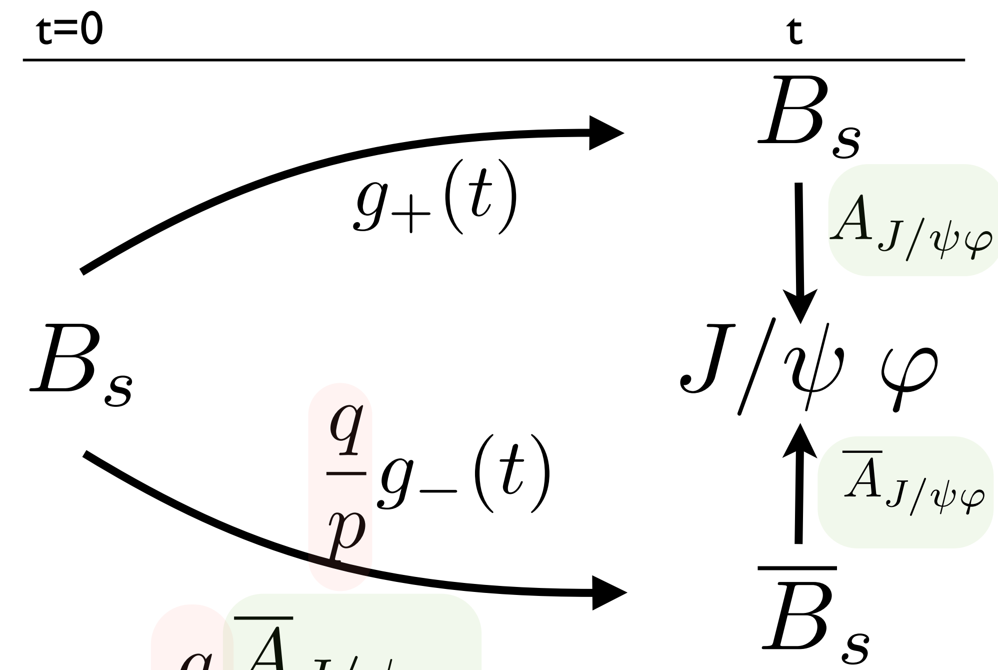
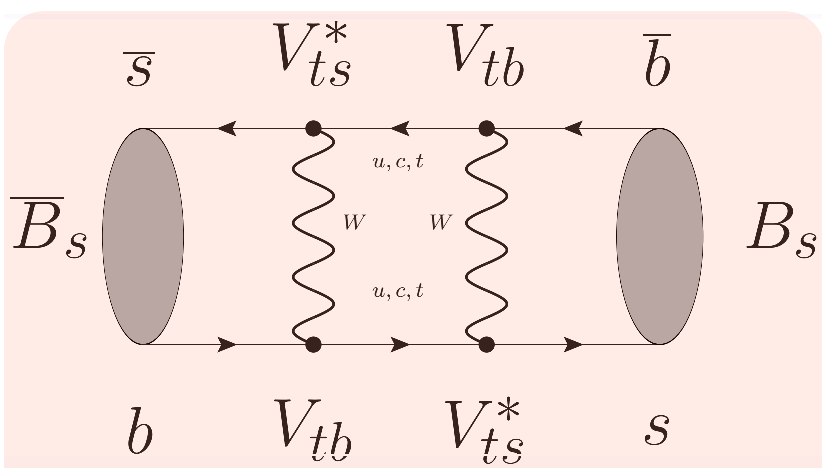


$$\lambda \equiv \frac{q}{p}\frac{\overline{A}_{J/\psi\varphi}}{A_{J/\psi\varphi}}$$

Interference between decay with/without mixing gives rise to CP-violating phase difference:

$$\phi_s = \arg(\lambda) = \phi_M - 2\phi_{c\bar{c}s}$$
$$= -2\beta_s + \Delta\phi^{NP}$$



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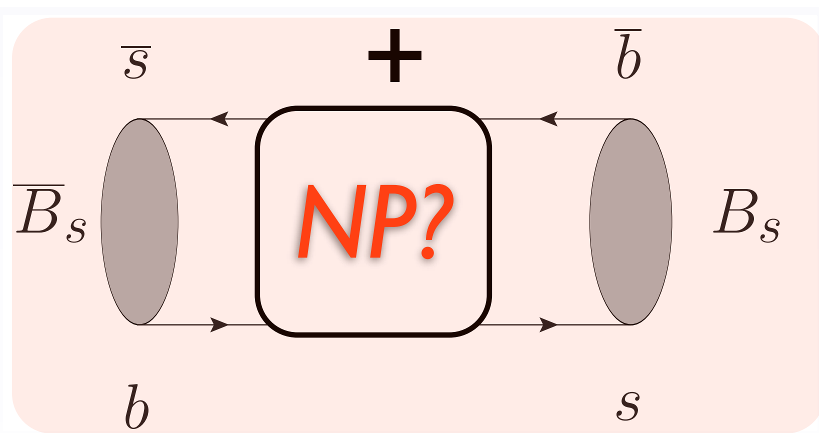

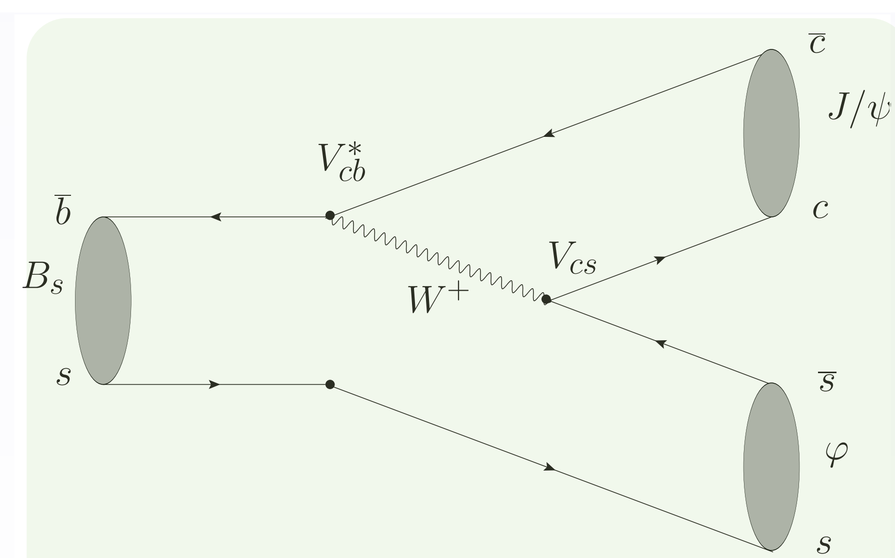

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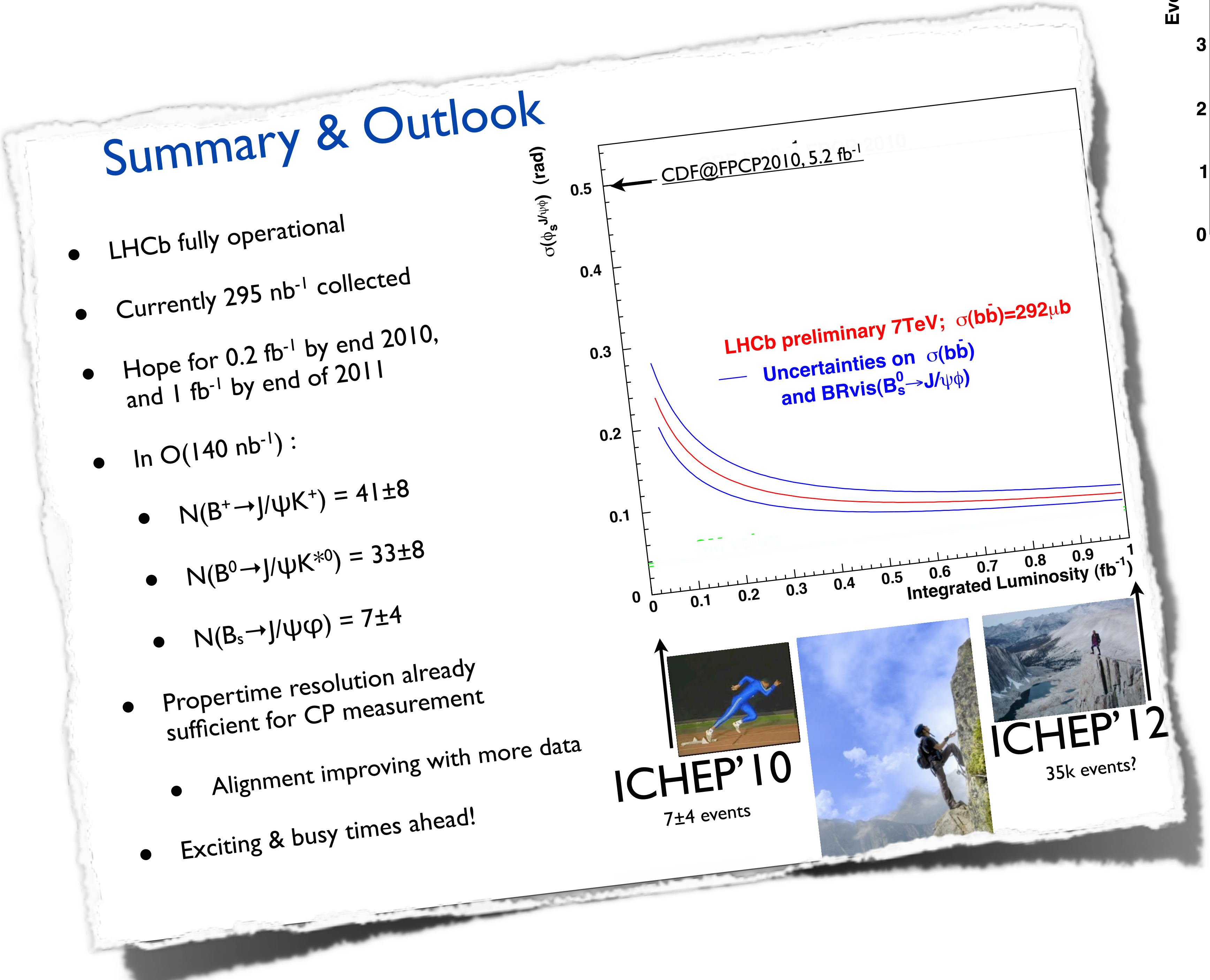
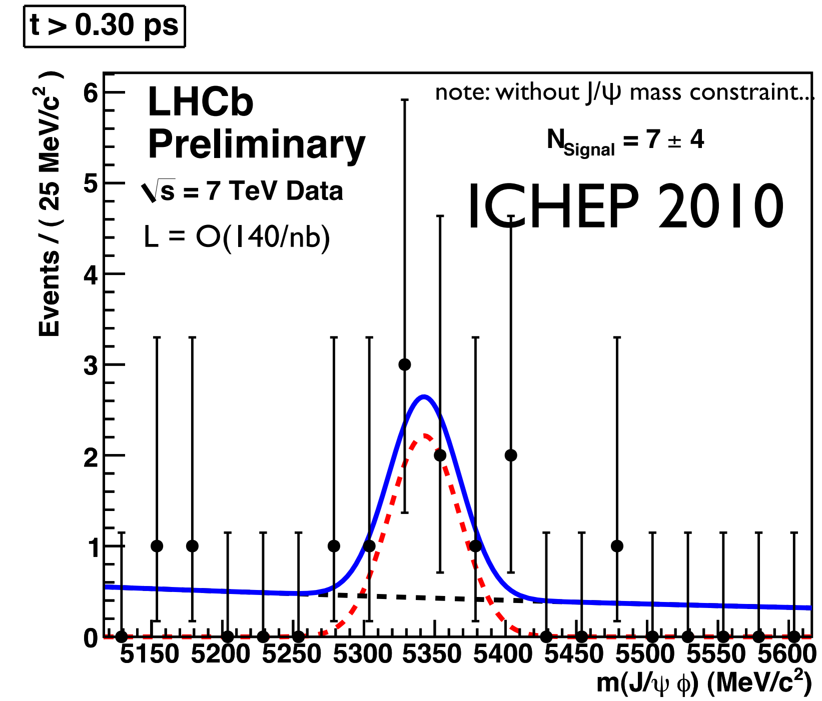
LHC*b*: $B_s \to J/\psi\varphi$



Summary & Outlook

- LHCb fully operational
- Currently 295 nb^{-1} collected
- Hope for 0.2 fb^{-1} by end 2010, and 1 fb^{-1} by end of 2011
- In O(140 nb^{-1}) :
  - $N(B^+ \to J/\psi K^+) = 41 \pm 8$
  - $N(B^0 \to J/\psi K^{*0}) = 33 \pm 8$
  - $N(B_s \to J/\psi\varphi) = 7 \pm 4$
- Propertime resolution already sufficient for CP measurement
  - Alignment improving with more data
- Exciting & busy times ahead!



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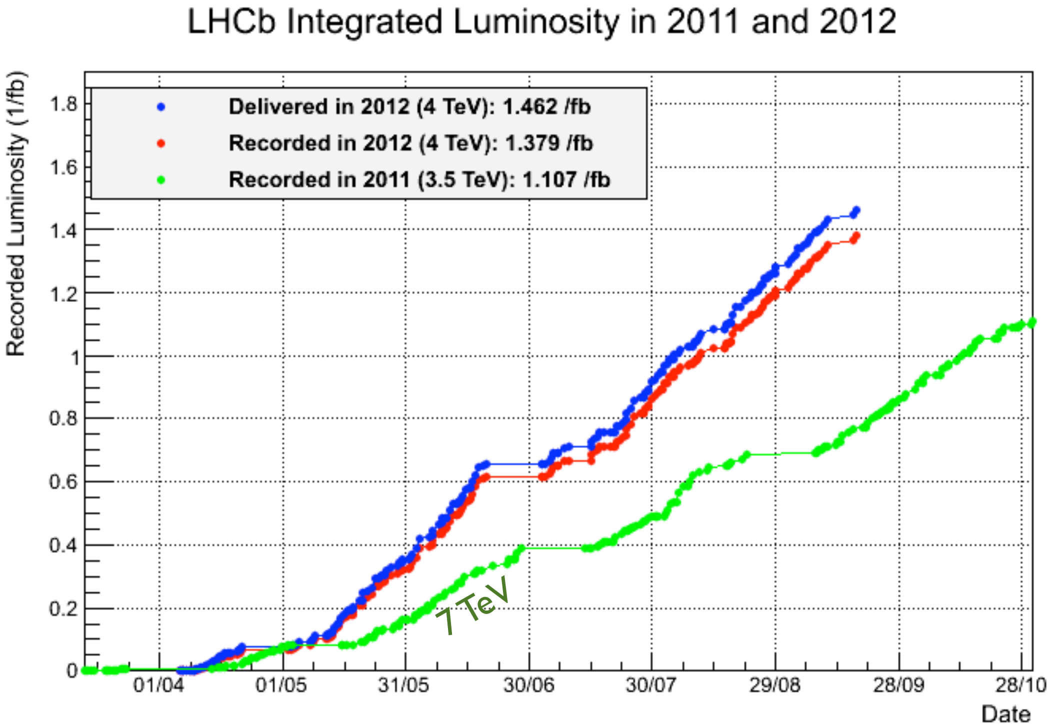

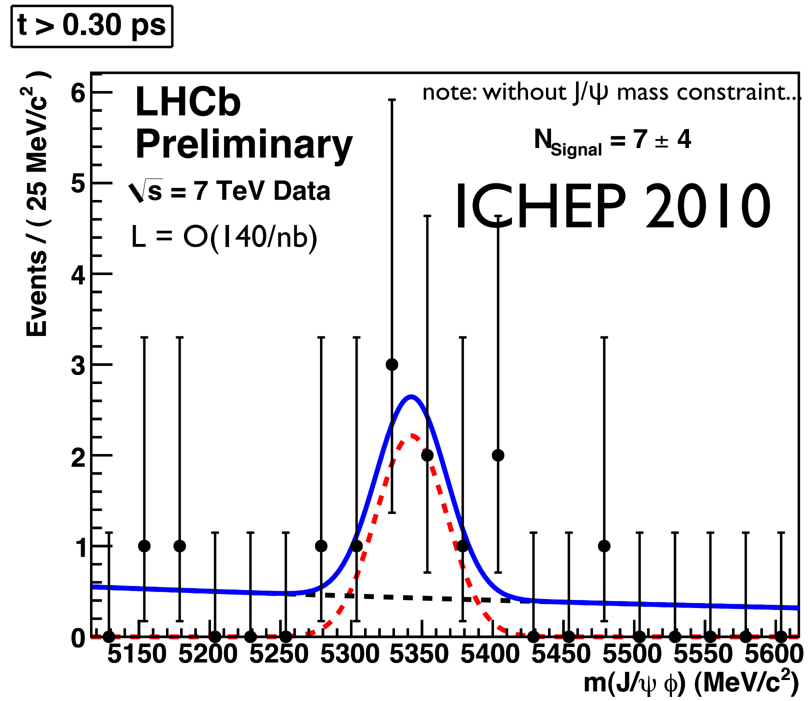

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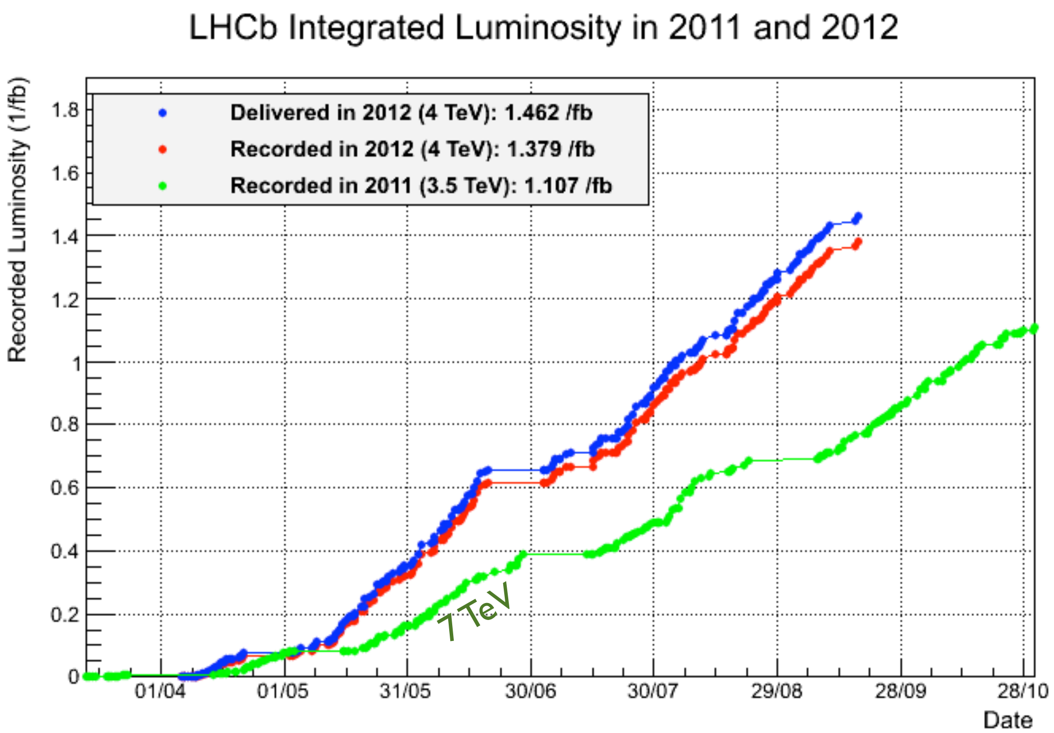
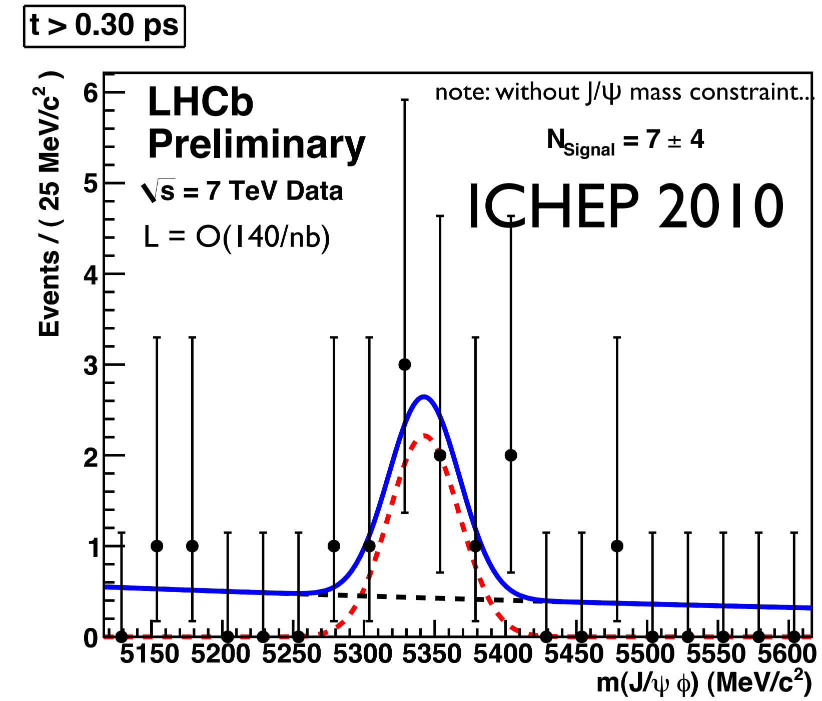
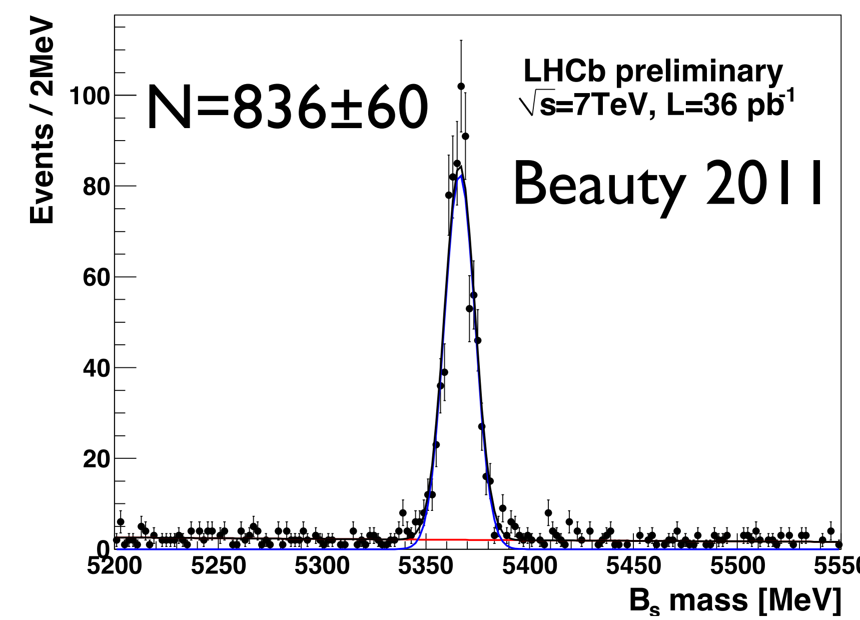


2010: 0.04 fb^{-1}





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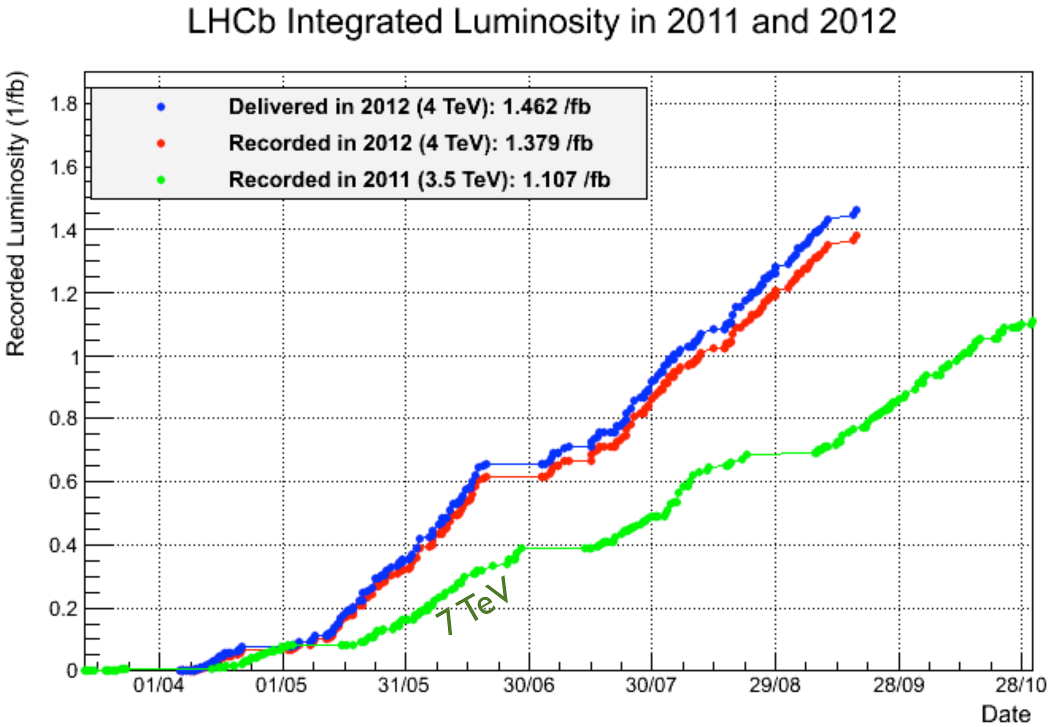

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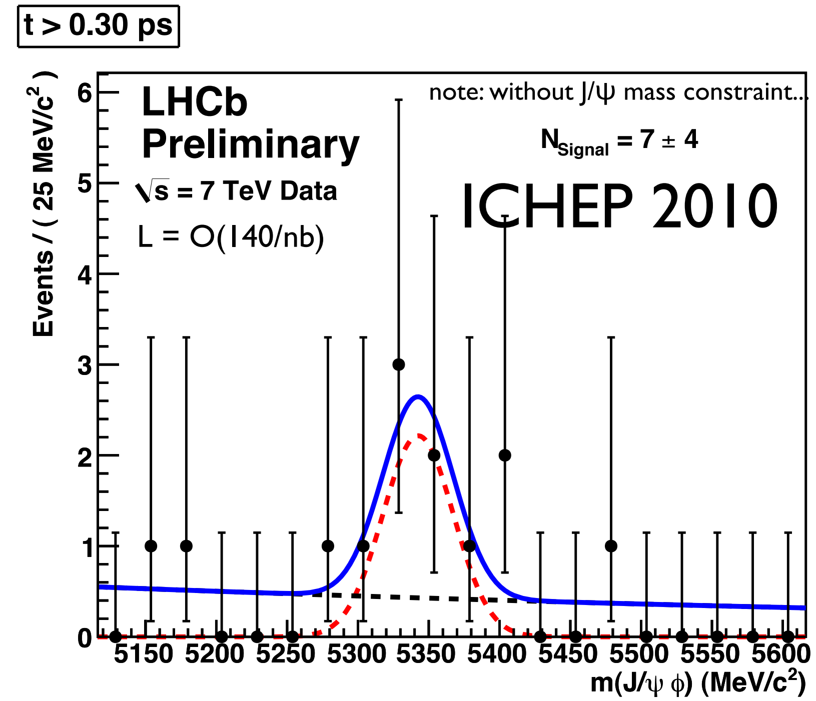

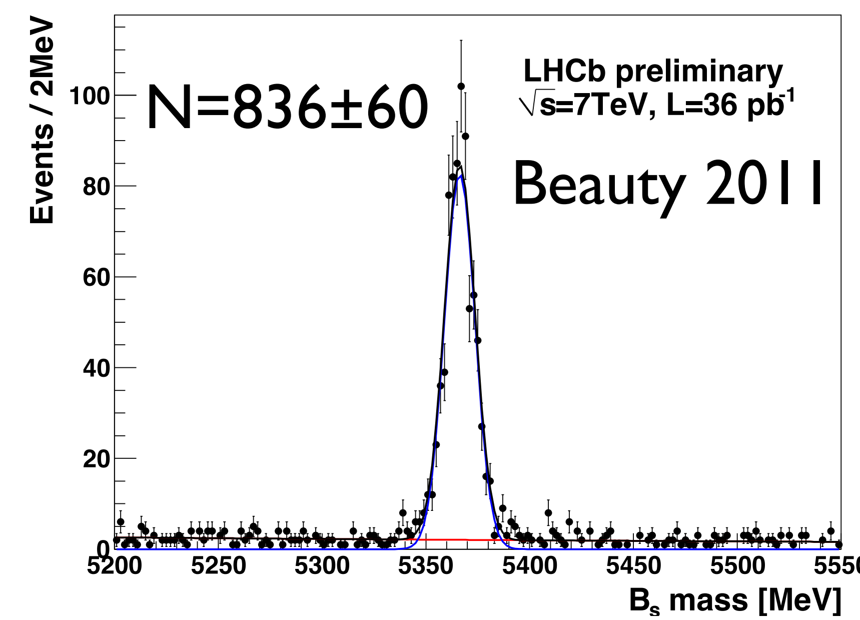

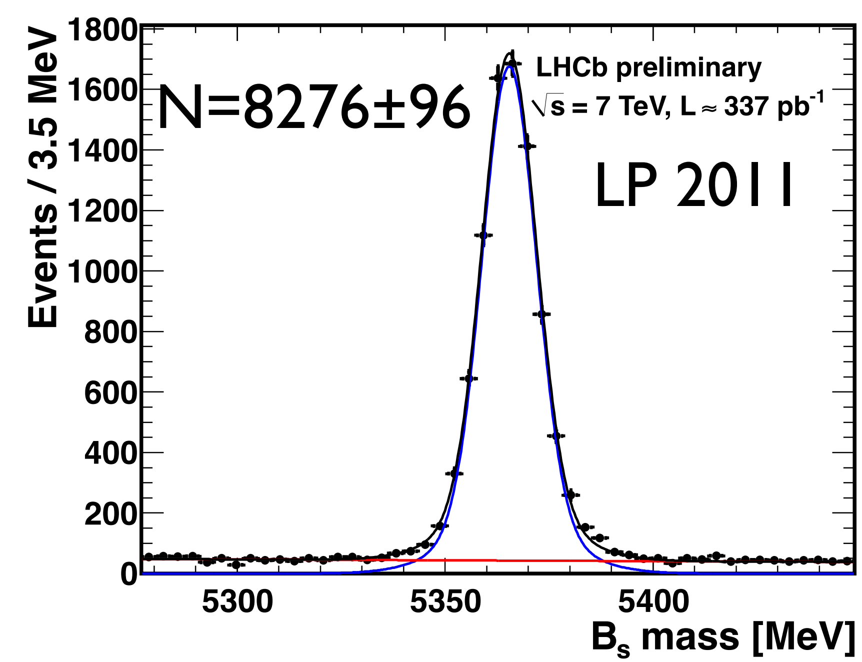

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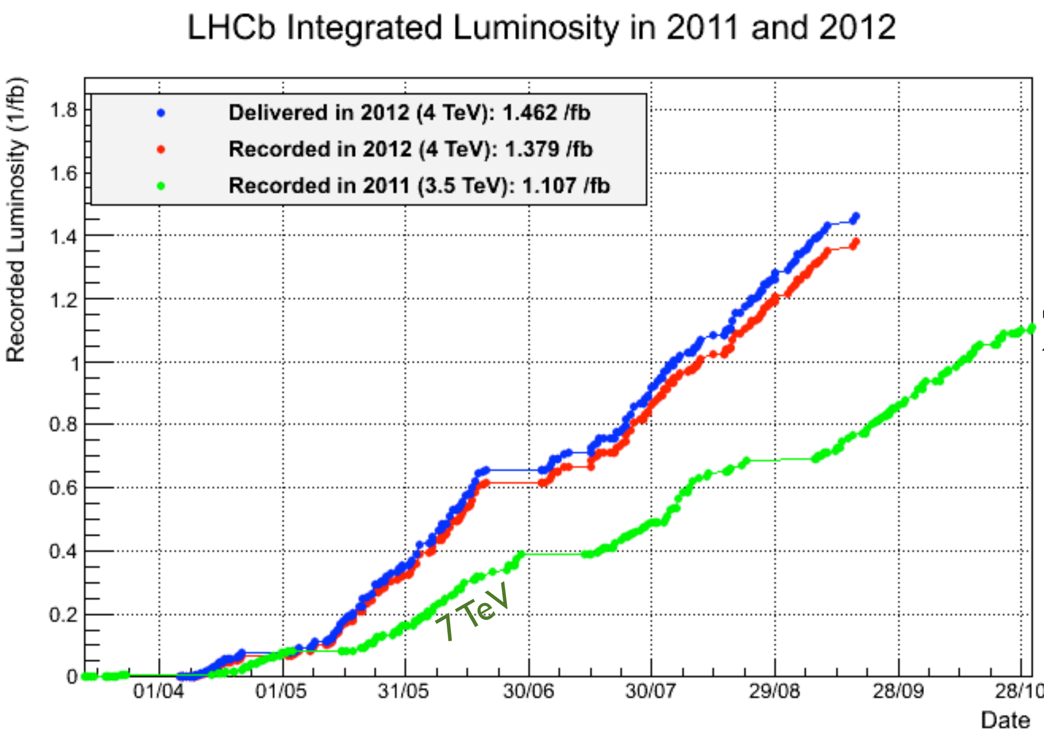
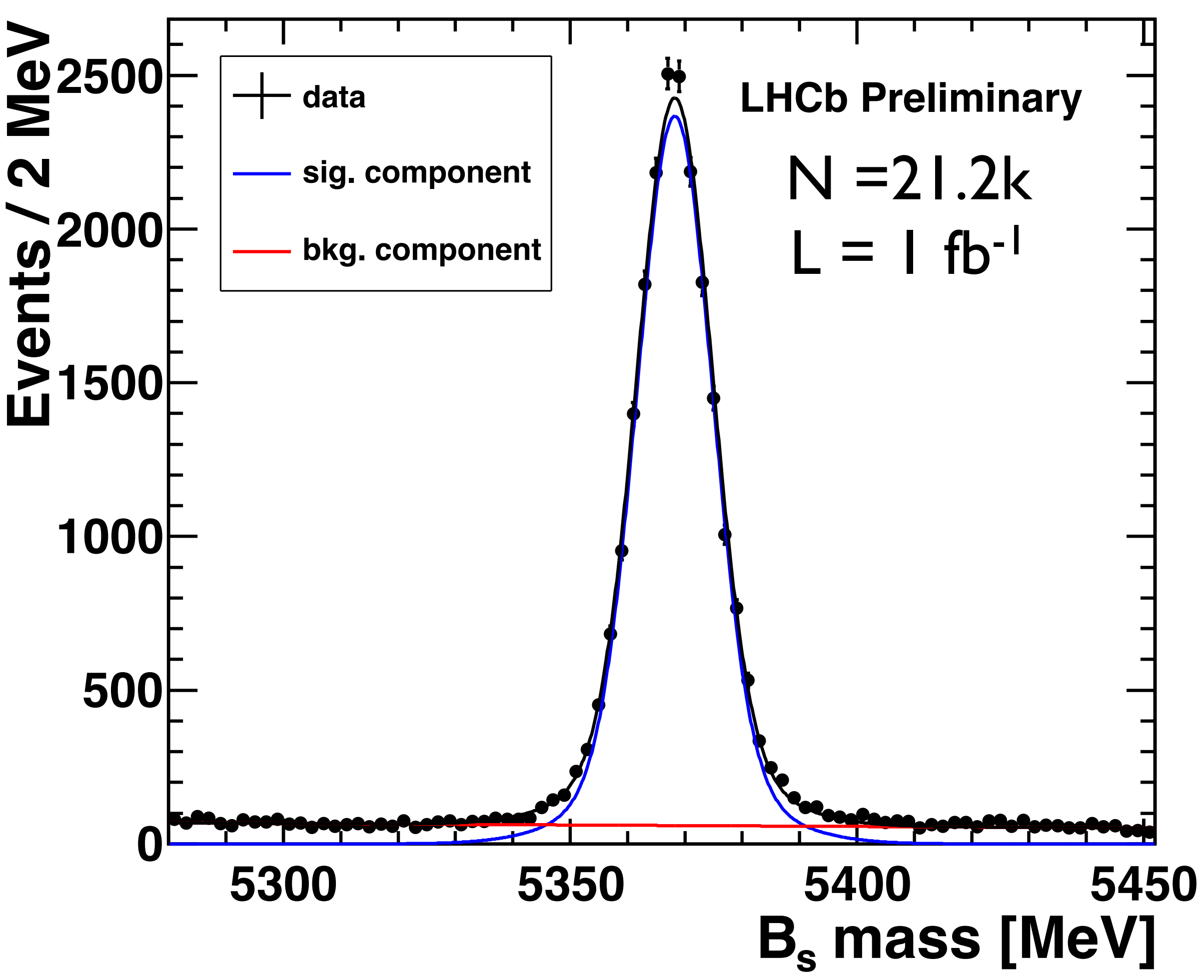
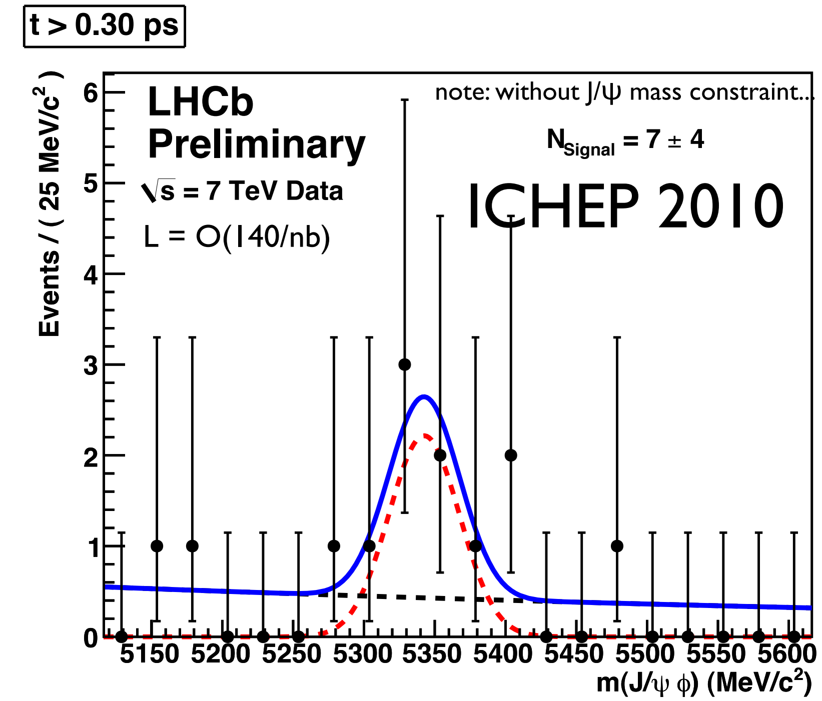
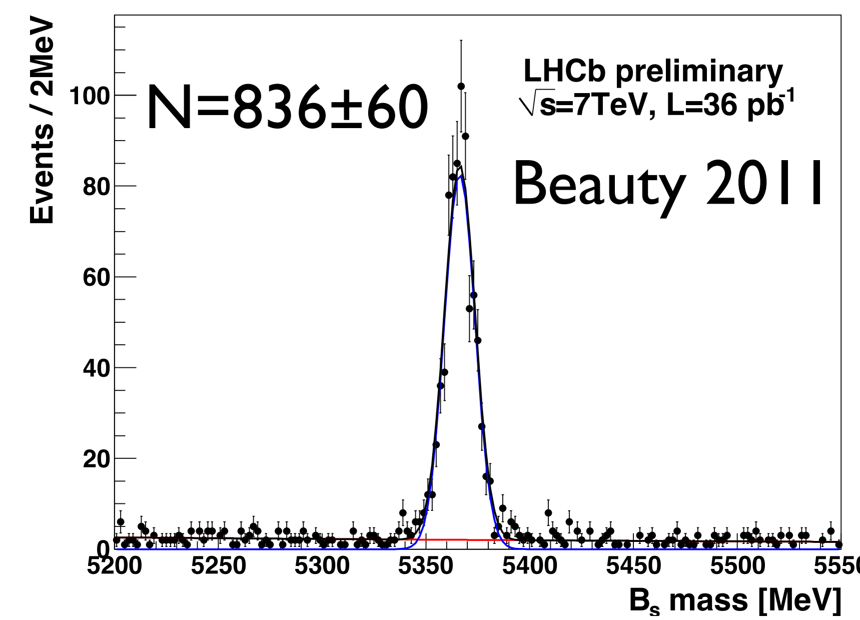


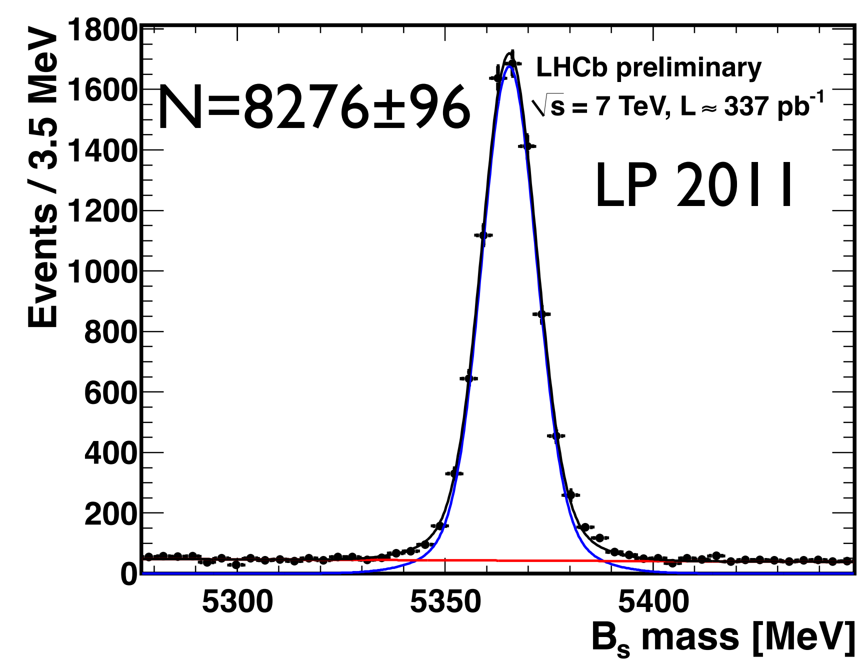
2011: +1 fb^{-1}

2010: 0.04 fb^{-1}









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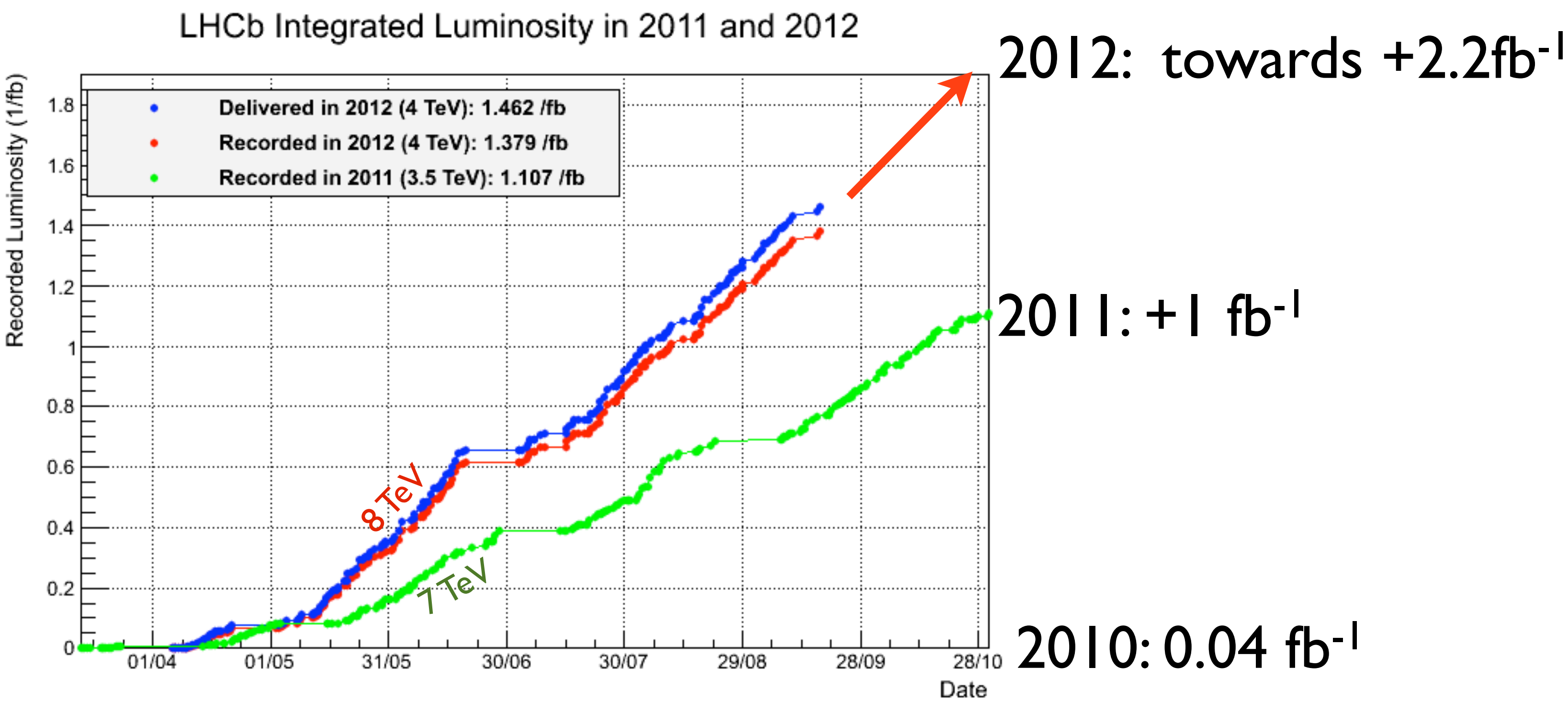

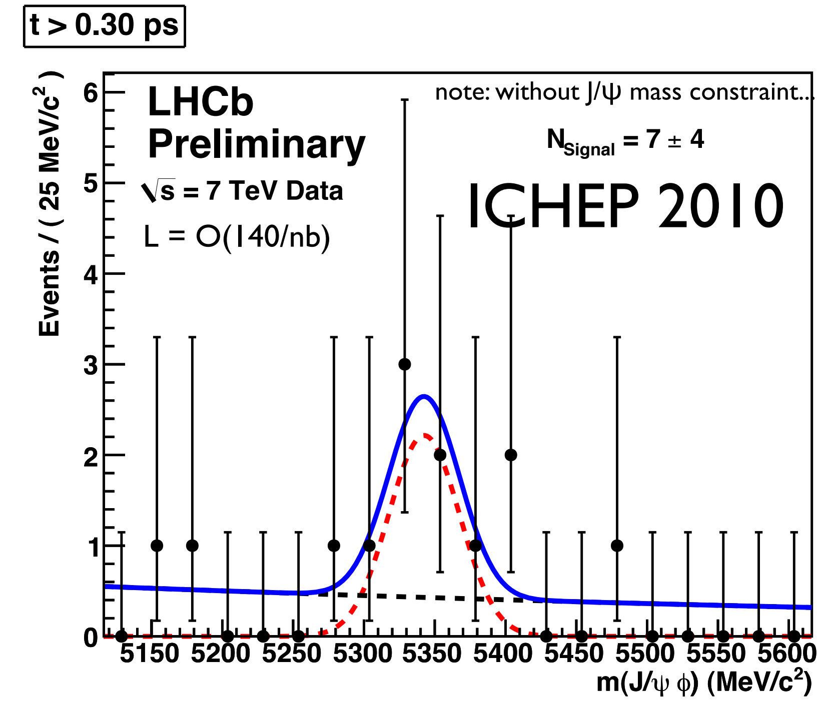

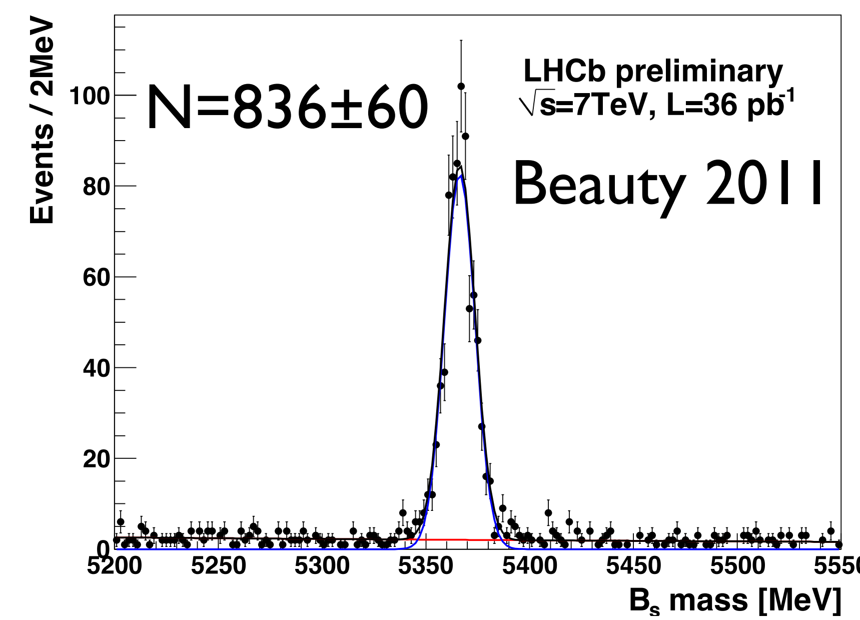

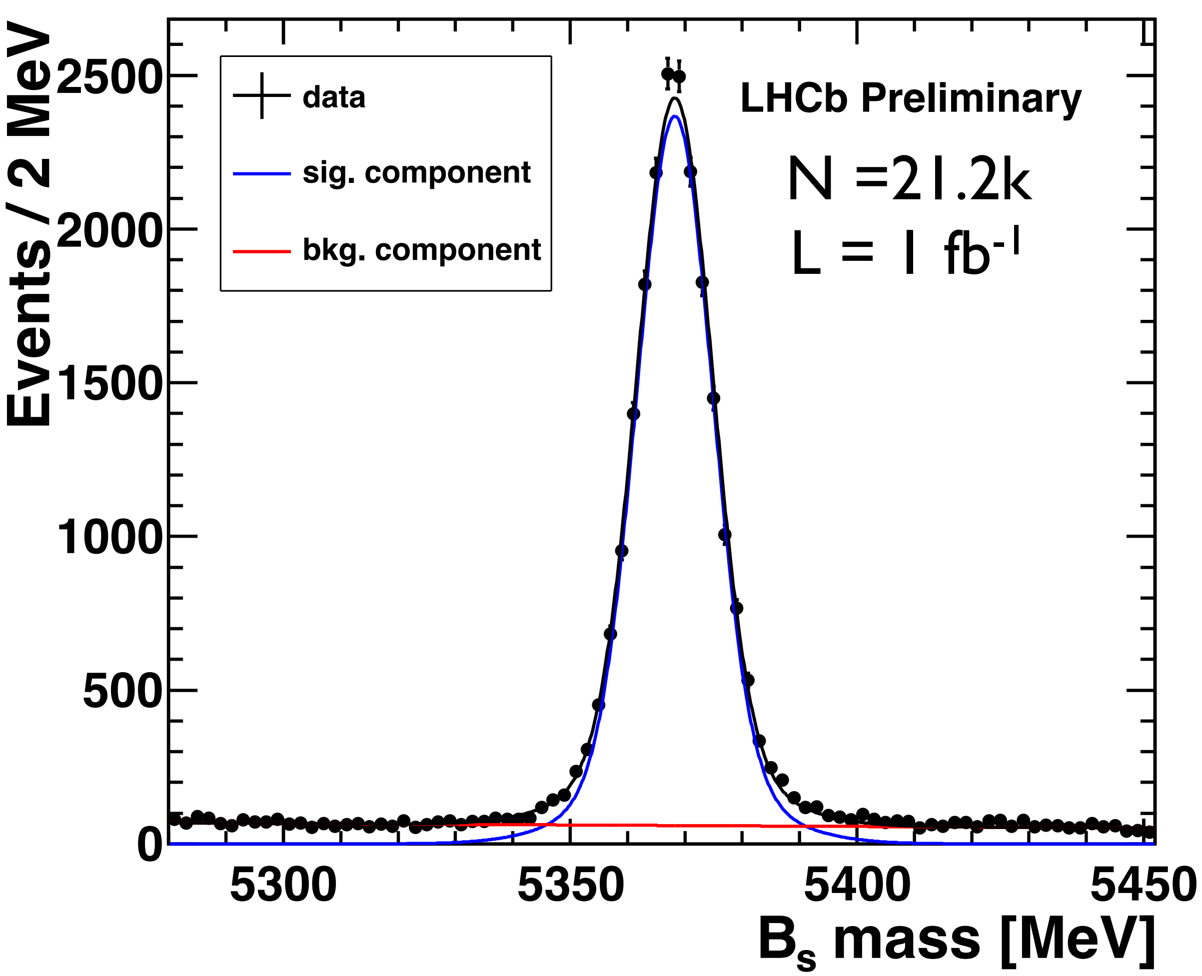

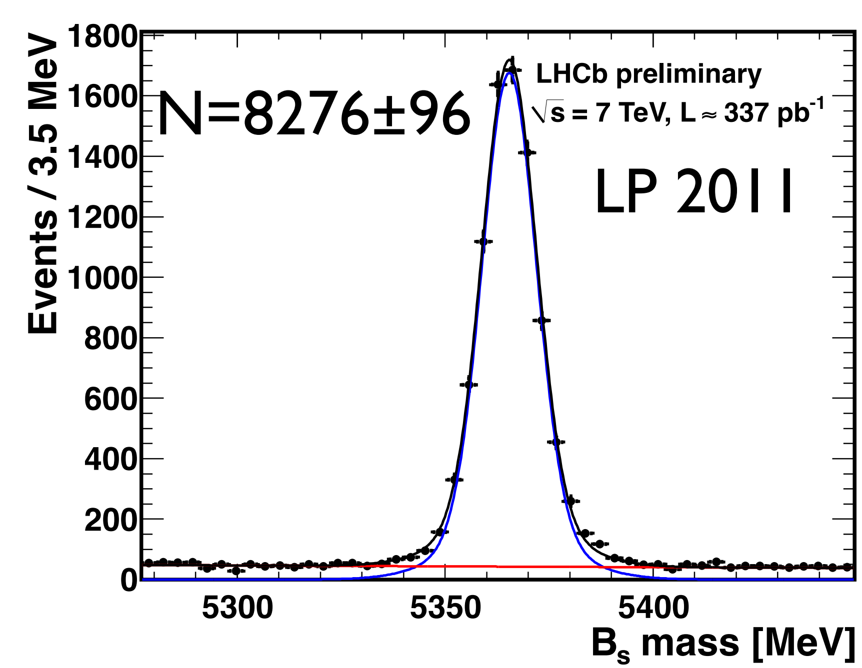

CP violation in $B_s \to J/\psi\varphi$: ingredients

- For CP eigenstate f with eigenvalue η_f, define

$$A_{\mathrm{CP}} \equiv \frac{\Gamma\left(\overline{B}_s^0 \to f\right) - \Gamma\left(B_s^0 \to f\right)}{\Gamma\left(\overline{B}_s^0 \to f\right) + \Gamma\left(B_s^0 \to f\right)} = \eta_f \sin\phi_s \sin(\Delta m_s t)$$

  - Δm_s is the B_s-$\overline{B}_s$ mixing frequency

    ➡ see talk Julian Wishahi (previous session)

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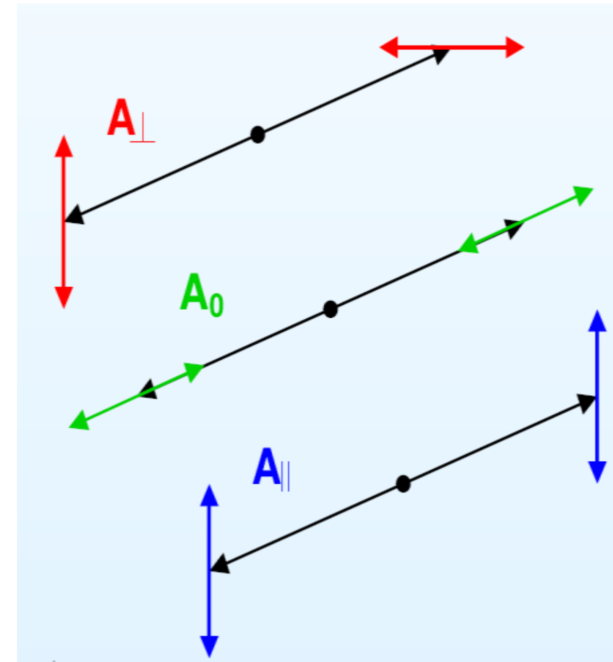
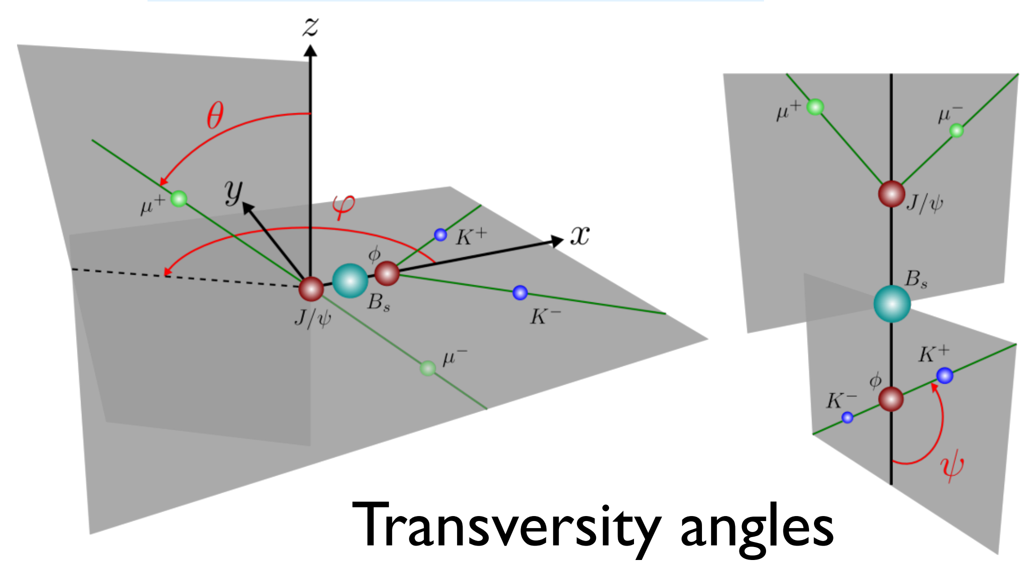
- $B_s \rightarrow J/\psi\varphi$: admixture of CP even/odd → angular analysis to disentangle
- Need flavour tagging -- which has a non-zero mistag probability w
- Decay time measurement has finite resolution σ_t

$$A_{\mathrm{CP}} \approx (1-2w) e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2} \eta_f \sin\phi_s \sin(\Delta m_s t)$$

CP violation in $B_s \to J/\psi\varphi$: ingredients



- PS → VV : 3 polarization amplitudes
  - Describe in transversity basis
    - L=0,2 : A_0, $A_\parallel$ (CP even)
    - L=1 : $A_\perp$ (CP odd)
- K^+K^- S-wave (CP odd)



Transversity angles
$\Omega = \{\theta, \phi, \psi\}$

- 4 Amplitudes → 10 combinations: $$\frac{d^4\Gamma(B_s^0 \to J/\psi K^+K^-)}{dt\,d\Omega} \propto \sum_{k=1}^{10} f_k(\Omega) h_k(t)$$

CP violation in $B_s \to J/\psi\varphi$: ingredients

- 4 Amplitudes → 10 components $$\frac{d^4\Gamma(B_s^0 \to J/\psi K^+K^-)}{dt d\Omega} \propto \sum_{k=1}^{10} f_k(\Omega) h_k(t)$$

$$h_k(t) \;=\; N_k e^{-\Gamma_s t}\left[a_k \cosh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + b_k \sinh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + c_k \cos(\Delta m_s t) + d_k \sin(\Delta m_s t)\right]$$

k	$f_k(\theta,\psi,\varphi)$	N_k	a_k	b_k	c_k	d_k
1	$2\cos^2\psi\left(1-\sin^2\theta\cos^2\phi\right)$	$\lvert A_0(0)\rvert^2$	1	D	C	$-S$
2	$\sin^2\psi\left(1-\sin^2\theta\sin^2\phi\right)$	$\lvert A_\parallel(0)\rvert^2$	1	D	C	$-S$
3	$\sin^2\psi\sin^2\theta$	$\lvert A_\perp(0)\rvert^2$	1	$-D$	C	S
4	$-\sin^2\psi\sin 2\theta\sin\phi$	$\lvert A_\parallel(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_\parallel)$	$S\cos(\delta_\perp-\delta_\parallel)$	$\sin(\delta_\perp-\delta_\parallel)$	$D\cos(\delta_\perp-\delta_\parallel)$
5	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin^2\theta\sin 2\phi$	$\lvert A_0(0)A_\parallel(0)\rvert$	$\cos(\delta_\parallel-\delta_0)$	$D\cos(\delta_\parallel-\delta_0)$	C	$-S\cos(\delta_\parallel-\delta_0)$
6	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin 2\theta\cos\phi$	$\lvert A_0(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_0)$	$S\cos(\delta_\perp-\delta_0)$	$\sin(\delta_\perp-\delta_0)$	$D\cos(\delta_\perp-\delta_0)$
7	$\frac{2}{3}(1-\sin^2\theta\cos^2\phi)$	$\lvert A_s(0)\rvert^2$	1	$-D$	C	S
8	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$	$\lvert A_s(0)A_\parallel(0)\rvert$	$C\cos(\delta_\parallel-\delta_S)$	$S\sin(\delta_\parallel-\delta_S)$	$\cos(\delta_\parallel-\delta_S)$	$D\sin(\delta_\parallel-\delta_S)$
9	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$	$\lvert A_s(0)A_\perp(0)\rvert$	$\sin(\delta_\perp-\delta_S)$	$-D\sin(\delta_\perp-\delta_S)$	C	$S\sin(\delta_\perp-\delta_S)$
10	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$	$\lvert A_s(0)A_0(0)\rvert$	$C\cos(\delta_0-\delta_S)$	$S\sin(\delta_0-\delta_S)$	$\cos(\delta_0-\delta_S)$	$D\sin(\delta_0-\delta_S)$

- $\frac{d^4\Gamma(\overline{B}_s^0 \to J/\psi K^+K^-)}{dt d\Omega}$: $\phi_s, A_\perp, A_s \to -\phi_s, -A_\perp, -A_s$ which results in $c_k, d_k \to -c_k, -d_k$

$$S = \frac{-2\Im(\lambda)}{1+|\lambda|^2} \qquad D = \frac{-2\Re(\lambda)}{1+|\lambda|^2} \qquad C = \frac{1-|\lambda|^2}{1+|\lambda|^2}$$

Assumptions:

1) all four amplitudes have the same λ

CP violation in $B_s \to J/\psi\varphi$: ingredients

- 4 Amplitudes → 10 components $$\frac{d^4\Gamma(B_s^0 \to J/\psi K^+K^-)}{dt d\Omega} \propto \sum_{k=1}^{10} f_k(\Omega) h_k(t)$$

$$h_k(t) = N_k e^{-\Gamma_s t} \left[a_k \cosh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + b_k \sinh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + c_k \cos(\Delta m_s t) + d_k \sin(\Delta m_s t)\right]$$

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4	$-\sin^2\psi\sin 2\theta\sin\phi$	$\lvert A_\parallel(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_\parallel)$	$S\cos(\delta_\perp-\delta_\parallel)$	$\sin(\delta_\perp-\delta_\parallel)$	$D\cos(\delta_\perp-\delta_\parallel)$
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8	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$	$\lvert A_s(0)A_\parallel(0)\rvert$	$C\cos(\delta_\parallel-\delta_S)$	$S\sin(\delta_\parallel-\delta_S)$	$\cos(\delta_\parallel-\delta_S)$	$D\sin(\delta_\parallel-\delta_S)$
9	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$	$\lvert A_s(0)A_\perp(0)\rvert$	$\sin(\delta_\perp-\delta_S)$	$-D\sin(\delta_\perp-\delta_S)$	C	$S\sin(\delta_\perp-\delta_S)$
10	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$	$\lvert A_s(0)A_0(0)\rvert$	$C\cos(\delta_0-\delta_S)$	$S\sin(\delta_0-\delta_S)$	$\cos(\delta_0-\delta_S)$	$D\sin(\delta_0-\delta_S)$

- $\frac{d^4\Gamma(\overline{B}_s^0 \to J/\psi K^+K^-)}{dt d\Omega}$: $\phi_s, A_\perp, A_s \to -\phi_s, -A_\perp, -A_s$ which results in $c_k, d_k \to -c_k, -d_k$

$$S = \frac{-2\Im(\lambda)}{1+|\lambda|^2} \approx -\sin\phi_s \qquad D = \frac{-2\Re(\lambda)}{1+|\lambda|^2} \approx -\cos\phi_s \qquad C = \frac{1-|\lambda|^2}{1+|\lambda|^2} \approx 0$$

Assumptions:
1) all four amplitudes have the same λ
2) | λ |=1

CP violation in $B_s \to J/\psi\varphi$: ingredients

- 4 Amplitudes → 10 components $$\frac{d^4\Gamma(B_s^0 \to J/\psi K^+K^-)}{dt d\Omega} \propto \sum_{k=1}^{10} f_k(\Omega) h_k(t)$$

$$h_k(t) = N_k e^{-\Gamma_s t}\left[a_k \cosh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + b_k \sinh\left(\tfrac{1}{2}\Delta\Gamma_s t\right) + c_k \cos(\Delta m_s t) + d_k \sin(\Delta m_s t)\right],$$

k	$f_k(\theta,\psi,\varphi)$	N_k	a_k	b_k	c_k	d_k
1	$2\cos^2\psi\left(1-\sin^2\theta\cos^2\phi\right)$	$\lvert A_0(0)\rvert^2$	1	D	C	$-S$
2	$\sin^2\psi\left(1-\sin^2\theta\sin^2\phi\right)$	$\lvert A_\parallel(0)\rvert^2$	1	D	C	$-S$
3	$\sin^2\psi\sin^2\theta$	$\lvert A_\perp(0)\rvert^2$	1	$-D$	C	S
4	$-\sin^2\psi\sin 2\theta\sin\phi$	$\lvert A_\parallel(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_\parallel)$	$S\cos(\delta_\perp-\delta_\parallel)$	$\sin(\delta_\perp-\delta_\parallel)$	$D\cos(\delta_\perp-\delta_\parallel)$
5	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin^2\theta\sin 2\phi$	$\lvert A_0(0)A_\parallel(0)\rvert$	$\cos(\delta_\parallel-\delta_0)$	$D\cos(\delta_\parallel-\delta_0)$	C	$-S\cos(\delta_\parallel-\delta_0)$
6	$\frac{1}{2}\sqrt{2}\sin 2\psi\sin 2\theta\cos\phi$	$\lvert A_0(0)A_\perp(0)\rvert$	$C\sin(\delta_\perp-\delta_0)$	$S\cos(\delta_\perp-\delta_0)$	$\sin(\delta_\perp-\delta_0)$	$D\cos(\delta_\perp-\delta_0)$
7	$\frac{2}{3}(1-\sin^2\theta\cos^2\phi)$	$\lvert A_s(0)\rvert^2$	1	$-D$	C	S
8	$\frac{1}{3}\sqrt{6}\sin\psi\sin^2\theta\sin 2\phi$	$\lvert A_s(0)A_\parallel(0)\rvert$	$C\cos(\delta_\parallel-\delta_S)$	$S\sin(\delta_\parallel-\delta_S)$	$\cos(\delta_\parallel-\delta_S)$	$D\sin(\delta_\parallel-\delta_S)$
9	$\frac{1}{3}\sqrt{6}\sin\psi\sin 2\theta\cos\phi$	$\lvert A_s(0)A_\perp(0)\rvert$	$\sin(\delta_\perp-\delta_S)$	$-D\sin(\delta_\perp-\delta_S)$	C	$S\sin(\delta_\perp-\delta_S)$
10	$\frac{4}{3}\sqrt{3}\cos\psi(1-\sin^2\theta\cos^2\phi)$	$\lvert A_s(0)A_0(0)\rvert$	$C\cos(\delta_0-\delta_S)$	$S\sin(\delta_0-\delta_S)$	$\cos(\delta_0-\delta_S)$	$D\sin(\delta_0-\delta_S)$

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Assumptions:
1) all four amplitudes have the same λ
2) | λ |=1

Note: at this point, there exists a two-fold discrete ambiguity:

$$(\phi_s, \Delta\Gamma_s, \delta_\parallel, \delta_\perp) \leftrightarrow (\pi-\phi_s, -\Delta\Gamma_s, 2\pi-\delta_\parallel, \pi-\delta_\perp)$$

CP violation in $B_s \to J/\psi\varphi$: ingredients

- Signal PDF: flavour tagged, time dependent, angular dependent:

$$S(t,\vec{\Omega};\vec{\lambda}) = \epsilon(t,\vec{\Omega}) \times \left(\frac{1+qD}{2} s(t,\vec{\Omega};\vec{\lambda}) + \frac{1-qD}{2}\overline{s}(t,\vec{\Omega};\vec{\lambda})\right) \otimes R_t$$

time & angular acceptance

flavour tagging

time resolution

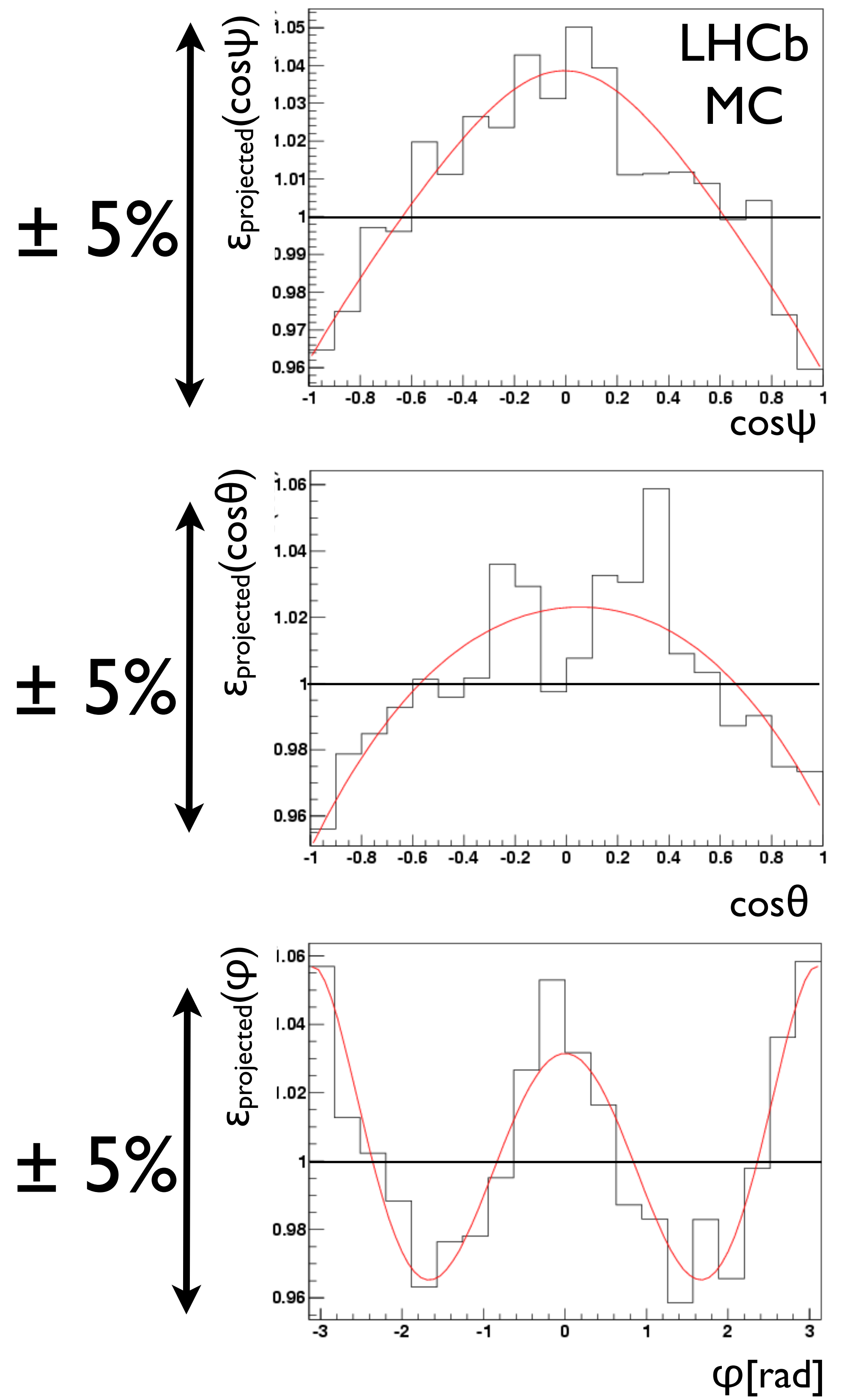
$$\vec{\lambda} = (\Gamma_s, \Delta\Gamma_s, \Delta m_s, \phi_s, |A_0|^2, |A_\perp|^2, \delta_\parallel, \delta_\perp, F_S, \delta_S)$$

$$|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$$

$$F_S = \frac{|A_S|^2}{|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 + |A_S|^2} = \frac{|A_S|^2}{1 + |A_S|^2}$$

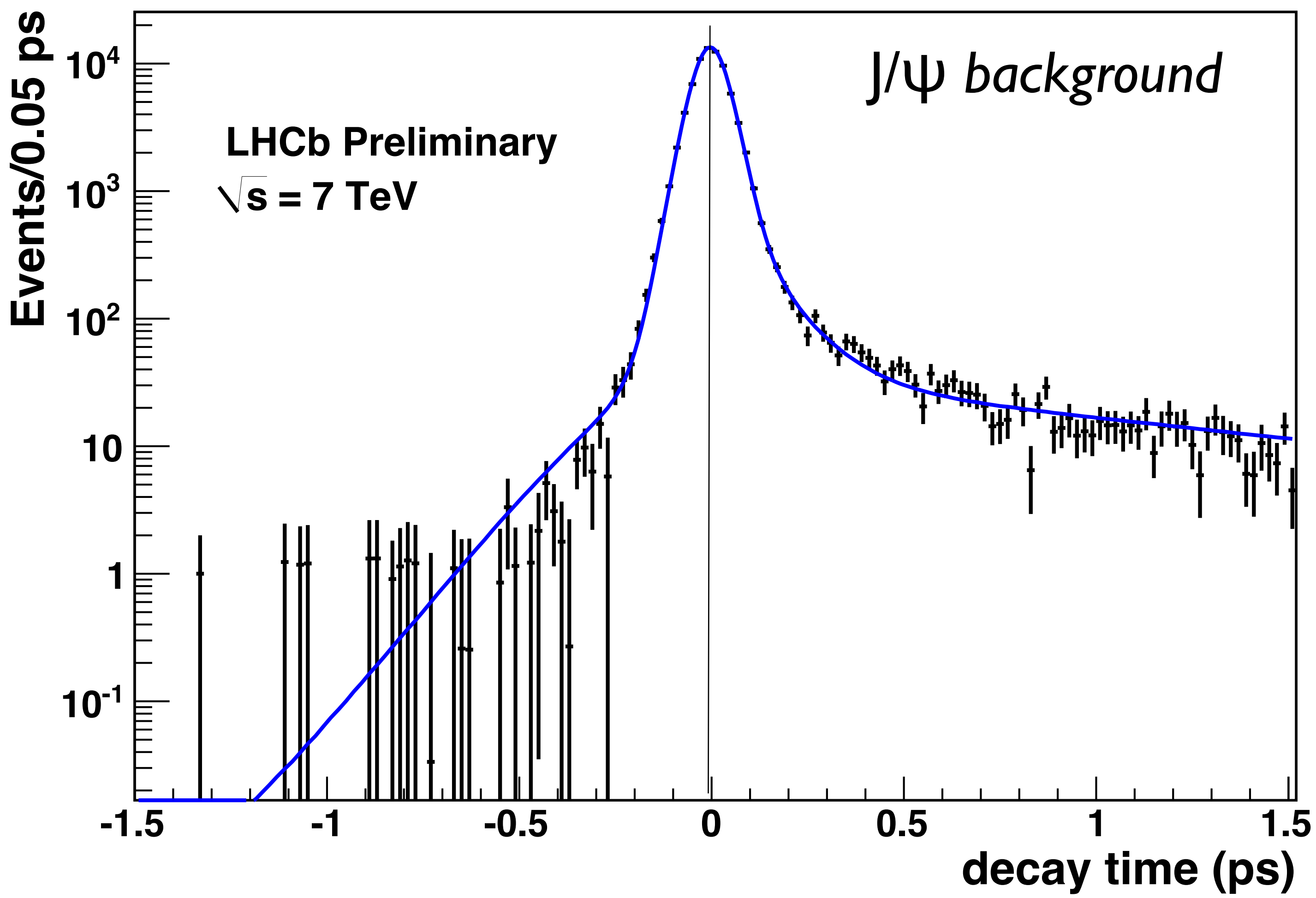
LHC*b*: $B_s \to J/\psi\varphi$ - Angular Acceptance

- Determine from MC simulation
- Max deviation from uniform: 5%
- Due to
  1. acceptance of detector: $10 < \theta < 400$ mrad
  2. implicit momentum cuts in reconstruction
- Verified using momentum distributions of final state particles
  - re-weight MC to match data to estimate systematic uncertainty
- Implemented using
  1. 'Moments' of the angular functions
  2. 3D parameterization using orthogonal polynomials
  3. 3D histogram



LHC*b*: $B_s \to J/\psi\varphi$ - Decay Time Resolution

- Measure using prompt J/ψ background
  - isolated using s-weights(*)
- Verify on MC that this background is representative for the signal
- Effective resolution: σ_t ~ (45 ± 2) fs
- Dilution(**) for Δm_s=17.7 ps^{-1}: $\langle D_{res} \rangle_{eff}$ = 0.728 ± 0.019



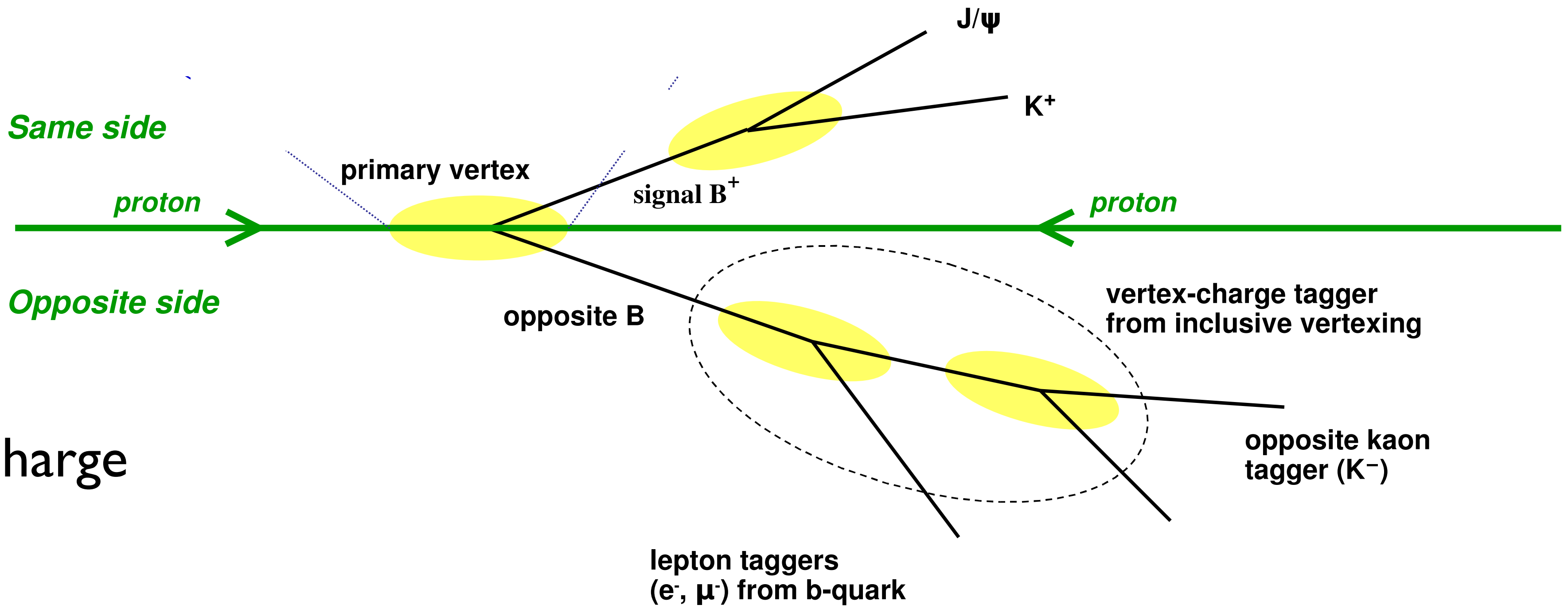
(*) M. Pivk and F. Le Diberder, "sPlot: a statistical tool to unfold data distributions", NIM A555 (2005) 356-369.

(**) H. G. Moser and A. Roussarie, "Mathematical methods for B0 anti-B0 oscillation analyses," Nucl. Instrum. Meth. A **384** (1997) 491.

LHC*b*: $B_s \to J/\psi\varphi$ - Flavour Tagging

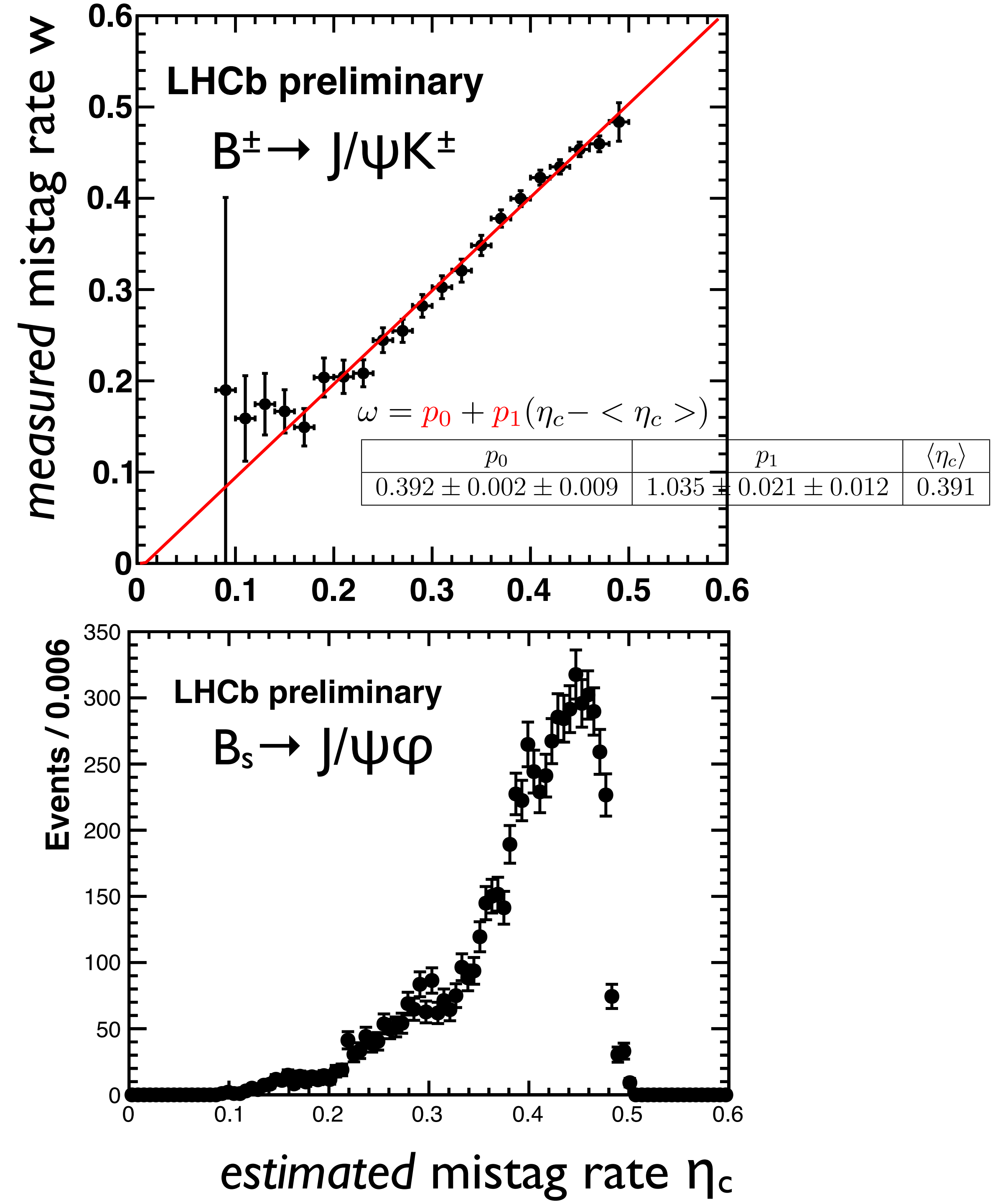
- Opposite side only for now
- Combine 4 observables into an *estimated* wrong tag probability η_c:

1. high-p_t muons
2. high-p_t electrons
3. high-p_t kaons
4. opposite side vertex charge

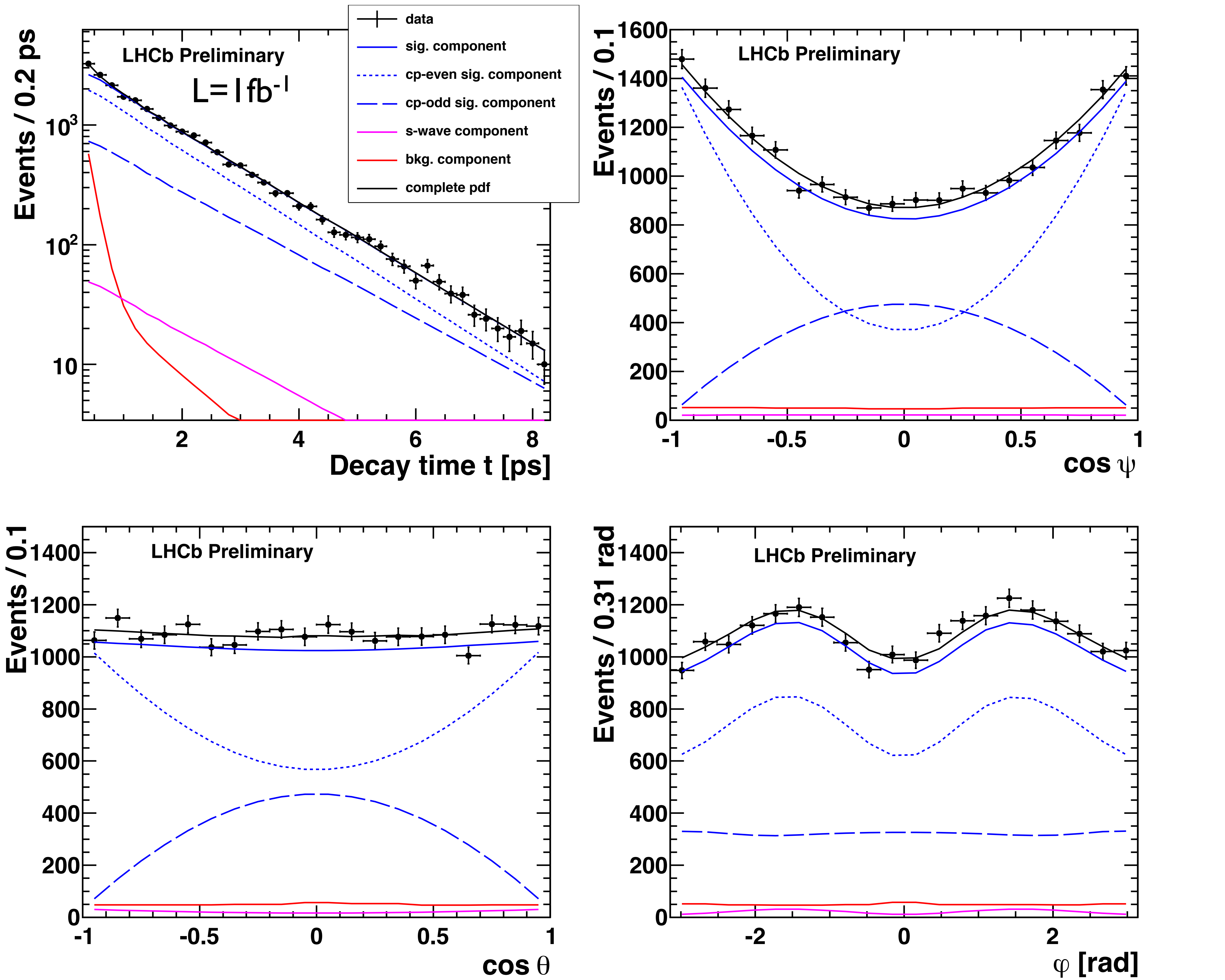


LHC*b*: $B_s \to J/\psi\varphi$ - Flavour Tagging

- Opposite side only for now
- Combine 4 observables into an *estimated* wrong tag probability η_c:
  1. high-p_t muons
  2. high-p_t electrons
  3. high-p_t kaons
  4. opposite side vertex charge
- Calibrate on $B^\pm \to J/\psi K^\pm$ data
- Tagging power $\varepsilon D^2 = (2.29 \pm 0.27)\%$



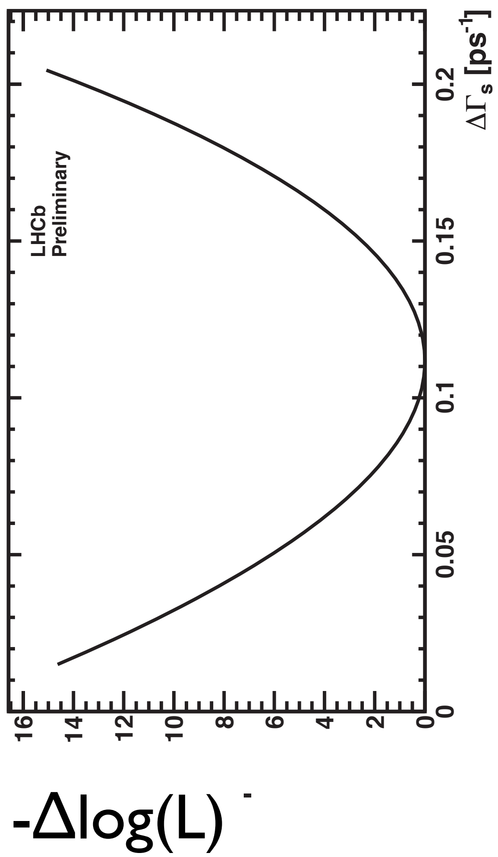
$B_s \to J/\psi\varphi$: fit projections

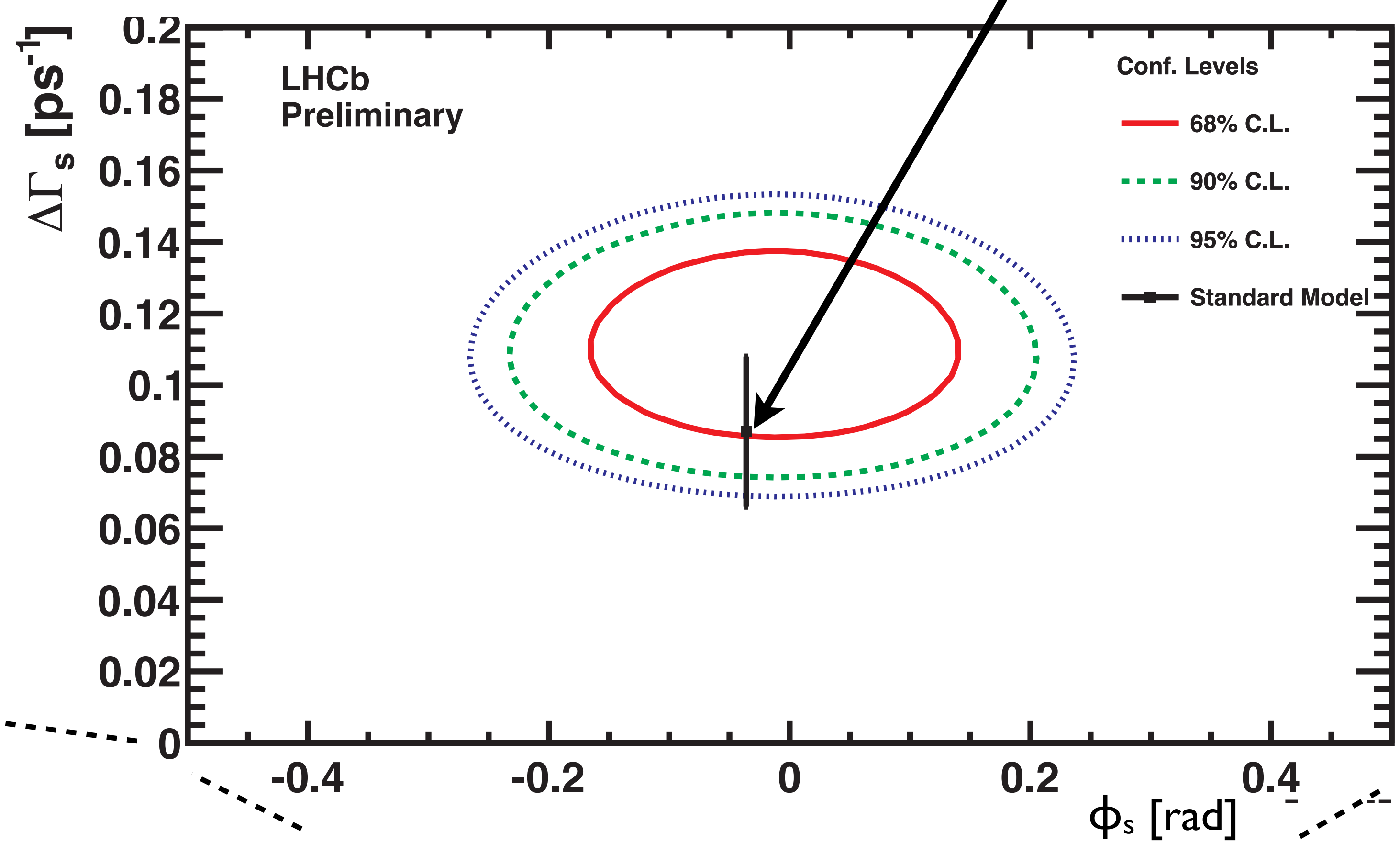


$B_s \rightarrow J/\psi\varphi$: $\Delta\Gamma_s$ vs. ϕ_s

Standard Model
(eg. Charles e.a. PRD84(2011)033005)

LHCb-CONF-2012-02



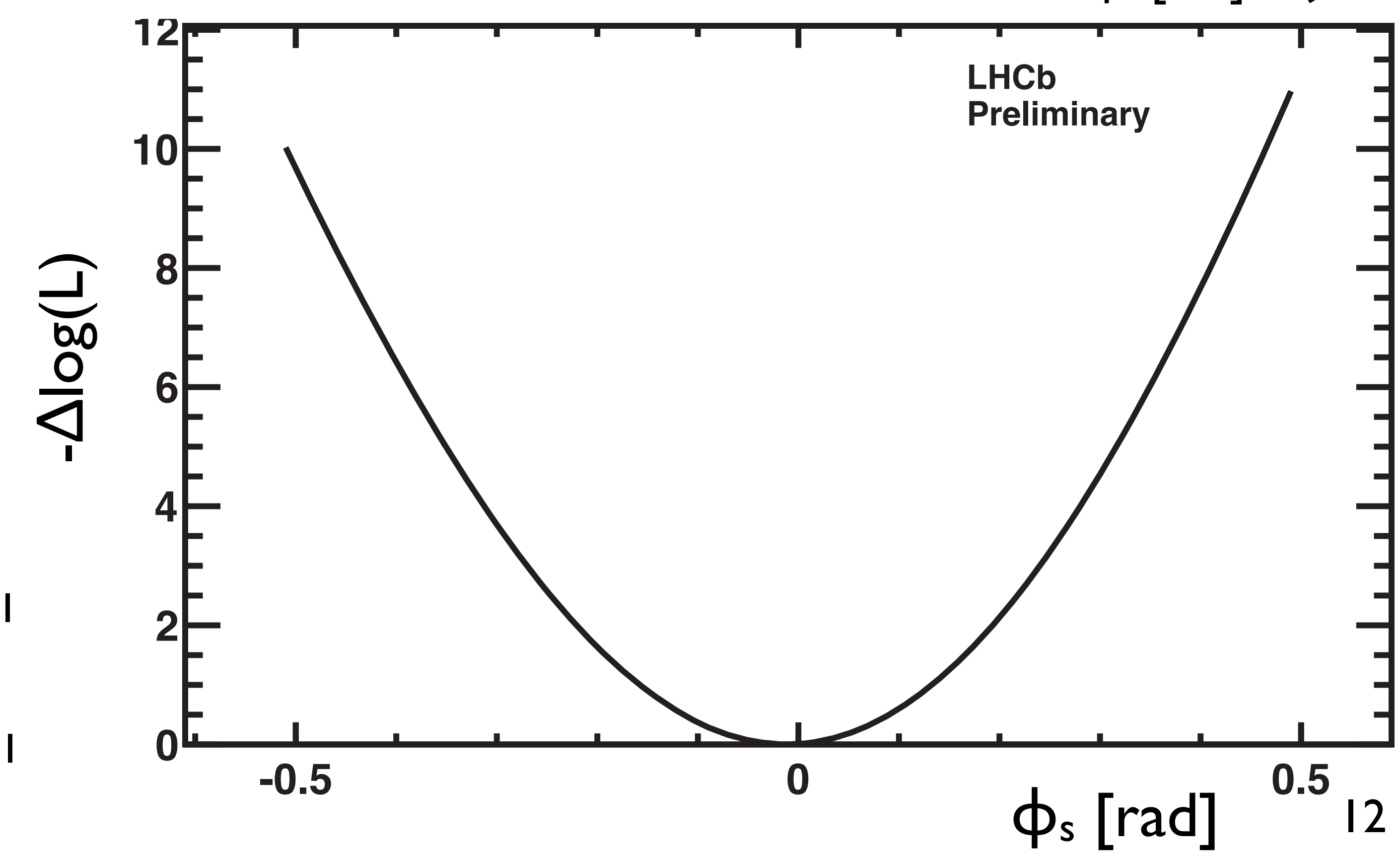


Most precise measurement of ϕ_s

- ϕ_s = -0.001 ± 0.101(stat) ± 0.027 (sys) rad
- Consistent with SM

Observation of $\Delta\Gamma_s \neq 0$:

- $\Delta\Gamma_s$ = 0.116 ± 0.018 (stat) ± 0.006 (sys) ps^{-1}
- Γ_s = 0.658 ± 0.005 (stat) ± 0.007 (sys) ps^{-1}



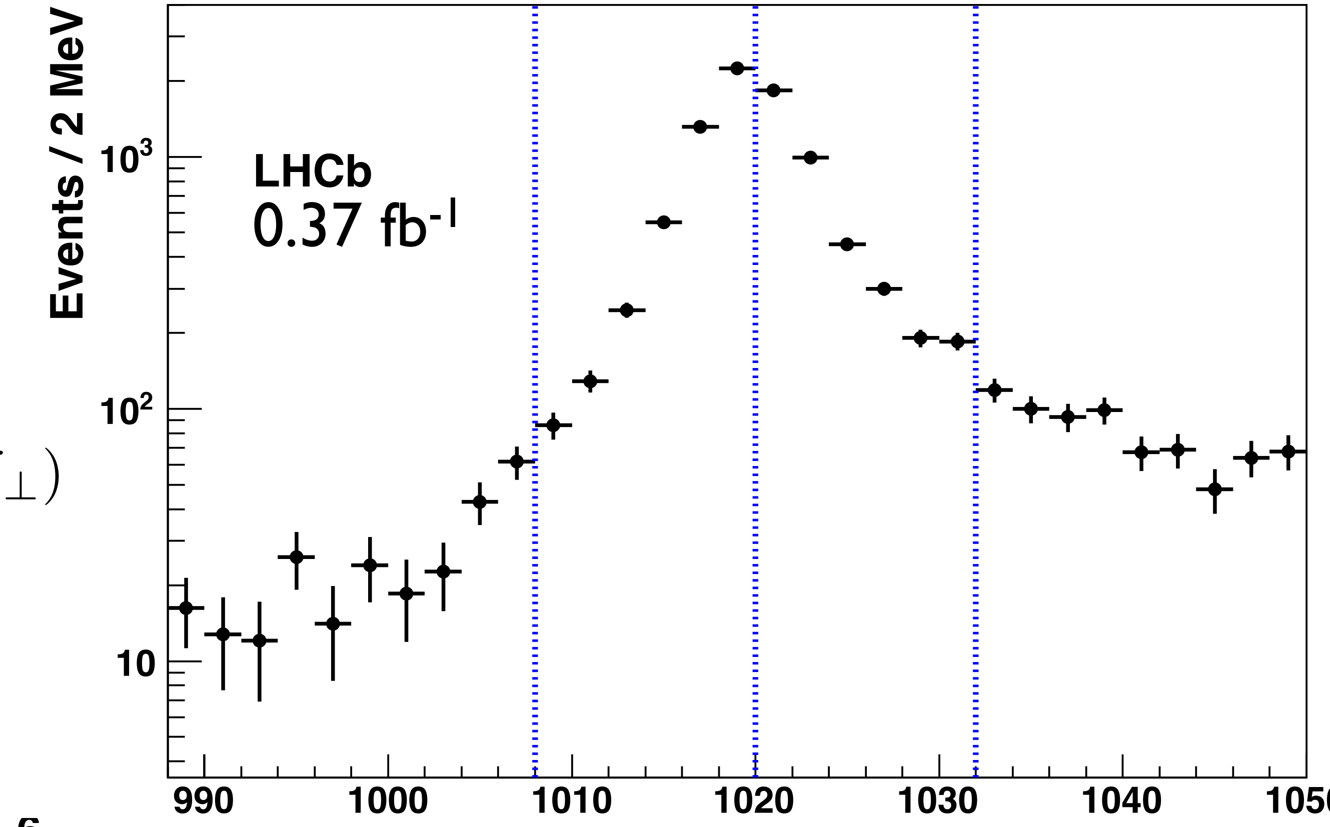
What about the discrete ambiguity?

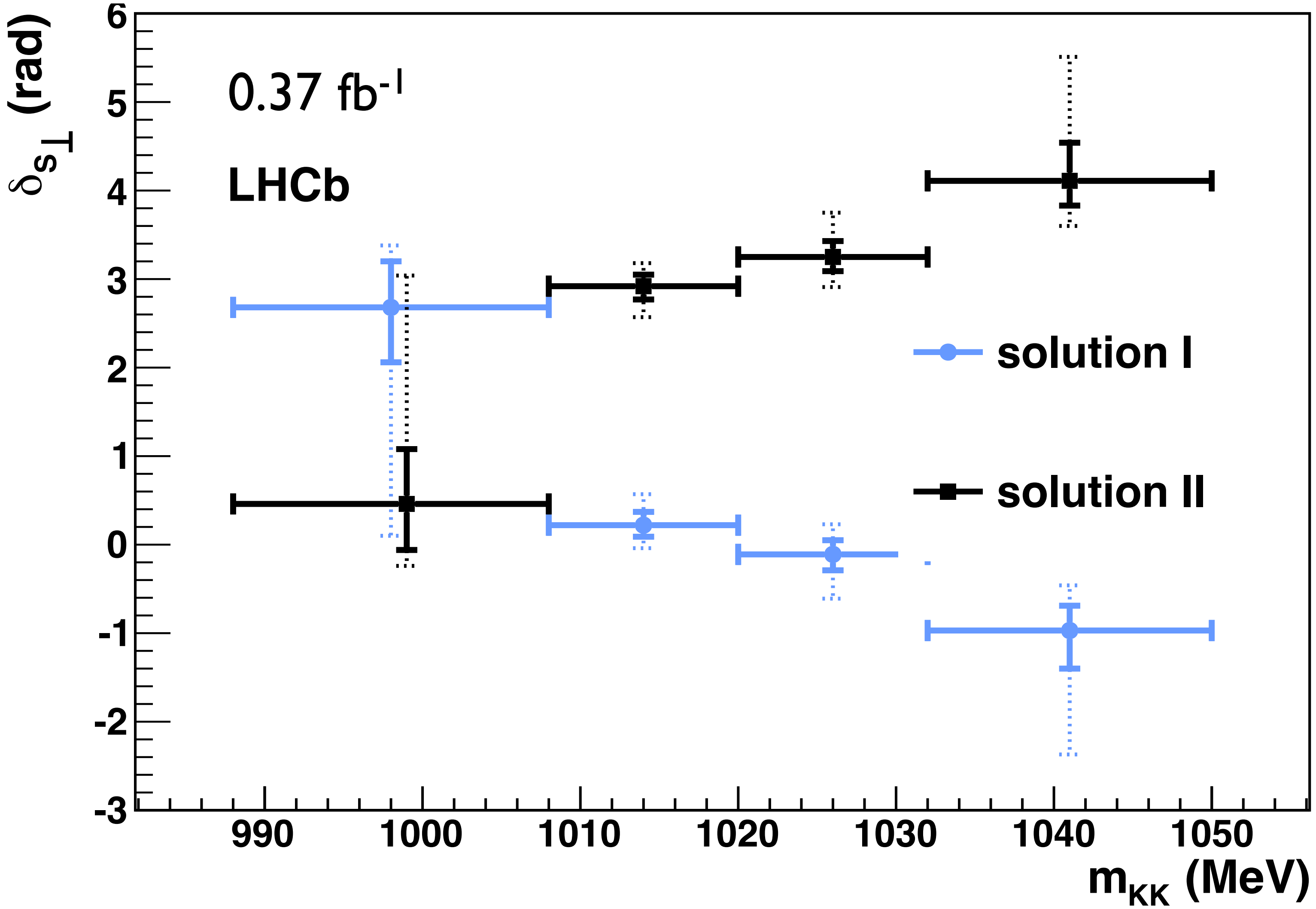
$$(\phi_s, \Delta\Gamma_s, \delta_\parallel, \delta_\perp) \leftrightarrow (\pi - \phi_s, -\Delta\Gamma_s, 2\pi - \delta_\parallel, \pi - \delta_\perp)$$

10.1103/PhysRevLett.108.241801

- Use known P-wave BW phase evolution across φ(1020) to decide which $\delta_\perp$ solution is correct
    - as in BaBar's cos(2β) paper [Phys. Rev. D 71, 032005 (2005)]

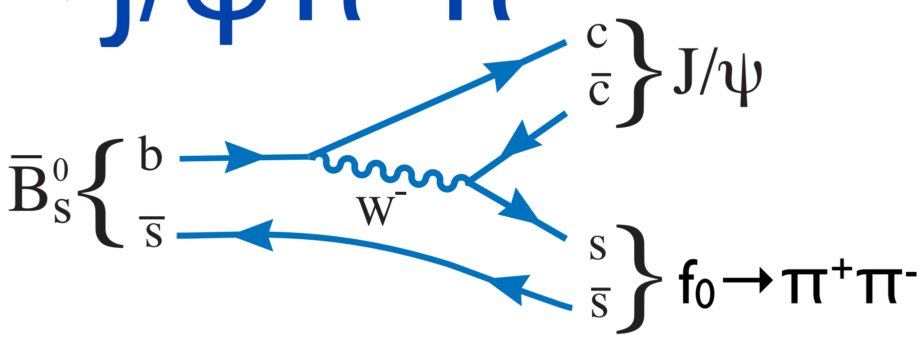
➡ $\Delta\Gamma > 0, \Phi_s \sim 0$





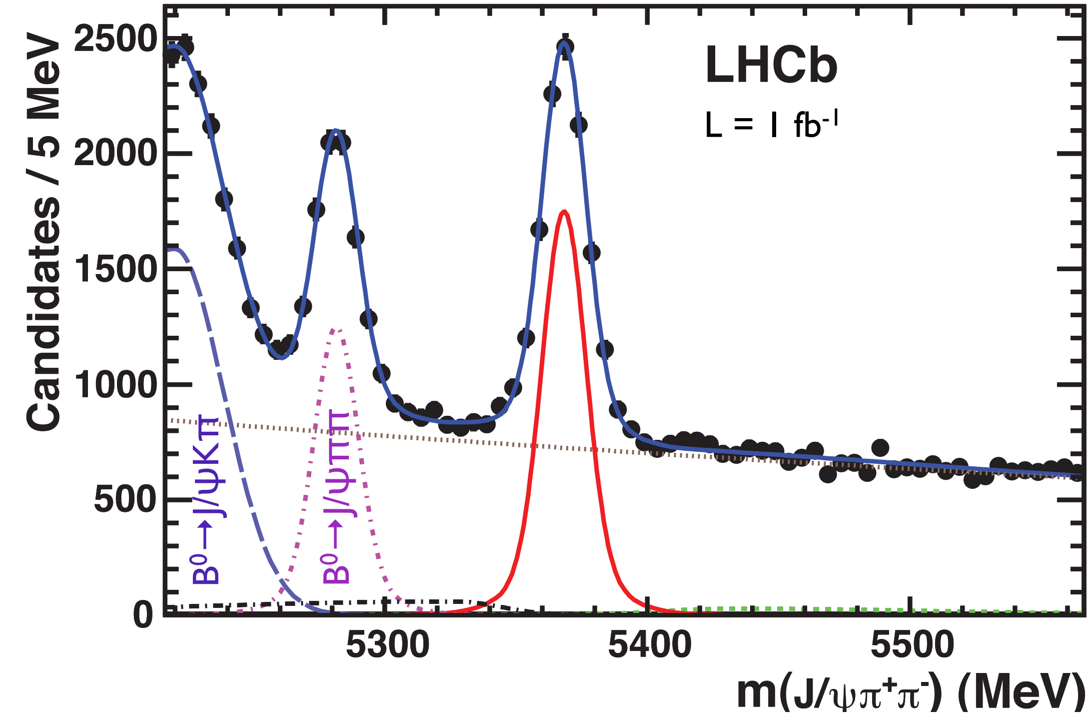
See also Francesca Dordei, "Lifetime Measurements @ LHCb", monday 11:30

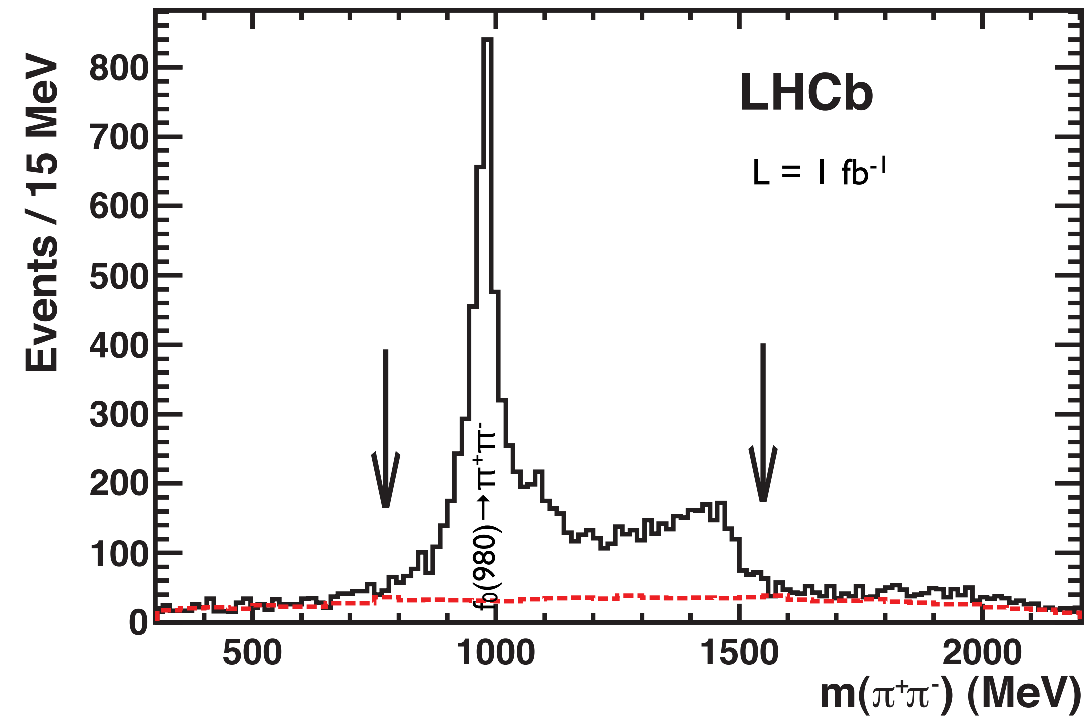
$B_s \rightarrow J/\psi\pi^+\pi^-$



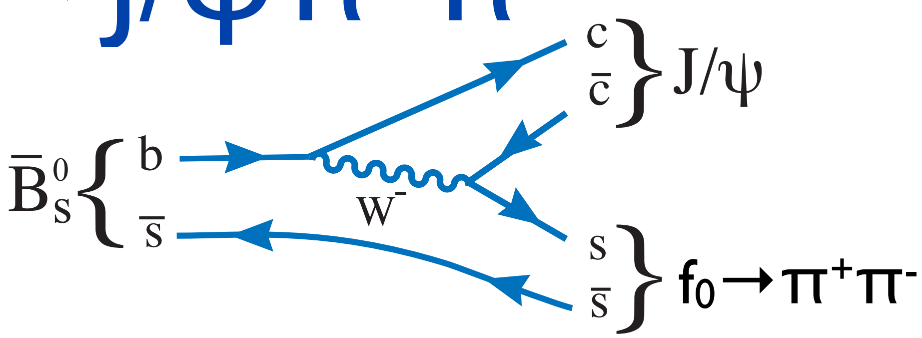
LHCb-PAPER-2012-005

- f_0 is a scalar with an $s\bar{s}$ component
- Decays predominantly into $\pi^+\pi^-$
- The region 775 MeV < m(ππ) < 1550 MeV is dominated by $f_0(980)$, with some $f_2(1270)$, $f_0(1370)$ and NR





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



LHCb-PAPER-2012-005

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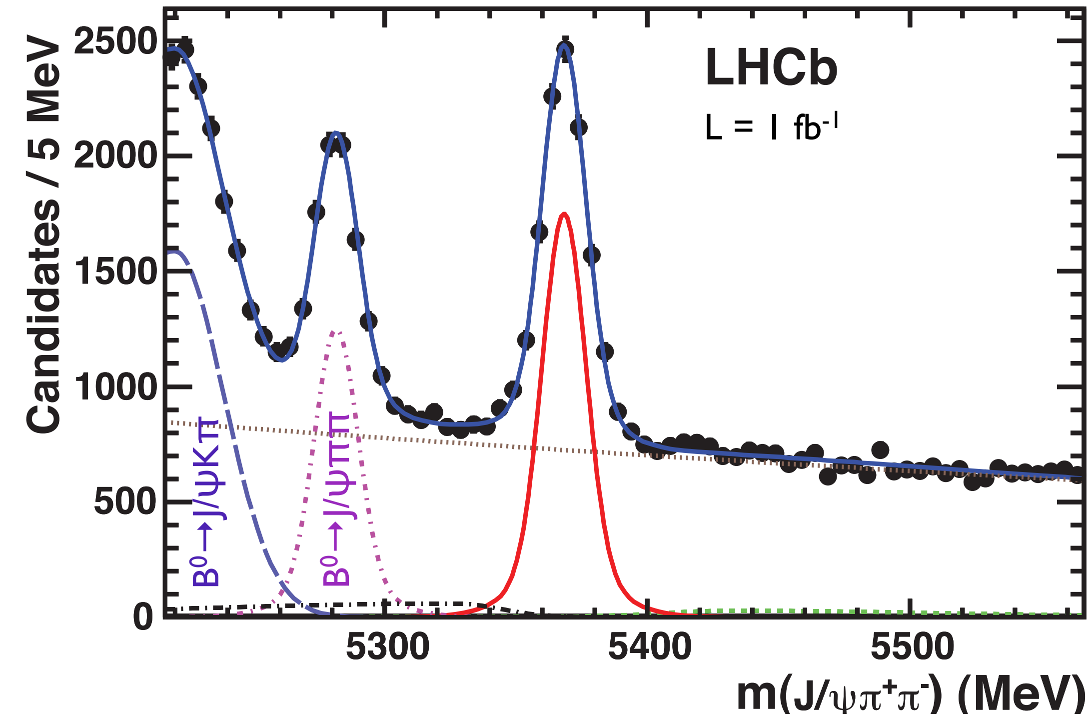
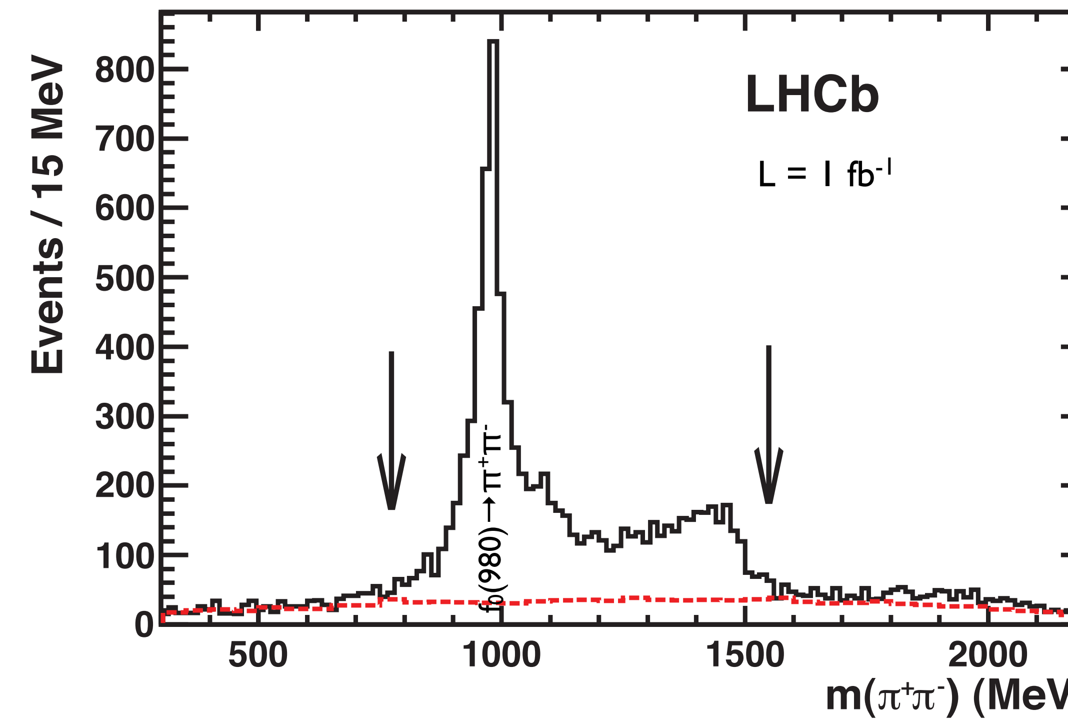
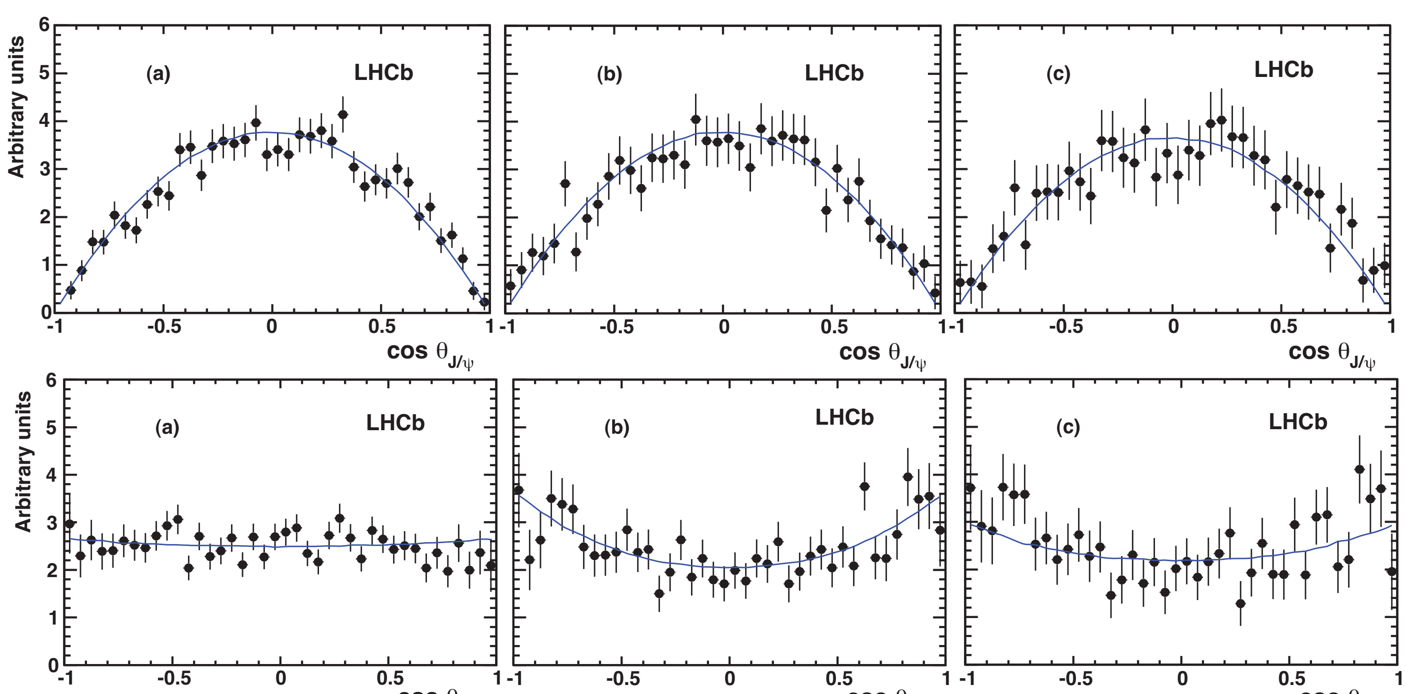
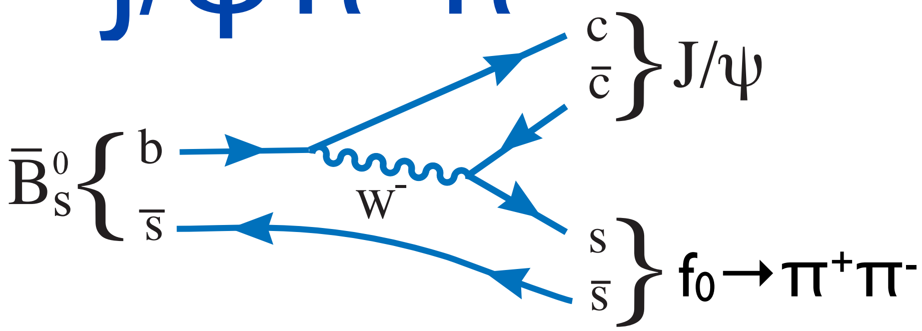
- The region 775 MeV < m(ππ) < 1550 MeV is dominated by $f_0(980)$, with some $f_2(1270)$, $f_0(1370)$ and NR
- CP-odd fraction >0.977 @ 95%CL
  ⇒ No angular analysis needed!







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



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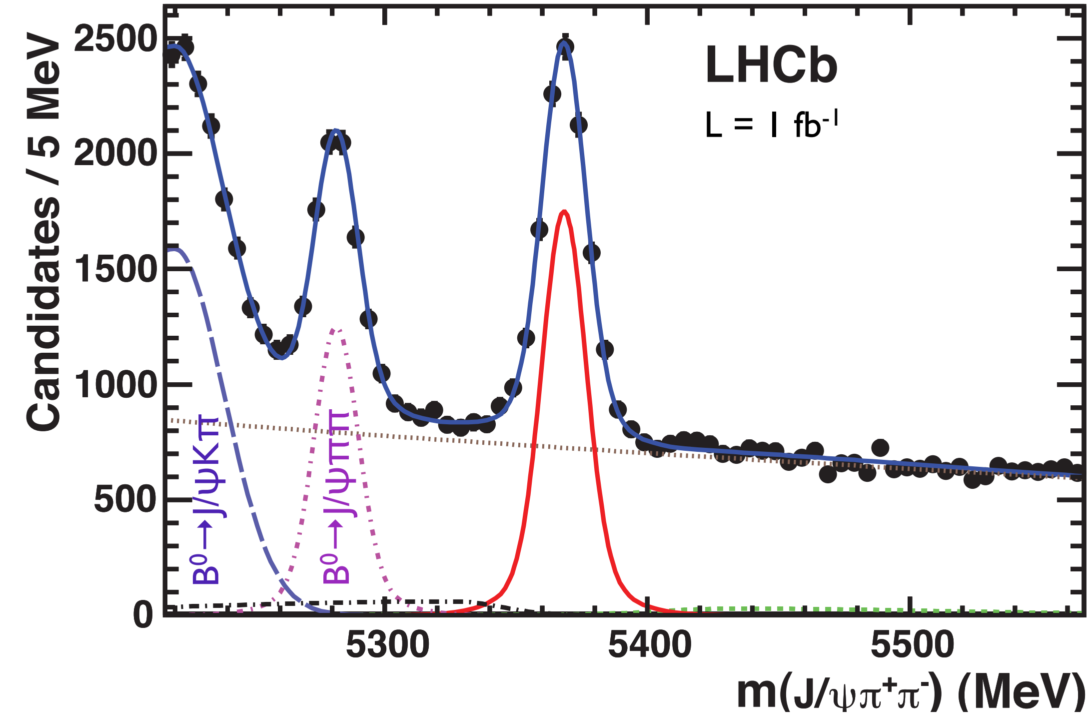
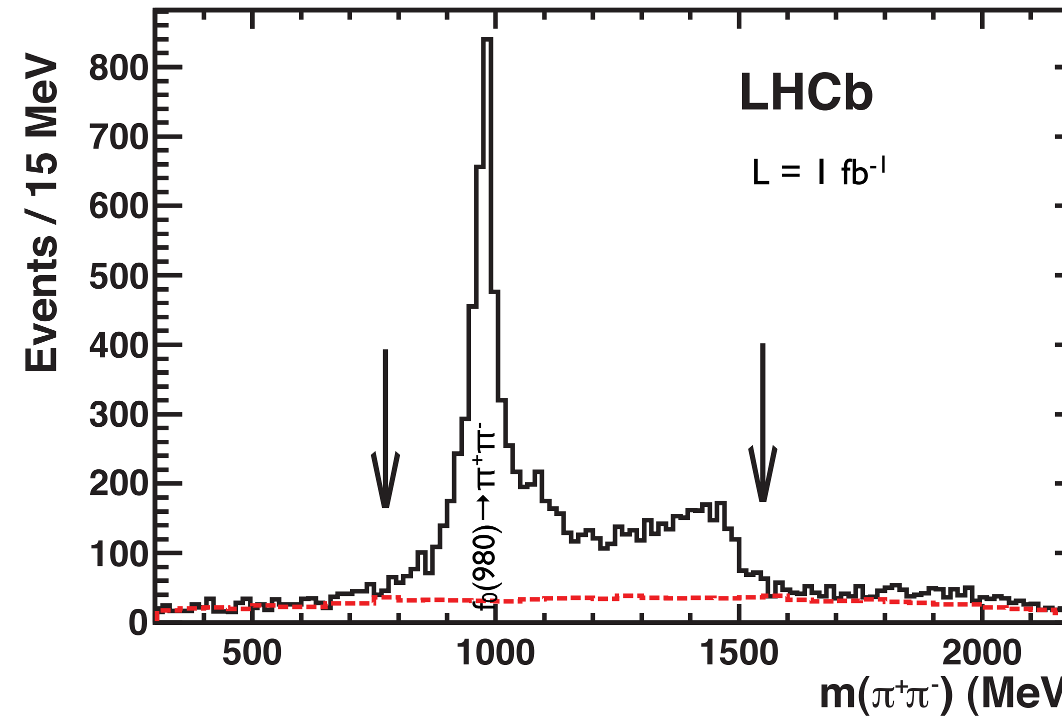
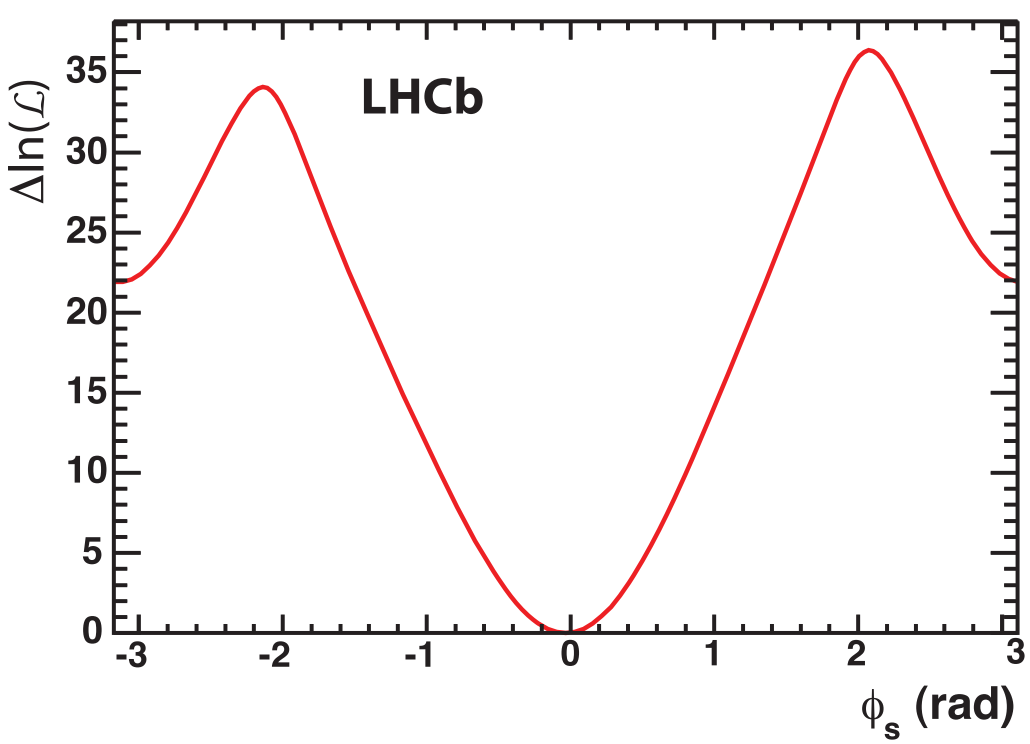


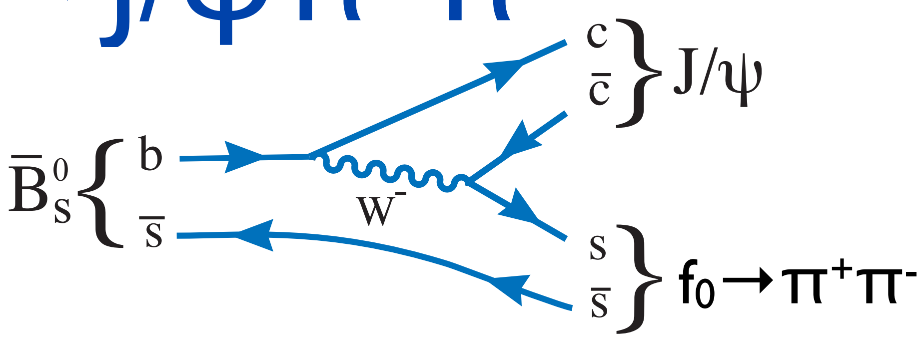


LHCb-PAPER-2012-006



$$\phi_s^{J/\psi\pi\pi} = -0.019^{+0.173+0.004}_{-0.174-0.003} \text{ rad}$$

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



LHCb-PAPER-2012-005

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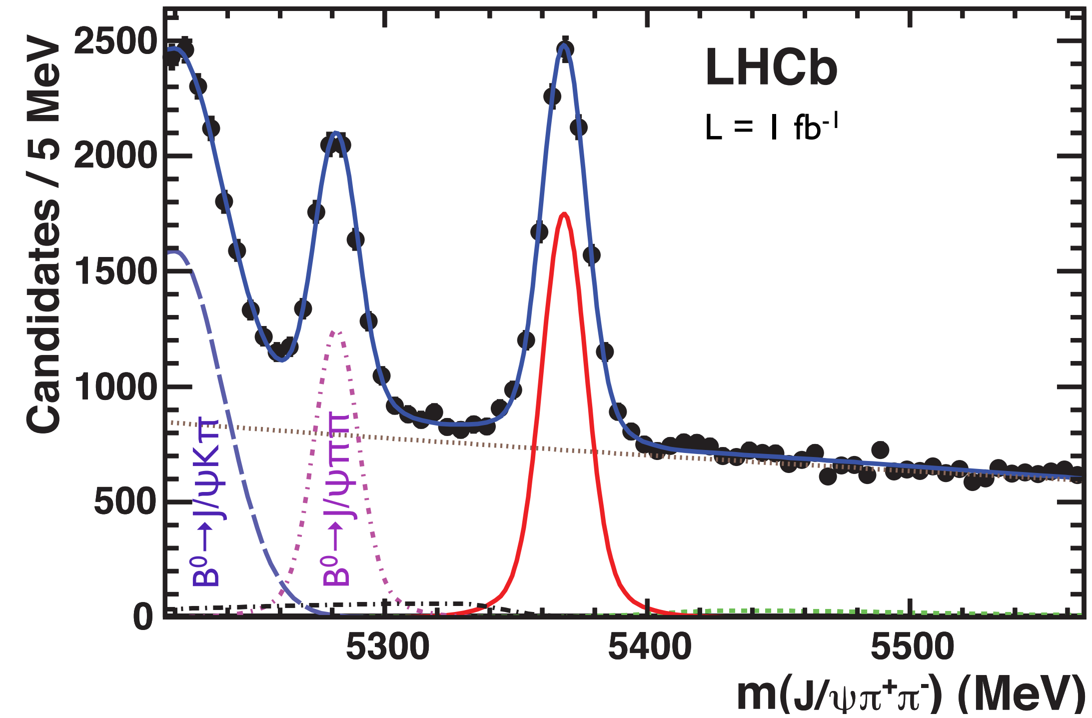
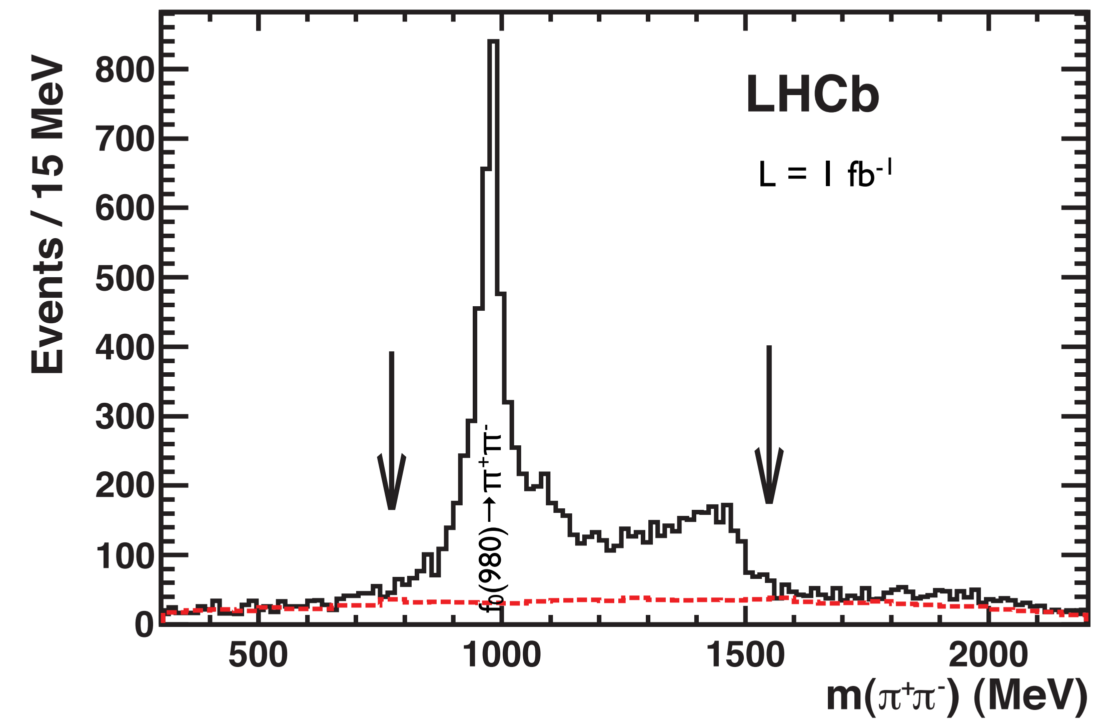
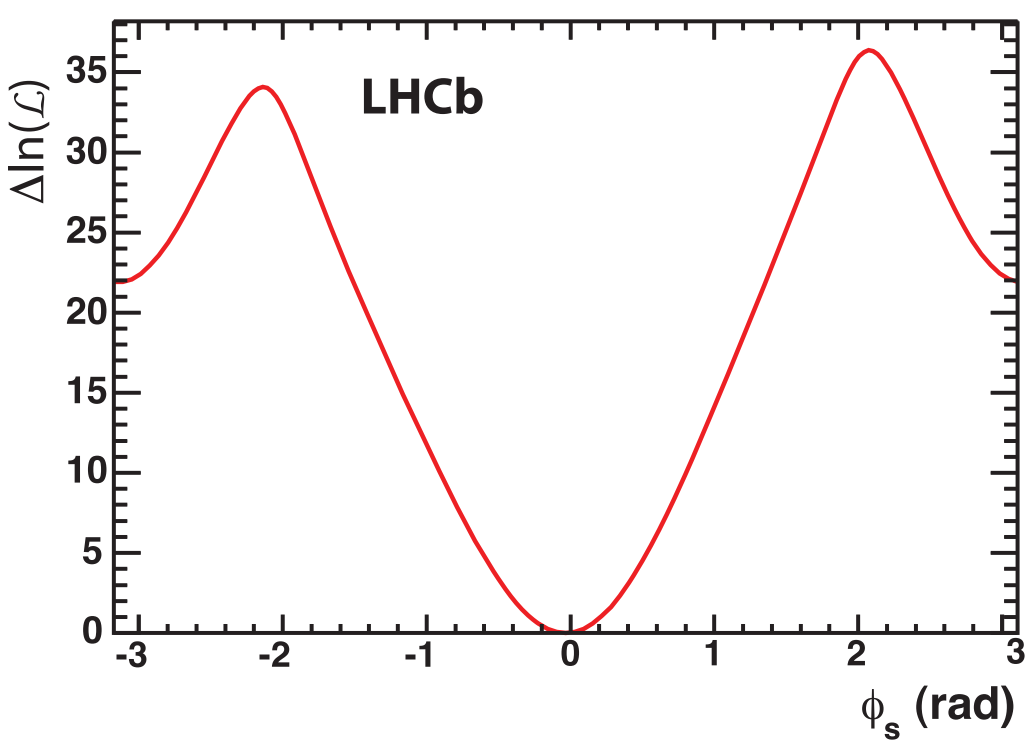




LHCb-PAPER-2012-006

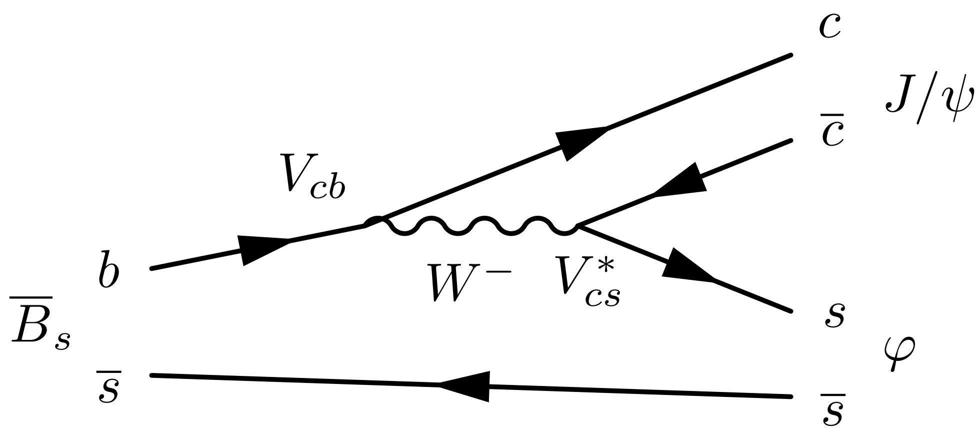


$$\phi_s^{J/\psi\pi\pi} = -0.019^{+0.173+0.004}_{-0.174-0.003}\ \text{rad}$$

- Joint fit with $B_s \to J/\psi\varphi$:

$$\phi_s^{\text{combined}} = -0.002 \pm 0.083 \pm 0.027\ \text{rad}$$

But what about penguins?



$$A_{B_s \to J/\psi\phi} = V_{cb} V_{cs}^* T$$

See also: Robert Fleischer in 25 min, Martin Jung in 50 min...

[1] S. Faller, R. Fleischer, and T. Mannel, *Precision physics with $B_s^0 \to J/\psi\phi$ at the LHC: the quest for new physics*, Phys. Rev. **D79** (2009) 014005, arXiv:0810.4248.

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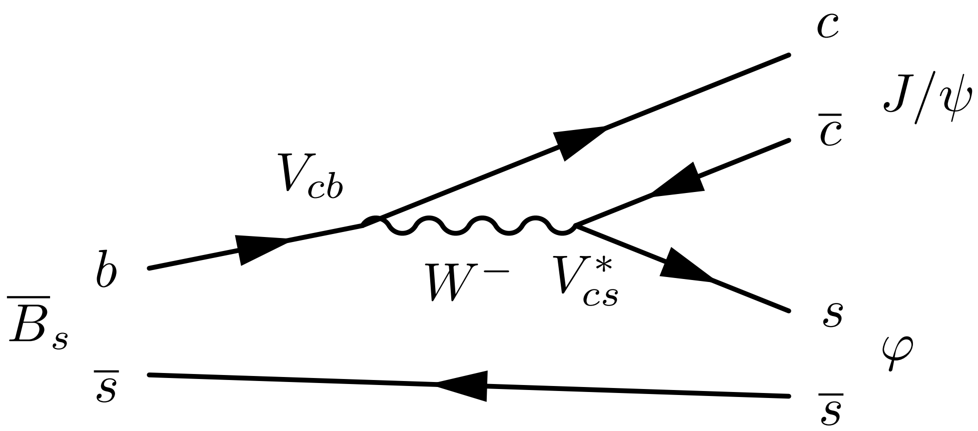

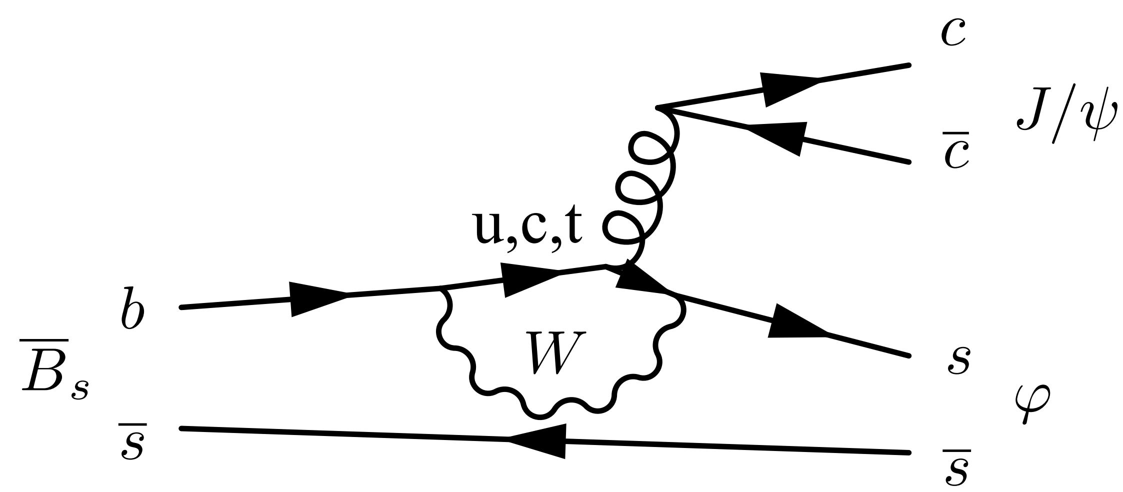

$$A_{B_s \to J/\psi\phi} = V_{cb}V_{cs}^* T + V_{ub}V_{us}^* P_u + V_{cb}V_{cs}^* P_c + V_{tb}V_{ts}^* P_t$$

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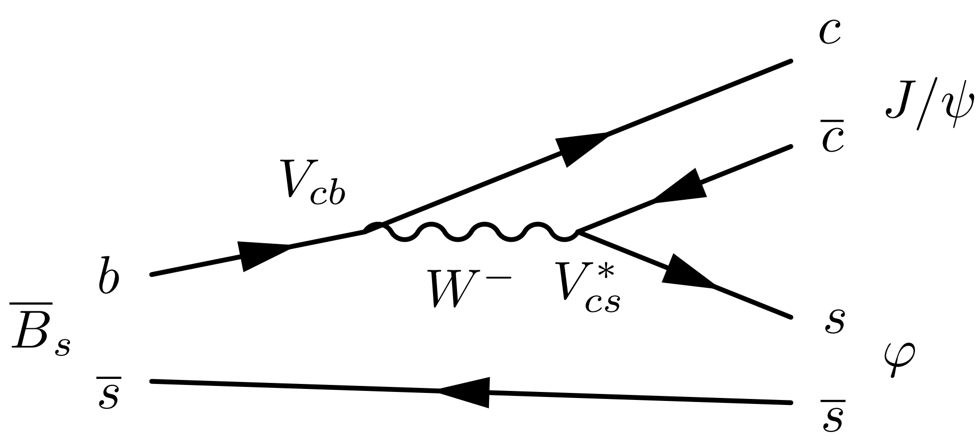

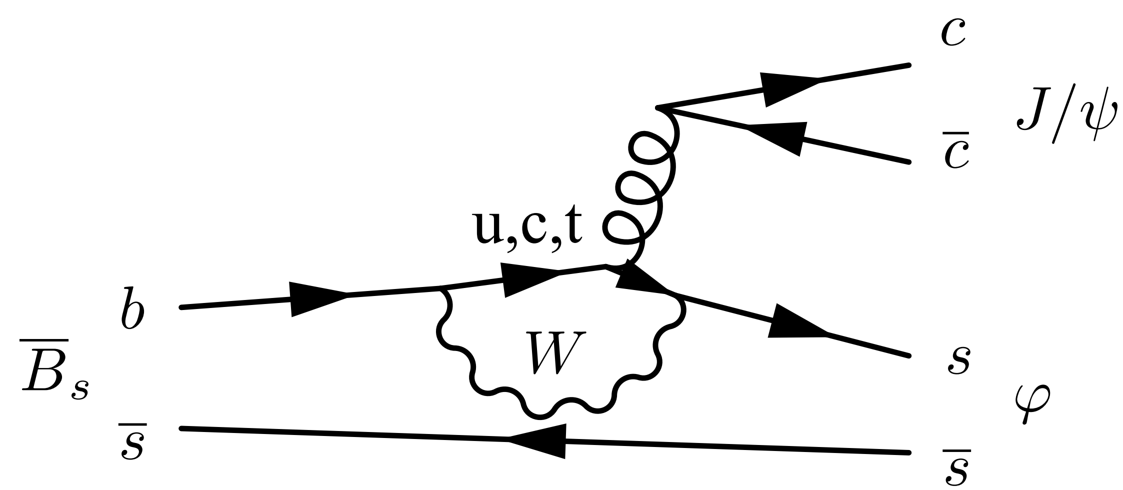

$$A_{B_s\to J/\psi\phi} = \underbrace{V_{cb}V_{cs}^*}_{\mathcal{O}(\lambda^2)}(T + P_c - P_t) + \underbrace{V_{ub}V_{us}^*}_{\mathcal{O}(\lambda^4)}(P_u - P_t)$$

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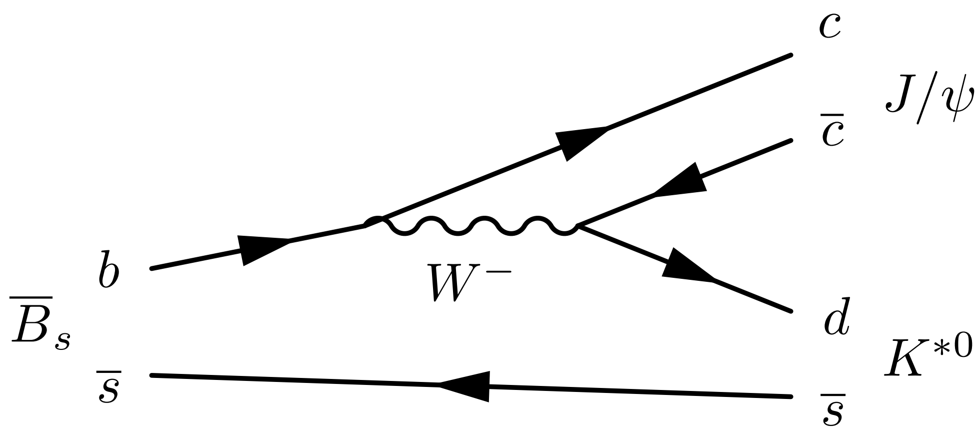

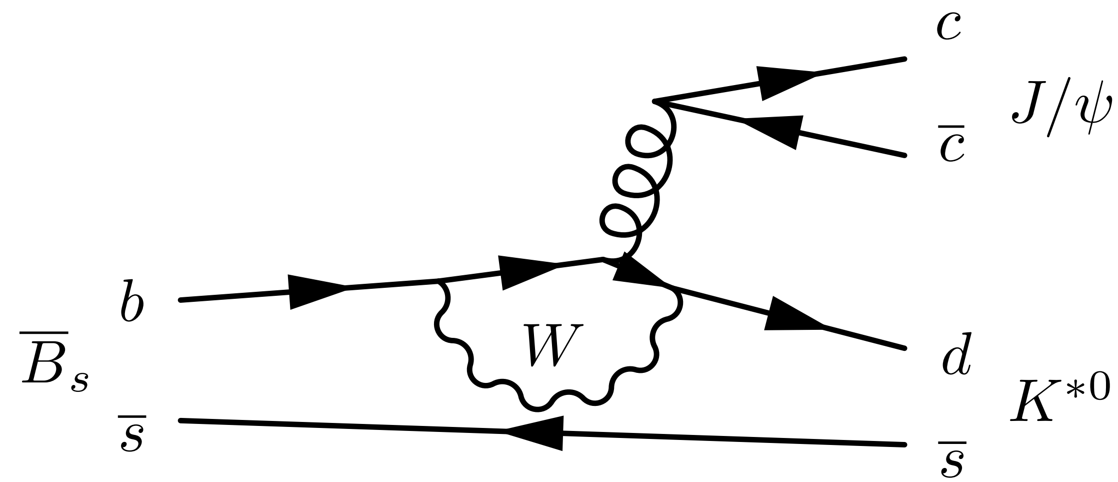

$$A_{B_s \to J/\psi\phi} = \underbrace{V_{cb}V_{cs}^*}_{\mathcal{O}(\lambda^2)}(T + P_c - P_t) + \underbrace{V_{ub}V_{us}^*}_{\mathcal{O}(\lambda^4)}(P_u - P_t)$$

$$A_{B_s \to J/\psi\overline{K}^{*0}} = \underbrace{V_{cb}V_{cd}^*}_{\mathcal{O}(\lambda^3)}(T + P_c - P_t) + \underbrace{V_{ub}V_{ud}^*}_{\mathcal{O}(\lambda^3)}(P_u - P_t)$$

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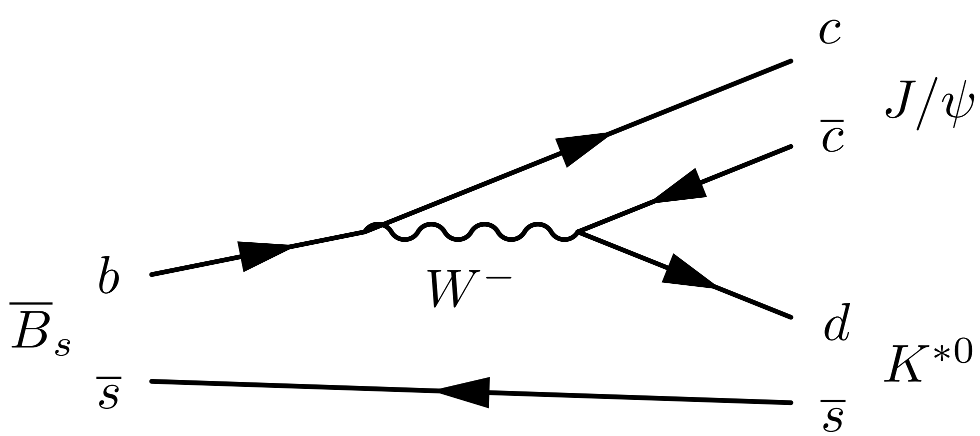

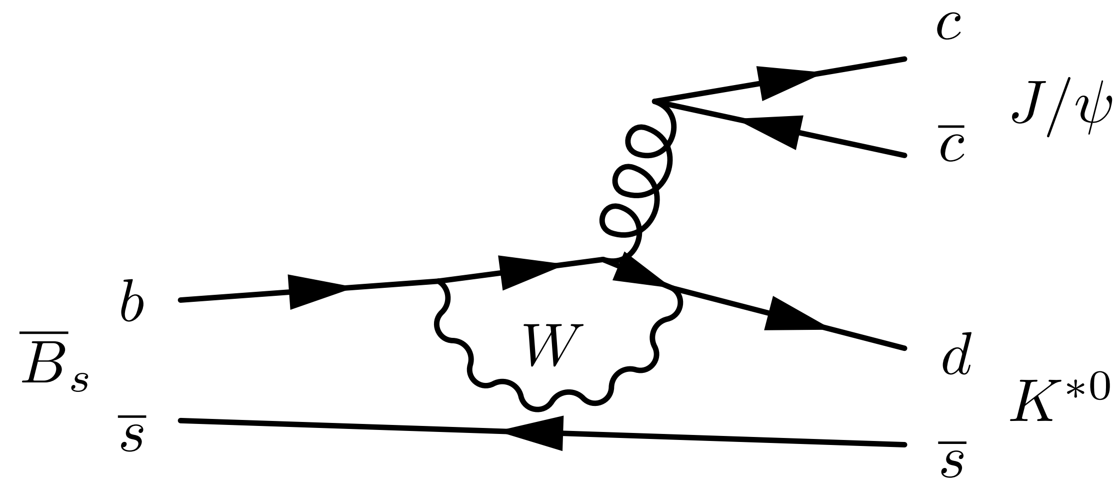

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SU(3) SU(3)

$$A_{B_s \to J/\psi \overline{K}^{*0}} = \underbrace{V_{cb}V_{cd}^*}_{\mathcal{O}(\lambda^3)}(T + P_c - P_t) + \underbrace{V_{ub}V_{ud}^*}_{\mathcal{O}(\lambda^3)}(P_u - P_t)$$

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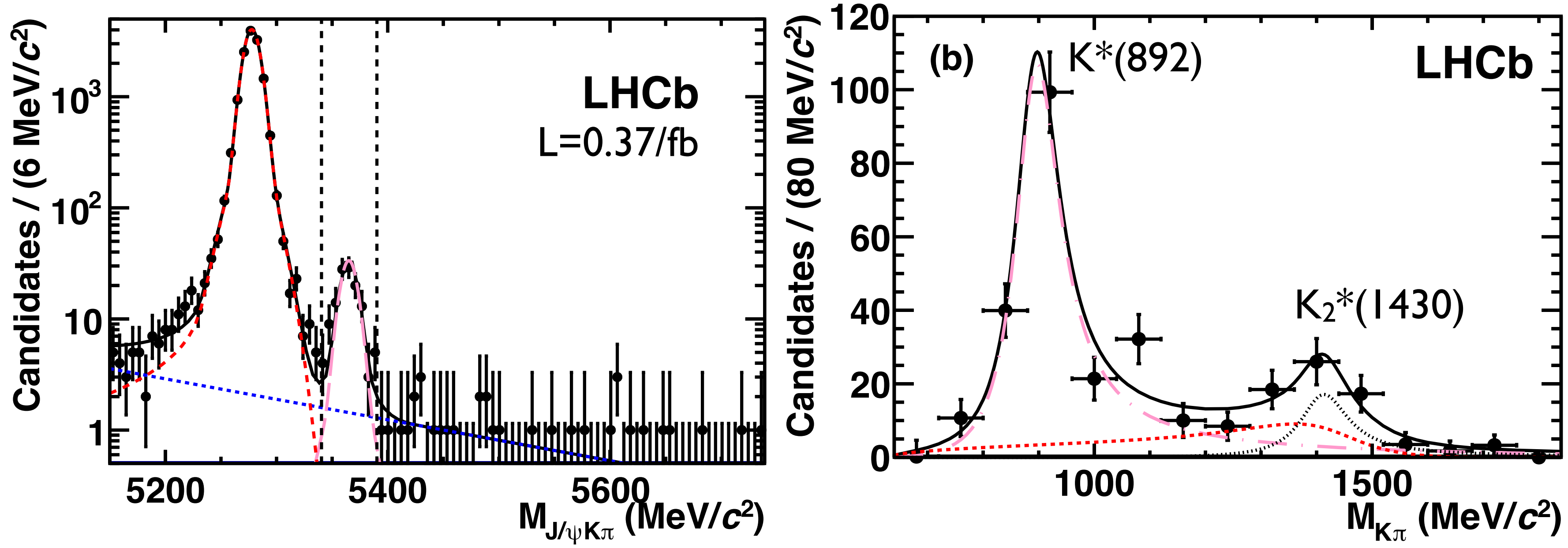
LHCb: $B_s \to J/\psi\ \overline{K}^{*0}$

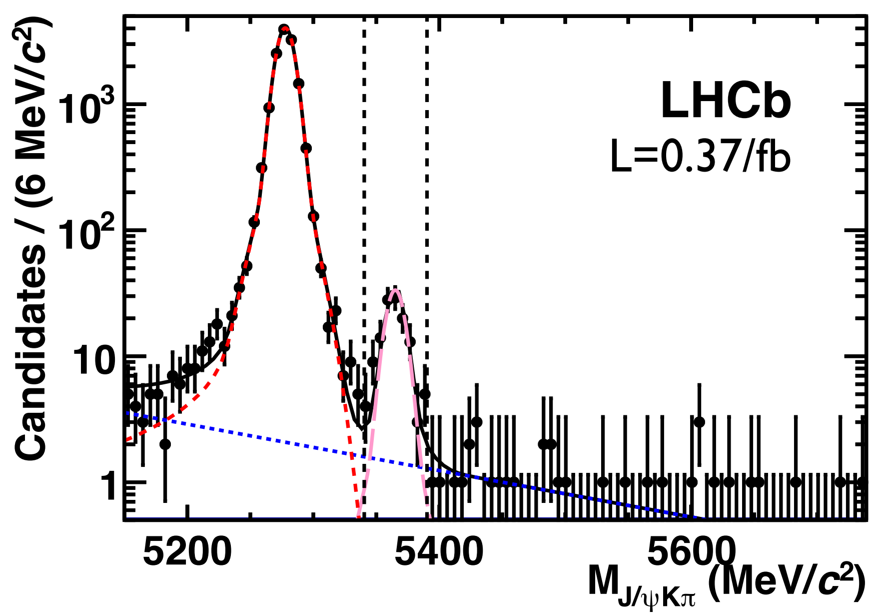
$$\frac{\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0})}{\mathcal{B}(B^0 \to J/\psi K^{*0})} = (3.43^{+0.34}_{-0.36} \pm 0.50)\%.$$

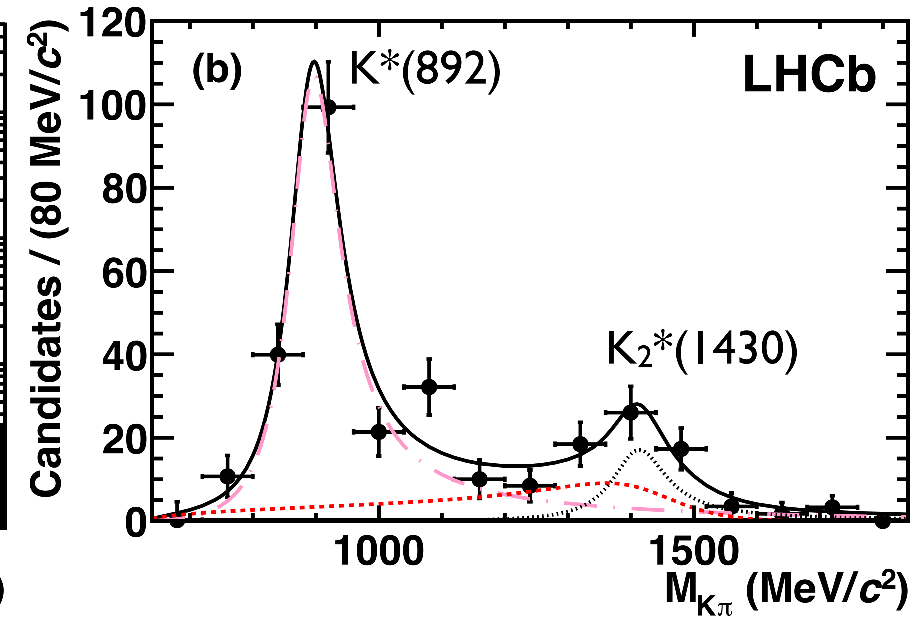


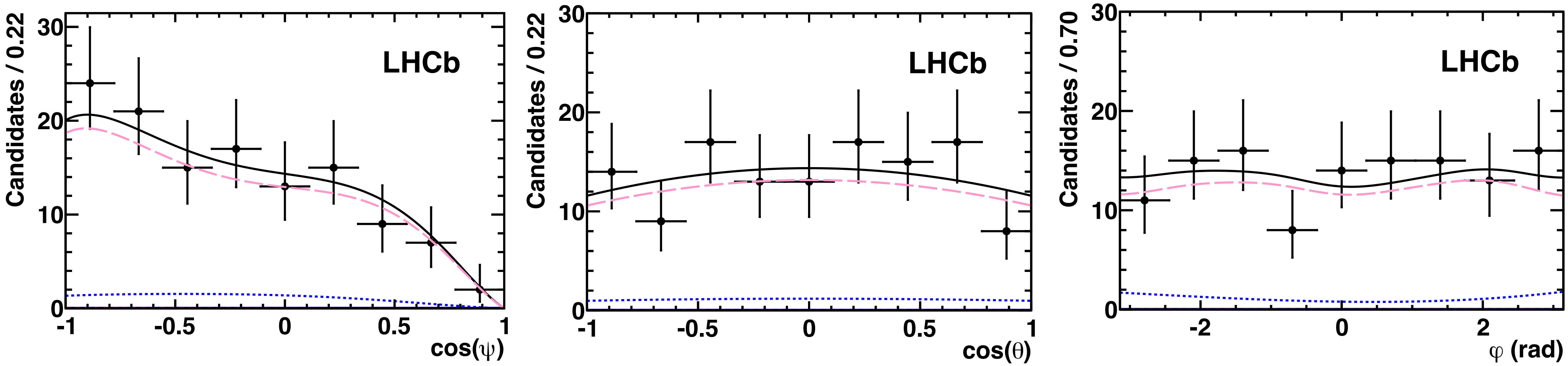
arXiv:1208.0738v1 [hep-ex] 3 Aug 2012

LHCb: $B_s \to J/\psi\ \overline{K}^{*0}$

$$\frac{\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0})}{\mathcal{B}(B^0 \to J/\psi K^{*0})} = (3.43^{+0.34}_{-0.36} \pm 0.50)\%.$$







f_L = 0.50 ± 0.08 ± 0.02

$f_{//}$ = 0.19 $^{+0.10}_{-0.08}$ ± 0.02

$|A_S|^2$= 0.07 $^{+0.15}_{-0.07}$ (within 40 MeV/c^2 of K^{*0}(892) mass)

Summary

- Using 1 fb^{-1}, i.e. 21.2k $B_s \to J/\psi\ phi(KK)$,
  - $\phi_s = -0.001 \pm 0.101(stat) \pm 0.027\ (sys)$ rad
  - $\Delta\Gamma_s = 0.116 \pm 0.018\ (stat) \pm 0.006\ (sys)\ ps^{-1}$
  - $\Gamma_s = 0.658 \pm 0.005\ (stat) \pm 0.007\ (sys)\ ps^{-1}$

LHCb-CONF-2012-002

- With 0.37 fb^{-1}, using $B_s \to J/\psi KK$ the two-fold ambiguity is resolved
  - The 'proper' solution is the one with $\Delta\Gamma_s > 0$ and $\phi_s \sim 0$

LHCb-PAPER-2011-028

- With 1 fb^{-1}, the resonant structure of $B_s \to J/\psi\pi\pi$ has been studied
  - 775 MeV < $m(\pi\pi)$ < 1550 MeV found to be CP-odd

LHCb-PAPER-2012-005

- And this range is subsequently used to measure:
  - $\phi_s = -0.019\ ^{+0.173}_{-0.174}\ ^{+0.004}_{-0.003}$ rad

LHCb-PAPER-2012-006

- Using 0.37 fb^{-1}, measure Br and polarization of $B_s \to J/\psi\ \overline{K^*}(K\pi)$:

  $Br(B_s \to J/\psi\ \overline{K^*}(892)) = (4.4\ ^{+0.5}_{-0.4} \pm 0.8)\ 10^{-5}$
  $f_L = 0.50 \pm 0.08 \pm 0.02$
  $f_{//} = 0.19\ ^{+0.10}_{-0.08} \pm 0.02$
  $|A_S|^2 = 0.07\ ^{+0.15}_{-0.07}$ within 40 MeV/c^2 of $K^{*0}(892)$

LHCb-PAPER-2012-014

- On schedule to collect about 2.2 fb^{-1} at 8 TeV in 2012!

BACKUP

$B_s \rightarrow J/\psi\varphi$: Numerical Results...

Parameter	Value	Stat.	Syst.
Γ_s [ps^{-1}]	0.6580	0.0054	0.0066
$\Delta\Gamma_s$ [ps^{-1}]	0.116	0.018	0.006
$\|A_\perp(0)\|^2$	0.246	0.010	0.013
$\|A_0(0)\|^2$	0.523	0.007	0.024
F_S	0.022	0.012	0.007
$\delta_\perp$ [rad]	2.90	0.36	0.07
$\delta_\parallel$ [rad]	[2.81, 3.47]		0.13
δ_s [rad]	2.90	0.36	0.08
ϕ_s [rad]	-0.001	0.101	0.027

	Γ_s	$\Delta\Gamma_s$	$\|A_\perp\|^2$	$\|A_0\|^2$	ϕ_s
Γ_s	1.00	-0.38	0.39	0.20	-0.01
$\Delta\Gamma_s$		1.00	-0.67	0.63	-0.01
$\|A_\perp(0)\|^2$			1.00	-0.53	-0.01
$\|A_0(0)\|^2$				1.00	-0.02
ϕ_s					1.00

Source	Γ_s [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	$A_\perp^2$	A_0^2	F_S	$\delta_\parallel$ [rad]	$\delta_\perp$ [rad]	δ_s [rad]	ϕ_s [rad]
Description of background	0.0010	0.004	-	0.002	0.005	0.04	0.04	0.06	0.011
Angular acceptances	0.0018	0.002	0.012	0.024	0.005	0.12	0.06	0.05	0.012
t acceptance model	0.0062	0.002	0.001	0.001	-	-	-	-	-
z and momentum scale	0.0009	-	-	-	-	-	-	-	-
Production asymmetry ($\pm$ 10%)	0.0002	0.002	-	-	-	-	-	-	0.008
CPV mixing & decay ($\pm$ 5%)	0.0003	0.002	-	-	-	-	-	-	0.020
Fit bias	-	0.001	0.003	-	0.001	0.02	0.02	0.01	0.005
Quadratic sum	0.0066	0.006	0.013	0.024	0.007	0.13	0.07	0.08	0.027

$B_s \rightarrow J/\psi\phi$: internal Δm_s

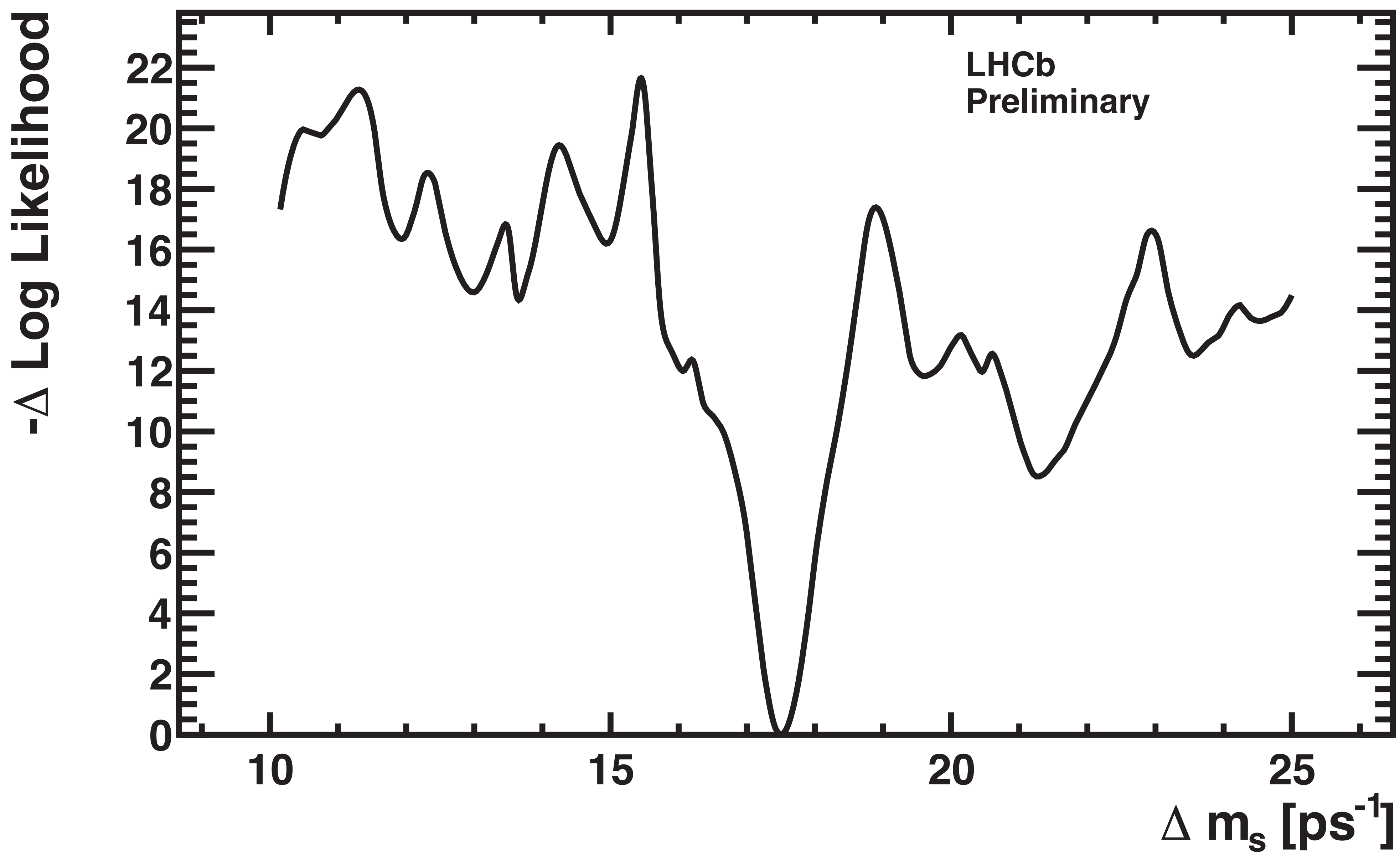


Figure 8: Likelihood profile scan for Δm_s.

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

Table 5: Fit fractions (%) of contributing components for the preferred model. For P- and D-waves λ represents the final state helicity. Here ρ refers to the $\rho(770)$ meson.

Components	3R+NR	3R+NR+ρ	3R+NR+$f_0(1500)$	3R+NR+$f_0(600)$
$f_0(980)$	107.1 ± 3.5	104.8 ± 3.9	73.0 ± 5.8	115.2 ± 5.3
$f_0(1370)$	32.6 ± 4.1	32.3 ± 3.7	114 ± 14	34.5 ± 4.0
$f_0(1500)$	-	-	15.0 ± 5.1	-
$f_0(600)$	-	-	-	4.7 ± 2.5
NR	12.84 ± 2.32	12.2 ± 2.2	10.7 ± 2.1	23.7 ± 3.6
$f_2(1270)$, $\lambda = 0$	0.76 ± 0.25	0.77 ± 0.25	1.07 ± 0.37	0.90 ± 0.31
$f_2(1270)$, $\lvert\lambda\rvert = 1$	0.33 ± 1.00	0.26 ± 1.12	1.02 ± 0.83	0.61 ± 0.87
ρ, $\lambda = 0$	-	0.66 ± 0.53	-	-
ρ, $\lvert\lambda\rvert = 1$	-	0.11 ± 0.78	-	-
Sum	153.6 ± 6.0	151.1 ± 6.0	214.4 ± 15.7	179.6 ± 8.0
$-\ln\mathcal{L}$	58945	58944	58943	58935
χ^2/ndf	1415/1343	1418/1341	1416/1341	1409/1341
Probability(%)	8.41	7.05	7.57	9.61

6.1 *CP* content

The main result in this paper is that *CP*-odd final states dominate. The $f_2(1270)$ helicity ±1 yield is $(0.21 \pm 0.65)\%$. As this represents a mixed *CP* state, the upper limit on the *CP*-even fraction due to this state is $< 1.3\,\%$ at 95% confidence level (CL). Adding the $\rho(770)$ amplitude and repeating the fit shows that only an insignificant amount of $\rho(770)$ can be tolerated; in fact, the isospin violating $J/\psi\rho(770)$ final state is limited to $< 1.5\%$ at 95% CL. The sum of $f_2(1270)$ helicity ±1 and $\rho(770)$ is limited to $< 2.3\%$ at 95% CL. In the $\pi^+\pi^-$ mass region within ±90 MeV of 980 MeV, this limit improves to $< 0.6\%$ at 95% CL.

LHCb: $B_s \to J/\psi\ K^{*0}$

Table 1: Summary of the measured $B_s^0 \to J/\psi \overline{K}^{*0}$ angular properties and their statistical and systematic uncertainties.

Parameter name	$\|A_S\|^2$	f_L	$f_{\|\|}$
Value and statistical error	$0.07^{+0.15}_{-0.07}$	0.50 ± 0.08	$0.19^{+0.10}_{-0.08}$
Angular acceptance	0.044	0.011	0.016
Background angular model	0.038	0.017	0.013
Assumption $\delta_S(M_{K\pi})$ = constant	0.026	0.005	0.002
B^0 contamination	0.036	0.004	0.007
Fit bias	–	–	0.005
Total systematic error	0.073	0.021	0.022

Table 2: Angular parameters of $B^0 \to J/\psi K^{*0}$ needed to compute $\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0})$. The systematic uncertainties from background modelling and the mass PDF are found to be negligible in this case.

Parameter name	$\|A_S\|^2$	f_L	$f_{\|\|}$
Value and statistical error	0.037 ± 0.010	0.569 ± 0.007	0.240 ± 0.009
Angular acceptance	0.044	0.011	0.016
Assumption $\delta_S(M_{K\pi})$ = constant	0.026	0.005	0.002
Total systematic error	0.051	0.012	0.016

Table 3: Parameter values and errors for $\frac{\mathcal{B}(B_s^0 \to J/\psi \overline{K}^{*0})}{\mathcal{B}(B^0 \to J/\psi K^{*0})}$.

Parameter	Name	Value
Hadronization fractions	f_d/f_s	3.75 ± 0.29
Efficiency ratio	$\varepsilon^{\rm tot}_{B^0}/\varepsilon^{\rm tot}_{B_s^0}$	0.97 ± 0.01
Angular corrections	$\lambda_{B^0}/\lambda_{B_s^0}$	1.01 ± 0.04
Ratio of K^{*0} fractions	$f^{(s)}_{K^{*0}}/f^{(d)}_{K^{*0}}$	1.09 ± 0.08
B signal yields	$N_{B_s^0}/N_{B^0}$	$\left(8.5^{+0.9}_{-0.8} \pm 0.8\right) \times 10^{-3}$