New physics search in $B_s \rightarrow J/\psi \phi$ and $B_s \rightarrow \phi \phi$

Olivier Leroy on behalf of the LHCb collaboration
(including ATLAS and CMS results)

1. Introduction, phenomenology
2. $B_s \rightarrow J/\psi \phi$ at LHCb
3. Comparison with ATLAS and CMS
4. $B_s \rightarrow \phi \phi$ at LHCb
5. Conclusion and prospects
References

- $B_s \rightarrow J/\psi \phi$
  - CMS note 2006-121
    - Private communications with U. Langenegger
  - ATLAS
    - Private communications with M. Smizanska
    - A. Dewhusrt talk, 15/02/2008
  - S. Koenig talk for ATLAS/CMS, SUSY07, 31/07/2007

- $B_s \rightarrow \phi \phi$
  - LHCb note 2007-047
Introduction (1)

- The phase $\Phi$ arising from interference between $B$ decay with and without mixing is a sensitive probe of NP.

$$\Phi = - \arg(\lambda_f)$$

$$\lambda_f = \frac{q \bar{A}_f}{p \bar{A}_f} = \eta_f e^{-i(\Phi_M - 2 \Phi_D)}$$

$$\text{Re}\lambda_f = \eta_f \cos \Phi; \quad \text{Im}\lambda_f = -\eta_f \sin \Phi$$

- $B_s \rightarrow J/\psi \phi$ decay is dominated by a tree: NP may enter in mixing box.

- $B_s \rightarrow \phi \phi$ decay is dominated by a penguin: NP may enter in mixing box and/or in penguin.

$\Phi$ is observable, $\Phi_D$ and $\Phi_M$ are not.
The observable weak phase is: \( \Phi^{\text{measured}} \equiv \Phi = \Phi^{\text{SM}} + \Phi^{\text{NP}} \)

In the standard model:

\[
\Phi^{\text{SM}}(B^0_s \rightarrow J/\psi \phi) \simeq 2 \arg(V_{ts}^* V_{tb}) - 2 \arg(V_{cb} V_{cs}^*) = -2 \beta_s
\]

\[
\Phi^{\text{SM}}(B^0_s \rightarrow \phi \phi) \simeq 2 \arg(V_{ts}^* V_{tb}) - 2 \arg(V_{ts} V_{tb}^*) = 0
\]

In presence of NP:

\[
\Phi(B^0_s \rightarrow J/\psi \phi) = -2 \beta_s + \Phi^{\text{NP}}_{\text{M}}
\]

\[
\Phi(B^0_s \rightarrow \phi \phi) = \Phi^{\text{NP}}_{\text{M}} - 2 \Phi^{\text{NP}}_{\text{D}}
\]

→ Probe new physics phases in the box (\( \Phi^{\text{NP}}_{\text{M}} \)) and in the penguin (\( \Phi^{\text{NP}}_{\text{D}} \))
**P→VV decays**

- $B_s$ is a pseudo scalar, $\phi$ and $J/\psi$ are vectors mesons
- Final state is a mixture of CP-even and CP-odd eigenstates
  - decompose decay amplitudes in term of linear polarization, when $J/\psi$ and $\phi$ are:
    - $A_0$: longitudinally polarized (CP-even)
    - $A_{||}$: transversely polarized and $\parallel$ to each other (CP-even)
    - $A_{\perp}$: transversely polarized and $\perp$ to each other (CP-odd)

- $\Rightarrow$ 3 angles $\theta$, $\varphi$, $\psi$ describe directions of final decay products $J/\psi \rightarrow \mu\mu$ and $\phi \rightarrow K^+K^-$
- In the coordinate system of the $J/\psi$ rest frame (where the $\phi$ meson moves in the $x$ direction, the $z$ axis is perpendicular to the decay plane of $\phi \rightarrow K^+K^-$, and $p_y(K^+) \geq 0$), $(\theta, \varphi)$ are the polar and azimuthal angles of the $\mu^+$.
  - In the $\phi$ rest frame, $\psi$ is the angle between $p(K^+)$ and $-p(J/\psi)$
    - Similar definition for $B_s \rightarrow \phi\phi$ (see backup)

- Strong phases: $\delta_{\perp} = \arg[A_{\perp}(0)]$, $\delta_{||} = \arg[A_{||}(0)]$, $\delta_0 = \arg[A_0(0)]$
**Differential decay rates**

\[
\frac{d^4 \Gamma(B_s^0 \to f)}{dt \, d\Omega} \propto \sum_{k=1}^{6} h_k(t) g_k(\Omega)
\]

\[
\frac{d^4 \Gamma(\bar{B}_s^0 \to f)}{dt \, d\Omega} \propto \sum_{k=1}^{6} \bar{h}_k(t) g_k(\Omega)
\]

\(f = J/\psi \phi \) or \( \phi \phi \)

<table>
<thead>
<tr>
<th>(k)</th>
<th>(h(t))</th>
<th>(g_{J/\psi \phi}(\theta, \psi, \varphi))</th>
<th>(g_{\phi \phi}(\theta_1, \theta_2, \varphi))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(</td>
<td>A_0(t)</td>
<td>^2)</td>
</tr>
<tr>
<td>2</td>
<td>(</td>
<td>A_{</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>(</td>
<td>A_{\perp}(t)</td>
<td>^2)</td>
</tr>
<tr>
<td>4</td>
<td>(\text{Re}{A_0^*(t)A_{</td>
<td></td>
<td>}(t)})</td>
</tr>
<tr>
<td>5</td>
<td>(\text{Im}{A_{</td>
<td></td>
<td>}(t)A_{\perp}(t)})</td>
</tr>
<tr>
<td>6</td>
<td>(\text{Im}{A_0^*(t)A_{\perp}(t)})</td>
<td>(\frac{1}{\sqrt{2}} \sin 2\psi \sin 2\theta \cos \varphi)</td>
<td>(-\sqrt{2} \sin \theta_1 \sin \theta_2 \sin \varphi)</td>
</tr>
</tbody>
</table>
Time dependent $B_s$ decay amplitudes

$$|A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) + \sin \Phi \sin (\Delta m_s t) \right]$$

$$|A_{\|}(t)|^2 = |A_{\|}(0)|^2 e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) + \sin \Phi \sin (\Delta m_s t) \right]$$

$$|A_{\perp}(t)|^2 = |A_{\perp}(0)|^2 e^{-\Gamma_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) + \cos \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) - \sin \Phi \sin (\Delta m_s t) \right]$$

$$\text{Re}\{A_{\|}^*(t)A_{\|}(t)\} = |A_{\|}(0)||A_{\|}(0)| e^{-\Gamma_s t} \cos (\delta_{2} - \delta_{1}) \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos \Phi \sin \left( \frac{\Delta \Gamma_s t}{2} \right) \right] + \sin \Phi \sin (\Delta m_s t)$$

$$\text{Im}\{A_{\|}^*(t)A_{\perp}(t)\} = |A_{\|}(0)||A_{\perp}(0)| e^{-\Gamma_s t} \left[ -\cos \delta_{1} \sin \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right. + \sin \delta_{1} \cos (\Delta m_s t) - \cos \delta_{1} \cos \Phi \sin (\Delta m_s t)$$

$$\text{Im}\{A_{\perp}^*(t)A_{\perp}(t)\} = |A_{\perp}(0)||A_{\perp}(0)| e^{-\Gamma_s t} \left[ -\cos \delta_{2} \sin \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right. + \sin \delta_{2} \cos (\Delta m_s t) - \cos \delta_{2} \cos \Phi \sin (\Delta m_s t)$$

\[ \Phi^{\text{measured}} \equiv \Phi \equiv \Phi^{\text{SM}} + \Phi^{\text{NP}} \]

8 physics parameters:
- $\Phi, \Gamma_s, \Delta \Gamma_s, \Delta m_s, R_{\perp}, R_{0}, \delta_{1}, \delta_{2}$
- $\Delta m_s = M_H - M_L$
- $\delta_{1} = \arg(A_{\|}^*A_{\perp}) = \delta_{\perp} - \delta_{\|}$
- $\delta_{2} = \arg(A_{\perp}^*A_{\perp}) = \delta_{\perp} - \delta_{0}$

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Time dependent $\bar{B}_s$ decay amplitudes

\[
|\tilde{A}_0(t)|^2 = |\tilde{A}_0(0)|^2 e^{-\tau_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right] - \sin \Phi \sin(\Delta m_s t) \\
|\tilde{A}_\parallel(t)|^2 = |\tilde{A}_\parallel(0)|^2 e^{-\tau_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right] + \sin \Phi \sin(\Delta m_s t) \\
|\tilde{A}_\perp(t)|^2 = |\tilde{A}_\perp(0)|^2 e^{-\tau_s t} \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) + \cos \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right] + \sin \Phi \sin(\Delta m_s t) \\
\text{Re}\{\tilde{A}_0(t)\tilde{A}_\parallel(t)\} = \tilde{A}_0(0)|\tilde{A}_\parallel(0)| e^{-\tau_s t} \cos(\delta_2 - \delta_1) \left[ \cosh \left( \frac{\Delta \Gamma_s t}{2} \right) - \cos \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right] - \sin \Phi \sin(\Delta m_s t) \\
\text{Im}\{\tilde{A}_\parallel(t)\tilde{A}_\perp(t)\} = |\tilde{A}_\parallel(0)||\tilde{A}_\perp(0)| e^{-\tau_s t} \left[ -\cos \delta_1 \sin \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right] - \sin \delta_1 \cos(\Delta m_s t) + \cos \delta_1 \cos \Phi \sin(\Delta m_s t) \\
\text{Im}\{\tilde{A}_0(t)\tilde{A}_\perp(t)\} = |\tilde{A}_0(0)||\tilde{A}_\perp(0)| e^{-\tau_s t} \left[ -\cos \delta_2 \sin \Phi \sinh \left( \frac{\Delta \Gamma_s t}{2} \right) \right] - \sin \delta_2 \cos(\Delta m_s t) + \cos \delta_2 \cos \Phi \sin(\Delta m_s t)\]

\[\Phi \longleftrightarrow \pi - \Phi\]
\[\Delta \Gamma_s \longleftrightarrow -\Delta \Gamma_s\]
\[\delta_1 \longleftrightarrow \pi - \delta_1\]
\[\delta_2 \longleftrightarrow \pi - \delta_2\]

Tagged analyses sensitive to both $\cos \Phi$ and $\sin \Phi$ (2-fold ambiguity)
Untagged analysis

If $\Delta \Gamma_s \neq 0$, untagged analysis still sensitive to $\Phi$, but

- Strong correlations between $\Phi$ and strong phases
- If $\Phi \sim 0$, only possible to fit ($\delta_1 - \delta_2$), and poor sensitivity to $\Phi$
- 4-fold ambiguity
**Roadmap to measure $\Phi$ on real data:**
- Trigger and select $B_s \rightarrow J/\psi \phi$, $\phi\phi$
- Measure proper time
- Measure 3 transversity angles
- Tag initial $B_s$ flavour
- Unbinned maximum likelihood fit of time and angular $B$ decay rates
  - 6 observables: proper time, 3 angles, $q (=0,-1,+1$ for untagged, $B_s$, $\bar{B}_s$) and mass
  - 8 physics parameters: $\Phi$, $\Delta\Gamma_s$, $\Gamma_s$, $\Delta m_s$, $R_\perp$, $R_0$, $\delta_1$, $\delta_2$
  - + detector parameters (resolutions, acceptances, tagging, ...)
- Crucial role of control channels to extract detector parameters without relying too heavily on MC

**Simulation studies performed in 2 steps:**
1. Full Monte Carlo simulation
   - Pythia / EvtGen / Geant4 / trigger / reconstruction
   - Background = 34M $b\bar{b}$ inclusive (5 minutes of data taking in nominal conditions)
   - Extract:
     - Annual signal event yield
     - Background fraction
     - Mass, proper time, angle distributions; resolutions and acceptances
     - Flavour tagging performance
2. Inject parameters from the full MC in hundreds of toy MC, to estimate the sensitivity to the phase $\Phi$ (and the other physics parameters)
**B_s→J/ψφ selection**

- \( BR^{vis}[B_s→J/ψ(\mu\mu)φ(K^+K^-)]= (30.9±11.0)\times10^{-6} \)
- "Easy" trigger on muon
  - Trigger efficiencies w.r.t. offline selected events
    - L0: 93.5%
    - High Level Trigger: 84.9%
    - Total: 79.4%
- Reconstruct \( J/ψ→\mu\mu; \ φ→K^+K^- \); standard PID/kinematical cuts
- \( B_s \) mass resolution \(~14\text{MeV}\)
- Untagged yield \(~130k / 2\text{fb}^{-1} \)
- \( B_b\bar{b} / S \sim 0.12 \), mainly from combinatorics

![Graph showing Bs mass distribution](image)
Flavour tagging in LHCb

$B_s \rightarrow J/\psi \phi$: efficiency $\varepsilon \sim 57\%$, mistag rate $\omega \sim 33\%$, $\varepsilon(1-2\omega)^2 \sim 6.6\%$
**$B_s \rightarrow J/\psi \phi$ proper time model**

- Proper time resolution $\sim 36$ fs
- None flat acceptance
- Exponential background distribution with $\tau = 1$ ps
- Example:
  - Distribution of proper time for pure-$CP$ even $B_s$ decay
  - Amplitude of oscillation proportional to:
    - $\sin 2\beta_s$
    - $\exp(-0.5(\sigma_r \Delta m_s)^2)$
    - tagging dilution $1 - 2\omega$

---

Red solid line: tagged as initially $B_s^0$
Blue dashed: tagged as initially $B_s^0$

$2\beta_s = -0.2$ rad
($\sim 5 \times \text{SM value}$)
Perform hundreds of toy MC, maximum likelihood fit with:
- 6 observables $m$, $t$, $\cos \theta$, $\varphi$, $\cos \psi$, $q$
- 8 free parameters $\Phi$, $\Delta \Gamma_s$, $\Gamma_s$, $\Delta m_s$, $R_\perp$, $R_0$, $\delta_1$, $\delta_2$

Approximations:
- Flat background in mass and transversity angles
- Angular acceptance and resolution ignored

<table>
<thead>
<tr>
<th>Physics Parameters</th>
<th>Input Value</th>
<th>RMS of fitted parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \Gamma_s$</td>
<td>0.10 [ps$^{-1}$]</td>
<td>0.0079</td>
</tr>
<tr>
<td>$\Gamma_s$</td>
<td>0.68 [ps$^{-1}$]</td>
<td>0.0027</td>
</tr>
<tr>
<td>$\Delta m_s$</td>
<td>17.77 [ps$^{-1}$]</td>
<td>0.007</td>
</tr>
<tr>
<td>$2\beta_s$</td>
<td>0.04</td>
<td>0.022</td>
</tr>
<tr>
<td>$R_0$</td>
<td>0.6</td>
<td>0.0027</td>
</tr>
<tr>
<td>$R_\perp$</td>
<td>0.2</td>
<td>0.0035</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>0 [rad]</td>
<td>0.083</td>
</tr>
<tr>
<td>$\delta_2$</td>
<td>$\pi$ [rad]</td>
<td>0.075</td>
</tr>
</tbody>
</table>

Pulls of fitted quantities normally distributed

With 2fb$^{-1}$ (one nominal year), $\sigma(2\beta_s) \sim 0.02$
- $5\sigma$ NP discovery, if $2\beta_s^{\text{true}} > 0.1$!

Standard Model: $2\beta_s = 0.0368 \pm 0.0017$
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New physics search in Bs→JψΦ and Bs→ΦΦ

**B_s→J/ψΦ sensitivity studies**

- No significant variation of σ(2β_s) seen as a function of 2β_s and Γ_s
- Variations as a function of ΔΓ_s, mistag and proper time resolution
- Expect systematics from mistag rate, angular and proper time acceptance and background distributions
  - Will be estimated from control channels, in particular B_d→J/ψK*

![Graphs showing sensitivity to various parameters](image_url)
Comparison with ATLAS/CMS

lider

- 3-angle analyses performed
  - CMS: untagged
  - ATLAS: tagged

- With respect to LHCb:
  - Lumi x5 higher, but higher trigger thresholds and smaller bandwidth
    - Similar signal event yield
  - No K/π separation
    - Tagging and background rejection more difficult
  - Worse proper time resolution

\[ \sigma_m = 14 \text{ MeV} \quad \text{CMS} \]
\[ \sigma_m = 16.6 \text{ MeV} \quad \text{ATLAS} \]

\[ \sigma_t = 77 \text{ fs} \quad \text{CMS} \]
\[ \sigma_t = 83 \text{ fs} \quad \text{ATLAS} \]
<table>
<thead>
<tr>
<th></th>
<th>ATLAS</th>
<th>CMS</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated lumi. (fb⁻¹)</td>
<td>2.5</td>
<td>2.5</td>
<td>0.5</td>
</tr>
<tr>
<td>(1/4 of nominal year)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bₛ→J/ψφ events</td>
<td>23k</td>
<td>27k</td>
<td>33k</td>
</tr>
<tr>
<td>Mass resolution (MeV)</td>
<td>16.6</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>Proper time resolution (fs)</td>
<td>83</td>
<td>77</td>
<td>36</td>
</tr>
<tr>
<td>Angles</td>
<td>Acceptance and resolution considered to be negligible /flat</td>
<td>Resolution neglected, non flat acceptance included</td>
<td>Acceptance and resolution neglected</td>
</tr>
<tr>
<td>Flavour tagging</td>
<td>μ, e, Qjet (OS) 4.6</td>
<td>Not yet 0</td>
<td>μ, e, K, Qvtx, OS+SS 6.6</td>
</tr>
<tr>
<td>Assumptions</td>
<td>One strong phase fixed</td>
<td>ΔΓₛ/Γₛ =0.2</td>
<td>See before</td>
</tr>
<tr>
<td>σ(2βₛ)</td>
<td>0.16</td>
<td>0.18</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Standard Model: 2βₛ=0.0368±0.0017
B_s \rightarrow \phi \phi \text{ at LHCb}
B_{s} \rightarrow \phi \phi \text{ selection}

- BR^{vis}[B_{s} \rightarrow \phi (K^{+}K^{-})\phi (K^{+}K^{-})] = (3.4 \pm 2.1) \times 10^{-6} \text{ from CDF, PRL 95 031801 (2005)}
- Hadronic Trigger (E_T and IP cuts), less efficient than lepton trigger
  - Trigger efficiencies w.r.t offline selected events
    - LO: 36.8%
    - High Level Trigger: 50.7%
    - Total: 18.7%
- Reconstruct $\phi \rightarrow K^{+}K^{-}$; standard PID/kinematical cuts
- $B_{s}$ mass resolution $\sim 12$ MeV
- Untagged yield $\sim 3.1k / 2fb^{-1}$
- $B_{bb}/S < 0.8$ at 90%CL, mainly from combinatorics
- Proper time resolution $\sim 43fs$
- Tagging efficiency $\sim 60\%$; mistag rate $\sim 30\%$

![Graphs showing mass resolution and proper time resolution](image)

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New physics search in Bs->JpsiPhi and Bs->PhiPhi
Assume a single new physics CP violating phase $\Phi$ such that:

- $\lambda_\perp = \lambda_\parallel = \lambda_0 = \eta_f e^{i\Phi}$

- $\lambda_i$ could all be different but this assumption simplifies the time dependent analysis
  - only fine tuning of the individual phases would lead to a null result in the presence of new physics

Perform hundreds of toy MC

- 6 observables: $m, t, \cos\theta_1, \cos\theta_2, \varphi, q$
- 7 free physics parameters: $\Phi, \Delta\Gamma_s, \Gamma_s, R_\perp, R_\parallel, \delta_1, \delta_2$
- Same approximations than $J/\psi\phi$ studies:
  - Flat background in mass and transversity angles
  - Exponential lifetime distribution for background
  - Angular acceptance and resolution ignored
**$B_s \rightarrow \phi \phi$ sensitivity studies**

- 500 toys with $\Phi = 0.2$

<table>
<thead>
<tr>
<th>$\chi^2 / \text{ndf}$</th>
<th>31.88 / 96</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>20.59</td>
</tr>
<tr>
<td>Mean</td>
<td>0.1941</td>
</tr>
<tr>
<td>Sigma</td>
<td>0.1002</td>
</tr>
</tbody>
</table>

- Pull normally distributed
- $\sigma(\Phi) \sim 0.11$ for 2fb$^{-1}$
  - Current combined BaBar/Belle uncertainty on $S(\phi K_s) = 0.17$, on $S(\eta' K_s) \sim 0.07$
  - No significant variation seen as a function of input $\Phi$, $R_\perp$, $R_\parallel$, $\delta_1$, $\delta_2$ and proper time resolution
  - Expect systematics from mistag rate, proper time and angular acceptance and background distributions
    - Will be estimated from control channels
Conclusions and prospects

- **$B_s \to J/\psi \phi$ hot topic and promising way to discover NP**
  - Tevatron expects $\sigma(2\beta_s)\sim 0.14$ by the end of runII
  - LHCb with 2fb$^{-1}$ (one nominal year)
    - 130k $B_s \to J/\psi(\mu\mu)\phi$, $\sigma(2\beta_s)\sim 0.02$
    - Could expect some deteriorations with more realistic MC and real data
      - However, if true $2\beta_s$ value is the current D0 one =0.57 (NP-like), we should measure it with ~0.1fb$^{-1}$!
  - ATLAS/CMS with 10fb$^{-1}$ (one nominal year)
    - ATLAS: $\sigma(2\beta_s)\sim 0.08$
    - CMS: $\sigma(2\beta_s)\sim 0.09$

- **$B_s \to \phi\phi$ with 2fb$^{-1}$ at LHCb**
  - 3.1k $B_s \to \phi\phi$ events, $\sigma(\Phi)\sim 0.11$
    - Competitive with the gluonic penguins studies at b-factories

- **Complementary channels to probe NP phases in $B_s-\bar{B}_s$ box and in $b \to s\bar{s}s$ penguin diagrams**

- **Ongoing/future studies:**
  - More realistic fitting model, especially angular background and acceptance
  - More decay channels: $J/\psi(\eta, \phi, \eta_c)\phi$, $J/\psi(\eta, \eta, \eta', \eta')$, $D_s(*)D_s(*)$, ...
Backup

1. Phenomenology
2. Selection
3. Proper time
4. Angles
5. Tagging
6. Sensitivity studies
7. Other interesting channels
8. Systematics
9. Comparison with other
10. $B_s \rightarrow \phi \phi$
Phenomenology
Discussion related to $B_s \to J/\psi\phi / \phi\phi$

- Uncertainty on $\Phi^{SM}(J/\psi\phi)$? assumed $-2\beta_s = -0.037 \pm 0.002$
  - Penguin pollution?
- Uncertainty on $\Phi^{SM}(\phi\phi) < 1\%$?
  - e.g. M. Raidal, PRL 89, 231803 (2002)
- Best strategy to search for NP
  - Best set of parameters to fit?
  - e.g. A. Datta et al., PRD 71, 096002 (2005)
    - 10 observables
    - Can we assume $\lambda_{\perp} = \lambda_{\parallel} = \lambda_0 = \eta_{fe} e^{i\Phi}$?
- List of motivated NP models predicting $2\beta_s > 0.1$ and compatible with all observations
- Complementarities with other measurements:
  - $B_d \to J/\psi K^*$
    - Test of SU(3) flavour symmetry
    - Test of factorization of the four-quark operators $Q_k$ into hadronic matrix elements of quark currents
  - $B_s \to D_s K (\gamma - 2\beta_s)$
  - $a_{fs}$ sensitive to $\text{Im}(\Gamma_{12}/M_{12})$ and the same NP phase in $M_{12}$
  - $\Delta \Gamma_s$ measurements
- Many other modes:
  - $PS \to VV$: $B_s \to J/\psi(\eta_{c}\phi)$, higher $\psi$ resonances, $D_s^* D_s^*$, ...
  - Pure CP even modes: $\eta_{c}\phi, J/\psi\eta, J/\psi\eta', D_s D_s, ...$
  - Penguins: $B_s \to K^* K^*$, ...
- Resolving the 2-fold ambiguity in $\Phi$ using BaBar method for $J/\psi K^*$?
Mixing induced CP violation

- SM, $2\beta_s$ = the CP violating phase arising from interference between $B_s$ decay without and with oscillation to a common final state $f$

- Sensitive to New Physics because of the box diagram
  - And $\beta_s$ precisely known in the SM
  - Golden way to measure $\beta_s$: time and angular dependent analysis of flavour tagged $B_s \rightarrow J/\psi \phi$
    - High visible BR $\sim 3.1 \times 10^{-5}$
    - But PS-$\rightarrow$VV, $f$ is a mixture of CP-odd and CP-even eigenstates
      - Angular analysis required
A way to introduce $\beta_s$

- $V_{\text{CKM}}$ can be written with 4 independent parameters:
  - the « usual » Wolfenstein parameters $\lambda, A, \rho, \eta$
    \[
    V_{\text{CKM}} = \begin{pmatrix}
    1 - \frac{1}{2} \lambda^2 & \lambda & A \lambda^3 (\rho - i \eta) \\
    -\lambda & 1 - \frac{1}{2} \lambda^2 & A \lambda^2 \\
    A \lambda^3 (1 - \rho - i \eta) & -A \lambda^2 & 1
    \end{pmatrix} + \mathcal{O}(\lambda^4)
    \]
  - Or $|V_{us}|, |V_{ub}|, |V_{cb}|, |V_{td}|$ [Branco 1988]
  - Or 4 independent phases: $\gamma, \beta, \beta_s, \beta_K$
    \[
    \gamma = \text{arg} \left( \frac{-V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right)
    \]
    \[
    \beta = \text{arg} \left( \frac{-V_{cd} V_{cb}^*}{V_{td} V_{tb}^*} \right)
    \]
    \[
    \beta_s = \text{arg} \left( \frac{-V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right)
    \]
    \[
    \beta_K = \text{arg} \left( \frac{-V_{us} V_{ud}^*}{V_{cs} V_{cd}^*} \right)
    \]

- References:
  - R. Aleksan, B. Kayser, and D. London. Determining the Quark Mixing Matrix from CP-Violating
  - See also: J. Silva, hep-ph/0410351
bd and bs unitarity triangles

SM values, both triangles on the same scale, bs triangle shifted by etabar-0.3 to be visible

\[ V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0 \]

\[ \gamma = \arg \left( -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right) \]

\[ \beta = \arg \left( -\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*} \right) = (21.5 \pm 0.5)^\circ \]

\[ V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0 \]

\[ \beta_s = \arg \left( -\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \right) = (1.05 \pm 0.05)^\circ \]
bd and bs unitarity triangles

\[ V_{CKM}^\dagger V_{CKM} = V_{CKM} V_{CKM}^\dagger = 1 \Rightarrow 12 \text{ relations, among which} \]

\[ V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \]

\[ \beta = \arg \left( \frac{V_{cd} V_{cb}^*}{V_{td} V_{tb}^*} \right) \]

\[ V_{us} V_{ub}^* + V_{cs} V_{cb}^* + V_{ts} V_{tb}^* = 0 \]

\[ \beta_s = \arg \left( \frac{V_{ts} V_{tb}^*}{V_{cs} V_{cb}^*} \right) \]

Despite all the contacted persons from CDF/D0, HFAG and PDG agree that the natural convention for \( \beta_s \) would be \( \beta_s < 0 \) in the SM (natural because of perfect d-s symmetry), it seems too late to change it NOW.

So that we have to leave with (yet another) strange convention (the one on this slide)
New physics search in $B_s \rightarrow J\psi \Phi$ and $B_s \rightarrow \Phi \Phi$

Olivier Leroy

6 unitarity triangles, angle definitions

\[(ds) \quad V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0\]
\[(sb) \quad V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0\]
\[(db) \quad V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0\]
\[(cu) \quad V_{us}^*V_{cd} + V_{cs}^*V_{cs} + V_{ub}^*V_{cb} = 0\]
\[(tc) \quad V_{ud}^*V_{td} + V_{us}^*V_{ts} + V_{ub}^*V_{tb} = 0\]
\[(tu) \quad V_{ud}^*V_{td} + V_{us}^*V_{ts} + V_{ub}^*V_{tb} = 0\]

\[
\gamma = \arg \left( -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} \right) \]
\[
\beta = \arg \left( -\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*} \right) \]
\[
\beta_s = \arg \left( -\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \right) \]
\[
\beta_K = \arg \left( -\frac{V_{us}V_{ud}^*}{V_{cs}V_{cd}^*} \right) \]
The « natural d-s symmetry » $\beta_s$ convention

$$V_{\text{CKM}}^{\dagger} V_{\text{CKM}} = V_{\text{CKM}} V_{\text{CKM}}^{\dagger} = 1 \Rightarrow 12 \text{ relations, among which}$$

$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$$

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

From d-s exchange:

$$V_{us} V_{ub}^* + V_{cs} V_{cb}^* + V_{ts} V_{tb}^* = 0$$

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

With this definition, opposite to the 2 previous sides, $\beta_s$ is negative in the SM. Convention unfortunately not chosen by PDG/HFAG, for historical reasons...
In $B_s \rightarrow J/\psi \phi$, we measure (up to 2-fold ambiguity):

$$2\beta_s^{\text{measured}} = 2\beta_s - 2\theta_{NP}^s$$

- $\theta_{NP}^s$ is a New Physics phase:
- $M_{12}^{NP} = r_s^2 \exp(2i\theta_{NP}^s) M_{12}^{SM}$
- $\theta_{NP}^s$ also appears in $a_f$ measurement
  - see e.g. Z. Ligeti et al., arxiv.org/abs/hep-ph/0604112v3

Often:

- $\phi_s = \phi_{M/G} = \text{arg} \left( -\frac{M_{12}}{\Gamma_{12}} \right)$ (which appears in $a_f$)
- In the Standard Model:
  - $\phi_s = \text{arg} \left( -\frac{M_{12}}{\Gamma_{12}} \right) = (4.2 \pm 1.4) \times 10^{-3}$
  - $\beta_s = \text{arg} \left( -\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \right) = (1.84 \pm 0.09) \times 10^{-2}$
  - See e.g. A. Lenz, arxiv.org/abs/0802.0977v1

Old LHCb publications used $\phi_s = -2\beta_s$
B decay rates, using $\lambda_f$

\[
\Gamma[B_q(t) \rightarrow f] = N_f |A_f^{(q)}|^2 e^{-\Gamma_q t} \left\{ \frac{1 + |\lambda_f^{(q)}|^2}{2} \cosh \frac{\Delta \Gamma_q t}{2} \right. \\
\left. + \frac{1 - |\lambda_f^{(q)}|^2}{2} \cos(\Delta M_q t) - \Re \lambda_f^{(q)} \sinh \frac{\Delta \Gamma_q t}{2} - \Im \lambda_f^{(q)} \sin (\Delta M_q t) \right\},
\]

(1.58)

\[
\Gamma[\bar{B}_q(t) \rightarrow f] = N_f |A_f^{(q)}|^2 (1 + a) e^{-\Gamma_q t} \left\{ \frac{1 + |\lambda_f^{(q)}|^2}{2} \cosh \frac{\Delta \Gamma_q t}{2} \\
\right. \\
\left. - \frac{1 - |\lambda_f^{(q)}|^2}{2} \cos(\Delta M_q t) - \Re \lambda_f^{(q)} \sinh \frac{\Delta \Gamma_q t}{2} + \Im \lambda_f^{(q)} \sin (\Delta M_q t) \right\},
\]

(1.59)

\[
\Gamma[B_q(t) \rightarrow \bar{f}] = N_f \left| A_f^{(q)} \right|^2 (1 - a) e^{-\Gamma_q t} \left\{ \frac{1 + |\lambda_f^{(q)}|^2}{2} \cosh \frac{\Delta \Gamma_q t}{2} \\
\right. \\
\left. - \frac{1 - |\lambda_f^{(q)}|^2}{2} \cos(\Delta M_q t) - \Re \frac{1}{\lambda_f^{(q)}} \sinh \frac{\Delta \Gamma_q t}{2} + \Im \frac{1}{\lambda_f^{(q)}} \sin (\Delta M_q t) \right\},
\]

(1.60)

\[
\Gamma[\bar{B}_q(t) \rightarrow \bar{f}] = N_f \left| A_f^{(q)} \right|^2 e^{-\Gamma_q t} \left\{ \frac{1 + |\lambda_f^{(q)}|^2}{2} \cosh \frac{\Delta \Gamma_q t}{2} \\
\right. \\
\left. + \frac{1 - |\lambda_f^{(q)}|^2}{2} \cos(\Delta M_q t) - \Re \frac{1}{\lambda_f^{(q)}} \sinh \frac{\Delta \Gamma_q t}{2} - \Im \frac{1}{\lambda_f^{(q)}} \sin (\Delta M_q t) \right\}.
\]

(1.61)
B decay rate including mistag

\[ (1 - \omega_{\text{tag}})|A_{0}(t)|^2 + \omega_{\text{tag}}|A_{0}(t)|^2 = \frac{|A_{0}(0)|^2}{2} \left[ (1 + \cos \phi_{s}) e^{-\Gamma_{L}t} + (1 - \cos \phi_{s}) e^{-\Gamma_{R}t} \right. \]
\[ + 2 \left( 1 - 2\omega_{\text{tag}} \right) e^{-\Gamma_{L}t} \sin(\Delta m_{s}t) \sin \phi_{s} \]
B decay rate: tagged

1. The sinusoidal $\Delta m_s$ terms appear multiplied by the $1 - 2\omega_{tag}$ term. Unlike the one-angle case, however, they are not suppressed by $\sin \phi_s$ in the imaginary cross terms. Therefore we expect a substantially improved measurement of both $\Delta m_s$ and $\omega_{tag}$.

2. The $\sin \delta_1$ and $\sin \delta_2$ terms are present and unlike in the untagged case, they are separated from the $\phi_s$ term. They appear in a way which changes the phase of the $\Delta m_s$ oscillation. We therefore expect a clean fit for $\delta_1$ and $\delta_2$ to be possible with some correlation with $\Delta m_s$. 
Untagged decay rate

\[ |A_0(t)|^2 + |\bar{A}_0(t)|^2 = \frac{|A_0(0)|^2}{2} \left[ (1 + \cos \phi_s) e^{-\Gamma_L t} + (1 - \cos \phi_s) e^{-\Gamma_R t} \right] \]  

(33)

\[ |A_{||}(t)|^2 + |\bar{A}_{||}(t)|^2 = \frac{|A_{||}(0)|^2}{2} \left[ (1 + \cos \phi_s) e^{-\Gamma_L t} + (1 - \cos \phi_s) e^{-\Gamma_R t} \right] \]  

(34)

\[ |A_{\perp}(t)|^2 + |\bar{A}_{\perp}(t)|^2 = \frac{|A_{\perp}(0)|^2}{2} \left[ (1 - \cos \phi_s) e^{-\Gamma_L t} + (1 + \cos \phi_s) e^{-\Gamma_R t} \right] \]  

(35)

\[
\begin{align*}
\text{Re}\{A_0^*(t)A_{||}(t)\} &+ \text{Re}\{\bar{A}_0^*(t)\bar{A}_{||}(t)\} = \frac{1}{2} |A_0(0)||A_{||}(0)| \cos(\delta_2 - \delta_1) \left[ (1 + \cos \phi_s) e^{-\Gamma_L t} \\
&+ (1 - \cos \phi_s) e^{-\Gamma_R t} \right] \\
\text{Im}\{A_{||}^*(t)A_{\perp}(t)\} &+ \text{Im}\{\bar{A}_{||}^*(t)\bar{A}_{\perp}(t)\} = \frac{-1}{2} |A_{||}(0)||A_{\perp}(0)| \left[ (e^{-\Gamma_R t} - e^{-\Gamma_L t}) \cos \delta_1 \sin \phi_s \right]
\end{align*}
\]  

(36)

\[
\begin{align*}
\text{Im}\{A_{\perp}^*(t)A_{||}(t)\} &+ \text{Im}\{\bar{A}_{\perp}^*(t)\bar{A}_{||}(t)\} = \frac{-1}{2} |A_{\perp}(0)||A_{||}(0)| \left[ (e^{-\Gamma_R t} - e^{-\Gamma_L t}) \cos \delta_2 \sin \phi_s \right]
\end{align*}
\]  

(37)

1. Unlike the one-angle case, a \(\sin \phi_s\) term remains. However, it would only be possible to consider measuring \(\phi_s\) with any decent accuracy if the strong phases were known from some external source or could be simultaneously fit.

2. In principle it is possible to fit for everything simultaneously. However for small \(\phi_s\) (as in the case of the SM expectation) the imaginary cross terms are strongly suppressed (vanishing in the limit \(\sin \phi_s = 0\)). In this case it would be impossible to fit for both \(\delta_1\) and \(\delta_2\); it would only be possible to fit to the combination \(\delta_1 - \delta_2\) arising in the real cross term.

3. It is only if \(\phi_s\) were different from zero (and preferably large) and the \(\delta_i\) had values different from 0 (mod 2\(\pi\)) that it would be possible to reliably fit simultaneously the full set \(\Gamma_s, \Delta \Gamma_s, R_{\perp}, R_0, \delta_1, \delta_2\) and \(\phi_s\). Otherwise this fit becomes problematic. In fact D0 [17] do present just such a fit but their central values are \(\phi_s = 0.76\) rad, \(\delta_1 = 3.3\) rad and \(\delta_2 = 0.7\) rad. We have repeated our study using their central values, and our fit runs without error. The fit fails as expected if we use central values of \(\phi_s = -0.04\) rad, \(\delta_1 = 0\) rad and \(\delta_2 = \pi\) rad.
Observables in $P \rightarrow VV$

\[ A_{\lambda} = \text{Amp}(B \rightarrow V_1 V_2)_{\lambda} = a_{\lambda} e^{i\delta_{\lambda}} + A_{\lambda}^q e^{i\Phi_q}, \]
\[ \tilde{A}_{\lambda} = \text{Amp}(\bar{B} \rightarrow V_1 V_2)_{\lambda} = a_{\lambda} e^{i\delta_{\lambda}} + \tilde{A}_{\lambda}^q e^{-i\Phi_q}, \]
\[ \mathcal{A} = \text{Amp}(B \rightarrow V_1 V_2) = A_0 g_0 + A_{\parallel} g_{\parallel} + i A_{\perp} g_{\perp}, \]
\[ \tilde{\mathcal{A}} = \text{Amp}(\bar{B} \rightarrow V_1 V_2) = \tilde{A}_0 g_0 + \tilde{A}_{\parallel} g_{\parallel} - i \tilde{A}_{\perp} g_{\perp}, \]

\[ \Gamma(B \rightarrow V_1 V_2) = e^{-\Gamma t} \sum_{\lambda \in \sigma} (\Lambda_{\lambda \sigma} + \Sigma_{\lambda \sigma} \cos(\Delta M t) \pm \rho_{\lambda \sigma} \sin(\Delta M t)) g_{\lambda} g_{\sigma}. \]

where $a_{\lambda}$ and $A_{\lambda}^q$ represent the helicity-dependent SM and NP amplitudes, respectively, the $\delta_{\lambda}$ are the SM strong phases, and the helicity index $\lambda$ takes the values $\{0, \parallel, \perp\}$
the full decay amplitudes

\[ \Lambda_{\lambda \lambda} = \frac{1}{2} (|A_{\lambda}|^2 + |\tilde{A}_{\lambda}|^2), \quad \Sigma_{\lambda \lambda} = \frac{1}{2} (|A_{\lambda}|^2 - |\tilde{A}_{\lambda}|^2), \quad \Lambda_{\perp i} = -\text{Im}(A_{\perp} A^*_i - \tilde{A}_{\perp} \tilde{A}^*_i), \]
\[ \Lambda_{\parallel 0} = \text{Re}(A_{\parallel} A^*_0 + \tilde{A}_{\parallel} \tilde{A}^*_0), \quad \Sigma_{\perp i} = -\text{Im}(A_{\perp} A^*_i + \tilde{A}_{\perp} \tilde{A}^*_i), \quad \Sigma_{\parallel 0} = \text{Re}(A_{\parallel} A^*_0 - \tilde{A}_{\parallel} \tilde{A}^*_0), \]
\[ \rho_{\perp i} = \text{Re}(e^{-i\Phi^q_{\mu}} [A^*_i A_{\perp} + \tilde{A}^*_i \tilde{A}_{\perp}]), \quad \rho_{\perp \perp} = \text{Im}(e^{-i\Phi^q_{\mu}} A^*_i \tilde{A}_{\perp}), \]
\[ \rho_{\parallel 0} = -\text{Im}(e^{-i\Phi^q_{\mu}} [A^*_i \tilde{A}_0 + \tilde{A}^*_i A_0]), \quad \rho_{ii} = -\text{Im}(e^{-i\Phi^q_{\mu}} A^*_i A_{i}), \]

\[ i = \{0, \parallel\} \]
\[ \Lambda_{\lambda \lambda} = a^2 + (A_{\lambda}^q)^2 + 2a_\lambda A_{\lambda}^q \cos \delta_\lambda \cos \Phi_q, \]
\[ \Sigma_{\lambda \lambda} = 2a_\lambda A_{\lambda}^q \sin \delta_\lambda \sin \Phi_q, \]
\[ \Lambda_{\perp i} = 2[a_\perp A_i^q \cos \delta_\perp - a_i A_i^q \cos \delta_i] \sin \Phi_q, \]
\[ \Lambda_{\parallel 0} = 2[a_\parallel a_0 \cos (\delta_\parallel - \delta_0) + a_\parallel A_0^q \cos \delta_\parallel \cos \Phi_q + a_0 A_0^q \cos \delta_0 \cos \Phi_q + A_0^q A_0^q], \]
\[ \Sigma_{\perp i} = -2[a_\perp a_i \sin (\delta_\perp - \delta_i) + a_\perp A_i^q \sin \delta_\perp \cos \Phi_q - a_i A_i^q \sin \delta_i \cos \Phi_q], \]
\[ \Sigma_{\parallel 0} = 2[a_\parallel A_0^q \sin \delta_\parallel + a_0 A_0^q \sin \delta_0] \sin \Phi_q, \]
\[ \rho_{ii} = a_i^2 \sin 2\phi_M^q + 2a_i A_i^q \cos \delta_i \sin (2\phi_M^q + \Phi_q) + (A_i^q)^2 \sin (2\phi_M^q + 2\Phi_q), \]
\[ \rho_{\perp \perp} = -a_\perp^2 \sin 2\phi_M^q - 2a_\perp A_\perp^q \cos \delta_\perp \sin (2\phi_M^q + \Phi_q) - (A_\perp^q)^2 \sin (2\phi_M^q + 2\Phi_q), \]
\[ \rho_{\perp i} = 2[a_\perp a_\perp \cos (\delta_\perp - \delta_\perp) \cos 2\phi_M^q + a_\perp A_\perp^q \cos \delta_\perp \cos (2\phi_M^q + \Phi_q) + a_\perp A_\perp^q \cos \delta_\perp \cos (2\phi_M^q + \Phi_q) \]
\[ + A_i^q A_\perp^q \cos (2\phi_M^q + 2\Phi_q)], \]
\[ \rho_{\parallel 0} = 2[a_\parallel a_0 \cos (\delta_\parallel - \delta_0) \sin 2\phi_M^q + a_\parallel A_0^q \cos \delta_\parallel \sin (2\phi_M^q + \Phi_q) + a_0 A_\parallel^q \cos \delta_0 \sin (2\phi_M^q + \Phi_q) \]
\[ + A_0^q A_\parallel^q \sin (2\phi_M^q + 2\Phi_q)]. \]
Angles and proper time are correlated: Angles vary with $t$ and $t$ vary with angles.

$\text{pdf}(t, \cos \theta)$ integrating over $\phi$ and $\cos \psi$

$2\beta_s = 0.4$

$2\beta_s = 0.04$
Tevatron results

✦ Recent CDF and D0 $\beta_s$ results of tagged $B_s \rightarrow J/\psi\phi$ analyses

<table>
<thead>
<tr>
<th></th>
<th>CDF</th>
<th>D0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated lumi.</td>
<td>1.35 fb$^{-1}$</td>
<td>2.8 fb$^{-1}$</td>
</tr>
<tr>
<td>Selection</td>
<td>NNet</td>
<td>Cut based</td>
</tr>
<tr>
<td>$S/B$</td>
<td>~1</td>
<td>~1/4</td>
</tr>
<tr>
<td>$\epsilon_{tag}(1-2w)^2$</td>
<td>4.81%</td>
<td>4.68%</td>
</tr>
<tr>
<td>Assumptions</td>
<td>Strong phases from $B_d \rightarrow J/\psi K^*$</td>
<td></td>
</tr>
<tr>
<td>$2\beta_s$</td>
<td>[0.32, 2.82] @68%CL</td>
<td>0.57$^{+0.24}_{-0.30}$</td>
</tr>
</tbody>
</table>

Standard Model: $2\beta_s = 0.0368 \pm 0.0017$

✦ UTfit claims that the above results, once combined, means: “First >3 sigmas evidence for New Physics” arXiv:0803.0659

✦ Tevatron prospects: 2x6fb$^{-1}$ end of run II, would be $\sigma(2\beta_s) \sim 0.3/\sqrt{12/2.8} = 0.14$
Recent CDF and DO $\beta_s$ results of tagged $B_s \rightarrow J/\psi \phi$ analyses

05/03/2008 released arXiv:0803.0659, first evidence of New Physics in Bs sector

Claim for >3 sigmas evidence for NP in b-s transition

Polemical subject

$$C_{B_s} \ e^{2i\phi_{B_s}} = \frac{<B_s|H_{\text{eff,full}}|\bar{B_s}>}{<B_s|H_{\text{eff,SM}}|\bar{B_s}>}$$

$$\Delta m_s = C_{B_s} \cdot \Delta m_{s}^{\text{SM}}$$

$$\beta_{s}^{\text{exp}} = \beta_{s} - \phi_{B_s}$$

$$\Phi_{B_s} = (-19.9 \pm 5.6)^\circ \ U (-68.2 \pm 4.9)^\circ$$

>3.7$\sigma$ from zero
About the $\phi \rightarrow K^+K^-$ resonance

- What is the impact of KK S-wave to $\beta_s$ measurement?
  It is possible to estimate its contribution to the decay rates and model its proper time?
- Can we use it to measure $\cos(2\beta_s)$?
  - answer from Bill Dunwoodie (next slide):
    we won't know before we do it and get the behaviour
Resolving the 2-fold ambiguity

Question:
Would your BaBar $B_d \rightarrow J/\psi K^*$ method work for $B_s \rightarrow J/\psi \phi$?

Answer from Bill Dunwoodie:

In the $J/\psi$ $K$ $\pi$ case, the $P_{\perp}$ and $P_{\parallel}$ amplitudes are significant, and have non-zero phase w.r.t. each other and w.r.t. $P_0$. If you have just $S$ and $P_0$ waves, you measure only the cosine of the relative phase, so you can’t tell whether the $S$ wave is leading or trailing $P_0$ in phase. It is the interference terms involving $P_{\perp}$ and $P_{\parallel}$ with the $S$-wave which determine this, and you get a different answer depending on which mathematically ambiguous solution you choose. This is why, when you plot $S-P_0$ phase as a function of mass you get two branches, and why each branch is correlated one-to-one with one of the ambiguous solutions. Each branch provides the same intensity distribution, so the ambiguity still exists. However, since the $S$-wave phase is known to vary slowly in the $K^*(890)$ region, while the $P$-wave phase executes rapid BW motion, Wigner Causality allows the selection of the physical solution.

You can certainly follow the same procedures for $J/\psi K K$, given enough data, and I think that this is the only means by which your question can be answered. Whether the interpretation of the outcome will be as clear as for $J/\psi$ $K$ $\pi$ will depend on the behaviour of $P_{\perp}$ and $P_{\parallel}$ and the mass dependence of any interference with the $S$-wave, in addition to the mass dependence of $S-P_0$ interference. The $P$-wave phase will vary rapidly through the phi mass region, and the $S$-wave should be far enough above the $a0(980)/f0(980)$ that its phase motion would not be expected to be rapid, so it would seem that one should be able to resolve the mathematical ambiguity. However, it seems to me that the outcome will depend very heavily on the behaviour of $P_{\perp}$ and $P_{\parallel}$, and I don’t know that this can be predicted reliably.
**Constraint NP in \( B_s - \bar{B}_s \) mixing**

- NP in the mixing amplitude, parametrized with \( h_s \) et \( \sigma_s \):
  \[
  M_{12} = (1 + h_s \exp(2i\sigma_s)) M_{12}^{SM}
  \]

- LHCb can exclude important region of the phase parameter space with few data (0.2 fb\(^{-1}\))

After measurement of \( \beta_s \) by LHCb with \( \sigma(2\beta_s) = \pm 0.1 \) (\( \sim 0.2 \) fb\(^{-1}\))
MSSM Flavor Physics as an example

FCNC
\[ q_i \rightarrow \tilde{q}_i \times \tilde{q}_i \rightarrow q_j \]

\[(m_{\tilde{q}}^2)_{23(13)}\]

Off-diagonal terms
Flavor Structure
Luminosity frontier

Squark/slepton mass matrix

\[
\begin{pmatrix}
  m_{11}^2 & m_{12}^2 & m_{13}^2 \\
  m_{21}^2 & m_{22}^2 & m_{23}^2 \\
  m_{31}^2 & m_{32}^2 & m_{33}^2 \\
\end{pmatrix}
\]

Diagonal terms
Mass Spectrum
Energy frontier (LHC, LC)

Generic parameterization
for \( b \rightarrow s \) (23\( \rightarrow \)13 for \( b \rightarrow d \))

\[ (\delta^d_{LL})_{23} = \frac{(m_{\tilde{d}_L}^2)_{23}}{M_{\tilde{q}}^2} \]

\[ (\delta^d_{RR})_{23} = \frac{(m_{\tilde{d}_R}^2)_{23}}{M_{\tilde{q}}^2} \]

\[ (\delta^d_{LR})_{23} = \frac{(m_{\tilde{d}_{LR}}^2)_{23}}{M_{\tilde{q}}^2} \]

\[ (\delta^d_{RL})_{23} = \frac{(m_{\tilde{d}_{RL}}^2)_{23}}{M_{\tilde{q}}^2} \]

Left-handed
Right-handed

\( M_{\tilde{q}} \): average squark mass

New physics search in Bs->JpsiPhi and Bs->PhiPhi
Examples of NP affecting $\Phi$ and being compatible with $\Delta m_s = 17.8 \text{ps}^{-1}$

- hep-ph/0703117 (little higgs model with T parity)
- hep-ph/0703112 (susy, extra $Z'$, little Higgs)
- ...

New physics search in $B_s \rightarrow J\psi \phi$ and $B_s \rightarrow \phi \phi$
Tree and Penguin Diagrams

The $\bar{b} \rightarrow \bar{c}c\bar{s}$ transitions are dominated by a single weak phase: $V_{cs}V_{cb}^*$

$$A(\bar{b} \rightarrow \bar{c}c\bar{s}) = V_{cs}V_{cb}^*(A_T + P_c) + V_{us}V_{ub}^*P_u + V_{ts}V_{tb}^*P_t$$

$$A(\bar{b} \rightarrow \bar{c}c\bar{s}) = V_{cs}V_{cb}^*(A_T + P_c - P_t) + V_{us}V_{ub}^*(P_u - P_t)$$

$$V_{ts}V_{tb}^* = -V_{us}V_{ub}^* - V_{cs}V_{cb}^*$$

$\sim A\lambda^2(1 - \lambda^2/2)$

$\sim A\lambda^4(\rho + i\eta)$
For larger time the CP-odd behaviour becomes dominant, especially for large $\Delta \Gamma$.

CP-even: $e^{-\Gamma_L t} \cos^2 \theta$, CP-odd: $e^{-\Gamma_H t} \sin^2 \theta$

Since $\tau_H > \tau_L$ we see more CP-odd as time increases.
Angular distribution

A RooPlot of "cos(θ)"

A RooPlot of "cos(ψ)"

A RooPlot of "ψ"
Selection
$B_s \rightarrow J/\psi(\mu\mu)\phi$ trigger and selection

- $\text{BR}^{\text{vis}}[B_s \rightarrow J/\psi(\mu\mu)\phi(K^+K^-)] = (30.9\pm11.0) \times 10^{-6}$

- "Easy" trigger on muon

- Two kinds of selections
  - Lifetime unbiased (LHCb, ongoing, not shown today)
    - Trigger without IP cut ($p_t$ and mass cuts only)
    - Flat time acceptance, simplified fitting procedure
      - But large prompt background
  - Lifetime biased (LHCb, ATLAS, CMS)
    - Trigger and selection cut on IP of decays products to reject prompt background from PV
    - But time-dependent efficiency must be taken into account
Background level: The selection is applied blindly to the DC04-v2 stripped inclusive $b\bar{b}$ data (~27M events). The results in the enlarged $\pm600$ MeV/$c^2$ mass window before applying the trigger are:

- **12 low mass background** candidates divided as:
  - 1 $B_s \rightarrow J/\psi \phi$ with an additional $\gamma$ (from the $B_s$); not counted as combinatorial background (outside the signal region);
  - 2 $B_s \rightarrow J/\psi \phi$ with 2 additional $\gamma$ (from the $B_s$); not counted as combinatorial background (outside the signal region);
  - 7 $B_s \rightarrow J/\psi \phi$ with an additional $\pi^0$ (from the $B_s$); not counted as combinatorial background (outside the signal region);
  - 2 $B_s \rightarrow J/\psi \phi$ with two additional charged $\pi$ (from the $B_s$); not counted as combinatorial background (outside the signal region).

- **1 partially reconstructed decay** of the type:
  - 1 $B^0 \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)(K_{l1}(1270)\rightarrow K^- \pi^+ \pi^0)$, with the pion misidentified as a kaon, not counted as combinatorial background (outside the signal region).

- **10 signal candidates**.

- **4 ghosts candidates**:
  - 1 $B^0 \rightarrow (J/\psi \rightarrow \mu^+ \mu^-)\pi^0 K^-$ with an additional ghost $K^+$, counted as combinatorial background;
  - 1 $B_s \rightarrow (D^- \rightarrow K^+ \pi^- \pi^0)\mu^+ \nu\mu$ with an additional ghost $\mu^-$, counted as combinatorial background;
  - 1 $B_s \rightarrow (D^- \rightarrow K^+ \pi^- \pi^0)\mu^+ \nu$, using the $\mu^+$, a primary $K^+$, a ghost $K^-$, and a $\mu^-$ from the decay in flight of a primary pion, counted as combinatorial background;
  - 1 signal decay with a ghost due to the inefficiency of the associator, not counted as combinatorial background.

- **From primary vertex (same collision)**: 9 events with at least one of the final states originating from the same primary vertex as the $b$ hadron in the event partially reconstructed, all events are counted as combinatorial background.

- **From different primary vertices**: 1 event reconstructing partially a $b$ decay, with 1 track taken from a different collision, counted as combinatorial background.

- **$b\bar{b}$**: 2 events with tracks from different $b$ hadrons:
  - 1 event with the $\phi$ from $B_s^+ \rightarrow (D^{*0} \rightarrow \pi^0(D^0 \rightarrow K^0\phi))D^{*-}D^0$ and the $J/\psi$ from $B_s^+ \rightarrow J/\psi \pi^+ \pi^0 K^0$, counted as combinatorial background;
  - 1 event taking tracks from a 11 charged tracks $B_s^+$ decay and from another $b$ hadron, counted as combinatorial background.

After removal of the non-dangerous backgrounds, the total number of events to be considered for the combinatorial background level estimate is 15. Using the mass window trick presented in Section 8.7, a central value of $B/S_{BG} = 0.12 \pm 0.03$, where the error is from statistics only, and we assumed the same trigger efficiency on background and signal events.
Muon ID

Look at preselected $J/\psi \rightarrow \mu\mu$ in inclusive $b\bar{b}$ events.

(loose muons, $p_T>500$ MeV/c, Vertex $\chi^2<15$)

$\text{DLL}(\mu-\pi) > -5$ cut reduces the background of $\sim \frac{1}{2}$.

N. Mangiafave, G. Lanfranchi

New physics search in $B_s \rightarrow J\psi\Phi$ and $B_s \rightarrow \Phi\Phi$
Kaon ID

Plots of preselected $\phi \rightarrow KK$ in $B_s \rightarrow J/\psi(\mu\mu)\chi$ events.

\[
\chi^2(\phi)<20, \ p_T(\phi)>1\text{GeV/c}
\]
\[
\chi^2(\text{track})/\text{ndof}<6
\]
\[
\text{IPS}(B)<5, \ \chi^2(B)<20
\]
\[
m(\phi)\pm20\text{ MeV/c}^2
\]

$\phi(KK)$ mass

B mass

M. Musy

New physics search in Bs-$\rightarrow$JpsiPhi and Bs-$\rightarrow$PhiPhi

M. Calvi 26/11/07 (54)
**B→J/ψ(μμ)X unified selection (X=K⁺, K*, Kₛ, φ)**

- **Coherent selection of the 4 channels in order to extract as much as possible information from data (rather than MC)**
  - Opposite side tagging
    - NNet for OS taggers calibrated with B⁺→J/ψK⁺, mistag extracted from B_d→J/ψK* and transfered to Bₕ→J/ψφ and B_d→J/ψKₛ without too heavy corrections.
  - Proper time resolution model
    - Studied in J/ψK⁺, J/ψK* and exported to J/ψφ
  - Angular acceptance
    - Studied in J/ψK⁺ where the amplitude and strong phase are known and used (with eventual corrections) in Bₕ→J/ψφ

- **Selections proper time unbiased**
  - To avoid delicate time dependent efficiency corrections

---

Olivier Leroy

New physics search in Bs→JpsiPhi and Bs→PhiPhi
### Unified $B \rightarrow J/\psi X$ selections

<table>
<thead>
<tr>
<th></th>
<th>Yield LO, no HLT</th>
<th>$B_{(bb)}/S$</th>
<th>$B_{(incl. J/\psi)}/S$</th>
<th>$B_{(B_{uds}\rightarrow J/\psi X)}/S$</th>
<th>m.b. rate (300MeV mass window)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s \rightarrow J/\psi \phi$</td>
<td>120k</td>
<td>1</td>
<td>2</td>
<td>0.15</td>
<td>1 Hz</td>
</tr>
<tr>
<td>$B \rightarrow J/\psi K^*$</td>
<td>650k</td>
<td>?</td>
<td>8</td>
<td>0.6</td>
<td>5 Hz</td>
</tr>
<tr>
<td>$B \rightarrow J/\psi K^+$</td>
<td>1M</td>
<td>0.18</td>
<td>1</td>
<td>0.1</td>
<td>&lt;0.3 Hz</td>
</tr>
<tr>
<td>$B \rightarrow J/\psi K_S$</td>
<td>150k</td>
<td>0.5</td>
<td>2.7</td>
<td>0.2</td>
<td>&lt;0.3 Hz</td>
</tr>
</tbody>
</table>

- **Main background is prompt $J/\psi$ but “easy” to isolate because $\tau \sim 0$ ps**
New physics search in Bs→J/ψ(μμ)φ selection

**Selection**

**J/ψ cuts:**
- Chi2Trk/nDoF<5
- Pt(μ+) & Pt(μ-) > 500 MeV/c
- DLL(μ-π) > -5
- J/ψ Vertex χ2/nDoF<6
- J/ψ pt>1 GeV/c
- |M(J/ψ)−M(J/ψ, true)| < 3σ

**φ cuts:**
- DLL(K-π) > 0
- Vertex Phi χ2 <6
- pt(ϕ)>1000 MeV/c
- |M(ϕ)−M(ϕ, true)| < 3σ

**B cuts:**
- B IPS<5 & B χ2/nDoF<5

- Total selection efficiency (LO, no HLT) = 1.92%
  - Event yield (2 fb⁻¹, no HLT) ~ 120k
- Current HLT dimuon efficiency~75%
  - ~ 90k /2fb-1 after trigger and selection
**Bs → J/ψ φ signal: Mass and Time PDF**

Double gaussian:

\[ \sigma_1 \text{ (core)} = 13 \text{ MeV/c}^2 \]
\[ \sigma_2 = 21.5 \text{ MeV/c}^2 \]

fraction = 53%

Selection is lifetime unbiased

the time PDF is a simple exponential:
Unified selection: $B_s \rightarrow J/\psi \phi$ results

<table>
<thead>
<tr>
<th>$B_s \rightarrow J/\psi \phi$</th>
<th>Yield L0+HLT</th>
<th>B(bb)/S</th>
<th>B(incl. $J/\psi$)/S</th>
<th>B($B_{uds} \rightarrow J/\psi X$)/S</th>
<th>m.b. rate (300MeV mass window)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72k</td>
<td>1</td>
<td>2</td>
<td>0.15</td>
<td>1 Hz</td>
<td></td>
</tr>
</tbody>
</table>

- Main background is prompt $J/\psi$ but “easy” to isolate because $\tau \sim 0$ ps
- e.q. $B_s \rightarrow J/\psi \phi$ selection in a sample of inclusive $J/\psi$ events:
J/ψ → μμ inclusive sample

Mass PDF

<table>
<thead>
<tr>
<th>mu'μK'K' Invariant Mass</th>
<th>Entries: 384</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \chi^2 ) / ndf</td>
<td>65.92 / 45</td>
</tr>
<tr>
<td>Prob</td>
<td>0.02266</td>
</tr>
<tr>
<td>Norm Gauss</td>
<td>10.6 ± 2.01</td>
</tr>
<tr>
<td>Mean Gauss</td>
<td>53.0 ± 2.9</td>
</tr>
<tr>
<td>Sigma Gauss</td>
<td>14 ± 1.1</td>
</tr>
<tr>
<td>Offset</td>
<td>21.03 ± 11.06</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.003316 ± 0.00851</td>
</tr>
</tbody>
</table>

- signal
- prompt background
- background from b

Time PDF

\( \sigma = 40 \text{ fs} \)

\[
\begin{array}{c}
<table>
<thead>
<tr>
<th>Proper Time for J/ψ(μ,μ) sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries: 384</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>RMS</td>
</tr>
<tr>
<td>( \chi^2 ) / ndf</td>
</tr>
<tr>
<td>Prob</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Sigma</td>
</tr>
</tbody>
</table>
\end{array}
\]

Results from the selection on \( \sim 10^6 \) J/ψ → μμ inclusive Monte Carlo sample with muons in acceptance (L\sim 0.3 \text{ pb}^{-1}):

Background for lifetime-unbiased selection is dominated by prompt component mainly J/ψ→μμ prompt + \phi prompt.

The B/S is 3σ mass window is \sim 2.

Background in well separated in proper time
Prompt background: minimum bias L0 yes

2 events out of $1.7 \times 10^6$ minimum bias L0 yes events survive the selection in +- 300 MeV/c mass window:

→ rate of Minimum Bias ~ 1 Hz

Background composition: 1 fake $J/\psi$ from decays in flight and 1 $J/\psi \rightarrow \mu \mu$ prompt.

→ Decays in flight in real life will play a role (see later)
Long lived background: $B_{u,d,s} \rightarrow J/\psi X$

Mass PDF

<table>
<thead>
<tr>
<th>mu' mu K' K' Invariant Mass</th>
<th>1723</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^2$/NDF</td>
<td>94.33/48</td>
</tr>
<tr>
<td>Prob</td>
<td>0.1607</td>
</tr>
<tr>
<td>Norm Gauss</td>
<td>204.4 $\pm$ 8.1</td>
</tr>
<tr>
<td>Mean Gauss</td>
<td>5267 $\pm$ 3.6</td>
</tr>
<tr>
<td>Sigma Gauss</td>
<td>10.91 $\pm$ 0.48</td>
</tr>
<tr>
<td>Offset</td>
<td>13.44 $\pm$ 18.91</td>
</tr>
<tr>
<td>Slope</td>
<td>-0.001539 $\pm$ 0.000508</td>
</tr>
</tbody>
</table>

10/04/2008

Time PDF

<table>
<thead>
<tr>
<th>Proper Time long lived background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Errors</td>
</tr>
<tr>
<td>$\chi^2$/NDF</td>
</tr>
<tr>
<td>Peak</td>
</tr>
<tr>
<td>Normalisation</td>
</tr>
<tr>
<td>Mean Gaussian</td>
</tr>
<tr>
<td>Sigma Gaussian</td>
</tr>
<tr>
<td>[Blank]</td>
</tr>
<tr>
<td>p-value</td>
</tr>
</tbody>
</table>

10/04/2008

Long lived background for this channel is not the main issue

Monte Carlo sample: $\sim 1.2 \times 10^6$ of $B_d,s,u \rightarrow J/\psi X$ events, in the right proportions ($B_d,B_u$: $B_s = 40\%: 40\%: 10\%$).

B/S in $3\sigma$ mass window is 0.15.

very fast decay length (it does not affect signal at high proper times)
Long lived background: stripped bb inclusive

15 events survive after selection out of ~13 10^6 bb inclusive sample: 4 are signal events, 8 background from b→ J/ψ X and 4 combinatorics. In 3σ mass window: 4 signal events and 4 background events (B/S~1)
Angular distributions for prompt background in the $J/\psi \rightarrow \mu \mu$ sample in $\pm 300$ MeV mass window:

- $\cos \theta$ and $\phi$ are not flat;
- there is a bump on the right (to be investigated);
- $\cos \psi$ is reasonably flat.
Angular distributions for long lived background

Angular distributions for background from Bd,s,u → J/Psi X samples.

here I find theta and phi reasonably flat, while cos(psi) shows a (strange!) parabolic behaviour. I still do not understand why..
Proper time resolution
Proper time resolution model

\[
R(x = t_{\text{rec}} - t_{\text{true}}) = \frac{N}{\sqrt{2\pi}} \left[ f(\sigma) e^{-\frac{1}{2} \left( \frac{x}{S(\sigma)} \right)^2} \otimes e^{-\frac{1}{2} \left( \frac{x}{\tau(\sigma)} \right)^2} + f_2(\sigma) e^{-\frac{1}{2} \left( \frac{x}{S_{\text{fixed}}} \right)^2} + \left( 1 - f_1(\sigma) - f_2(\sigma) \right) e^{-\frac{1}{2} \left( \frac{x-M(\sigma)}{S(\sigma)} \right)^2} \right]
\]
In resolution model, the per-event proper time error \( \sigma_{\text{rec}} \) is a per-event-error.

A conditional pdf can be created by substituting the width of the resolution function by this per-event-error and weighing it with a pdf describing the per-event-errors.
After reconstruction and PV refitting, Curve of one fit over all data, compared with data per time bin
Angles
Theoretical distribution of transversity angles
Transversity angles

[Diagram showing the J/ψ rest frame and the φ rest frame, with particles J/ψ, K⁺, K⁻, and muons depicted.]

Olivier Leroy
New physics search in Bs→JpsiPhi and Bs→PhiPhi
Theoretical distribution of transversity angles

A RooPlot of \( \cos(\theta) \)

A RooPlot of \( \cos(\psi) \)

A RooPlot of \( \phi \)
$B_s \rightarrow J/\psi \phi$ angular model

**Approximations:**
- Perfect resolution
- Flat acceptance
- Background distribution flat
Angular resolutions

- angular resolution of $B_s \rightarrow J/\psi(\mu\mu)\phi$ unified selection = (reconstructed angle - true angle)

Does not affect $\beta_s$ sensitivity

- Even if 2 times worse in real data

<table>
<thead>
<tr>
<th></th>
<th>Theta</th>
<th>Phi</th>
<th>Psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC04</td>
<td>0.019</td>
<td>0.019</td>
<td>0.015</td>
</tr>
<tr>
<td>DC06</td>
<td>0.033</td>
<td>0.033</td>
<td>0.024</td>
</tr>
</tbody>
</table>
Angular acceptances

- DC06 angular acceptance of $B_s \rightarrow J/\psi \phi$ unified selection = 
  \[
  \frac{\text{angle distribution after all cuts}}{\text{theoretical angle distribution}}
  \]

- Angular acceptances are not flat, especially for $\phi$
  - Must be taken into account
Angular acceptance studies

- Detailed study to understand where the distortions come from
- e.g. cuts on $p_T(\text{both } \mu)>0.5\text{GeV}$ distort $\cos \theta$ distributions
  - but distortions similar for $B_s \to J/\psi\phi$ and $B_d \to J/\psi K^*$
- $J/\psi\phi / J/\psi K^*$ symmetry NOT conserved if cut on the $K/\pi$ ($p_T>1.5\text{GeV}$)

- Main message: $B_d \to J/\psi K^*$ is a good control channel to estimate angular acceptances on $B_s \to J/\psi\phi$
- To fight against background: better to cut $J/\psi$ side rather than on the $\phi/K^*$ side
Toy MC study

“Simple” case:
- Flat angular background
- Flat angular acceptance

Flat angular background
- bkg cosθ
- acc cosθ

Flat angular acceptance
- bkg cosψ
- acc cosψ

bkg φ
- acc φ
New physics search in $B_s\rightarrow J\psi\phi$ and $B_s\rightarrow \Phi\Phi$

Worse case:
- Non trivial angular background
- Non trivial angular acceptance

Toy MC study

Angular background

Angular acceptance

$14k\, sig + 28k\, bkg$

$\text{mean} = -0.020 \pm 0.12$

$\sigma = 0.725 \pm 0.082$
\[ B_s \rightarrow J/\psi(\mu^+\mu^-) \phi(K^+K^-) \]

without acceptance

• Four-body decay, described by 3 angles \( \Omega_i \)

Note: angles in decay frame (not wrt detector)

• 3 final CP-states with amplitudes \( A_j \)

• Angular and amplitude dependence factorize in distribution \( g \):

\[
g(\vec{A}, \vec{\Omega}) = \sum_{i=1}^{6} h_i(\vec{A}) f_i(\vec{\Omega})
\]

(e.g.: \((1-A_\perp)(1-\cos^2\theta) + A_\perp \cos^2\theta + \ldots\))

• Normalized pdf:

\[
g(\vec{A}, \vec{\Omega}) \rightarrow \frac{h_i(\vec{A}) f_i(\vec{\Omega})}{h_j(\vec{A}) \int f_j(\vec{\Omega}) d\Omega}
\]
Including acceptance in fit

• Fitting with acceptance \( \varepsilon(\Omega) \):

\[
\frac{d \ln L}{dA} = \frac{d}{dA} \left[ \ln \left( \frac{h_i(A)f_i(\Omega)\varepsilon(\Omega)}{h_j(A)\int f_j(\Omega)\varepsilon(\Omega)d\Omega} \right) \right] = \frac{d}{dA} \left[ \ln \left( \frac{h_i(A)f_i(\Omega)}{h_j(A)\Phi_j} \right) \right]
\]

• So when we maximize the likelihood:

\( \Rightarrow \) The exact shape of \( \varepsilon(\Omega) \) is irrelevant

\( \Rightarrow \) The ‘weights’ \( \Phi_i \) take into account the acceptance of every amplitude function

\( \Phi_i = \text{“Integrated efficiency per amplitude”} \)
In case the previous was not clear

\[
\frac{d \ln L}{dA} = \frac{d}{dA} \left[ \ln \left( c \frac{g \varepsilon(\Omega)}{\int g \varepsilon(\Omega) d\Omega} \right) \right], \quad g(\Omega, A) = f_i(\Omega) h_i(A)
\]

1. Take \(c\) and \(\varepsilon\) out of logarithm (\(A\)-independent)
2. Take \(h_i\) out of normalization integral (\(\Omega\)-independent)
3. Rewrite integral as sum

\[
\int g \varepsilon(\Omega) d\Omega = h_i(A) \int f_i(\Omega) \varepsilon(\Omega) d\Omega
\]

The measure: events are generated according to \(gd\Omega\) in MC. \(gd\Omega\) is chance to get certain \(\Omega\) \(\Rightarrow\) write as sum

\[
\frac{1}{N_{\text{gen}}} \sum_{\text{gen}} \frac{f_i(\Omega)}{g} \varepsilon(\Omega) \Rightarrow \Phi_i \propto \sum_{j}^{N_{\text{acc}}} \frac{f_i(\Omega_j)}{g}
\]

“normalization constants”
Normalization ‘weights’

• In practice:
  – Don’t need the exact shape of the acceptance!
  – Determine ‘weights’ $\Phi_i$ from MC
  – Fit data with normalization $h_i \Phi_i$
    $\Rightarrow$ Fast and simple!
• Note:
  – Independent of $A_i$
  – $\Phi_i$ only needed to know up to constant
  – Easy to generalize to time-dependent case
• For reference:
  • Described by Stéphane T’Jampens (thesis)
  • Used in BaBar analyses

https://oraweb.slac.stanford.edu/pls/slacquery/BABAR_DOCUMENTS.DetailedIndex?P_BP_ID=3629 (French)
Pure signal: angular acceptance

\[
\text{sigpdf}_{\text{obs}}(\Omega, A) = \frac{h_i(A)f_i(\Omega)\varepsilon(\Omega)}{h_j(A)\int f_j(\Omega)\varepsilon(\Omega)\,d\Omega}
\]

\[
\frac{d\ln L}{dA} = \frac{d}{dA} \left[ \ln \left( \frac{h_i(A)f_i(\Omega)}{h_j(A)\Phi_j} \right) \right]
\]

- Numbers \( \Phi_i \) from full MC correct for acceptance

\[
\Phi_j = \int f_j(\Omega)\varepsilon d\Omega = \frac{1}{N} \sum_{\text{rec}} \frac{f_j(\Omega)}{g}
\]
Background amplitudes

\[ \text{pdf} = x \frac{A_i(t) f_i(\Omega)}{h_j(A)dt \int f_j(\Omega) \varepsilon(\Omega) d\Omega} + (1 - x) \frac{B_i(t) f_i(\Omega)}{B_j(t)dt \int f_j(\Omega) \varepsilon(\Omega) d\Omega} \]

If background distribution (given signal acceptance) can be described by signal angle basis functions, then we can solve likelihood equation:

\[ \frac{d \ln L}{d \lambda} = \frac{d}{d \lambda} \left[ \ln \left( x \frac{A_i(t) f_i(\Omega)}{\int A_j dt(A) \Phi_j} + (1 - x) \frac{h_i(B) f_i(\Omega)}{\int B_j dt \Phi_j} \right) \right] \]
Some more details

\[ \text{pdftot}(\Omega, A) = x \frac{h_i(A)f_i(\Omega)}{h_j(A)\int f_j(\Omega)\varepsilon(\Omega)d\Omega} \varepsilon(\Omega) + (1-x) \frac{h_i(B)f_i(\Omega)}{h_j(B)\int f_j(\Omega)\varepsilon(\Omega)d\Omega} \varepsilon(\Omega) \]

\[ \Rightarrow \frac{d \ln L}{dA} = \frac{d}{dA} \left[ \ln \left( x \frac{h_i(A)f_i(\Omega)}{h_j(A)\Phi_j} \varepsilon(\Omega) + (1-x) \frac{h_i(B)f_i(\Omega)}{h_m(B)\Phi_m} \varepsilon(\Omega) \right) \right] \]

- Constant N and \( \varepsilon(\Omega) \) drop out of equation
Example plot $\text{sum}(t, m, \Omega)$

- Not trivial to plot this (fitting is easier)
- Quality plot does not say much about quality fit

Red: background
Green: signal
Blue: sum

T. Du Pree
From CDF thesis, Michael Milnik.

Empirical description of the background:

\[
Z_B(\omega | z_0, \phi, z_1, \phi, z_2, \phi, z_3, \phi, z_1, \psi, z_2, \psi, z_3, \psi) = \frac{\pi (2 + z_2, \phi)}{1 - z_1, \phi \cos^2 \theta + z_2, \phi \cos^4 \theta} \times \\
\frac{2 - z_1, \phi 2/3 + z_2, \phi 2/5}{1 + z_1, \psi \cos(\psi) + z_2, \psi \cos^2(\psi) + z_3, \psi \cos^3(\psi)} + \frac{z_4, \psi \cos^4(\psi) + z_5, \psi \cos^5(\psi)}{2 + 2/3 z_2, \psi + 2/5 z_4, \psi} \\
- \frac{9}{32\pi} \sin^2 \psi \sin 2\theta \sin \phi \\
+ \frac{9}{32\pi} \frac{1}{\sqrt{2}} \sin 2\psi \sin^2 \theta \sin 2\phi \\
+ \frac{9}{32\pi} \frac{1}{\sqrt{2}} \sin 2\psi \sin 2\theta \cos \phi.
\]
Tagging
**B_{s} \rightarrow J/\psi(\mu\mu)\phi** flavour tagging performance DC04

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{tag}}$ (%)</th>
<th>$\omega$ (%)</th>
<th>$\varepsilon_{\text{eff}}$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu^{\pm}$</td>
<td>6.8</td>
<td>34.0</td>
<td>0.7 ± 0.05</td>
</tr>
<tr>
<td>$e^{\pm}$</td>
<td>3.3</td>
<td>31.5</td>
<td>0.46 ± 0.04</td>
</tr>
<tr>
<td>$K^{\pm}$</td>
<td>28.7</td>
<td>38.0</td>
<td>1.64 ± 0.08</td>
</tr>
<tr>
<td>Vertex</td>
<td>21.3</td>
<td>39.2</td>
<td>1.04 ± 0.07</td>
</tr>
<tr>
<td><strong>SS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K^{\pm}/\pi^{\pm}$</td>
<td>27.2</td>
<td>34.2</td>
<td>2.71 ± 0.10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>54.5</td>
<td>32</td>
<td>7.08 ± 0.23</td>
</tr>
</tbody>
</table>

*Above are final DC04 performance*

- Values used in LHCb 2006-47, 2007-065 and 2007-101 are previous (worse) DC04 performance: $\varepsilon D^2 = 6.6\%$
### $B_s \rightarrow J/\psi(\mu\mu)\phi$ flavour tagging performance

**DC06 (Brunel v31)**

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_{\text{eff}}$</th>
<th>$\varepsilon_{\text{tag}}$</th>
<th>$\omega$</th>
<th>$%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muon</td>
<td>$0.76 \pm 0.05$</td>
<td>$6.2$</td>
<td>$32.5$</td>
<td></td>
</tr>
<tr>
<td>Electron</td>
<td>$0.45 \pm 0.04$</td>
<td>$2.8$</td>
<td>$29.9$</td>
<td></td>
</tr>
<tr>
<td>Kaon oppo. side</td>
<td>$1.49 \pm 0.07$</td>
<td>$15.3$</td>
<td>$34.4$</td>
<td></td>
</tr>
<tr>
<td>Kaon same side</td>
<td>$2.13 \pm 0.09$</td>
<td>$25.5$</td>
<td>$35.6$</td>
<td></td>
</tr>
<tr>
<td>Q vertex</td>
<td>$1.11 \pm 0.07$</td>
<td>$32.8$</td>
<td>$40.8$</td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td>$6.20 \pm 0.14$</td>
<td>$56.6$</td>
<td>$33.5$</td>
<td></td>
</tr>
</tbody>
</table>

M. Musy, 21/05/2008
## Some control channels

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield (k) per 2 fb(^{-1})</th>
<th>(B_{bb}/S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B^+ \to J/\psi(\mu\mu)K^+)</td>
<td>1740</td>
<td>0.4</td>
</tr>
<tr>
<td>(B^+ \to D^0\pi^+)</td>
<td>1000</td>
<td>0.1</td>
</tr>
<tr>
<td>(B^+ \to \overline{D}^0(*)\mu^+\nu)</td>
<td>2400</td>
<td>0.7</td>
</tr>
<tr>
<td>(B_d \to J/\psi(\mu\mu)K^{*0})</td>
<td>1017</td>
<td>0.16</td>
</tr>
<tr>
<td>(B_d \to D^*-\mu^+\nu)</td>
<td>9000</td>
<td>0.26</td>
</tr>
<tr>
<td>(B_s \to D_s(*)\mu^+\nu)</td>
<td>1930</td>
<td>0.36</td>
</tr>
<tr>
<td>(B_s \to D_s^+\pi^-)</td>
<td>179</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

- **Uncertainty examples (2fb\(^{-1}\))**
  - \(B_s \to D_s(*)\mu^+\nu\) \(\sigma(\omega_{SS})/\omega_{SS} \sim 1.7\%\) (double tagging)
  - \(B^+ \to D^0\pi^+\) \(\sigma(\omega_{OS})/\omega_{OS} \sim 0.6\%\)
  - \(B_s \to D_s^+\pi^-\) \(\sigma(\omega)/\omega \sim 1.1\%\)

- **High stat. \(\Rightarrow\) precise measurement in many sub-categories**

---

Olivier Leroy New physics search in Bs->JpsiPhi and Bs->PhiPhi
### Mistag Fractions after selection & LO (only signal) Brunel v30

**Bd → J/ψ K*:**

<table>
<thead>
<tr>
<th>Tagger</th>
<th>ε(%)</th>
<th>ω(%)</th>
<th>ε(1-2ω)²(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muon</td>
<td>5.35 ± 0.11</td>
<td>32.6 ± 1.0</td>
<td>0.65 ± 0.07</td>
</tr>
<tr>
<td>Electron</td>
<td>4.01 ± 0.09</td>
<td>36.0 ± 1.2</td>
<td>0.32 ± 0.05</td>
</tr>
<tr>
<td>Kaon opp. side</td>
<td>23.16 ± 0.2</td>
<td>38.6 ± 0.5</td>
<td>1.20 ± 0.1</td>
</tr>
<tr>
<td>Pion same side</td>
<td>17.6 ± 0.2</td>
<td>39.9 ± 0.6</td>
<td>0.72 ± 0.08</td>
</tr>
<tr>
<td>Vertex Charge</td>
<td>22.96 ± 0.2</td>
<td>46.0 ± 0.5</td>
<td>0.15 ± 0.084</td>
</tr>
</tbody>
</table>

**Bs → J/ψ φ**

<table>
<thead>
<tr>
<th>Tagger</th>
<th>ε(%)</th>
<th>ω(%)</th>
<th>ε(1-2ω)²(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muon</td>
<td>5.87 ± 0.09</td>
<td>32.4 ± 0.8</td>
<td>0.72 ± 0.06</td>
</tr>
<tr>
<td>Electron</td>
<td>4.33 ± 0.08</td>
<td>36.1 ± 0.9</td>
<td>0.33 ± 0.04</td>
</tr>
<tr>
<td>Kaon opp. side</td>
<td>24.6 ± 0.2</td>
<td>38.9 ± 0.4</td>
<td>1.20 ± 0.08</td>
</tr>
<tr>
<td>Kaon same side</td>
<td>26.5 ± 0.2</td>
<td>35.0 ± 0.4</td>
<td>2.38 ± 0.11</td>
</tr>
<tr>
<td>Vertex Charge</td>
<td>23.96 ± 0.2</td>
<td>45.4 ± 0.4</td>
<td>0.20 ± 0.04</td>
</tr>
</tbody>
</table>
Sensitivity studies
Proper time distribution

Figure 6.5: Signal decay rates [ps] of a $\bar{b} \rightarrow \bar{c}c\bar{s}$ transition to pure CP-even eigenstates. The red solid line is for an initially tagged $B_u$, whereas the blue dashed line is for an initially tagged $\bar{B}_s$. The top left plot shows the analytical decay rates, the top right one shows the effect of the wrong-tag, the bottom left plot shows the effect of a constant proper time resolution, and the bottom right one shows the combination of all the effects together with an acceptance function.
Figure 6.8: Projection of the likelihood onto the proper time distribution [ps], for \( B_s \rightarrow J/\psi \phi \), in the signal region. The mixing parameters are the nominal ones. The left plot is for events initially tagged as \( B_s \), and the left plot is for events initially tagged as \( \bar{B}_s \). The solid blue curve is the projection of all contributions, i.e. signal and background. The dotted red line is the CP-even signal contribution, the dashed-dotted red line is the CP-odd signal contribution, and the dashed black line corresponds to the background.
The effect of an improved or degraded proper time resolution ($\Sigma_\tau$).
And the effect of a larger $B/S$
Full result of sensitivity studies

<table>
<thead>
<tr>
<th>parameter errors</th>
<th>Ideal</th>
<th>Resolution</th>
<th>Acceptance</th>
<th>Background</th>
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</thead>
<tbody>
<tr>
<td>$\Gamma_s$</td>
<td>0.0025</td>
<td>0.0025</td>
<td>0.0026</td>
<td>0.0027</td>
</tr>
<tr>
<td>$\Delta \Gamma_s$</td>
<td>0.0075</td>
<td>0.0074</td>
<td>0.0076</td>
<td>0.0079</td>
</tr>
<tr>
<td>$R_1$</td>
<td>0.0032</td>
<td>0.0031</td>
<td>0.0032</td>
<td>0.0035</td>
</tr>
<tr>
<td>$R_0$</td>
<td>0.0025</td>
<td>0.0024</td>
<td>0.0025</td>
<td>0.0027</td>
</tr>
<tr>
<td>$\delta_1$</td>
<td>0.071</td>
<td>0.080</td>
<td>0.075</td>
<td>0.083</td>
</tr>
<tr>
<td>$\delta_2$</td>
<td>0.064</td>
<td>0.071</td>
<td>0.068</td>
<td>0.075</td>
</tr>
<tr>
<td>$\Delta m_s$</td>
<td>0.007*</td>
<td>0.007*</td>
<td>0.007*</td>
<td>0.007*</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td>0.019</td>
<td>0.022</td>
<td>0.022</td>
<td>0.022</td>
</tr>
<tr>
<td>$\omega_{tag}$</td>
<td>0.0036*</td>
<td>0.0036*</td>
<td>0.0036*</td>
<td>0.0036*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Gamma_s$</th>
<th>$\Delta \Gamma$</th>
<th>$R_1$</th>
<th>$R_0$</th>
<th>$\delta_1$</th>
<th>$\delta_2$</th>
<th>$\Delta m_s$</th>
<th>$\phi_s$</th>
<th>$\omega_{tag}$</th>
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</thead>
<tbody>
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<td>1.0</td>
<td>-0.64</td>
<td>0.50</td>
<td>-0.22</td>
<td>-0.02</td>
<td>0.01</td>
<td>0.00</td>
<td>-0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>$\Delta \Gamma_s$</td>
<td>1.0</td>
<td>-0.66</td>
<td>0.23</td>
<td>0.01</td>
<td>-0.01</td>
<td>0.00</td>
<td>-0.02</td>
<td>-0.01</td>
</tr>
<tr>
<td>$R_1$</td>
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<td>-0.18</td>
<td>-0.05</td>
<td>-0.01</td>
<td>0.03</td>
<td>0.04</td>
<td>0.04</td>
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<tr>
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<td>-0.01</td>
<td>-0.03</td>
<td>0.03</td>
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<tr>
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<td>0.25</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.03</td>
<td>0.00</td>
<td>-0.03</td>
</tr>
<tr>
<td>$\delta_2$</td>
<td>1.0</td>
<td>0.27</td>
<td>0.00</td>
<td>1.0</td>
<td>-0.03</td>
<td>-0.03</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$\Delta m_s$</td>
<td>1.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.0</td>
<td>-0.03</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>$\phi_s$</td>
<td>1.0</td>
<td>-0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>1.0</td>
<td>0.03</td>
<td>1.0</td>
</tr>
<tr>
<td>$\omega_{tag}$</td>
<td>1.0</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>
$B_s \rightarrow J/\psi \phi$

Figure 10: Three-angle variation studies: From top-left we show here the effect on the $-2\beta_\psi$ sensitivity $\sigma(-2\beta_\psi)$ when the central value of $\Gamma_{\psi}, \Delta \Gamma_{\psi}, \omega_{123\psi}$ and $-2\beta_\psi$ is varied.
**B_s → J/ψφ** mistag fitting

*Figure 14* Fit distributions for $\omega_{\text{tag}}$. In this case $\delta_1 = -0.46$ and $\delta_2 = 2.92$. Shown are (i) central value (ii) Minuit error (iii) pull distribution (iv) 5 different LL scans.

All parameters free in the fit
5.2.2 Remarks upon extracting $\omega_{\text{tag}}$ and knowledge of the strong phases.

As our studies indicate, the data appears rich enough to be able to extract $\omega_{\text{tag}}$, at least in the situation where $-2\delta_s$ is close to its expected SM value. This is understood as follows: consideration of the form of the differential cross section shows that the relevant (imaginary interference) terms may be recast to read (when $-2\delta_s = 0$)

$$ (1 - 2\omega_{\text{tag}}) \times \sin(\delta - \Delta m_t) $$

where we see that the fit can determine the sinusoid period ($\Delta m_t$) as well as its phase offset from the time distribution alone. This would leave the amplitude information to determine $(1 - 2\omega_{\text{tag}})$. This expectation is true for all values of the two strong phases. We have tested this by performing a series of fits for the strong phases, set to combinations of $0, \pi/4, \pi/2, \pi$ and $3\pi/2$. In addition, we have also used world average values of $\delta_s = -0.46$ and $\delta_t = 2.92$ resulting from $J/\psi K^*$ decays [15, 16]. In all cases we find the fits well behaved and the errors parabolic for all parameters, except for the $\delta$'s.

When $-2\delta_s \neq 0$ the situation is more complicated. A similar recasting can be done to give

$$ \frac{(1 - 2\omega_{\text{tag}})}{2} \times (1 + \cos(2\delta_s)) \sin(\delta - \Delta m_t) $$

$$(1 - \cos(2\delta_s)) \sin(\delta + \Delta m_t)$$

It is somewhat more difficult to make the simplistic arguments of factorisation, but it is certainly true that:

- there is phase offset information related to the $\delta$'s,
- there is amplitude information related to $(1 - 2\omega_{\text{tag}})(1 + \cos(2\delta_s))$, and
- there is amplitude information related to $(1 - 2\omega_{\text{tag}})\sin(2\delta_s)$ from the other diagonal and real interference cross section components.

It is thus plausible that the fit has enough information to separately determine all quantities. To test this we have performed a series of fits with $-2\delta_s$ ranging from $0 \rightarrow \pi$. We have also performed a set of fits with $-2\delta_s = -0.8$ and the strong phases set to combinations of $0, \pi/4, \pi/2, \pi$ and $3\pi/2$ and also set $\delta_s = -0.46, \delta_t = 2.92$. In all cases we find the fits well behaved and the errors parabolic for all parameters, except for the $\delta$'s. To clarify this, some of the distributions are shown in Figures 11 to 14 in appendix D.

However, caution is needed and the situation in reality is not as simple as these rather idealised studies would suggest. The Log Likelihood (LL) scan for $\delta_t$ nicely illustrates this. The studies undertaken have used the luxury of starting all fit parameters close to their generated values. In this case the fits tend to always converge to the correct central values. For well behaved parabolic parameters this is safe and for those for which there will be external constraints available (such as $\Gamma_{\psi}^c, \Delta m_t$ and $\omega_{\text{tag}}$) it is even more secure. However, the situation for the strong phases is evidently rather different. The LL scans are not parabolic and in the worst scenario a second false minimum can be found, which would in turn affect other parameters.

In practice this will be controlled by performing a series of analyses, with different assumptions about strong phases. LL scans should be performed to understand the structure of the LL surface. The $\omega_{\text{tag}}$ parameters will be compared to, and probably at least loosely constrained by, the values obtained from control channels. However, it will always remain true that care will be needed in this sector.
Figure 15  Fit distributions for $\delta_2$. In this case $\delta_1 = -0.46$ and $\delta_2 = 2.92$. Shown are (i) central value (ii) Minuit error (iii) pull distribution (iv) 5 different LL scans.

All parameter free in the fit
New physics search in Bs→J/ψφ and Bs→ΦΦ

Olivier Leroy

Figure 9: Background: Three-angle simultaneous studies (tagged data): Δφ and ΔΓ distributions

ΔΓ

Entries: 1110
Mean: 0.1004 ± 0.00327
RMS: 0.007901 ± 0.000167

ΔΓ_error

Entries: 1110
Mean: 0.007973 ± 0.00003
RMS: 0.0001313 ± 0.000007

Γ̂_S

Entries: 1110
Mean: -0.03923 ± 0.000069
RMS: 0.02225 ± 0.000472

Γ̂_S_ERROR

Entries: 1110
Mean: 0.02233 ± 0.0005
RMS: 0.0085 ± 0.0016

Γ̂_S_full

Entries: 1110
Mean: 0.0003
RMS: 0.0032
χ²/ndf: 11.41/12
Constant: 290 ± 7.6
Mean: 0.0246 ± 0.0004
RMS: 0.0073 ± 0.0029
**B_s→J/ψφ parameters version v1, April 30, 2008**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Signal</th>
<th>Prompt background</th>
<th>Long-lived background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events in the 3σ mass window (fractions)</td>
<td>100k (33.3%)</td>
<td>180k (60%)</td>
<td>20k (6.7%)</td>
</tr>
<tr>
<td>Mass m (MeV)</td>
<td>$f_1G(m-M_{B_s},\sigma_1)+(1-f_1)G(m-M_{B_s},\sigma_2)$</td>
<td>Exp($-\alpha_1 m$)</td>
<td>Exp($-\alpha_2 m$)</td>
</tr>
<tr>
<td>$M_{B_s}=5369.6$</td>
<td>$\sigma_1=30$, $\sigma_2=60$</td>
<td>$\alpha_1=0.00007$</td>
<td>$\alpha_2=0.0025$</td>
</tr>
<tr>
<td>Proper time t (fs)</td>
<td>$S_1(t) \otimes Res1$</td>
<td>$\delta(t) \otimes Res2$</td>
<td>Exp($\tau=360) \otimes Res3$</td>
</tr>
<tr>
<td>$f_1=0.76$, $\sigma_1=30$, $\sigma_2=60$</td>
<td>No Acc, No Res</td>
<td>No Acc, No Res</td>
<td>No Acc, No Res</td>
</tr>
<tr>
<td>$f_1=0.6$, $\sigma_1=36$, $\sigma_2=58$</td>
<td>No Acc, No Res</td>
<td>Flat</td>
<td>Flat</td>
</tr>
<tr>
<td>Angles</td>
<td>$S_2$(angles)</td>
<td>$B_1$(angles)</td>
<td>$B_2$(angles)</td>
</tr>
<tr>
<td>No Acc, No Res</td>
<td>No Acc, No Res, Flat</td>
<td>No Acc, No Res, Flat</td>
<td></td>
</tr>
<tr>
<td>Tagging parameters</td>
<td>$w_{tag}=0.341$, $\varepsilon_{tag}=0.573$</td>
<td>$\varepsilon_{tag}=0.3$</td>
<td>$\varepsilon_{tag}=0.6$</td>
</tr>
</tbody>
</table>

$G$ means Gaussian: first parameter is the mean, second is the sigma.
$\delta(t)$ is the Dirac function. “No Acc”, means a flat acceptance, “No Res” means a perfect resolution.
B_s\rightarrow J/\psi\phi parameters version v1, April 30, 2008

Physics parameters input:

<table>
<thead>
<tr>
<th>Physics Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>\Delta \Gamma_s</td>
<td>0.084 [ps^{-1}]</td>
</tr>
<tr>
<td>\Gamma_s</td>
<td>0.696 [ps^{-1}]</td>
</tr>
<tr>
<td>\Delta M_s</td>
<td>17.77 [ps^{-1}]</td>
</tr>
<tr>
<td>2\beta_s</td>
<td>0.0368</td>
</tr>
<tr>
<td>R_0</td>
<td>0.56</td>
</tr>
<tr>
<td>R_\perp</td>
<td>0.233</td>
</tr>
<tr>
<td>\delta_{\parallel}</td>
<td>-2.93 [rad]</td>
</tr>
<tr>
<td>\delta_{\perp}</td>
<td>2.91 [rad]</td>
</tr>
</tbody>
</table>

Strong phases convention:

- \delta_0 = 0
- \delta_\perp = \text{arg}[A_\perp(0)A_0^*(0)]
- \delta_{\parallel} = \text{arg}[A_{\parallel}(0)A_0^*(0)]
### B_s → J/ψφ sensitivity

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Input</th>
<th>RMS of 200 toys fitted param. 2 fb⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔΓ_s</td>
<td>0.084 [ps⁻¹]</td>
<td>0.009</td>
</tr>
<tr>
<td>Γ_s</td>
<td>0.696 [ps⁻¹]</td>
<td>0.003</td>
</tr>
<tr>
<td>ΔM_s</td>
<td>17.77 [ps⁻¹]</td>
<td>0.04</td>
</tr>
<tr>
<td>ω</td>
<td>0.341</td>
<td>0.012</td>
</tr>
<tr>
<td>2β_s</td>
<td>0.0368</td>
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</tr>
<tr>
<td>δ_∥</td>
<td>-2.93 [rad]</td>
<td>0.08</td>
</tr>
<tr>
<td>δ_⊥</td>
<td>2.91 [rad]</td>
<td>0.11</td>
</tr>
</tbody>
</table>
New physics search in $B_s \rightarrow J\psi \Phi$ and $B_s \rightarrow \Phi \Phi$

<table>
<thead>
<tr>
<th>parameter</th>
<th>Ideal</th>
<th>Resolution</th>
<th>Acceptance</th>
<th>Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma_s$</td>
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<td>0.0027</td>
<td>0.0029</td>
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<tr>
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<tr>
<td>$\Delta m_s$</td>
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</tr>
<tr>
<td>$-2\beta_s$</td>
<td>0.019</td>
<td>0.022</td>
<td>0.023</td>
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</tr>
</tbody>
</table>

Table 1  Repeating results of note-101 as baseline. All is fine - same results near enough.

<table>
<thead>
<tr>
<th>parameter</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
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</tr>
<tr>
<td>$\Delta \Gamma_s$</td>
<td>0.008</td>
<td>0.008</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>$R_L$</td>
<td></td>
<td>0.0046</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R_0$</td>
<td></td>
<td>0.0035</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta_1$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\delta_2$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta m_s$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$-2\beta_s$</td>
<td>.027</td>
<td>.028</td>
<td>.031</td>
<td>.012</td>
</tr>
</tbody>
</table>

Table 2  Changing things. Only 5-10 toys each

Change A: Change inputs to

- $\omega_{tag}$ 0.33 $\rightarrow$ 0.35  \textbf{i.e. $\epsilon D^2$ from 6.6% to 5.2%}

- Number of events 130$k$ $\rightarrow$ 120$k$.

- Tag efficiency stays at 0.57

Change B: Background: change long lived from 101 (1 fs, B/S=0.12) to roadmap (0.3 fs, B/S = 1)

Change C: Background: add prompt background with SigPromptLong$=0.25:0.5:0.25$. Note that it is essential to calculate the B/S fractions separately for tagged and untagged due to the very different tagging efficiencies. The result is that in the tagged category the fractions are SigPromptLong$=1/3:1/3:13$ approx (i.e. equal) but in the tagged category prompt dominates.
Precision on $2\beta_s$ and other parameters as a function of the time resolution in the 30–80fs range, from a fit including (or not including) per-event error. (S. Vecchi, A. Carbone)

Events generated with gaussian time resolution (of different values) and fitted:

- (red) with a constant time resolution
- (black) with event-per-event resolution
- (blue) const. time resolution, signal only
- (green) event-per-event resolution, signal only

If $\sigma(\tau)<60$ fs the use of a fixed time resolution does not seem to degrade $\beta_s$ precision.
**ΔΓ_s (HFAG)**

<table>
<thead>
<tr>
<th>Fit results from CDF, D0, ALEPH and DELPHI data</th>
<th>without constraint from tau(Bs -&gt; flavour specific)</th>
<th>with constraint from tau(Bs -&gt; flavour specific)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1/Γ_s$</td>
<td>$1.514 +0.034 -0.037$ ps</td>
<td>$1.470 +0.026 -0.027$ ps</td>
</tr>
<tr>
<td>$τ$(short) = $1/Γ_L$</td>
<td>$1.420 +0.040 -0.040$ ps</td>
<td>$1.419 +0.039 -0.038$ ps</td>
</tr>
<tr>
<td>$τ$(long) = $1/Γ_H$</td>
<td>$1.622 +0.097 +0.090$ ps</td>
<td>$1.525 +0.062 -0.063$ ps</td>
</tr>
<tr>
<td>$ΔΓ_s$ (95% CL range)</td>
<td>$[-0.009 ; +0.179 ]$ ps-1</td>
<td>$[-0.038 ; +0.125 ]$ ps-1</td>
</tr>
<tr>
<td>$ΔΓ_s$</td>
<td>$+0.088 +0.047 -0.048$ ps-1</td>
<td>$0.049 +0.040 -0.043$ ps-1</td>
</tr>
<tr>
<td>$ρ(ΔΓ_s, 1/Γ_s)$</td>
<td>$+0.56$</td>
<td>$+0.37$</td>
</tr>
<tr>
<td>$ΔΓ_s/Γ_s$ (95% CL range)</td>
<td>$[-0.011 ; +0.278 ]$</td>
<td>$[-0.052 ; +0.180 ]$</td>
</tr>
<tr>
<td>$ΔΓ_s/Γ_s$</td>
<td>$+0.133 +0.074 -0.074$</td>
<td>$+0.069 +0.058 -0.062$</td>
</tr>
<tr>
<td>$ρ(ΔΓ_s/Γ_s, 1/Γ_s)$</td>
<td>$+0.57$</td>
<td>$+0.38$</td>
</tr>
</tbody>
</table>
ΔΓ_s (HFAG)

- Combined results on the decay-width difference in the Bs system are extracted from a global fit including all direct measurements of ΔΓ_s/Γ_s, as well as the lifetime measurements using Bs -> J/psi phi decays and flavour-specific Bs decays (CDF, D0, ALEPH and DELPHI data). This combination is performed under the assumption of no CP violation in Bs mixing. The results in the table below are shown both with and without constraining the quantity

\[ \frac{1}{\Gamma_s} \left( 1 + \frac{(\Delta \Gamma_s/\Gamma_s)^2}{4} \right) / \left( 1 - \frac{(\Delta \Gamma_s/\Gamma_s)^2}{4} \right) \]

to the flavour-specific Bs lifetime average.
Other interesting channels
Other interesting channels

- P2VV: $B_s \rightarrow J/\psi (ee)\phi$, higher $\psi$ resonances, $D_s D_s^*$, ...
- Pure CP even modes: $\eta_c \phi$, $J/\psi \eta$, $J/\psi \eta'$, $D_s D_s$, ...
# Properties of channel contributing to $\beta_s$ (DC04)

<table>
<thead>
<tr>
<th>Channel</th>
<th>Yield</th>
<th>Bkgr./Sig.</th>
<th>$\sigma_\tau$</th>
<th>$\sigma_{mass}$</th>
<th>$\omega_{tag}$</th>
<th>$\epsilon_{tag}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$[10^3/2fb^{-1}]$</td>
<td>[fs]</td>
<td>[MeV/c^2]</td>
<td>[%]</td>
<td>[%]</td>
<td></td>
</tr>
<tr>
<td>$B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\phi(K^+K^-)$</td>
<td>131</td>
<td>0.12</td>
<td>36</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s^0 \rightarrow \eta_c(h^+h^-h^+h^-)\phi(K^+K^-)$</td>
<td>3.0</td>
<td>0.6</td>
<td>30</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\eta(\pi^+\pi^-\pi^0(\gamma\gamma))$</td>
<td>3.0</td>
<td>3.0</td>
<td>34</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s^0 \rightarrow J/\psi(\mu^+\mu^-)\eta(\gamma\gamma)$</td>
<td>8.5</td>
<td>2.0</td>
<td>37</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s^0 \rightarrow D_s^- (K^+K^-\pi^-)D_s^+ (K^+K^-\pi^+)$</td>
<td>4.0</td>
<td>0.3</td>
<td>56</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$B_s^0 \rightarrow D_s^- (K^+K^-\pi^-)\pi^+$</td>
<td>120</td>
<td>0.4</td>
<td>40</td>
<td>14</td>
<td>31</td>
<td>63</td>
</tr>
</tbody>
</table>
### $\beta_s$ sensitivity (DC04)

<table>
<thead>
<tr>
<th>Channels (sensitivity for $\phi_s$ with 2 fb$^{-1}$)</th>
<th>$\sigma(\phi_s)$ [rad]</th>
<th>Weight $\left(\frac{\sigma}{\sigma_i}\right)^2$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B_s^0 \to D_s^-(K^+K^-\pi^-)D_s^+(K^+K^-\pi^+)$</td>
<td>0.133</td>
<td>2.6</td>
</tr>
<tr>
<td>$B_s^0 \to J/\psi(\mu^+\mu^-)\eta(\pi^+\pi^-\pi^0(\gamma\gamma))$</td>
<td>0.142</td>
<td>2.8</td>
</tr>
<tr>
<td>$B_s^0 \to J/\psi(\mu^+\mu^-)\eta(\gamma\gamma)$</td>
<td>0.109</td>
<td>3.9</td>
</tr>
<tr>
<td>$B_s^0 \to \eta_c(h^+h^-h^+h^-)\phi(K^+K^-)$</td>
<td>0.108</td>
<td>3.9</td>
</tr>
<tr>
<td>Combined sensitivity for pure CP eigenstates</td>
<td>0.059</td>
<td>13.2</td>
</tr>
<tr>
<td>$\overline{B_s^0} \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$</td>
<td>0.023</td>
<td>86.8</td>
</tr>
<tr>
<td>Combined sensitivity for all CP eigenstates</td>
<td>0.021</td>
<td>100.0</td>
</tr>
</tbody>
</table>
### $\beta_s$ sensitivity (DC04)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>J/\psi\phi</th>
<th>$\eta_c\phi$</th>
<th>D_sD_s</th>
<th>J/\psi\eta (\gamma\gamma)</th>
<th>J/\psi\eta (\pi\pi\pi)</th>
<th>D_s\pi</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 fb^{-1} yield [ k events ]</td>
<td>131</td>
<td>3</td>
<td>4</td>
<td>8.5</td>
<td>3</td>
<td>120</td>
</tr>
<tr>
<td>Background level $B/S$</td>
<td>0.12</td>
<td>0.6</td>
<td>0.3</td>
<td>2.0</td>
<td>3.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Mass $\sigma_{B_s}$ [ MeV/c ]</td>
<td>14</td>
<td>12</td>
<td>6</td>
<td>34</td>
<td>20</td>
<td>14</td>
</tr>
<tr>
<td>Acceptance $s_{\text{low}}$ [ ps^{-1} ]</td>
<td>2.81</td>
<td>1.25</td>
<td>1.6</td>
<td>1.86</td>
<td>1.54</td>
<td>1.36</td>
</tr>
<tr>
<td>Mean $&lt;\tau_{\text{fit}}^{\text{err}}&gt;$ [ fs ]</td>
<td>29.5</td>
<td>26.2</td>
<td>44.4</td>
<td>30.4</td>
<td>25.5</td>
<td>32.9</td>
</tr>
<tr>
<td>Scale factor $\Sigma_{\tau}$</td>
<td>1.22</td>
<td>1.16</td>
<td>1.26</td>
<td>1.22</td>
<td>1.32</td>
<td>1.21</td>
</tr>
<tr>
<td>Wrong tag $\omega_{\text{tag}}$ [% ]</td>
<td>33</td>
<td>31</td>
<td>34</td>
<td>35</td>
<td>30</td>
<td>31</td>
</tr>
<tr>
<td>Tagging $\varepsilon_{\text{tag}}$ [% ]</td>
<td>57</td>
<td>66</td>
<td>57</td>
<td>63</td>
<td>62</td>
<td>63</td>
</tr>
</tbody>
</table>
Systematics
Systematics

- Not expected to be the systematically dominated during the first year
- Expect systematics from mass, proper time, angular model, background, flavour tagging, ...
- Use of control channels
Comparison with other
In 2008, assuming 50 days of running with a peak luminosity of \(5 \times 10^{31}\) for ATLAS (CMS), an integrated luminosity of 20 pb-1 could be achieved. For LHCb, assuming running with 68 colliding bunches at \(1.2 \times 10^{31}\), this would translate into order 5 pb-1.

In 2009, 140 days of running are assumed at present, with an efficiency factor twice as big as in 2008. Then, with an estimated peak luminosity of \(10^{33}\) for ATLAS (CMS), an integrated luminosity of 2.5 fb-1 could be reached. If we assume that LHCb will run with a peak luminosity of \(2 \times 10^{32}\), we would be at the 0.5 fb-1 level.
Comparison with Atlas/CMS

- Hypothesis end 2009 (1/4 of a nominal year...)
  - ATLAS/CMS, L = 10^{33} cm^{-2}s^{-1}, L_{int} = 2.5 fb^{-1}
  - LHCb (DC04), L = 2 \times 10^{32} cm^{-2}s^{-1}, L_{int} = 0.5 fb^{-1}

<table>
<thead>
<tr>
<th></th>
<th>Stat</th>
<th>B/S</th>
<th>\varepsilon D^2 (%)</th>
<th>\sigma_{+} (fs)</th>
<th>\sigma(2\beta_s)</th>
<th>\sigma(\Delta \Gamma_s/\Gamma_s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATLAS</td>
<td>23k</td>
<td>0.3</td>
<td>4.6</td>
<td>83</td>
<td>0.16</td>
<td>0.05^{(1)}</td>
</tr>
<tr>
<td>CMS</td>
<td>27k</td>
<td>0.3</td>
<td>0</td>
<td>77</td>
<td>0.18</td>
<td>0.04^{(2)}</td>
</tr>
<tr>
<td>LHCb</td>
<td>33k</td>
<td>0.12</td>
<td>6.6</td>
<td>36</td>
<td>0.04</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Standard Model: 2\beta_s = 0.0368 \pm 0.0017 (4.6% rel. uncertainty !)

HFAG: \Delta \Gamma_s/\Gamma_s = 0.069 \pm 0.085

[A. Lenz and U. Nierste, JHEP 06 (2007) 072]. \Delta \Gamma_s = 0.088 \pm 0.017 ps^{-1} (19% rel. uncertainty)

Remarques:
- LHCb uses many channels for \beta_s, i.e not only B_s \rightarrow J/\psi(\mu\mu)\phi
- No flavour tagging yet in CMS

^{(1)} A. Dewhurst 15/02/08
^{(2)} CMS note 2006/121, Table 9, for \Delta \Gamma_s/\Gamma_s (input) = 0.1
Atlas potential in CPV in $B_s \rightarrow J/\psi \Phi$

Method:

- Simultaneous maximum likelihood fit for parameters: $\phi_s$, $\Gamma_s$, $\Delta \Gamma_s$, $A_{\perp}, A_{\parallel}$, $\delta_1, \delta_2$.
- Experimental inputs: 3 angles, proper decay time, flavour tag; background fraction and composition.
- Independent measurement of $\Delta m_s$ in flavour explicit channel.

Sensitivity after 30 fb$^{-1}$:

$$(3 \text{ years}) \delta(\phi_s) = 0.067$$

$\sigma(2\beta s)$: 2.5 fb$^{-1}$: 0.23

10 fb$^{-1}$: 0.12

--- can be evidence of NP

More details at dedicated talk in this workshop. (O.Leroy)
New physics search in $B_s \rightarrow J\psi \phi$ and $B_s \rightarrow \Phi \Phi$
New physics search in $B_s \rightarrow J_{psi}\phi$ and $B_s \rightarrow \phi\phi$

Atlas/CMS

Angular distributions:
- $\phi$
- $\cos\theta$
- $\cos\psi$

Observed vs. predicted

Angular efficiency
proper decay time cut

HLT inefficiency

implicit cut in HLT degrades $\varepsilon(t)$
$\Rightarrow$ correct with $B^0 \rightarrow J/\psi K^{*0}$ data
Backgrounds

main background processes:

1. prompt $pp \rightarrow J/\psi X$
   - $\phi$ from fragmentation or fake reconstruction
   - from primary vertex
   - isotropic angular distribution

2. $b \rightarrow J/\psi X$
   - $\phi$ from fragmentation or fake reconstruction
   - isotropic angular distribution

3. $B^\circ \rightarrow J/\psi K^{*0} \rightarrow \mu^+ \mu^- K^+ \pi^-$
   - misidentified Kaon
   - angular distribution has same functional description as signal - with other parameters
# Offline Analysis

<table>
<thead>
<tr>
<th>$\mu^\pm$:</th>
<th>$K^\pm$:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_T &gt; 3$ GeV</td>
<td>$P_T &gt; 0.5$ GeV / 0.7 GeV (CMS)</td>
</tr>
<tr>
<td>$</td>
<td>\eta</td>
</tr>
<tr>
<td>$\chi^2/DoF &lt; 6$</td>
<td>$\chi^2/DoF &lt; 6$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$J/\psi$:</th>
<th>$\phi$:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$</td>
<td>\Delta m_{J/\psi}</td>
</tr>
<tr>
<td>$P_T &gt; 4$ GeV</td>
<td>$P_T &gt; 1$ GeV</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$B_s^0$:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_T &gt; 10$ GeV / pointing angle ($\vec{P}_T, sec.\ Vertex$) &lt; 12° (CMS)</td>
<td></td>
</tr>
<tr>
<td>proper time delay $&gt; 0.5$ ps / significance $&gt; 3$ (CMS)</td>
<td></td>
</tr>
<tr>
<td>$\chi^2/DoF &lt; 10$</td>
<td></td>
</tr>
<tr>
<td>$</td>
<td>\Delta m_{B_s^0}</td>
</tr>
</tbody>
</table>
Flavour tagging comparison ATLAS/LHCb

<table>
<thead>
<tr>
<th></th>
<th>O.S.</th>
<th>S.S.</th>
<th>combined</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>$\varepsilon_{tag} D^2 [10^{-2}]$</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Q_{vtx}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ATLAS</strong></td>
<td>0.25</td>
<td>0.7</td>
<td>$X$ 3.63</td>
</tr>
<tr>
<td><strong>CMS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only untagged analysis so far available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LHCb</strong></td>
<td>0.5</td>
<td>0.7</td>
<td>1.6 1.0</td>
</tr>
</tbody>
</table>
Flavour Tagging in ATLAS

same side tag:

- jet charge or soft $\pi, K$
- tag efficiency:
  $\varepsilon_{tag} = 0.62$
- wrong tag:
  $W_{tag} = 0.39$

other side tag:

- lepton tag
- $\varepsilon_{tag}(e/\mu) = 0.012/0.025$
- $W_{tag}(e/\mu) = 0.27/0.24$
ATLAS B trigger

☐ Full ATLAS trigger:
  — LVL1: hardware, coarse detector granularity, 2 μs latency
  — LVL2: full granularity, LVL1 confirmation + partial rec., 10 ms processing
  — EF (event filter): full event access, “offline” algorithms 1 s processing

☐ Strategy for B physics trigger:
  — High luminosity (> 2×10^{33} cm^{-2}s^{-1}):
    • LVL1: dimuon, p_T > 6 GeV/c each
  — Low luminosity (or end of) fills:
    • LVL1: add single muon, p_T > 6–8 GeV/c
    • LVL2: look for objects around muon
      – 2nd muon (with lower threshold) in muon RoI
      – Single e/\gamma or e^+e^- pair in EM RoI
      – Hadronic b decay products in Jet RoI

<table>
<thead>
<tr>
<th>Trigger level</th>
<th>Total output rate</th>
<th>Output rate for B physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVL1</td>
<td>75 kHz</td>
<td>10–15 kHz</td>
</tr>
<tr>
<td>LVL2</td>
<td>2 kHz</td>
<td>1–1.5 kHz</td>
</tr>
<tr>
<td>EF</td>
<td>200 Hz</td>
<td>10–15 Hz</td>
</tr>
</tbody>
</table>
CMS trigger and B physics

- Trigger to cover widest range of discovery physics (Higgs, SUSY, …)
  - Level 1: 3.2μs buffer, → 100 kHz
  - (nominal)
  - HLT (High-Level Trigger): 1s buffer, 40 ms processing, → 100 Hz

- B events:
  - Level 1:
    - single μ (p_T > 14 GeV/c)
    - or di-μ (p_T > 3 GeV/c each)
  - HLT:
    - Limited time budget
    - restrict B reconstruction to RoI around μ
    - or use reduced number of hits/track (D_sπ)

<table>
<thead>
<tr>
<th>Trigger level</th>
<th>Total output rate (at startup)</th>
<th>Output rate relevant for B physics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>50 kHz</td>
<td>14 kHz (1μ)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.9 kHz (2μ)</td>
</tr>
<tr>
<td>HLT</td>
<td>100 Hz</td>
<td>~ 5 Hz of incl. b,c→μ+jet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ O(1 Hz) for each excl. B mode</td>
</tr>
</tbody>
</table>

New physics search in Bs→JpsiPhi and Bs→PhiPhi
CMS trigger

Level 1 Triggers
- muons and calorimeters,  
  Latency: 3.2μs,  
  40 MHz → 100 kHz

High-level Triggers (HLT)
- fast (local) reconstruction,  
  100kHz → 100Hz

B-physics triggers
- Level 1: single- or di-muon trigger  
  1μ: $p_\perp > 7(14)$ GeV/c,  
  2μ: $p_\perp > 3(7)$ GeV/c  
- HLT: exclusive and inclusive b/c triggers at ~5Hz  
  partial reconstruction,  
  displaced di-muons

Single muon  
Di-muon
Study properties of $B_s$ system
- width and mass difference of two weak eigenstates: $\Delta \Gamma_s$, $\Delta m_s$
- height of the Unitarity Triangle ($\eta$) and possible hint for NP:
  $\phi_{CKM} = 2\lambda^2 \eta \sim 0.03_{SM}$

Trigger
- L1: di-muon with $p_\perp > 3$ GeV
- HLT 1: partial (~6 hits) track reconstruction
- HLT 2: $J/\psi$ and vertexes reconstruction
- HLT 3: kinematic ($p_\perp$, mass) and topological ($L_{xy}$, $\Delta \alpha$ etc) selections
- HLT 4: $\phi$ and $B_s$ reconstruction and corresponding selections

Off-line Analysis
- almost the same as HLT but with complete information
- angular analysis to measure $\Delta \Gamma_s$

Results
- $\sim 10k$ events collected @ 1.3 fb$^{-1}$
- Rel. errors on $\bar{\Gamma}_s$, $\Delta \Gamma_s$, $\Delta \Gamma_s/\bar{\Gamma}_s$ are 3.4%, 19%, 20%
$B_s \rightarrow \phi \phi$
## Comparison $B_s \to J/\psi \phi$ / $\phi\phi$

<table>
<thead>
<tr>
<th></th>
<th>$B_s \to J/\psi \phi$</th>
<th>$B_s \to \phi\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible Branching ratio</td>
<td>$(30.9 \pm 11.0) \times 10^{-6}$</td>
<td>$(3.4 \pm 2.1) \times 10^{-6}$</td>
</tr>
<tr>
<td>Trigger efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LO / HLT / total (%)</td>
<td>93.3 / 84.9 / 79.4</td>
<td>36.8 / 50.7 / 18.7</td>
</tr>
<tr>
<td>Untagged yield (2fb$^{-1}$)</td>
<td>131k</td>
<td>3.1k</td>
</tr>
<tr>
<td>Background ($B_{bb}/S$)</td>
<td>0.12</td>
<td>&lt;0.8 at 90%CL</td>
</tr>
<tr>
<td>Mass resolution (MeV)</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Proper time resolution (fs)</td>
<td>36</td>
<td>43</td>
</tr>
<tr>
<td>Flavour tagging</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\varepsilon / \omega / \varepsilon(1-2\omega)^2$ (%)</td>
<td>57 / 33 / 6.6</td>
<td>60 / 30 / 9.6</td>
</tr>
<tr>
<td>Toy MC sensitivity assumptions</td>
<td>Perfect angular resol.</td>
<td>Perfect angular resol.</td>
</tr>
<tr>
<td></td>
<td>Flat angular acceptance</td>
<td>Flat angular acceptance</td>
</tr>
<tr>
<td></td>
<td>Bkg mass and angle flat</td>
<td>Bkg mass and angle flat</td>
</tr>
<tr>
<td></td>
<td>Bkg proper time $\tau=1$ps</td>
<td>Bkg proper time $\tau=1$ps</td>
</tr>
<tr>
<td>$\sigma(\Phi)$ (2fb$^{-1}$)</td>
<td>0.022</td>
<td>0.11</td>
</tr>
</tbody>
</table>
New physics search in $B_s \rightarrow \phi\phi$
$B_s \rightarrow \phi\phi$
New Physics through Tree-Penguin comparison

\[ \begin{align*}
\mathcal{B}_d & \quad \begin{array}{c}
\bar{d} \\
 b & \rightarrow \\
 V_{cb} \quad W^- \quad V_{cs}^* & \rightarrow \\
 \bar{c} & \rightarrow \\
 \mathcal{K}_s & \rightarrow \\
 \end{array} \\
\end{align*} \]

Tree

\[ \begin{align*}
\mathcal{B}_s & \quad \begin{array}{c}
\bar{s} \\
 b & \rightarrow \\
 V_{cb} \quad W^- \quad V_{cs}^* & \rightarrow \\
 \bar{c} & \rightarrow \\
 \phi & \rightarrow \\
 \end{array} \\
\end{align*} \]

Penguin

\[ \begin{align*}
\mathcal{B}_d & \quad \begin{array}{c}
\bar{d} \\
 b & \rightarrow \\
 V_{tb} \quad W^- \quad V_{ts}^* & \rightarrow \\
 \bar{s} & \rightarrow \\
 \mathcal{K}_s & \rightarrow \\
 \end{array} \\
\end{align*} \]
Angles definition for $B_s \to \phi\phi$

- Work in helicity base to treat the two identical $\phi$ particles in a symmetric way.
- Use three independent angles $\theta_1$, $\theta_2$ and $\varphi \equiv \varphi_1 + \varphi_2$.
- $(\theta_i, \varphi_i)$ are polar and azimuthal angles of $K^+_i$ in the rest frame of their mother $\phi_i$.

$$A_0(t) \equiv H_0(t),$$

$$A_{||}(t) \equiv (H_{+1}(t) + H_{-1}(t))/\sqrt{2},$$

$$A_{\perp}(t) \equiv (H_{+1}(t) - H_{-1}(t))/\sqrt{2}.$$
**B_s \rightarrow \phi \phi \text{ decay rate}**

- Time dependent differential decay rate

\[
\frac{d\Gamma(t)}{d \cos \theta_1 d \cos \theta_2 d \varphi_1 d \varphi_2} \propto \left| \sum_{\lambda=0,\pm1} H_{\lambda}(t) D_{\lambda,0}^{1*}(\varphi_1, \theta_1, 0) D_{\lambda,0}^{1*}(\varphi_2, \theta_2, 0) \right|^2
\]

- Turn helicity amplitudes $H_{\lambda}(t)$ into transversity amplitudes $A_j(t)$, $j=0, // \pm \perp$

\[
H_0(t) = A_0(t) \\
H_{+1}(t) = \left( A_{//}(t) + A_{\perp}(t) \right) / \sqrt{2} \\
H_{-1}(t) = \left( A_{//}(t) - A_{\perp}(t) \right) / \sqrt{2}
\]

- The differential rate doesn’t depend on $\varphi_1 - \varphi_2$

\[
\frac{d\Gamma(t)}{d \cos \theta_1 d \cos \theta_2 d \chi} \propto \left| A_0(t) \right|^2 f_1(\theta_1, \theta_2, \chi) + \left| A_{//}(t) \right|^2 f_2(\theta_1, \theta_2, \chi) + \\
\left| A_{\perp}(t) \right|^2 f_3(\theta_1, \theta_2, \chi) + \text{Im} \left( A_{//}^*(t) A_{\perp}(t) \right) f_4(\theta_1, \theta_2, \chi) + \\
\text{Re} \left( A_0^*(t) A_{//}(t) \right) f_5(\theta_1, \theta_2, \chi) + \text{Im} \left( A_0^*(t) A_{\perp}(t) \right) f_6(\theta_1, \theta_2, \chi)
\]
SM relations

- 6 parameters $\phi_j$ and $|\lambda_j|$ in three independent decays

$$\lambda_j \equiv |\lambda| e^{i\phi_j} \equiv e^{i\phi_{\text{mix}}} \frac{A_j(\overline{B}_s \to \phi\phi)}{A_j(B_s \to \phi\phi)}$$

- In SM it is much simpler:
  - No weak phase in decay $\phi_j = \phi_s$
  - No direct CP violation in this decay $|\lambda_j| = 1$

- NP can lead to violation of both conditions

- We assume they are satisfied in SM test
  - Strategy: assume SM relations and measure $\phi_s$, compare it with $\phi_s$ from $B_s \to J/\psi\phi$
    and SM prediction to look for discrepancy
  - For simplicity: only one quantity to measure; no ambiguity in measurement of $\phi_s$
    because of terms with $\text{Re}\lambda = \cos\phi_s$ (next slide)
**Signal model**

- True 4D distribution \( h(\theta_1, \theta_2, \chi, t) \) from slide 20-23
- Neglect angular resolution
- Gaussian time resolution
- Gaussian mass resolution

\[
\text{pdf} \ 4D(\theta_1, \theta_2, \chi, t) = G(t - t'; \sigma t) \otimes h(\theta_1, \theta_2, \chi, t')
\]

- Acceptance as a function of reconstructed time

\[
\text{pdfSig0}(\theta_1, \theta_2, \chi, t, m) = \exp(m - m_B; \sigma m) \times \text{pdf} \ 4d(\theta_1, \theta_2, \chi, t)
\]

\[
\text{pdfSig}(\theta_1, \theta_2, \chi, t, m) = \text{acc}(t) \times \text{pdfSig0}(\theta_1, \theta_2, \chi, t, m)
\]
Background model

- Background PDF is a product of a flat mass distribution, three flat angular distributions, an exponential time distribution and an acceptance function.
- Total PDF

\[
\text{pdfTotal} = f \cdot \text{pdfSig} + (1 - f) \cdot \text{pdfBg}
\]
Reference values

- 4k signal events, B/S = 0.9
- \( R_t = \frac{|A_{\perp}|^2}{(|A_0|^2 + |A_\parallel|^2 + |A_{\perp}|^2)} = 0.25, \)
- \( R_p = \frac{|A_{\parallel}|^2}{(|A_0|^2 + |A_\parallel|^2 + |A_{\perp}|^2)} = 0.25, \)
- \( \delta_1 = \text{arg}(A_{\perp}/A_{\parallel}) = 0, \delta_2 = \text{arg}(A_{\perp}/A_0) = \pi \)
- \( \Gamma_s = 0.67 \text{ ps}^{-1}, \Delta \Gamma/\Gamma = 15\% \)
- \( \phi_s = 0.2 \)
- \( \sigma t = 0.042 \text{ ps} \)
- \( w_{\text{tag}} = 0.30, \text{eff}_{\text{tag}} = 0.60 \) (taken from \( B_s \rightarrow D_s \pi \))
- \( \Delta m_s = 17.0 \text{ ps}^{-1} \)
- \( \sigma m = 12 \text{ MeV} \)
- \( \Gamma_{bg} = 1.85 \text{ ps}^{-1} \)
- Signal acceptance = \( (0.084 \ t_{\text{rec}})^3/(0.027 + t_{\text{rec}}^3) \)
- Background acceptance = \( (10 \ t_{\text{rec}})^3/(0.00012 + t_{\text{rec}}^3) \)
Fit procedure

- Define a set of reference input values
- For the given set of input values generate 500 toy experiments
- Fit for free parameters ($f_s$, $R_t$, $R_p$, $\delta_1$, $\delta_2$, $B/S$) in each experiment
- Obtain resolutions and pulls
- Vary one input parameter at a time and repeat
The sensitivity results for $B_s \to \phi \phi$ include figures 10, 11, and 12. Figure 10 shows the distribution of $\delta^{\text{eff}}$ for $\delta^{\text{eff}} = 0.20$ from 500 toy experiments, right: the corresponding pull distribution.

Figure 11 shows the distribution of $R^{\text{eff}}$ for $R^{\text{eff}} = 0.25$ from 500 toy experiments; right: the corresponding pull distribution.

Figure 12 shows the distribution of $R^{\text{eff}}$ for $R^{\text{eff}} = 0.25$ from 500 toy experiments; right: the corresponding pull distribution.
**Variation of $\Phi^{NP}$ sensitivity ($B_s \rightarrow \phi\phi$)**

<table>
<thead>
<tr>
<th>$\mathcal{B}$ ($\times 10^{-5}$)</th>
<th>$\sigma(\phi_{NP})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>13°</td>
</tr>
<tr>
<td>0.7</td>
<td>8.1°</td>
</tr>
<tr>
<td>1.4</td>
<td>5.7°</td>
</tr>
<tr>
<td>2.1</td>
<td>4.6°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B/S</th>
<th>$\sigma(\phi_{NP})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.5°</td>
</tr>
<tr>
<td>0.9</td>
<td>5.7°</td>
</tr>
<tr>
<td>2</td>
<td>6.1°</td>
</tr>
<tr>
<td>5</td>
<td>7.2°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\Delta \Gamma_s/\Gamma_s$</th>
<th>$\sigma(\phi_{NP})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>7.2°</td>
</tr>
<tr>
<td>0.15</td>
<td>5.7°</td>
</tr>
<tr>
<td>0.05</td>
<td>4.9°</td>
</tr>
</tbody>
</table>
(B_s \rightarrow \phi \phi) Variation with input assumptions

Benchmark number in red

<table>
<thead>
<tr>
<th>BR (10^{-5})</th>
<th>\sigma (\phi^{NP})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35</td>
<td>0.22 ± 0.01</td>
</tr>
<tr>
<td>0.7</td>
<td>0.143 ± 0.007</td>
</tr>
<tr>
<td>1.4</td>
<td>0.100 ± 0.004</td>
</tr>
<tr>
<td>2.1</td>
<td>0.080 ± 0.004</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B/S</th>
<th>\sigma (\phi^{NP})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.096 ± 0.004</td>
</tr>
<tr>
<td>0.9</td>
<td>0.100 ± 0.004</td>
</tr>
<tr>
<td>2.0</td>
<td>0.106 ± 0.006</td>
</tr>
<tr>
<td>5.0</td>
<td>0.126 ± 0.007</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>\Delta \Gamma/\Gamma</th>
<th>\sigma (\phi^{NP})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.126 ± 0.006</td>
</tr>
<tr>
<td>0.15</td>
<td>0.100 ± 0.004</td>
</tr>
<tr>
<td>0.25</td>
<td>0.085 ± 0.004</td>
</tr>
</tbody>
</table>

- No significant variation seen as a function of input \phi^{NP}, R_{p,t} strong phases and proper time resolution
- Expect systematics from mistag rate, proper time acceptance and background distributions. Will be estimated from control channels
References

- S. Nandi et al. « New Physics in b -> s bar(s) s Decay. II: Study of B -> V1 V2 Modes », arXiv:hep-ph/0510245v3
- Qin Chang et al., « Constraints on the anomalous tensor operators from B\to\phi K"(\ast), \eta K"(\ast)$ and $\eta K$ decays », arXiv:hep-ph/0610280v4
- CDF « First Evidence for $B_s^0 \to \phi \phi$ Decay and Measurements of Branching Ratio and $A_{CP}$ for $B^{+} \to \phi K^{+}$ », arXiv:hep-ex/0502044v3
- N. Brook et al, « LHCb's Potential to Measure Flavour-Specific CP-Asymmetry in Semileptonic and Hadronic $B^{0}\_s$ Decays », LHCb-2007-054
- ... to be completed