The $B_s$ as a Piece of the New Physics Puzzle

Hal Evans

Assumption

- we will have already discovered beyond the SM Physics at the Tevatron/LHC

Question to address at next generation exp’s

- How can B-physics contribute to our understanding of the nature of the new physics

Specific questions to ask

1) What is the discriminating power of $b$-measurements to different beyond the SM flavors?
2) What are the projected sensitivities of upcoming exp’s?
3) What are their limiting experimental and theoretical errors?
Acknowledgements

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any mistakes are purely due to me!
# New Physics in the B System*

<table>
<thead>
<tr>
<th>Class</th>
<th>Properties</th>
<th>Example</th>
</tr>
</thead>
</table>
| SM    | • CP & Flavor violation only CKM  
        $H_{eff}^{\Delta F=2} \propto \sum V_{CKM}^i C_i(\mu)Q_i$ (Q_i = VLL in SM)  
        • 1 CPV phase | depressingly many |
| A (MFV) | • Wilson coeff’s of SM op’s modified by new particles | SHDM(II), CMSSM  
• tan\( \beta \) = small |
| B      | • new op’s possible  
        • CPV & FV still only in CKM | SHDM(II), CMSSM  
• tan\( \beta \) = large |
| C      | • new CPV phases in SM op’s  
        • no new op’s | MSSM  
• tan\( \beta \) = small  
• non-diag M(sqrk) |
| D      | • new CPV phases  
        • new op’s  
        • new Flavor changing contrib’s | • multi-Higgs  
• SUSY: spont. CPV  
• LR Symmetric |
| E      | • CKM not unitary | 4 Generations  
• tree FCNCs |

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* Buras, hep-ph/0101336
**Models & Their Consequences**

**Class A (Minimal Flavor Violation)**


\[ C_1^{\text{Wt}} = C_1^{\text{Wt}}(\text{SM}) [1 + f] \]

**Class B (General MFV)**


\[ C_1^{\text{Wt}} = C_1^{\text{Wt}}(\text{SM}) [1 + f_q] \]

\[ f_d \neq f_s \neq f_\epsilon \]

\[ \Delta M_q = \Delta M_q(\text{SM}) [1 + f_q] \]

\[ \sin 2\beta \sim \sin 2\beta(\text{SM}) F [(1 + f_d),(1 + f_s),(1 + f_\epsilon)] \]
More Models…

Class C (Minimal Insertion Approx) Ali & Lunghi, hep-ph/0105200
- all $M(\text{gluino, squark}) \sim \text{TeV}$ except lightest stop
- only 1 unsuppressed off-diagonal elem’s in squark mass matrix
  - $c_L - t_2 \sim$ excluded by $b \rightarrow s \gamma$
  - $\Delta M_s$: $C_1^{Wtt} = C_1^{Wtt}(\text{SM}) [1 + f]$
  - $\varepsilon_K, \Delta M_d, \sin 2\beta$: $C_1^{Wtt} = C_1^{Wtt}(\text{SM}) [1 + f + g] \quad (g = g_R + ig_I)$

Class D (LR Sym + Spont CPV) Ball, et al, hep-ph/9910211
- very restrictive model
  - generally: sign[$\varepsilon$] opp. sign[$a(\psi K_s)$] (same in SM)
  - $M_{12} = M_{12}^{SM} \left(1 + \kappa e^{i\sigma_q}\right) \quad q = d, s$
  - $\kappa, \sigma_q$ related mainly to (2) param’s governing spont CPV
# Unitarity Triangle Predictions

<table>
<thead>
<tr>
<th>Model</th>
<th>$\epsilon_K$</th>
<th>$\Delta M_d$</th>
<th>$\Delta M_s / \Delta M_d$</th>
<th>$\sin 2\beta_{\text{eff}}$</th>
<th>$\gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (MFV)</td>
<td>$\neq$ SM</td>
<td>$\neq$ SM</td>
<td>$=$ SM</td>
<td>$\sim$ SM</td>
<td>$&lt; $ SM</td>
</tr>
<tr>
<td>B (GMVF)</td>
<td>$\neq$ SM</td>
<td>$\neq$ SM</td>
<td>$&gt;$ SM</td>
<td>$\neq$ SM</td>
<td>$&gt; $ SM</td>
</tr>
<tr>
<td>B (2HDM-II)</td>
<td>$\sim$ SM</td>
<td>$\sim$ SM</td>
<td>$\sim$ SM</td>
<td>$\sim$ SM</td>
<td>$?$</td>
</tr>
<tr>
<td>B (MSSM)</td>
<td>$\sim$ SM</td>
<td>$\sim$ SM</td>
<td>$&lt; $ SM</td>
<td>$\sim$ SM</td>
<td>$&lt; $ SM</td>
</tr>
<tr>
<td>C (MIA)</td>
<td>$\neq$ SM</td>
<td>$\neq$ SM</td>
<td>$\neq$ SM</td>
<td>$\neq$ SM</td>
<td>$\neq$ SM</td>
</tr>
<tr>
<td>D (SB LR) fit</td>
<td>$\sim$ SM</td>
<td>$\sim$ SM</td>
<td>$(0.61.1)SM$</td>
<td>$&lt; 0.1$</td>
<td>$?$</td>
</tr>
</tbody>
</table>

- Measurements & constraints included in fits to specific models
  - $\lambda$, $|V_{cb}|$, $|V_{ub}/V_{cb}|$, $B_q$, $f_{Bi}$, $m_t$, ...
  - $\epsilon_K$, $\Delta M_d$, $b\rightarrow\gamma$, ...

- Other B measurements also see effects:
  - $b\rightarrow s\gamma$, $b\rightarrow d\gamma$: rates and asymmetries
  - $b\rightarrow s^* f$: asymmetries
  - $B_s\rightarrow J/\psi\phi$: asymmetry
  - ...

16 July, 2001

Hal Evans
95% CL Allowed Contours from Fit

\[ f_{B_s} \sqrt{B_{B_s}} = 215 \pm 40 \text{ MeV}, \quad B_K = 0.94 \pm 0.15 \]

- \( f = 0 \quad \text{SM} \)
- \( f = 0.2 \quad \text{mSUGRA} \)
- \( f = 0.45 \quad \text{non-mSUGRA} \)
- \( f = 0.75 \quad \text{non-SUGRA + nEDM} \)

Ali and London: hep-ph/0002167

16 July, 2001

Hal Evans
$1\sigma$ Allowed Contours from Fit

$\Delta M_s = 18.0 \pm 0.05 \text{ ps}^{-1}$

$a(\psi K_s) = 0.5 \pm 0.05$

Various $R_{sd} = \frac{1 + f_s}{1 + f_d}$

Buras, Chankowski, Rosiek, Slawianowska: hep-ph/0107048
95% CL Allowed Contours from Fit

<table>
<thead>
<tr>
<th>$f$</th>
<th>$g_R$</th>
<th>$g_I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0.4</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>-0.5</td>
</tr>
</tbody>
</table>

Ali and Lunghi: hep-ph/0105200
Allowed Region from all Constraints

\[ M_2 = \text{mass of } W_R \]

\[ M_H = \text{extra Higgs masses} \]

Decoupling limit \((M_2, M_H \to \infty)\) excluded

Ball, Frere, Matias: hep-ph/9910211
More Constraints: $\Delta \Gamma_s$ & $\phi_s$

- **CPV Phase in $B_s$**
  - $A(t)[B_s \to J/\psi \phi] \Rightarrow \sin \phi_s$
    $$\phi_s = \arg(-M_{12}\Gamma^*_s) = \arg\left[-\frac{V_{cs}V_{cb}^*}{V_{ts}V_{tb}^*}\right] \sim 0.03 \text{ in the SM (signs?)}$$
  - like $\sin 2\beta$ this is free of hadronic uncertainties to $O(10\%)$
  - New Physics $\Rightarrow \phi_s = \phi_s^{SM} + \phi_s^{NP} \sim \phi_s^{NP} = \arg(1 + ae^{i\phi})$

- **$B_s$ Width Difference**
  - $\Delta \Gamma_s = \Gamma_L - \Gamma_H = 2 |\Gamma_{12}| \cos \phi_s$
  - $\Delta \Gamma_{CP} = 2(\Gamma_{CP+} - \Gamma_{CP-}) = 2 |\Gamma_{12}| = \Delta \Gamma_s / \cos \phi_s$
    - Note that $\Delta \Gamma_s$ only decreases with New Physics

- various methods to disentangle $\Delta \Gamma_s$ & $\cos \phi_s$
  - Dunietz, Fleischer, Nierste: hep-ph/0012219

- $\Delta \Gamma_s$ coupled to $\Delta M_s$ in the SM
  $$\frac{\Delta \Gamma_s}{\Delta M_s} \propto \left(\frac{m_b}{m_W}\right)^2$$
$\phi_s$ in New Physics Models

<table>
<thead>
<tr>
<th>Model</th>
<th>$a$</th>
<th>$\theta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vector d-quarks ($\Rightarrow$ bsZ)</td>
<td>$&lt; 0.25$</td>
<td>any</td>
</tr>
<tr>
<td>4$^{th}$ Generation</td>
<td>$&gt; 1$</td>
<td>any</td>
</tr>
<tr>
<td>RPV SUSY</td>
<td>$&gt; 1$</td>
<td>any</td>
</tr>
</tbody>
</table>

## Experimental Statistics

<table>
<thead>
<tr>
<th>Exp</th>
<th>Start</th>
<th>$\int L , dt , [fb^{-1}]$</th>
<th>b-Events</th>
<th>Time [yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BaBar/Belle</td>
<td>1999</td>
<td>60-100</td>
<td>$6.5 \times 10^6$</td>
<td>1</td>
</tr>
<tr>
<td>DCF/DØ</td>
<td>2001</td>
<td>2</td>
<td>$0.4 \times 10^{12}$</td>
<td>2 (run Ila) run Ila + Izb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15</td>
<td>$3.0 \times 10^{12}$</td>
<td></td>
</tr>
<tr>
<td>BTeV</td>
<td>2005/6</td>
<td>2</td>
<td>$0.2 \times 10^{12}$</td>
<td>1</td>
</tr>
<tr>
<td>Atlas/CMS</td>
<td>2006</td>
<td>10</td>
<td>$5 \times 10^{12}$</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30</td>
<td>$15 \times 10^{12}$</td>
<td>3 (low lumi)</td>
</tr>
<tr>
<td>LHCb</td>
<td>2006?</td>
<td>2</td>
<td>$1 \times 10^{12}$</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>$5 \times 10^{12}$</td>
<td>5</td>
</tr>
</tbody>
</table>
# $B_s$ Experimental Sensitivities

<table>
<thead>
<tr>
<th>Meas</th>
<th>SM</th>
<th>Current</th>
<th>CDF/DØ</th>
<th>BTeV</th>
<th>Atlas/CMS</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>sin $2\beta$</td>
<td>$0.71 \pm 0.09$</td>
<td>$0.61 \pm 0.12$</td>
<td>0.03 (IIa)</td>
<td>0.025</td>
<td>0.015</td>
<td>0.010</td>
</tr>
<tr>
<td>t-res [fs]</td>
<td>45/100</td>
<td>43</td>
<td>63</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta M_s$ [ps⁻¹]</td>
<td>14 – 26</td>
<td>&gt; 14.9</td>
<td>&lt; 20/50</td>
<td>&lt; 48</td>
<td>&lt; 30</td>
<td>&lt; 60</td>
</tr>
<tr>
<td>$\Delta \Gamma_s / \Gamma_s$</td>
<td>(9.3±4.0)%</td>
<td>&lt; 52%</td>
<td>(4-8)%</td>
<td>0.10</td>
<td>0.11</td>
<td>0.011</td>
</tr>
<tr>
<td>$\phi_s$ (J/ψφ)</td>
<td>0.03</td>
<td>$x_s = 20$</td>
<td>—</td>
<td>0.025</td>
<td>0.014 (3 y)</td>
<td>0.02 (3 y)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$x_s = 40$</td>
<td>—</td>
<td>0.035</td>
<td>0.03 (3 y)</td>
<td>0.03 (3 y)</td>
</tr>
</tbody>
</table>

all sensitivities per year unless otherwise noted

## Main Exp Limitations
- Statistics
- Proper Time Resolution
- Backgrounds

## Main Theor Uncertainties
- $f_B \sqrt{B_B}$
- $m_q$
Gauging the Impact of Flavor Physics

Goal
- Compare discriminating power of Flavor Physics for different new physics models
- Quantifies where Flavor Physics makes an impact

Strategy
- Develop standard tests
- Apply these to current situation and expected future

1) Predictions for benchmark SUSY points
2) Allowed regions for classes of models
   a) Define outputs: $\bar{\rho}, \bar{\eta}$ plots, $\phi_s$, model params...?
   b) Define inputs: standard current parameter sets
   c) Improvement path: collect expected sens’s vs time

Problems
- do we miss something by narrowing our goals?