Results from the B-Factories

J. Michael Roney
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(BaBar Collaboration)

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San Francisco
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e+e- B-factories have a very broad scientific program

- CP & T-violation
- Precision CKM measurements
- Rare decays
- Searches for Processes beyond the SM
- Hadron production in Initial State Radiation
- Spectroscopy (see e.g. Yuan Changzheng presentation Tues. pm)
- ...

..... can only scratch the surface in this sampling of results
Flavour physics at the luminosity frontier
asymmetric B factories

BaBar
$\gamma(4s)$

$\sqrt{s} = 10.58 \text{ GeV}$

$e^+ \rightarrow \gamma(4s) \rightarrow e^-$

$\beta\gamma = 0.56$

$B_{\Delta z} \sim c\beta\gamma t_B \sim 200 \mu m$

Belle
$\gamma(4s)$

$\gamma(4s)$

$\beta\gamma = 0.42$

Results from the B-Factories

J. Michael Roney
Delivered luminosities far beyond design...

Integrated luminosity of B factories

> 1 ab\(^{-1}\)

On resonance:
- \(\Upsilon(5S)\): 121 fb\(^{-1}\)
- \(\Upsilon(4S)\): 711 fb\(^{-1}\)
- \(\Upsilon(3S)\): 3 fb\(^{-1}\)
- \(\Upsilon(2S)\): 25 fb\(^{-1}\)
- \(\Upsilon(1S)\): 6 fb\(^{-1}\)

Off resonance/scan:
- \(\sim 100\) fb\(^{-1}\)

\~ 550 fb\(^{-1}\)

On resonance:
- \(\Upsilon(4S)\): 433 fb\(^{-1}\)
- \(\Upsilon(3S)\): 30 fb\(^{-1}\)
- \(\Upsilon(2S)\): 14 fb\(^{-1}\)

Off resonance:
- \(\sim 54\) fb\(^{-1}\)
Delivered luminosities far beyond design...

Integrated luminosity of B factories

\( > 1 \text{ ab}^{-1} \)

On resonance:
- \( \Upsilon(5S) \): 121 fb\(^{-1}\)
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- \( \sim 100 \text{ fb}^{-1} \)

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Off resonance:
- \( \sim 54 \text{ fb}^{-1} \)
In SM weak charged transitions mix quarks of different generations - encoded in unitary CKM matrix:

\[
(d' \ s' \ b') = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}
\]

Unitarity → 4 independent parameters
one is the complex phase and sole source of CP violation in SM

In the Wolfenstein parameterisation:

\[
V_{\text{CKM}} = \begin{pmatrix}
1 - \frac{\lambda^2}{2} & \lambda & \lambda^3 (\rho - i\eta) \\
-\lambda & 1 - \frac{\lambda^2}{2} & A\lambda^2 \\
A\lambda^3 (1 - \rho - i\eta) & -A\lambda^2 & 1
\end{pmatrix} + O(\lambda^4)
\]

\[
\lambda^2 = \frac{|V_{us}|^2}{|V_{ud}|^2 + |V_{us}|^2}; \quad A^2 \lambda^4 = \frac{|V_{cb}|^2}{|V_{ud}|^2 + |V_{us}|^2}; \quad \bar{\rho} + i\eta = -\frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*}
\]
Physics beyond the SM signaled by breakdown of unitarity of CKM matrix: non-closure of the ‘unitarity triangle’

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

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

Area of triangle in complex plane ~ CP violation

\[ B^0 \rightarrow J/\Psi K^0 \]
\[ B \rightarrow D K \]

• Make as many precision measurements as possible that **overconstrain** the four CKM parameters \((A, \lambda, \rho, \eta)\)

• New Physics would be revealed in discrepancies between measurements

• Generally requires non-perturbative QCD input to convert measurements to a SM CKM interpretation (but exceptions where single weak phase dominate as in \(J/\phi\) \(Ks\))

Results from the B-Factories

J. Michael Roney
Belle and \textit{BABAR} designed to measure and test CKM framework

- Sum of angles: \(\alpha + \beta + \gamma = (177 \pm 9)^\circ\)
  \[
  \alpha = (88.5 \pm 4.5)^\circ \quad \beta = (21.4 \pm 0.8)^\circ \quad \gamma = (67 \pm 8)^\circ
  \]

- Sides of triangle from semileptonic B decays:
  \( |V_{cb}| \) (Lattice QCD for FF) \hspace{1cm} |V_{cb}| \) (HF Sum Rules for FF)

  \[
  |V_{cb}|^{\text{LQCD}}_{\text{excl}} = (39.04 \pm 0.55_{\text{exp}} \pm 0.74_{\text{th}}) \times 10^{-3}
  \]
  \[
  |V_{cb}|^{\text{LQCD}}_{\text{incl}} = (42.01 \pm 0.46_{\text{exp}} \pm 0.59_{\text{th}}) \times 10^{-3}
  \]
  \[
  |V_{cb}|^{\text{average}} = (40.81 \pm 0.90_{\text{exp}} \pm 1.14_{\text{th}}) \times 10^{-3}
  \]
  \[
  |V_{cb}|^{\text{HF}}_{\text{excl}} = (40.93 \pm 0.57_{\text{exp}} \pm 0.94_{\text{th}}) \times 10^{-3}
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  \]
  \[
  |V_{cb}|^{\text{average}} = (41.67 \pm 0.38_{\text{exp}} \pm 0.50_{\text{th}}) \times 10^{-3}
  \]

  NB: errors scaled by 2.4

  \[
  |V_{ub}|^{\text{LQCD}}_{\text{excl}} = (3.26 \pm 0.16_{\text{exp}} \pm 0.24_{\text{th}}) \times 10^{-3}
  \]
  \[
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  NB: errors scaled by 3.0

Data generally well described by CKM framework

Results from the B-Factories
\( \alpha = \phi_2 \) accessible via \( b \rightarrow u \) transitions in \( B \rightarrow \pi \pi, B \rightarrow \rho \rho, \) or \( B \rightarrow \rho \pi \)
e.g. \( B \rightarrow \pi^+ \pi^- \) and \( B \rightarrow \bar{B} \rightarrow \pi^+ \pi^- \) interference

Time-dependent decay rate of a \( B \) or a \( \bar{B} \) meson decaying into common \( CP \) eigenstate

\[
P(\Delta t) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left\{ 1 + q \left[ S_{CP} \sin(\Delta m_d \Delta t) + A_{CP} \cos(\Delta m_d \Delta t) \right] \right\}
\]

\( S_{CP} = \sin 2\alpha ; A_{CP} = 0 \) at tree level

With additional penguin diagrams ('pollution')
\( S_{CP} = \sqrt{1-A_{CP}^2} \sin 2\alpha_{\text{eff}} ; A_{CP} \neq 0 \) allowed

Isospin analysis using, e.g. \( B \rightarrow \pi^0 \pi^0 \), recovers \( \sin 2\alpha \)
(penguin dominates over colour suppressed internal tree)

\( A_{CP} \): direct \( CP \) violation \( (= -C_{CP}) \)
\( S_{CP} \): mixing induced \( CP \) violation
\( q \): flavor of \( B_{tag}, q = +1 \) for \( B_{tag} = B^0 \)
\( \tau_{B^0} \): \( B \) life time
\( \Delta m_d \): mass difference of \( B_H \) and \( B_L \)
\( \Delta t \): decay time difference of \( B_{CP} \) and \( B_{tag} \)

Results from the B-Factories

J. Michael Roney
• New published result on $B \rightarrow \pi^+ \pi^-$ from $BA_{BAR}$ and Belle
  ($BA_{BAR}$ also has $B \rightarrow \pi^0 \pi^0$ on full dataset)

• $B \rightarrow \rho \rho$: $VV$ final state, helicity analysis to measure CP
  ○ $B \rightarrow \rho^+ \rho^-$ older from $BA_{BAR}$ and Belle
  ○ $B \rightarrow \rho^0 \rho^0$ full dataset from $BA_{BAR}$ and Belle (new 2012)

• $B \rightarrow (\rho \pi)^0$ new result from $BA_{BAR}$: warning about lack of
  robustness in extracting $\alpha = \phi_2$ with current statistics
Angle $\alpha = \phi_2$

$B \rightarrow \pi^+ \pi^-$

BaBar PRD 87 052009(2013)

467 $\times 10^6$ $B\bar{B}$ pairs

Belle arXiv:1302.0551

772 $\times 10^6$ $B\bar{B}$ pairs

$S_{CP}^{\pi^+\pi^-} = -0.68 \pm 0.10 \pm 0.03$

$A_{CP}^{\pi^+\pi^-} = +0.25 \pm 0.08 \pm 0.02$

$S_{CP}^{\pi^+\pi^-} = -0.636 \pm 0.082 \pm 0.027$

$A_{CP}^{\pi^+\pi^-} = +0.328 \pm 0.061 \pm 0.027$

$\Rightarrow$ clear mixing induced $CP$ and presence of penguins

Results from the B-Factories

J. Michael Roney
Overall fits for $\alpha = \phi_2$ using $B \to \pi\pi$, $B \to \rho\rho$, or $B \to \rho\pi$

$\phi_2/\alpha = (88.5^{+4.7}_{-4.4})^\circ$

$\phi_2/\alpha = (88.7 \pm 3.1)^\circ$
$B^\pm \rightarrow D^{(*)0}K^{(*)\pm}$ decays dominate $\gamma = \phi_3$ measurements

$$V = \begin{pmatrix} 1 - \lambda^2 / 2 & \lambda & A\lambda^3(1 - \rho - i\eta) \\ -\lambda & 1 - \lambda^2 / 2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

$$V_{ub} |e^{-i\gamma}$$

**color allowed**

$A_1 \propto V_{cb} V^*_{us} \sim A\lambda^3$

$$|A_{total}|^2 = |A_1|^2 + |A_2|^2 + 2|A_1||A_2|\cos(-\gamma + \delta)$$

$\mathcal{B}(B^+ \rightarrow D^0 K^+) \leq \mathcal{B}(B^+ \rightarrow \bar{D}^0 K^+)$

$$r_b = \left| \frac{A(B^+ \rightarrow D^0 K^+)}{A(B^+ \rightarrow \bar{D}^0 K^+)} \right|$$

Unknowns: $\gamma, r_b, \delta_b + \delta_D$

$r_b$ & $\delta_b$ B hadronic parameters extracted with $\gamma$

$\delta_D$ measured at charm factories

Theoretically clean: no penguin pollution

strong phase from B and D decay
$B^\pm \to D^{(*)0}K^{(*)\pm}$ decays dominate $\gamma = \phi_3$ measurements

Different methods for extracting $\gamma = \phi_3$ depending on the D decay mode final state

**GLW** [M. Gronau, D. London, D. Wyler, PLB253, 483 (1991); PLB 265, 172 (1991)]
- $D^0$ to two-body CP eigenstates $K^+K^-$, $\pi^+\pi^-$ (even), $K^0\pi^0$, $K_S\omega$ (odd)

**ADS** [D. Atwood, I. Dunietz, A. Soni, PRL 78, 3357 (1997)]
- $D^0$ to doubly Cabibbo suppressed decays $K^+\pi^-$, $K^+\pi^-\pi^0$, ...

**GGSZ (Dalitz)** [D. Atwood et al., PRL 78, 3257 (1997); A. Giri et al., PRD 68, 054018 (2003)]
- $D^0$ to 3-body decays $K_S\pi^+\pi^-$, $K_SK^+K^-$, $\pi^+\pi^0\pi^0$, etc.
  - Dalitz plot fitted to determine how the strong phase of $D^0$ decay amplitude varies over the Dalitz plane
  - model independent analysis

**$BABAR$ and Belle** have reconstructed the most sensitive decay modes using all or nearly all of their full datasets

**$BABAR$** PRD 87 052015 (2013)

$\gamma = \left( \begin{array}{c} 69+17 \\ -16 \end{array} \right)^0 \quad \text{(mod 180°)}$

exp+DP model systematic $= \pm 4^\circ$

**Belle** CKM2012 arXiv:1301.2033

$\gamma = \left( \begin{array}{c} 68+15 \\ -14 \end{array} \right)^0 \quad \text{(mod 180°)}$

Physics of the B Factories to be submitted EPJC

$\gamma = (67 \pm 11)^0 \quad \text{(mod 180°)}$
\[ B^\pm \rightarrow D^{(*)0}K^{(*)\pm} \] decays dominate \( \gamma = \phi_3 \) measurements

Different methods for extracting \( \gamma = \phi_3 \) depending on the D decay mode final state

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**BABAR and Belle**

- \( \gamma = (67 \pm 11)^0 \) (mod 180^0)
- LHCb with 3fb^{-1}
  \( \gamma = (67 \pm 12)^0 \) (mod 180^0)

**BABAR** PRD87 052015 (2013)
\( \gamma = (69^{+17}_{-16})^0 \) (mod 180^0)
exp+DP model systematic= \( \pm 4^0 \)

**Belle**
\( \gamma = (68^{+15}_{-14})^0 \) (mod 180^0)

Physics of the B Factories to be submitted

Results from the B-Factories
• Well established canon of SM that weak interactions maximally violate parity (P) and charge conjugation (C) - neutrinos are LH, antineutrinos are RH.
• CP also measured to be violated in neutral kaon and B-meson systems - phenomena well described within CKM framework
• The CPT Theorem (Locally Lorentz-invariant QFT conserves CPT) → if there is CP violation, there is also violation of time reversal invariance (T)
• Difficult to establish experimentally T violation independent of CPT: need a system where we experimentally know what QM state is in before it decays.

\[ e^+e^- \rightarrow \gamma(4S) \rightarrow B(\alpha) B(\bar{\alpha}) \] is an entangled P-wave state: EPR tells us the state of a B-meson prior to its decay if its EPR-entangled partner decays and is identified – it’s how BaBar and Belle measure CP violation ...

can also use this to search for direct T violation and test CPT using this approach

BABAR uses this approach to measure a non-zero T violation - strength predicted by CPT and the CP violation measured by BABAR and Belle

\[ |i\rangle = \frac{1}{\sqrt{2}} \left[ B^0(t_1)\bar{B}^0(t_2) - \bar{B}^0(t_1)B^0(t_2) \right] = \frac{1}{\sqrt{2}} \left[ B_{CP+}(t_1)B_{CP-}(t_2) - B_{CP-}(t_1)B_{CP+}(t_2) \right] \]

Define ratio

\[ A_T = \frac{P(a \rightarrow b) - P(b \rightarrow a)}{P(a \rightarrow b) + P(b \rightarrow a)} \]

a: Flavour eigenstate \(B^0\) or \(\bar{B}^0\) identified by semileptonic decay: \(\ell^+\) or \(\ell^-\)

b: \(CP\) eigenstate \(B_{CP+}\) or \(B_{CP-}\) identified by decay to: \(J/\psi K_S\) or \(J/\psi K_L\)

Measure time-ordered decays of both B-mesons, time difference defined as:

\[ \Delta t = t_{CP} - t_{flavour} \]

\(> 0\) for \(B^0 \rightarrow B_{CP-}\)

\(< 0\) for \(B_{CP-} \rightarrow B^0\)
- Time dependent rate $8$ decays

$$g_{\alpha, \beta}^\pm (\Delta \tau) \propto e^{-\Gamma \Delta \tau} \{1 + S_{\alpha, \beta}^\pm \sin(\Delta m_d \Delta \tau) + C_{\alpha, \beta}^\pm \cos(\Delta m_d \Delta \tau)\}$$

$S$ and $C$ probe interference in decay-mixing and decay

ML fit to determine $8$ pairs of $S_{\alpha, \beta}^\pm$ and $C_{\alpha, \beta}^\pm$ parameters

$\pm \{\Delta t > 0, \Delta t < 0\}$

- $\alpha$ flavour tag $\{\ell^+, \ell^\prime\}$
- $\beta$ CP tag $\{K_L, K_S\}$

$$A_T (\Delta t) \approx \frac{C_T^+}{2} \cos \Delta m_d \Delta t + \frac{S_T^+}{2} \sin \Delta m_d \Delta t$$

Combined Fit results:

- $\Delta S_T^+ = -1.37 \pm 0.14 \pm 0.06$
- $\Delta C_T^+ = +0.10 \pm 0.14 \pm 0.08$
- $\Delta S_T^- = +1.17 \pm 0.18 \pm 0.11$
- $\Delta C_T^- = +0.04 \pm 0.14 \pm 0.08$

Expected:

- $-2 \sin 2\beta$
- $0.0$
- $+2 \sin 2\beta$
- $0.0$

$14\sigma$ signal
Consistent with $\sin 2\beta$
results on CP Violation and with CPT invariance

Results from the B-Factories

J. Michael Roney
Simple purely leptonic pseudo-scalar decays carry information about product of CKM element and strong interaction ‘decay constant’

\[ BF(B \rightarrow \ell \nu)_{SM} = \frac{G_F^2 m_B m_\ell^2}{8\pi} \left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 \left|V_{ub}\right|^2 f_B^2 \tau_M \left(1 + \delta_{EM}^{B\ell}}\right) \]

- Interesting because some New Physics theories have charged Higgs contributing to observed decay rate

• Additional tree level contribution from a charged Higgs
  - It does not suffer from helicity suppression, but gets the same \(m_1\) dependence from Yukawa coupling
  - Branching fraction theoretical expression depends on the NP model

\[ B(B \rightarrow l\nu)_{2HDM} = B(B \rightarrow l\nu)_{SM} \times (1 - tan^2\beta \frac{m_B^2}{m_H^2})^2 \]


\[ B(B \rightarrow l\nu)_{SUSY} = B(B \rightarrow l\nu)_{SM} \times (1 - \frac{tan^2\beta}{1 + \epsilon_0 tan\beta \frac{m_B^2}{m_H^2}})^2 \]

A.G. Akeroyd and S.Recksiegel

J. Michael Roney
Uses full reconstruction tagging

- **fully reconstruct** one of the B’s to tag B flavour/charge, determine its momentum, and exclude decay products of this B from further analysis.

Signal Decays:
- $B \rightarrow \tau \nu$
- $B \rightarrow D(*) \tau \nu$,
- $B \rightarrow K \nu \nu$
- $B \rightarrow X_u l \nu$,  

---

Powerful tool for B decays with neutrino

→ unique feature at e+e- B factories

At the $\Upsilon(4S)$ the $B^+$ and $B^-$ decay products overlap, this associates parent B with each particle.
B^- \rightarrow \tau^- \nu_\tau \text{ Results}

Main discriminating variable on the signal side: remaining energy in the calorimeter, not associated with any charged track or photon → Signal at $E_{ECL} = 0$

**Belle**

$Br(B \rightarrow \tau \nu) = [0.72^{+0.27}_{-0.25} \pm 0.11] \times 10^{-4}$

PRL 110 (2013) 131801

**BaBar**

$Br(B \rightarrow \tau \nu) = [1.83^{+0.53}_{-0.49} \pm 0.24] \times 10^{-4}$


All measurements combined:

$BF(B \rightarrow \tau \nu) = (1.15 \pm 0.23) \cdot 10^{-4}$

cf Standard Model:

$BF(B \rightarrow \tau \nu)_{SM} = (1.01 \pm 0.29) \times 10^{-4}$

(using $|V_{ub}| = (3.95 \pm 0.38 \pm 0.39) \times 10^{-4}$)

Results from the B-Factories
Results after ICHEP 2012

\[ BF(B \rightarrow \tau \nu) = (1.15 \pm 0.23) \cdot 10^{-4} \]
B → D(∗)τν Decays

Semileptonic decay sensitive to charged Higgs

\[
R(D) = \frac{\Gamma(B \rightarrow D\tau\nu)}{\Gamma(B \rightarrow D\ell\nu)} \quad R(D^*) = \frac{\Gamma(B \rightarrow D^*\tau\nu)}{\Gamma(B \rightarrow D^*\ell\nu)}
\]

- A well understood process, form factors measured for \( B \rightarrow D(\ast)\ell\nu \),
decays involving \( \tau \) have additional helicity amplitude
- Several experimental and theoretical uncertainties cancel in the ratio!
- non-SM contribution from \( H^\pm \) expected to change rates for \( B \rightarrow D(\ast)\tau\nu \)

Scalar Helicity Amplitude: (good to 1\% for \( m_{H^\pm} > 15\text{GeV} \))

\[
H_{S}^{2\text{HDM}} \approx H_{S}^{\text{SM}} \times \left(1 - \frac{\tan^2 \beta}{m_{H^\pm}^2} \frac{q^2}{1\mp m_c/m_b}\right)
\]

- for \( B \rightarrow D\tau\nu \)
- for \( B \rightarrow D^*\tau\nu \)

Results from the B-Factories

J. Michael Roney
Results from the B-Factories

\[
\mathcal{R}(D)_{\text{exp}} = 0.440 \pm 0.072 \quad \mathcal{R}(D^*)_{\text{exp}} = 0.332 \pm 0.030
\]

\[
\mathcal{R}(D)_{\text{SM}} = 0.297 \pm 0.017 \quad \mathcal{R}(D^*)_{\text{SM}} = 0.252 \pm 0.003
\]

Combined BaBar result: 3.4σ above SM

\[
\frac{\text{BF}(B \to D^{(*)}\tau\nu)}{\text{BF}(B \to D^{(*)}\ell\nu)} \text{ vs } \tan\beta/m_{H^\pm}\]

\[ \mathcal{R}(D)_{\text{exp}} = 0.440 \pm 0.072 \quad \mathcal{R}(D^*)_{\text{exp}} = 0.332 \pm 0.030 \]
\[ \quad \downarrow 2.0\sigma \quad \quad \downarrow 2.7\sigma \]
\[ \mathcal{R}(D)_{\text{SM}} = 0.297 \pm 0.017 \quad \mathcal{R}(D^*)_{\text{SM}} = 0.252 \pm 0.003 \]


Missing Mass Squared

If discrepancy with SM holds, result cannot be explained by Type II 2HDM; excluded over full parameter space at 99.8%CL

Can be accommodated in more general extensions of Type III 2HDM

Combined BaBar result: 3.4\sigma above SM


First observation of B → D*τν by Belle (2007)

Belle did not publish a measurement of the ratio directly for all modes and so did not quote average R values. Publications based on fraction of Belle data
At May 2013 FPCP meeting Andrej Bozek (Belle) presented a ‘private average’ of the published Belle results

Belle Deviations from SM based on A. Bozek average of Belle results (FPCP 2013)

R(D*) = 3.0σ  
R(D) = 1.4σ  
R(D(*) = 3.3σ

Bozek reports a combined BaBar and Belle deviation from the SM of 4.8σ
Searches for Light CP-odd Higgs

- $\Upsilon(2S,3S) \rightarrow \gamma A^0, A^0 \rightarrow \text{hadrons}$
- $\Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow \tau^+\tau^-, \mu^+\mu^-$

**Dark Higgs Searches**

- $e^+e^- \rightarrow A'h', h' \rightarrow A'A', A' \rightarrow h_1h_2 (h_i = e, \mu, \pi)$

**New BABAR result** - shown first here at Lepton Photon 2013:

Search for light Higgs decaying to two gluons or $s\bar{s}$ in radiative decays of the $\Upsilon(1S)$
BaBar Searches for Light CP-odd Higgs

Search for light Higgs decaying to two gluons or $s\bar{s}$ in radiative decays of the $\Upsilon(1S)$

$e^+e^- \to \Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$

$\Upsilon(1S) \to \gamma A^0; A^0 \to gg$ or $s\bar{s}$

Sample: $17.6 \times 10^6 \ Upsilon(1S)$ decays

At low Higgs mass, $m_A < 2m_\tau$:
- expect $s\bar{s}$ to dominate rate at high $\tan\beta$
- expect $gg$ to dominate rate at low $\tan\beta$
Lepton Flavour Violation in Tau Decays

LFV is long established way of seeking evidence of New Physics
• 48 channels probed by Belle and BABAR
• LHCb has recently entered the game
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• LHCb has recently entered the game
LHCb uses $D_s \rightarrow \tau \nu$ as source of taus

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Published on fb$^{-1}$ of data looking for LFV and Baryon number and Lepton number non-conserving decays

$$\mathcal{B}(\tau^- \rightarrow \mu^- \mu^+ \mu^-)$$

$$= \mathcal{B}(D_s^- \rightarrow \phi(\mu^+ \mu^-)\pi^-) \times \frac{f_{D_s}^{D_s}}{\mathcal{B}(D_s^- \rightarrow \tau^- \bar{\nu}_\tau)} \times \frac{\epsilon_{\text{REC&SEL}}}{\epsilon_{\text{sig}}} \times \frac{\epsilon_{\text{TRIG}}}{\epsilon_{\text{sig}}} \times \frac{N_{\text{sig}}}{N_{\text{cal}}}$$

LHCb 90(95)%CL Limits

$$\mathcal{B}(\tau^- \rightarrow \mu^- \mu^+ \mu^-) < 8.0 (9.8) \times 10^{-8}$$

$$\mathcal{B}(\tau^- \rightarrow \bar{p} \mu^+ \mu^-) < 3.3 (4.3) \times 10^{-7}$$

$$\mathcal{B}(\tau^- \rightarrow p \mu^- \mu^-) < 4.4 (5.7) \times 10^{-7}$$
**Precision Cross Section of** \( e^+e^- \rightarrow K^+K^-(\gamma) 
\)

**BABAR**, submitted to PRD arXiv 1306.3600

**Results from the B-Factories**

J. Michael Roney

**Precision Cross Section of** \( e^+e^- \rightarrow K^+K^-(\gamma) 
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**Results from the B-Factories**

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Physics Programme

- Test CKM at 1% level
  - CPV in B decays from new physics (non-CKM)
- B-recoil technique for \( B \rightarrow K^{(*)} \ell^+ \ell^- \), \( B \rightarrow \tau \nu \), \( B \rightarrow D^{(*)} \tau \nu \)
- \( \tau \) physics: lepton flavour violation, \( g-2 \), EDM, CPV, \(|V_{us}|\)
- Charm: mixing, CPV, ...
- Many other topics:
  - \( \Upsilon(5S) \) physics, ISR radiative return, spectroscopy, Dark Sector probe, low mass Higgs...
- Physics motivation is independent of LHC
  - If LHC finds NP, precision flavour input essential
  - If LHC finds no NP, high statistics B and \( \tau \) decays are unique way of probing >TeV scale physics

Belle II and LHCb (and ATLAS & CMS) are Complementary
Summary

• Belle and $BABAR$ are continuing to publish
  ▫ Completing Physics of the B-Factories Book summarizing the papers currently published by both collaborations
  ▫ Completing the CKM program but also going into new areas – e.g. T-violation; light Higgs searches, Dark Sector searches
  ▫ CKM is generally describing the data well
• $3.4\sigma$ tension with SM in $BABAR$ $B \rightarrow D^{(*)}\tau\nu$ decays, earlier published Belle results see similar hints
  ▫ eagerly awaiting new analysis on Belle full data set
• Looking forward to future data from Belle II at SuperKEKB and LHCb
Additional Slides
NMSSM Parameter Space

- $\text{BF}(\Upsilon(1S) \rightarrow \gamma A^0)$ depends on non-singlet fraction
- High mass Higgs very difficult to exclude
Higgs Branching Fractions

\[ B(A^0 \rightarrow f\bar{f}) \propto \frac{m_f^2}{\tan^2 \beta} \quad \text{up-type fermions} \]
\[ B(A^0 \rightarrow f\bar{f}) \propto m_f^2 \tan^2 \beta \quad \text{down-type fermions} \]

Dominantly decays to gg or ss at low mass depending on \( \tan \beta \)

Relevant BF for this analysis
Contributions to $a_{\mu}^{\text{had}, \text{LO}}$ and $\Delta \alpha_{\text{had}}(M_Z^2)$


For most of these channels, BaBar provides the most precise measurements from ISR studies.