Latest results on radiative penguin B decays and Searches for Lepton-Number Violation in $B^+ \rightarrow X^- l^+ l'^+$
• Radiative Penguin B decays
  – Direct Asymmetries in $B \rightarrow X_s \gamma$ [to be submitted to PRD]
  – Search for $B \rightarrow \pi/\eta \ l^+l^-$ [arXiv:1303.6010]

• Lepton-Number Violation (LNV)
  – $B^+ \rightarrow X^-l^+l'^+$ [to be submitted to PRD-RC]
BaBar and PEP-II: $e^+e^- \rightarrow \Upsilon(nS)$

Asymmetric beam momenta, $\Upsilon(nS)$ production, low multiplicity, low background, $\pi/K$ particle identification, good muon and electron identification with wide coverage.

![BABAR Detector Diagram](image)

- $L(4S) = 424$ fb$^{-1}$
- $N(4S) = 471$ M
- $L(3S) = 28$ fb$^{-1}$
- $N(3S) = 121$ M
- $L(2S) = 14$ fb$^{-1}$
- $N(2S) = 99$ M
- $N(\tau\tau) \sim 450$ M

Similar number of B-mesons, charm-mesons and $\tau\tau$ pairs produced: $\sim 450$ million
**Typical Analysis Techniques**

\[ m_{ES} = \sqrt{E_{\text{beam}}^* - p_B^*} \]

\[ \Delta E = E_B^* - E_{\text{beam}}^* \]

---

**Event Topology**

- **Signal**
  - \[ \sigma_{M_{ES}} \approx 3\text{MeV} \]
  - \[ \sigma_{\Delta E} \approx 17\text{MeV} \]

- **Background**
  - \[ \sigma_{M_{ES}} \approx 3\text{MeV} \]
  - \[ \sigma_{\Delta E} \approx 17\text{MeV} \]

---

Plus: blinded analysis, multivariate discriminants, Maximum Likelihood (ML) fits
• B → X_sγ and B → X_s l^+l^- are flavor-changing neutral current (FCNC) processes, forbidden in SM at tree level.

• SM NNLO prediction: \( B(B \to X_s \gamma) = (3.14 \pm 0.22) \times 10^{-4} (E_{\gamma} > 1.6 \text{ GeV}) \)

• Effective Hamiltonian can be factorized in terms of short-distance (\( C_i \)) and long-distance (\( O_i \), Wilson Coefficients) terms:

\[
H_{\text{eff}} = \frac{4G_F}{\sqrt{2}} \sum_i C_i(\mu)O_i
\]

• New physics can enter into loops.
  – Can modify or introduce new Wilson coefficients
  – Signature is modified branching fractions, angular distributions, lepton flavor ratios, CP Asymmetries.
B → X_sγ : Direct A_{CP}

- The CP asymmetry A_{CP} is defined as:
  \[ A_{CP} = \frac{\Gamma(\bar{B} \to \bar{X}_s\gamma) - \Gamma(B \to X_s\gamma)}{\Gamma(\bar{B} \to \bar{X}_s\gamma) + \Gamma(B \to X_s\gamma)} \]

- The SM prediction is -0.6% < A_{CP} < 2.8%

- Present world average (WA) is A_{CP} = (-0.8 ± 2.9)%

- Difference for charged and neutral B decays:
  \[ \Delta A_{CP} = A_{CP}(B^+ \to X_s^+\gamma) - A_{CP}(B^0 \to X_s^0\gamma) \]

- \( \Delta A_{cp} \) depends on \( C_{7}^{\text{eff}} \) and \( C_{8}^{\text{eff}} \)

  \[ \Delta A_{CP}(X_s\gamma) = 4\pi^2\alpha_s \frac{\bar{\Lambda}_{78}}{m_b} \Im\left( \frac{C_{8}^{\text{eff}}}{C_{7}^{\text{eff}}} \right) \approx 0.12 \frac{\bar{\Lambda}_{78}}{100\text{MeV}} \Im\left( \frac{C_{8}^{\text{eff}}}{C_{7}^{\text{eff}}} \right) \]

  17 MeV < \( \bar{\Lambda}_{78} \) < 190 MeV

  Benzke et al PRL 106, 141801 (2011)

- In SM, \( C_{7}^{\text{eff}} \) and \( C_{8}^{\text{eff}} \) are real => \( \Delta A_{cp} = 0 \)
**B→X_sγ : Event Selection for A_{CP}**

- Full BaBar sample \((471\pm1)\times10^6 B\bar{B}\) pairs.
- Reconstruct **16** exclusive modes to measure \(A_{CP}\); further **22** modes reconstructed to eliminate peaking background.
- Two multivariate classifiers used.
  - **Signal Selecting Classifier (SSC):** based on signal properties. Factor 2 improvement compared to using \(\Delta E\) alone.
  - **Background Rejection Classifier (BRC):** Based on event shapes.
  - Trained in four \(X_s\) mass regions, selection criteria based on optimizing \(S/\sqrt{S+B}\).

<table>
<thead>
<tr>
<th>Decay Mode</th>
<th>Decay Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B^+ \rightarrow K^0_S\pi^+\gamma)</td>
<td>(B^+ \rightarrow K^0_S\pi^+\pi^-\gamma)</td>
</tr>
<tr>
<td>(B^+ \rightarrow K^+\pi^-\gamma)</td>
<td>(B^+ \rightarrow K^0_S\pi^+\pi^-\pi^-\gamma)</td>
</tr>
<tr>
<td>(B^+ \rightarrow K^+\pi^+\pi^-\gamma)</td>
<td>(B^+ \rightarrow K^0_S\pi^+\pi^-\pi^-\pi^-\gamma)</td>
</tr>
<tr>
<td>(B^+ \rightarrow K^+\pi^+\pi^-\pi^-\gamma)</td>
<td>(B^+ \rightarrow K^0_S\pi^+\pi^-\pi^-\pi^-\pi^-\gamma)</td>
</tr>
<tr>
<td>(B^+ \rightarrow K^+\pi^+\pi^-\pi^-\pi^-\gamma)</td>
<td>(B^+ \rightarrow K^0_S\pi^+\pi^-\pi^-\pi^-\pi^-\pi^-\gamma)</td>
</tr>
</tbody>
</table>

19th July 2013

Fergus Wilson, STFC/RAL
$B \to X_s \gamma$: Direct $A_{CP}$ results

- $1.6 < E^*_\gamma < 3.0$ GeV, $0.6 < m_{Xs} < 3.2$ GeV/c$^2$
- $B^+$ tagged by overall charge, $B^0$ by Kaon charge.
- Fit $m_{ES}$ for $B$ and $\bar{B}$ tagged samples simultaneously to extract $A_{CP}$

After corrections for backgrounds and detector $K^+/K^-$ response: $A_{CP} = (1.7 \pm 1.9 \pm 1.0)\%$

Agrees with SM: $-0.6\% < A_{CP} < 2.8\%$
B→X_sγ : ΔA_{CP} and Wilson Coefficients

- From simultaneous fit to charged and neutral B samples:
  - ΔA_{CP} = (5.0 ± 3.9 ± 1.5)%
- Set 90% CL constraints on Im(C_8^{eff}/C_7^{eff}):
  - -1.64 < Im(C_8^{eff}/C_7^{eff}) < 6.52.

- First ΔA_{CP}(X_sγ) measurement and first constraint on C_8^{eff}/C_7^{eff} ratio.
**B \to \pi/\eta \ell^+\ell^- : Introduction**

- SM mediated by γ or Z-penguin and WW box diagrams:

- Suppressed compared to \( b \to sl^+l^- : |V_{td}/V_{ts}|^2 \sim 0.04 \)

- SM predictions:

\[
B(B^+ \to \pi^+l^+l^-) = (1.4 - 3.3) \times 10^{-8}
\]
\[
B(B^+ \to \eta^+l^+l^-) = (2.5 - 3.7) \times 10^{-8}
\]

- New Physics can alter decay rates, flavor couplings, isospin, \( A_{CP} \) and \( A_{FB} \) asymmetries.
B→π/η l^+l^- : Analysis Method

• Fully reconstruct 8 B→π/η l^+l^- in 471 x 10^6 B\bar{B} pairs.
  - \pi^+, \pi^0, \eta\rightarrow\gamma\gamma, \eta\rightarrow\pi^+\pi^-\pi^0, recoiling against e^+e^- or \mu^+\mu^-
  - Veto J/ψ and ψ(2S) (but used to validate fit)
  - P_{l}>300 \text{ MeV/c} and E_γ>50 \text{ MeV}
  - Suppress B\bar{B} and q\bar{q} continuum backgrounds with multivariate discriminants (like BaBar B→K(*)l^+l^- angular analyses).

• Simultaneously fit to M_{ES} and ΔE.
B→π/η l⁺l⁻ : Preliminary Results

- Produce preliminary results for isospin-averaged, lepton-flavor averaged:

19th July 2013
Fergus Wilson, STFC/RAL
B→π/η l⁺l⁻ : Preliminary Results

• No signal seen.
• First results for B→η l⁺l⁻.
• Best limits for B⁰→π⁰ l⁺l⁻:
  \[ B(B^+ \rightarrow \pi^0 l^+ l^-) < 5.3 \times 10^{-8} \text{(90\%CL)} \]
• Not precise enough to match LHCb B⁺→π⁺μ⁺μ⁻.
• Limits are within a factor 2-3 of SM predictions.
Lepton Number Violation (LNV) in SM only possible at very high energies/densities.

Many, if not most, New Physics scenarios introduce LNV. Example scenario:
- Majorana neutrino exchange.

Many modes not searched for since CLEO

Search for 11 modes:
- $B^+ \rightarrow \rho^- (\rightarrow \pi^- \pi^0) \ l^+ l'^+$
- $B^+ \rightarrow K^{*-} (\rightarrow K^0_S \pi^- \text{ and } \rightarrow K^- \pi^0) \ l^+ l'^+$
- $B^+ \rightarrow D^- (\rightarrow K^- \pi^- \pi^+) \ l^+ l'^+$
- $B^+ \rightarrow K^-/\pi^- e^+ \mu^+$

Previous/related results:
Belle: PRD 84, 071106 (2011)
BaBar: PRD 85, 071102 (2012)
B⁺ → X⁻ l⁺ l’⁺: Event Selection

- Reconstruct the 11 modes.
- Construct multivariate discriminant (BDT) to reject backgrounds
- ML fit to 3 or 4 observables: $M_{ES}$, $\Delta E$, BDT, $[K^*/\rho/D$ mass]:

$$B^+ \to K^{*-} (\to K^- \pi^0) \mu^+ \mu^+$$

$$B^+ \to D^- e^+ \mu^+$$
B$^+ \rightarrow X^- \ l^+ \ l'^+$: Preliminary Results

- 11 updated measurements. 90% CL UL in range $(1.5 - 26.4) \times 10^{-7}$
- Order of magnitude improvement for CLEO results.
- Similar precision to Belle for $B^+ \rightarrow D^- l^+ l'^+$
Summary and Conclusion

• Improved $A_{cp}$ for $B \rightarrow X_s \gamma$
  – Compatible with Standard Model.
  – Smaller uncertainties than World Average.
  – First measurement of $\Delta A_{cp}$.
  – To be submitted to PRD.

• Search for $B \rightarrow \pi/\eta \ l^+\l^-$
  – Upper limits placed on 16 modes.
  – Best limit for $B^0 \rightarrow \pi^0 \ l^+\l^-$.
  – arXiv:1303.6010

• Search for LNV $B^+ \rightarrow X^- \ l^+\l'^+$
  – Upper limits place on 11 modes.
  – Order of magnitude improvement compared to CLEO results.
  – Commensurate with Belle results.
  – To be submitted to PRD-RC