Electroweak Penguin
Decays of B Mesons

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SCIPP

BABAR Collaboration
The origin of penguins

Told by John Ellis:

"Mary K. [Gaillard], Dimitri [Nanopoulos], and I first got interested in what are now called penguin diagrams while we were studying CP violation in the Standard Model in 1976... The penguin name came in 1977, as follows.

In the spring of 1977, Mike Chanowitz, Mary K. and I wrote a paper on GUTs [Grand Unified Theories] predicting the b quark mass before it was found. When it was found a few weeks later, Mary K., Dimitri, Serge Rudaz and I immediately started working on its phenomenology.

That summer, there was a student at CERN, Melissa Franklin, who is now an experimentalist at Harvard. One evening, she, I, and Serge went to a pub, and she and I started a game of darts. We made a bet that if I lost I had to put the word penguin into my next paper. She actually left the darts game before the end, and was replaced by Serge, who beat me. Nevertheless, I felt obligated to carry out the conditions of the bet.

For some time, it was not clear to me how to get the word into this b quark paper that we were writing at the time.... Later...I had a sudden flash that the famous diagrams look like penguins. So we put the name into our paper, and the rest, as they say, is history."

John Ellis in Mikhail Shifman’s “ITEP Lectures in Particle Physics and Field Theory”, hep-ph/9510397

http://www.symmetrymagazine.org/cms/?pid=1000424

\( \Upsilon, Z: \) electroweak penguin [this talk]

\( g: \) gluonic penguin [not today]
**A Window to New Physics?**

- **b → s,d transitions with high-energy photon or lepton pair in the final state**

  ![Diagram](image)

  - `radiative penguin`
  - `WW box`

- FCNC, forbidden at tree level: rare + sensitive to new physics at leading order

- → low-energy access to the TeV scale!

- relatively clean (only one hadronic current)
A WINDOW INTO THE B MESON

quark level:
- two-body decay
- mono-energetic photon

hadron level:
- $E_\gamma$ spectrum sensitive to internal B dynamics
- can extract HQE parameters, e.g.
  - quark mass: $m_b \sim E_\gamma/2$
  - Fermi motion: $\mu_\pi^2 \sim <E_\gamma^2> - <E_\gamma>^2$
- universal to (inclusive) B decays
Operator Product Expansion

\[ V_{tb} V_{td}^* \times C_7(m_b) \times \]

Wilson coefficient(s):
short-distance physics;
calculated pertubatively

New Physics enters here

- modification of SM coefficients:  \( C_j = C_j^{SM} + \epsilon_j e^{i\theta_j} \)
- addition of non-SM operators

JKeroseberg  DESY Seminar  26./27.2.2008
**Penguins – Then and Now**

1993

- **Observation of $B \rightarrow K^* \gamma$**
  - *Jürgen Kroseberg* DESY Seminar 26./27.2. 2008

2007

- **e.g. $B(B \rightarrow X_{s d} \gamma)$**
  - **CLEO II**
  - **PRL 71, 674 (1993)**

- **HFAG September 2007**
  - CLEO
  - Belle
  - BABAR
  - PDG2006
  - New Avg.
**Experimental Approaches**

- **fully inclusive**
  - consider only photon spectrum
  - (use minimal opposite-side ‘tag’)

- **semi-inclusive**
  - measure sum of exclusive final states

- **exclusive**
  - measure specific decay mode(s)

“experimentally clean”

“theoretically clean”
**Observables**

- **Branching fractions**
- **CP asymmetry:**
  \[
  A_{CP} = \frac{\mathcal{B}(B \rightarrow X_{s,d} \gamma) - \mathcal{B}(\bar{B} \rightarrow X_{s,d} \gamma)}{\mathcal{B}(B \rightarrow X_{s,d} \gamma) + \mathcal{B}(\bar{B} \rightarrow X_{s,d} \gamma)}
  \]
- **Isospin asymmetry:**
  \[
  \Delta_0^- = \frac{\Gamma(\bar{B}^0 \rightarrow X_{s,d} \gamma) - \Gamma(B^- \rightarrow X_{s,d} \gamma)}{\Gamma(\bar{B}^0 \rightarrow X_{s,d} \gamma) + \Gamma(B^- \rightarrow X_{s,d} \gamma)}
  \]
- **Photon energy spectrum, q^2 (**|q||=m_||**)** spectrum
- **Angular distributions (for di-lepton final states)**

...
Selection For This Talk

- **Inclusive** $b \to s \gamma$ (‘B tag’): BF, $E_\gamma$, $A_{CP}$, $A_\Delta_0$ (384 million BB pairs);

- **Semi-inclusive** $b \to s \gamma$: $A_{CP}$ (383M BB);
  **new BaBar result** [preliminary, to be submitted to PRL]

- **Exclusive** $b \to d \gamma$: $B \to \rho/\omega \gamma$ BF, $|V_{td}/V_{ts}|$;
  - recent Belle results [preliminary, see LP07] (657M BB);
  - early-’07 BaBar publication [PRL 98, 151802 (2007)] (347M BB)

- **Semi-inclusive** $b \to d \gamma$: (partial) BF (383M BB);
  recent BaBar result [preliminary, arXiv:0708.1652]

- **Exclusive** $b \to s l^+ l^-$: angular analysis of $B \to K^* l^+ l^-$;
  - **new BaBar result** [preliminary, to be submitted to PRL] (384M BB)
  - 2006 Belle publication [PRL 96, 251801 (2006)] (386M BB)
Need/Have Millions of B Mesons

NB: rare decays (BF of $10^{-4}$-$10^{-7}$)!

\[ e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B} \]

- PEP II Delivered Luminosity: 523.80/fb
- BaBar Recorded Luminosity: 503.51/fb
- BaBar Recorded Y(4s): 432.72/fb
- BaBar Recorded Y(3s): 23.69/fb
- Off Peak Luminosity: 47.10/fb

[~10% of data taken below the $\Upsilon(4S)$]

- ~430/fb $\rightarrow$ ~480 million $B\bar{B}$
- most current results use ~380 million $B\bar{B}$
- now running on $\Upsilon(3S)$ and $\Upsilon(2S)$ to search for new low-mass particles
PEP-II and BaBar at SLAC

Linear Accelerator

PEP-II storage ring

SLAC

BaBar

Main Linac

LCLS Injector

Damping Rings

SPEAR3

End Station A

LCLS

End Station B

NLCTA

SABER

PEP-II

LCLS Far Hall

LCLS Near Hall

CEH
The BaBar Detector

Electromagnetic Calorimeter
6580 CsI crystals
$e^+ \text{ ID, } \pi^0 \text{ and } \gamma \text{ reco}$

Instrumented Flux Return
19 layers of RPCs (+LSTs)
$\mu \text{ ID}$

Cherenkov Detector
144 quartz bars
$K, \pi, p \text{ separation (and lepton ID)}$

Drift Chamber
40 layers
tracking + dE/dx

Silicon Vertex Tracker
5 layers (double-sided Si strips)
vertexing + tracking (+ dE/dx)

$e^+ [3.1 \text{ GeV}]$

$e^- [9 \text{ GeV}]$

1.5T Magnet
Belle/KEK-B

- $3.5 \text{ GeV } e^+ \times 8.0 \text{ GeV } e^-$
- $\mathcal{L}_{\text{max}} = 1.71 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Continuous injection
  $\Rightarrow 1.2 \text{ fb}^{-1}/\text{day}$
- $\int \mathcal{L} dt > 750 \text{ fb}^{-1}$

- Sil. VD: 3(4) layers DSSD
- CDC: small cells $He + C_2H_6$
- TOF counters.
- Aerogel CC: $n = 1.015 \sim 1.030$
- CsI(Tl) 16 $X_0$
- SC solenoid 1.5 T
- $\mu K_L$ detection 14-15 layers RPC+Fe

...and Tevatron!
B Meson Reconstruction

- e+e- collider: have precise knowledge of beam energy

- B selection via an energy difference and effective mass

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

\[ m_{ES} = \sqrt{(E_{beam}^*)^2 - P_B^2} \]

\[ \sigma(\Delta E) \sim 15-80 \text{ MeV} \] (mode dependent)

\[ \sigma(m_{ES}) \sim 3 \text{ MeV} \]
huge backgrounds, in particular from \( e^+e^- \rightarrow q\bar{q} \)

‘continuum’ events (\( q = u,d,s \))

suppress using, e.g., event shape information

**Continuum Suppression**

- **B decays:** (more) isotropic
  - [Diagram: more isotropic distribution]

- **Continuum:** (more) jet-like
  - [Diagram: more jet-like distribution]

Combine various variables (in a Fisher Discriminant, Neural Network, Decision Tree, …) and use for cuts and/or fitting:
**Signal Extraction**

- ‘blind’ analysis: optimize procedure w/o looking at signal region
- validate analysis using control samples from real data
- perform multi-dimensional likelihood fits (or subtract background and count signal events)

**Example Plots**

- \( \Delta E \) vs. \( \Delta E \) (GeV)
- \( m_{ES} \) vs. \( m_{ES} \) (GeV/c^2)
- Helicity vs. \( \cos \theta_{Helicity} \)
- \( \rho^0 \) transformed NN output vs. NN
(Semi-)Inclusive $b \rightarrow s\gamma$: BF

Status of branching fraction measurements
(note theory breakthrough in 2006; can now compare to NNLO!):

Measured BF are extrapolated down to $E^{\ast}_\gamma < 1.6$ GeV
(based on HQE fits to $b \rightarrow c\nu$ and $b \rightarrow s\gamma$ moments)

Theory; Misiak et al
PRL 98, 022002 (2007)

$$3.15 \pm 0.23$$

$\text{BaBar inc.}$
$3.94 \pm 0.31 \pm 0.36 \pm 0.21$

$\text{BaBar semi.}$
$3.29 \pm 0.18^{+0.62}_{-0.40}^{+0.07}_{-0.08}$

$\text{CLEO}$
$3.21 \pm 0.43 \pm 0.27^{+0.18}_{-0.10}$

$\text{BELLE}$
$3.55 \pm 0.32^{+0.30}_{-0.31}^{+0.11}_{-0.07}$

$\text{ALEPH}$
$3.11 \pm 0.80 \pm 0.72$

$\text{World Av.}$
$3.55 \pm 0.26$
Inclusive $b \rightarrow s \gamma$: The Challenge
Incl. $b \rightarrow s \gamma$: Previous Methods

"fully inclusive" (or lepton tag)

Pros
- no $X_s$ fragmentation sensitivity
- theoretically clean

Cons
- high background, no $B$ constraint!
- measure $E_{\gamma}^*$ in $\Upsilon(4s)$ frame

"semi-inclusive" (sum of exclusive)

Pros
- lower background
- good $E_{\gamma}$ resolution in $B$-frame

Cons
- missing $X_s$ decay modes
- $X_s$ fragmentation systematic

Measure only the $\gamma$ (and tag lepton)

Fully reconstruct $X_s$ final states

\[ E_{\gamma} = \frac{M_B^2 - M(X_s)^2}{2M_B}. \]
 Measure high-energy $\gamma$ recoiling against a fully reconstructed hadronic $B$ decay

Photon energy spectrum is extracted from fits to $m_{ES}$ in bins of $E_\gamma$

Through full reconstruction of $B_{\text{reco}}$ [and $Y(4S)$ momentum], flavor, charge and four-momentum of signal $B$ are known
  - can measure photon energy in the $B$ rest frame and CP asymmetry

Fits to $m_{ES}$ provide information on
  - total number of $BB$ pairs $\Rightarrow$ BF normalization
  - non-peaking background $\Rightarrow$ continuum subtraction

Independent of lepton-tagged sample used in previous analysis

**Downside:** small efficiency of $B_{\text{reco}}$ tag (about 0.3%)
**Inclusive** $b \rightarrow s \gamma$: $E_\gamma$ Spectrum

- **BB Background Subtraction**
  - Used for BG normalization

- **Spectrum before BG subtraction**
  - Data
  - BB

- **BG-subtracted spectrum**
  - 119 ± 22 Signal Events for $E_\gamma > 1.9$ GeV

- **Efficiency/Resolution Corrected spectrum**

- **Efficiency Corrections**

- **$E_\gamma$ Resolution Corrections**
**Incl. $b \to s \gamma$: Branching Fraction**

Include systematics

Normalize to entire tag sample

Integrate

$BF(b \to s \gamma) \ [E_{\gamma} > 1.9 \text{ GeV}] = (3.66 \pm 0.85 \pm 0.60) \times 10^{-4}$

Extrapolate (using hep-ph/0507253)

$BF(b \to s \gamma) \ [E_{\gamma} > 1.6 \text{ GeV}] = (3.91 \pm 0.91 \pm 0.64) \times 10^{-4}$

[World average: $(3.55 \pm 0.26) \times 10^{-4}$]
Incl. b → sγ: HQE Parameters

- Measure photon energy moments as a function of minimum $E_\gamma$
- Good agreement with previous results based on different methods and largely independent data samples

**Extraction of HQE parameters:**

\[ m_b = 4.46^{+0.21}_{-0.23} \text{ GeV}; \mu_\pi^2 = 0.64^{+0.39}_{-0.38} \text{ GeV}^2 \]

Also measure...
Isospin: \[ \Delta_{0^-} = -0.06 \pm 0.15 \pm 0.07 \]

CP: \[ A_{CP} = +0.10 \pm 0.18 \pm 0.05 \] (recoil analysis)

Could be enhanced by new physics, e.g. \( A_{CP} \) to about 15%  
(T. Hurth, E. Lunghi hep-ph/0312260)
Semi-inclusive $b \rightarrow s\gamma (A_{CP})$

**New result** [preliminary; to be submitted to PRL]
- based on 383 million $B\bar{B}$ pairs
  [previous analysis: 83 million]
- reconstruct 16 exclusive, flavor ‘self-tagging’ final states
  [previous analysis: 13]
- $|\Delta E|<0.1\text{GeV}$
- select hadronic mass range $0.6< M(X_s)<2.8$ GeV; corresponding to $E_\gamma > 1.9$ GeV
Semi-inclusive $b \rightarrow s \gamma$: Signals

Signal

continuum background

BB background

(preliminary)
**Semi-incl. b \rightarrow sγ: Systematics**

\[
A_{\text{true}}^{CP} = \left( A_{\text{measured}}^{CP} \right) \frac{\Delta D}{2} \frac{1}{\langle D \rangle} A_{\text{Detector}}^{CP}
\]

- **signal+background shape modeling**
- **differences in \( \pi^+ \) and \( \pi^- \) mistagging rates**
- **detector reconstruction (charge asymmetry)**

\[
\Delta D = \bar{\omega} - \omega \\
\langle D \rangle = 1 - \frac{(\bar{\omega} + \omega)}{2}
\]

**MisID rate**

\( \omega: \pi^+ \rightarrow K^+ \)  
\( \bar{\omega}: \pi^- \rightarrow K^- \)
Semi-incl. $b \to s\gamma$: Result

$$A_{CP}(b \to s\gamma) = -0.019 \pm 0.030 \pm 0.019$$

(preliminary) stat. syst.

previous results:

\begin{center}
\begin{tabular}{lcc}
Experiment/Method & $A_{CP}$ \\
CLEO/Inclusive (10M $B\bar{B}$) & $-0.079 \pm 0.108 \pm 0.022$ \\
Belle/Pseudoreconstruction (140M $B\bar{B}$) & $0.002 \pm 0.050 \pm 0.030$ \\
BaBar/Inclusive (89M $B\bar{B}$) & $-0.110 \pm 0.115 \pm 0.017$ \\
BaBar/Semi (89M $B\bar{B}$) & $0.025 \pm 0.050 \pm 0.015$
\end{tabular}
\end{center}

consistent with zero, uncertainties almost cut in half; most precise measurement to date
one of the core B factory measurements; highly relevant within and outside ‘B physics’

a lot of recent activity (both experiment and theory); more to come soon

no hint of new physics yet; agreement with SM poses severe constraints on BSM models

essential to use (and eventually combine) all available methods and data to get best precision possible

no way of knowing what’s ‘good enough’

e.g.: type-II charged Higgs mass constraint

[from Misiak et al PRL 98, 022002 (2007)]
**Exclusive** $b \rightarrow d\gamma$

i.e. $B \rightarrow (\rho^{\pm,0},\omega)\gamma$

- **SM BF suppressed** by $|V_{td}/V_{ts}|^2 \sim 0.04$ w.r.t. $b \rightarrow s\gamma$
- higher **NP sensitivity**
- experimentally very **tough**!
- second sizable SM diagram
- expect significant ($\sim 10\%$) SM $A_{CP}$
- **BF constrains** $|V_{td}/V_{ts}|$ in SM (similar to $\Delta m_d/\Delta m_s$)
B \rightarrow (\rho, \omega)\gamma : Data Analysis

- **reconstruct** $\rho^{+/0} \rightarrow \pi \pi^{0/-}, \omega \rightarrow \pi \pi^{-}\pi^{0}$

- **background suppression/discrimination** is key:
  - continuum [Neural Net with event shape, ‘B tagging’ information, …]
  - $B \rightarrow K^{*}\gamma$ [particle ID]
  - $B \rightarrow (\rho^{\pm,0}, \omega)(\pi^{0}, \eta)$ [veto and helicity angle]

- **perform** likelihood fits; Belle: 2D, BaBar 4/5D
  - $m_{ES}, \Delta E$ [+NN output, decay angles]

**e.g.**

- $B^{+} \rightarrow \rho^{+}\gamma \rightarrow (44^{+15}_{-14})$ events
- $B^{0} \rightarrow \omega\gamma \rightarrow (17^{+8}_{-7})$ events

(preliminary)
$B \rightarrow (q, \omega)\gamma$ : BF Results

\[ (\rho^+, \rho^0, \omega) \gamma \text{ (combined)} \]
\[ (\rho^+, \rho^0) \gamma \text{ (combined)} \]

\[ \begin{align*}
\rho^+\gamma & \\
\rho^0\gamma & \\
\omega\gamma & \\
\end{align*} \]

<table>
<thead>
<tr>
<th>Branching Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<tr>
<td>0</td>
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</tbody>
</table>

**BaBar**

<table>
<thead>
<tr>
<th>$B$</th>
<th>$\mathcal{B} \times 10^{-7}$</th>
<th>$\Sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \rightarrow \rho^+\gamma$</td>
<td>$8.6^{+3.0}<em>{-2.8}^{+0.7}</em>{-0.8}$</td>
<td>(3.2$\sigma$)</td>
</tr>
<tr>
<td>$B^0 \rightarrow \rho^0\gamma$</td>
<td>$7.6 \pm 1.7 \pm 0.6$</td>
<td>(4.9$\sigma$)</td>
</tr>
<tr>
<td>$B^0 \rightarrow \omega\gamma$</td>
<td>$4.2^{+2.0}_{-1.8} \pm 0.4$</td>
<td>(2.6$\sigma$)</td>
</tr>
</tbody>
</table>

**Belle**

<table>
<thead>
<tr>
<th>$B$</th>
<th>$\mathcal{B} \times 10^{-7}$</th>
<th>$\Sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \rightarrow \rho^+\gamma$</td>
<td>$11.0^{+3.7}_{-3.3}$</td>
<td>(3.8$\sigma$)</td>
</tr>
<tr>
<td>$B^0 \rightarrow \rho^0\gamma$</td>
<td>$7.9^{+2.2}_{-2.0}$</td>
<td>(4.9$\sigma$)</td>
</tr>
<tr>
<td>$B^0 \rightarrow \omega\gamma$</td>
<td>$4.0^{+2.4}_{-2.0}$</td>
<td>(2.2$\sigma$)</td>
</tr>
</tbody>
</table>

$B \rightarrow \rho\gamma$

$B \rightarrow (\rho, \omega)\gamma$

316 fb$^{-1}$

598 fb$^{-1}$
**B → (Q, ω)γ : CKM Constraint**

- together with $B \rightarrow K^*\gamma$, measures $|V_{td}/V_{ts}|$ within SM
- hadronic uncertainties partially cancel in ratio

\[
\frac{B(B \rightarrow \rho/\omega\gamma)}{B(B \rightarrow K^*\gamma)} = S_{\rho/\omega} \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_{\rho/\omega}/m_B^2}{1 - m_{K^*}/m_B^2}\right) \zeta^2 (1 + \Delta R)
\]

Compare with $|V_{td}/V_{ts}|$ from $B_s$ mixing (first observed in 2006)

\[
\frac{\Delta m_d}{\Delta m_s} = \frac{1}{\zeta^2} \frac{m_{B_s}}{m_{B_d}} \left|\frac{V_{td}}{V_{ts}}\right|^2
\]

B $\rightarrow (q,\omega)\gamma$ : CKM Result

\[ |V_{td}/V_{ts}| \text{ from } B\rightarrow \rho/\omega\gamma \]
\[ 0.202\pm0.017^{(exp)}\pm0.015^{(theo)} \]

\[ |V_{td}/V_{ts}| \text{ from } B_s \text{ mixing} \]
\[ 0.2060\pm0.0007^{(exp)}\pm0.008^{(theo)} \]

- Independent physics providing same constraint within SM; new physics could enter two processes differently
- Excellent agreement (within still sizable uncertainties)
B → (ρ, ω)γ : CKM Result

WHERE DO WE GO FROM HERE?

- Improve exclusive measurements and...

- Independent physics providing same constraint within SM; new physics could enter two processes differently

- Excellent agreement (within still sizable uncertainties)
Semi-Inclusive $B \rightarrow X_d \gamma$

- **LP07 result (preliminary)**
- based on **383 million BB pairs**
- reconstruct $B \rightarrow X_d \gamma$ in **seven exclusive decay modes** (acc. to MC, account for about 50% of decays in measured mass range)
- **two bins in** hadronic mass $M(X_d)$:
  - **[0.6..1.0]** GeV: $B \rightarrow (\rho^{\pm,0}, \omega) \gamma$ **cross check** (barely observed themselves!)
  - **[1.0..1.8]** GeV: **analysis region**
to validate procedure, perform analysis in the mass range \([0.6..1.0]\) GeV (dominated by \(\rho\) and \(\omega\) resonances) and restrict to \(\pi^+\pi^-/\pi^0\gamma\), and \(\pi^+\pi^-\pi^0\gamma\) final states

expect 66±26 signal events
[from published \(B \rightarrow (\rho^\pm, 0, \omega)\gamma\) measurements]

find 73±25 (stat.)
Semi-Incl. $B \rightarrow X_d \gamma$: Signal Fit

$m_{ES}$

$\Delta E$

projection

background subtracted ('sPlot')
**Semi-Incl. \( B \rightarrow X_d \gamma \): Result**

\[
\sum_{X_d=1}^{7} B(B \rightarrow X_d \gamma) \big|_{1.0 < M(X_d) < 1.8 \text{GeV}} = \left[ 3.1 \pm 0.9(\text{stat.}) \pm 0.7(\text{syst.}) \right] \times 10^{-6}
\]

*(preliminary)*

**to do (in progress): turn into inclusive \( b \rightarrow d \gamma \) BF**

- extent measurement to low \( M(X_d) \) range (for all 7 modes)
- correct for not reconstructed part of the \( X_d \) fragmentation
- extrapolate to full \( M(X_d) \) range

then **use in measurement of** \( |V_{td}/V_{ts}| \)
b → dγ: Summary/Outlook

- exciting times!
- exclusive measurements have been moving from limits to observed signals
- now have precise SM reference from B_s mixing
- first evidence outside rho/omega mass region; proof of principle for semi-inclusive measurement
- keep pushing (and consider additional observables)

\[ R(\rho^0/K^*\gamma) = \frac{\Delta(\rho^0)}{2\Gamma(B^0 \rightarrow \rho^0 \gamma)} \]


B → ρ^0γ TDPCPV

\[ q=+1 \quad q=-1 \]

Events/(2.5 ps)

\[ \Delta t (ps) \]

Raw asymmetry/(2.5 ps)

\[ \Delta t (ps) \]
$$B \rightarrow K^{(*)} \ell^+ \ell^-$$

Rich phenomenology for standard model tests:
- additional scale: $q^2$ (di-lepton invariant mass squared)
- additional degrees of freedom (angular distributions)
- SM BF prediction: $\text{BF} (B \rightarrow K^* \ell^+ \ell^-) \approx 10^{-6}$


$$C_7 \quad (\gamma \text{ penguin}) \quad C_9 \quad (\text{semileptonic vector}) \quad C_{10} \quad (\text{semileptonic axial-vector})$$
$B \rightarrow K(\star) l^+l^-$: $BF$ and $A_{CP}$

$$K^* l^+l^-$$

$$\text{Br}(B \rightarrow Kl^+l^-) = (0.34 \pm 0.07 \pm 0.02) \times 10^{-6}$$

$$\text{Br}(B \rightarrow K^*l^+l^-) = (0.78^{+0.19}_{-0.17} \pm 0.11) \times 10^{-6}$$

$$Kl^+l^-$$

$$A_{CP} \equiv \frac{\Gamma(B \rightarrow K(\star) l^+l^-) - \Gamma(B \rightarrow K^*(\star) l^+l^-)}{\Gamma(B \rightarrow K(\star) l^+l^-) + \Gamma(B \rightarrow K^*(\star) l^+l^-)}$$

$$R_K \equiv \frac{\Gamma(B \rightarrow K\mu^+\mu^-)}{\Gamma(B \rightarrow Ke^+e^-)}$$

$$A_{CP}(B^+ \rightarrow K^+l^+l^-) = -0.07 \pm 0.22 \pm 0.02$$

$$A_{CP}(B \rightarrow K^*l^+l^-) = +0.03 \pm 0.23 \pm 0.03$$

$$R_K = 1.06 \pm 0.48 \pm 0.08 \quad \text{SM: 1.0}$$

$$R_{K^*} = 0.91 \pm 0.45 \pm 0.06 \quad \text{SM: 0.75}$$
$B \rightarrow K^{(*)} \ell^+\ell^-$: BF and $A_{CP}$

$K^* \ell^+\ell^-$

$\text{Br}(B \rightarrow K\ell^+\ell^-) = (0.34 \pm 0.07 \pm 0.02) \times 10^{-6}$

$\text{Br}(B \rightarrow K^*\ell^+\ell^-) = (0.78^{+0.19}_{-0.17} \pm 0.11) \times 10^{-6}$

$A_{CP} (B^+ \rightarrow K^+\ell^+\ell^-) = -0.07 \pm 0.22 \pm 0.02$

$A_{CP} (B \rightarrow K^*\ell^+\ell^-) = +0.03 \pm 0.23 \pm 0.03$

$R_K = 1.06 \pm 0.48 \pm 0.08 \quad \text{SM : 1.0}$

$R_{K^*} = 0.91 \pm 0.45 \pm 0.06 \quad \text{SM : 0.75}$

NEED UPDATE!
(IN PROGRESS)
$B \to K^* l^+ l^-$: Angular Analysis

- **$A_{FB}$** – forward-backward asymmetry of the $l^+ l^-$ helicity angle
- **$F_L$** – longitudinal component of polarization

\[ \frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_K} = \frac{3}{2} F_L \cos^2 \theta_K + \frac{3}{4} (1 - F_L)(1 - \cos^2 \theta_K) \]

\[ \frac{1}{\Gamma} \frac{d\Gamma}{d \cos \theta_l} = \frac{3}{4} F_L (1 - \cos^2 \theta_l) + \frac{3}{8} (1 - F_L)(1 + \cos^2 \theta_l) + A_{FB} \cos \theta_l \]

- Vector ($C_7, C_9$) and axialvector ($C_{10}$) contributions interfere
- Relative strength of $V$ and $A$ couplings varies with $q^2$
  → can test the magnitudes and signs of $C_9$ and $C_{10}$. 

Vector ($C_7, C_9$) and axialvector ($C_{10}$) contributions interfere

Relative strength of $V$ and $A$ couplings varies with $q^2$

→ can test the magnitudes and signs of $C_9$ and $C_{10}$. 

Jürgen Kroseberg

DESY Seminar

26./27.2. 2008
$B \rightarrow K^* \ell^+\ell^- : \text{(B)SM} A_{FB}$

$q^2 = q_{\text{min}}^2$

$q^2 = q_{\text{max}}^2$

$C_7^{\text{eff}} = -C_7(\text{SM})$

$C_{10}^{\text{eff}} \rightarrow -C_{10}(\text{SM})$ or $(C_7^{\text{eff}} \rightarrow -C_7(\text{SM}), C_9^{\text{eff}} \rightarrow -C_9(\text{SM}))$

$s_0 = (4.07^{+0.16}_{-0.13}) \text{ GeV}^2$

$s_0$: Ali, Kramer, Zhu, hep-ph/0601034
\[ B \rightarrow K^* \ell^+\ell^- : (B)SM \ F_L \]
**B \rightarrow K^* \ell^+\ell^- : Analysis Overview**

- **New results** [preliminary; to be submitted to PRL]
- based on 384 million BB pairs [previous analysis: 232 million]
- reconstruct $K^* \rightarrow K\pi, K\pi^0, K_S\pi$ plus $e^+e^-, \mu^+\mu^-$ pairs
- tight particle ID for $K, e, \mu$
- $\Delta E +$ Neural Networks to suppress backgrounds
- veto charmonium resonances $B \rightarrow K^* J/\psi, K^* \psi'$ [BF~$10^{-3}$; powerful control sample to validate analysis]
- split data in two regions of the di-lepton mass $q^2<6.25$ GeV$^2$ and $q^2>10.24$ GeV$^2$
- extract $F_L$ and $A_{FB}$ from multi-stage fit (to $m_{ES}$ and helicity angles)
$B \rightarrow K^{(*)} \ell^+\ell^-$: Fits

**low $q^2$**

- $F_L$
  - $\cos(\theta_K)$
  - $\cos(\theta_l)$

**high $q^2$**

- $A_{FB}$
  - $\cos(\theta_K)$
  - $\cos(\theta_l)$
**B → K^{(*)} \ell^+\ell^− : RESULTS**

<table>
<thead>
<tr>
<th>( q^2 )</th>
<th>( F_L )</th>
<th>( A_{FB} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>low</td>
<td>0.35 ± 0.16 ± 0.04</td>
<td>+0.24^{+0.18}_{-0.23} ± 0.06</td>
</tr>
<tr>
<td>high</td>
<td>0.71^{+0.20}_{-0.22} ± 0.05</td>
<td>+0.76^{+0.52}_{-0.32} ± 0.07</td>
</tr>
</tbody>
</table>
B → K* \ell^+\ell^- : Compare with Belle

Belle also see large positive forward-backward asymmetries:

\[ A_{FB} (bkg-sub) \]

PRL 96, 251801(2006) - uses 386M \( B\bar{B} \) pairs

Errors are comparable to BaBar results
**B → K^* l^+l^- : Summary/Outlook**

- all results statistics-limited
- angular analysis starting to probe SM
- future measurement might include more q^2 bins and additional observables
- also update exclusive BF + inclusive measurements
- for B→K^*μμ, can now compare to Tevatron (and LHC-B will join the game at some point)

---

**B → K^* l^+l^-**

<table>
<thead>
<tr>
<th>q^2 &gt; (2m_μ)^2</th>
<th>1 &lt; q^2 &lt; 6 GeV^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belle: PRD 72, 092005 (2005)</td>
<td></td>
</tr>
<tr>
<td>Theory: Gambino et al., PRL 94, 061803 (2005)</td>
<td></td>
</tr>
</tbody>
</table>

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**A_{FB} LHC-B (2 fb^{-1})**
INTERPLAY WITH LHC

e.g.: MSSM constraint

\[ m_i = 1000 \text{ GeV/c}^2 \rightarrow m_i = 500 \text{ GeV/c}^2 \]

LEP Exclusion

b\rightarrow s\gamma (HFAG, winter '06)

courtesy of P. Bechtle

\[ m_h - \text{max, (b)} \]
And There Is Much More...

- exclusive $b \rightarrow s\gamma$
- time-dependent CP violation
  [photon polarization?] 
- exclusive $b \rightarrow d\ell^+\ell^-$
- $B_s$ penguins
  [Belle Y(5S) run]
- [...]
Conclusions

- rich and active field
- window for direct NP observations is closing
- NP constraints will remain important
- BaBar running is ending; sizable part of data still to be analyzed
- will likely need continuation of B program - (Belle), superBxxx, LCH[-B], ?? - to make detailed sense of future discoveries