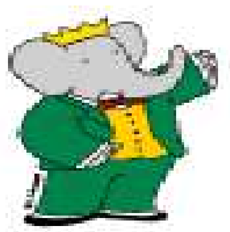
New Results on
Radiative and Dilepton Decays of B Mesons
at *BaBar*

SCIPP Seminar, April 19, 2005



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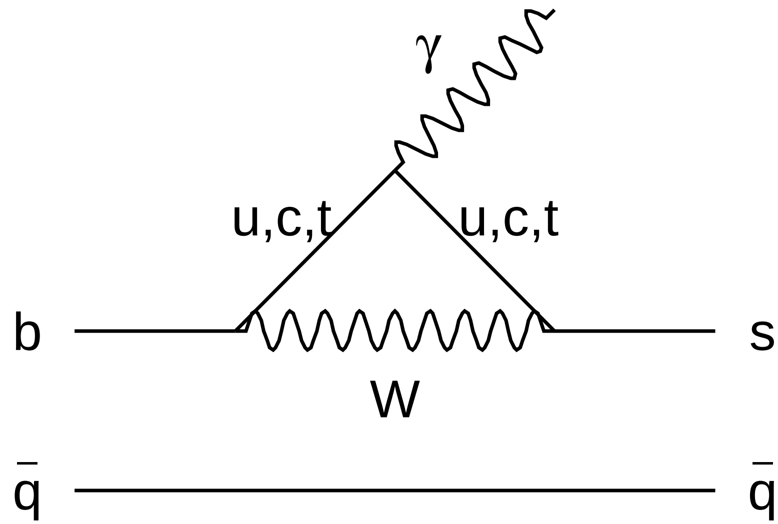
Radiative and Dilepton Decays of B Mesons:

- **do not occur at tree level (unlike dominant B decays),**
- **thus branching fractions ($\mathcal{B}$) tend to be small (rare decays);**
- **leading diagrams in Standard Model (SM) involve loops (heavy quarks, W boson), and**
- **relatively low SM uncertainty for $\mathcal{B}$ and CP asymmetry (A_{CP}), so**
- **good place to look for non-SM physics**
  (new particles can show up virtually in the loops).

B final states with new *BaBar* data:

- **$X_s\gamma$** (two independent measurements; X_s is any strange state)
- **$K^*\gamma$** (time-dependent A_{CP} measurement)
- **$D^{*0}\gamma$** (search)
- **$K^{(*)}\ell^+\ell^-$** (both $\mu^+\mu^-$ and e^+e^- included)

Radiative Penguin Processes



$b \to s\gamma$ in the Standard Model

(plus diagram with radiation from W; $b \to d\gamma$ is similar).

Amplitude is dominated by t quark in loop. Thus

$$\mathcal{B}(B \to X_d\gamma)/\mathcal{B}(B \to X_s\gamma) \approx (|V_{td}|/|V_{ts}|)^2 \approx 0.04 \,.$$

Non-SM contributions might have, *e.g.*, H^- or chargino in loop.

Inclusive $B \to X_s\gamma$ in the Standard Model:

- $\mathcal{B}(B \to X_s\gamma) = (3.57 \pm 0.30) \times 10^{-4}$ $(E_\gamma > 1.6\,\mathrm{GeV})$ to NLO (incl. 2 loops)
  Gambino and Misiak (2001), Buras, Czarnecki, Misiak and Urban (2002).

- Current world average: $(3.52^{+0.30}_{-0.28}) \times 10^{-4}$.
  Heavy Flavor Averaging Group (2004), take with grain of salt.

- Direct *CP* asymmetry is expected to be small:

$$A_{CP}(b \to s\gamma) \equiv \frac{\Gamma(b \to s\gamma) - \Gamma(\overline{b} \to \overline{s}\gamma)}{\Gamma(b \to s\gamma) + \Gamma(\overline{b} \to \overline{s}\gamma)} = 0.0044^{+0.0024}_{-0.0014}\,.$$

  New physics could increase this to as much as ~ 0.10.

- If $b \to s\gamma$ and $b \to d\gamma$ are not distinguished, predicted

$$A_{CP}(b \to s\gamma + b \to d\gamma) \sim 10^{-9}$$

  from U-spin symmetry and CKM unitarity – Hurth, Lunghi, Porod (2005).
  Could be ~ 0.02 in certain new physics models.

Photon Energy Spectrum in Inclusive $B \to X_s\gamma$

- **Not affected by new physics.**
- **Two-body $b \to s\gamma$, smeared by motion of b quark inside B meson, characterized by Heavy Quark Effective Theory (HQET) parameters**:
  - m_b **(b quark mass),**
  - μ_π^2 **(a sort-of Fermi momentum squared).**

  Warning: running quantities –
  meanings differ among theoretical approaches ("schemes").
- **Shape function needed to extract CKM element $|V_{ub}|$ from inclusive $B \to X_u\ell\nu$ measurements.**

Parameterized calculations of spectrum:

- Kagan and Neubert (1999, "**KN**").
- Benson, Bigi and Uraltsev (2004 eprint, "BBU", **Kinetic Scheme**).
- Neubert (2004 eprints, **Shape Function Scheme**).

The $B \rightarrow X_s\gamma$ calculations

- **Smooth spectra, no resonances, *i.e.*, no $K^*(892)$**
- **Newer theories predict truncated moments and partial branching fractions above various minimum E_γ cuts, as function of HQET parameters.**
- **Lowest moments more robust than shapes $\Longrightarrow$ measure the moments.**

But experiments still need predicted spectra

- **to estimate experimental efficiency**
- **to optimize selection cuts**
- **to fit the measured spectrum**

Photon energy in B rest frame is related to the mass of X_s:

$$\boxed{E_\gamma = \frac{m_B^2 - m_{X_s}^2}{2m_B}\ .}$$

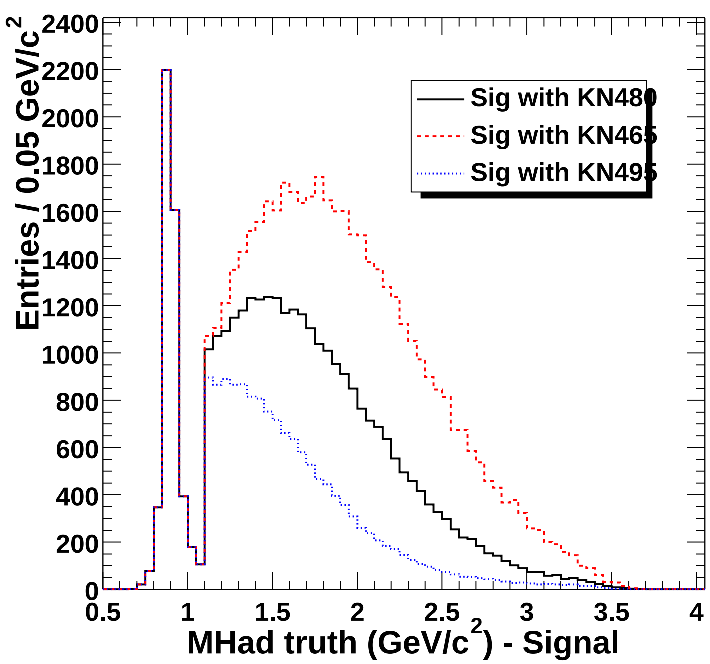
Models: we replace m_{X_s} spectrum below some cutoff by $K^*(892)$ Breit-Wigner of same area. Above cutoff, X_s is fragmented via JETSET.

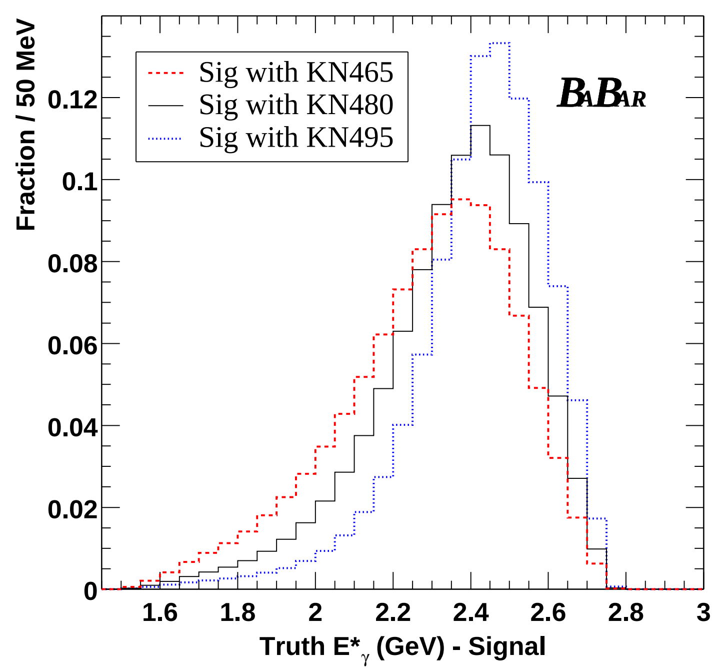
Notation: "KN465" is this model based on KN with $m_b = 4.65\,GeV/c^2$.

Photon Energy Spectrum in Inclusive B → $X_s\gamma$

Left: KN spectrum examples (using KN's recommended μ_π^2 for each m_b) with area below 1.1 GeV/c^2 replaced by K^*. ("MHad" here is used for m_{X_s}.)

Right: Resulting photon energy spectra in $\Upsilon(4S)$ frame.





Normalized to same $\mathcal{B}(B \to K^*\gamma)$

Normalized to unit area

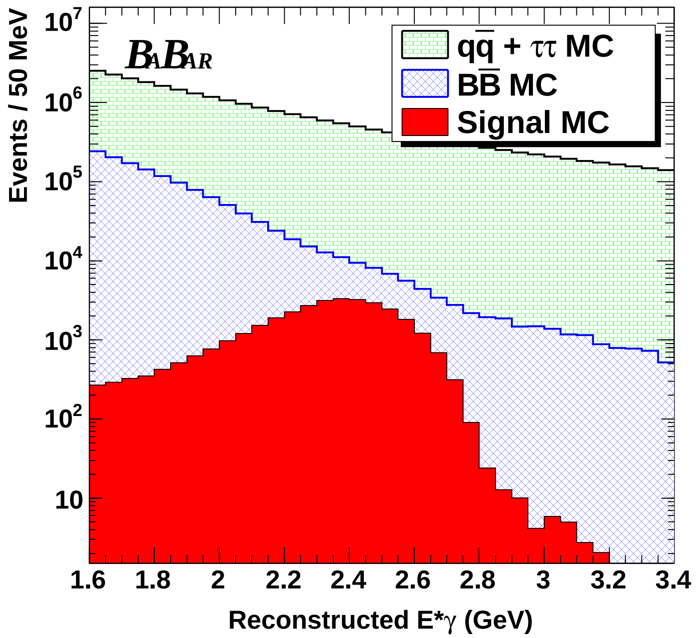
Backgrounds to High-Energy Photon from $B \to X_s\gamma$

Other $B\bar{B}$ States

- Photon from meson decay, mostly π^0 or η.
- Neutral hadron fakes γ.
- Electron from $B \to Xe\nu$ fakes γ.

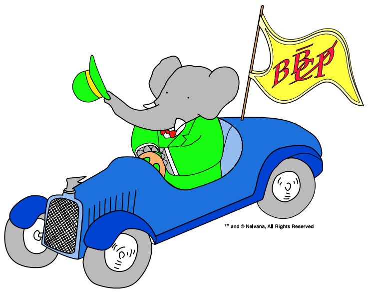
"Continuum" (e.g., other $q\bar{q}$):

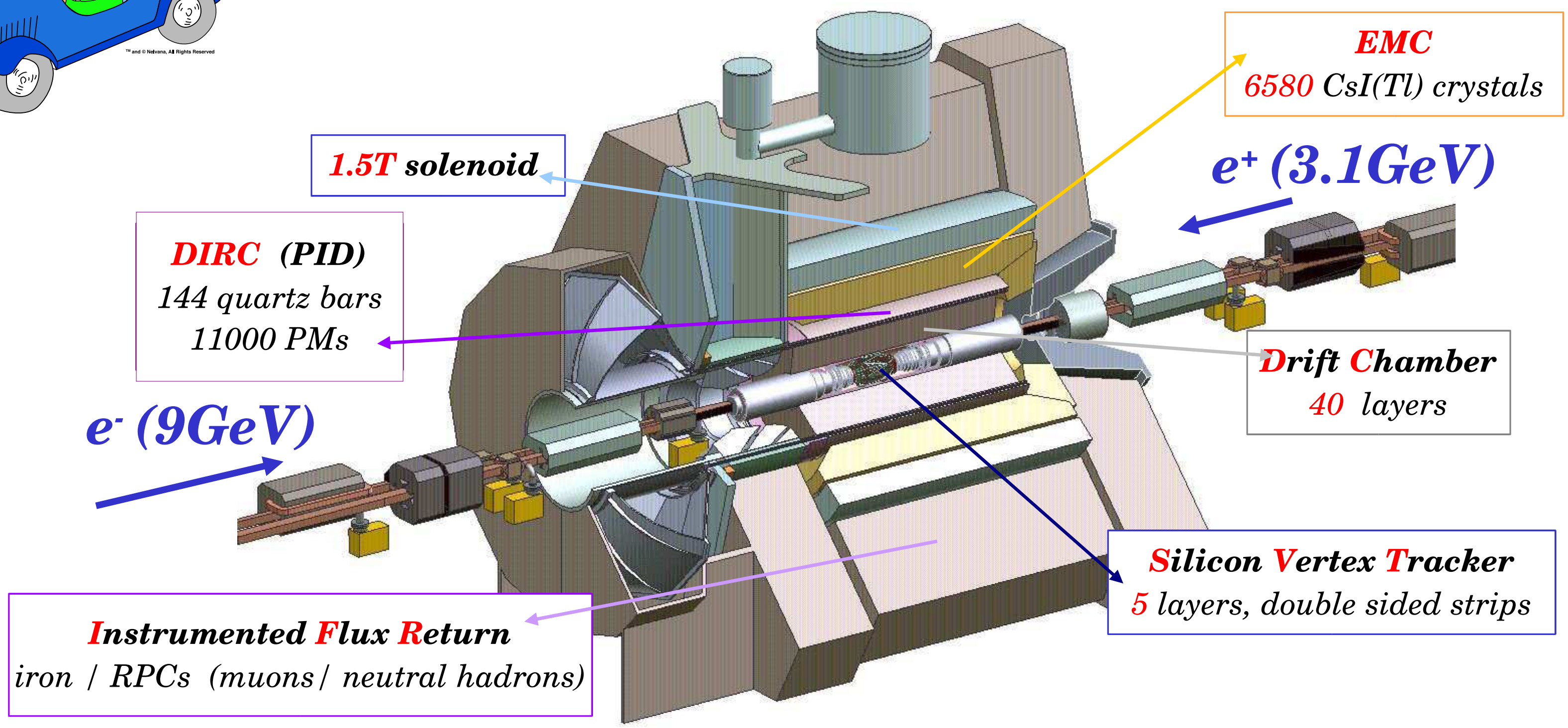
- Photon from meson decay, mostly π^0 or η.
- Neutral hadron fakes γ.
- Initial state radiation.



From simulation, illustrated for photon energy in $\Upsilon(4S)$ frame.

The *BABAR* Detector





Two Independent *BaBar* Measurements of $\mathrm{B} \to \mathrm{X_s}\gamma$:

Both measurements (based on ≈ 88.5 million $B\overline{B}$ events):
– photon is vetoed if a parent $\pi^0(\eta)$ candidate is found.
– (differing) topological cuts to reduce the jetlike continuum background.

Sum of exclusive final states

- **Reconstruct $\mathrm{X_s}\gamma$ in 38 exclusive modes**
- **Kinematic constraints to separate signal from most remaining backgrounds**
- **Efficiency and fraction of unmeasured modes sensitive to $\mathrm{X_s}$ fragmentation**
- **Photon energy spectrum (from $\mathrm{m_{X_s}}$) is directly in B rest frame**

Fully-inclusive, with lepton tagging

- **Detect photon, do not reconstruct X_s state.**
- **High-momentum lepton "tag" to greatly reduce continuum background**
- **Then subtract continuum using off-resonance data ($\approx 40\,\mathrm{MeV}$ below $\Upsilon(4\mathrm{S})$)**
- **Little sensitivity to fragmentation details**
- **Photon energy spectrum is in $\Upsilon(4\mathrm{S})$ cm frame.**

BaBar B $\rightarrow$ $X_s\gamma$ from a Sum of Exclusive States

38 X_s States in all:

- $K^{\pm}$ or K_S^0 plus one to four pions, including up to two π^0, or
- $K^{\pm}$ or K_S^0 plus one η, plus zero to two pions (one can be π^0), or
- Three kaons (one can be K_S^0) plus zero or one pion.

Standard *B*-Factory quantities for constraining exclusive states:

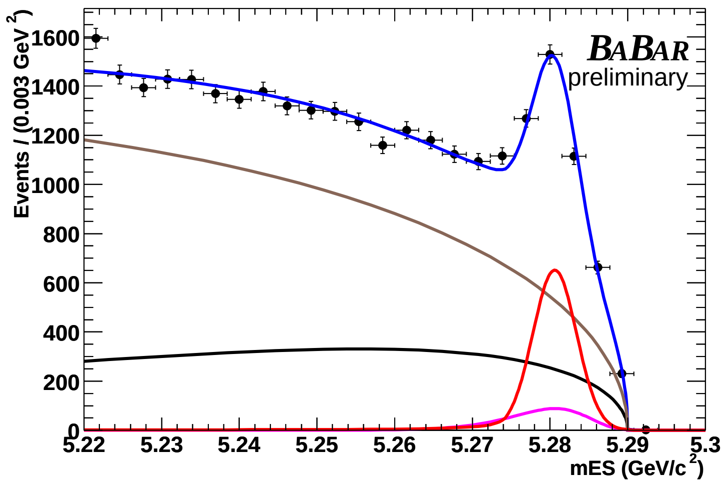
$$\Delta E \equiv E_B^* - \sqrt{s}/2 \quad \text{and} \quad m_{ES} \equiv \sqrt{(\sqrt{s}/2)^2 - {p_B^*}^2}$$

where E_B^* and p_B^* are B energy and momentum in $\Upsilon(4S)$ (*) frame.

- **Select best *B* candidate from minimum $|\Delta E|$, max. cut of 0.07 to 0.10 GeV.**
- **Fit m_{ES} spectrum to sum of signal, continuum background and $B\overline{B}$ plus crossfeed background, in each 100-MeV bin of m_{X_s}.**
- **Similar fit in full m_{X_s} range, for partial branching fraction.**

BaBar B → $X_s\gamma$ from a Sum of Exclusive States

Fit to Data for full m_{X_s} range (0.6 to 2.8 GeV)



Signal: yield floated, "Crystal Ball" shape is fit to MC simulation.

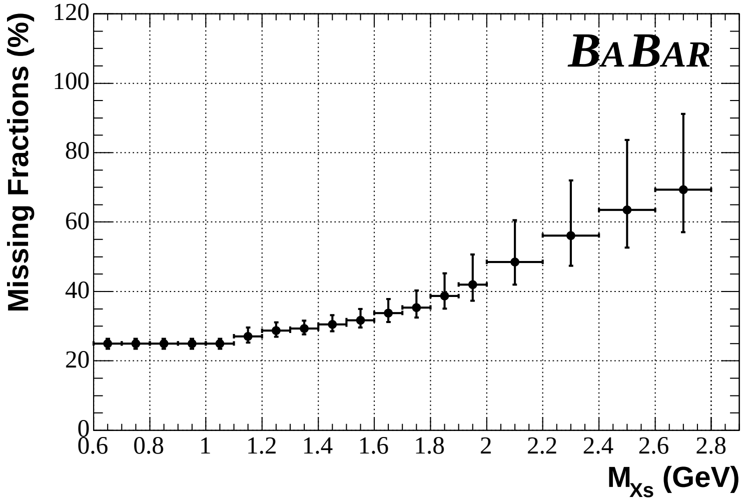
Continuum: from MC, with single-parameter ARGUS shape.

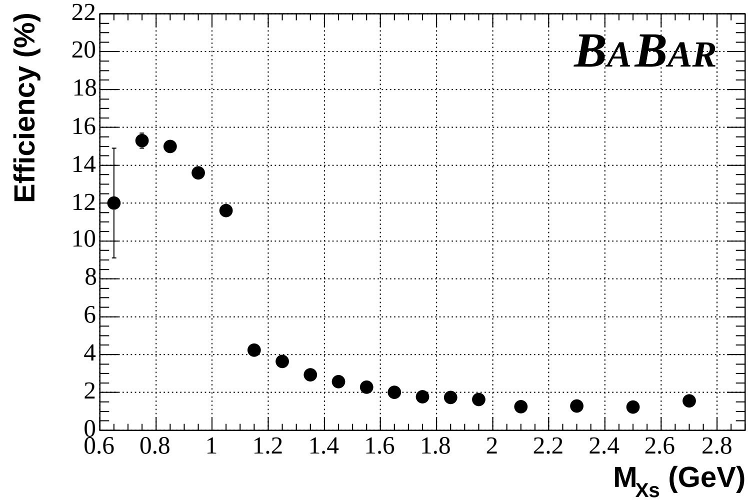
Peaking $B\overline{B}$ plus crossfeed, from MC ("Novosibirsk" shape).

Non-peaking $B\overline{B}$ plus crossfeed, ARGUS parameter floated.

BaBar $B \to X_s\gamma$ from a Sum of Exclusive States

Fragmentation: multiplicity increases with m_{X_s}. Measured mix of observed modes is used to correct fragmentation model and to estimate uncertainties on fraction of missing states.





Missing States

Dominant syst. uncertainty at > 2.2 GeV.
Note: K_L^0 is $\sim 25\%$ of all states.

Efficiency, not incl. missing states

Efficiency highest for low-multiplicity, hence for K^* region (mult. always 2).

BABAR $\mathrm{B} \to \mathrm{X_s}\gamma$ from a Sum of Exclusive States

Systematic Uncertainties for One-Bin Analysis ($0.6 < m_{X_s} < 2.8$ GeV):

Systematic	Uncertainty
Particle Detection	6.1%
Fitting	+9.5% -2.9%
Peaking Background	1.6%
Fragmentation	5.9%
Missing States	+13.8% -7.6%
Miscellaneous	2.0%
Total Experimental	+19.0% -12.0%
Signal-model-dep.	+2.1% -2.4%

To get the branching fraction *vs.* photon energy E_γ:

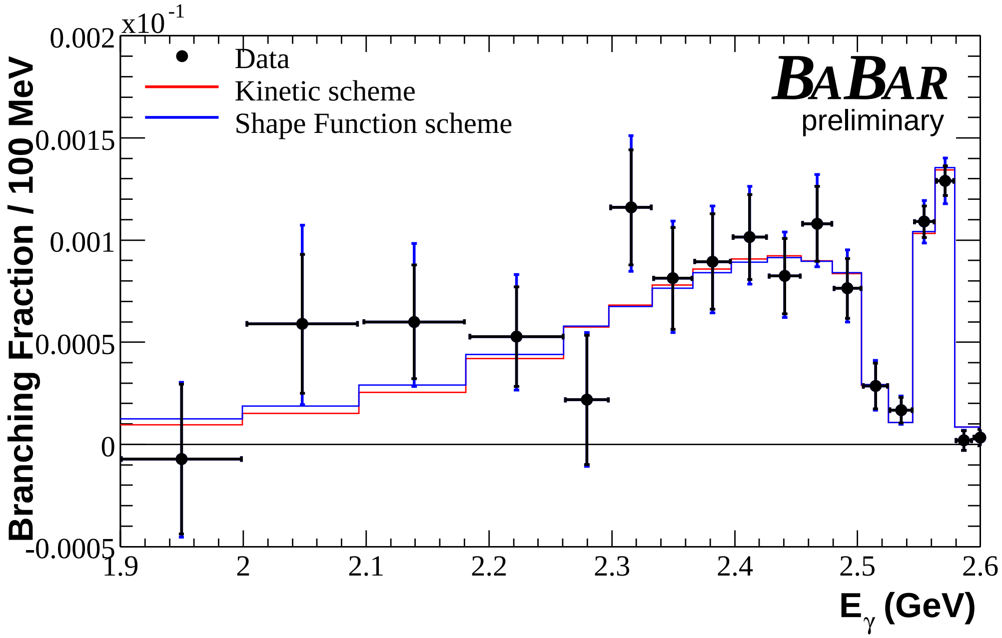
1) Correct fitted yield for efficiency and missing fractions.

2) Normalize to total $B\overline{B}$ pairs (88.9 million).

3) Convert 100-MeV m_{X_s} bin limits to E_γ bins.

BABAR $\mathrm{B} \to \mathrm{X_s}\gamma$ from a Sum of Exclusive States

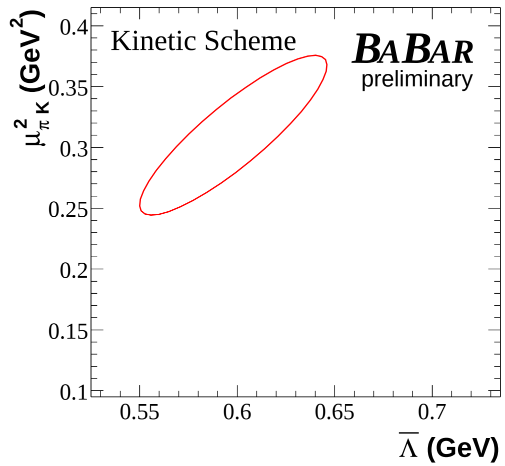
Photon Energy Spectrum

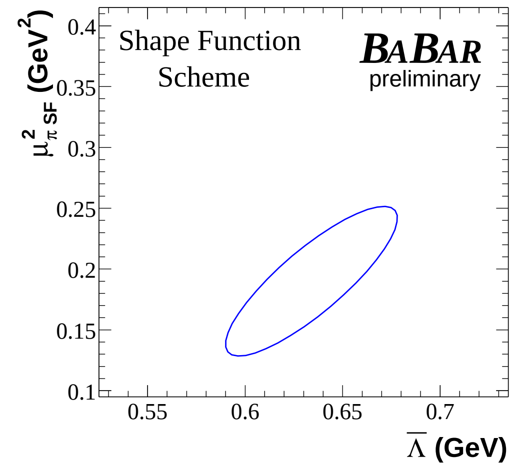


Fits are to BBU (Kinetic Scheme) and **Neubert (Shape Function Scheme,) with $\bar{\Lambda} = m_B - m_b$, μ_π^2, and the K^* transition point free.**

BABAR B $\rightarrow X_s\gamma$ from a Sum of Exclusive States

One-sigma
Error Ellipses





Preliminary Results for HQET Parameters and Partial Branching Fraction

Scheme	$\bar{\Lambda}$(GeV)	μ_π^2(GeV^2)	PBF (10^{-4}), $E_\gamma > 1.9$ GeV
Kinetic	$0.59\,^{+0.05}_{-0.04}$	$0.30\,^{+0.07}_{-0.05}$	$3.27 \pm 0.18\,^{+0.62}_{-0.39}\,^{+0.12}_{-0.12}$
Shape Func.	$0.63\,^{+0.04}_{-0.04}$	$0.19\,^{+0.06}_{-0.05}$	$3.31 \pm 0.18\,^{+0.63}_{-0.40}\,^{+0.02}_{-0.03}$

Errors on PBF are statistical, systematic and from variation of HQET parameters. Systematics dominate.

Prelim. Results, *BaBar* $B \rightarrow X_s\gamma$ from a Sum of Exclusive States

Extrapolated Branching Fraction (to $E_\gamma > 1.6\,\mathrm{GeV}$)

$$\boxed{\mathcal{B}(\mathbf{B} \rightarrow \mathbf{X_s}\gamma) = (\mathbf{3.42} \pm \mathbf{0.19}\,{}^{+0.64}_{-0.41}\,{}^{+0.07}_{-0.08}) \times \mathbf{10^{-4}} \quad \text{(ave. from two schemes)}}$$

Errors are statistical, systematic and from variation of HQET parameters.

Truncated 1st, 2nd and 3rd Moments – plots later *vs.* cut. For $E_\gamma > 1.999\,\mathrm{GeV}$:

$$\boxed{\langle \mathbf{E}_\gamma \rangle = \mathbf{2.314} \pm \mathbf{0.025}^{+0.027}_{-0.014}\,\mathbf{GeV} \quad \langle (\mathbf{E}_\gamma - \langle \mathbf{E}_\gamma \rangle)^2 \rangle = \mathbf{0.0273} \pm \mathbf{0.0039}\,{}^{+0.0037}_{-0.0022}\,\mathbf{GeV^2}}$$

Isospin Asymmetry:

$$\boxed{\boldsymbol{\Delta}_{0+} \equiv \frac{\Gamma(\mathbf{B^0}) - \Gamma(\mathbf{B^\pm})}{\Gamma(\mathbf{B^0}) + \Gamma(\mathbf{B^\pm})} = -\mathbf{0.006} \pm \mathbf{0.058}\,{}^{+0.009}_{-0.008} \pm \mathbf{0.024}\,.}$$

Errors are statistical, systematic, and from the B production ratio.

Direct *CP* Asymmetry for sum of 12 final states (published)

$$\boxed{\mathbf{A_{CP}} = \mathbf{0.025} \pm \mathbf{0.050}\,(\mathbf{stat.}) \pm \mathbf{0.015}\,(\mathbf{syst.})}$$

BaBar Fully-Inclusive Measurement of $B \to X_s\gamma$

Background reduction is the primary challenge.

Continuum background

- **Must be subtracted using off-resonance data.**
- **Only 10.5% of total luminosity was taken off-resonance, *i.e.*, low statistics.**
- **Strong cuts needed to suppress it *before* subtraction: event topology, and especially high-momentum lepton tag from "other B".**
  Net continuum/signal reduction $\sim 10^{-3}$.

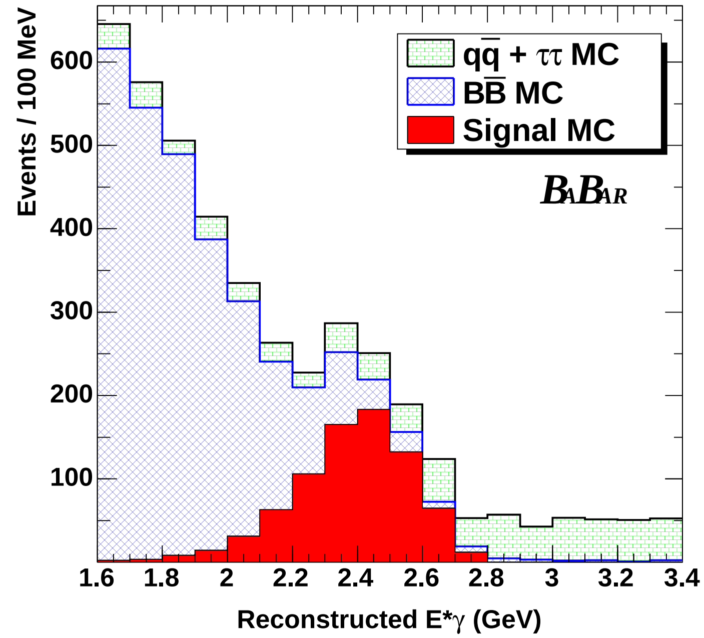
$B\bar{B}$ background

- **Cuts (photon quality, $\pi^0(\eta)$ veto, etc.) reduce it 8 times more than signal.**
- **Remaining $B\bar{B}$ background estimated by simulation. For $2.0 < E^*_\gamma < 2.7$ GeV, 81% is π^0 or η decay, 8% hadrons (mostly $\bar{n}$), 4% electrons.**
- **Nearly all components checked against data and corrected, *e.g.*, $\pi^0(\eta)$ inclusive spectra measured using signal selection criteria (except $\pi^0(\eta)$ veto).**

BABAR Fully-Inclusive Measurement of $B \to X_s\gamma$

Photon Spectra from MC Simulation, after Cuts – note the Linear Scale!

- Reconstructed E^*_γ in cm frame.
- "Step" at 2.3 GeV is due to relaxed $\pi^0(\eta)$ veto cut above that energy.
- "Signal" is KN480 model, including K^*.
- Off-resonance yield for 2.0 to 2.7 GeV is $\approx 1.9\times$ MC expectation, due mostly to un-modelled processes, *e.g.*, QED, 2-photon.
- Continuum dominates statistical precision.



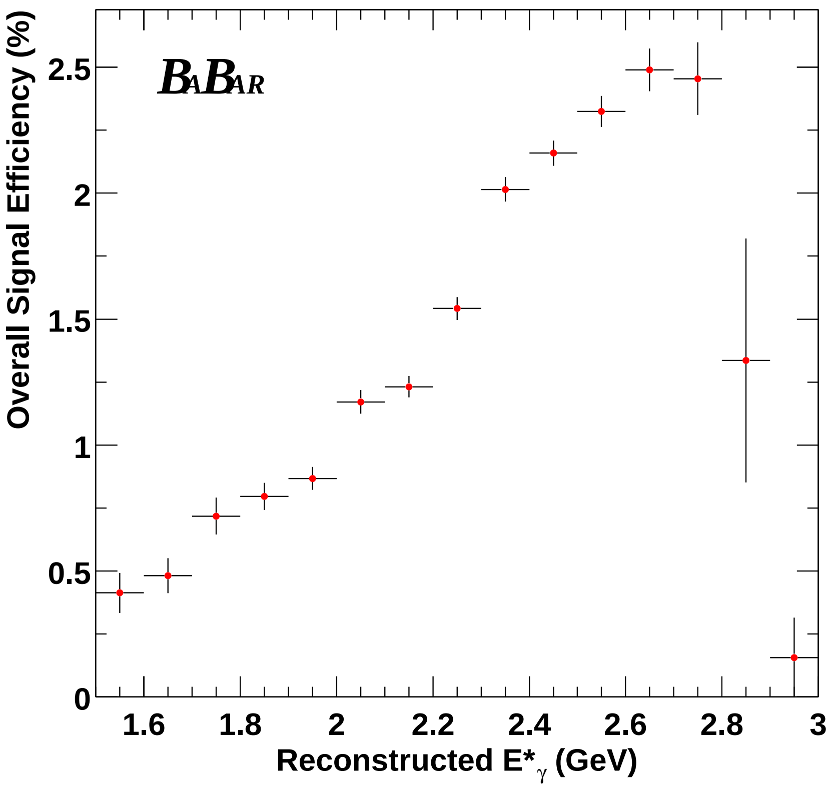
Normalized to on-resonance data luminosity.

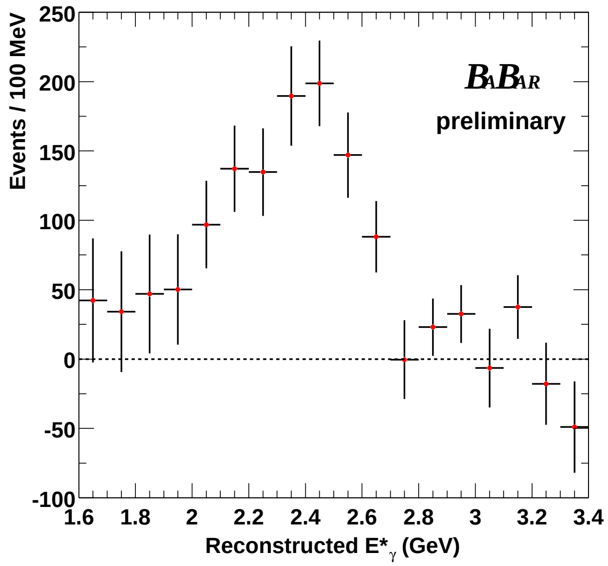
Regions below 1.9 GeV and above 2.9 GeV are "Control Regions" for checking $B\overline{B}$ and continuum subtraction, respectively.

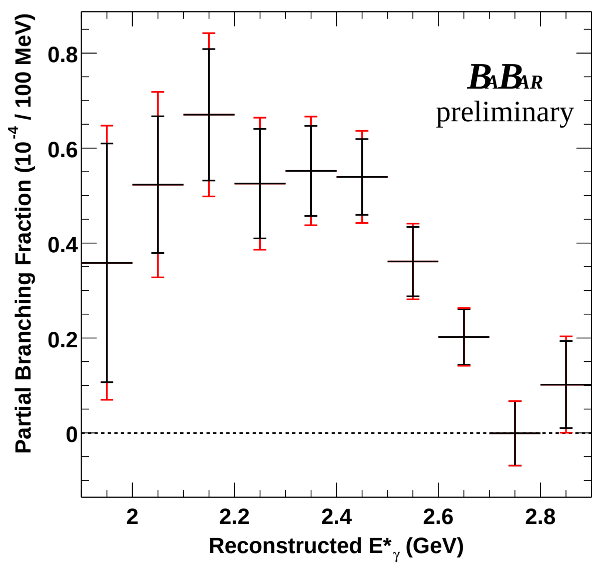
BABAR Fully-Inclusive Measurement of B → $X_s\gamma$

Overall Signal Efficiency

- **Selection cuts optimized for statistical precision in $2.0 < E^*_\gamma < 2.7$ GeV.**
- **Strong energy-dependence to efficiency, due primarily to topological cuts.**
- **But no significant dependence on fragmentation model.**







Signal = On-res. data minus scaled Off-res. data minus corrected $B\bar{B}$

Errors: stat. $\oplus$ $B\bar{B}$ systematics

1.6 to 1.9 GeV Control Region:
$123 \pm 64\,(\text{stat.}) \pm 54\,(\text{syst.})$ events;
KN465 (KN480) model $\Longrightarrow$ 39 (17).

Branching Frac. *vs.* E^*_γ (c.m.)

$$= \frac{\text{Signal Yield}}{2N_{B\bar{B}} * \text{Efficiency}} .$$

Inner error bars: stat. only;
Outer: stat. $\oplus$ all syst. $\oplus$ conservative model-dependence.

Syst. correlated between bins.

BABAR Fully-Inclusive Measurement of $B \to X_s\gamma$

Systematic Uncertainties on Branching Frac. for $2.0 < E^*_\gamma < 2.7$ GeV.

Systematic	Uncertainty
Photon Detection and Quality	3.3%
Topological Cuts	3.0%
Fragmentation-Dependence	1.4%
Lepton ID	2.2%
Tag Efficiency	3.0%
$B\overline{B}$ Background	5.7%
Miscellaneous	1.7%
Total Experimental	8.4%
Signal-model-dependence	4.8%

Model-Dependence Uncertainty

- For wide range of KN and BBU model parameters, a linear relation holds between predicted efficiency and $\langle E^*_\gamma \rangle$ over 2.0 to 2.7 GeV.
- KN460 matched measured mean, hence used for efficiencies. (This is *not* necessarily a best fit – fits have not yet been done.)
- Uncertainty on efficiency was translated from measured $\langle E^*_\gamma \rangle$ uncertainty.

Preliminary Results for *BaBar* Fully-Inclusive $B \to X_s\gamma$

Truncated First Moments in B Rest Frame

- **Compute $\langle E^*_\gamma \rangle$ above, *e.g.*, 2.0 GeV.**
- **To obtain $\langle E_\gamma \rangle$ above 2.0 GeV in B rest frame, add small correction Δ for effects of calorimeter resolution, Lorentz boost, and cut on E^*_γ *vs.* true E_γ.**
- **A wide range of KN and BBU models was used to estimate Δ and its model-dependence.**
- **Measured for minimum cuts of 1.9, 2.0, 2.1 and 2.2 GeV (see plots).**

Example $\pm$ stat. $\pm$ syst. $\pm$ model-dependence (all numbers in GeV):

Cut	$\langle E^*_\gamma \rangle$ (with cut on E^*_γ)	Δ	$\langle E_\gamma \rangle$ (with cut on E_γ)
2.0	$2.304 \pm 0.016 \pm 0.010 \pm 0.005$	0.012 ± 0.007	$2.316 \pm 0.016 \pm 0.010 \pm 0.012$

Higher moments not yet available from this analysis.

Comparisons

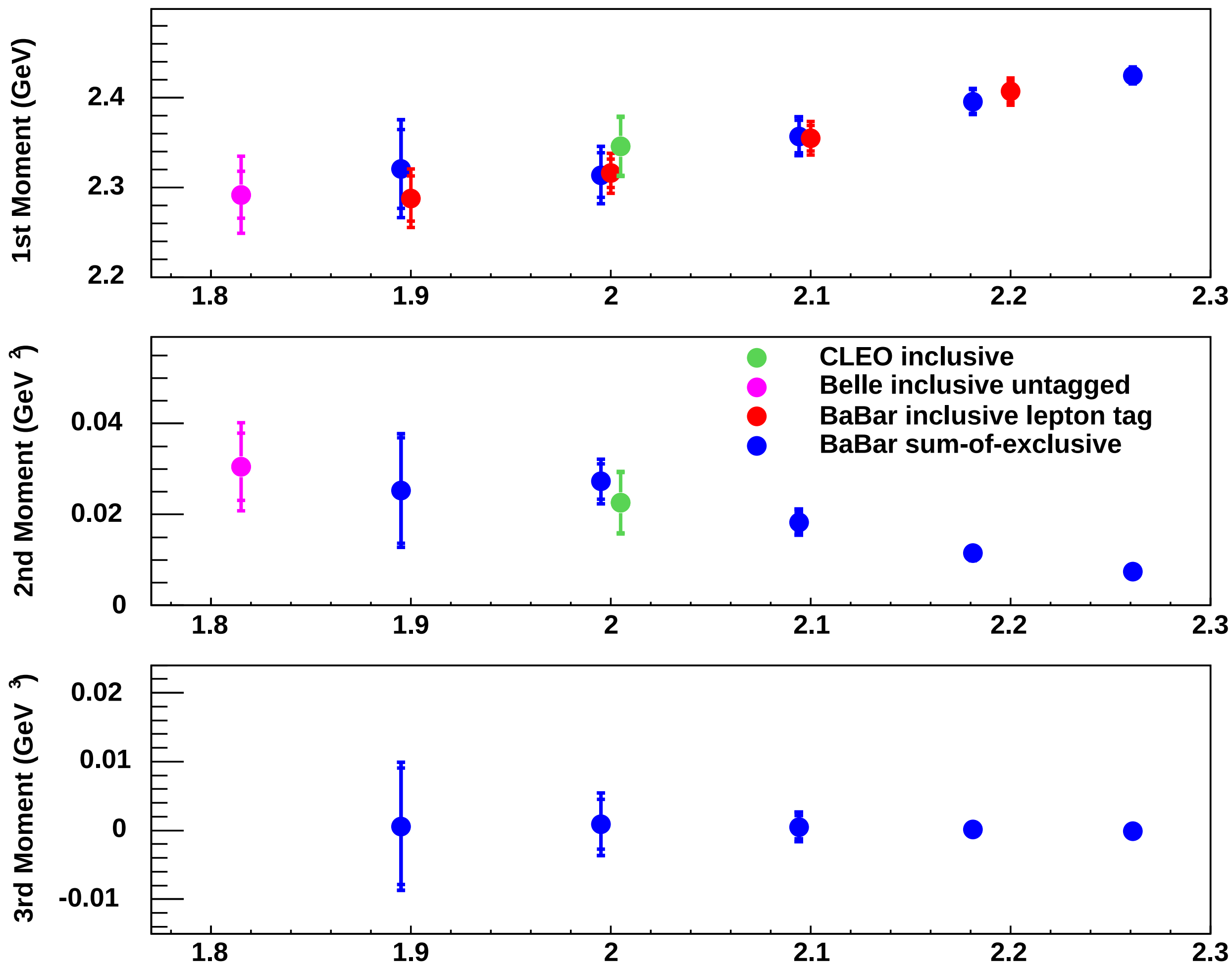
Truncated Moments in $B \to X_s\gamma$ *vs.* minimum E_γ in B rest frame

1st $\equiv \langle \mathbf{E} \rangle$

2nd $\equiv \langle (\mathbf{E} - \langle \mathbf{E} \rangle)^2 \rangle$

3rd $\equiv \langle (\mathbf{E} - \langle \mathbf{E} \rangle)^3 \rangle$

***BaBar* data preliminary**



Preliminary Results for *BABAR* Fully-Inclusive $B \to X_s\gamma$

Partial Branching Fractions in the B Rest Frame

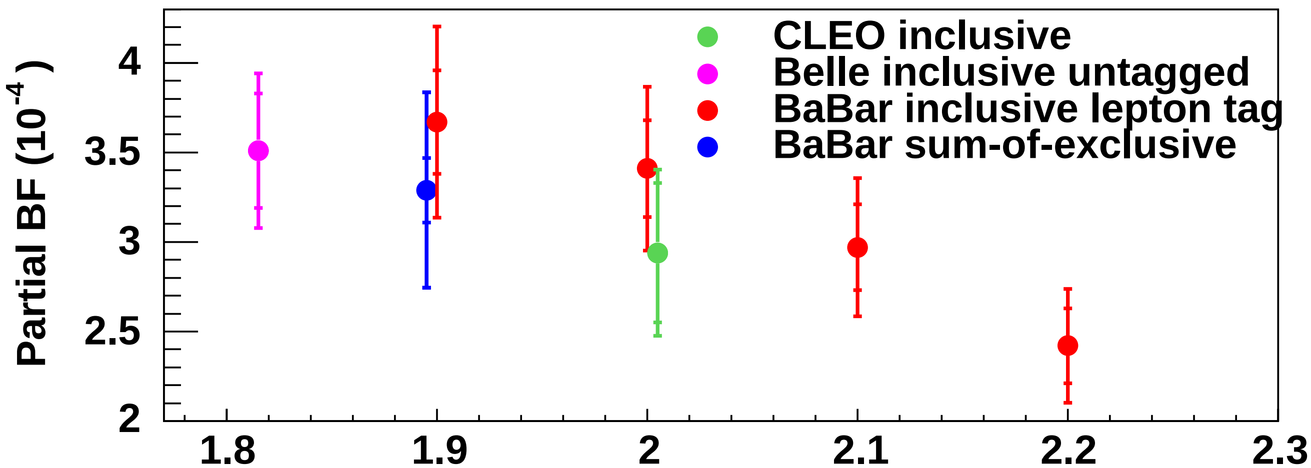
- **Obtain Partial Branching Fraction (PBF) for E^*_γ above, *e.g.*, 2.0 GeV.**
- **Apply correction factor of 1.07 ± 0.02 (model-dependence uncertainty) to convert to PBF for $E_\gamma > 2.0$ GeV in B rest frame.**
- **Correction is 1.13 ± 0.03 for a 2.2 GeV cut, 1.05 for 1.9 GeV cut.**
- **An additional factor of 0.96 ± 0.016 is applied to remove $B \to X_d\gamma$.**

Partial Branching Fractions ± stat. ± syst. ± model-dependence:

Energy range (GeV)	Corrected PBF ($\times 10^{-4}$) for true E_γ range, B frame
1.9 to 2.7	$3.67 \pm 0.29 \pm 0.34 \pm 0.29$
2.0 to 2.7	$3.41 \pm 0.27 \pm 0.29 \pm 0.23$
2.1 to 2.7	$2.97 \pm 0.24 \pm 0.25 \pm 0.17$
2.2 to 2.7	$2.42 \pm 0.21 \pm 0.20 \pm 0.13$

Comparisons of Measured Partial Branching Fractions

- $\mathcal{B}(\mathrm{B} \to \mathrm{X_s}\gamma)$ *vs.* **Minimum Cut on E_γ in the B Rest Frame**
- ***BaBar*** **data are preliminary**



Preliminary Results for *BABAR* Fully-Inclusive $B \to X\gamma$

CP Asymmetry

Positively (negatively) charged lepton from non-signal B tags the signal as containing a $b(\overline{b})$ quark.

$$A_{CP} = \frac{N^+ - N^-}{N^+ + N^-} \frac{1}{1-2\omega}$$

where mistag rate $\omega = (11.9 \pm 0.4)\%$, of which 9.3% is $B\overline{B}$ mixing.

- **The A_{CP} measurement is done (optimized) for $2.2 < E^*_\gamma < 2.7\,\text{GeV}$.**
- **Additive bias correction of -0.005 ± 0.013 is applied for detector and background charge asymmetry, measured with control samples.**
- **Result:**

$$A_{CP}(b \to s\gamma + b \to d\gamma) = -0.110 \pm 0.115\,(\text{stat.}) \pm 0.017\,(\text{syst.})\ .$$

Time-Dependent CP-violating Asymmetry in $B^0 \to K^{*0}\gamma$

- **Measure time-dependent CP asymmetry via interference with $B\overline{B}$ mixing.**
- **If both $B^0, \overline{B}^0$ can decay to CP eigenstate f, difference in proper decay times of signal B and other (tag) B has distribution**

$$\mathcal{P}_{\pm}(\Delta t) = \frac{e^{-|\Delta t|/\tau}}{4\tau} \times \left[1 \pm S_f \sin(\Delta m_d \Delta t) \mp C_f \cos(\Delta m_d \Delta t) \right] ,$$

  where upper (lower) sign is for tagging B decaying as $B^0(\overline{B}^0)$, τ is B lifetime, and Δm_d is mixing frequency.

- **C_f term survives integration over all Δt – corresponds to "direct" CP violation ($A_{CP} \approx 0.66 C_f$), also observable in CP-conjugate decay modes.**
- **S_f term has information accessible only via time-dependence.**
  For tree processes in SM, S_f can be large ($\sin 2\beta \approx 0.73$ for $B^0 \to J/\psi K^0_S$), C_f very small (0 for $B^0 \to J/\psi K^0_S$).
- **To date, CP-violation at tree-level is consistent with arising from the SM CKM-matrix phase.**

BABAR Time-Dependent CP Asymmetry in $B^0 \to K^{*0}\gamma$

- **New degree of sensitivity to non-SM physics in radiative penguin process.**
- **First mode investigated: $B^0 \to K^{*0}\gamma\ (K^{*0} \to K^0_S\pi^0)$.**
  (*BABAR* pub. based on 119 million $\Upsilon(4S) \to B\overline{B}$ decays)
- **In SM, photon polarization from $b \to s\gamma$ ($\overline{b} \to \overline{s}\gamma$) is mostly left-handed (right-handed), suppressing interference**

$$\Longrightarrow S_{K^{*0}\gamma} \approx -2m_s/m_b \sin 2\beta \approx -0.04$$

- **Direct CP-violating asymmetry in non-CP-eigenstate modes of $B \to K^*\gamma$:**
  $\mathbf{A_{CP} = -0.01 \pm 0.07}$ (PDG, based on CLEO and *BABAR*).

Updated *BABAR* measurement for $B^0 \to K^{*0}\gamma\ (K^{*0} \to K^0_S\pi^0)$

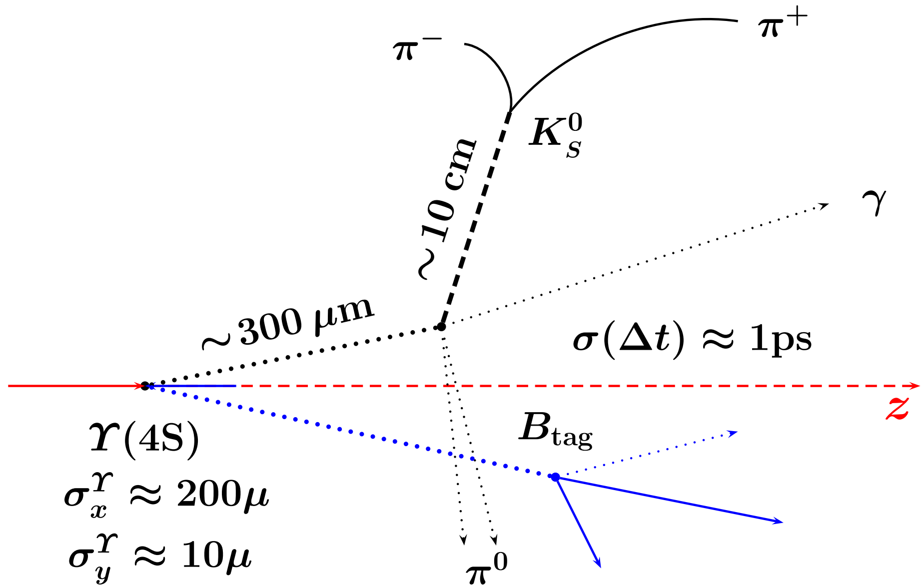
- 232 million $\Upsilon(4S) \to B\overline{B}$ decays.
- Signal events are selected using m_{ES}, ΔE, and background-suppressing topological cuts.
- Remaining tracks in the event are assigned to the other B, and used to determine its decay vertex position and tag "flavor".

BABAR Time-Dependent CP Asymmetry in $B^0 \rightarrow K^{*0}\gamma$

Vertexing (Lab Frame)

Δt and its uncertainty mainly depend on B vertex positions in z (beamline) direction.

Vertex fit constrains $\Upsilon(4S)$ vertex to run-by-run average e^+e^- interaction point.

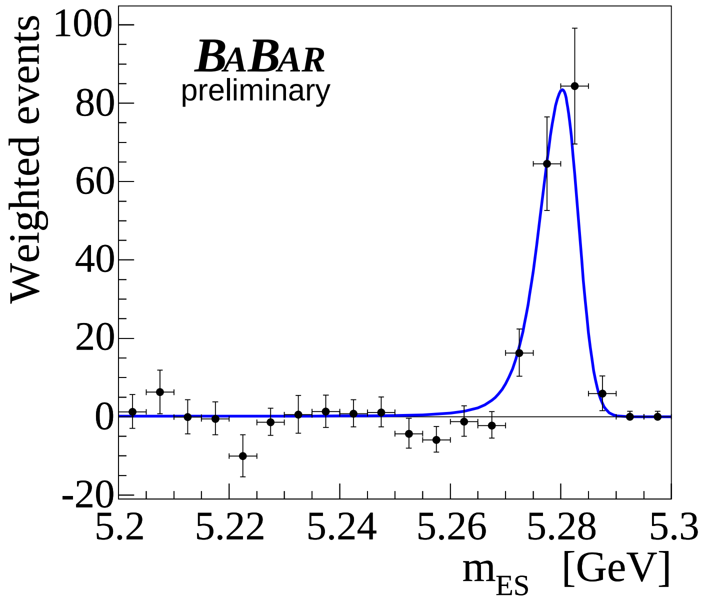


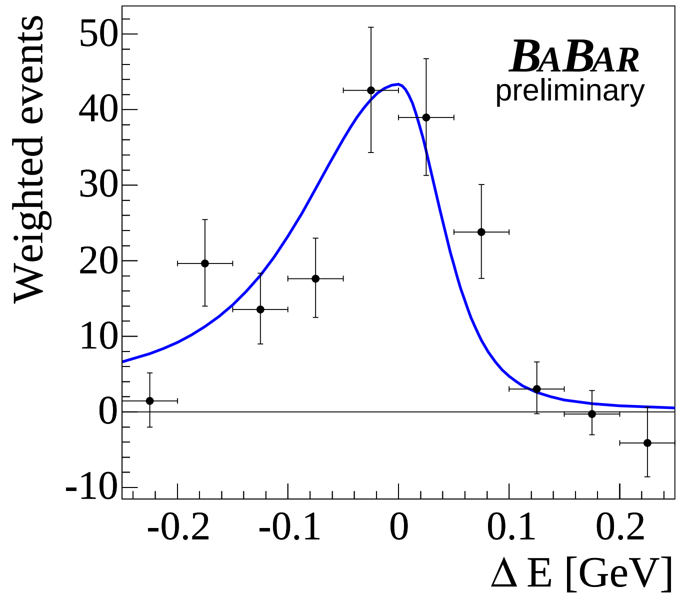
- $\sigma(\Delta t) \approx 1$ ps, **compare to oscillation period** $2\pi/\Delta m_d \approx 12.6$ ps.
- **Measured** Δt, m_{ES}, ΔE, m_{K^*}, **flavor tag, etc. are inputs to unbinned maximum-likelihood fit.**
- **Fit uses separate one-dimensional probability distribution functions (PDFs) for signal,** $B\overline{B}$ **background, continuum.**

BABAR Time-Dependent CP Asymmetry in $B^0 \to K^{*0}\gamma$

Results of Maximum Likelihood Fit (Preliminary)

To visualize $K^*\gamma$ ($K^{*0} \to K^0_S\pi^0$) **signal, event-weighting technique** (Pivk and Le Diberder, arXiv:physics/0402083) **presents background-subtracted data:**





Signal (points) and signal PDF (curves). Note photon-resolution tail on ΔE.

BABAR Time-Dependent CP Asymmetry in $B^0 \to K^{*0}\gamma$

Results of Maximum Likelihood Fit (Preliminary)

157 ± 16 signal events found, with

$$S_{K^{*0}\gamma} = -0.21 \pm 0.40 \pm 0.05 \quad C_{K^{*0}\gamma} = -0.40 \pm 0.23 \pm 0.04 \ \text{(preliminary)}$$

errors are $\pm$ statistical $\pm$ systematic.

- **Largest systematic uncertainty is from possible CP asymmetry in $B\bar{B}$ background, 0.04 (0.03) on $S_{K^{*0}\gamma}$ ($C_{K^{*0}\gamma}$).**
- **Smaller uncertainties for vertexing and detector alignment.**

Results of this statistics-limited measurement are consistent with the SM expectation of small *CP*-violating asymmetry.

Same technique for $B^0 \to K_S^0\pi^0\gamma$ with $1.1 < m_{K_S^0\pi^0} < 1.8\,\text{GeV}$:

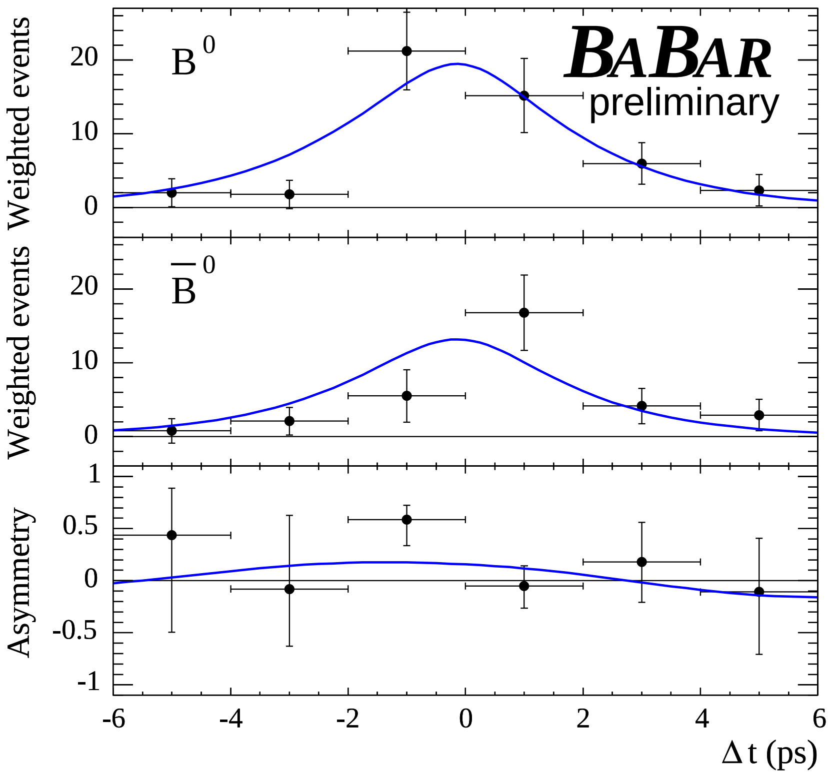
59 ± 13 signal events and 130 ± 40 $B\bar{B}$ background events, with

$$S_{K_S^0\pi^0\gamma} = -0.9 \pm 1.0 \pm 0.2 \quad C_{K_S^0\pi^0\gamma} = -1.0 \pm 0.5 \pm 0.3 \ \text{(preliminary)}$$

BABAR Time-Dependent CP Asymmetry in $B^0 \to K^{*0}\gamma$

"Background-subtracted" Δt distributions for $B^0 \to K^{*0}\gamma$ ($K^{*0} \to K^0_S \pi^0$).

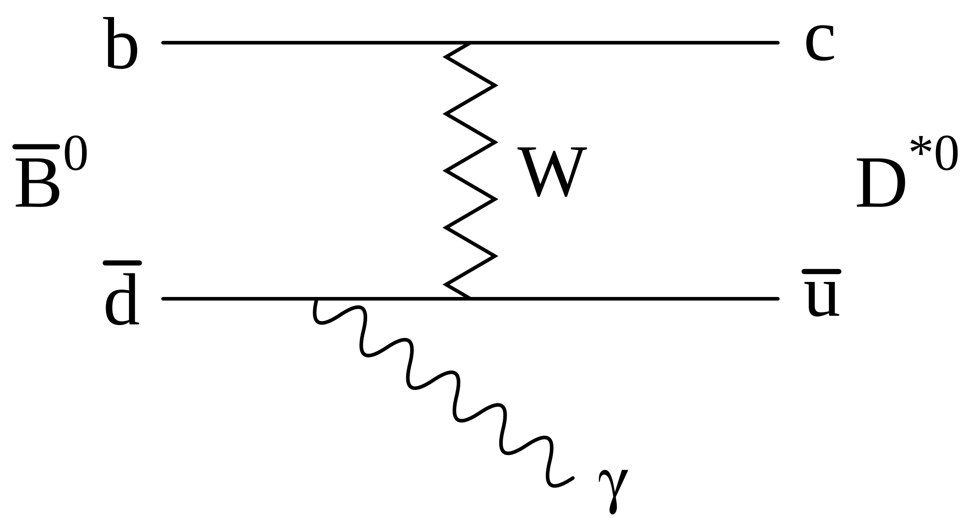
Curves are signal PDFs for best-fit S_f, C_f



- **Top:** B^0 **tag;**
- **Middle:** $\overline{B}^0$ **tag;**
- **Bottom: asymmetry.**

A Search for $\bar{B}^0 \to D^{*0}\gamma$ at *BABAR*

The rare decay $\bar{B}^0 \to D^{*0}\gamma$ is one radiative process which does not occur via a penguin diagram. Rather, it involves color-suppressed W-exchange:



Predicted SM branching fraction $\sim 10^{-6}$.
A color-octet component to B wave function could raise this by factor of 10.

Previous limit (CLEO): $\mathcal{B}(\bar{B}^0 \to D^{*0}\gamma) < 5.0 \times 10^{-5}$ at 90% C.L.

A Search for $\overline{\mathbf{B}}^{\mathbf{0}} \to \mathbf{D}^{*\mathbf{0}}\gamma$ at *BABAR*

We report a new *BABAR* search based on 87.8 million $\Upsilon(4S) \to \mathbf{B}\overline{\mathbf{B}}$ decays.

- **$\mathbf{D}^{*0}$ candidates are reconstructed in six modes (23.9% of $\mathcal{B}(\overline{\mathbf{B}}^{\mathbf{0}} \to \mathbf{D}^{*0}\gamma)$):**

  $\mathbf{D}^{*0} \to \mathbf{D}^{\mathbf{0}}\,(\pi^{\mathbf{0}}, \gamma)$, with

  $\mathbf{D}^{\mathbf{0}} \to \mathbf{K}^{-}\pi^{+}$, $\mathbf{K}^{-}\pi^{+}\pi^{\mathbf{0}}$, $\mathbf{K}^{-}\pi^{+}\pi^{-}\pi^{-}$.

- **Among many cuts needed to suppress $B\overline{B}$ and continuum backgrounds:**
  - For the primary photon ($E^*_\gamma \approx 2.3\,\mathrm{GeV}$), a $\pi^0(\eta)$ veto is applied, along with shower-shape and isolation requirements.
  - Tight cuts are made on the mass of D^0 candidates and on the D^{*0}- D^0 mass difference ($2\,\mathrm{MeV}$ for the π^0 mode, $9\,\mathrm{MeV}$ for the γ mode, both $\approx 2\sigma$).
  - Topological cuts reduce $q\overline{q}$ continuum background.
- **Most cuts optimized iteratively (with most other cuts applied) for maximum signal sensitivity.**
- **All cuts finalized before looking at signal-region on-resonance data.**

A Search for $\overline{\mathrm{B}}^0 \to \mathrm{D}^{*0}\gamma$ at *BABAR*

Use m_{ES} and ΔE to define the Signal Region:

$$5.275 < m_{ES} < 5.285\,\mathrm{MeV/c^2} \quad -0.10 < \Delta E < +0.08\,\mathrm{GeV}\,.$$

Signal efficiency 1.8%, with relative systematic error 17% to 22%.

But background still dominates:

Expected signal in signal box $= 0.4 \times (\mathcal{B}(\overline{\mathrm{B}}^0 \to \mathrm{D}^{*0}\gamma)/10^{-6})$ events,

Expected background in signal box $= 9.4 \pm 1.7$ events.

Background (some of which peaks in m_{ES}) estimated from simulation:

2.9 events from $\overline{\mathrm{B}}^0 \to \mathrm{D}^{*0}\pi^0$

5.1 events from other $\mathrm{B}\overline{\mathrm{B}}$

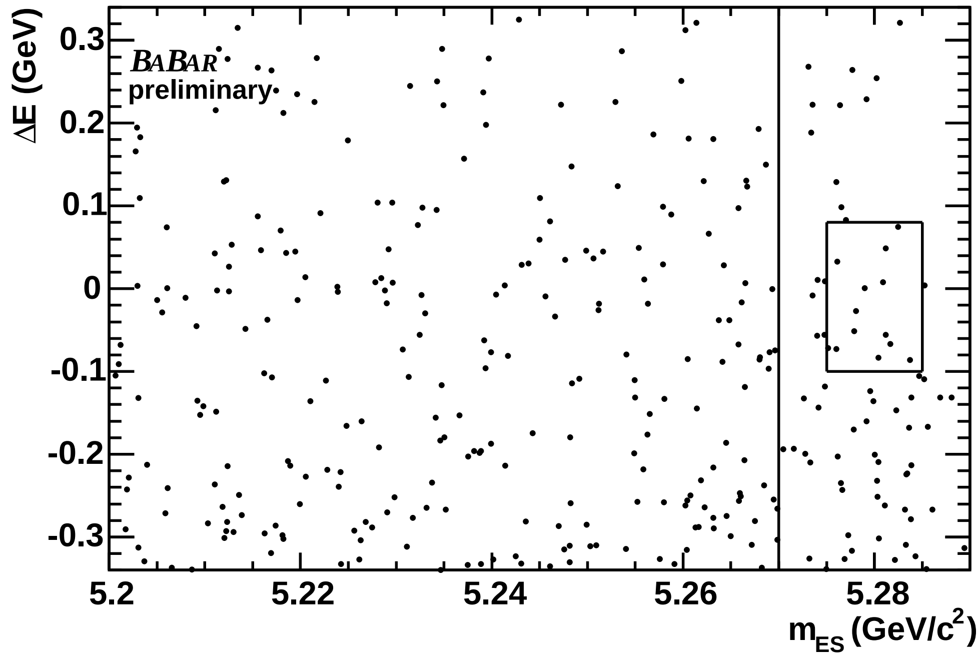
1.4 events from $q\overline{q}$ continuum

A Search for $\bar{B}^0 \to D^{*0}\gamma$ at *BaBar*

The Data:

Signal Box at right,
Sideband is region left of line.

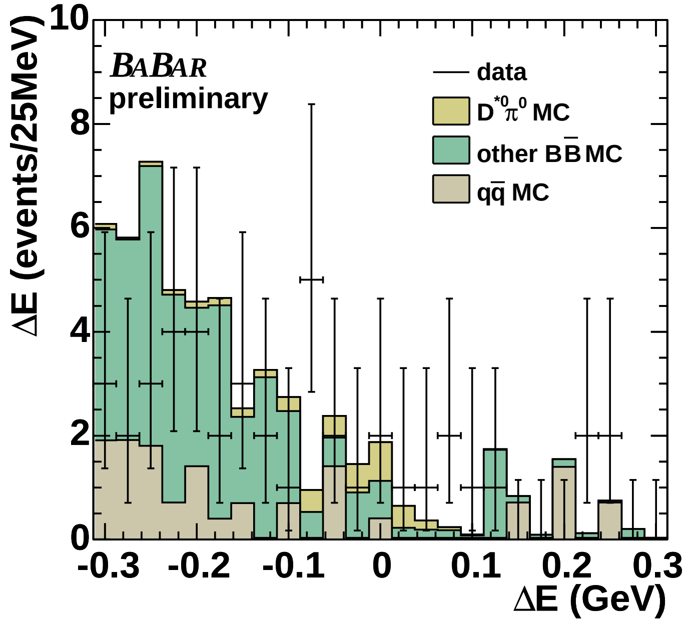
13 Events in Signal Box.



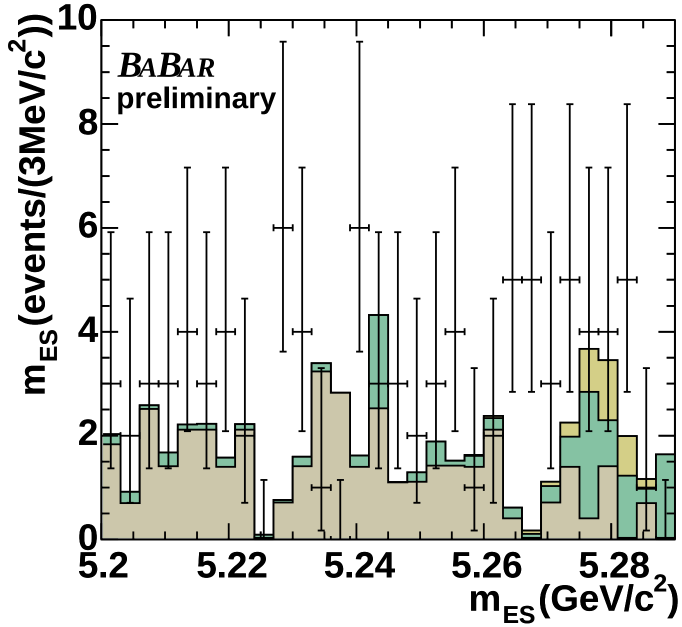
Sideband and $\bar{B}^0 \to D^{*0}\pi^0$ control-sample checks of backgrounds suggest systematic uncertainty 0.4 to 1.3 times the MC expectation of 9.4 events.
Thus observed data are consistent with background.

A Search for $\bar{B}^0 \to D^{*0}\gamma$ at BABAR

Projected data distributions compared to MC backgrounds do not show any anomalies:



ΔE for m_{ES} in signal range.



m_{ES} for ΔE in signal range.

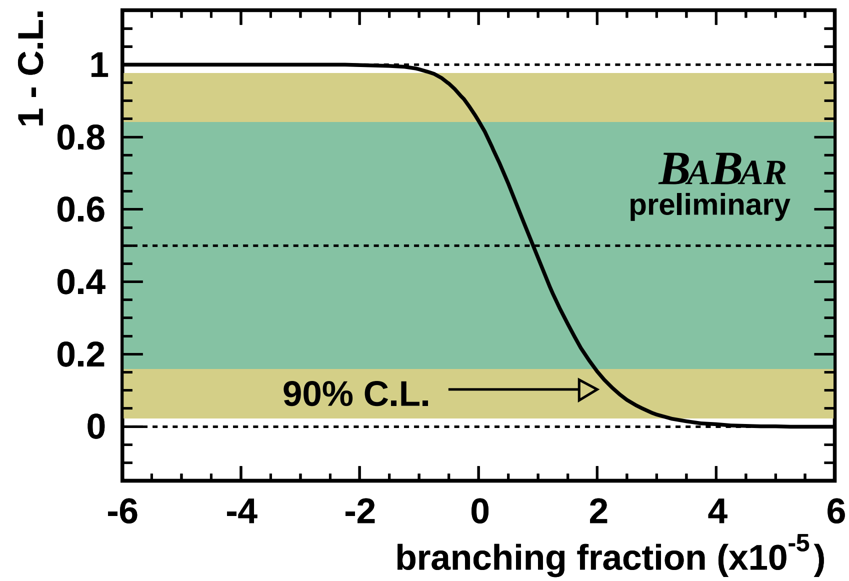
MC components are $\bar{B}^0 \to D^{*0}\pi^0$, other $B\bar{B}$ and $q\bar{q}$, top to bottom.

A Search for $\overline{\mathrm{B}}^0 \to \mathrm{D}^{*0}\gamma$ at *BABAR*

Branching Fractions are found via a frequentist approach
(adapted from R. Barlow, Comp. Phys. Commun. **149**, 97 (2002))

The 6 decay modes are treated separately, incl. systematic uncertainties; for backgrounds, coherent factor of 0.4 to 1.3 is applied to MC predictions for each decay mode.

Central value: $0.9\,^{+1.1}_{-0.9} \times 10^{-5}$ consistent with 0.

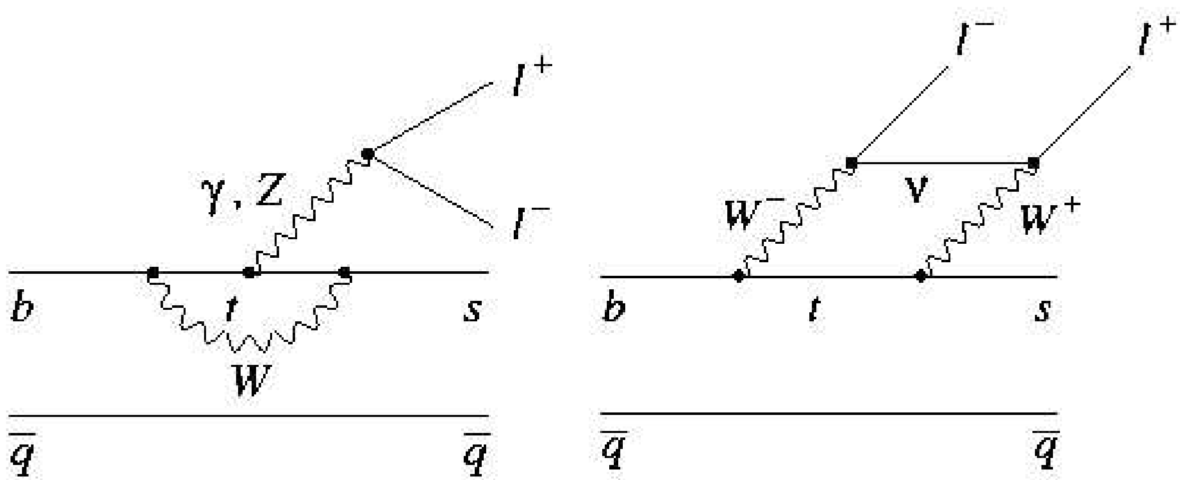


$$\mathcal{B}(\overline{\mathrm{B}}^0 \to \mathrm{D}^{*0}\gamma) < 2.3 \times 10^{-5} \text{ at } 90\% \text{ C.L.}$$

Factor of two better than previous limit.
Much more *BABAR* data already in hand.

Dileptons: $B \to K^{(*)}\ell^+\ell^-$ Decays

- **Dilepton decays $B \to X_s\ell^+\ell^-$ add two types of lowest-order process to EM penguin of $B \to X_s\gamma$: Z^0 penguin and W box diagram.**
- **Dilepton invariant mass-squared q^2 provides an extra kinematic degrees of freedom, as does angular information for a lepton of specified charge.**



Dileptons: $\mathbf{B \to K^{(*)}\ell^+\ell^-}$ Decays

Standard Model Expectations

- $\mathcal{B}(\mathrm{B \to K}\ell^+\ell^-) \approx \mathbf{0.5 \times 10^{-6}}$ and $\mathcal{B}(\mathrm{B \to K^*}\ell^+\ell^-) \approx \mathbf{1.5 \times 10^{-6}}$, **both to** $\sim 30\%$. **Uncertainties dominated by form factor computations.**
- $\mathcal{B}(\mathrm{B \to K^* e^+ e^-})$ **has large contribution from pole in EM penguin at** $\mathrm{q^2} = \mathbf{0}$. **Effect for** $\mathrm{B \to K^*}\mu^+\mu^-$ **is very small;** $\mathrm{B \to K}\ell^+\ell^-$ **has no pole. Thus:**

$$\mathcal{R}_{\mathrm{K}} \equiv \mathcal{B}(\mathrm{B \to K}\mu^+\mu^-)/\mathcal{B}(\mathrm{B \to Ke^+e^-}) = \mathbf{1.0}\ ,$$

$$\mathcal{R}_{\mathrm{K^*}} \equiv \mathcal{B}(\mathrm{B \to K^*}\mu^+\mu^-)/\mathcal{B}(\mathrm{B \to K^*e^+e^-}) \approx \mathbf{0.75}\ ,$$

  from Ali *et al.*, NNLO (2002).

- **Excluding pole region** ($\mathrm{q^2} < 0.1\,\mathrm{GeV^2}$), $\mathcal{R}_{\mathrm{K^*}} \approx 1.0$.
- **Direct** $|\mathrm{A_{CP}}| << 1\%$ **[Krüger *et al.* (2001)].**

Non-SM contributions could result in large $\mathrm{A_{CP}}$ and (*e.g.*, supersymmetric neutral Higgs boson) of order 10%-larger ratios. Angular asymmetries – not yet measured by *BaBar* – could also be very sensitive.

BABAR Measurement of $B \to K^{(*)}\ell^+\ell^-$ Decays

New *BABAR* measurement based on $208\,fb^{-1}$

- **Belle first established $K\ell^+\ell^-$ signal from $29\,fb^{-1}$ (2002). Published *BABAR* measurement (2003) is from $113\,fb^{-1}$.**
- **Measurements are for 8 decay modes:**

  (K or $K^* \to K\pi^\pm$) and ($B^\pm$ or B^0) and ($\mu^+\mu^-$ or e^+e^-)

  The four modes $B^\pm \to K^*\ell^+\ell^-$ and $B^0 \to K\ell^+\ell^-$ include a K^0_S (π^0 not used).
- **Bremsstrahlung-photon recovery for e^+e^- modes.**
- **Combinatorial continuum background – Fisher discriminant (topological variables, and $K\ell$ masses to reject semileptonic D decays).**
- **Combinatorial $B\overline{B}$ background, *e.g.*, two semileptonic B decays – suppressed with missing energy, etc.**
- **Signal – peaks in m_{ES} and ΔE.**
- **Peaking backgrounds and "crossfeed" (from signal-like states with one pion missing or randomly added)**

BABAR Measurement of $B \rightarrow K^{(*)}\ell^+\ell^-$ Decays

Peaking Backgrounds

- $B \rightarrow K^{(*)}J/\psi\,(\rightarrow \ell^+\ell^-)$ and $B \rightarrow K^{(*)}\psi(2S)(\rightarrow \ell^+\ell^-)$ –
  like signal, peaks in m_{ES} and ΔE, vetoed by cuts in $m_{\ell^+\ell^-}$ vs. ΔE plane.
  These provide high-statistics samples for validation of the analysis.
- $B \rightarrow D\pi$ with $D \rightarrow K^{(*)}\pi$ and both pions misidentified as muons – suppressed by vetoing $K^{(*)}\mu$ combinations consistent with such a source.
- Residual peaking backgrounds total 0 to 3 expected events per B decay mode, with systematic uncertainties below 1 event.

Systematic Uncertainties on Signal Efficiency:

- Dominant source is 4 to 7% model-dependence, from disagreement between theorists on form factors
- Total syst. uncertainties: 5 to 6% for K modes, 6 to 10% for K^* modes

BaBar Measurement of $\mathbf{B \to K^{(*)}\ell^+\ell^-}$ Decays

Maximum Likelihood Fits

- **Fits are to $\mathbf{m}_{ES}$, $\mathbf{\Delta E}$ and (for $\mathbf{K^*}$ modes) $\mathbf{m_{K\pi}}$.**
- **Signal**: shape parameters from MC simulation or charmonium control samples.
- **Combinatorial**: product of ARGUS shape in m_{ES}, linear function of ΔE, two-parameter function of $m_{K\pi}$; plus small fixed term with K^* peak. Yield and all parameters floated.
- **Crossfeed**: shapes from MC, yield floated.
- **Peaking Background**: same shapes as signal, yield fixed from MC.

Fit Systematics (Additive) include uncertainties on signal shape (based on data *vs.* MC for charmonium samples) and on peaking backgrounds, and varying parameterizations of combinatorial background.

For combined K or $\mathbf{K^*}$ results, efficiency-corrected data are fit together, constrained to same $\mathbf{\Gamma(B \to K^{(*)}\ell^+\ell^-)}$, except $\mathcal{R}_{\mathbf{K^*}}$ is constrained to expected 0.75.

BABAR Measurement of $B \to K^* \ell^+ \ell^-$ Decays

Combined Fit to four $B \to K^* \ell^+ \ell^-$ Modes

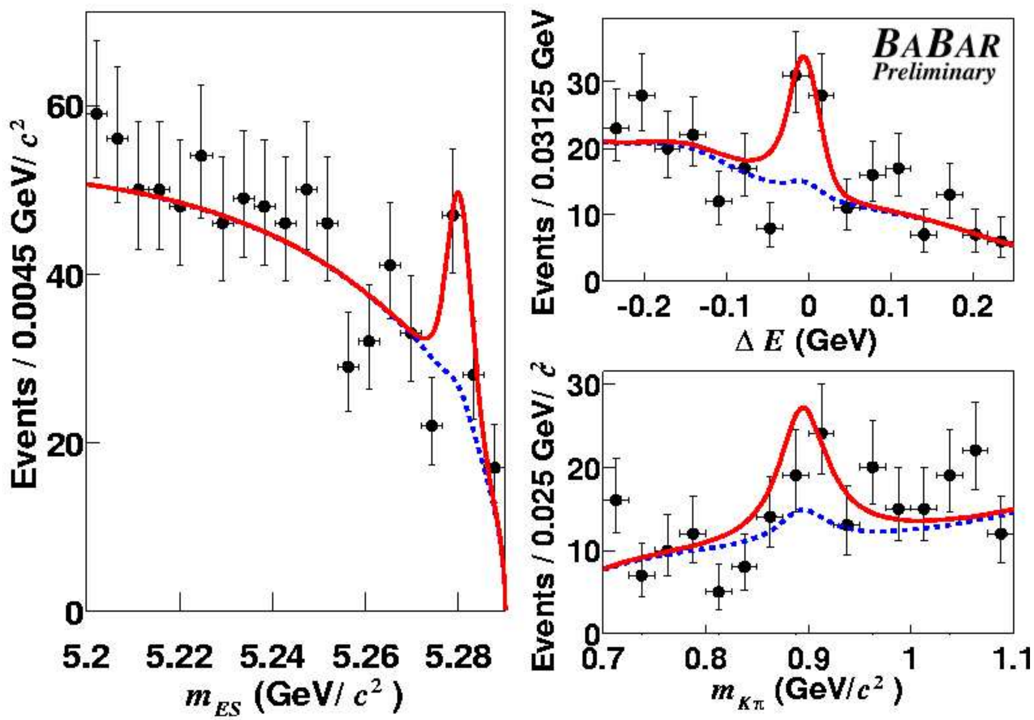
Each variable projected for other two in signal region:

$5.272 < m_{ES} < 5.286\ \mathrm{GeV/c^2}$

$-0.07 < \Delta E < 0.05\ \mathrm{GeV}\ (\mu\mu)$

$-0.11 < \Delta E < 0.07\ \mathrm{GeV}\ (ee)$

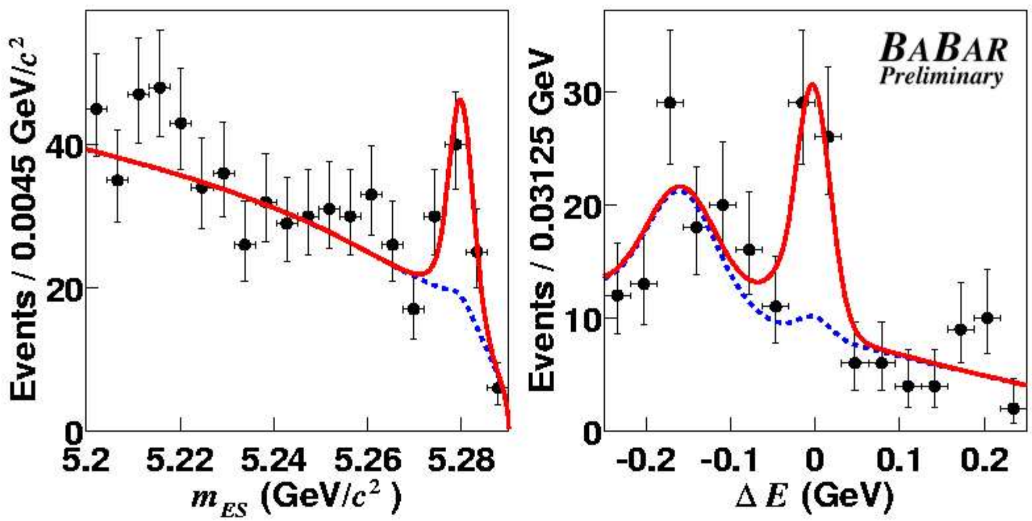
$0.817 < m_{K\pi} < 0.967\ \mathrm{GeV/c^2}$



Total: Solid Red, Backgrounds: Dotted Blue.

BABAR Measurement of $B \rightarrow K\ell^+\ell^-$ Decays

Combined Fit to four $B \rightarrow K\ell^+\ell^-$ Modes
(**Each variable is projected for other variable in signal region.**)



Total: Solid Red, Backgrounds: Dotted Blue.

- **The peak at low ΔE is from the feed-down component of the fit; it does not bias the signal extraction.**
- **No evidence from dilepton mass plots (K, K^*) of charmonium "leakage".**

BABAR Measurement of $\mathrm{B} \to \mathrm{K}^{(*)}\ell^+\ell^-$ Decays

Combined-Mode Preliminary Results

Mode	$\mathcal{B}$(Mode) (10^{-6}) $\pm$ Stat. Uncert.	Syst. Uncert. (10^{-6}) Effic.	Fit	Total	Significance (Stat. + Syst.)
$B \to K e^+e^-$	$0.33\,^{+0.09}_{-0.08}$	0.02	0.01	0.02	5.3σ
$B \to K \mu^+\mu^-$	$0.35\,^{+0.13}_{-0.11}$	0.02	0.02	0.03	3.8σ
$B \to K \ell^+\ell^-$	$0.34\,^{+0.07}_{-0.07}$	0.02	0.01	0.02	6.6σ
$B \to K^* e^+e^-$	$0.97\,^{+0.30}_{-0.27}$	0.06	0.13	0.15	4.5σ
$B \to K^* \mu^+\mu^-$	$0.90\,^{+0.35}_{-0.30}$	0.08	0.11	0.13	3.5σ
$B \to K^* \ell^+\ell^-$	$0.78\,^{+0.19}_{-0.17}$	0.05	0.10	0.12	5.7σ

- **B^+ and B^0 modes combined assuming same partial widths for corresponding modes. Results quoted as fractions of B^0 total width.**
- **$\mathrm{e}^+\mathrm{e}^-$ and $\mu^+\mu^-$ modes combined assuming expected values for ratios $\mathcal{R}_\mathrm{K}$ and $\mathcal{R}_{\mathrm{K}^*}$. Results quoted for $\mu^+\mu^-$.**
- **"Significance" from comparison of max. likelihood result for null-signal hypothesis to syst. variations of standard fit which yield smallest signal.**

Summary of *BaBar* Preliminary Results for $B \to K^{(*)}\ell^+\ell^-$ Decays

$$\mathcal{B}(B \to K\ell^+\ell^-) = (0.34 \pm 0.07 \pm 0.03) \times 10^{-6} ,$$

$$\mathcal{B}(B \to K^*\ell^+\ell^-) = (0.78\,^{+0.19}_{-0.17} \pm 0.12) \times 10^{-6} .$$

By comparing e^+e^- and $\mu^+\mu^-$ results,

$$\mathcal{R}_K = 1.06 \pm 0.48 \pm 0.05 \quad \text{(SM expectation = 1.00)},$$

$$\mathcal{R}_{K^*} = 0.93 \pm 0.46 \pm 0.06 \quad \text{(SM expectation = 0.75)}.$$

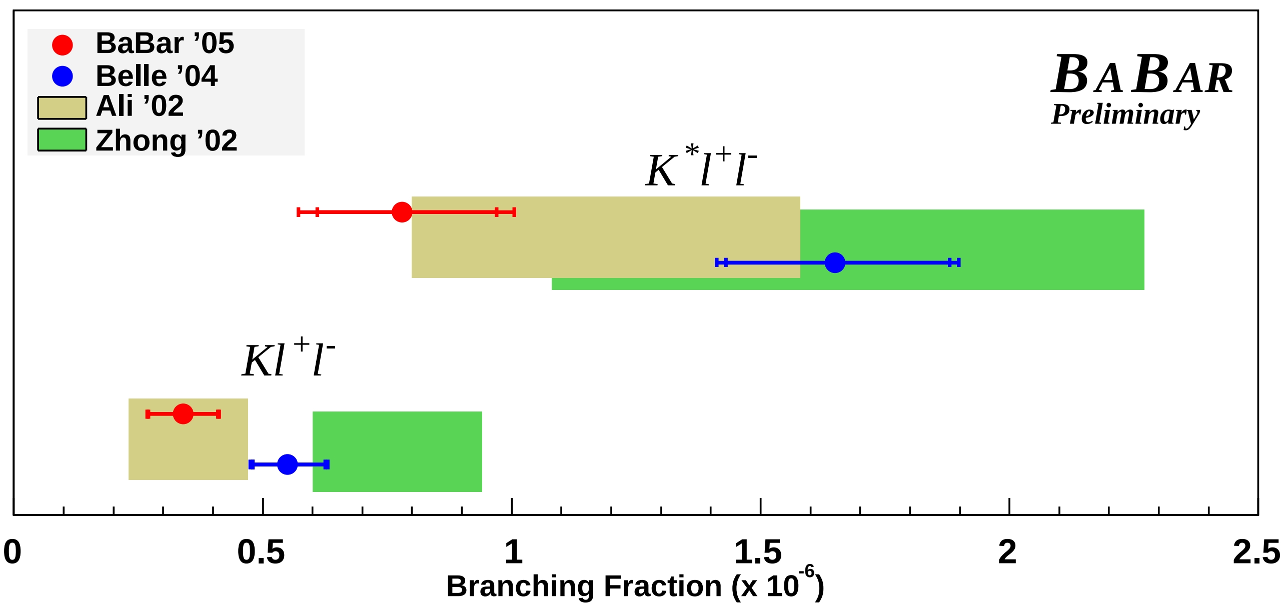
Direct CP-violating Asymmetries are measured from "self-tagging" modes:

$$A_{CP}(B^+ \to K^+\ell^+\ell^-) = -0.08 \pm 0.22 \pm 0.11 ,$$

$$A_{CP}(B \to K^*\ell^+\ell^-) = +0.03 \pm 0.23 \pm 0.12 ,$$

where systematic uncertainties are dominated by unknown asymmetries in peaking backgrounds, allowed to vary between -1 and +1.

BaBar $\mathcal{B}(\mathrm{B} \to \mathrm{K}^{(*)}\ell^+\ell^-)$ *vs.* Belle and Representaive Theories



- The Belle results are based on $250\,\mathrm{fb}^{-1}$.
- Belle uses same conventions as *BaBar* for combining e^+e^- and $\mu^+\mu^-$.
- The Belle and *BaBar* $\mathrm{B} \to \mathrm{K}\ell^+\ell^-$ and $\mathrm{B} \to \mathrm{K}^*\ell^+\ell^-$ branching fractions differ by 1.9σ and 2.6σ, respectively. ($\mathcal{R}_\mathrm{K}$, $\mathcal{R}_{\mathrm{K}^*}$ agree within large errors.)

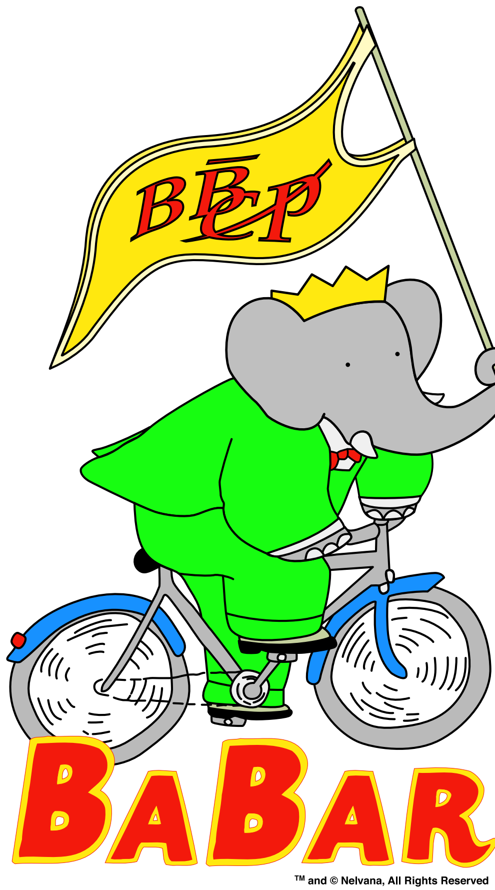
Conclusions and Prospects

We have presented preliminary new results from *BaBar* on radiative and dilepton B decays. This is only a a portion of ongoing work in this area.

- **Precision of $\mathcal{B}(B \to X_s\gamma)$ ($81\,fb^{-1}$) will improve with more data (at least fully-inclusive), but SM theory errors must also decrease to find new physics.**
- **$B \to X_s\gamma$ photon spectrum results (especially moments) are becoming useful for determining HQET parameters, tie-in to $B \to X_u\ell\nu$, $|V_{ub}|$.**
- **Time-dependent CP asymmetries in radiative penguin processes ($211\,fb^{-1}$): statistics-limited – room for considerable improvement.**
- **Likewise for direct CP-violation searches in $B \to X_s\gamma(+B \to X_d\gamma)$ ($81\,fb^{-1}$)**
- **Search for $B^0 \to D^{*0}\gamma$ ($80\,fb^{-1}$): background-limited, but larger data samples should improve the limit.**
- **$B \to K^{(*)}\ell^+\ell^-$ measurements ($208\,fb^{-1}$) are mostly statistics-limited; this rich area is just starting to open up.**

Conclusions and Prospects

$\approx$ 220 fb^{-1} $\Upsilon(4S)$ data



$\sim$ 450 fb^{-1} by Summer 2006