Measurements of $b \rightarrow s\gamma$ *Decays at BaBar*

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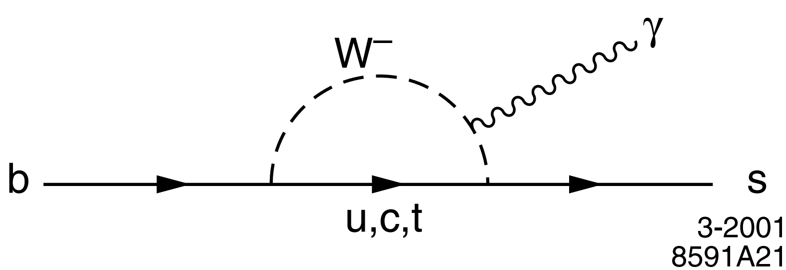
On behalf of the BaBar Collaboration

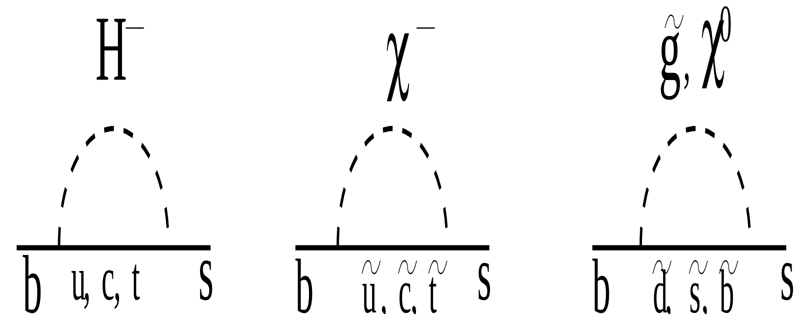
Outline

- Overview of the inclusive $b \to s\gamma$ decays
- Experimental approaches for inclusive $b \to s\gamma$ measurements
- BaBar inclusive $b \to s\gamma$ measurements
- BaBar exclusive $b \to s\gamma$ analysis
- NNLO calculation on $b \to s\gamma$ branching fraction
- Summary

Overview of $b \to s\gamma$

- $b \to s\gamma$ is a FCNC process, only happens at loop level in SM
- Inclusive $b \to s\gamma$ can be used to study HQE parameters
- Theory uncertainty on Branching Fraction is 10% at NLO
- SM predicts $A_{CP}(b \to s, d\gamma) \approx 10^{-9}$



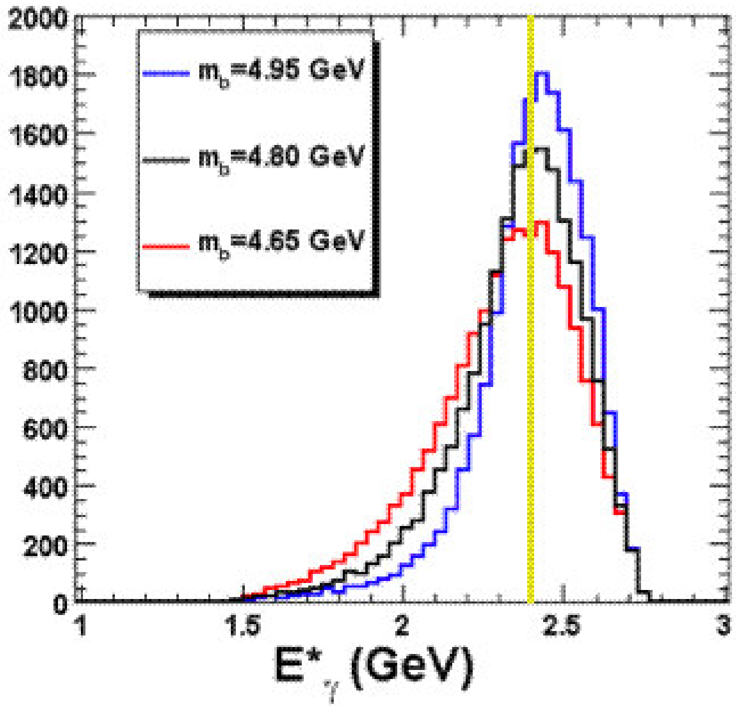


- New Physics contributes at same level as SM
- Measurable changes in Branching Fraction and A_{CP} are indications of New Physics
- Add constraints in new physics search, such as in MSSM, Higgs in 2 Higgs Doublet Model

- BF at NLO (for $E_\gamma > 1.6 GeV$), $\mathcal{B}(B \to X_s\gamma) = (3.61^{+0.37}_{-0.49}) \times 10^{-4}$
  T. Hurth *et al*, Nucl. Phys. B 704, 56(2005)

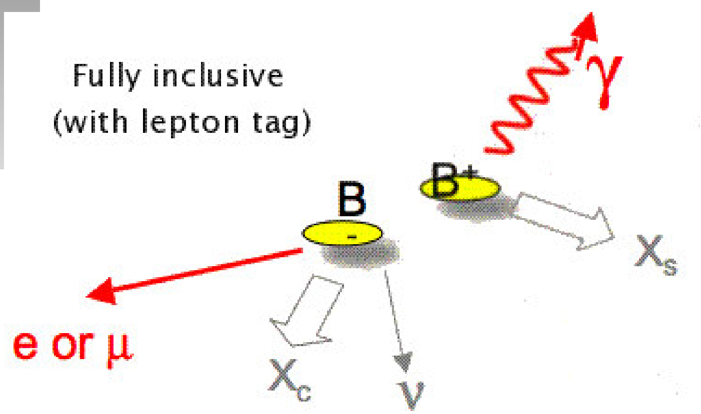
Photon Spectrum and Shape Function

- Fermi motion of b quark in B meson leads to the modification of Photon spectrum E_γ, decribed by Shape Function (SF)
- SF is universal for inclusive $\bar{B} \to X_s \gamma$ and $\bar{B} \to X_u l \nu$ from B meson decays
- Photon spectrum and its moments are related to HQE parameters, $m_b \approx 2 < E_\gamma >$, $\mu_\pi^2 \approx < E^2 - < E >^2 >$

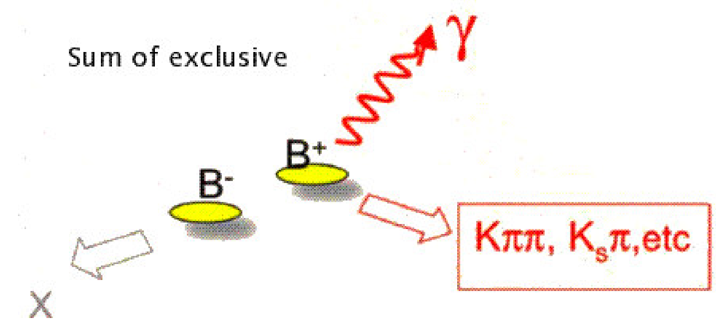


- Kinetic Scheme (m_b, μ_π^2, μ_G^2 *et al*, Benson *et al*, NPB710,371(2005)) and SF scheme (m_b, μ_π^2, Bosch *et al*, NPB 699,335(2004)) are often used to fit E_γ
- The HQE parameters from $b \to s\gamma$ spectrum can be applied to extract CKM element $|V_{ub}|$ from $b \to ul\nu$

Inclusive $\bar{B} \rightarrow X_s\gamma$ Analysis Approaches

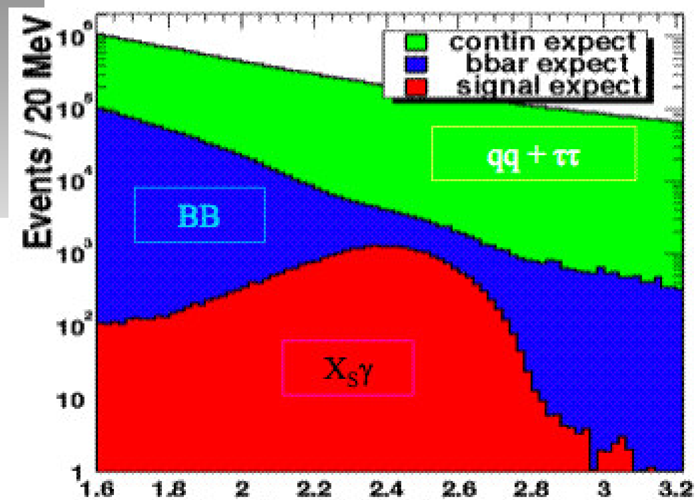


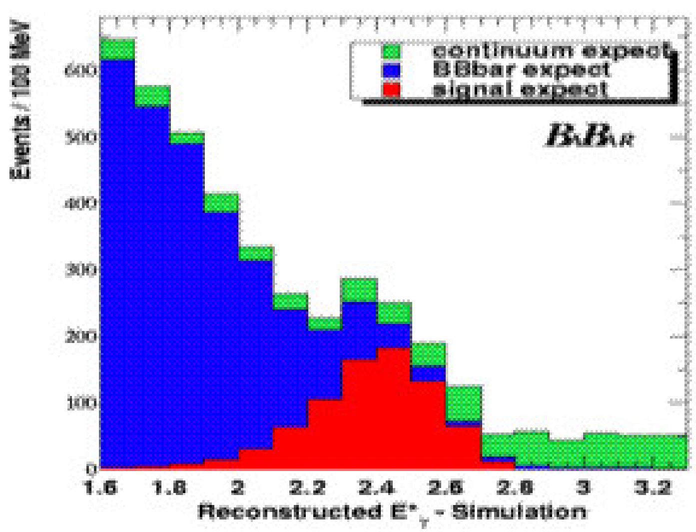
- Advantage:
  Insensitive to final state
  Fragmentation, theoretically clean
- Disadvantage:
  A lot of background
  E^*_γ is measured in $\Upsilon(4S)$ frame



- Advantage:
  Low background
  Good photon resolution
- Disadvantage:
  Sensitive to details of X_s
  fragmentation
  Missing X_s Modes

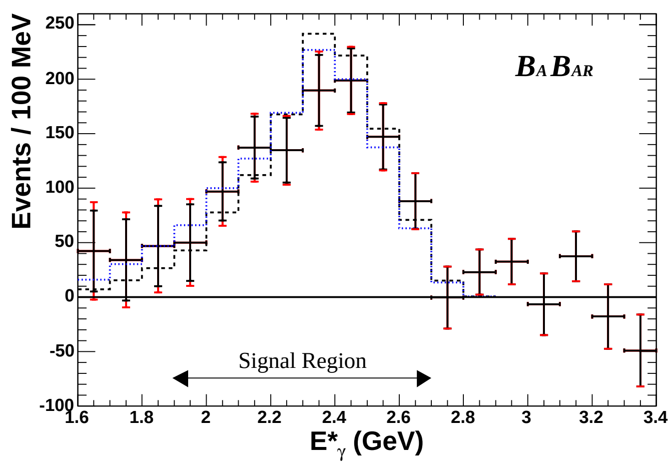
Inclusive $\bar{B} \to X_s\gamma$





- Require E^*_γ>1.9 GeV (* means in CMS). Lowest possible E^*_γ cut is preferred to minimize model dependence
- Veto π^0 and η backgrounds
- Dramatically reduce continuum background with opposite-side lepton tag and event shape variables
- Subtract remaining continuum background with off-peak data
- Plots show the E^*_γ spectrum before and after cuts

Inclusive $\bar{B} \to X_s\gamma$

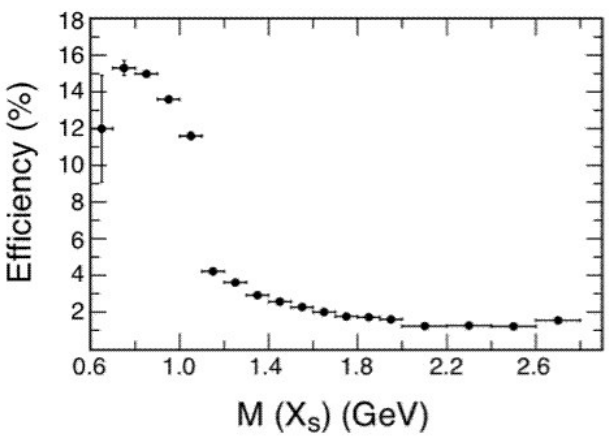


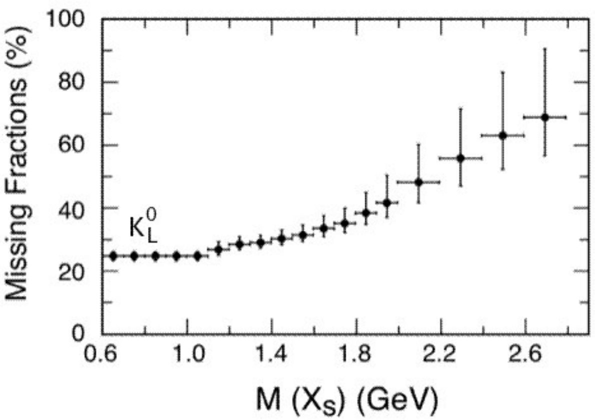
- $\mathcal{BF}(E_\gamma > 1.9GeV) =$
  $(3.67 \pm 0.29 \pm 0.34 \pm 0.29) \times 10^{-4}$
  $\mathcal{BF}(E_\gamma > 1.6GeV) =$
  $(3.94 \pm 0.31 \pm 0.36 \pm 0.21) \times 10^{-4}$
  Extrapolated to 1.6 GeV using Kinetic Scheme
- $A_{CP} = \frac{\Gamma(b \to (s+d(\gamma) - \Gamma(\bar{b} \to (\bar{s}+\bar{d}(\gamma)}{\Gamma(b \to (s+d(\gamma) + \Gamma(\bar{b} \to (\bar{s}+\bar{d}(\gamma)}$
  $= -0.110 \pm 0.115(stat) \pm 0.017(sys)$

- 89 M $B\bar{B}$ events
- $b \to s\gamma$ efficiency is energy dependent
- Photon Spectrum is before effeciency correction
- Spectrum from best fit to kinetic scheme(black) and shape function scheme (blue)
- Moments($E_\gamma > 1.9GeV$) :
  first moment:
  $2.288 \pm 0.025 \pm 0.017 \pm 0.015GeV$
  second moment:
  $0.0328 \pm 0.0040 \pm 0.0023 \pm 0.0036GeV^2$
- Published (171803,PRL97(2006))

Sum of Exclusive $\bar{B} \to X_s\gamma$

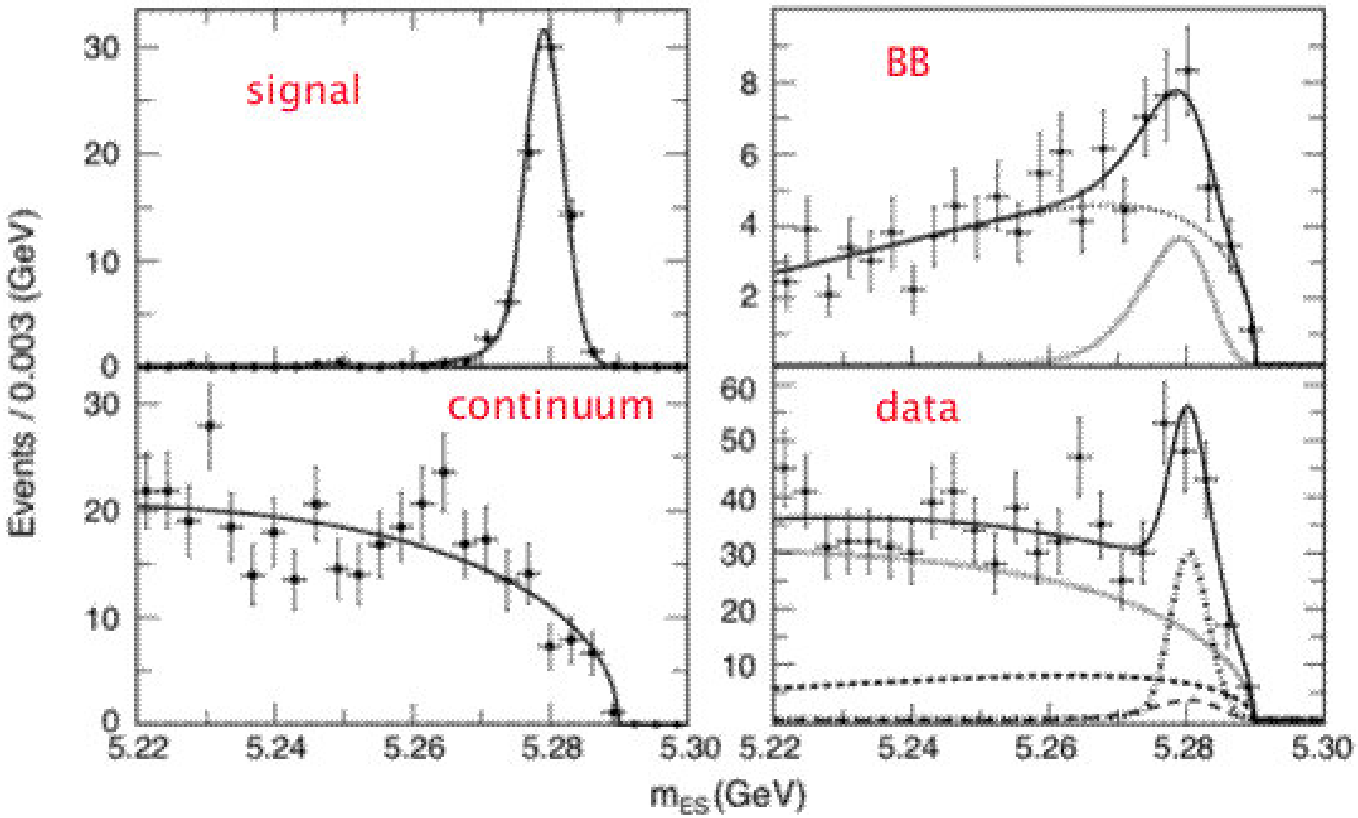
- Sum of 38 exclusive modes with $K(n\pi)\gamma$ ($n \leq 4$), $K(n\pi)\eta\gamma$ ($n \leq 2$), and $3K(n\pi)\gamma$ ($n \leq 1$) final states
- Background reduced with π^0 and η vetoes
- Event shape variables used to reduce continuum background
- Uses JETSET to model Xs fragmentation
- $E_\gamma = \frac{M_B^2 - M(X_s)^2}{2M_B}$
- Efficiency decreases with $M(X_s)$, Missing fraction (and its uncertainty) increases with $M(X_s)$



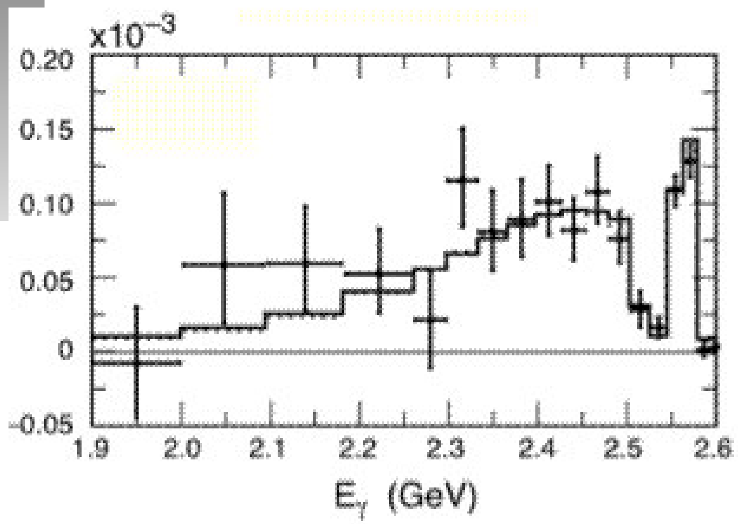


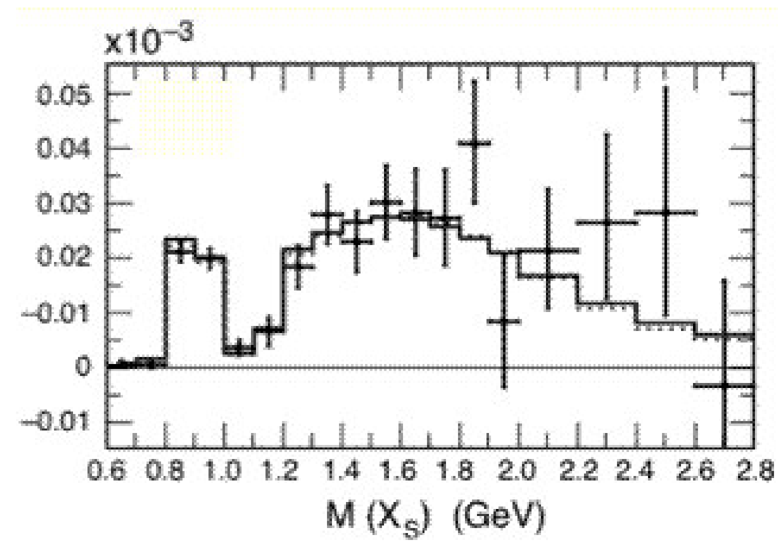
Sum of Exclusive $\bar{B} \to X_s\gamma$

- Fit $m_{ES} = \sqrt{(E^*_{beam})^2 - (p^*_B)^2}$ in bins of $M(X_s)$
- As an example, m_{ES} fits for $1.4 < M(X_s) < 1.5$ GeV region are shown below



Sum of Exclusive $\bar{B} \to X_s \gamma$

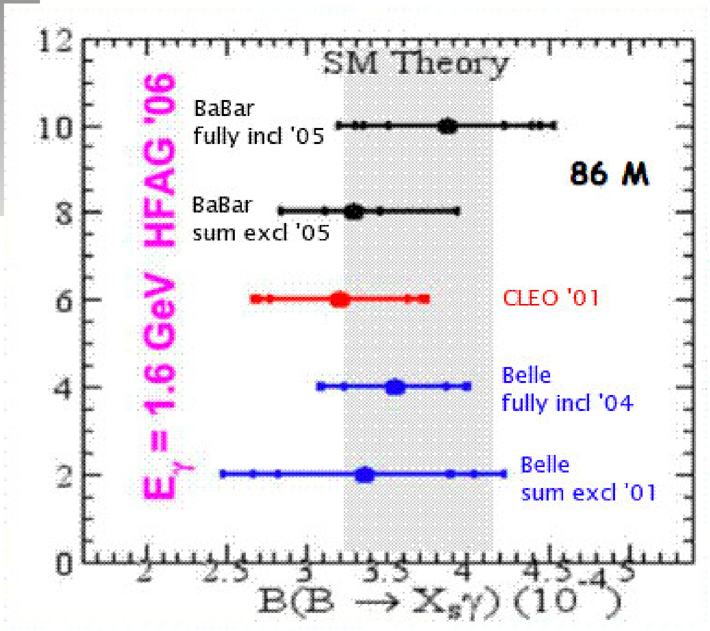


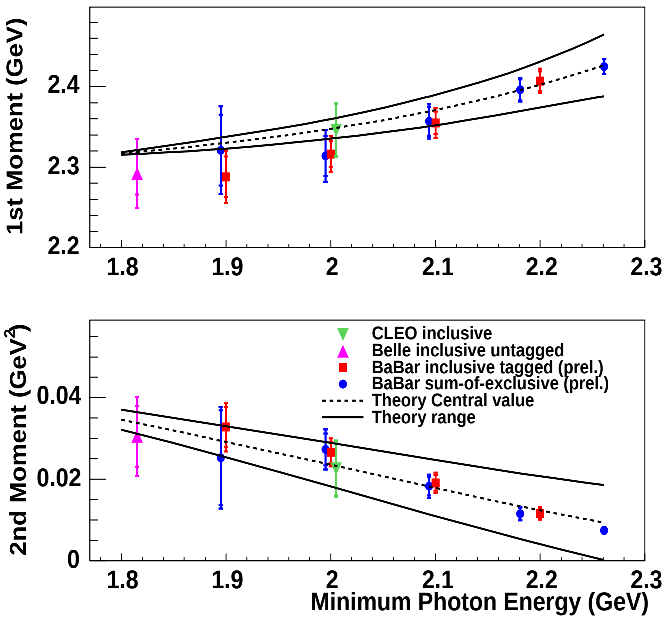


- 89 M $B\bar{B}$ events
- BF(Averaging two schemes):
  $\mathcal{B} = (3.27 \pm 0.18^{+0.55+0.04}_{-0.40-0.06}) \times 10^{-4}$
  for E_γ > 1.9 GeV
  Extrapolated to 1.6 GeV,
  $\mathcal{B} = (3.35 \pm 0.19^{+0.56+0.04}_{-0.41-0.09}) \times 10^{-4}$
- Aubert *et al*,PRD72, 052004(2005)

- Moments ($E_\gamma > 1.9 GeV$:
  1st: $2.31 \pm 0.038^{+0.017}_{-0.038}$ GeV
  2nd: $0.0253 \pm 0.0101^{+0.0041}_{-0.0028}$ GeV^2
- Isospin asymmetry:
  $\Delta_{0-} = \frac{\Gamma(\bar{B}^0 \to X_{s\bar{d}}\gamma) - \Gamma(B^- \to X_{s\bar{u}}\gamma)}{\Gamma(\bar{B}^0 \to X_{s\bar{d}}\gamma) + \Gamma(B^- \to X_{s\bar{u}}\gamma)}$
  $= -0.006 \pm 0.058 \pm 0.009 \pm 0.024$

Inclusive $\bar{B} \to X_s\gamma$ ***Summary***





- All BF extrapolated to 1.6 GeV
- BaBar inclusive measurement in kinetic scheme:
  $\mathcal{B}(\bar{B}->X_s\gamma) = (3.94 \pm 0.31 \pm 0.36 \pm 0.21) \times 10^{-4}$
- All measurements are consistent with SM theory

$\bar{B} \to X_s\gamma$ ***at NNLO!***

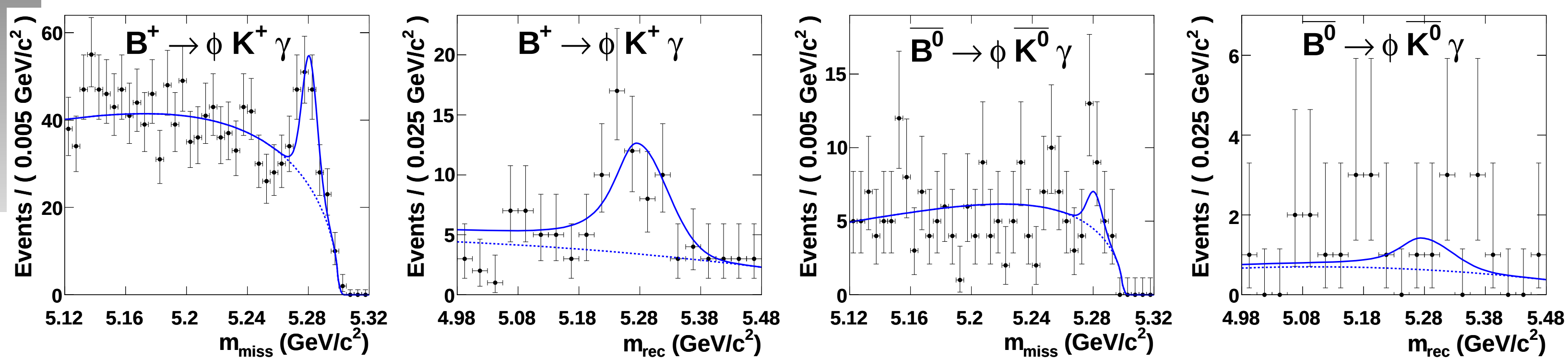
- Recently new NNLO calculations for BF are out from theory side
- $\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6GeV} = (3.15 \pm 0.23) \times 10^{-4}$
  uncertainty from:
  - Non-perturbative $\mathcal{O}(\alpha_s \frac{\lambda}{m_b})$, 5%
  - Parametric ($\alpha_s(M_Z), \mathcal{B}^{exp}$,...,$3\%$
  - High-order $\mathcal{O}(\alpha_s^3)$, 3%
  - m_c interpolation ambiguity, 3%

  M. Misiak *et al*, hep-ph/0609232
- Taking into account photon energy cut-off effect with above approach
  $\mathcal{B}(\bar{B} \to X_s\gamma)_{E_\gamma > 1.6GeV} = (2.98 \pm 0.26) \times 10^{-4}$
  T. Becher *et al*, hep-ph/0610067
- The NNLO calculations is 1.2 to 1.4 σ below experimental world average, this makes $\bar{B} \to X_s\gamma$ measurement more interesting

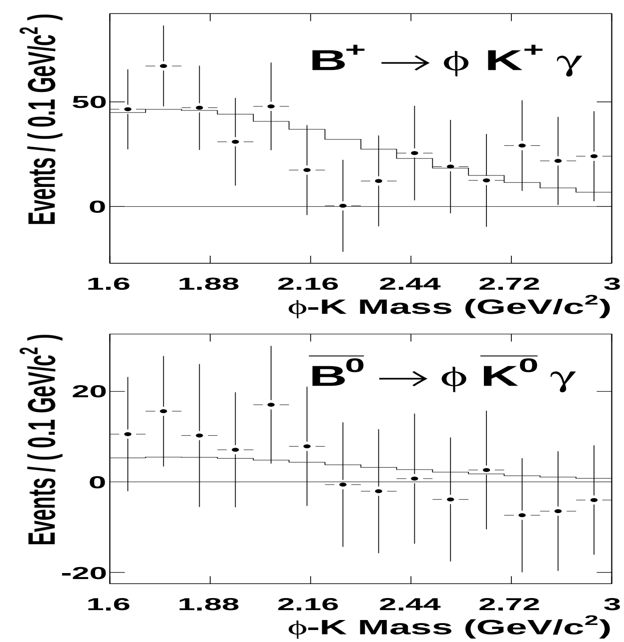
Exclusive Radiative $B \to X_s\gamma$

- Exclusive $B \to X_s\gamma$ decays are experimentally clean
- A sensitive probe of Standard Model
- Direct CP Asymmetry is small in SM
- Measurement of large CP Asymmetry is a sign of new physics

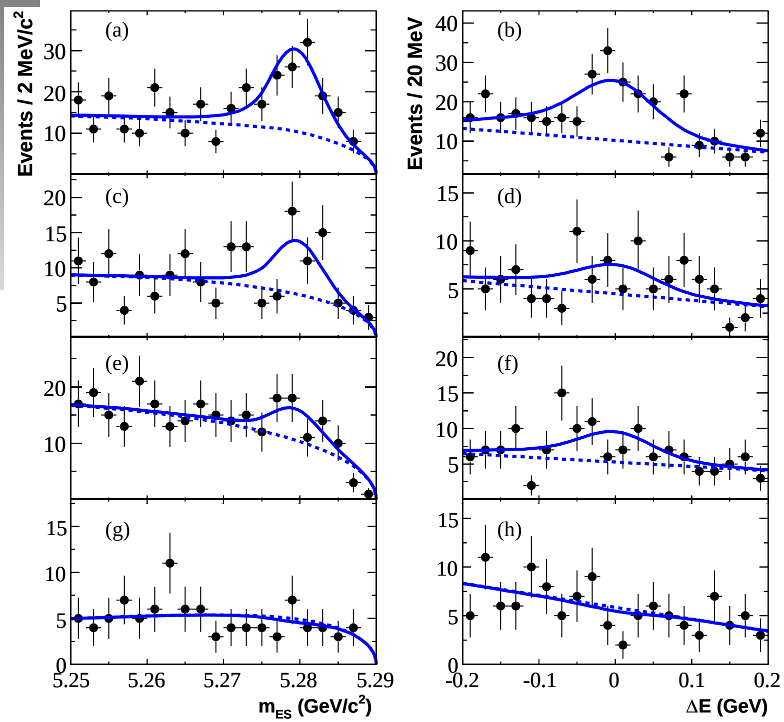
Exclusive $B \to \phi K \gamma$

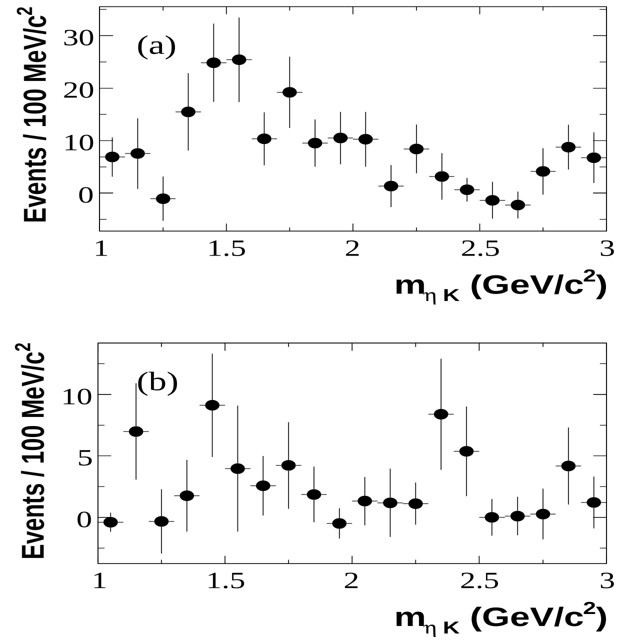


- 227 M $B\bar{B}$ events
- $\mathcal{B}(B^- \to \phi K^- \gamma)$
  $= 3.5 \pm 0.6 \pm 0.4 \times 10^{-6}$
- $A_{CP}(B^- \to \phi K^- \gamma)$
  $= (-26 \pm 14 \pm 5)\%$
- $\mathcal{B}(\bar{B}^0 \to \phi \bar{K}^0 \gamma) < 2.7 \times 10^{-6}$
  at 90% C.L
- Submitted to PRD



Exclusive $B \to \eta(\eta')K\gamma$





- $\mathcal{B}(B^+ \to \eta K^+ \gamma)$
  $= 10.0 \pm 1.3 \pm 0.5 \times 10^{-6}$
- $\mathcal{B}(B^0 \to \eta K^0 \gamma)$
  $= 11.3^{+2.8}_{-2.6} \pm 0.6 \times 10^{-6}$

- $\mathcal{B}(B^+ \to \eta' K^+ \gamma) < 4.2 \times 10^{-6}$
  $\mathcal{B}(B^0 \to \eta' K^0 \gamma) < 6.6 \times 10^{-6}$
  at 90% C.L
- $A_{ch}(B^+ \to \eta K^+ \gamma) =$
  $-0.009 \pm 0.12 \pm 0.01$
- 232 M $B\bar{B}$ events

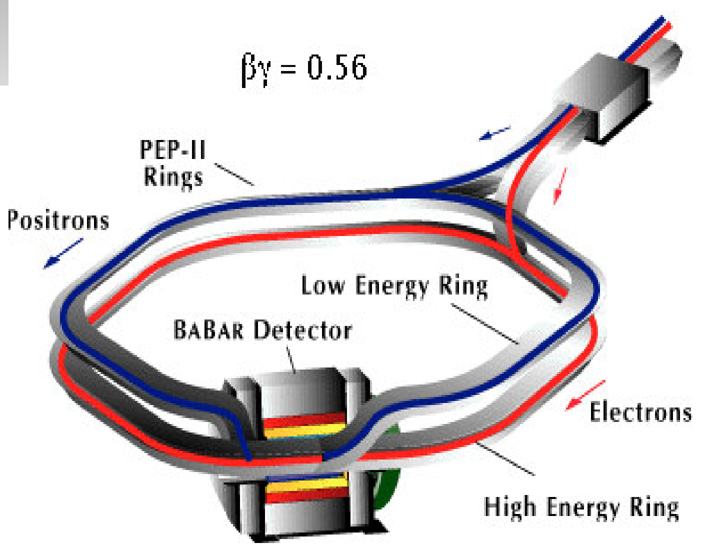
Summary

- Review both Inclusive and exclusive $\bar{B} \to X_s\gamma$ measurements at Babar
- Inclusive $\bar{B} \to X_s\gamma$ measurements are consistent with Standard Model
- Two recent exclusive $b \to s\gamma$ measurements are consistent with Belle's
- New theoretical calculation at NNLO for inclusive $\bar{B} \to X_s\gamma$ opens window for New Physics
- BaBar updating Inclusive $b \to s\gamma$ with much bigger statistics (89 M to 400 M $B\bar{B}$, new measurements are expected to improve experimental uncertainty

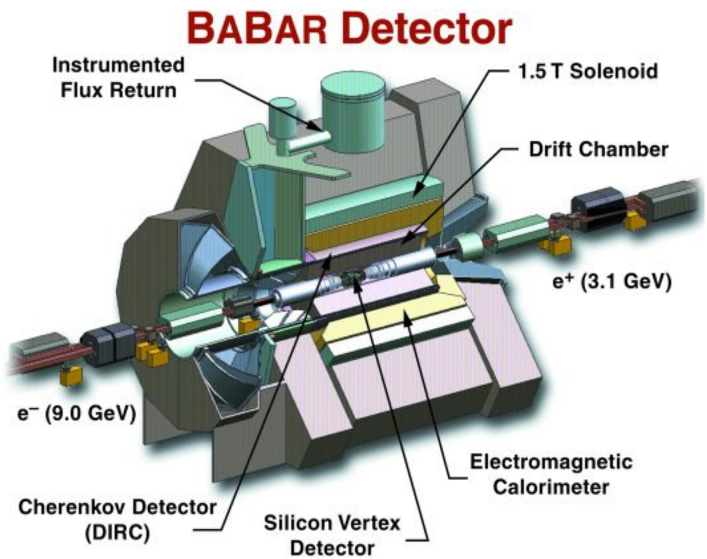
Backup Slides

Backup

BaBar Experiment

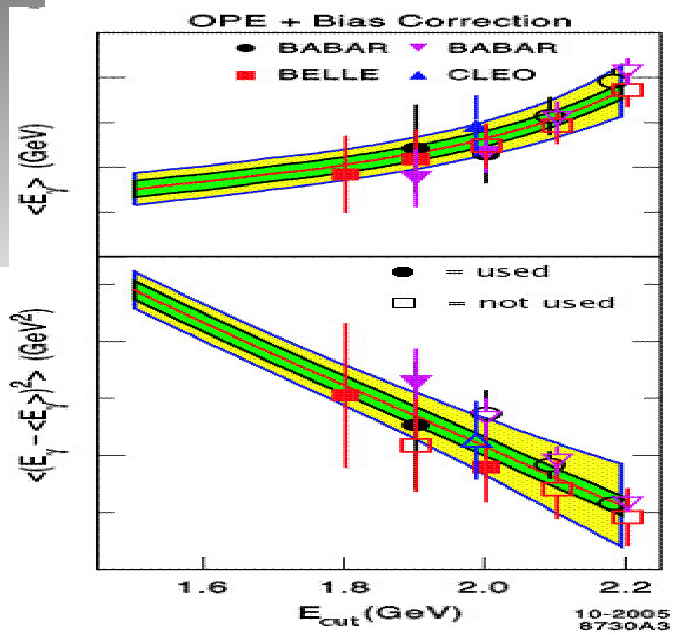


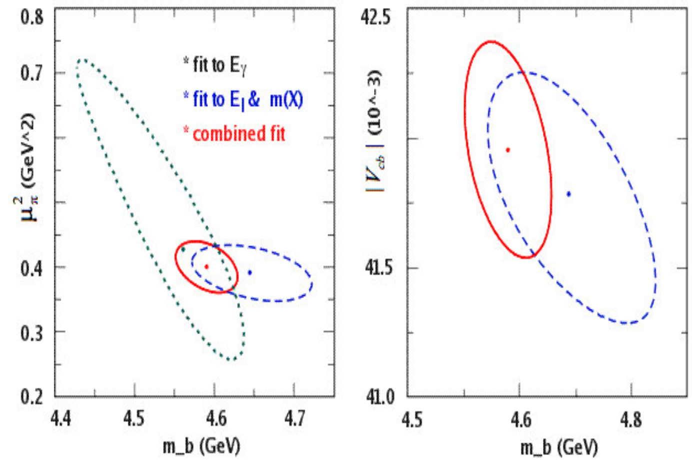
- PEP II: asymmetric e^+e^- Collider
- HER stores a 9 GeV e^- beam
- LER stores a 3.1 GeV e^+ beam



- BaBar: the particle detector
- Nice PID: 4σ K/π separation at 3.0 GeV/c to 2.5σ at 4.0 GeV/c
- Good EMC energy resolution at $1-2\%$ for 1.0 GeV photon

Extraction of HQE parameters from E_γ Moments



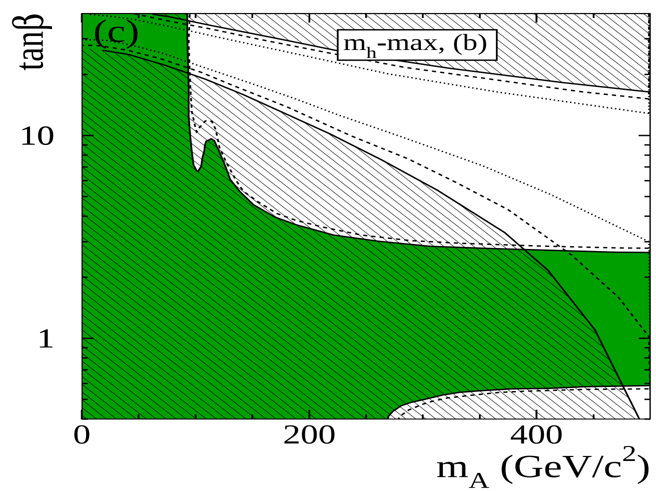


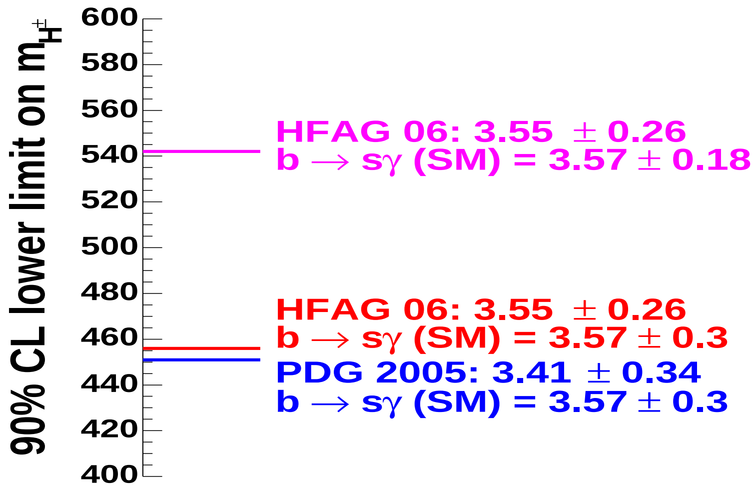
- Combined fit to $b \to cl\nu$ and $b \to s\gamma$ moments

- HQE parameters (in kinetic scheme, Buchmuller *et al*, PRD73, 073008(2006)):
  $m_b = 4.590 \pm 0.025_{exp} \pm 0.030_{HQE}\ GeV$
  $\mu_\pi^2 = 0.401 \pm 0.019_{exp} \pm 0.035_{HQE}\ GeV^2$
  $|V_{cb}| = (41.96 \pm 0.23_{exp} \pm 0.35_{HQE} \pm 0.59_{\Gamma_{sl}}) \times 10^{-3}$

- m_b can be used for $|V_{ub}|$

$b \to s\gamma$ constraints on New Physics





- Green shade: excluded by LEP
- hatched part: excluded by current $b \to s\gamma$ measurement
- dashed line: excluded by $b \to s\gamma$ with 800 fb^{-1}
- dotted line: excluded by $b \to s\gamma$ with 800 fb^{-1}, assume 5% theoretical uncertainty
- red and blue: current limits on $H^{\pm}$ mass constrained from $b \to s\gamma$
- pink: Limits can be pushed up with 5% theoretical uncertainty