Radiative Penguin Decays at BaBar

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On behalf of the BaBar Collaboration

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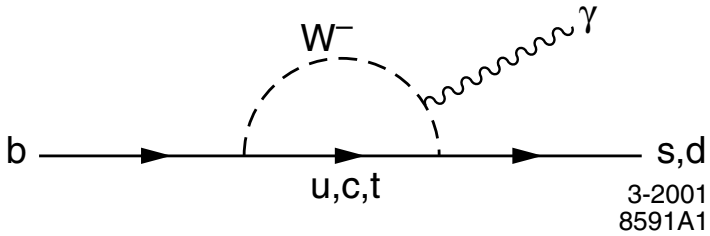
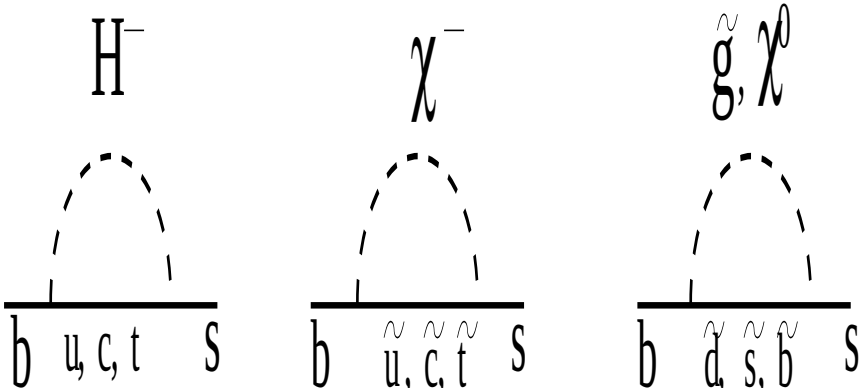
Outline

- BaBar $b \to s\gamma$ decays
  - A New method in Inclusive $b \to s\gamma$ measurement
  - Time Dependent CP Violation analysis of $B \to K^*(K_S\pi^0)\gamma$
- First BaBar Semi-Inclusive $b \to d\gamma$ measurement
- Summary

Overview of $b \to s\gamma$ Decays

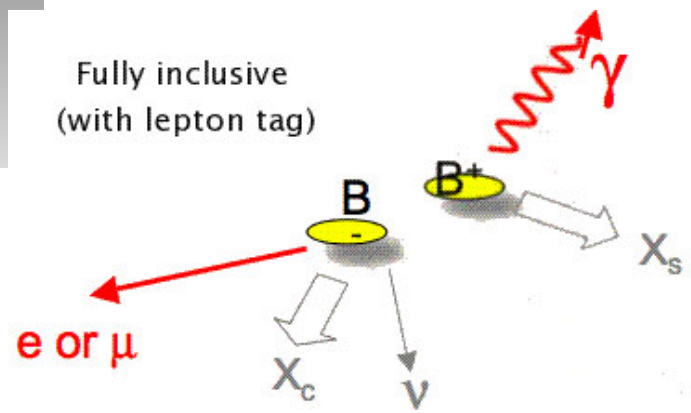
- Radiative penguin decay $b \to s\gamma$ is a FCNC process, only happens at loop level in SM
- Inclusive γ spectrum can be used to extract HQE parameters (see Kerstin's talk)
- Theory uncertainty on BF is 10% at NLO (NPB 704, 56(2005)) now down to 7% at NNLO (PRL 98(2007)022002)

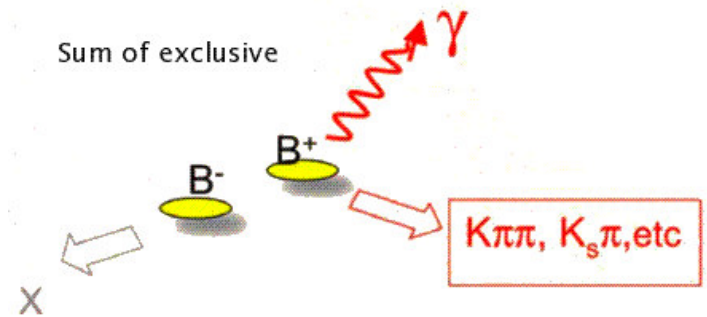




- New Physics can contribute at same level as SM
- Measurable changes in BF and A_{CP} are indications of New Physics beyond SM
- $b \to s\gamma$ can add constraints in new physics search, such as in MSSM, Higgs in 2 Higgs Doublet Model

Inclusive $b \to s\gamma$ Analysis Approaches



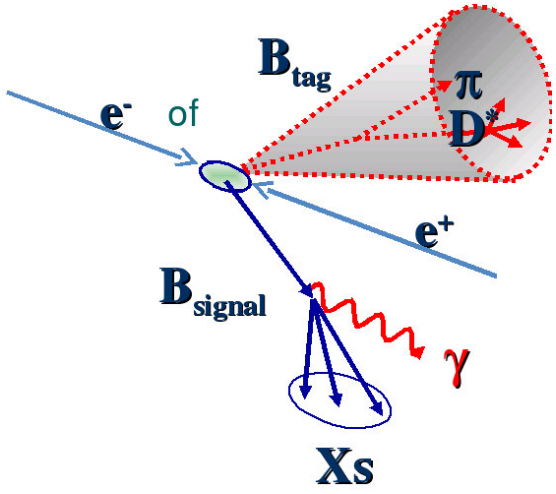


- Advantage:
  Insensitive to final state
  Fragmentation, theoretically clean
- Disadvantage:
  A lot of background
  E_γ^* is measured in $\Upsilon(4S)$ frame
- PRL 97, 171803(2006)

- Advantage:
  Low background
  Good photon resolution
- Disadvantage:
  Sensitive to details of X_s fragmentation
  Missing X_s Modes
- PRD 72, 052004 (2005)

New $b \to s\gamma$ Analysis Approaches

- First measurement with the new B_{reco} method
- Measure high-energy γ from B_{signal} which recoils against a fully reconstructed hadronic B_{reco} decay
- Photon spectrum is extracted from fits to mES in bins of E_γ
  $m_{ES} = \sqrt{((E^*_{beam})^2 - (P^*_B)^2)}$

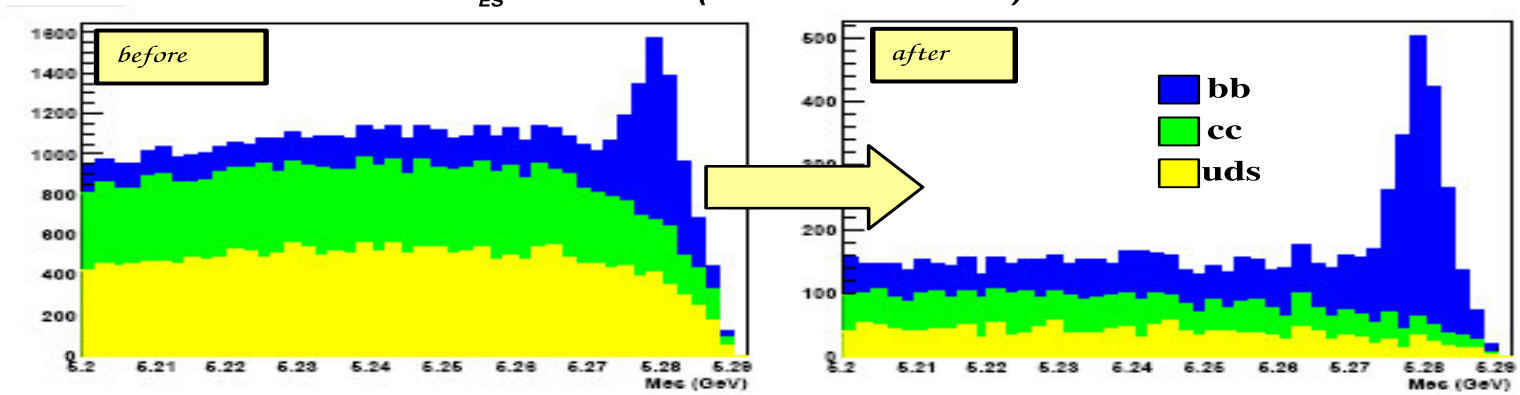


- Advantage:
  - Can measure photon spectrum in B rest frame and CP asymmetry
  - non-peaking continuum background in m_{ES}, thus can be substracted
  - BF normalization is determined from total number of Bs in the full reconstructed sample
- Disadvantage: Small B reconstruction efficiency about 0.3%

Inclusive $b \to s\gamma$: Event Selection

- 210 fb^{-1} BaBar Run1-4 data
- B_{reco} sample: well-measured $B \to D^{(*)}X$ decays
  (X: relevant combinations of $\pi^{\pm}$, π^0,$K^{\pm}$, K^0_S with $|\sum(q)| = 1$)
- $E_\gamma > 1.3GeV$ at B_{signal} rest frame
- Reduce continuum background with Fisher discriminant (mostly event shape variables)

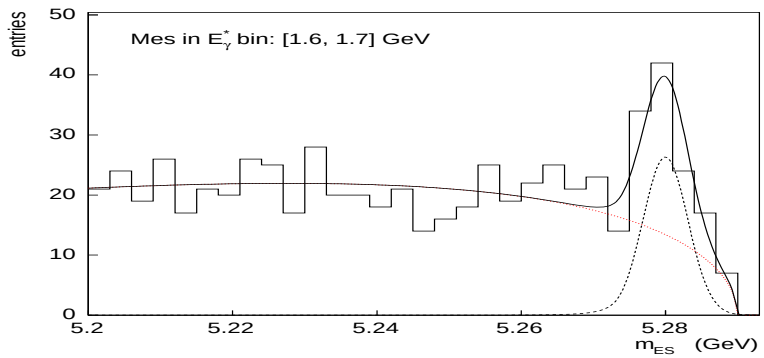
m_{ES} distribution (from MC simulation)



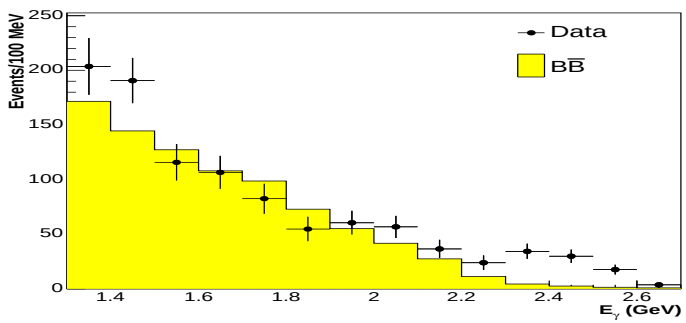
- Veto high energy γ from π^0 and η, also veto ρ decay if γ candidate combined with a $\pi^{\pm}$ is consistent with $\rho^{\pm} \to \pi^{\pm}\pi^0$

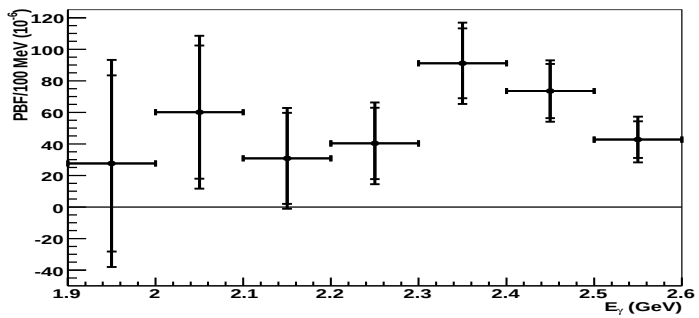
Inclusive $b \to s\gamma$: m_{ES} Fits and E_γ spectrum

Charged B $1.6 < E_\gamma < 1.7GeV$



- Signal yield was from m_{ES} fit
- Dominant Systematic Errors:
  m_{ES} Fit Parameterization 12%
  $B\bar{B}$ background modelling 10%
  Detector response 4%





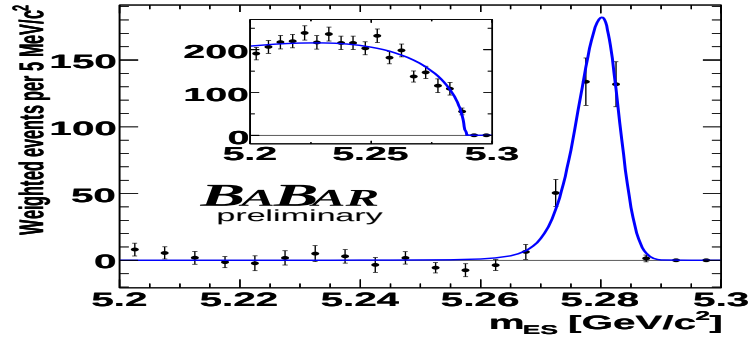
- After substracting $B\bar{B}$ background from the fit, then applying efficiency correction and photon resolution, the corrected E_γ Spectrum is obtained.
- BF($E_\gamma > 1.9GeV$) = $3.66 \pm 0.85_{stat} \pm 0.59_{sys} \times 10^{-4}$
- Extrapolated BF: (using PRD 73, 073008(2006))
  BF($E_\gamma > 1.6GeV$) = $3.91 \pm 0.91_{stat} \pm 0.63_{sys} \times 10^{-4}$

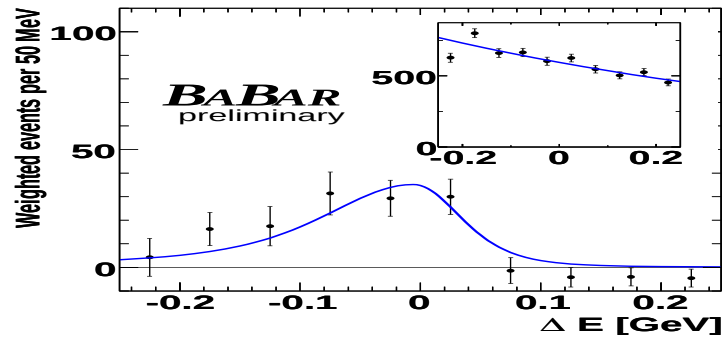
$B^0 \to K^{*0}(K_S\pi^0)\gamma$ Decays: The Motivation

- In SM, $b \to s\gamma$ proceeds through loop diagram
- $b \to s\gamma_L$ and $\bar{b} \to \bar{s}\gamma_R$ are not CP eigenstates of each other and thus the interference between the direct decay $B^0 \to K^{*0}(K_S\pi^0)\gamma$ and the decay via B^0 mixing $B^0 \to \bar{B^0} \to K^{*0}(K_S\pi^0)\gamma$ is suppressed at the order of $\frac{m_s}{m_b}$
- This inteference can be detected through CPV study. It's a great place to look for new physics if a large mixing-induced CP violation signal is observed
- The analysis strategy is to fit the distribution
  $P_\pm(\Delta t) = \frac{e^{-|\Delta t|/\tau_B}}{4\tau_B} \times [1 \pm S sin(\Delta m_d \Delta t) \mp C cos(\Delta m_d \Delta t)]$
  where S is the CPV due to interference between the direct decay and the decay through B^0 mixing: $B^0 \to \bar{B^0} \to K^{*0}\gamma$
  C is the direct CPV between $B^0 \to K^{*0}\gamma$ and $\bar{B^0} \to \bar{K^{*0}}\gamma$
- Current theoretical estimate: $S = -0.022 \pm 0.015^{+0}_{-0.01}$ (PLB 642,478(2006))
- C is constrained to be within 0.028 of zero (HFAG)

$B^0 \to K^{*0}(K_S\pi^0)\gamma$: Data selection and Fits

- 391 fb^{-1} Data
- Photon quality cuts and π^0/η veto
- Select K^* based on kinetic and angular constraints
- Reconstruct B^0 based on m_{ES}, $|\Delta E|$, and angular cut
- Reconstruct $B^+ \to K^{*+}(K_S\pi^+)\gamma$ and veto it if $0.8 < m_{K^*} < 1.0$ GeV
- 16% signal efficiency

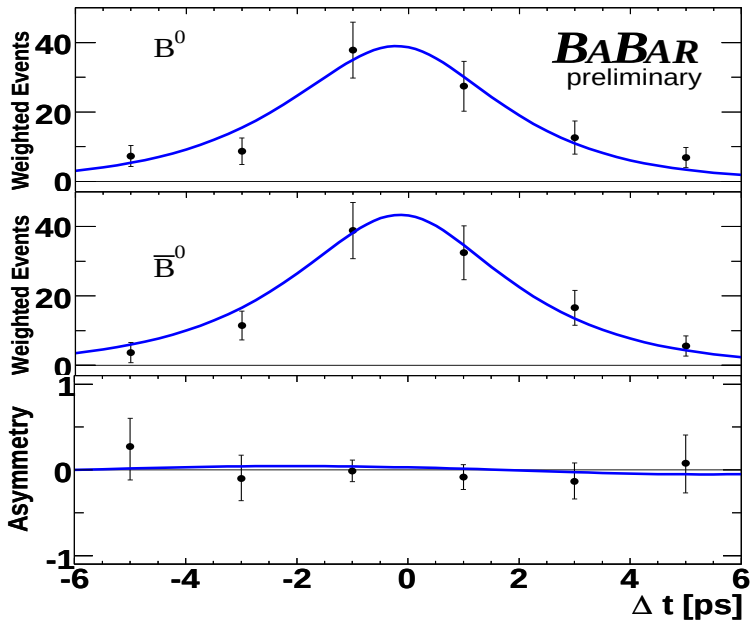




- Unbinned ML Fit to signal, BB, and continuum
- Five Observables: m_{ES}, ΔE, L_2/L_0, $m(K_S\pi^0)$, Δt
- continuum is easy to be separated from signal, peaking background from B decays could impact the results

$B^0 \to K^{*0}(K_S\pi^0)\gamma$ Decays: The Results

source	ΔS	ΔC
Beamspot	0.0040	0.0010
SVT Alignment	0.0020	0.0010
Data/MC resolution function	0.0110	0.0180
Embedded Toys	0.035	0.0150
PDF parameters	0.0129	0.0094
PDF shape	0.0212	0.0042
BB bkgrd	0.0285	0.0179
τ_B and Δm_d	0.0014	0.0004
Tag-side interference	0.0014	0.0146
Total	0.0519	0.0345



- Signal events $N_{sig} = 316 \pm 22$
- $S = -0.08 \pm 0.31 \pm 0.05$, $C = -0.15 \pm 0.17 \pm 0.03$

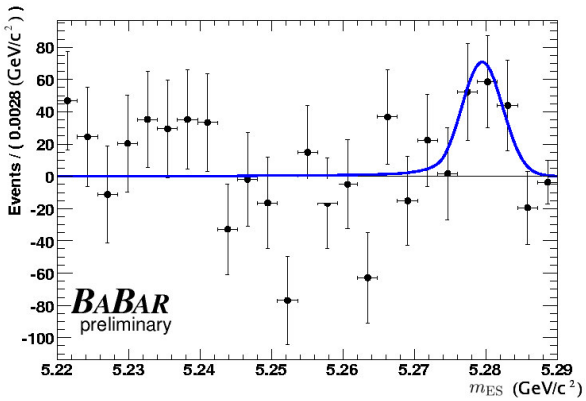
The results are consistent with SM calculation and previous measurements.

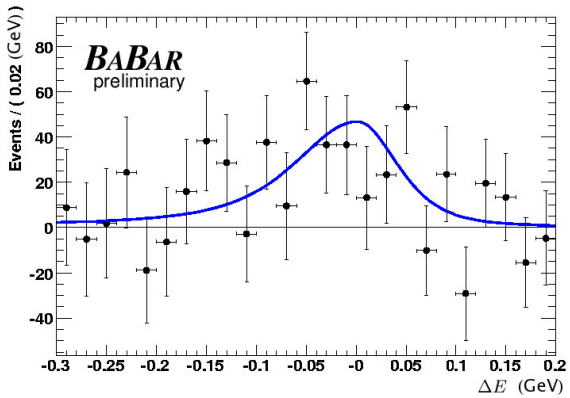
Sum of Exclusive $b \to d\gamma$

- FCNC process only happens at loop level, with possible new physics comparable to SM contributions
- $b \to d\gamma$ is CKM supressed wrt to $b \to s\gamma$ in SM by a factor of 20
- Exclusive $B \to \rho(\omega)\gamma$ and $B \to K^*\gamma$ measurements can be combined to extract$|V_{td}/V_{ts}|$ in SM
- The experimental and theoretical uncertainties are still large for exclusive measurements, it's necessary to do an inclusive $b \to d\gamma$ analysis and extend the hadronic mass to higher non-resonant mass region other than $\rho(\omega)$
- This analysis provides a first effort in measuring inclusive $b \to d\gamma$
- Two hadronic mass (M_{X_d}) region:
  0.6-1.0 GeV, for $B \to \rho(\omega)\gamma$ cross-check
  1.0-1.8 GeV, for analysis, 7 exclusive chanels were reconstructed and accounted for 50% $b \to d\gamma$ cross section
- Background reduced with photon quality cuts, and π^0 and η vetoes
- Use JETSET for M_{X_d} framentation
- Signal was determined by 2-d unbinned ML fit to m_{ES} and ΔE distributions

Sum of Exclusive $b \to d\gamma$: Systematics

source	Relative Uncertainty (%)
Tracking effi ciency	1.7
Charged particle ID	2.0
γ selection	2.5
π^0/η reconstruction	1.7
π^0/η veto	1.0
NN effi ciency	5.0
PDF shape	13.0
B bkgrd Normalization	$^{+10.5}_{-3.0}$
Fit Bias	7.1
B counting	1.1
Combined	$^{+19.3}_{-16.5}$
Signal Model	3.4
X_d fragmentation	13.6
Combined	14.7





- 383 million $B\bar{B}$ events; $N_{sig} = 178 \pm 53$
- $\sum_{X_d=1}^{7} \mathcal{B}(\bar{B} \to X_d\gamma)|_{1.0<M(X_d)<1.8GeV}$ = $(3.1 \pm 0.9^{+0.6}_{-0.5} \pm 0.5) \times 10^{-6}$ at 3.1σ

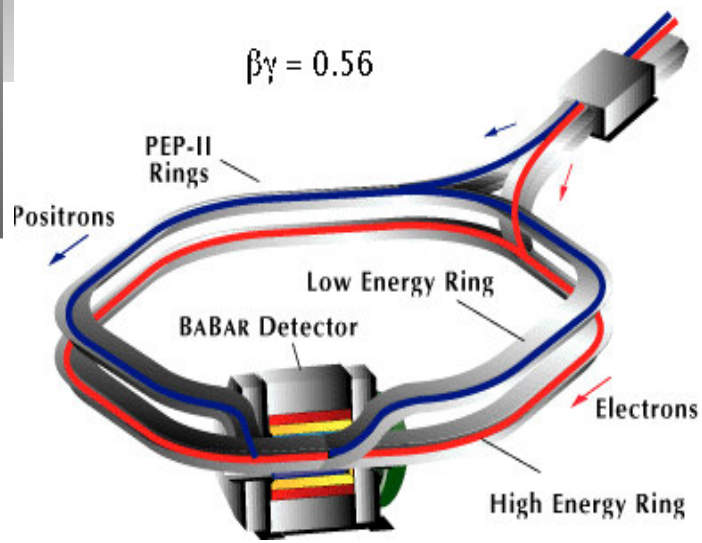
Summary

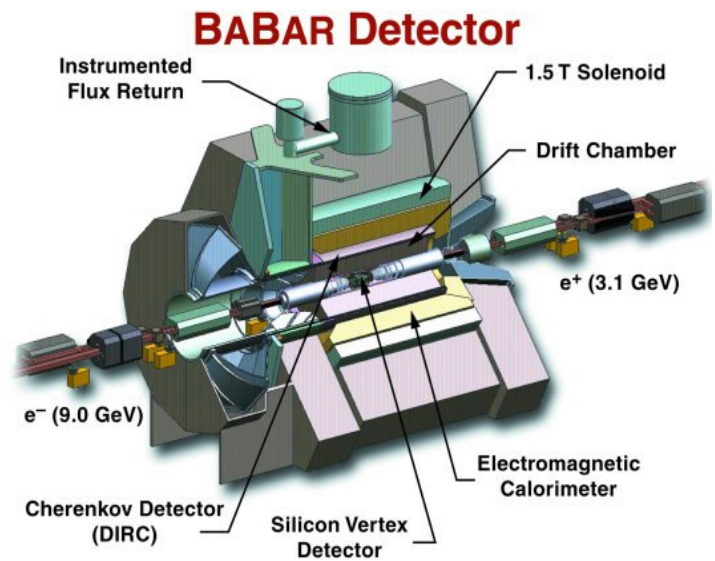
- Review a new inclusive $b \to s\gamma$ measurement with recoil method at BaBar, this method allows direct photon spectrum measurement in the B rest frame.
- The new inclusive $b \to s\gamma$ measurement is consistent with Standard Model calculation and previous measurements
- Time Dependent CP Violation measurement in $B^0 \to K^{*0}(K_S\pi^0)\gamma$ Decays were performed at BaBar, the S and C parameters were all consistent with SM calculaitons and previous measurements
- The first inclusive measurement of $b \to d\gamma$ was performed in $1.0 < M_{X_d} < 1.8$ mass region, 7 exclusive channels were reconsrtucted, 178 ± 53 signal events were found in 383 million $B\bar{B}$ events, and the BF in this hadronic mass region is given at $(3.1 \pm 0.9^{+0.6}_{-0.5} \pm 0.5) \times 10^{-6}$ at 3.1σ significance

Backup Slides

Backup

BaBar Experiment

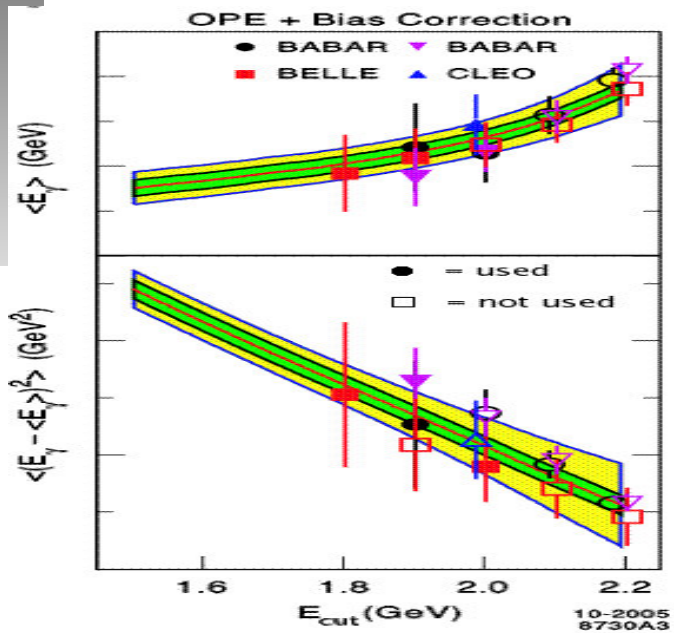


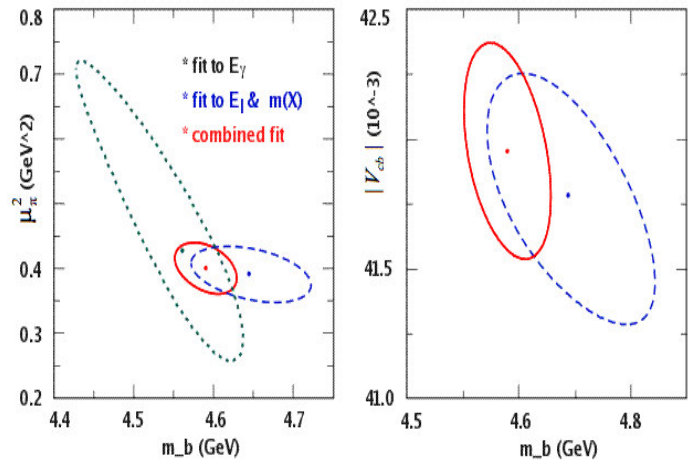


- PEP II: asymmetric e^+e^- Collider
- HER stores a 9 GeV e^- beam
- LER stores a 3.1 GeV e^+ beam

- 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





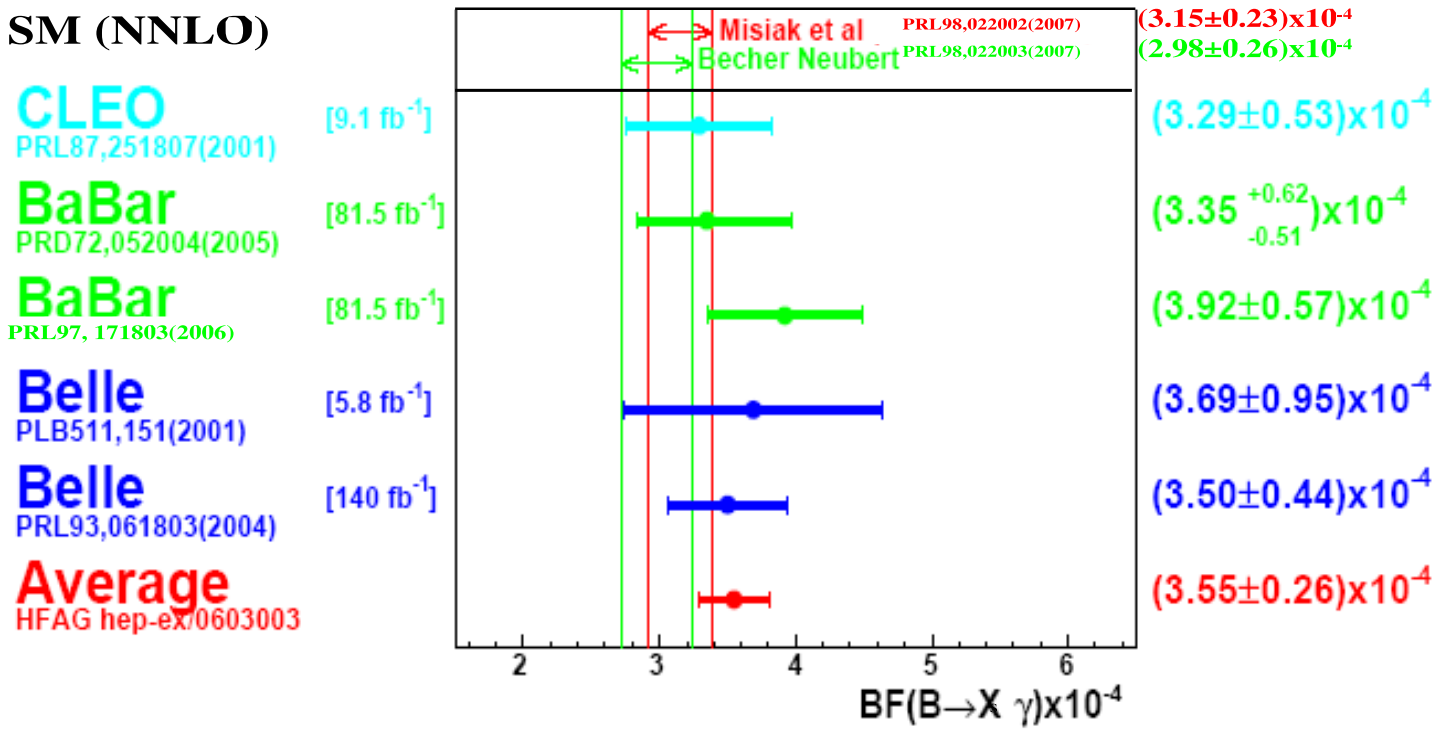
- Combined fit to $b \to cl\nu$ and $b \to s\gamma$ moments

- HQE parameters (in kinetic scheme, Buchmuller *et al*, PRD73, 073008(2006)):

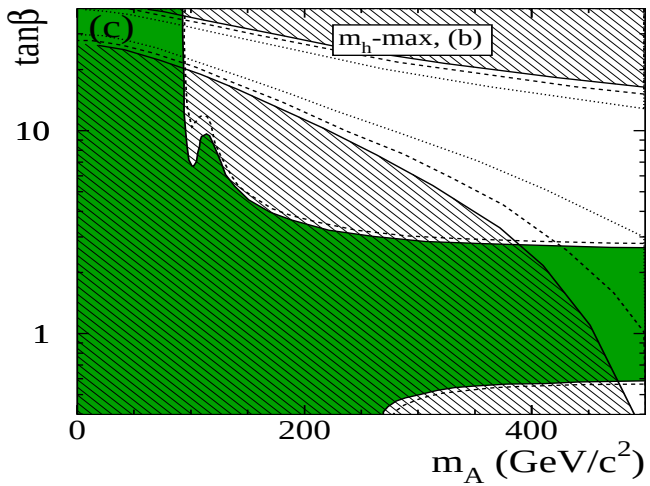
$$m_b = 4.590 \pm 0.025_{exp} \pm 0.030_{HQE}\ GeV$$
$$\mu_\pi^2 = 0.401 \pm 0.019_{exp} \pm 0.035_{HQE}\ GeV^2$$
$$|V_{cb}| = (41.96 \pm 0.23_{exp} \pm 0.35_{HQE} \pm 0.59_{\Gamma_{sl}}) \times 10^{-3}$$

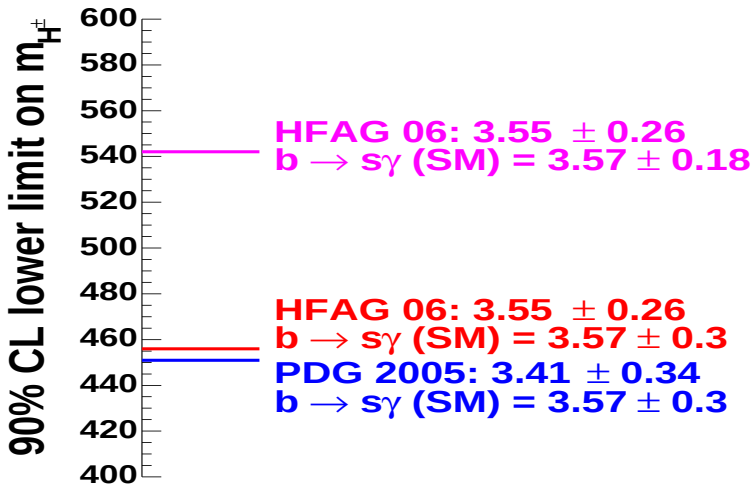
- m_b can be used for $|V_{ub}|$

Inclusive $b \to s\gamma$: A little Summary



$b \to s\gamma$ 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