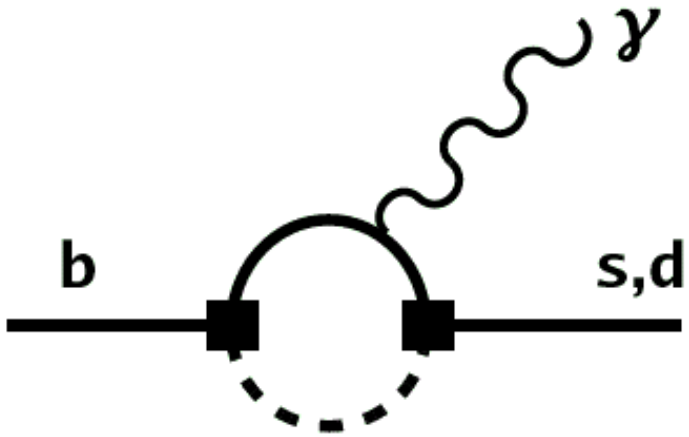
CP violation in radiative B decays at Belle

TCPV

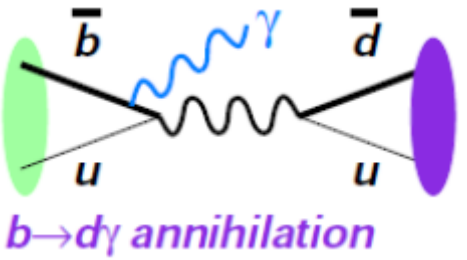
- $b \rightarrow s\gamma$ ($B \rightarrow Ks\pi^0\gamma$)

DCPV

Introduction



Charged b→dγ

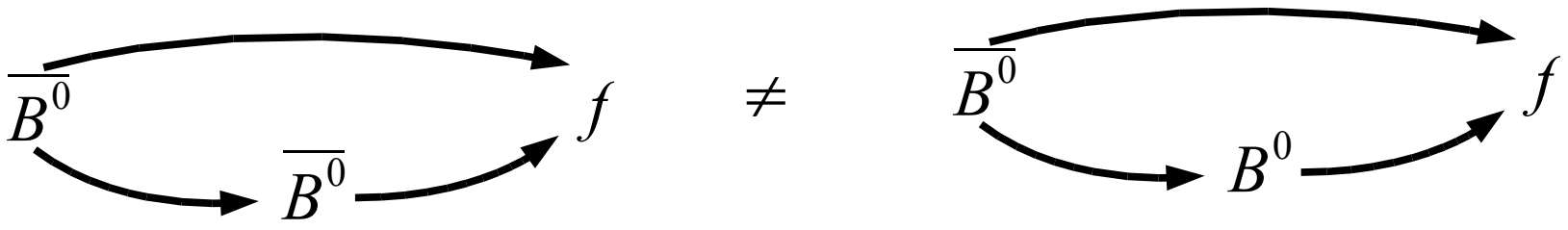


- b→(s,d) γ :FCNC(Flavor Changing Neutral Current) process.
- Sensitive to New Physics in the EW penguin (loop) diagram, doesn't require new phases.
- Theoretically clean (hadronic uncertainty small).
- b→dγ suppressed by $|V_{td}/V_{ts}|^2$ compared to b→sγ.

Measurements of the B.F. of inclusive and exclusive b → sγ processes.

- tCPV (photon polarization), very small in SM.
- Charge asymmetry (DCPV) of b → sγ.

Time-Dependent CP violation(tCPV)



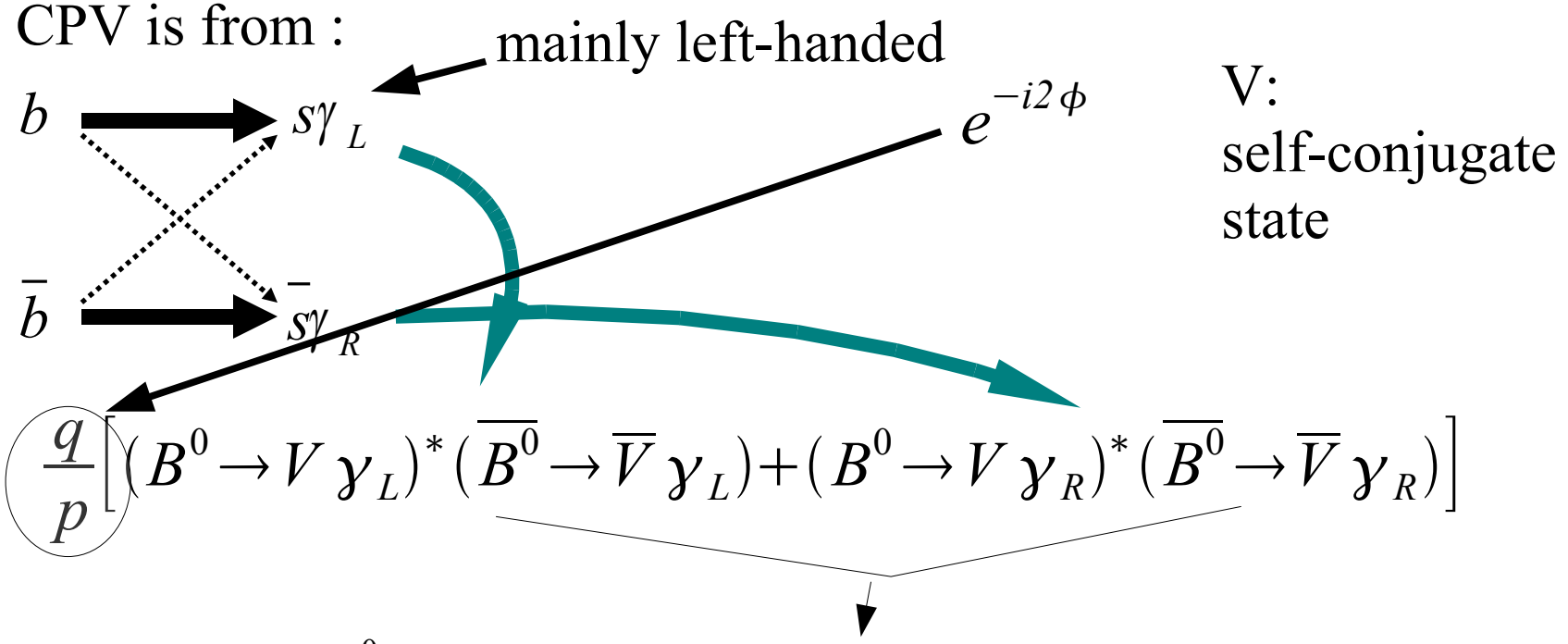
$$\mathrm{Im}\left(\frac{q}{p}\frac{\overline{A_f}}{A_f}\right) \qquad \text{Invariant quantity}$$

$$\frac{\Gamma(\overline{B^0}(t)\to f_{CP})-\Gamma(B^0(t)\to f_{CP})}{\Gamma(\overline{B^0}(t)\to f_{CP})+\Gamma(B^0(t)\to f_{CP})}=S\sin(\Delta Mt)+A\cos(\Delta Mt)$$

tCPV in Radiative B Decays

AGS method. -PRL 79,185(1997) (D.~Atwood, M.~Gronau and A.~Soni,)

CPV is from :



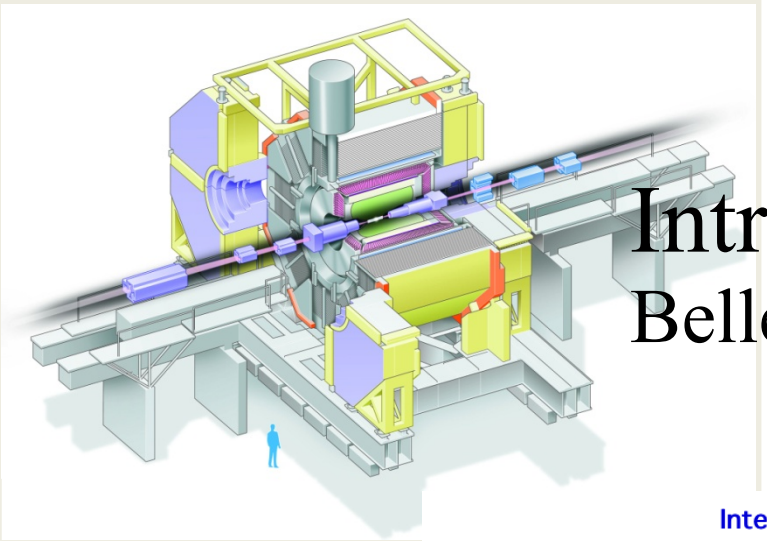
Eg: In B→ Ksπ^{0}γ decay, S ≈ − 2(m$_s$/m$_b$)sin 2φ$_1$

Final state can multibody states (P^{0}Q^{0}γ) with C eigenstate mesons.

- PRD 71,076003(D. Atwood, T. Gershon, M. Hazumi and A. Soni)-

Belle Detector & Luminosity

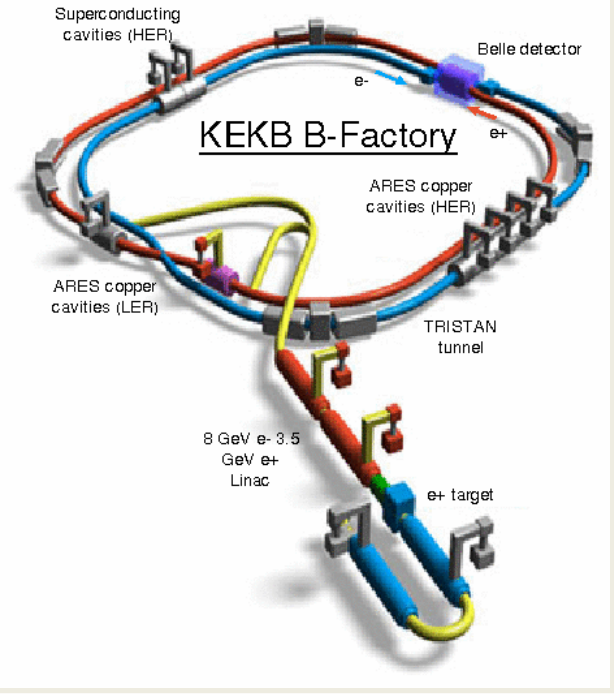
13 countries
55 institutes
~400 collaborators



Crab cavity installed!

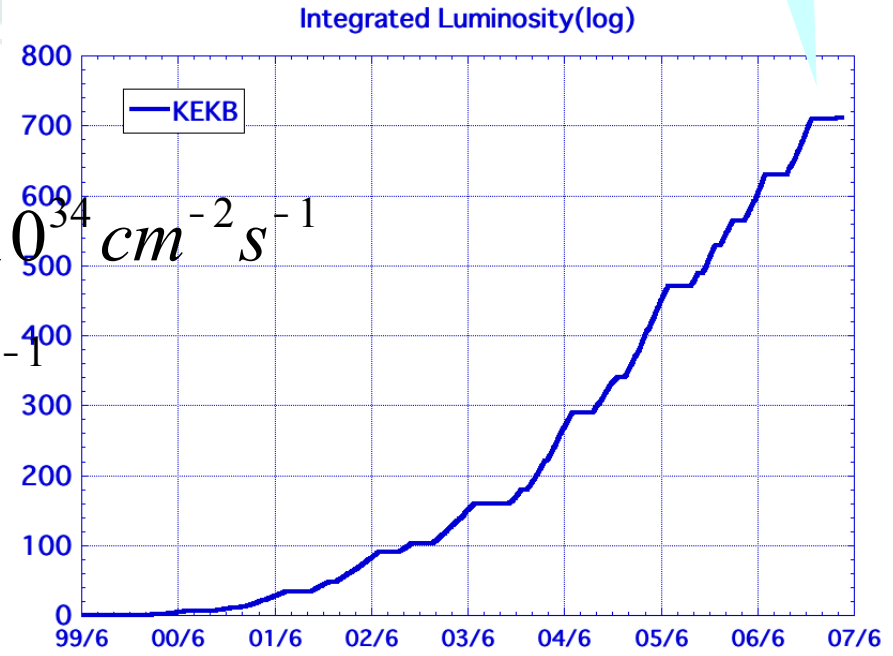
Introduction
Belle & KEKB

GeV (e^-) × 3.5GeV ($e+$)



$$L_{peak} = 1.71 \times 10^{34}\, cm^{-2} s^{-1}$$

$$\int Ldt = 710\, fb^{-1}$$

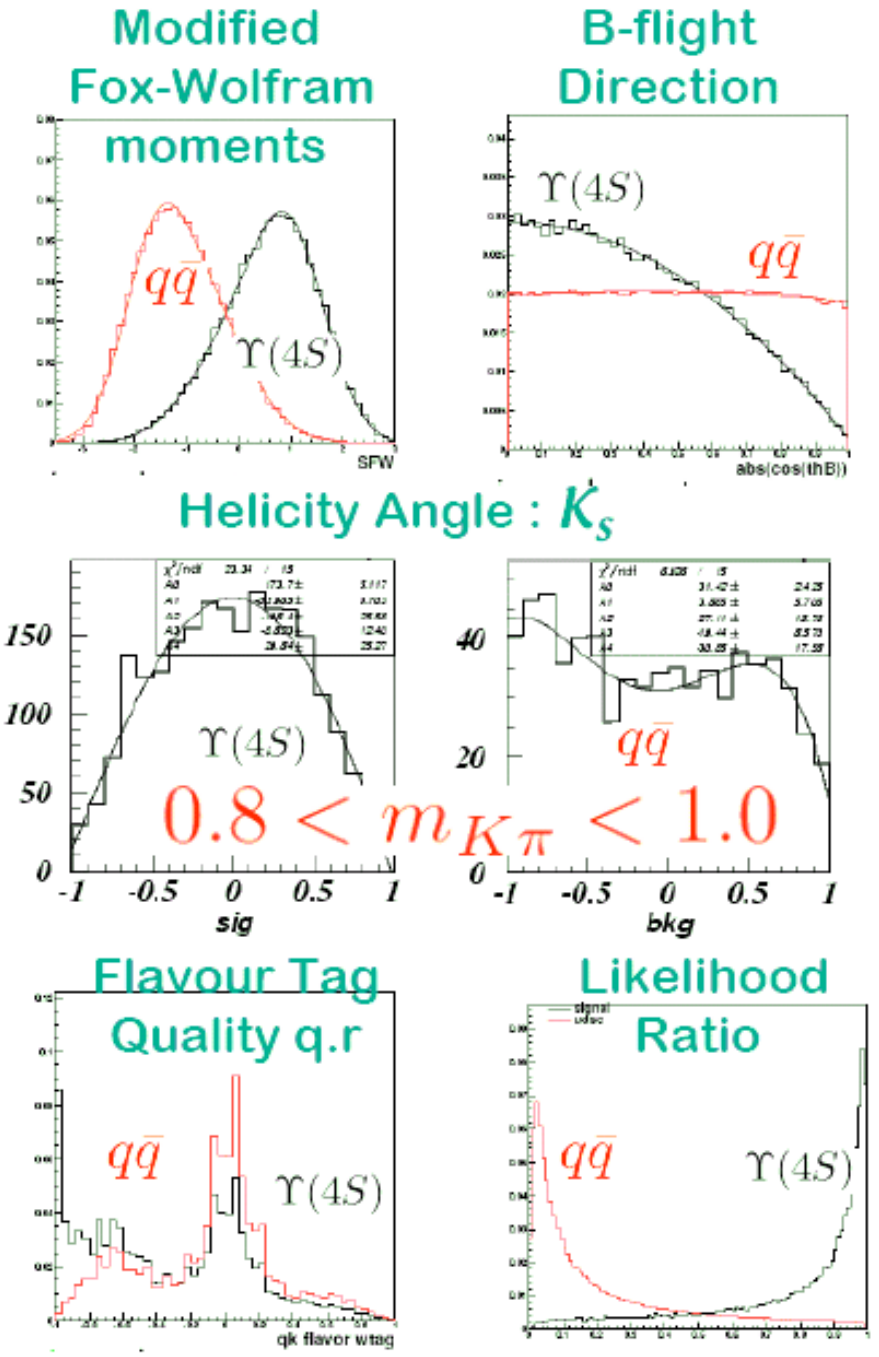


$B^0 \rightarrow K_s \pi^0 \gamma$ selection

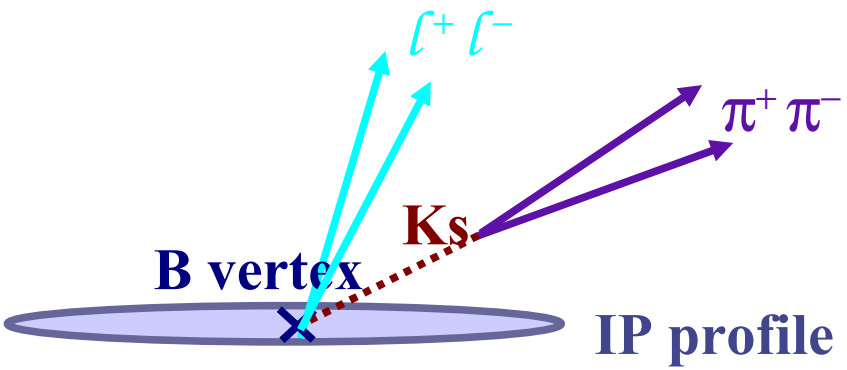
Extended from K* region to $M(K_s \pi^0) < 1.8$ GeV

Continuum supression:
Likelihood constructed from
- Modified Fox-Wolfram moments (Event Shape)
- $\cos(\theta_B)$
- Helicity in $K_s \pi^0$ system for three different $M(K_s \pi^0)$ regions

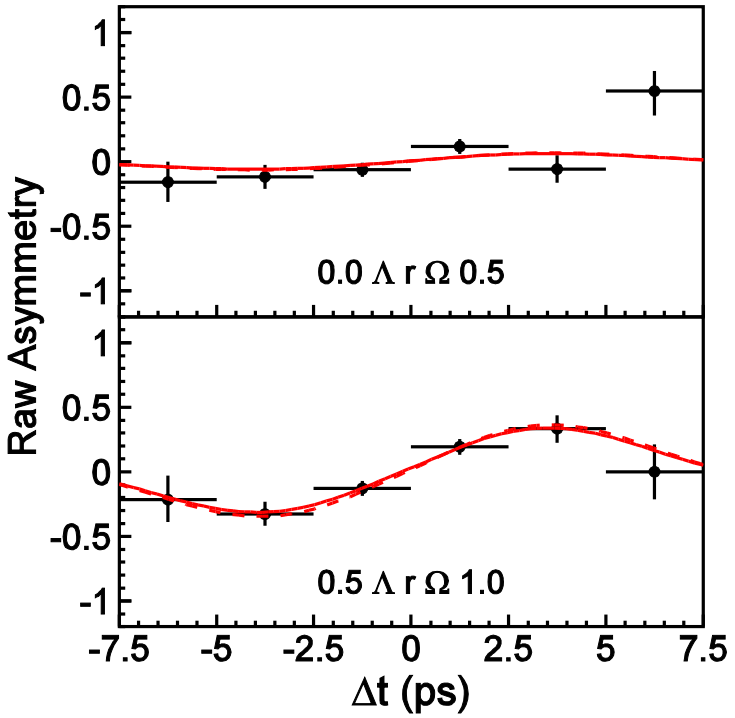
Flavor tag quality dependent Likelihood cuts.



Ks vertexing



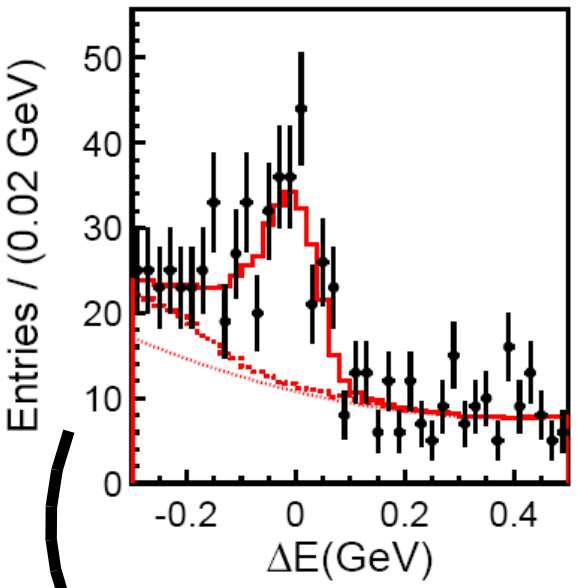
$$S(J/\psi\ K_S) = +0.666 \pm 0.046$$
$$A(J/\psi\ K_S) = +0.023 \pm 0.031$$

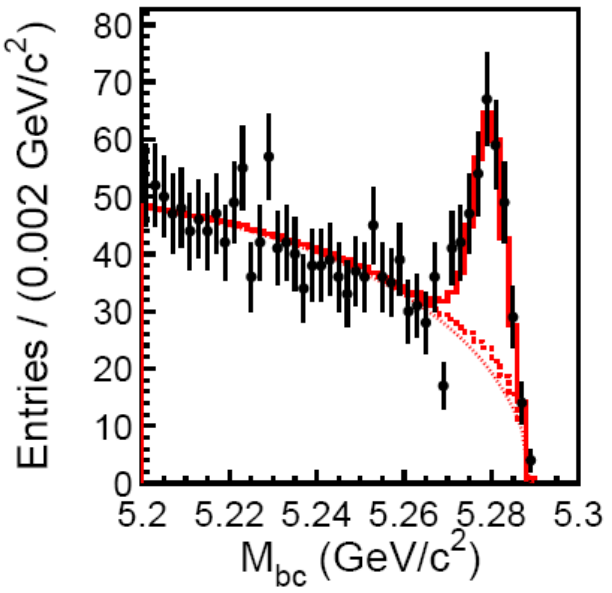


Using Ks vertexing:

$$S(J/\psi\ K_S) = +0.68 \pm 0.10$$
$$A(J/\psi\ K_S) = +0.02 \pm 0.04$$

$B^0 \rightarrow Ks\pi^0\gamma$ Signal yields





Data sample:
535 Million Bbbar

2D fit:
- Signal: (2D histogram)
- Continuum:
  Argus*2nd order
  Polynomial
- BBbar (2D histogram)

$M(Ks\pi^0)<1.8$ GeV:
Yield = 176.4±17
S/N = 1.42

With vertexing

$0.8<M(Ks\pi^0)<1.0$ GeV:
Yield = 112.5±12
S/N = 1.91

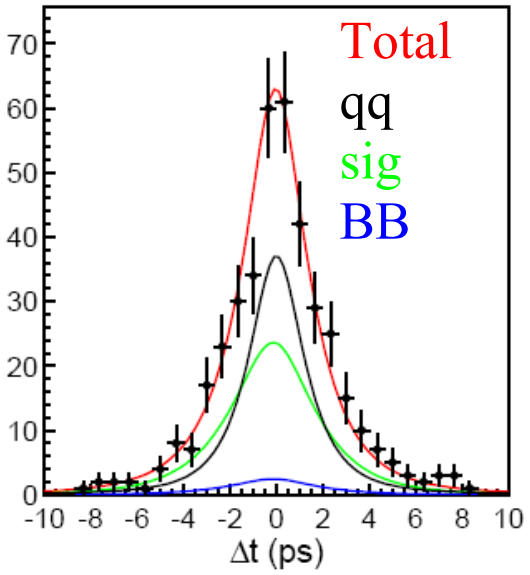
$B^0 \to K_S \pi^0 \gamma$ Lifetime and CP fit

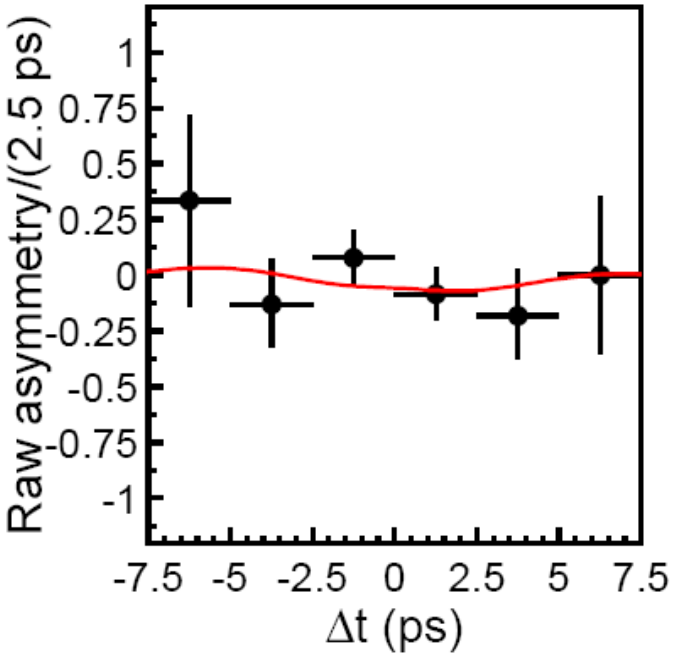
535 Million Bbbar

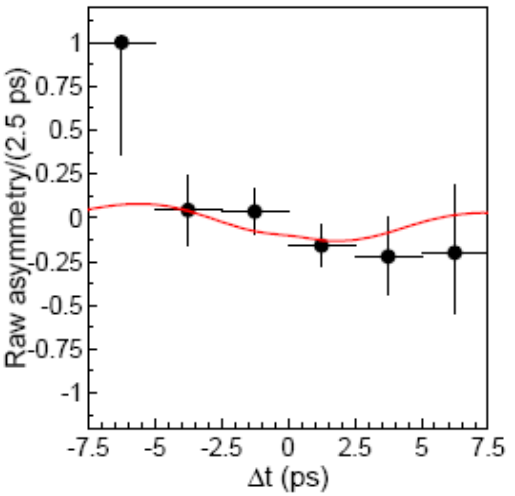
$M(K_S\pi^0)<1.8$ GeV

Good tag

$0.8<M(K_S\pi^0)<1.0$ GeV







$$\tau_{K^0_S\pi^0\gamma} = 1.53^{+0.19}_{-0.17}$$

Nominal:

τ_{B0}=1.530±0.009 ps

For $M(K_S\pi^0)<1.8$ GeV

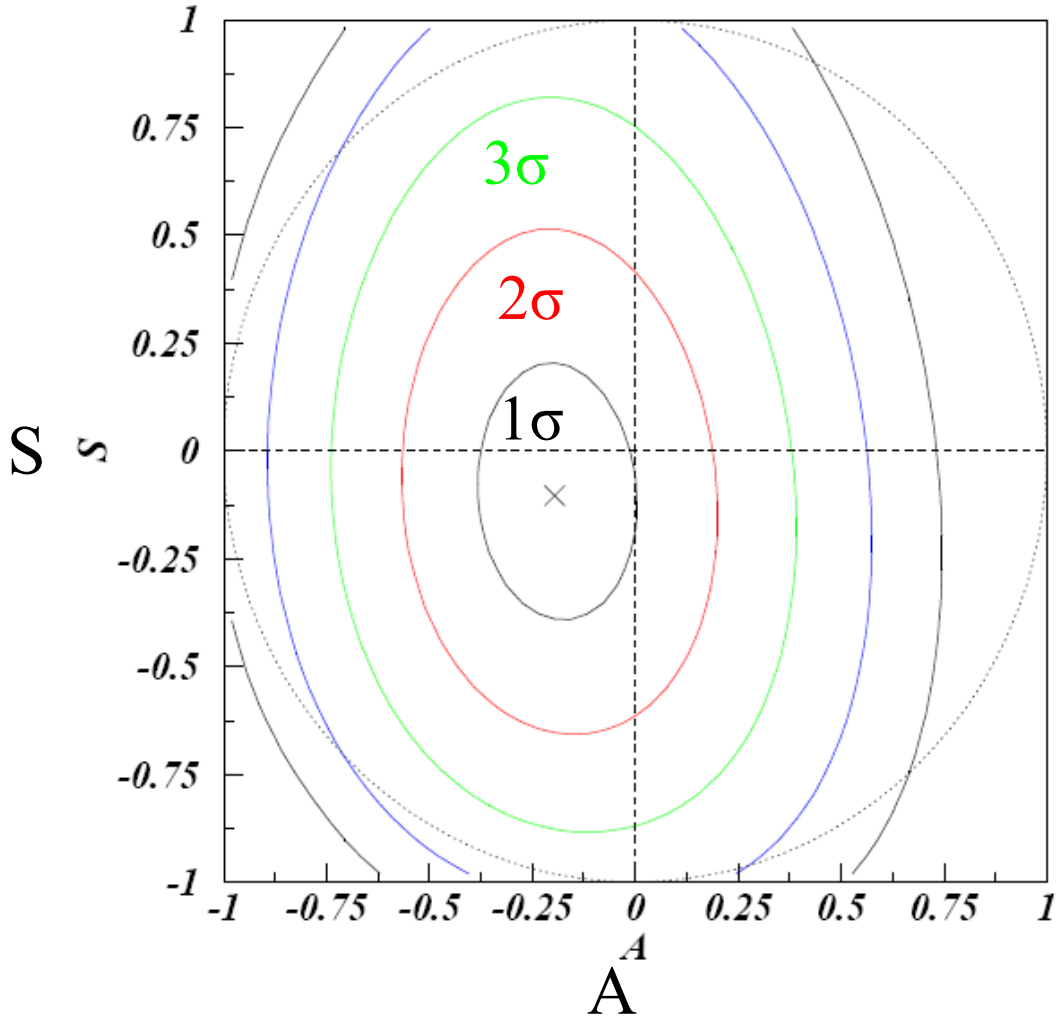
$$S = -0.10 \pm 0.31 \pm 0.07$$

$$A = -0.20 \pm 0.20 \pm 0.06$$

$$S = -0.32^{+0.36}_{-0.33} \pm 0.05$$

$$A = -0.20 \pm 0.24 \pm 0.05$$

Likelihood and Systematics



Systematic errors

category	$\mathcal{S}$	$\mathcal{A}$
physics	0.009201	0.012314
background Δt	0.007177	0.003541
flavor tagging	0.007120	0.004745
signal fraction	0.060995	0.032658
fit bias	0.005853	0.003742
resolution function	0.025238	0.009851
vertex reconstruction	0.009238	0.021139
tag-side interference	0.002000	0.041000
sum	0.068321	0.059094

Other Radiative B decay modes

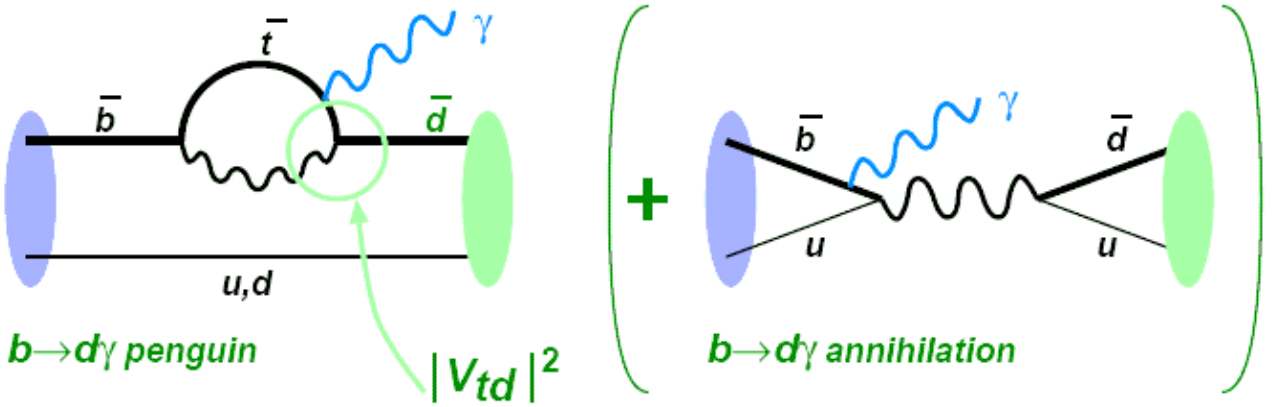
- tCPV for other $b \to s\gamma$ processes:($B^0 \to K^0\varphi\gamma$, $K^0\eta\gamma$,$K^0\eta'\gamma$).
- TCPV for $b \to d\gamma$ (Observed by Belle and Babar).
- DCPV for $b \to d\gamma$ ($B^+ \to \rho^+\gamma$): SM expectation ~20%.

-C.D. Lu, et al., PRD,72,094005

$b \to d\gamma$ in exclusive processes

- Sensitive to $|V_{td}|$, or $|V_{td}/V_{ts}|$ w.r.t. b→sγ.
- Sensitive to New Physics in the transition, since $|V_{td}|$ in SM is strongly suppressed.
- expect Large Direct CPV (penguin + annihilation)

-C.D. Lu, et al.,PRD72,094005(2005)-



Exclusive modes are straightforward experimentally:

$$B^- \to \rho^- \gamma\,,\ \bar{B}^0 \to \rho^0 \gamma\,,\ \bar{B}^0 \to \omega\,\gamma$$

(SU(3) breaking effect , annihilation contamination in the charged mode).
-PLB595,323(2004)-

$b \rightarrow d\,\gamma$ in exclusive processes

$B \rightarrow (\rho,\omega)\gamma$ Observed in Belle and Babar.

$$BF(B^- \rho^- \gamma) = 2\frac{\tau_{B^+}}{\tau_{B^0}} BF(\overline{B^0} \rightarrow \rho^0 \gamma) = 2\frac{\tau_{B^+}}{\tau_{B^0}} BF(\overline{B^0} \rightarrow \omega \gamma)$$

$$(1.32^{+0.34\,+0.10}_{-0.31\,-0.09}) \times 10^{-6} (5.1\sigma)$$

-PRL 96,221601 (2006)-

BABAR: $(1.25^{+0.25}_{-0.24} \pm 0.11) \times 10^{-6} (6.4\sigma)$

-PRL 98,151802 (2007)-

- DCPV for $B^+ \rightarrow \rho^+ \gamma$

Direct CP asymmetry in b→sγ

$$A_{CP}=\frac{\Gamma(b\to s\gamma)-\Gamma(\bar{b}\to\bar{s}\gamma)}{\Gamma(b\to s\gamma)+\Gamma(\bar{b}\to\bar{s}\gamma)}$$

Very small in SM: -Nucl.Phys.B704,56(2005)-

$$A_{CP}^{SM}=(4.2^{+1.7}_{-1.2})\times10^{-3}$$

HFAG: $A_{CP}=(4\pm37)\times10^{-3}$

- Belle 140 fb^{-1}: $(2\pm50\pm30)\times10^{-3}$
- BaBar 82 fb^{-1}: $(25\pm50\pm15)\times10^{-3}$
- CLEO 9.1fb^{-1}: $(-79\pm108\pm22)\times10^{-3}$

- To update with semi-inclusive reconstruction.

- BaBar inclusive: $A_{CP}(B\to X_{(s+d)}\gamma)=-0.110\pm0.115\pm0.017$
- Note Possible cancellation of $A_{CP}(B\to X_s\gamma)$ and $A_{CP}(B\to X_d\gamma)$

Summary

- TCPV in $B^0 \to K_S \pi^0 \gamma$: $M(K_S \pi^0) < 1.8$ GeV

$$S = -0.10 \pm 0.31 \pm 0.07$$
$$A = -0.20 \pm 0.20 \pm 0.06$$

- Expecting TCPV and DCPV in $b \to d\gamma$
- All results are statistically limited.

BACKUP

Exclusive B mode techniques

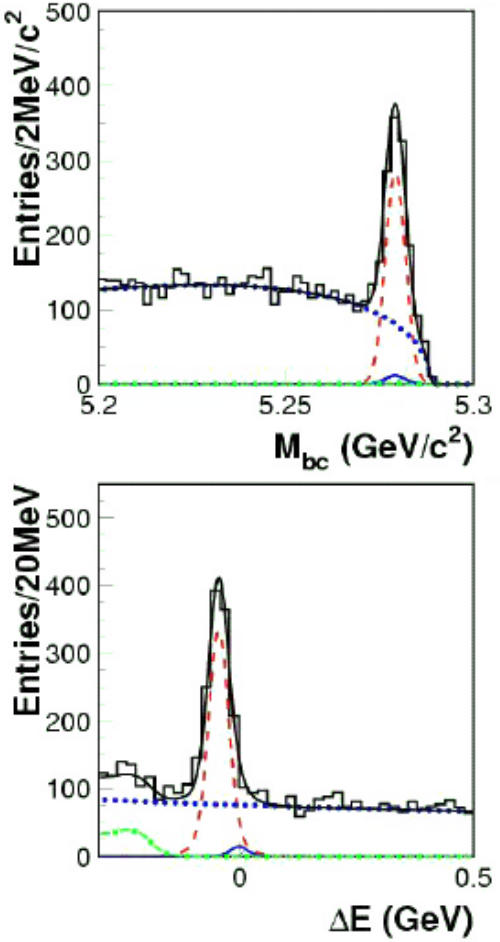
Two main variables:

Beam-constrained mass
(independent of particle id)

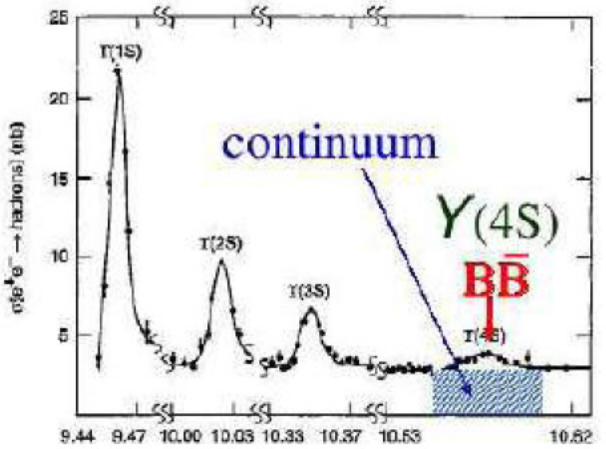
$$M_{bc} = \sqrt{E^{*2}_{beam} - |\vec{p}^{\,*}_B|^2}$$

Energy difference

$$\Delta E = E_B - E_{beam}$$

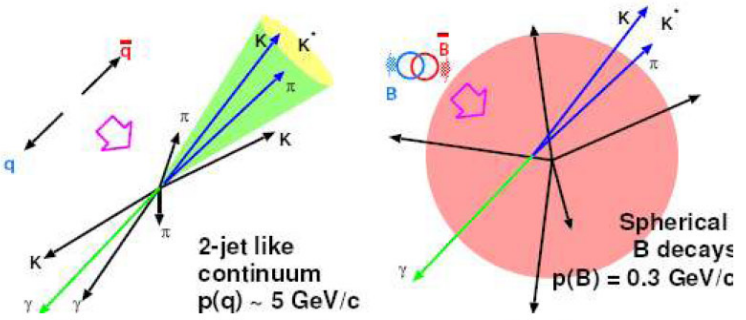


Continuum



Event Shape discrimination

continuum B B



Inclusive b→sγ branching fraction

NNLO prediction:

$\mathcal{B}(B\to X_s\gamma;\ E_\gamma>1.6\ \text{GeV}) = (2.98\pm0.26)\times10^{-4}$

[Becher & Neubert, PRL 98,022003 (2007)]

Experimental average: (HFAG)

$\mathcal{B}(B\to X_s\gamma;\ E_\gamma>1.6\ \text{GeV}) = (3.55\pm0.24^{+0.09}_{-0.10}\pm0.03)\times10^{-4}$

1.4σ deviation