

Workshop on the Interplay Between Collider and Flavo(u)r Physics

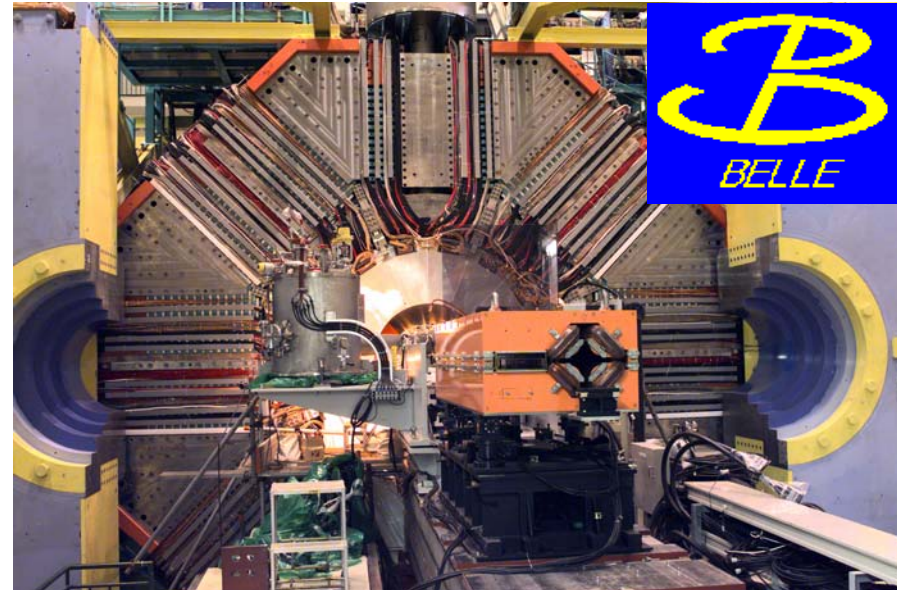
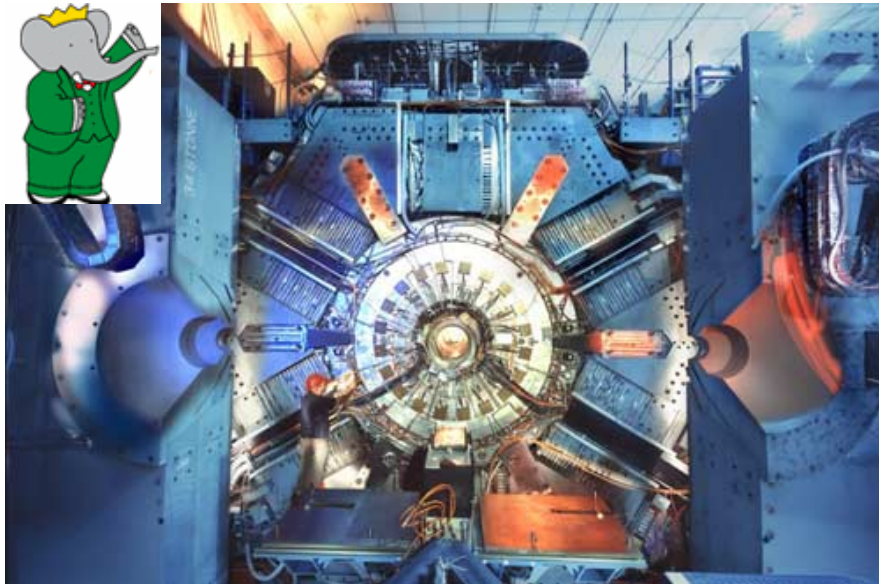
B Factory Results and Prospects

Outline:

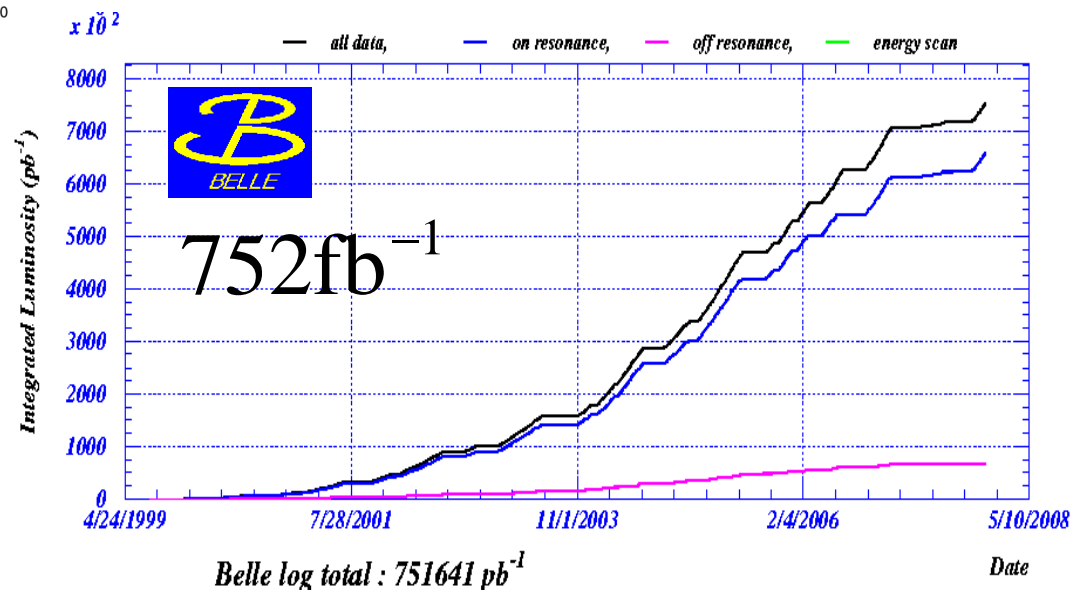
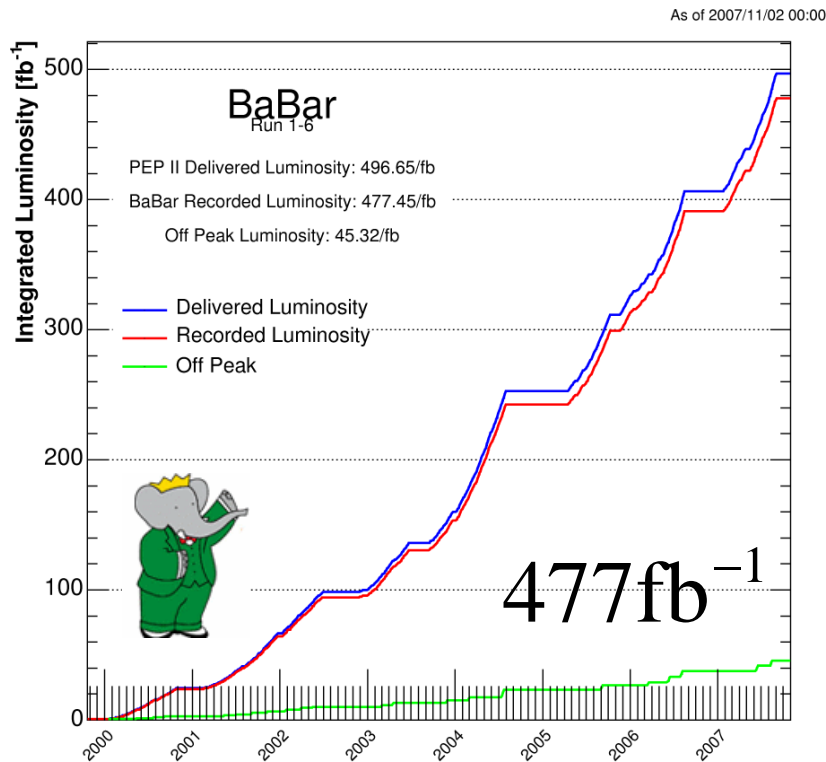
- a few words on CKM
- $b \rightarrow s(g, \gamma, l^+l^-)$
- $b \rightarrow d(g, \gamma)$
- rare decays and D mixing

James D. Olsen

Princeton University
(on behalf of BaBar and Belle)



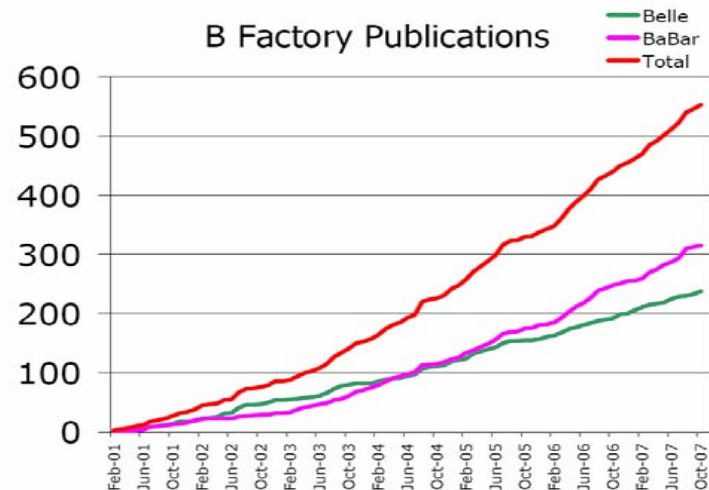
Status of the B Factories



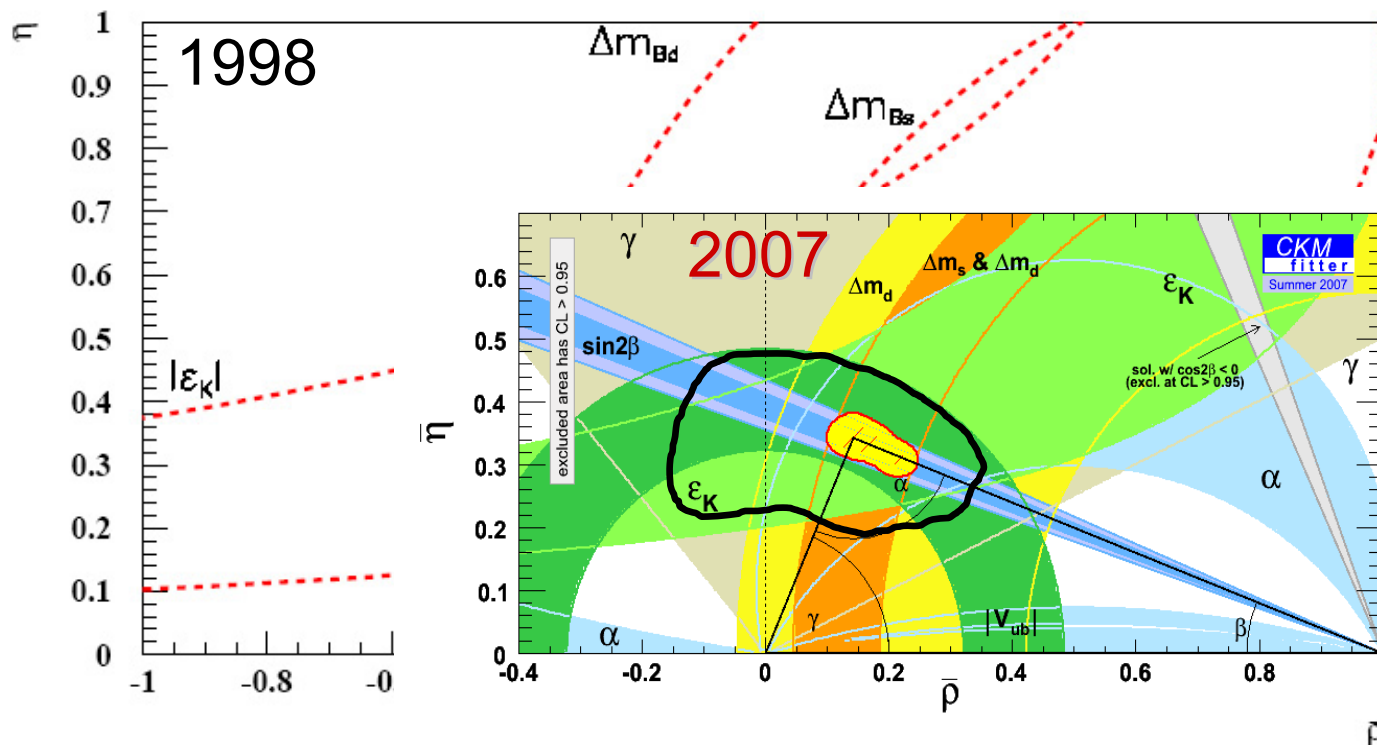
Expected by summer 2008:

$$L(\text{Belle}) = 1 \text{ ab}^{-1}, L(\text{BaBar}) = 0.750 \text{ ab}^{-1}$$

Most analyses use $\sim 490 \text{ fb}^{-1}$ (Belle) or $\sim 350 \text{ fb}^{-1}$ (BaBar), so expect effective **doubling** of total dataset by next summer

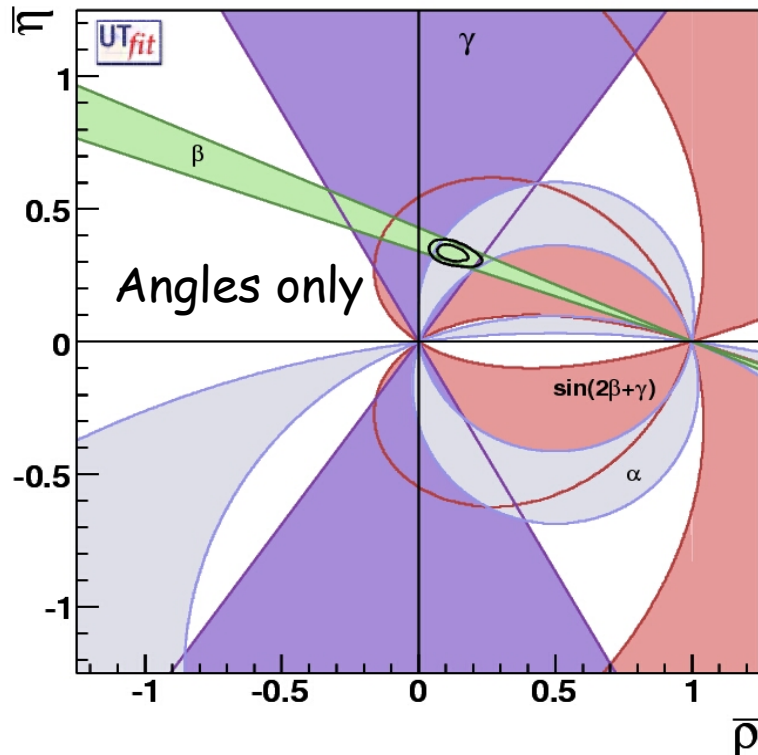


Impact of the B Factories and Tevatron



Enormous progress in the past decade has led to a paradigm change:
Use precision CKM measurements to search for New Physics (NP)

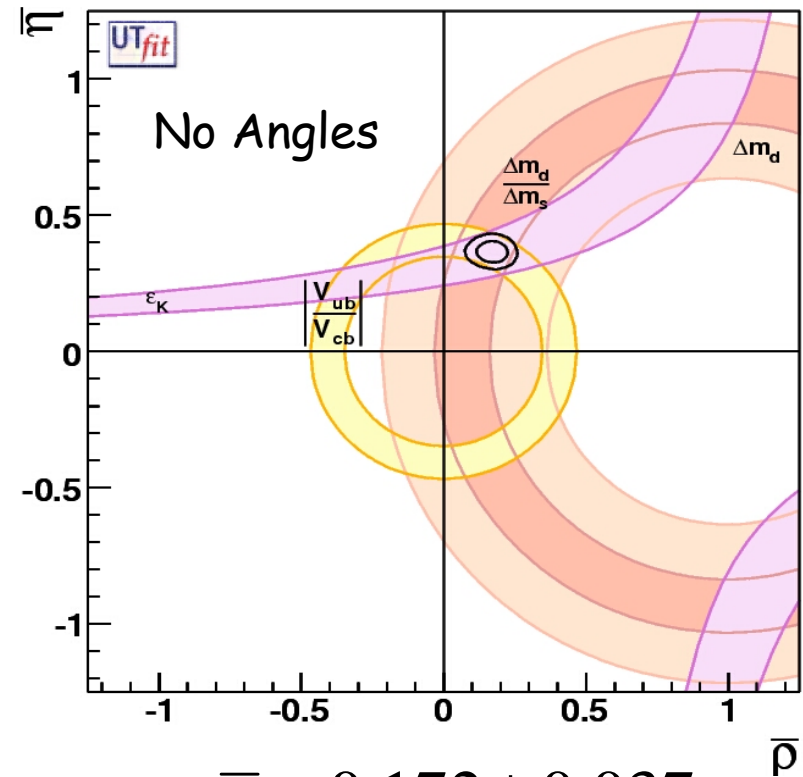
Over-constraining CP Violation



$$\bar{\rho} = 0.120 \pm 0.038$$

$$\bar{\eta} = 0.332 \pm 0.021$$

Errors dominated by statistics

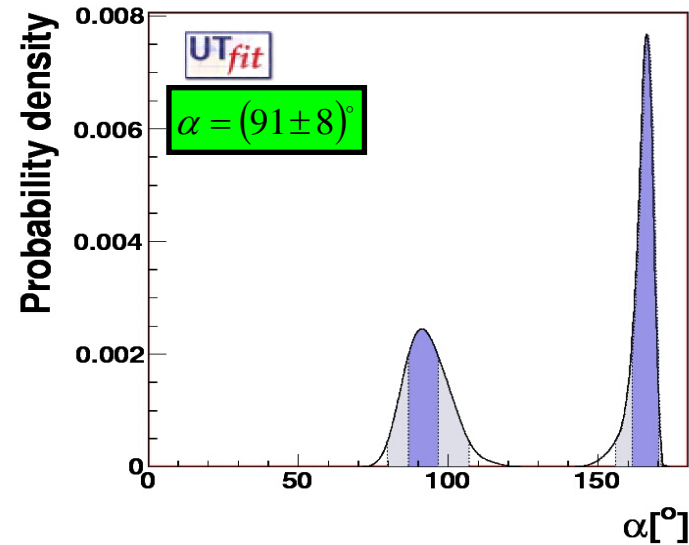
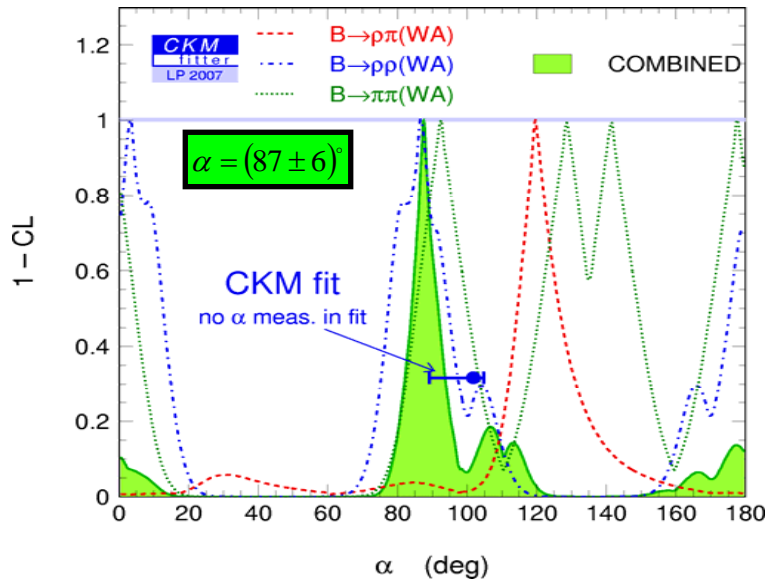


$$\bar{\rho} = 0.172 \pm 0.037$$

$$\bar{\eta} = 0.365 \pm 0.026$$

Errors dominated by systematics (thy+exp)

Status and Prospects for α

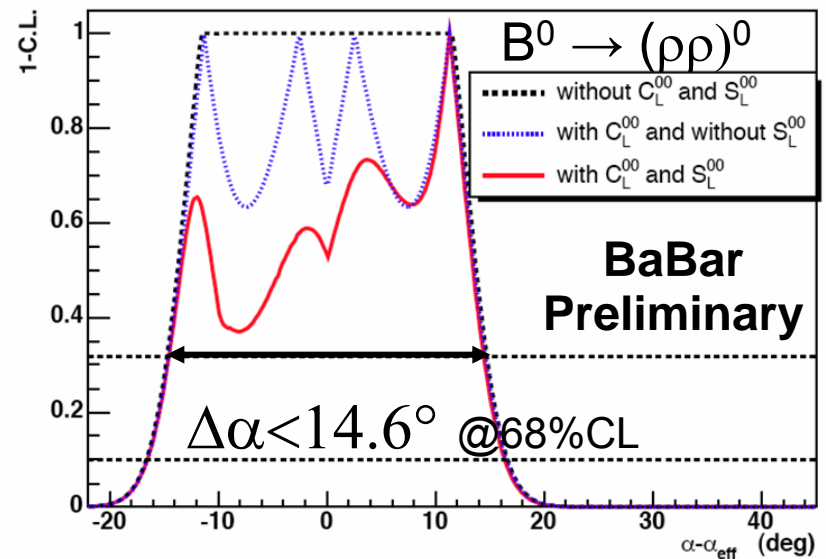


First time-dependent CPV measurement in $B^0 \rightarrow \rho^0 \rho^0$:

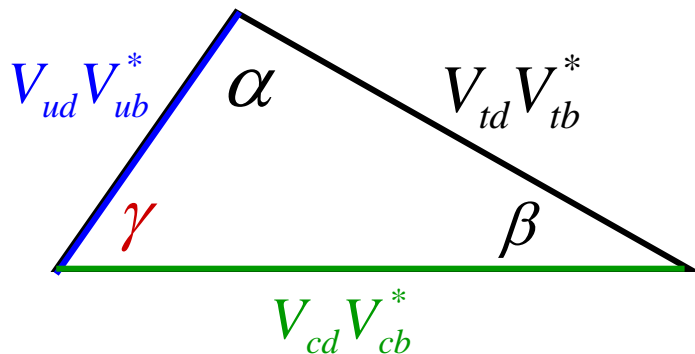


$$\begin{aligned}
 B &= (0.84 \pm 0.29 \pm 0.17) \times 10^{-6} \\
 f_L &= 0.70 \pm 0.14 \pm 0.05 \\
 S_L^{00} &= 0.5 \pm 0.9 \pm 0.2 \\
 C_L^{00} &= 0.4 \pm 0.9 \pm 0.2
 \end{aligned}$$

Final B Factory errors: $\sigma_S \sim 0.50$

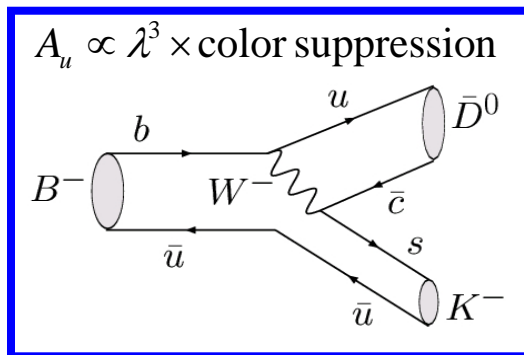
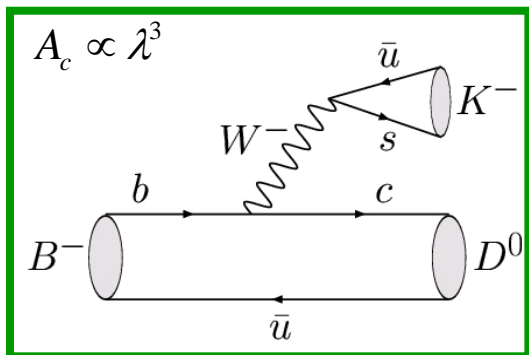


Measuring γ



Method	Modes	Adv.	Disadv.
GLW	$D^0(\text{CP}_{\pm})$	Constraints	Low stats, small interf.
ADS	$D^0(K\pi)$	Large interf.	Low stats
GGSZ	$D^0(K_s \text{hh})$ Dalitz	Large stats, Dalitz info	Dalitz model

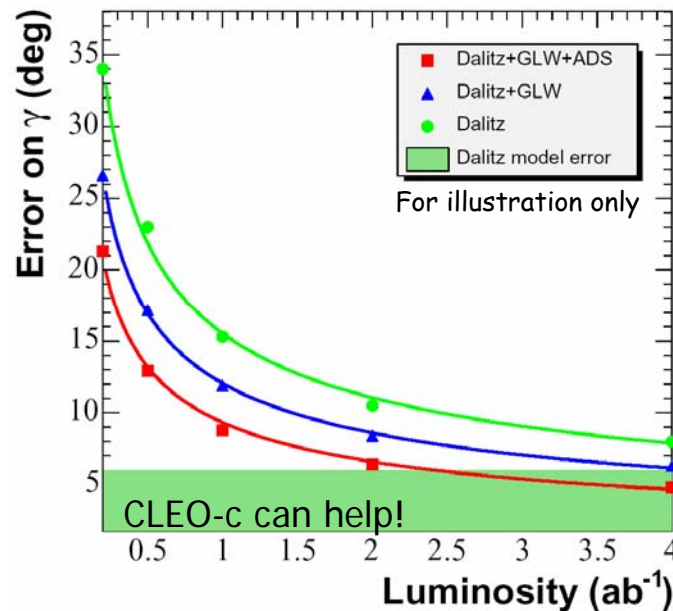
Can also measure $\sin(2\beta+\gamma)$ in tdcpv $B^0 \rightarrow DX$ decays



$$A_{CP} \equiv \frac{\Gamma(B^- \rightarrow DK^-) - \Gamma(B^+ \rightarrow DK^+)}{\Gamma(B^- \rightarrow DK^-) + \Gamma(B^+ \rightarrow DK^+)}$$

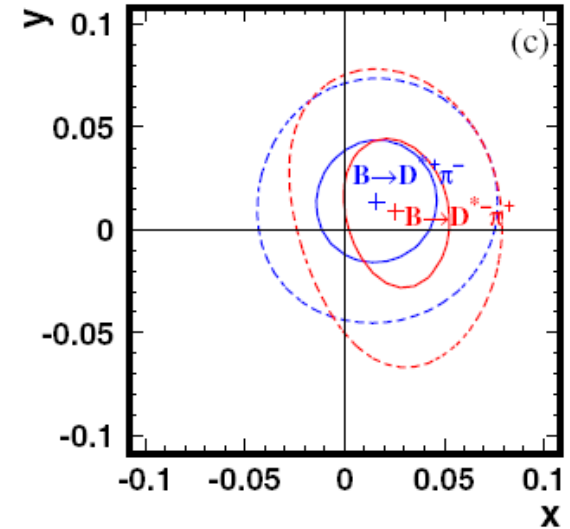
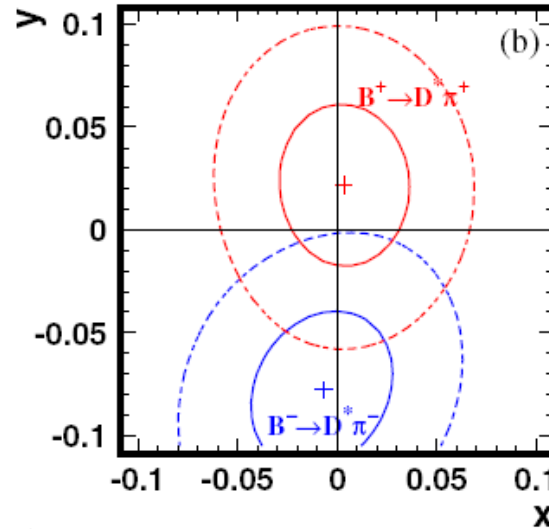
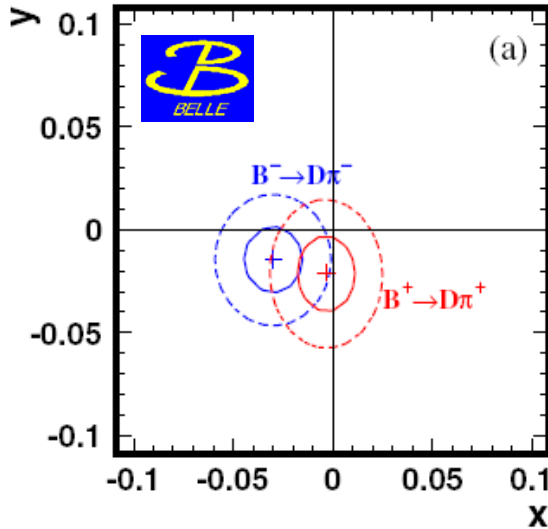
$$\propto r_B \sin \gamma \sin \delta$$

Combine all measurements!



Status and Prospects for γ

Belle data using $B \rightarrow DK$, D^*K , and D^*K^* with 357fb^{-1} :



$$\gamma = \left(53^{+15}_{-18} \pm 3 \pm 9 \right)^\circ$$

$$r_B = 0.16 \pm 0.07 \text{ (DK)}$$

$$= 0.18 \pm 0.12 \text{ (D}^*K\text{)}$$

$$= 0.56^{+0.24}_{-0.18} \text{ (D}^*K^*\text{)}$$

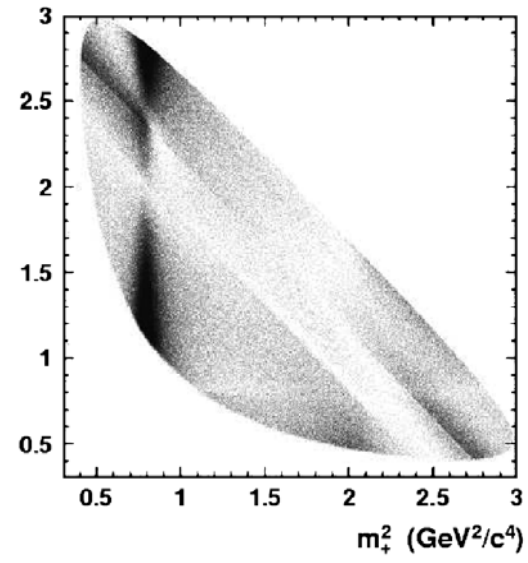


208fb^{-1}

$$\gamma = \left(92 \pm 41 \pm 11 \pm 12 \right)^\circ$$

$$r_B < 0.14 \text{ (DK)}$$

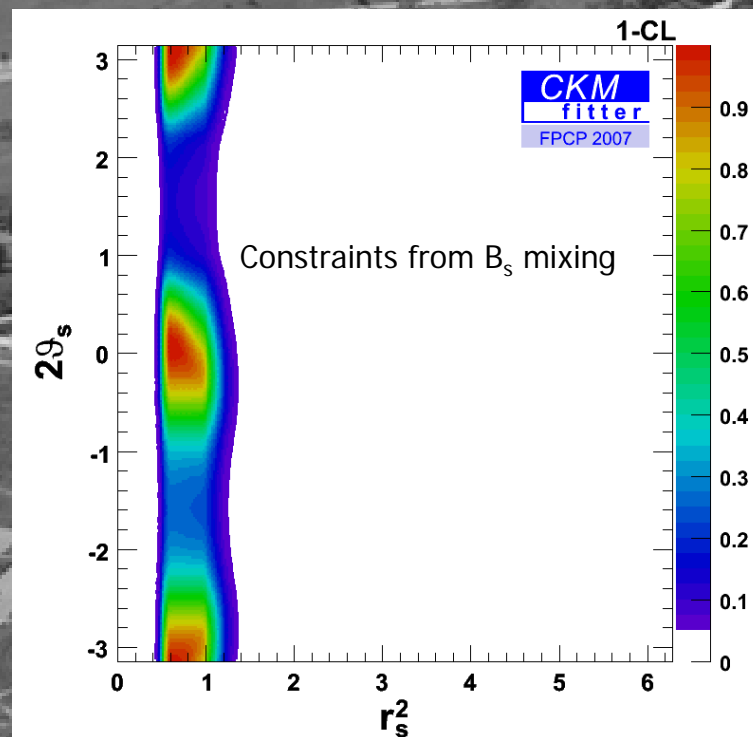
$$0.02 < r_B < 0.20 \text{ (D}^*K\text{)}$$



Depending on r_B , can get to $\sigma_{\text{stat}} \sim 8^\circ - 14^\circ$ with full dataset

Searching for New Physics in $b \rightarrow s$:

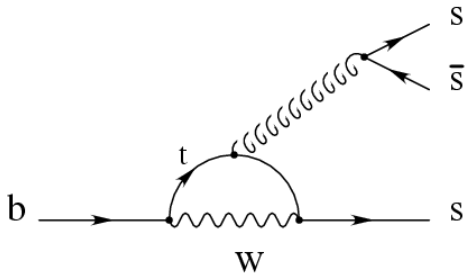
$b \rightarrow sg, b \rightarrow s\gamma, b \rightarrow sl^+l^-$



CP Violation in $b \rightarrow sg$

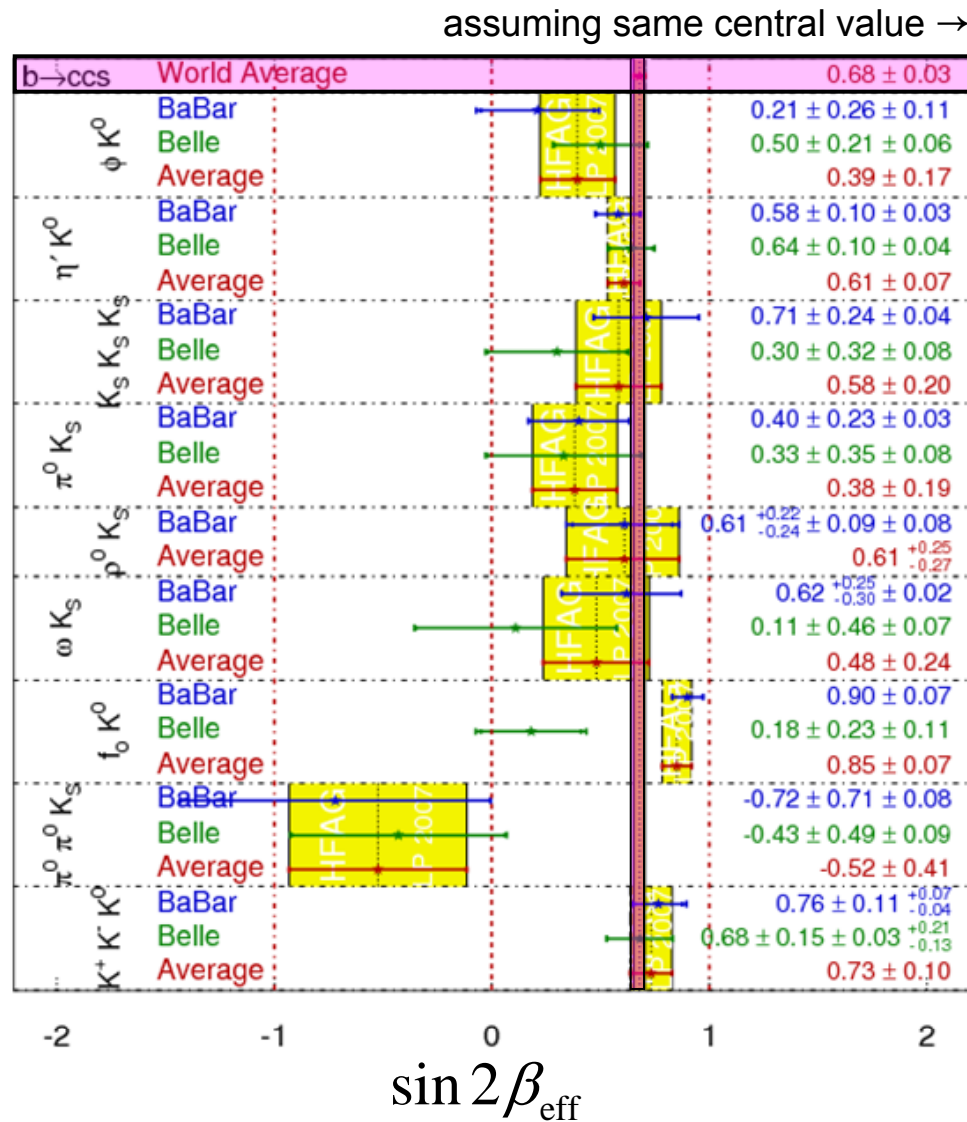
In the Standard Model :

$$|S| \approx \sin 2\beta \text{ for all } b \rightarrow sq\bar{q}$$

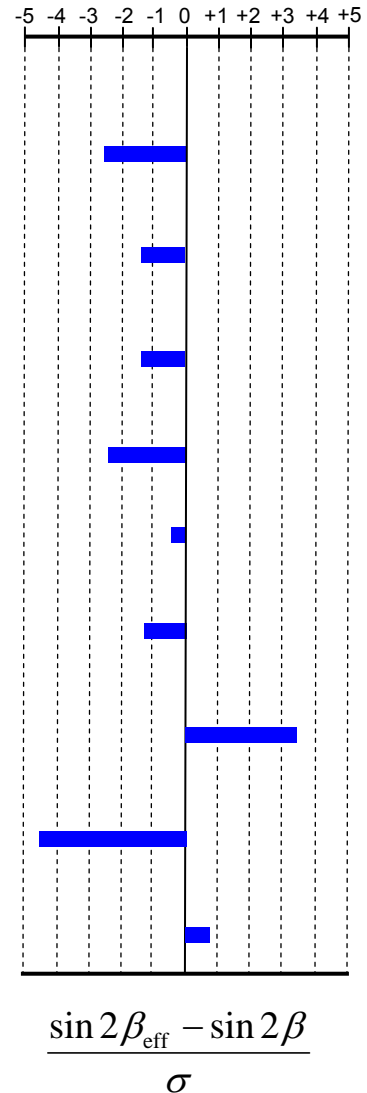


Assuming no change in central values by summer 2008, still two modes with $> 3\sigma$ discrepancy

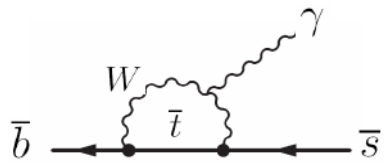
Interpretation limited by hadronic uncertainties



Summer 2008

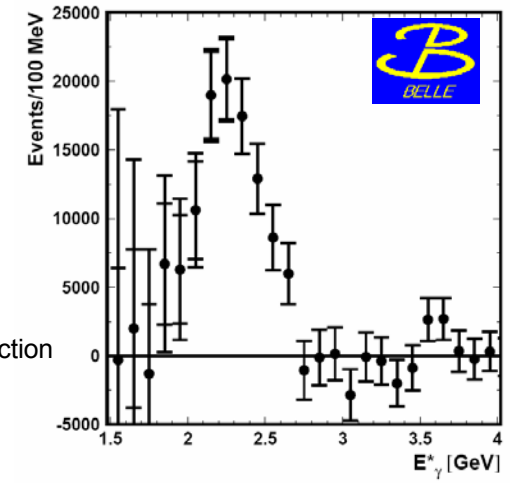
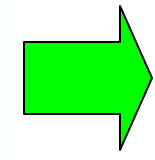
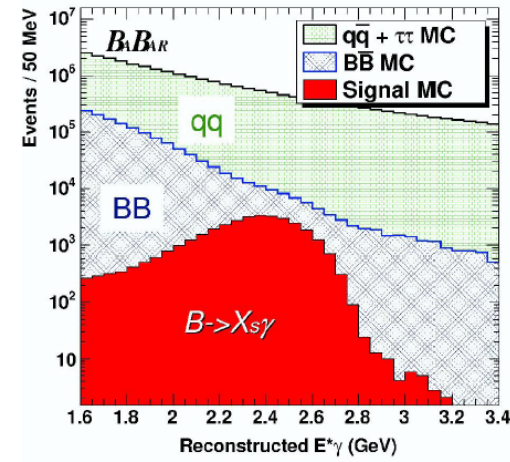


BR and A_{CP} in $b \rightarrow s\gamma$



Analysis techniques:

- I) Fully inclusive (hadronic or leptonic tag)
- II) semi-inclusive (sum of exclusive modes)



$$BF(b \rightarrow s\gamma) \times 10^6 = 355 \pm 24(\text{exp})_{-10}^{+9}(\text{s.f.}) \pm 3(d\gamma)$$

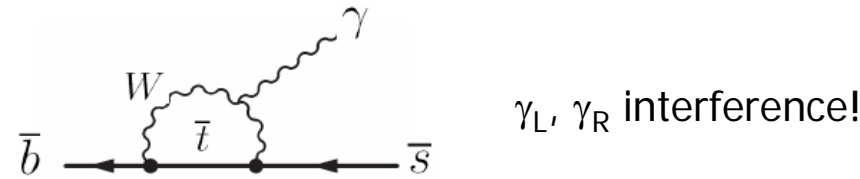
$$A_{CP}(b \rightarrow s\gamma) = (0.4 \pm 3.7)\%$$

Mode	L(fb ⁻¹)	E _{min}	\mathcal{B} at E _{min}	Modified \mathcal{B} (E _{min} = 1.6)
CLEO Inc. [3]	9.1	2.0	306 ± 41 ± 26	329 ± 44 ± 28 ± 6 ± 6
Belle Semi.[4]	5.8	2.24	—	369 ± 58 ± 46 ⁺⁵⁶ ₋₆₀
Belle Inc.[5]	140	1.8	351 ± 32 ± 29	350 ± 32 ⁺³⁰ ₋₃₁ ± 2 ± 2
BABAR Semi.[6]	81	1.9	327 ± 18 ⁺⁵⁵⁺⁴ ₋₄₃₋₉	349 ± 20 ⁺⁵⁹⁺⁴ ₋₄₆₋₃
BABAR Inc.[7]	81	1.9	367 ± 29 ± 34 ± 29	392 ± 31 ± 36 ± 30 ± 4 ± 6

Updated analyses from BaBar using > 300fb⁻¹ are coming!

- BF is systematics limited, fighting to < 5% difficult but not impossible
- A_{CP} (Δ₀- too!) statistics limited ("forever"), should scale with lumi

CP Violation in $B^0 \rightarrow (K_S \pi^0) \gamma$



$$A_{CP} \equiv \frac{\Gamma[\bar{B}^0 \rightarrow (K_S \pi^0) \gamma] - \Gamma[B^0 \rightarrow (K_S \pi^0) \gamma]}{\Gamma[\bar{B}^0 \rightarrow (K_S \pi^0) \gamma] + \Gamma[B^0 \rightarrow (K_S \pi^0) \gamma]}$$

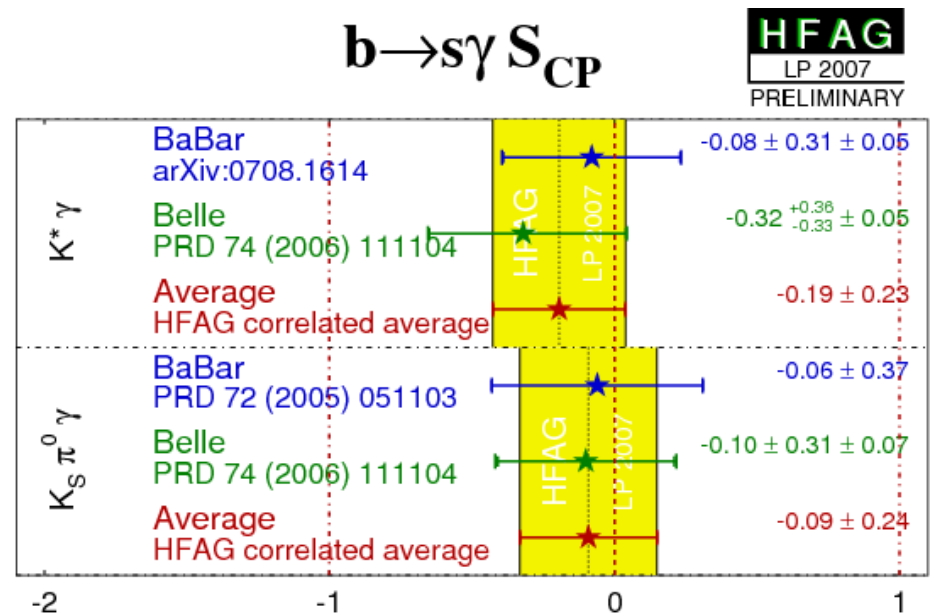
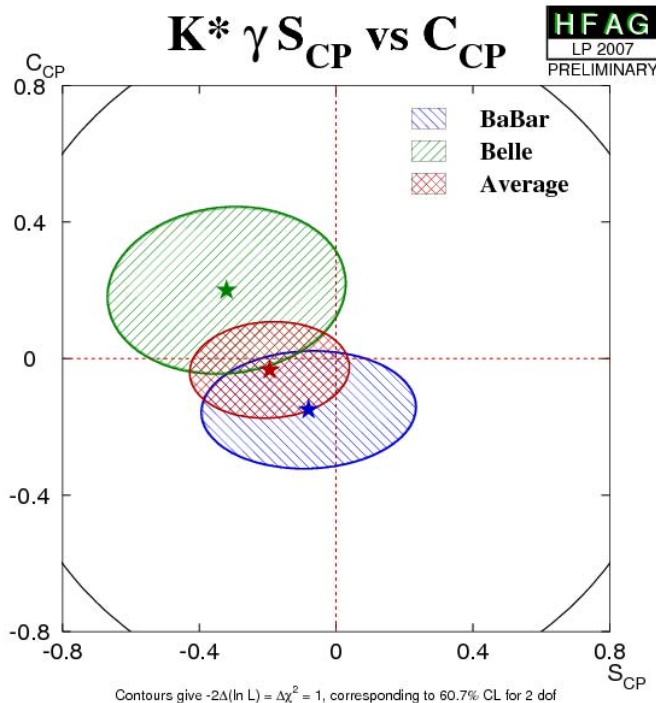
$$= S \sin(\Delta m \Delta t) - C \cos(\Delta m \Delta t)$$

SM spin-flip penalty: $S \propto m_s/m_b^* \sin 2\beta$

$$S^{SM} = S^{SM, s_R} + S^{SM, \text{soft gluons}} = -0.022 \pm 0.015^{+0}_{-0.01}$$

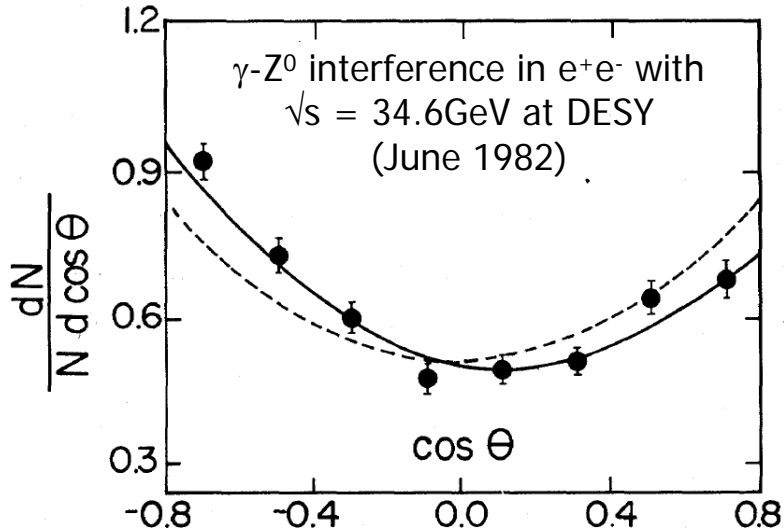
Ball and Zwicky Phys.Lett.B642:478-486,2006

- measurements statistics dominated (forever); expected final B Factory error ~ 0.17
- alternative analysis measuring photon helicity directly in $B \rightarrow K\pi\pi\gamma$ possible, but VERY difficult

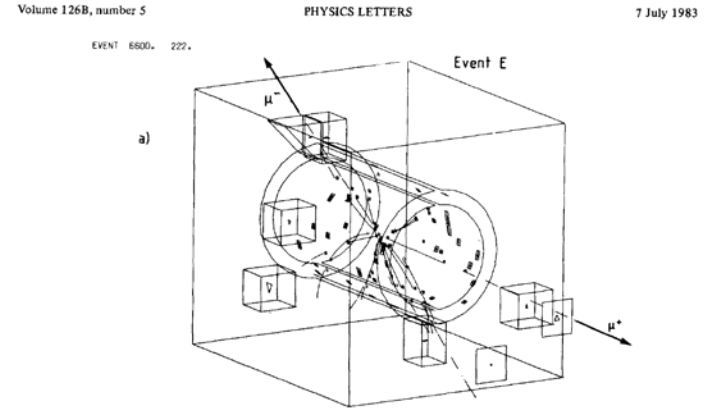


NP in FCNC: $B \rightarrow K^{(*)} l l$

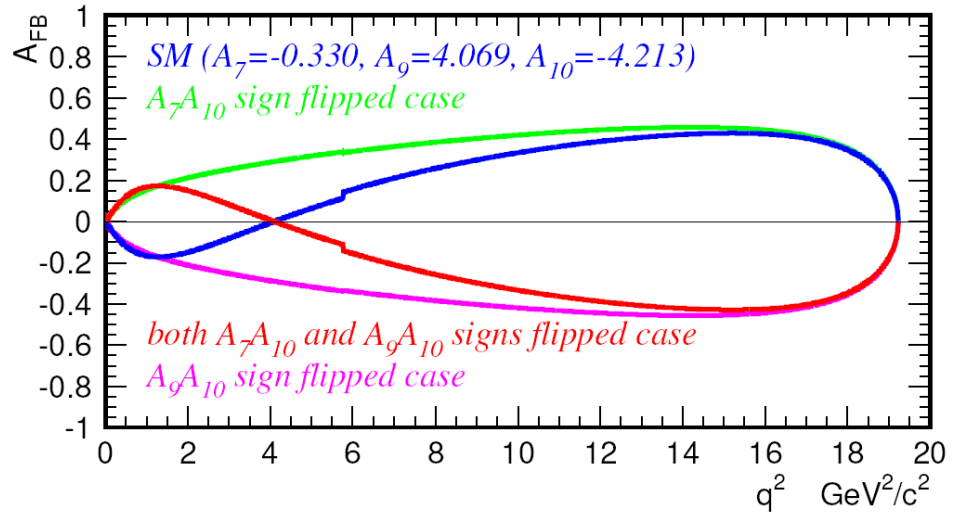
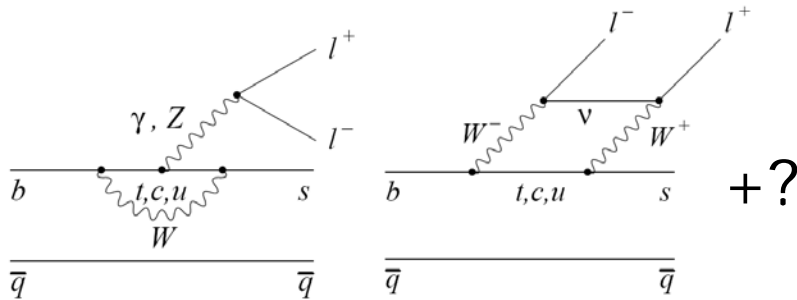
Historical example of interference and a new particle (Z^0):



Observation of Z^0 in UA1 (July 1983)



Modern opportunity in $B \rightarrow K^{(*)} l l$:



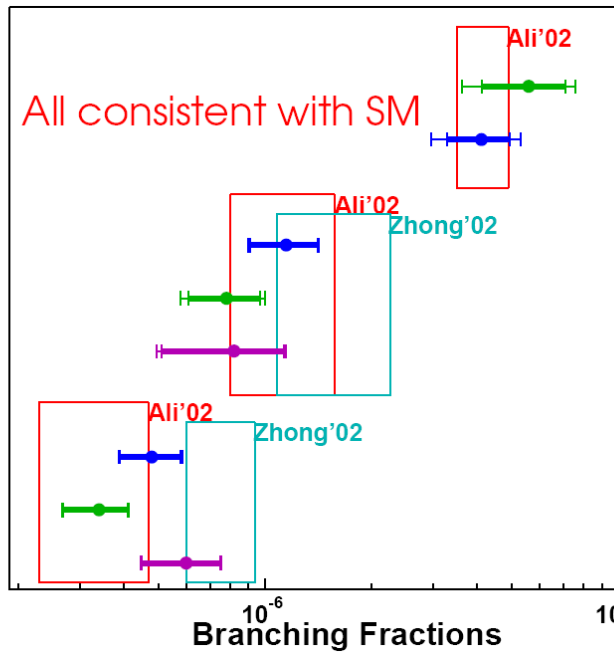
Results and Prospects for $B \rightarrow K^{(*)} \Pi$

M. Nakao LP07

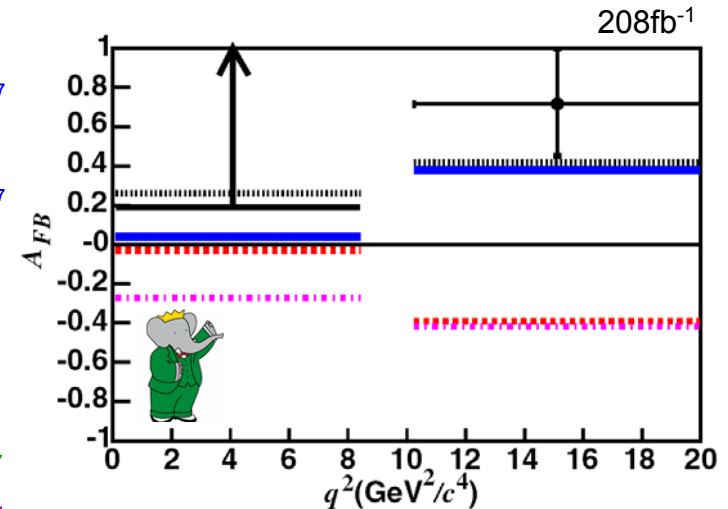
BaBar $X, I^+ I^-$ [89M BB]
PRL93,081802(2004)
Belle $X, I^+ I^-$ [152M BB]
PRD72,092005(2005)

Belle $K^+ I^-$ [152M BB]
PRL91,261601(2003)
BaBar $K^+ I^-$ [229M BB]
PRD73,092001(2006)
CDF $K^0 \mu^+ \mu^-$ [1 fb $^{-1}$]
CKM06 WS(2006)

Belle $K I^+ I^-$ [152M BB]
PRL91,261601(2003)
BaBar $K I^+ I^-$ [229M BB]
PRD73,092001(2006)
CDF $K^+ \mu^+ \mu^-$ [1 fb $^{-1}$]
CKM06 WS(2006)

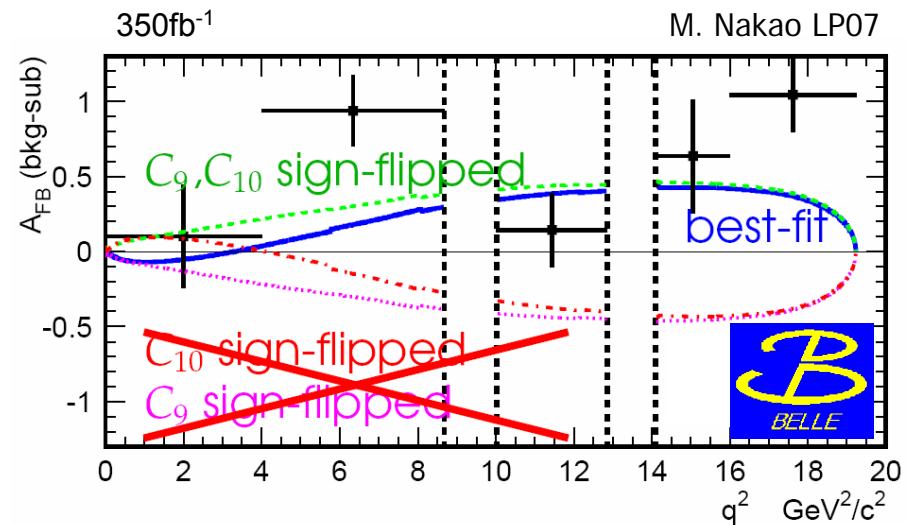


$(56 \pm 15 \pm 13) \times 10^{-7}$
 $(41.1 \pm 8.3^{+8.5}_{-8.1}) \times 10^{-7}$
 $(11.5^{+2.6}_{-2.4} \pm 0.8) \times 10^{-7}$
 $(7.8^{+1.9}_{-1.7} \pm 1.1) \times 10^{-7}$
 $(8.2 \pm 3.1 \pm 1.0) \times 10^{-7}$
 $(4.8^{+1.0}_{-0.9} \pm 0.3) \times 10^{-7}$
 $(3.4 \pm 0.7 \pm 0.2) \times 10^{-7}$
 $(6.0 \pm 1.5 \pm 0.4) \times 10^{-7}$



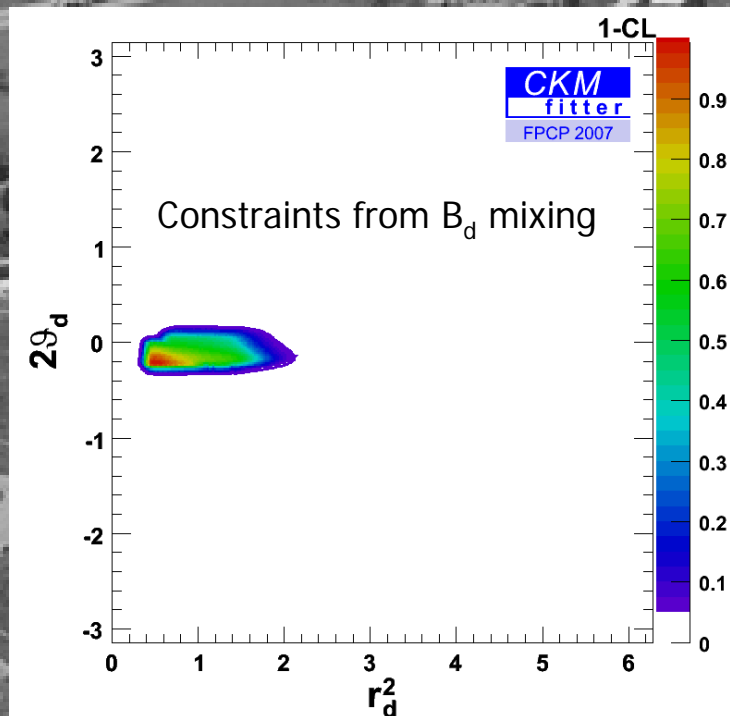
- BFs consistent with predictions
- A_{FB} inconsistent with C_9/C_{10} sign flip
- some "tension" (2σ) with SM @ low- q^2

B Factory dataset will triple in these modes by summer 2008 (more data \rightarrow more bins!)

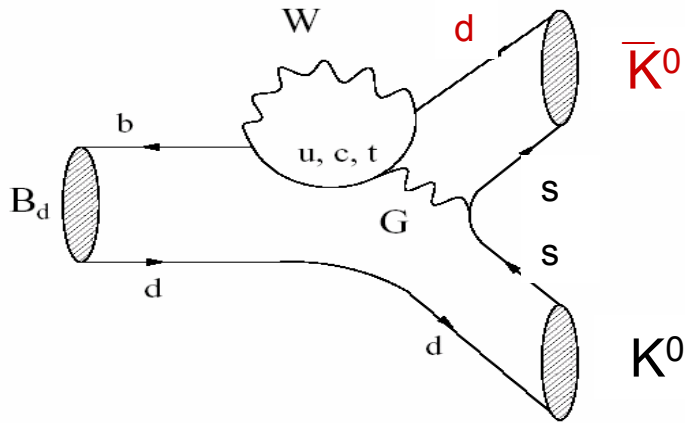


Searching for New Physics in $b \rightarrow d$:

$b \rightarrow dg, b \rightarrow d\gamma$



CP Violation in $B^0 \rightarrow K^0 K^0$



Weak phases from mixing and decay cancel if top dominates:

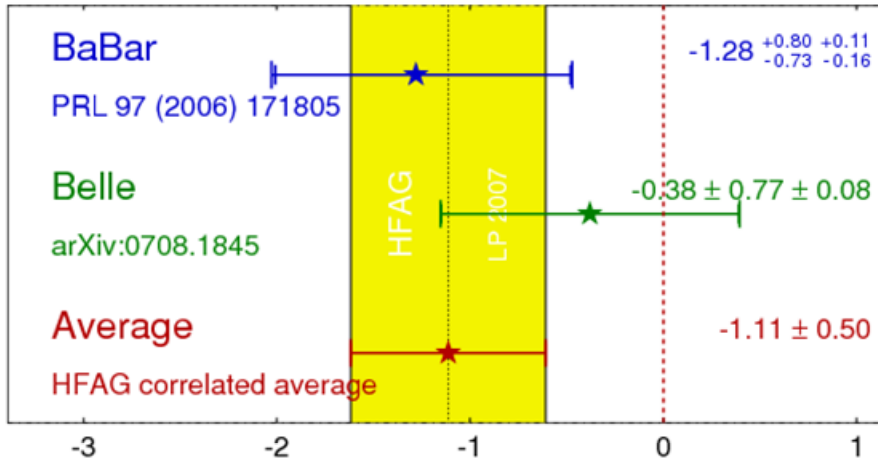
$$0.02 < S_{KK} \text{ (SM)} < 0.13$$

$$-0.17 < C_{KK} \text{ (SM)} < -0.15$$

Fleischer and Recksiegel, Eur.Phys.J.C38:251-259,2004

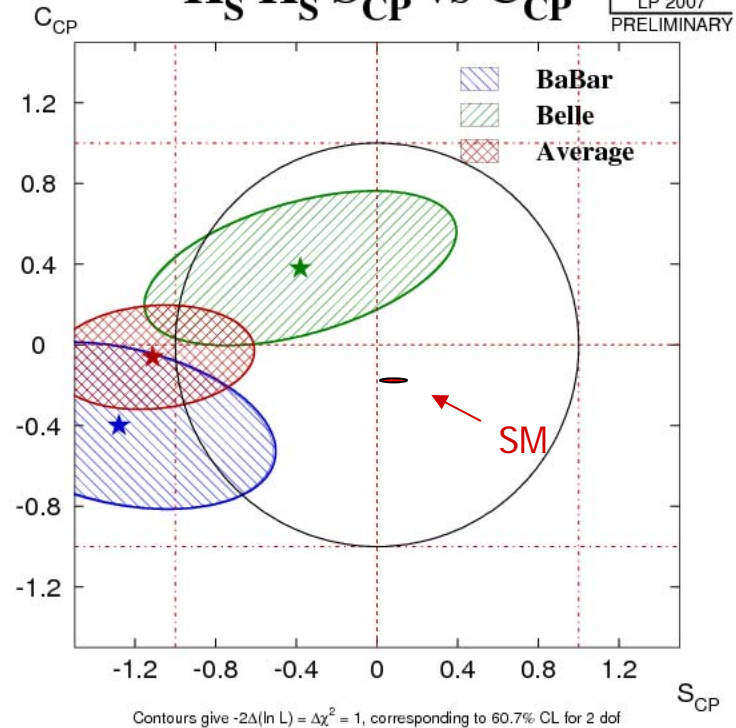
$K_S K_S S_{CP}$

HFAG
LP 2007
PRELIMINARY



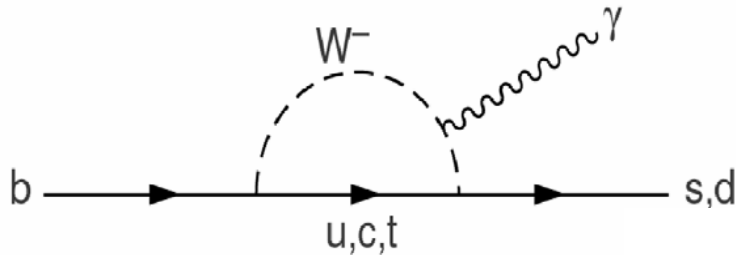
$K_S K_S S_{CP}$ vs C_{CP}

HFAG
LP 2007
PRELIMINARY



Final error from the B Factories ~ 0.36

CP Violation in $B \rightarrow \rho\gamma$



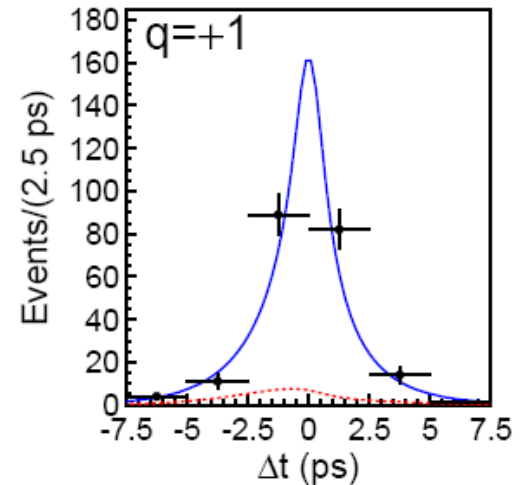
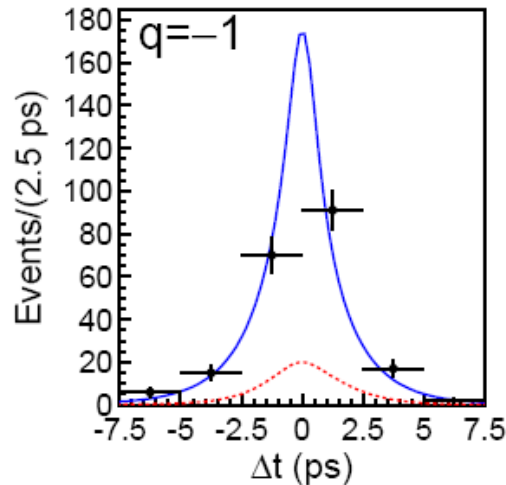
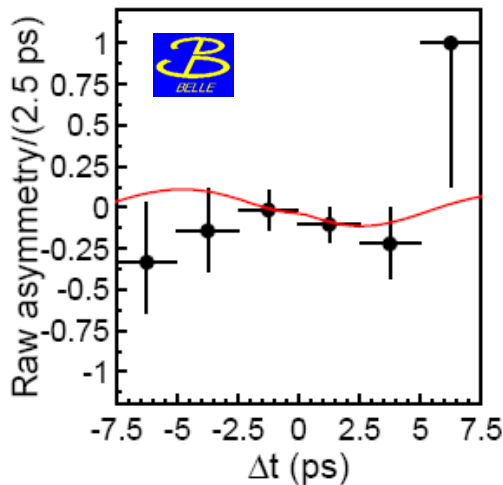
Weak phase ~cancels plus spin-flip penalty (m_d/m_b) → we really expect ~0!

$$S(\rho\gamma) = \left(\underbrace{0.01}_{m_D/m_b} + \underbrace{0.02}_{LD\ WA} + \underbrace{0.20}_{soft\ g} \right) \pm 1.6\% = (0.2 \pm 1.6)\%$$

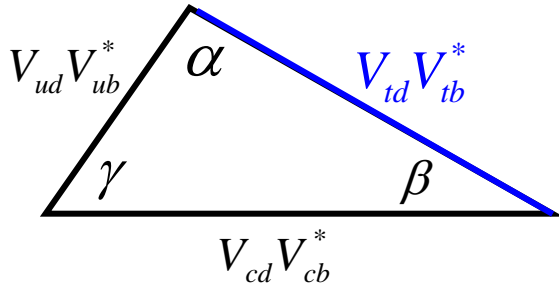
Ball, Jones, and Zwicky Phys.Rev.D75:054004,2007

Measured by Belle (600fb^{-1}):

$$S = 0.83 \pm 0.65 \pm 0.18$$

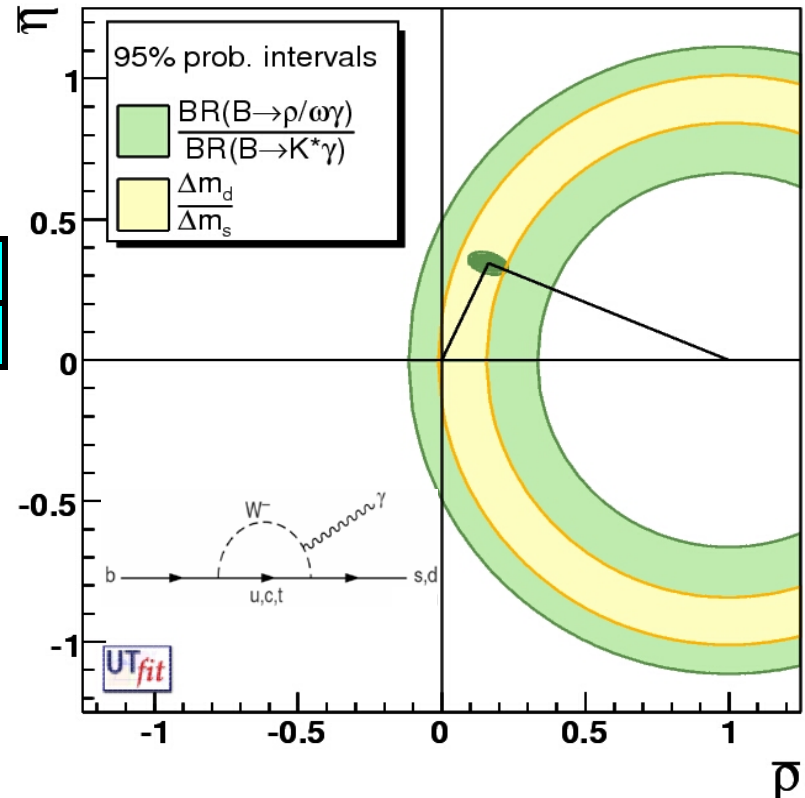
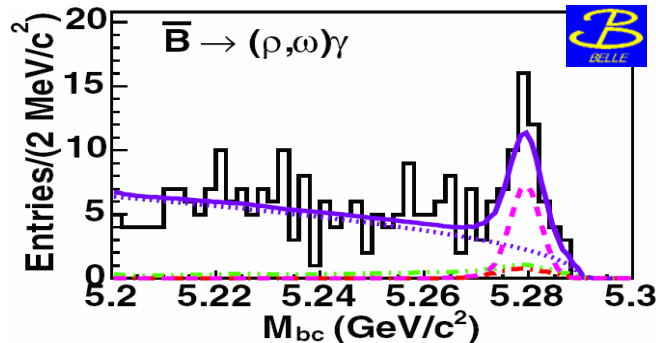
$$C = -A = 0.44 \pm 0.49 \pm 0.19$$



V_{td}/V_{ts} from $b \rightarrow (s,d) \gamma$



Observation of $B \rightarrow \rho \gamma$ by Belle and BaBar allows a complementary constraint on V_{td}/V_{ts}

BF x 10 ⁶	Belle (386M _{BB})	BaBar (347M _{BB})
$B \rightarrow (\rho, \omega) \gamma$	$1.13 \pm 0.20 \pm 0.11$ (5.9 σ)	$1.25^{+0.25}_{-0.24} \pm 0.08$ (6.4 σ)

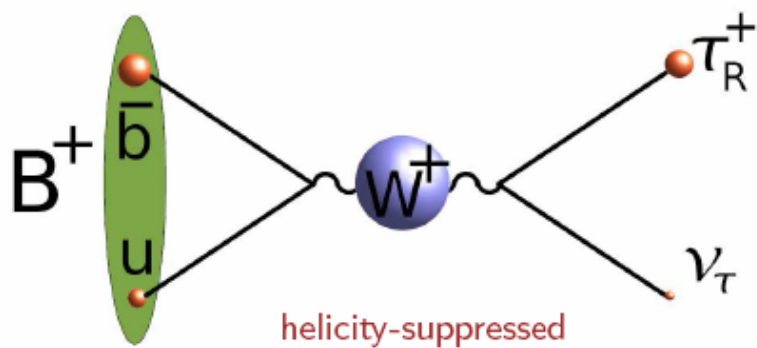


$\rho \gamma / K^* \gamma \rightarrow |V_{td}/V_{ts}| = 0.200 \pm 0.021$ (exp) ± 0.015 (thy) 
 mixing $\rightarrow |V_{td}/V_{ts}| = 0.2060 \pm 0.0007$ (exp) ± 0.0081 (thy)

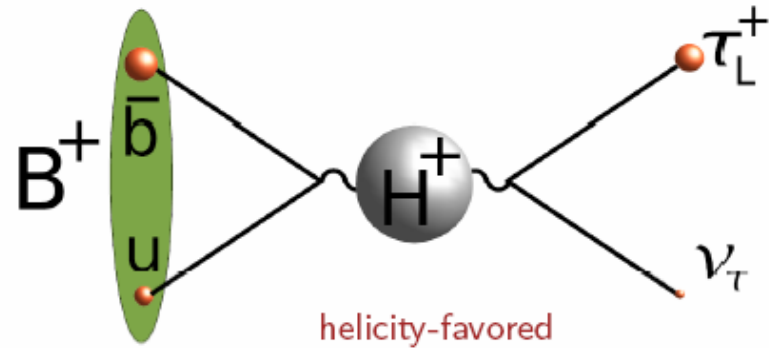
An aerial photograph of a university campus, likely the University of California, Berkeley, showing a large complex of buildings and a winding road. The text "New Physics in Rare Decays" is overlaid in yellow.

New Physics in Rare Decays

Searching for NP in $B \rightarrow \tau \nu$



helicity-suppressed



helicity-favored

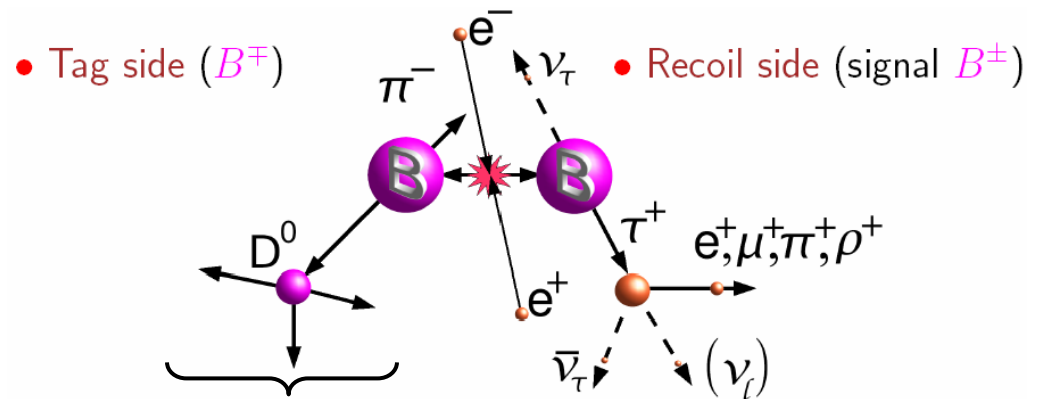
$$\mathcal{B} = \frac{G_F^2 m_B m_\tau^2}{8\pi} \left[1 - \frac{m_\tau^2}{m_{B^+}^2} \right]^2 \tau_{B^+} f_B^2 |V_{ub}|^2 \left[1 - \tan^2 \beta \frac{m_{B^+}^2}{m_{H^+}^2} \right]^2$$

SM: $\sim (1.6 \pm 0.4) \times 10^{-4}$

Difficult analysis:

- leptonic or hadronic tag (low ϵ)
- at least two neutrinos
- bkg in E_{extra} difficult to model

Analysis techniques:



hadronic or leptonic tag

Results and Prospects for $B \rightarrow \tau \nu$

SM: $\sim (1.6 \pm 0.4) \times 10^{-4}$

BaBar (350fb⁻¹):

$BF(B \rightarrow \tau \nu) = (0.9 \pm 0.6 \pm 0.1) \times 10^{-4}$ (leptonic)

$BF(B \rightarrow \tau \nu) = (1.8_{-0.9}^{+1.0} \pm 0.4 \pm 0.2) \times 10^{-4}$ (hadronic)

$BF(B \rightarrow \tau \nu) = (1.2 \pm 0.4 \pm 0.3 \pm 0.2) \times 10^{-4}$ (combined)

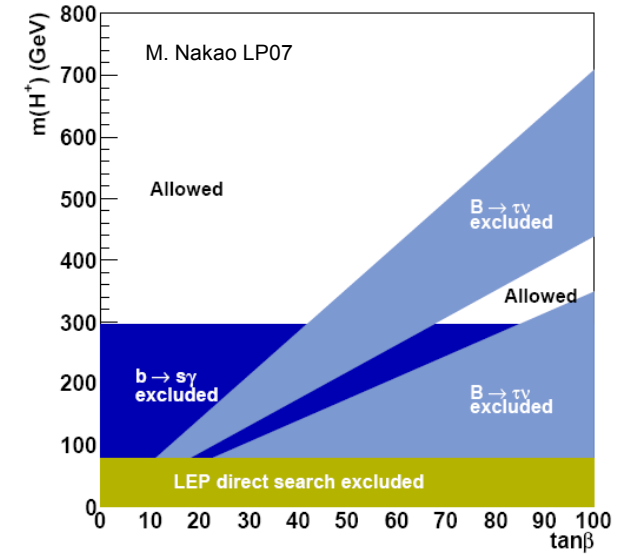
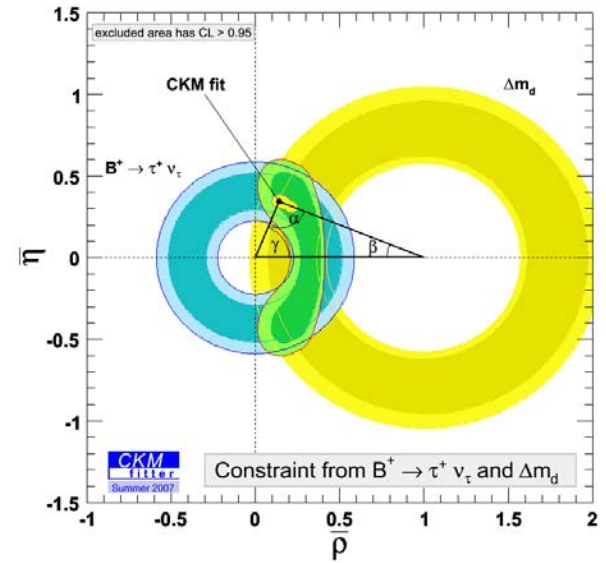
Belle hadronic tag (414fb⁻¹):

$BF(B \rightarrow \tau \nu) = (1.79_{-0.49-0.51}^{+0.56+0.46} \pm 0.22) \times 10^{-4}$

World Average:

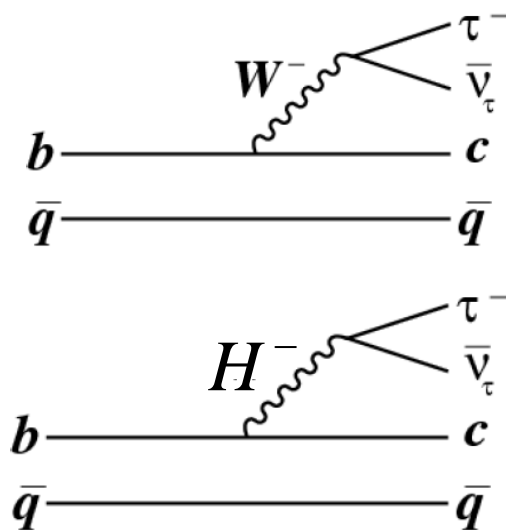
$BF(B \rightarrow \tau \nu) = (1.41_{-0.42}^{+0.43}) \times 10^{-4}$

Final B Factory error ~ 0.28 , but could do better with new tracking improvements from BaBar and leptonic tag analysis from Belle



Observation of Not-Rare $B \rightarrow D^{(*)}\tau\nu$

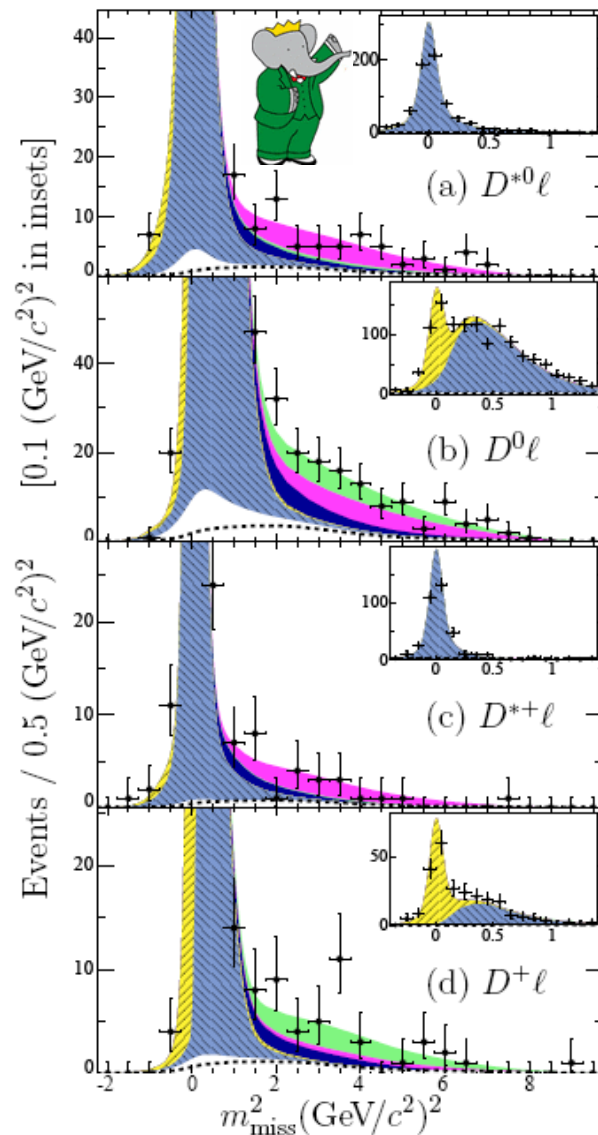
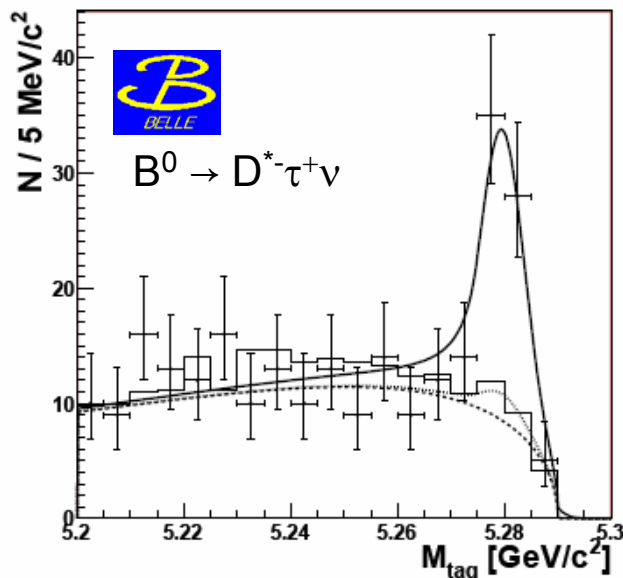
Sensitive to NP as in $B \rightarrow \tau\nu$
(small e, μ masses could hide NP)



Accurate SM predictions:

Decay Mode	\mathcal{B} (%)
$\bar{B}^0 \rightarrow D^- \tau^- \bar{\nu}_\tau$	0.69 ± 0.04
$\bar{B}^0 \rightarrow D^{*-} \tau^- \bar{\nu}_\tau$	1.41 ± 0.07
$B \rightarrow X_c \tau^- \bar{\nu}_\tau$	2.3 ± 0.25

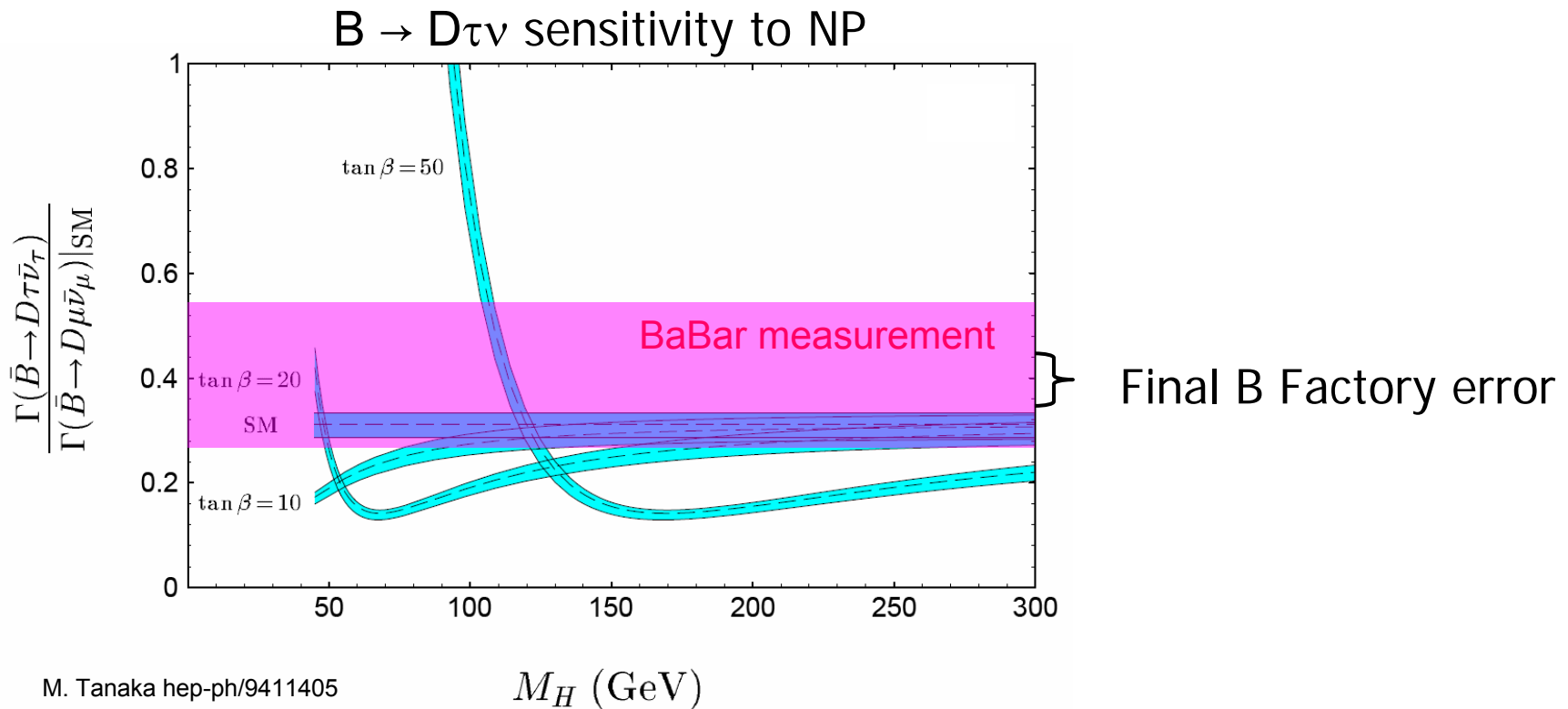
C. Chen and C. Geng, hep-ph/0608166
A. Falk et al., PLB 326 145 (1994)



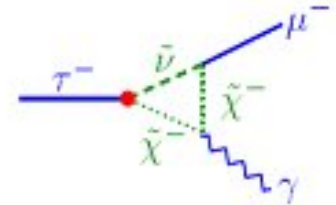
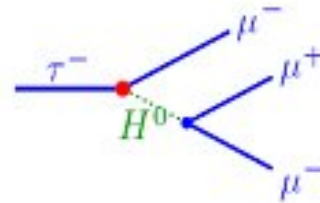
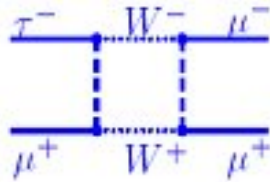
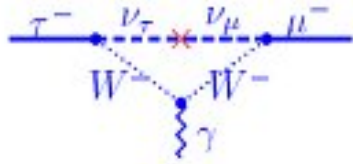
NP Prospects in $B \rightarrow D^{(*)}\tau\nu$

Belle	$B^0 \rightarrow D^{*-}\tau^+\nu$	$(2.02^{+0.40}_{-0.37} \pm 0.37)\%$	5.2σ (485fb ⁻¹)
BaBar	$B \rightarrow D^*\tau^+\nu$	$(1.81 \pm 0.33 \pm 0.11 \pm 0.06)\%$	6.2σ
	$B \rightarrow D\tau^+\nu$	$(0.90 \pm 0.26 \pm 0.11 \pm 0.06)\%$	3.5σ

(210fb⁻¹)



Lepton Flavor Violation in τ decays



Highly suppressed in SM!

	$B(\tau \rightarrow \ell\gamma)$	$B(\tau \rightarrow \ell\ell\ell)$
SM+ ν -mixing (PRL95(2005)41802,EPJC8(1999)513)	10^{-54}	10^{-14}
SUSY Higgs (PLB549(2002)159, PLB566(2003)217)	10^{-10}	10^{-7}
SM+Heavy Majorana ν_R (PRD66(2002)034008)	10^{-9}	10^{-10}
Non-Universal Z' (PLB547(2002)252)	10^{-9}	10^{-8}
SUSY SO(10) (NPB649(2003)189, PRD68(2003)033012)	10^{-8}	10^{-10}
mSUGRA+seesaw (EPJC14(2000)319, PRD66(2002)115013)	10^{-7}	10^{-9}

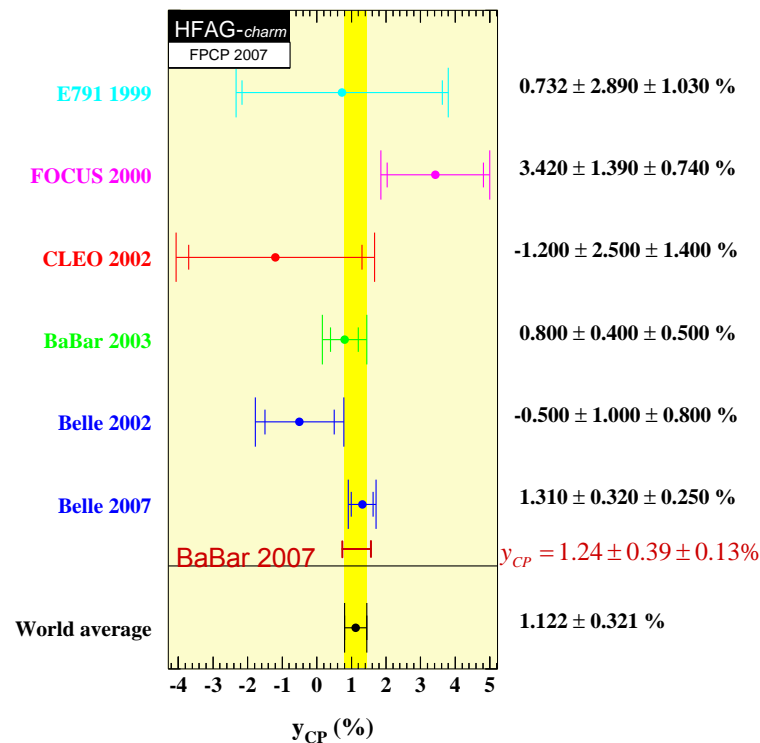
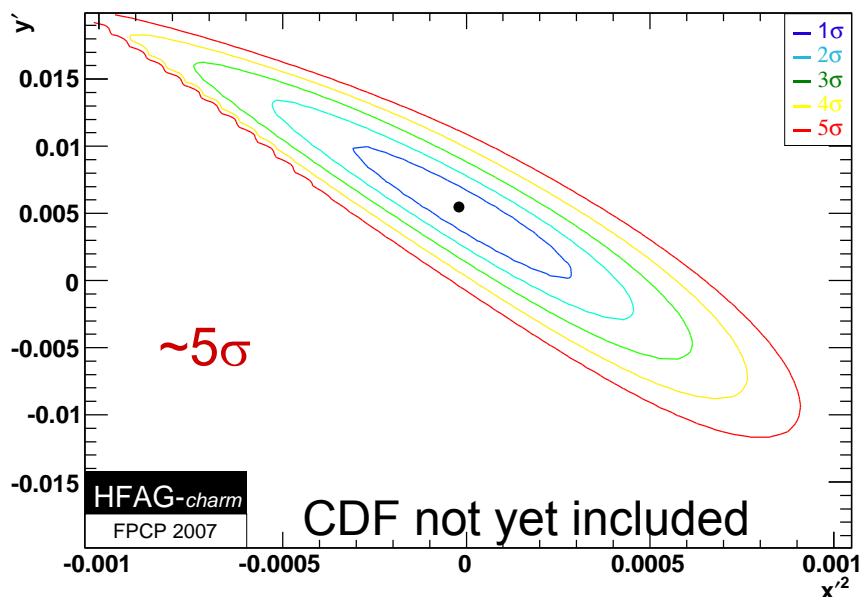
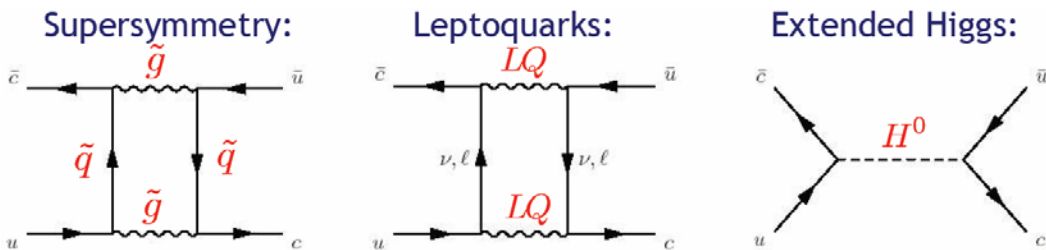
Expected asymptotic limits:

- $\tau \rightarrow \mu\gamma < 2-3 \times 10^{-8}$
- $\tau \rightarrow \mu\mu\mu < 2-3 \times 10^{-8}$
(competitive with LHC @ 30fb^{-1})

τ^- mode	Belle		BaBar	
	Br, 10^{-8}	Lum. fb^{-1}	Br, 10^{-8}	Lum. fb^{-1}
$\mu^- \gamma$	<4.5	535	<6.8	232
$e^- \gamma$	<12	535	<11	232
$\mu^- e^+ \mu^-$	<2.4	535	<5.6	376
$\mu^- e^+ e^-$	<2.8	535	<8.0	376
$\mu^- \mu^+ \mu^-$	<3.4	535	<5.3	376
$e^- \mu^+ \mu^-$	<4.3	535	<3.7	376
$\mu^+ e^- e^-$	<2.1	535	<5.8	376
$e^- e^+ e^-$	<3.6	535	<4.3	376

Status of D^0 Mixing

Sensitivity to NP:



New @ Lepton-Photon 2007:

- BaBar lifetime ratio (3.0σ)
- BaBar Dalitz $K\pi\pi^0$ ($\sim 2\sigma$)
- CDF $D \rightarrow K\pi$ analysis (3.2σ)
- still no sign of CP violation!

Summary and Outlook

- ❑ The last ~decade has seen enormous progress in the understanding of flavor physics
 - ❑ Precision measurements of CKM parameters have established KM as the dominant source CPV
 - ❑ Null searches for rare/forbidden decays has significantly reduced the phase space for NP
 - ❑ MFV is the most likely NP scenario
- ❑ B Factories will end operations in 2008
 - ❑ Total integrated luminosity $\sim 1.7\text{ab}^{-1}$
 - ❑ Approximately double the current dataset
 - ❑ Major effort to repeat measurements on the final datasets as soon as possible (major updates at ICHEP08)
- ❑ “Interplay” will continue into the LHC era
 - ❑ Once NP is discovered at LHC, we’ll know exactly where to look for it at Belle and Babar
 - ❑ The far-future belongs to LHCb and SuperB!