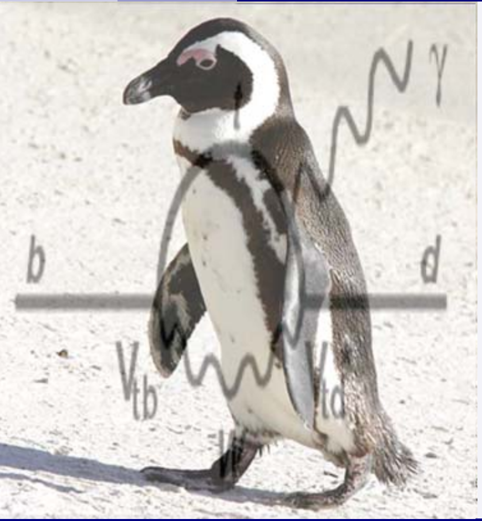
CKM 2008: 5th International Workshop on the CKM Unitarity Triangle

Rome, Italy, September 9-13, 2008

BELLE

BaBar

New Results on $|V_{td}/V_{ts}|$ from Radiative Decays



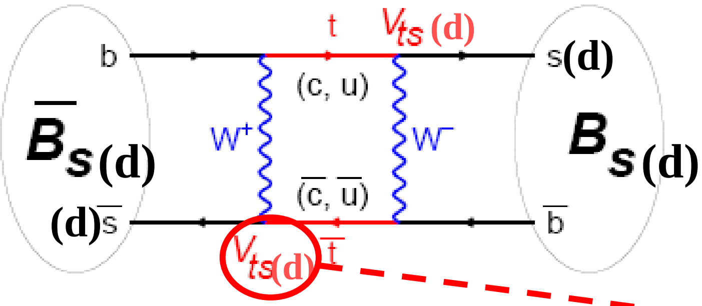
Bruce A. Schumm
Santa Cruz Institute for Particle Physics
University of California, Santa Cruz

for the BaBar and Belle Collaborations

Introduction

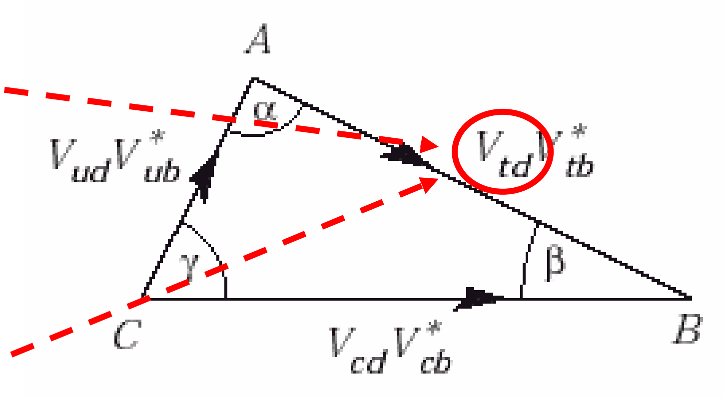
- Motivation
- $B \rightarrow (\rho,\omega)\gamma$ (“Standard” Approach)
- $B \rightarrow X_d$ (“Semi-Inclusive” Approach)
- Status of $|V_{td}/V_{ts}|$ and Conclusions

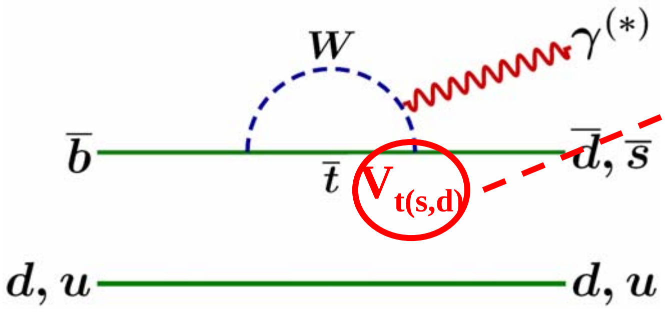
Measuring $|V_{td}/V_{ts}|$



B Mixing

Two independent diagrams provide sensitivity to CKM parameter V_{td}





Radiative Penguins

Note: In both cases, hadronic uncertainties minimized by comparing to corresponding V_{ts} process (B_s mixing, $b \to s\gamma$)

➔ Observable is $| V_{td} / V_{ts} |$

$|V_{td}/V_{ts}|$ from Penguins: Motivation

ICHEP '08 B Mixing Results [Farrington(CDF), Moulik(D0), averaged by DeLodovico(BaBar)]:

$$|V_{td}|/|V_{ts}| = 0.207 \pm 0.001_{\mathrm{exp}} \pm 0.006_{\mathrm{theo}}$$

How do penguins fit into the picture?

Mixing: $x_d = \Delta m_B/\Gamma_B \sim 1$ ➔ $\Delta m_B \sim \Gamma_B$

Penguins: $Br(b \rightarrow d\gamma) \sim 10^{-5}$ ➔ $\Gamma_{d\gamma} \sim \mathbf{10^{-5}}\, \Gamma_B$

SM effects suppressed by 10^{-5} relative to mixing

Furthermore (Ali, Asatrian, Greub, Phys. Lett B **429**, 87):

> *"These* [b → dγ] *vertices are CKM-suppressed in the standard model, but new physics contributions may not follow the CKM pattern in flavor-changing-neutral-current transitions and hence new physics effects may become more easily discernible in* $B \rightarrow X_d + \gamma$ *(and its charge conjugate) than in the corresponding CKM-allowed vertices* $b \rightarrow s\gamma$ *and* $b \rightarrow sg$*"*

With $|V_{td}/V_{ts}|$ precisely constrained by mixing, $b \rightarrow d\gamma$ is a compelling testbed for new physics.

Exclusive Approach: $B \to \rho(\omega)\,\gamma$

"Traditional" Approach: measure exclusive rate $Br(B \to \rho(\omega)\,\gamma)$; normalize with $Br(B \to K^*\,\gamma)$

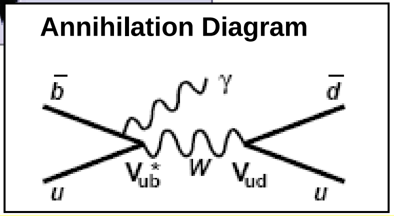
isopin factor: 1(.5) for $\rho^\pm(\rho^0)$(and ω)

form factor ratio

$$\frac{\mathcal{B}(B \to \rho\gamma)}{\mathcal{B}(B \to K^*\gamma)} = S_\rho \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/M_B^2}{1 - m_{K^*}^2/M_B^2}\right)^3 \zeta^2[1 + \Delta R]$$

well measured

annihilation amplitude corrections


Annihilation Diagram

Values of ς^2 and ΔR are state (ρ^+,ρ^0,ω) dependent and are available from

Ali, Parkhomenko, arXiv:hep-ph/0610149

Ball, Zwicky, J. High. Energy Phys. 0604, 046 (2006); Ball, Jones, Zwicky, Phys. Rev. D 75 054004 (2007)

at approximately 8% overall accuracy.

Measurement of $B(B \to \rho(\omega)\gamma)$

Belle: New result this Spring

351 fb^{-1} (2006) ➔ 598 fb^{-1} (April 2008)

BaBar: New (preliminary) result this Summer

316 fb^{-1} (April 2007) ➔ 423 fb^{-1} (July 2008)

Challenge: BRs are small ($<10^{-6}$); backgrounds are high

- continuum [Neural Net with event shape, B tagging information, …]
- $B \to K^*\gamma$; $K^* \to K\pi$ [particle ID]
- $B \to (\rho^{\pm,0},\omega)(\pi^0,\eta)$ [veto if γ found such that $M_{\gamma\gamma} \sim M_{(\pi,\eta)}$]

Measurement of B(B → ρ(ω) γ) (continued)

Remaining separation achieved by two-dimensional fit to the largely independent kinematic variables

$$M_{ES} = \sqrt{(E^{*2}_{beam} - p^{*2}_{B})}$$

"Energy-substituted mass"; since E_{beam} ~ M_B, largely a measurement of momentum balance

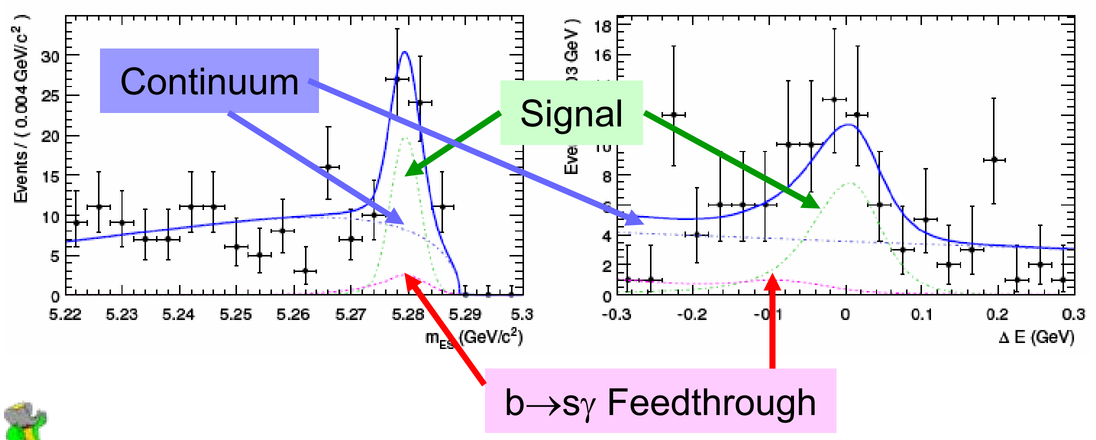
$$\Delta E^* = E^*_B - E^*_{beam}$$

E_B = E_{beam} for properly reconstructed candidate; total energy measurement

*In e^+e^- CMS frame

Example: BaBar $B^0 \rightarrow \rho^0 \gamma$

PRELIMINARY



Continuum

Signal

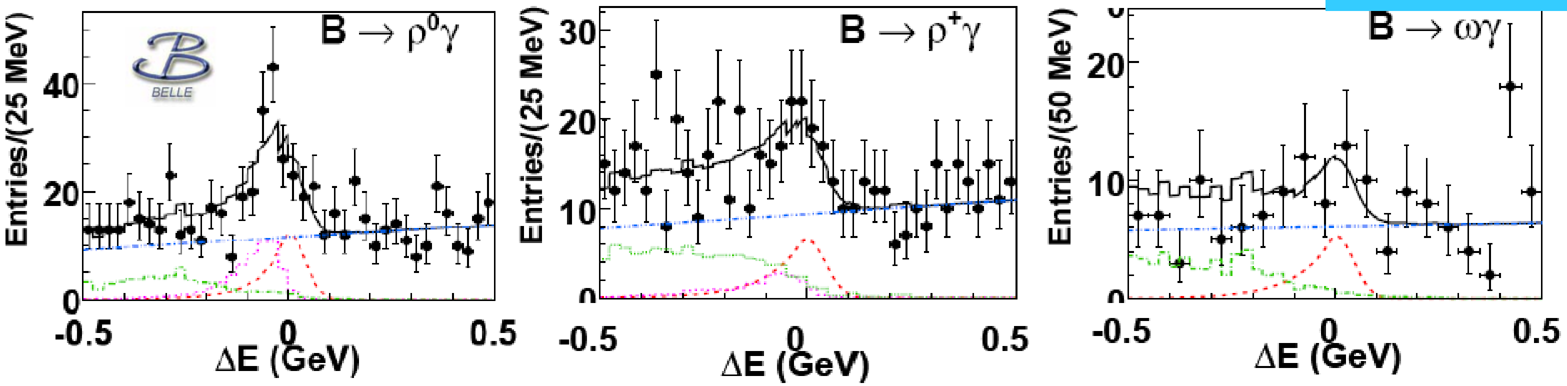
b→sγ Feedthrough

- "self-calibrating" continuum background subtraction
- efficiencies (~5-15%) estimated with control samples

Belle's April Update of $B \to \rho(\omega)\gamma$

- Increase sample from 351 fb^{-1} to 598 fb^{-1}
- Continuum: Fischer Discriminant with Fox-Wolfram moments, B flight information, vertex information
- Include photons from endcap calorimeter

Ji Lin, ICHEP '08

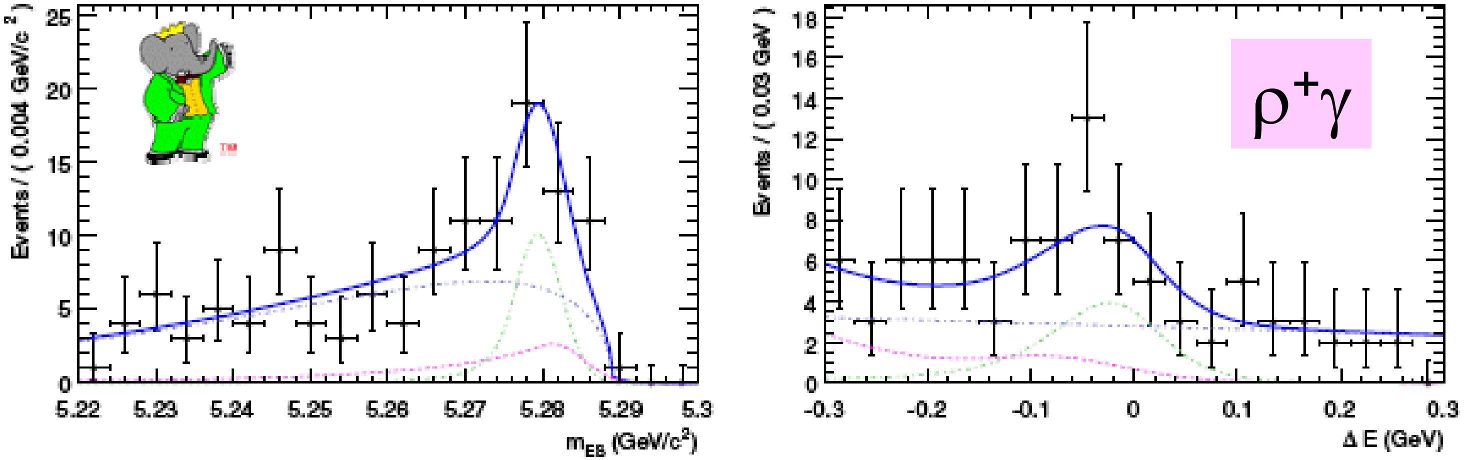


Mode	Belle '06 ($\times 10^{-7}$)	Belle '08 ($\times 10^{-7}$)
$\rho^+ \gamma$	$5.5^{+4.2\ +0.9}_{-3.6\ -0.8}$	$8.7^{+2.9\ +0.9}_{-2.7\ -1.1}$
$\rho^0 \gamma$	$12.5^{+3.7\ +0.7}_{-3.3\ -0.6}$	$7.8^{+1.7\ +0.9}_{-1.6\ -1.0}$
$\omega \gamma$	$5.6^{+3.4\ +0.5}_{-2.7\ -1.0}$	$4.0^{+1.9}_{-1.7} \pm 1.3$

BaBar's July Update of B → $\rho(\omega)\,\gamma$ (Preliminary)

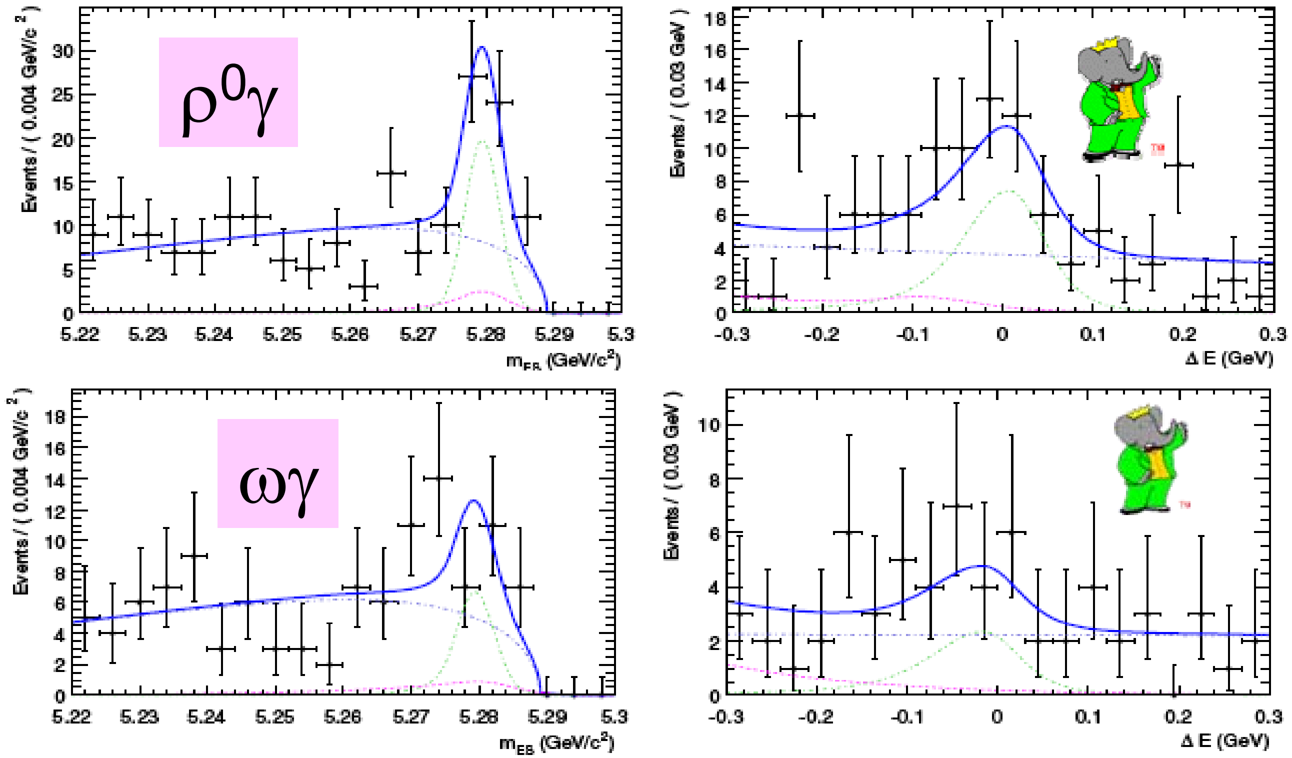
- Increase sample from 316 fb^{-1} to 423 fb^{-1} (final data set)
- Strategy: Focus on unconfirmed B → $\omega\gamma$ mode
- Continuum suppression: “Bagged Decision Tree” with 60 input event variables

➔ Relatively good signal-to-noise



BaBar's July Update of B → ρ(ω) γ continued

PRELIMINARY



Mode	BaBar '07 ($\times10^{-7}$)	BaBar '08 ($\times10^{-7}$)
$\rho^+\gamma$	$11.0^{+3.7}_{-3.3}\pm0.9$	$12.0^{+4.2}_{-3.7}\pm2.0$
$\rho^0\gamma$	$7.9^{+2.2}_{-2.0}\pm0.6$	$9.7^{+2.4}_{-2.2}\pm0.6$
$\omega\gamma$	$4.0^{+2.4}_{-2.0}\pm0.5$	$5.0^{+2.7}_{-2.3}\pm0.9$

PRELIMINARY

Isopsin-Averaged Branching Fractions

Assuming $SU_3(F)$ symmetry $[B(B\to\rho^0\gamma) \sim B(B\to\omega\gamma)]$ and

$$|\rho^0\rangle = \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle - |d\bar{d}\rangle\right) \qquad |\omega\rangle = \frac{1}{\sqrt{2}}\left(|u\bar{u}\rangle + |d\bar{d}\rangle\right)$$

(approximately true by static quark model) we can write

$$\Gamma(B^+ \to \rho^+\gamma) = 2\Gamma(B^0 \to \rho^0\gamma) = 2\Gamma(B^0 \to \omega\gamma)$$

from which it follows

$$\mathrm{B}[B \to (\rho,\omega)\gamma] \equiv \frac{1}{2}\left\{\mathrm{B}(B^+ \to \rho^+\gamma) + \frac{\tau_{B^+}}{\tau_{B^0}}\left[\mathrm{B}(B^0 \to \rho^0\gamma) + B(B^0 \to \omega\gamma)\right]\right\}$$

➔ Can combine ρ^+, ρ^0, ω results to derive $|V_{td}/V_{ts}|$ from

$$\frac{\mathrm{B}(B \to (\rho,\omega)\gamma)}{\mathrm{B}(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2 / M_B^2}{1 - m_{K^*}^2 / M_B^2}\right) \varsigma^2 [1 + \Delta R]$$

$|V_{td}/V_{ts}|$ from Exclusive (ρ,ω) Decays

BELLE:

$$\mathrm{B}(B \to (\rho,\omega)\gamma) = (11.4 \pm 2.0^{+1.0}_{-1.2}) \times 10^{-7}$$ yielding

$$|V_{td}/V_{ts}| = 0.195^{+0.020}_{-0.019} \pm 0.015$$

BaBar:

$$\mathrm{B}(B \to (\rho,\omega)\gamma) = (16.3^{+3.0}_{-2.8} \pm 1.6) \times 10^{-7}$$ yielding

$$|V_{td}/V_{ts}| = 0.233^{+0.025}_{-0.024}{}^{+0.022}_{-0.021}$$

PRELIMINARY

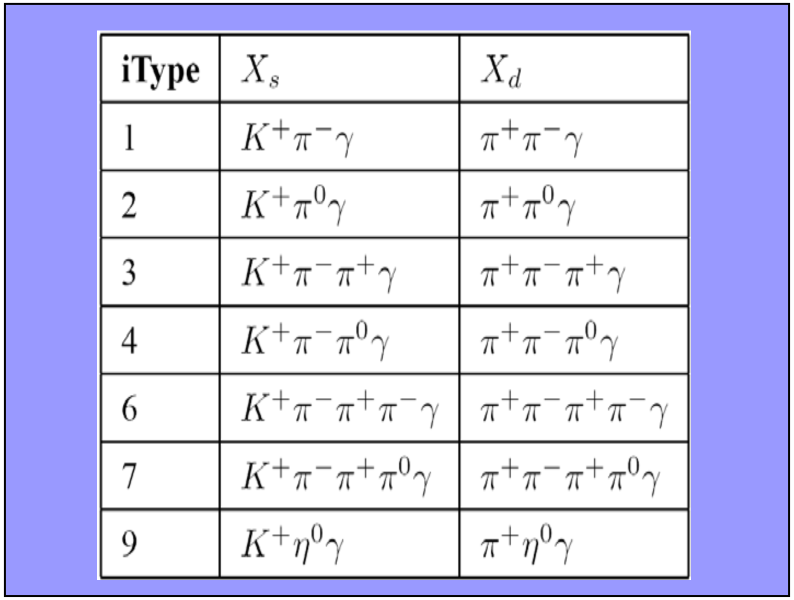
assuming the world-average $\mathrm{B}(B \to K^{*}\gamma) = (4.16 \pm 0.17) \times 10^{-5}$

Combining, for exclusive radiative decay overall:

$$|V_{td}/V_{ts}| = 0.210 \pm 0.015 \pm 0.018$$

Semi-Inclusive Approach: B → $X_d \gamma$ (Preliminary)

"New" Approach (BaBar): Reconstruct seven exclusive final states $X_d\gamma$ in range $0.6\ \mathrm{GeV}/c^2 < M_{Xd} < 1.8\ \mathrm{GeV}/c^2$



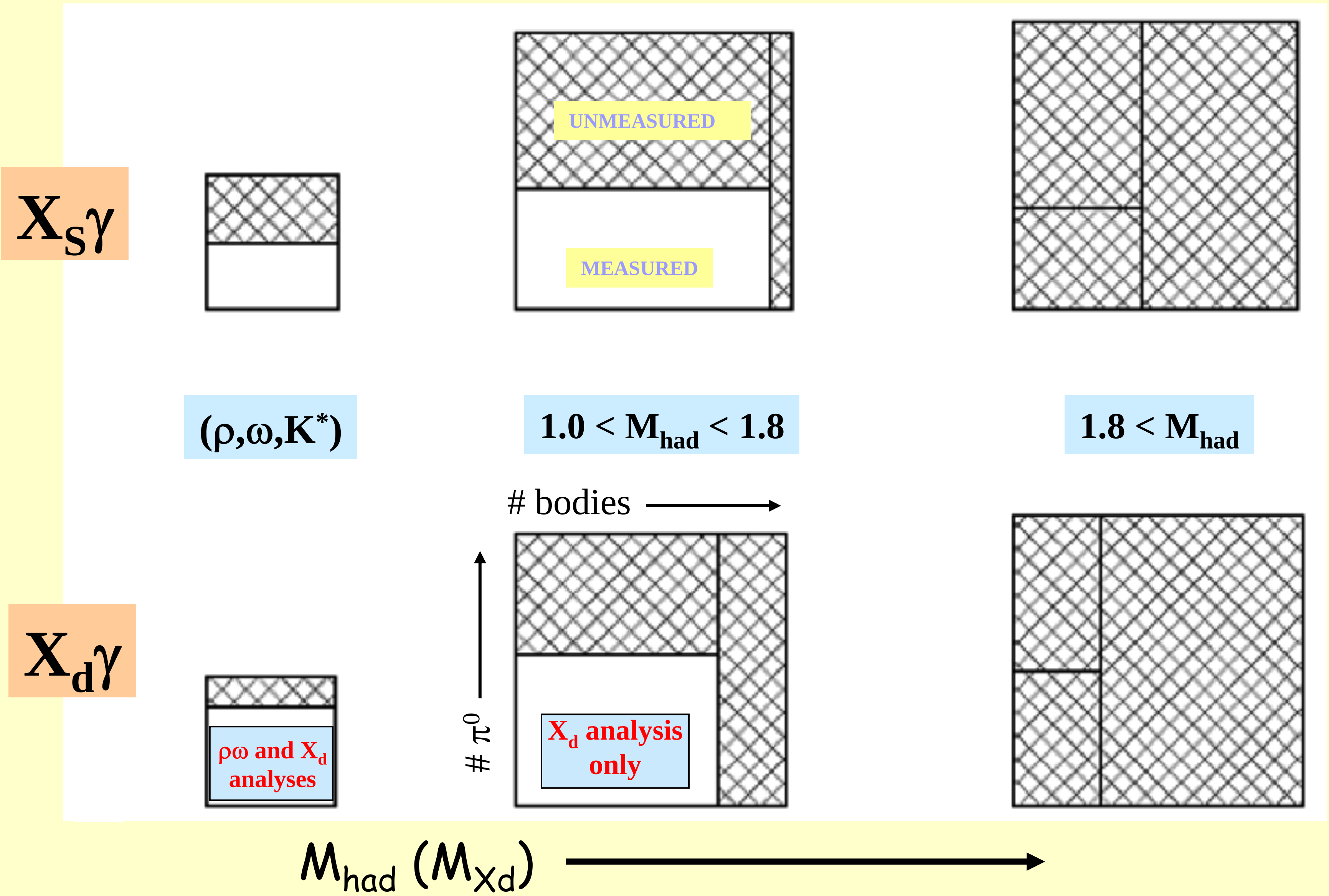
iType	X_s	X_d
1	$K^+\pi^-\gamma$	$\pi^+\pi^-\gamma$
2	$K^+\pi^0\gamma$	$\pi^+\pi^0\gamma$
3	$K^+\pi^-\pi^+\gamma$	$\pi^+\pi^-\pi^+\gamma$
4	$K^+\pi^-\pi^0\gamma$	$\pi^+\pi^-\pi^0\gamma$
6	$K^+\pi^-\pi^+\pi^-\gamma$	$\pi^+\pi^-\pi^+\pi^-\gamma$
7	$K^+\pi^-\pi^+\pi^0\gamma$	$\pi^+\pi^-\pi^+\pi^0\gamma$
9	$K^+\eta^0\gamma$	$\pi^+\eta^0\gamma$

$|V_{td}/V_{ts}|^2$ related to $\Gamma(b \to d\gamma)/\Gamma(b \to s\gamma)$ with ~1% theoretical uncertainty [**Ali, Asatrian, Greub, Phys. Lett. B 429, 87 (1998)**]

However, must correct for unmeasured regions:

- Higher-multiplicity final states
- Higher-mass hadronic component (i.e. $M_{Xd} > 1.8\ \mathrm{GeV}/c^2$)

Measured Regions for B → $X_{d(s)}\gamma$



$X_s\gamma$

UNMEASURED

MEASURED

(ρ,ω,K^*)

$1.0 < M_{had} < 1.8$

$1.8 < M_{had}$

bodies →

$X_d\gamma$

π^0 →

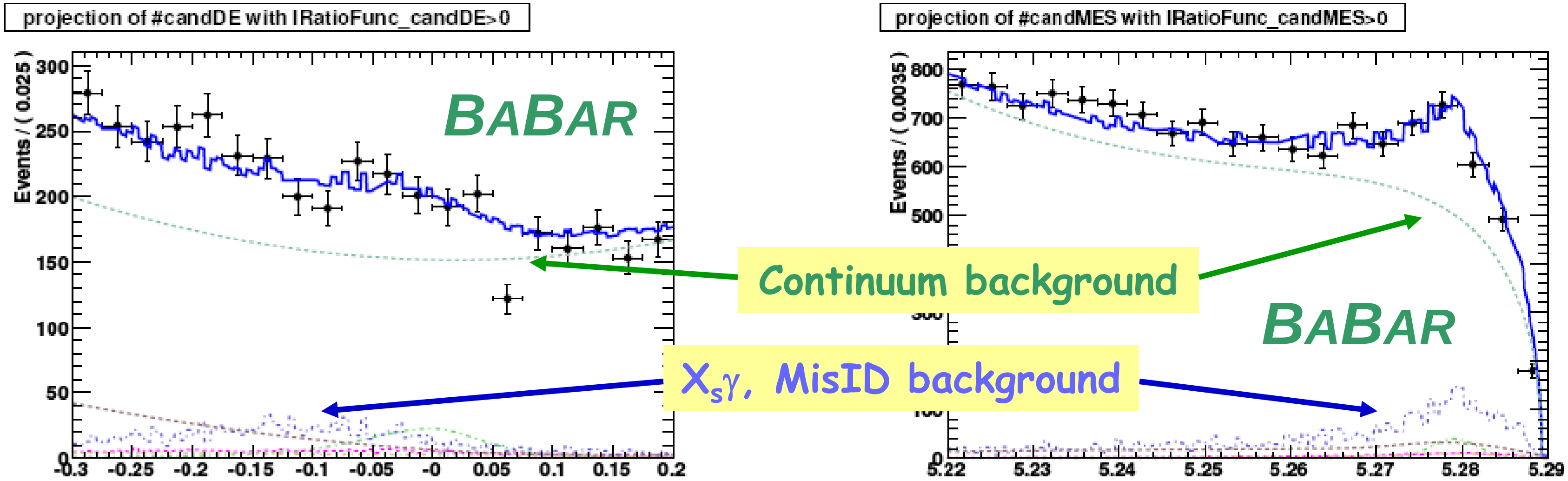
ρω and X_d analyses

X_d analysis only

M_{had} (M_{Xd}) →

$B \to X_{(s,d)} \gamma$ Partial Branching Fraction Results

Fit in high-mass $X_d \gamma$ region (first time measured):



Continuum background

$X_s\gamma$, MisID background

Yields and partial branching fractions:

PRELIMINARY

Mode	Mass Range	Yield	Efficiency	Partial B. F. $(\times 10^{-6})$
$b \to s\gamma$	$0.6 < M_{X_s} < 1.0$	1543 ± 46	8.5%	$23.7 \pm 0.7 \pm 1.7$
$b \to s\gamma$	$1.0 < M_{X_s} < 1.8$	2279 ± 75	6.1%	$48.7 \pm 1.6 \pm 4.1$
$b \to d\gamma$	$0.6 < M_{X_d} < 1.0$	66 ± 26	7.0%	$1.2 \pm 0.5 \pm 0.1$
$b \to d\gamma$	$1.0 < M_{X_d} < 1.8$	107 ± 47	5.2%	$2.7 \pm 1.2 \pm 0.4$

High-mass
$b \to X_d \gamma$

Correction for Missing Modes

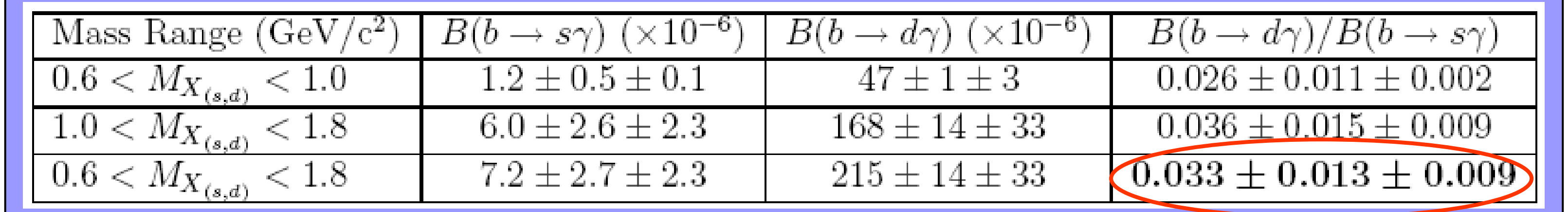
- Dominant systematic error for $1.0 < M_X < 1.8$ GeV/c^2
- Most difficult for $B \to X_d \gamma$ (not constrained by data)
- Can improve with statistics (internal constraints)

Try several models:

- M_X given by "KN Model" **Kagan & Neubert, Phys. Rev. D 58, 094012 (1998)**, with phase-space fragmentation
- As above, but with 50% replaced by mix of resonances
- Fix to measured $b \to s\gamma$ fragmentation

Errors: Statistical ± Experimental Systematic

BABAR



Mass Range (GeV/c^2)	$B(b \to s\gamma)$ $(\times 10^{-6})$	$B(b \to d\gamma)$ $(\times 10^{-6})$	$B(b \to d\gamma)/B(b \to s\gamma)$
$0.6 < M_{X_{(s,d)}} < 1.0$	$1.2 \pm 0.5 \pm 0.1$	$47 \pm 1 \pm 3$	$0.026 \pm 0.011 \pm 0.002$
$1.0 < M_{X_{(s,d)}} < 1.8$	$6.0 \pm 2.6 \pm 2.3$	$168 \pm 14 \pm 33$	$0.036 \pm 0.015 \pm 0.009$
$0.6 < M_{X_{(s,d)}} < 1.8$	$7.2 \pm 2.7 \pm 2.3$	$215 \pm 14 \pm 33$	$\mathbf{0.033 \pm 0.013 \pm 0.009}$

Primary experimental result

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Ratio of Total Widths and $|V_{td}/V_{ts}|$

Precise (~1%) expression for |Vtd/Vts| [Ali, Asatrian, Greub] is based on ratio of full widths $\Gamma(b\to d\gamma)/\Gamma(b\to s\gamma)$

Measured region $0.6 < M_X < 1.8$ is ~50% of width

Extrapolate to full mass region via "KN Model"; KN calculation suggests negligible difference and uncertainty in extrapolation of the ratio (because $m_s, m_d << 1.8$ GeV/c^2?)

This remains a bit of a caveat…

BABAR

$$\frac{\Gamma(b\to d\gamma)}{\Gamma(b\to s\gamma)} = 0.033 \pm 0.013 \pm 0.009$$

PRELIMINARY

Ali

Asatrian

Greub

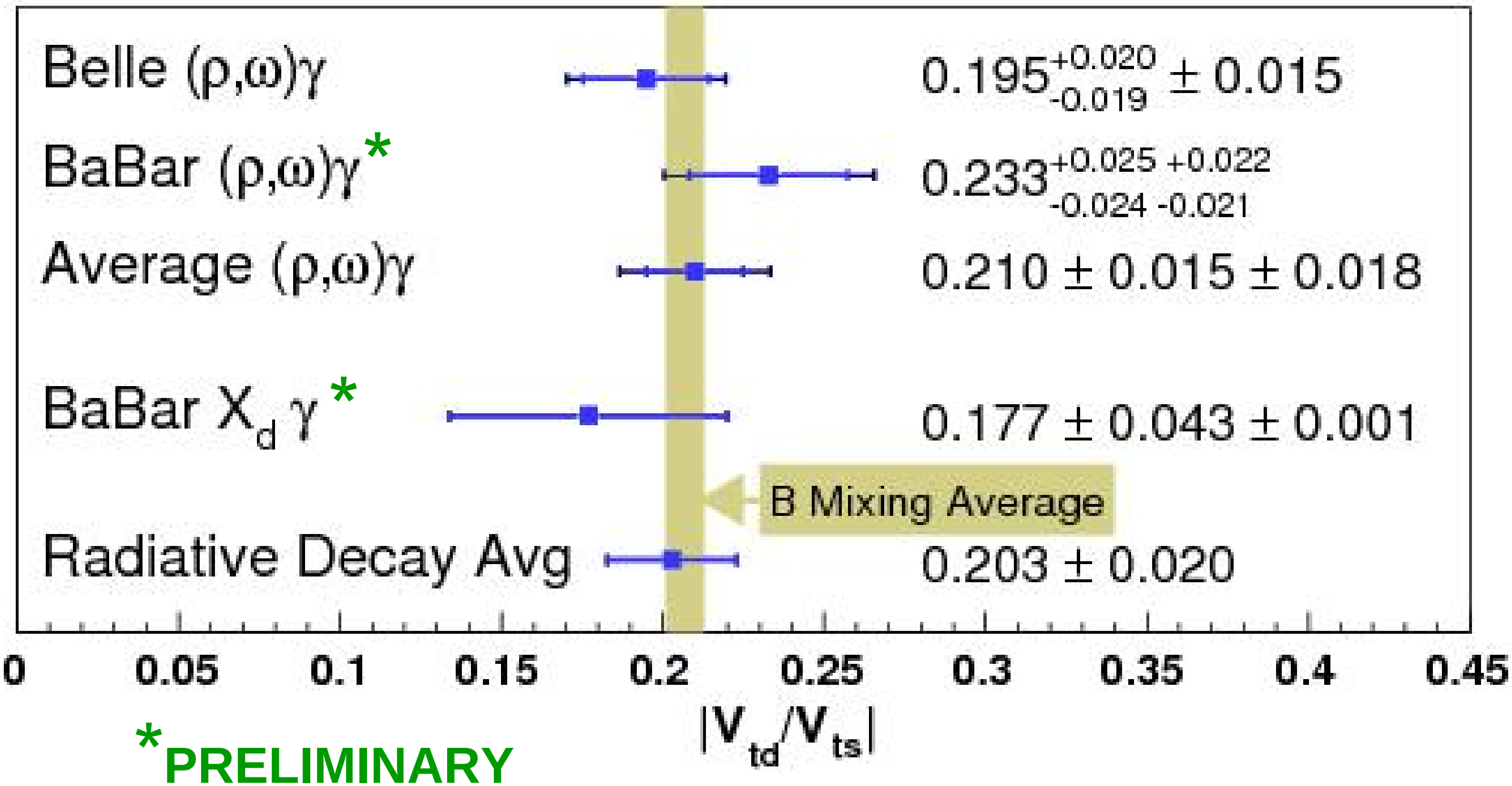
BABAR PRELIMINARY

$$|V_{td}/V_{ts}| = 0.177 \pm 0.043 \pm 0.001$$

Expt. Theory

arXiv:0807.4975 [hep-ex]; submitted to PRL

Global Status of $|V_{td}/V_{ts}|$



*PRELIMINARY

No evidence for non-Standard Model contribution to the decay width.

Concluding Remarks

- Radiative measurements of $|V_{td}/V_{ts}|$ are becoming precise:

$$|V_{td}/V_{ts}|_{rad} = 0.203 \pm 0.020$$

- Semi-inclusive approach works, and is independent of exclusive approach, with small theoretical uncertainty

- Agreement with SM (as constrained by B mixing) is good

In principle, the severe SM suppression of this radiative process (x10^{-6} of B mixing) should make it very sensitive to new physics contributions.

Have we fully thought through the meaning of this constraint?