Radiative $b \to d$ Penguins

Philip Bechtle (SLAC)

For the BaBar Collaboration

Rencontres de Moriond

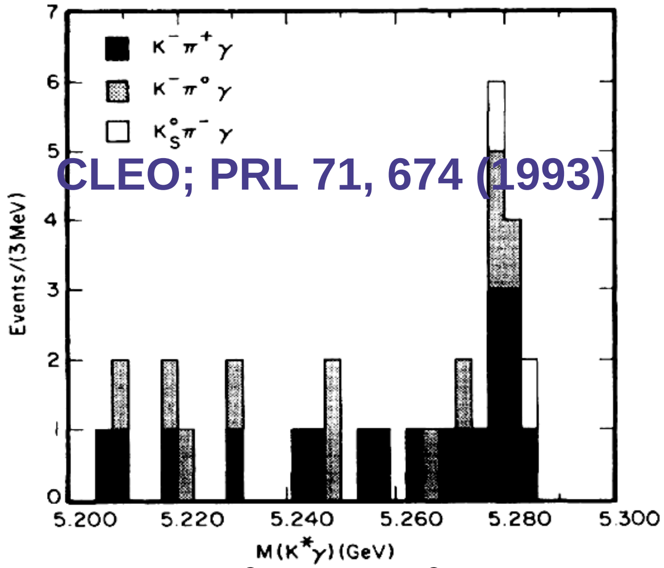
La Thuile

13.03.2007

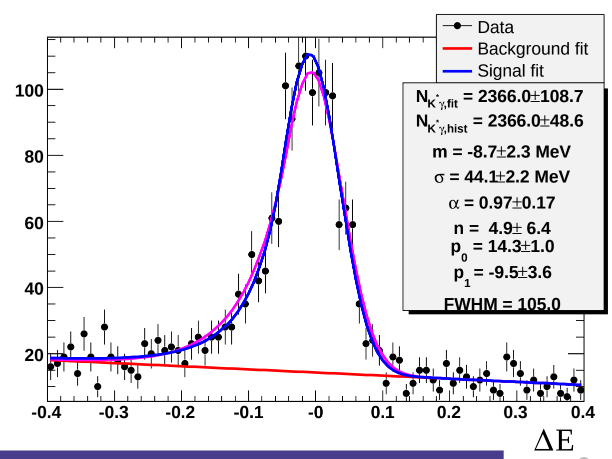
- $B \to \pi \ell^+ \ell^-$
- $B \to \rho^0 \gamma$, $\rho^\pm \gamma$ and $\omega\gamma$
- Extraction of $|V_{td}/V_{ts}|$ from $B \to \rho/\omega\gamma$

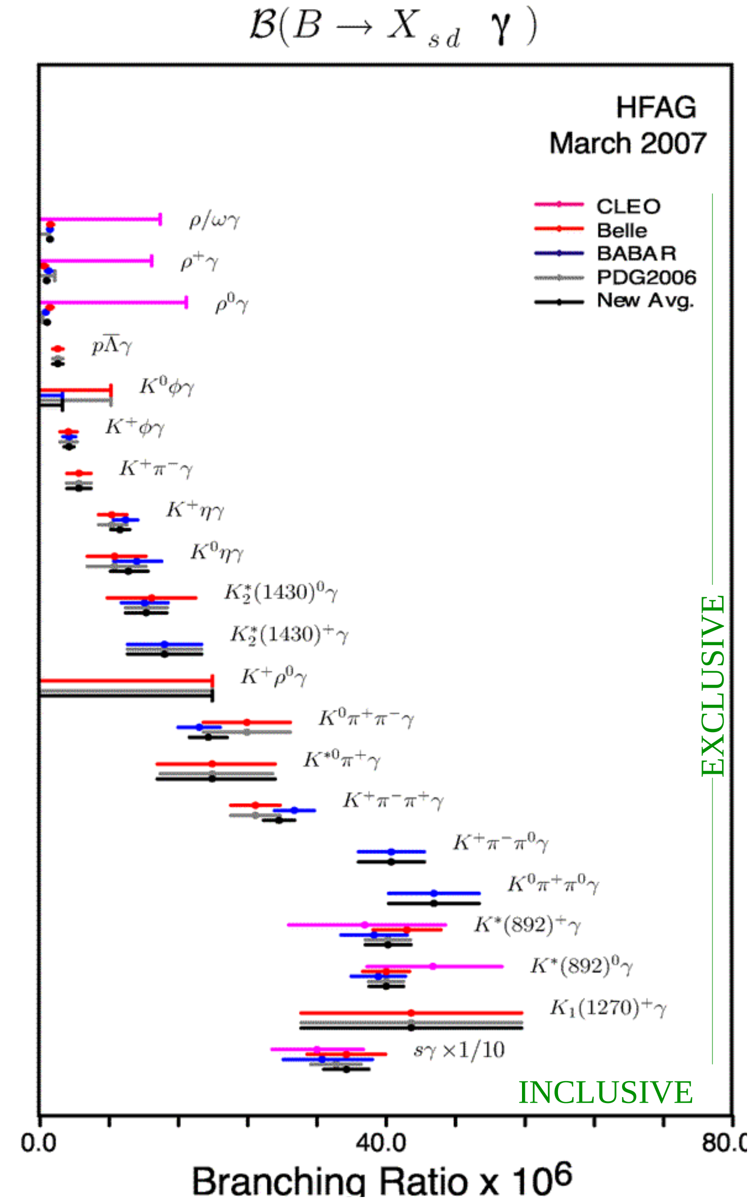
History of Electroweak Penguins

- From the first CLEO result on $B \to K^* \gamma \ldots$



- $\ldots$ to the use of $B^0 \to K^{*0}\gamma \to K^+\pi^-\gamma$ for improving the BaBar calorimeter calibration





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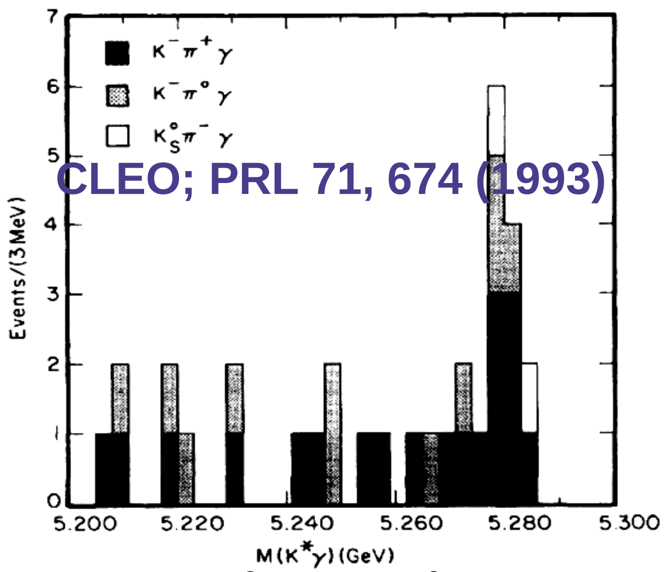

CLEO; PRL 71, 674 (1993)

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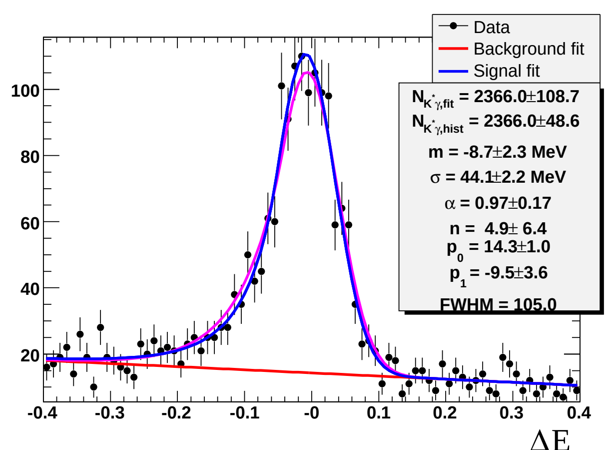
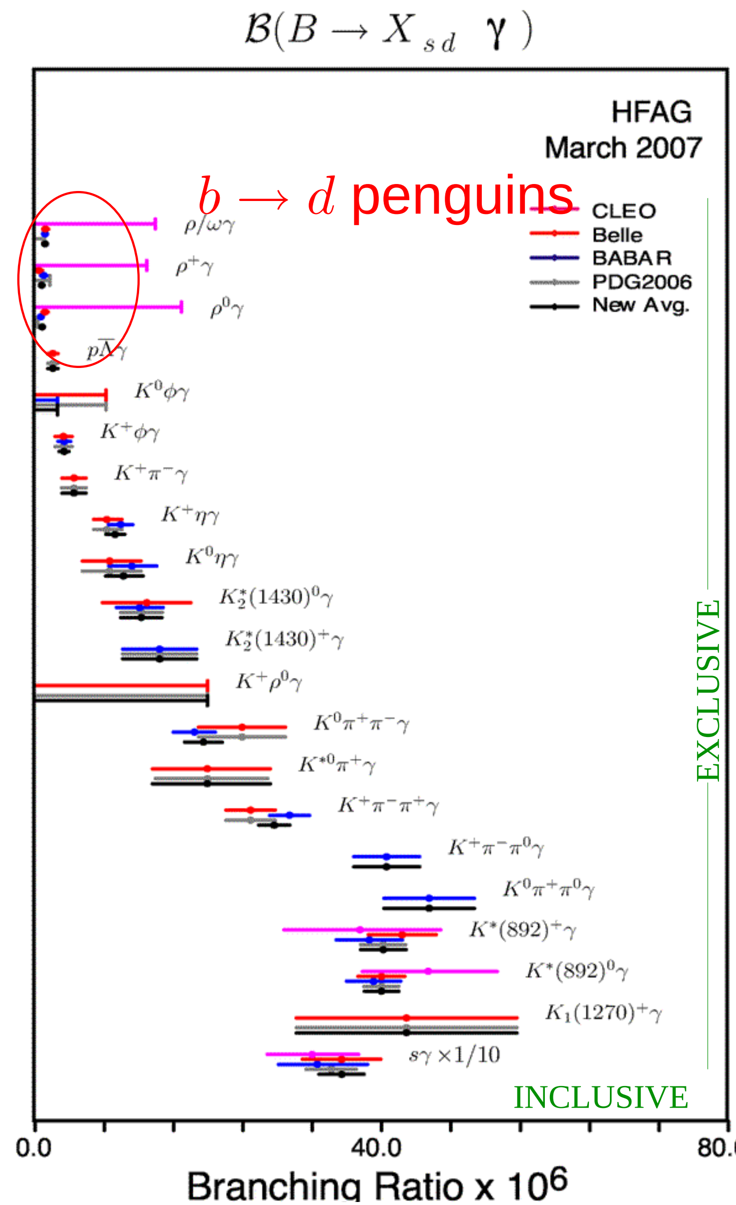
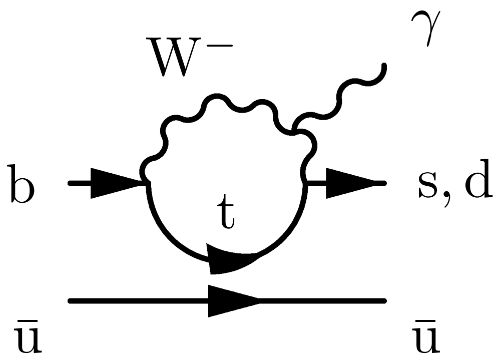
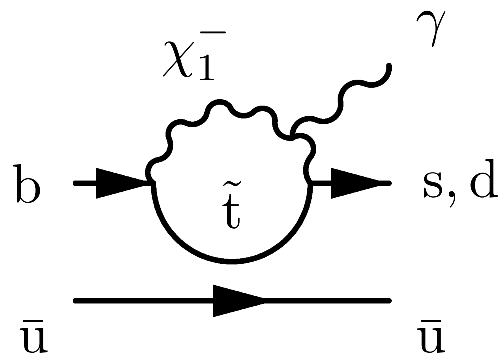




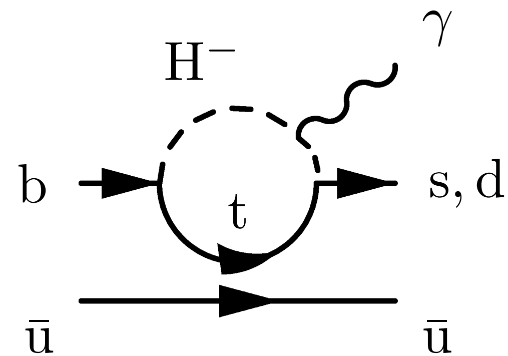
Electroweak Penguins and New Physics



SM radiative penguin

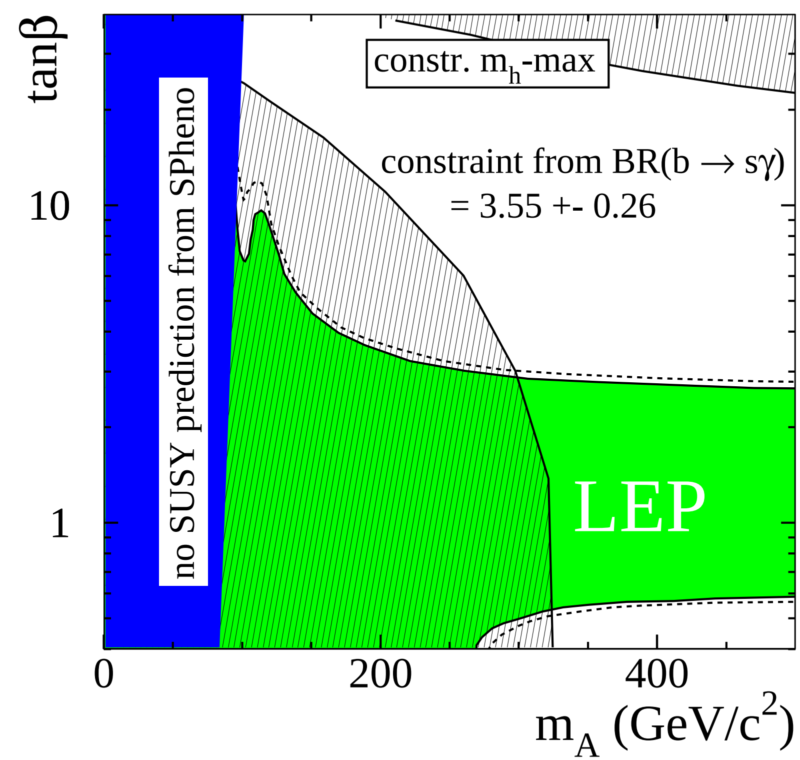


SUSY penguin

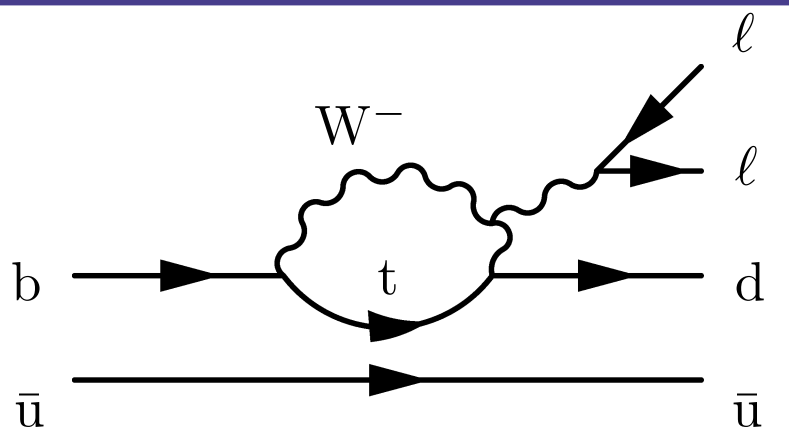


SUSY or 2HDM penguin

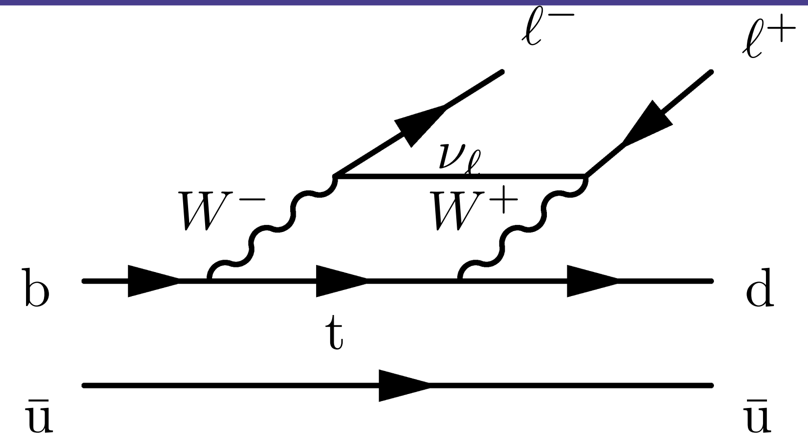
- New physics enters at the same level as the SM contribution
- Measure inclusive (experimentally difficult) or exclusive (theoretically difficult) rates
- Measure angular correlations (excl.), asymmetries (excl. or incl.) and time-dependent CP-violation (excl)
- Independent measurement of $|V_{td}/V_{ts}|$



$b \to d\ell^+\ell^-$ Transitions



$b \to d\ell\ell$ penguin



$b \to d\ell\ell$ box

- While the $b \to s$ penguin modes
  $\mathcal{B}(B \to K\ell\ell) = (3.4 \pm 0.7 \pm 0.2) \times 10^{-7}$ smallest B BF measured!
  $\mathcal{B}(B \to K^*\ell\ell) = (7.8 \pm 1.9 \pm 1.1) \times 10^{-7}$
  are very small **Phys.Rev. D73 (2006) 092001**,

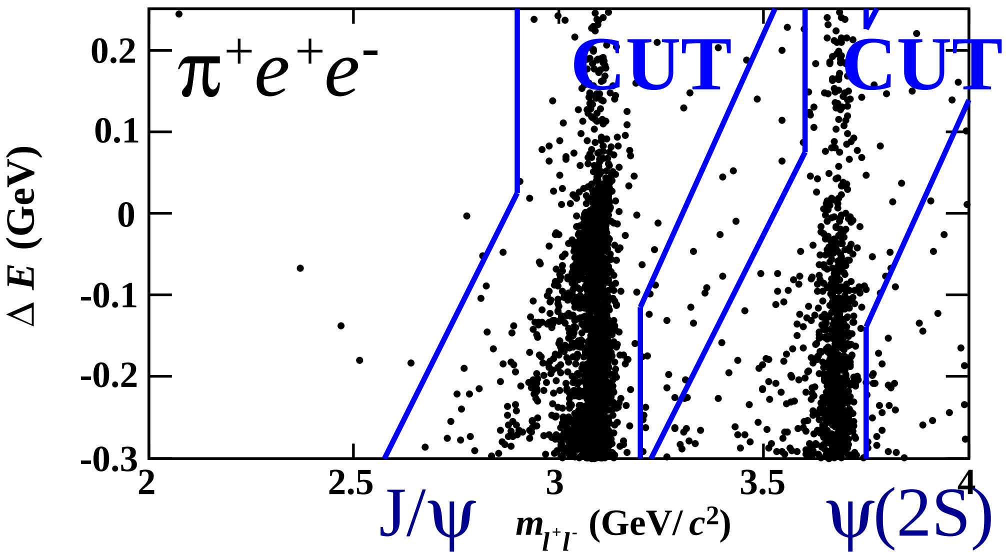
- The $B \to \pi\ell\ell$ BF is expected to be even smaller by a factor of 10 due to the small $|V_{td}/V_{ts}|$:
  $\mathcal{B}(B \to \pi\ell\ell) = 3.3 \times 10^{-8}$
  Aliev, Savci, Phys.Rev. D60 014005 (1999)

This tiny rate might be enhanced significantly by Non-SM-Physics

The Search for $B \to \pi\ell^+\ell^-$

- Experimental challenge in addition to the reduced BF with respect to $K^{(*)}\ell\ell$:
- Much more π in the background than K, charmonium background
- Babar analysis on 209 fb-1: hep-ex/0703018, submitted to PRL
- Select good π, e, μ
- Veto resonances decaying to $\ell\ell$
- Event shape Fisher Discriminant against continuum background
- Event shape Likelihood against BB background

MC: vetos against $B \to J/\psi\pi(K^{(*)})$ events

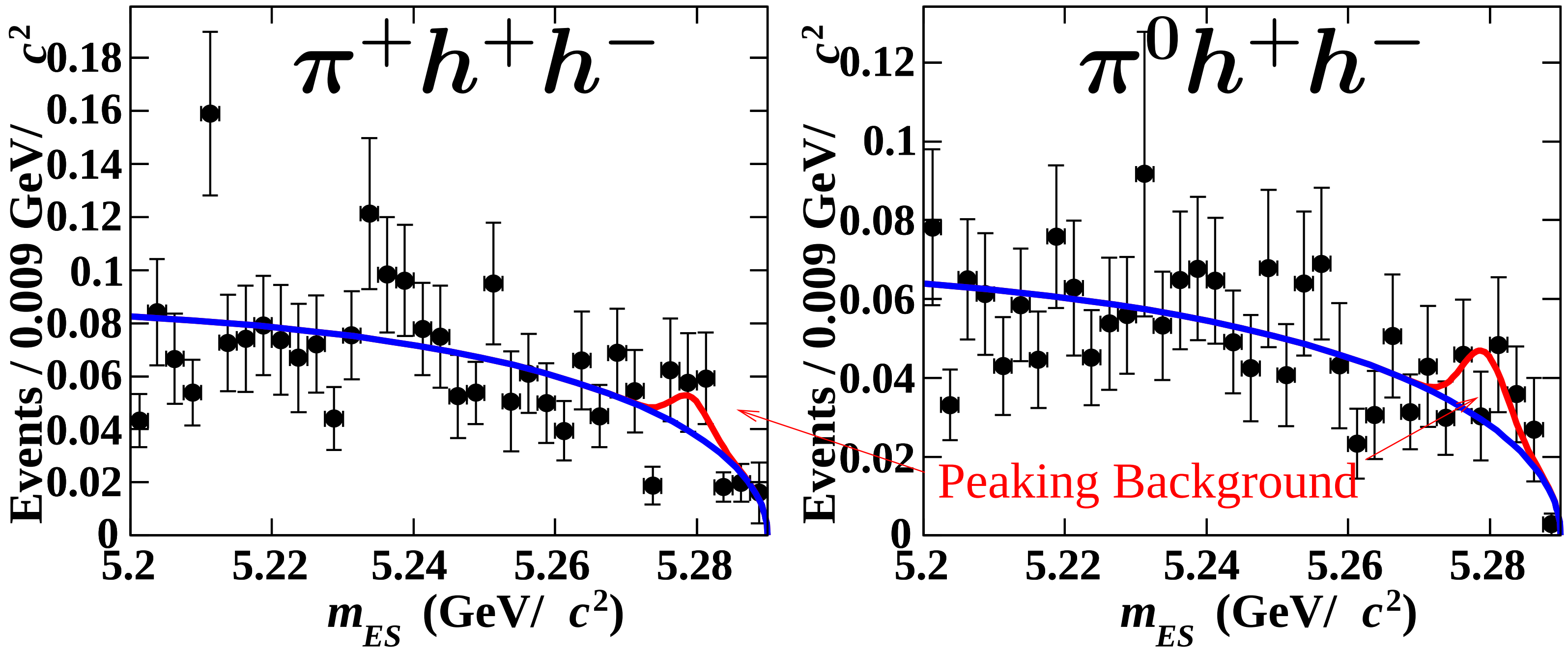


Tilted because of Bremsstrahlung

- $u\bar{u}, d\bar{d}, s\bar{s}$ combinatorics strongly reduced by requiring two high momentum leptons
- After peaking charmonium veto: Dominated by combinatorics from $c\bar{c}$ and $B\bar{B}$

$B \to \pi \ell^+ \ell^-$ Background Assessment

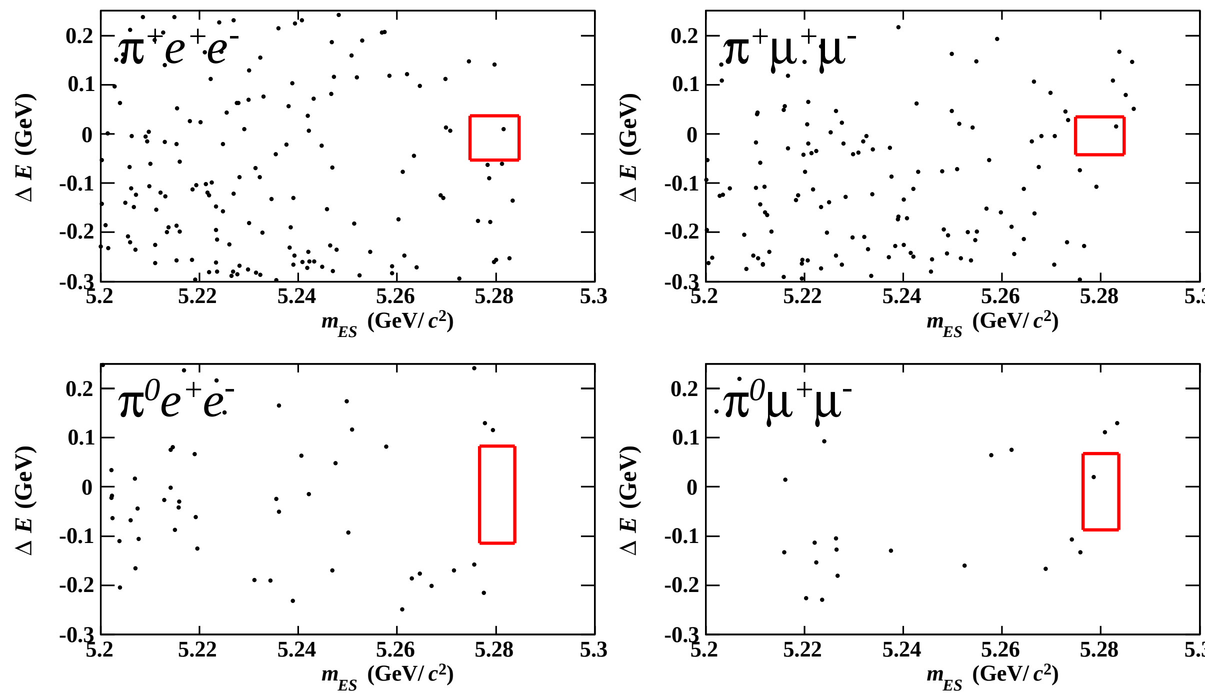
- Measure $B \to J/\psi(\psi(2S))\pi(K)$ contribution in data, check MC simulation
- Use sidebands in $m_{ES}, \Delta E$ as control sample
- Use $e\mu$ events as control samples
- Measure hadronic mistags by specifically reconstructing $\pi\ell h$ events and then re-weight these events with measured mistag rates:



hep-ex/0703018, submitted to PRL

$B \to \pi \ell^+ \ell^-$ Limits

- Extrapolate background from fit outside of signal box
- Frequentist limit using cut-and-count in signal box
- Factor 10^4 improvement of limit over previous limits
  Mark II, Phys.Rev. D41, 1384
- Within a factor of 3 of the SM prediction of $\mathcal{B}(B \to \pi \ell\ell) = 3.3 \times 10^{-8}$
  Aliev, Savci, Phys.Rev. D60 014005 (1999)

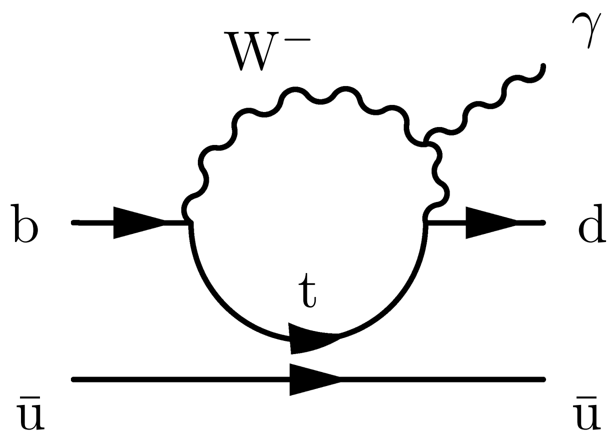


PRELIMINARY		exp.	BF UL
Mode	obs.	backg.	90 % CL (10^{-7})
$B^{\pm} \to \pi^{\pm}\ell\ell$	2	1.86 ± 0.38	1.17
$B^0 \to \pi^0\ell\ell$	1	0.71 ± 0.30	1.15
isospin combination			0.91
$B \to \pi e\mu$	1	2.77 ± 0.70	0.92

Limit Lepton FV →

hep-ex/0703018, submitted to PRL

$b \to d\gamma$ Transitions



$b \to d\gamma$ penguin

- First observation of $b \to d$ penguins from Belle with $350\,\mathrm{fb}^{-1}$ of data: **PRL 221601 (2006)**
- $|V_{td}/V_{ts}| \approx 0.2$, hence suppression of $b \to d$ with respect to $b \to s$
- Possibility to measure $|V_{td}/V_{ts}|$ independently of $\Delta m_d/\Delta m_s$

$$\frac{\Gamma(B \to \rho\gamma)}{\Gamma(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \frac{(m_B - m_\rho)^3}{(m_B - m_{K^*})^3} \left(\frac{T^\rho(0)}{T^{K^*}(0)}\right)^2 (1 + \Delta R)$$

- $\Delta R = 0.1 \pm 0.1$ **Ali, Lunghi, Parkhomenko, PLB595, 323 (2004)**, $\left(\frac{T^\rho(0)}{T^{K^*}(0)}\right)^{-1} = 1.17 \pm 0.09$ **Ball,Zwicky JHEP0604, 046 (2006), hep-ph/0603232**

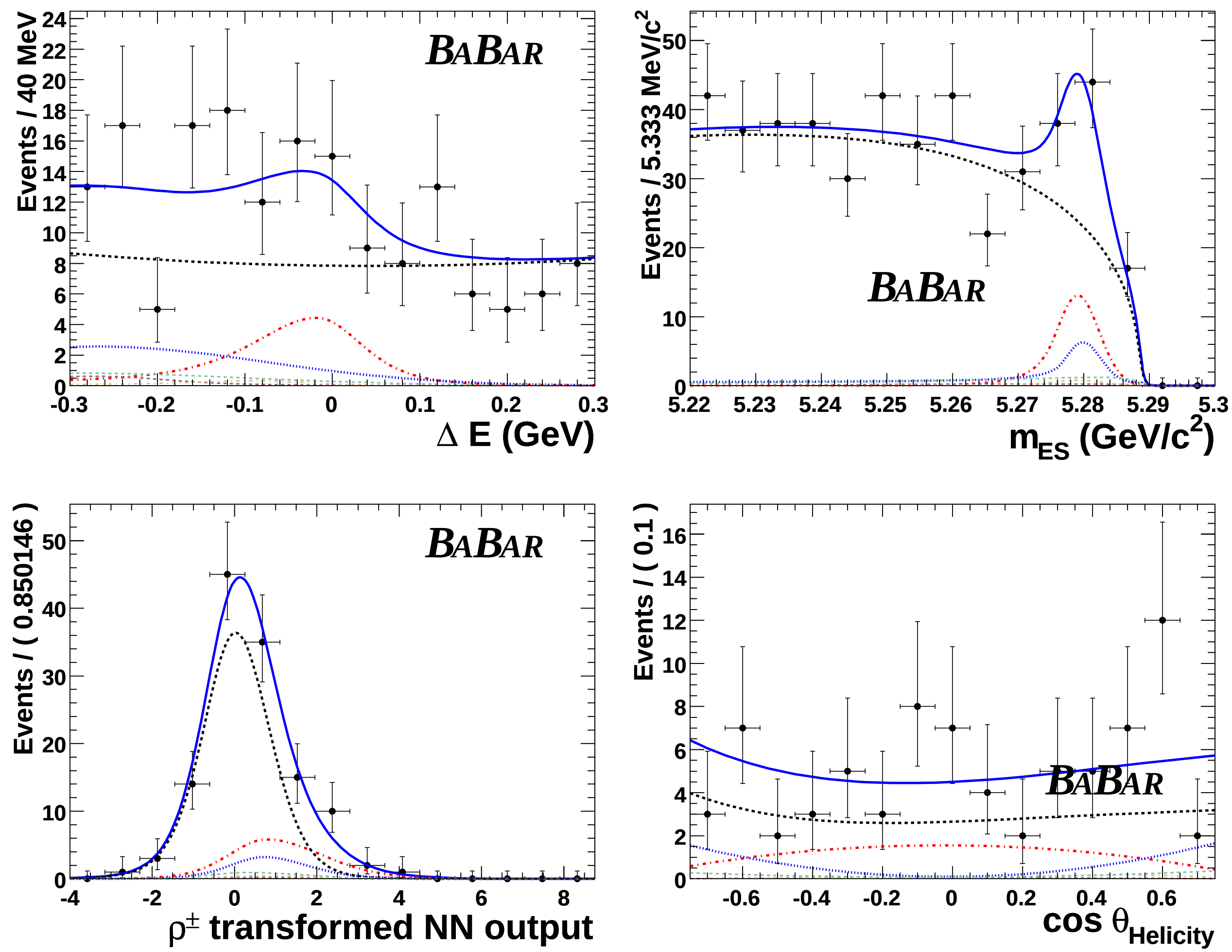
Measurement of $B \to \rho/\omega\gamma$

- Much smaller rates than $K^*\gamma$ ($\approx 4 \times 10^{-5}$):
  $\mathcal{B}(B^0 \to \rho^0\gamma) \sim 0.5 \times 10^{-6}$
  $\mathcal{B}(B^\pm \to \rho^\pm\gamma) \sim 1.0 \times 10^{-6}$
- High particle identification requirements for K suppression
- π Combinatorics: $\Gamma(\rho) = 150\,\mathrm{MeV}$
- BaBar measurement with 316fb-1: **hep-ex/0612017, accepted by PRL**
- High continuum background with $\pi^0/\eta \to \gamma\gamma$
  - Likelihood $\pi^0/\eta \to \gamma\gamma$ veto
  - Neural Net (NN) continuum suppression
    event shape, signal B decay (Δz etc), other B (p_ℓ etc)
- Many control samples checks, e.g.
- Check simulation of true $B \to K^*\gamma$ background by specifically reconstructing $K^*\gamma$, use off-peak data to check continuum

$B \to \rho/\omega\gamma$ Background Checks

$B \to \rho^+\gamma$ mode

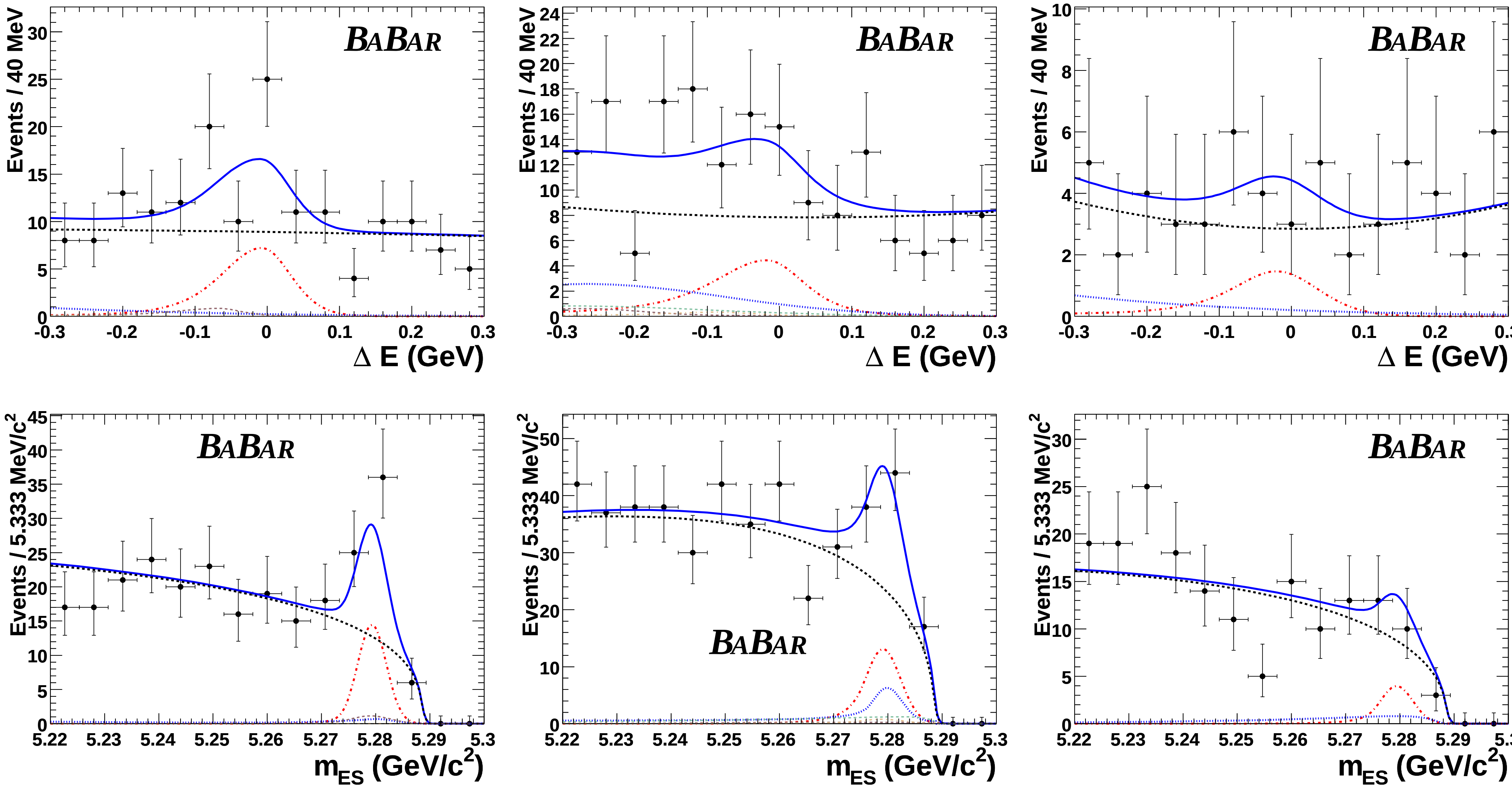
- Final step of the selection:
- Simultaneous fit to
  - m_{ES}
  - ΔE
  - transformed NN output
  - $\cos\theta_{\text{helicity}}$
  - For $\omega\gamma$: Dalitz angle



total signal continuum backg. total $B\bar{B}$ $K^*\gamma$

hep-ex/0612017, accepted by PRL

Measurement of $B \to \rho/\omega\gamma$



$B^0 \to \rho^0\gamma$ $B^\pm \to \rho^\pm\gamma$ $B^0 \to \omega\gamma$

hep-ex/0612017, accepted by PRL

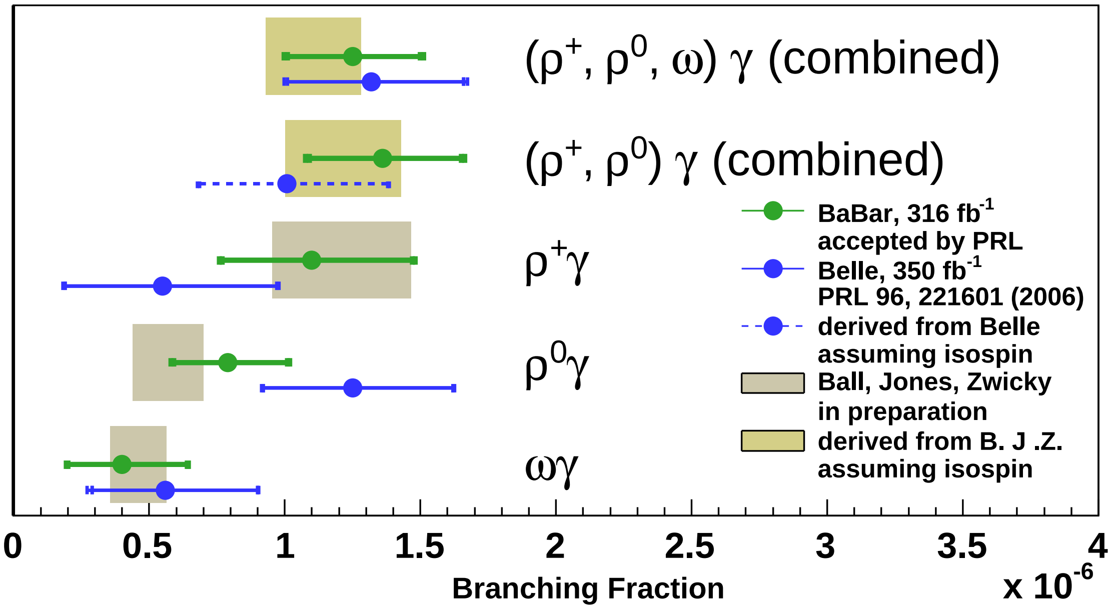
Comparison of Results

- BaBar results ($\mathcal{B}(10^{-6})$):

  hep-ex/0612017, accepted by PRL

- $\rho^0\gamma: \ 0.79^{+0.22}_{-0.20} \pm 0.06\,(4.9)$
- $\rho^{\pm}\gamma: \ 1.1^{+0.37}_{-0.33} \pm 0.09\,(3.8\sigma)$
- $\omega\gamma: \ 0.40^{+0.24}_{-0.20} \pm 0.05\,(2.2)$
- Confirmation of $B^0 \to \rho^0\gamma$
- First evidence of $B^{\pm} \to \rho^{\pm}\gamma$!

- BaBar and Belle Comparison



- Isospin test: $\frac{\Gamma(B^{\pm}\to\rho^{\pm}\gamma)}{2\Gamma(B^0\to\rho^0\gamma)} - 1 = -0.35 \pm 0.27$
- Combine all modes for best statistical significance with isospin constraint

  $B \to \rho/\omega\gamma: \ 1.25^{+0.25}_{-0.24} \pm 0.09\,(6.4\sigma)$

Extraction of $|V_{td}/V_{ts}|$

- Combined BF:

$$\mathcal{B}(B \to \rho/\omega\gamma)(10^{-6}): \quad \underbrace{1.25^{+0.25}_{-0.24} \pm 0.09}_{\text{BaBar}} \quad \underbrace{1.32^{+0.34+0.10}_{-0.31-0.09}}_{\text{Belle}} \quad \underbrace{1.28^{+0.20}_{-0.19} \pm 0.06}_{\text{Average}}$$

- Extract $|V_{td}/V_{ts}|$ from $\mathcal{B}(B \to \rho/\omega\gamma)$ average:

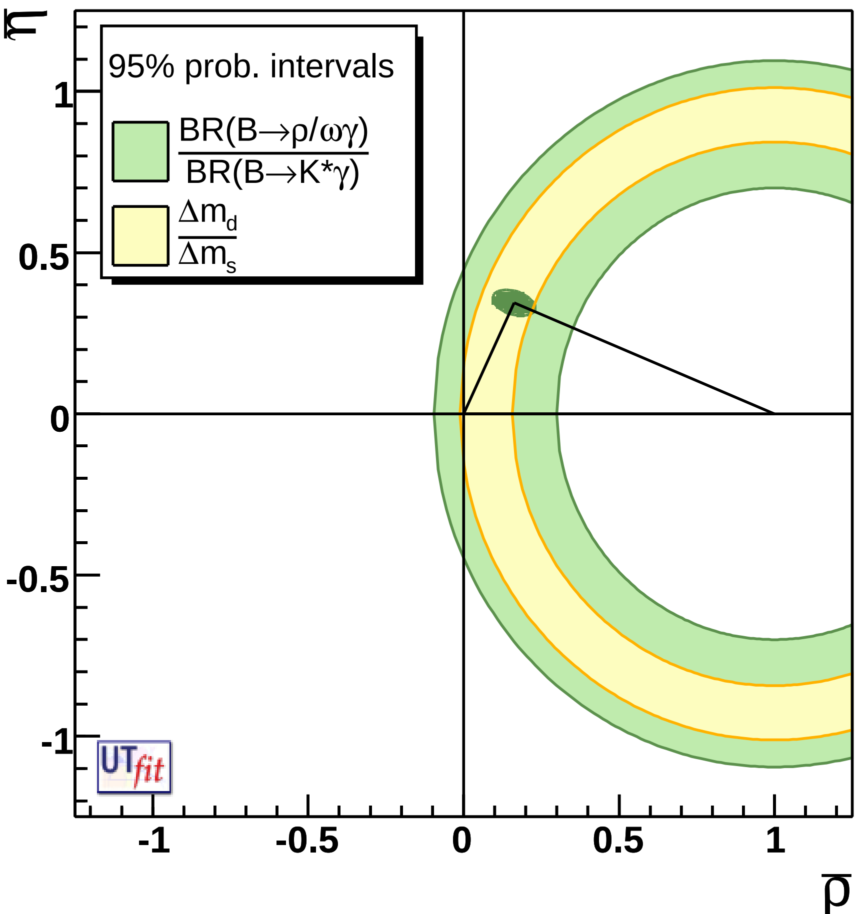
$$\left|\frac{V_{td}}{V_{ts}}\right|_{\rho/\omega\gamma} = 0.202\underbrace{^{+0.017}_{-0.016}}_{8.2\,\%} \pm \underbrace{0.015}_{7.4\,\%}$$

Ball, Jones, Zwicky hep-ph/0612081

- Compare with B_s mixing

$$\left|\frac{V_{td}}{V_{ts}}\right|_{\Delta m_d/\Delta m_s} = 0.2060 \pm 0.0007^{+0.0081}_{-0.0060}$$

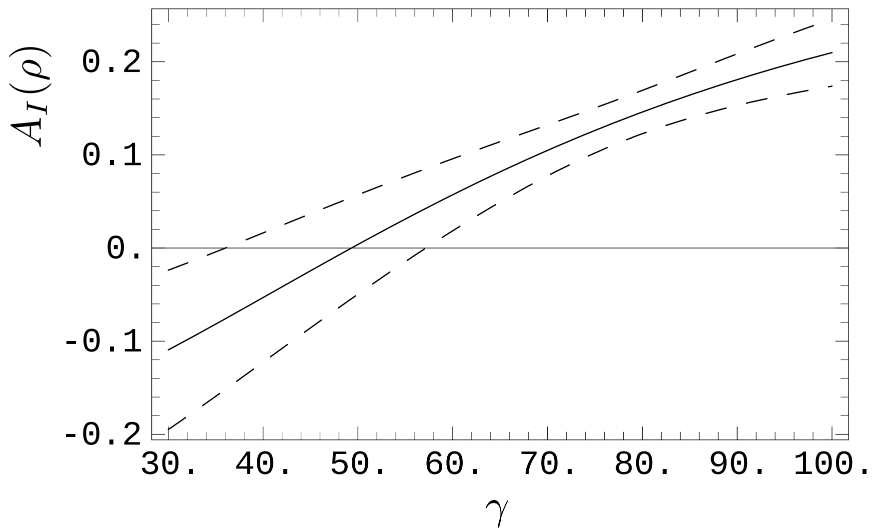
CDF Phys.Rev.Lett.97:242003 (2006)



Different diagrams: independent measurement of the same parameters

Radiative Penguins with 1 ab^{-1}

- $b \to d$ transitions:
  - Improved $|V_{td}/V_{ts}|$ from $B \to \rho/\omega\gamma$
  - 10% CP asymmetry in $B \to \rho/\omega\gamma$
  - $|V_{td}/V_{ts}|_{\rho\gamma}$ soon theory limited $\Rightarrow$ need improvement
  - Isospin asymmetry vs. CKM γ
    $A_I = \frac{2\Gamma(B^0 \to \rho^0\gamma)}{\Gamma(B^\pm \to \rho^\pm\gamma)} - 1$
    Completely independent measurement



Ball, Jones, Zwicky, Phys.Rev.D75 054004 (2007)

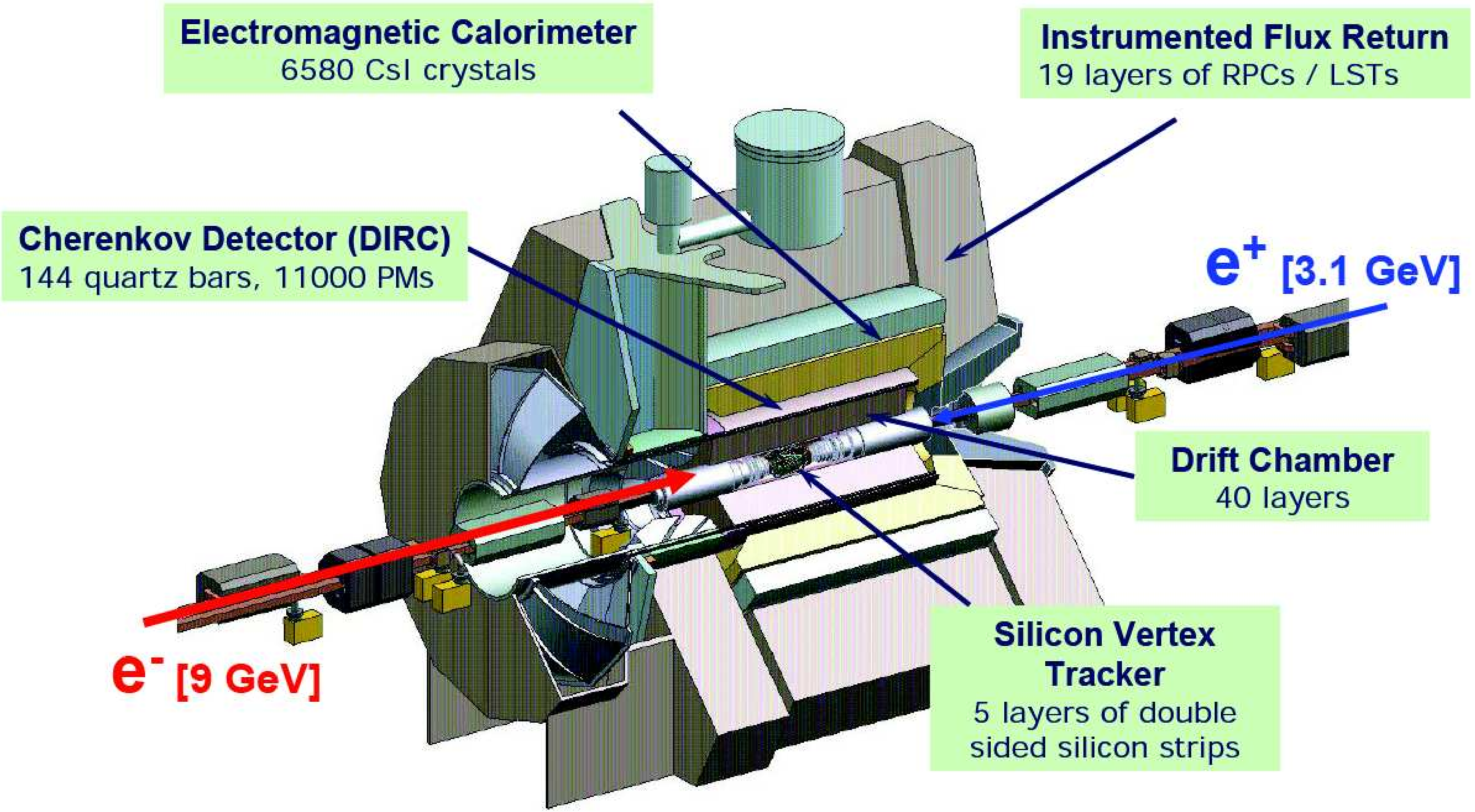
- Generally in radiative penguins
  - 1 % isospin asymmetries for $K^*\gamma$
  - Much improved angular correlations in $K^{(*)}\ell\ell$
  - <5 % measurement inclusive $b \to s\gamma$ BF
  - Interplay with LHC: Extract flavour information where the LHC can’t

Conclusions

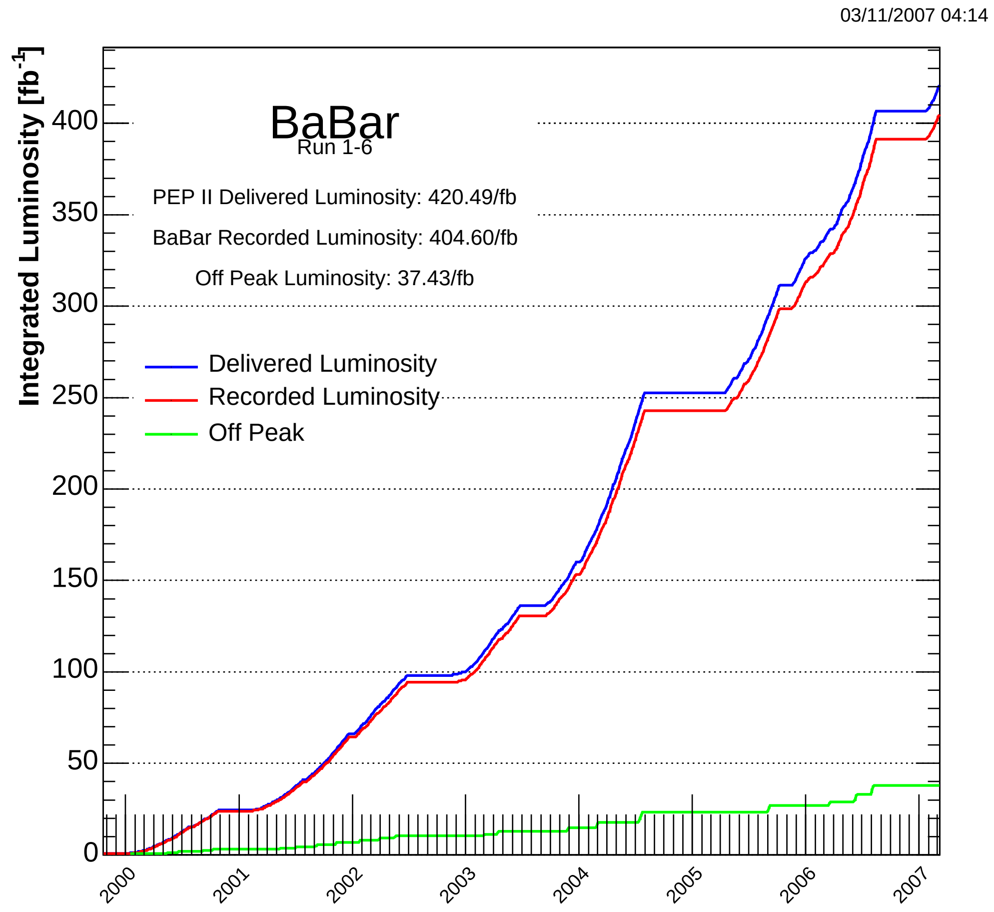
- Electroweak and Radiative Penguins have expanded into a diverse and intense field of physics in the last 14 years
- Strong program to explore $b \to d$ transitions
- Tremendous improvement in limit on $B \to \pi \ell^+ \ell^-$ from BaBar
- $\mathcal{B}(B \to \pi \ell^+ \ell^-) < 0.91 \times 10^{-7}$ within a factor of 3 of the SM
- First evidence for $B^+ \to \rho^+ \gamma$ from BaBar:
  $\mathcal{B}(B^\pm \to \rho^\pm \gamma) = (1.1^{+0.37}_{-0.33} \pm 0.09) \times 10^{-6}\,(3.8\sigma)$
  $\mathcal{B}(B^0 \to \rho^0 \gamma) = (0.79^{+0.22}_{-0.20} \pm 0.06 \times 10^{-6}\,(4.9)$
  $\mathcal{B}(B^0 \to \omega \gamma) = (0.40^{+0.24}_{-0.20} \pm 0.05 \times 10^{-6}\,(2.2)$
- Good agreement of $|V_{td}/V_{ts}|_{\rho\gamma} = 0.202 \pm 0.23$ with $\Delta m_d / \Delta m_s$ measurements and the SM
- $|V_{td}/V_{ts}|_{\rho\gamma}$ theory limited for the expected full BaBar dataset $\Rightarrow$ improvement needed
- Prospect to explore isospin and CP asymmetries in $B \to \rho/\omega\gamma$

Backup Slides

The BaBar Experiment

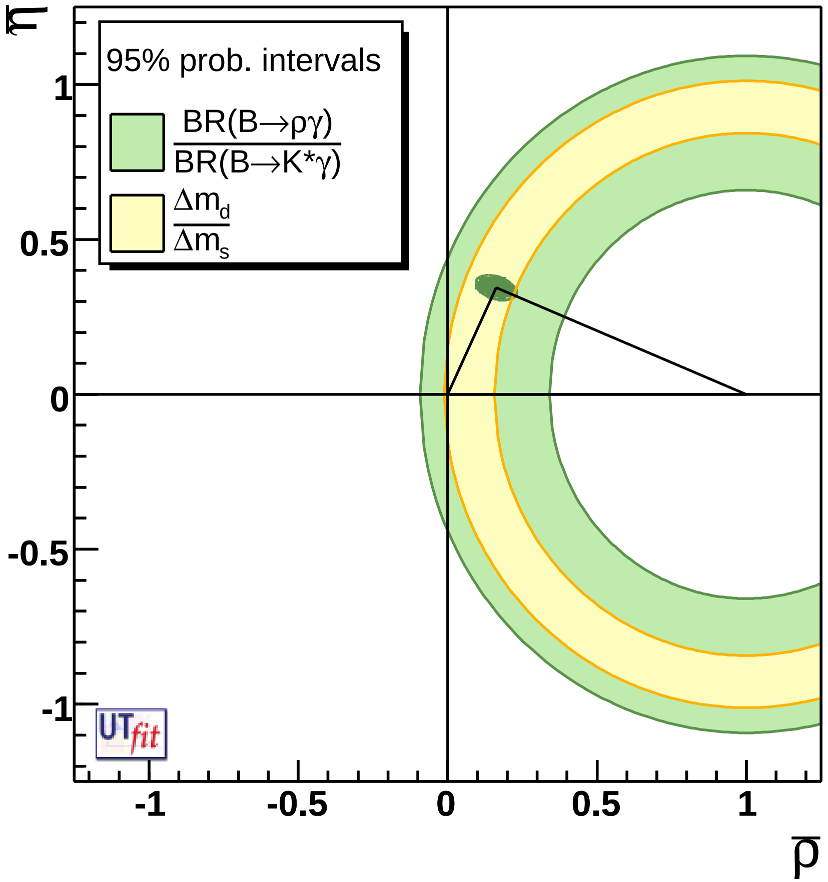


The BaBar Experiment



- $363\ \mathrm{fb}^{-1}$ at $\sqrt{s} = 10.58\,\mathrm{GeV} \Rightarrow$ 400 Million $\mathrm{B\bar{B}}$ (still growing at $> 10\,\mathrm{B\bar{B}}/s$)
- Off-Peak datataking (production of $\mathrm{u}, \mathrm{d}, \mathrm{s}, \mathrm{c}, \ell$) at $10\,\%$ of the luminosity

$|V_{td}/V_{ts}|_{\rho\gamma}$ without ω



$\pi\ell\ell$ Systematics

Systematic	$\pi^+e^+e^-$	$\pi^0e^+e^-$	$\pi^+\mu^+\mu^-$	$\pi^0\mu^+\mu^-$	$\pi^+e\mu$	$\pi^0e\mu$
Trk eff.	±3.0	±1.6	±3.0	±1.6	±3.0	±1.6
Electron ID	±0.7	±0.7			±0.4	±0.4
Muon ID			±1.9	±1.9	±1.0	±1.0
Pion ID	±0.5		±0.5		±0.5	
π^0 ID		±3.0		±3.0		±3.0
Fisher and $B\overline{B}$ likelihood	±1.4	±1.4	±1.7	±1.9	±1.4	±1.4
MC statistics	±0.1	±0.1	±0.1	±0.1	±0.1	±0.1
$B\overline{B}$ counting	±1.1	±1.1	±1.1	±1.1	±1.1	±1.1
signal m_{ES} model	±0.3	±5.1	±0.4	±4.9	±0.3	±5.1
signal ΔE model	±0.6	±5.1	±0.5	±5.4	±0.5	±5.2
signal ΔE radiative tail	±1.2	±1.3			±1.0	±1.4
C_i dependence	±1.2	±1.0	±0.6	±0.3		
form factor dependence	±1.1	±3.3	±4.2	±7.3	±3.0	±3.0
Total	±4.2	±9.0	±5.9	±11.2	±4.9	±8.9

hep-ex/0703018, submitted to PRL

$\rho/\omega\gamma$ Systematics

Source of error	$B^+ \to \rho^+\gamma$	$B^0 \to \rho^0\gamma$	$B^0 \to \omega\gamma$	$B \to (\rho,\omega)\gamma$	$B \to (\rho^+,\rho^0)\gamma$
Tracking efficiency	1.0%	2.0%	2.0%	1.5%	1.4%
PID	2.0%	4.0%	2.0%	2.7%	2.9%
Photon selection	1.9%	2.6%	1.7%	2.1%	2.2%
π^0 reconstruction	3.0%	-	3.0%	2.5%	1.9%
π^0 and η veto	2.8%	2.8%	2.8%	2.8%	2.8%
$\mathcal{NN}$ efficiency	1.0%	1.0%	1.0%	1.0%	1.0%
$\mathcal{NN}$ shape	0.4%	0.3%	2.3%	0.7%	0.4%
Signal PDF shapes	4.8%	3.3%	2.4%	2.6%	3.1%
B backgrounds	3.9%	2.9%	9.7%	2.9%	2.9%
$B\overline{B}$ sample	1.1%	1.1%	1.1%	1.1%	1.1%
$BF(\omega \to \pi^+\pi^-\pi^0)$	-	-	0.8%	0.1%	-
Combined	8.1%	7.5%	11.6%	6.7%	6.9%

hep-ex/0612017, accepted by PRL