Radiative and Electroweak Rare *B* Decays

— B decays with lepton(s) and photon —

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for Belle, BaBar, CLEO, CDF and D0 collaborations

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Outline — *B* decays with lepton/photon

- Radiative decays: $b \to s\gamma$ and $b \to d\gamma$

  Inclusive $B \to X_s\gamma$ (no new BF since ICHEP'02)

  $B \to K^*\gamma$, $B \to K\phi\gamma$, $B \to$ baryon + γ (FPCP'03)

  $B \to K_2^*\gamma$ (LP'03, new result)

  $B \to \rho\gamma$, $\omega\gamma$ (Moriond'03)

- Electroweak decays: $b \to s\ell^+\ell^-$

  $B \to K\ell^+\ell^-$, $B \to K^*\ell^+\ell^-$ (LP'03 new result)

  Inclusive $B \to X_s\ell^+\ell^-$ (LP'03 new result)

- Challenging modes with neutrino and/or helicity suppression

  $B \to K\nu\bar{\nu}$ (FPCP'03)

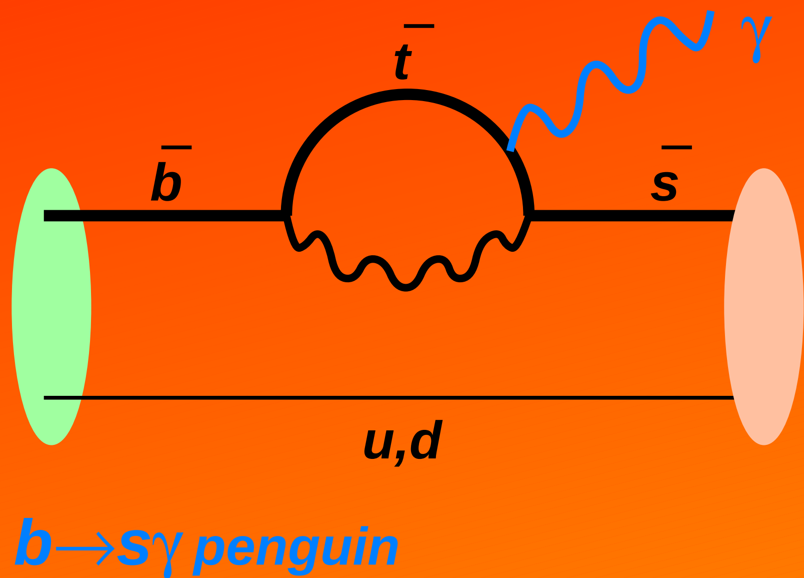
  $B \to \tau\nu$ (Moriond'03)

  $B \to \mu\nu$ (EPS'03)

  $B_{d,s} \to \ell^+\ell^-$ (LP'03, new result)

All results are preliminary, unless jornal ref. is given

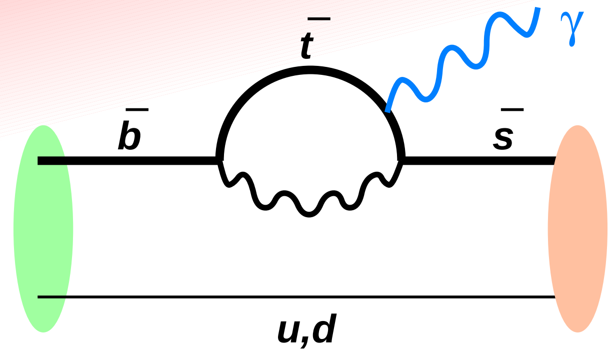
- KM mechanism successfully explains the large CPV in $B \to J/\psi K_S^0$
- What we wish is a theory (and experimental evidence) beyond SM, because the SM does not answer to our fundamental questions: Baryogenesis, Grand unification of forces, Quark/lepton families?
- If the surprising $B \to \phi K_S^0$ results are correct,



Radiative / electroweak / leptonic B decays are sensitive to new physics!

Leptons and photons are our friends, providing clean B samples for SM or beyond

$b \to s\gamma$



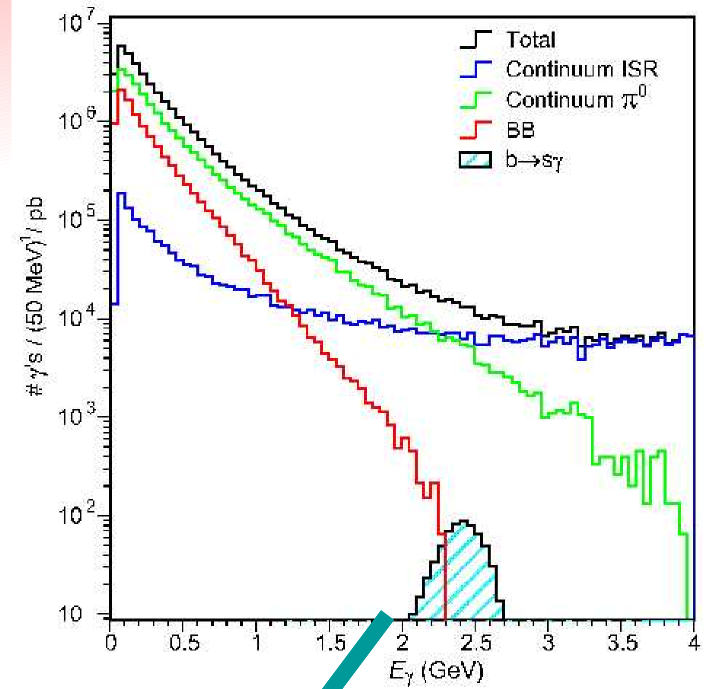
- Penguin diagram can accommodate heavy new particles (SUSY, H^+)
- Formulated in an effective hamiltonian: $\mathcal{H}_{\rm eff} \propto \sum_{i=1}^{10} C_i(\mu) O_i(\mu)$

$$\Gamma(b \to s\gamma) = \frac{G_F^2 \alpha_{\rm em} m_b^5}{32\pi^4} |V_{ts}^* V_{tb}|^2 \left(|C_7^{\rm eff}|^2 + 1/m_b,\ 1/m_c \text{ corrections} \right)$$

Normalized with $b \to c\ell\nu$: ($G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2$ cancels by assuming $\left|V_{ts}^* V_{tb}\right| = |V_{cb}|$)

- Probe new physics through Wilson coefficient $|C_7|$, NLO calculation for SM and various new physics scenarios
- A_{CP} in $B \to X_s\gamma$
  $b \to s\gamma$ penguin $\Leftrightarrow$ $b \to sg$ (charm loop contribution),
  A_{CP} if new CPV phase in $b \to s\gamma$ — very small ($< 1\%$) in SM
- Tool for B-meson dynamics

$B \to X_s\gamma$

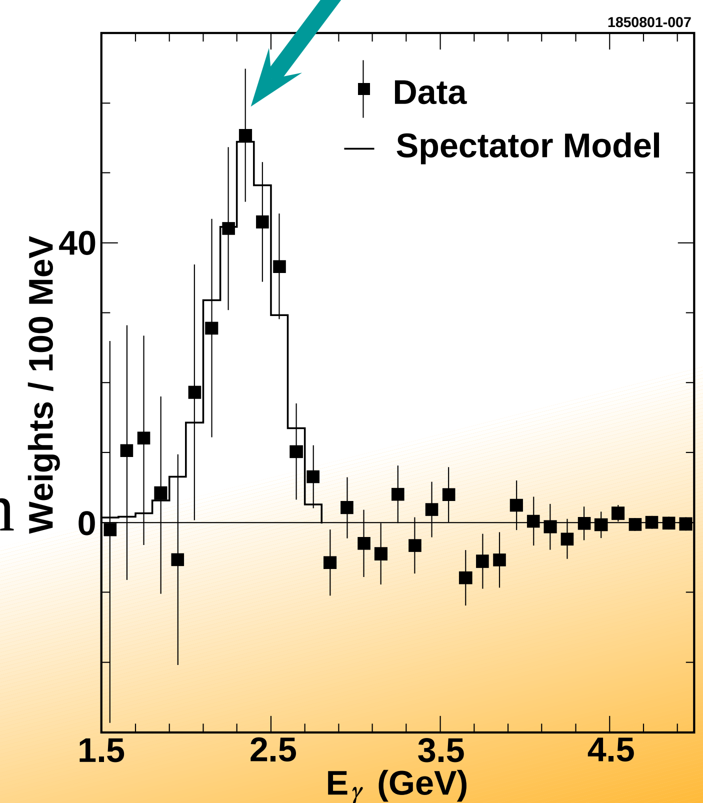


E_γ signal sits underneath a huge background

- Continuum $\Rightarrow$ off-resonance subtraction
  On:Off = 2:1 (CLEO), 9:1 (Belle/BaBar)
- π^0 background from B decays
  $\Rightarrow B \to \pi^0 X$ spectrum measurement

Three types of analyses

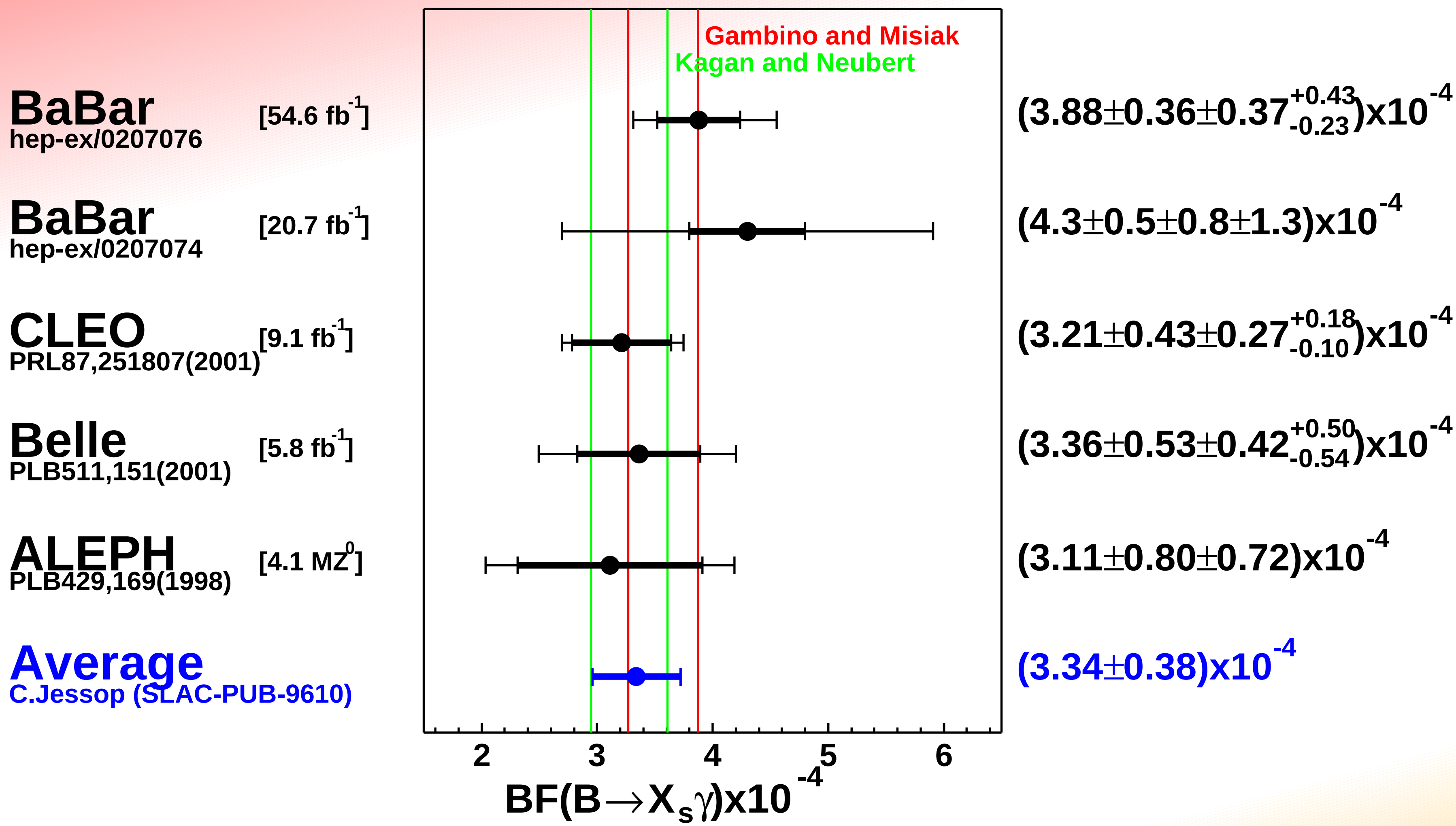
- Semi-inclusive (pseudo-reconstruction) technique (Belle/BaBar)
- Inclusive γ measurement + various background suppression (CLEO)
- Inclusive γ measurement + B tag with lepton (BaBar)



E_γ cut — source of large model error

2.0 GeV (CLEO), 2.1 GeV (BaBar), ~2.2 GeV (Belle)

$B \to X_s\gamma$ branching fractions

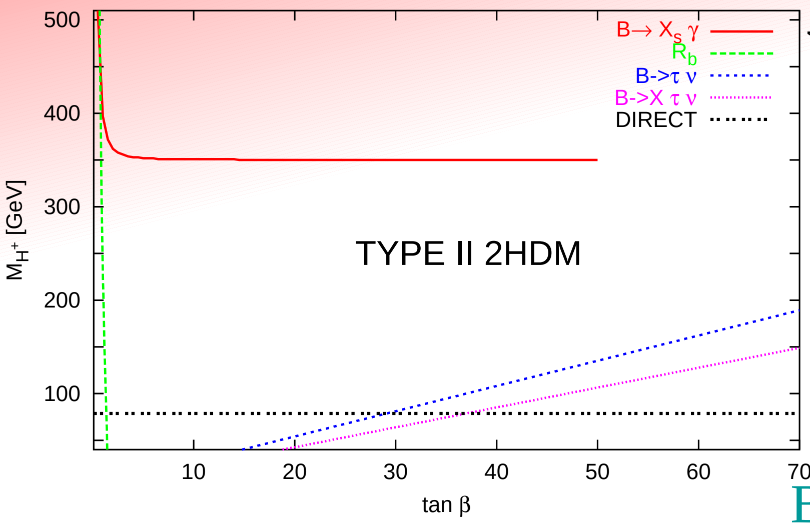


No deviation from SM — many constraints on new physics

To further reduce errors:

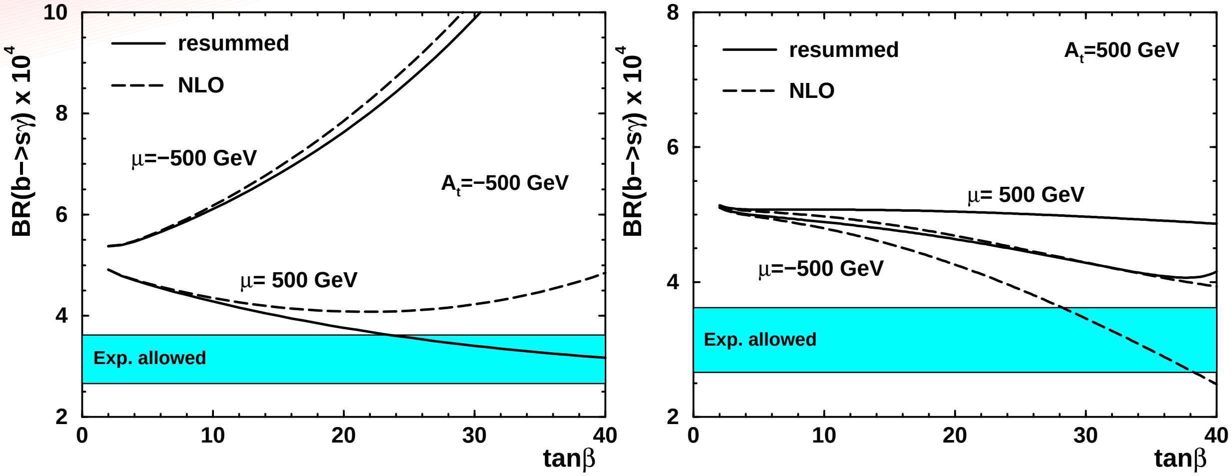
- Theory — need to go from NLO to NNLO
- Measurements — need to lower E_γ (more data)

$b \to s\gamma$ beyond the SM



Lower bounds on type-II charged Higgs mass (w/o SUSY)

Gambino-Misiak, Nucl. Phys. B611, 338



BF in particular MSSM scenario Carena et al., PLB499, 141

$m(H^+) = 200$ GeV, $m(\tilde{t}) = 250$ GeV, others 800 GeV

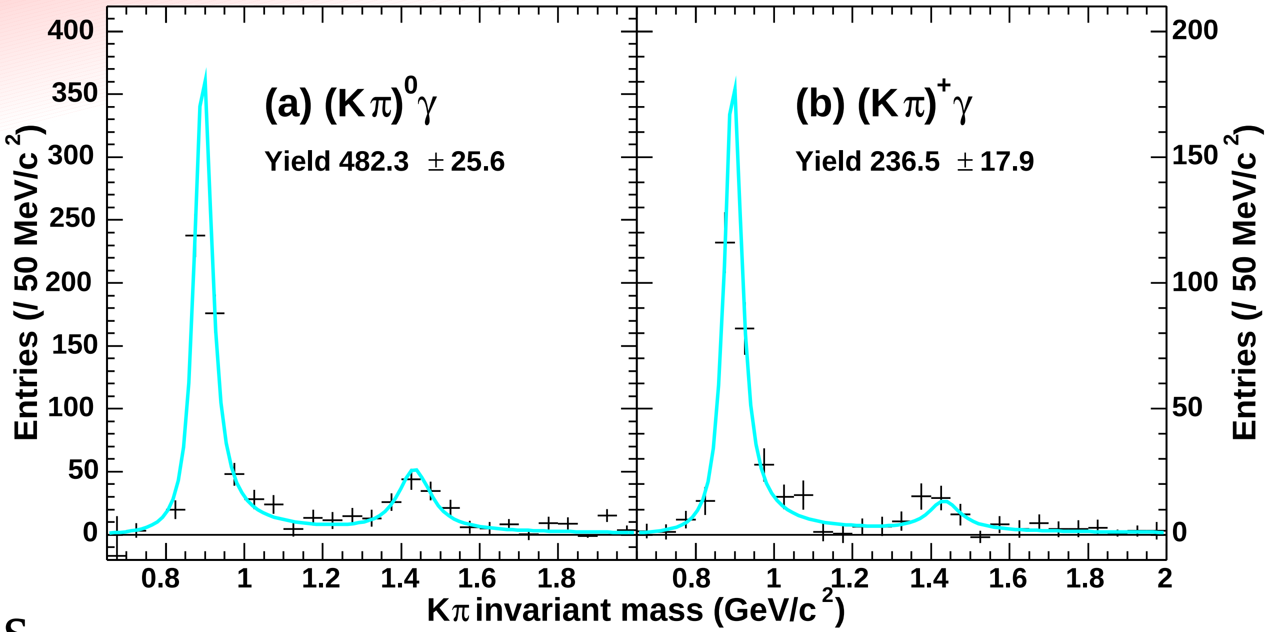
Type-II charged Higgs is very heavy, unless destructive SUSY contributions

type-I	both up and down quarks get their masses from the same Higgs doublet
type-II	up quark masses from Yukawa couplings to H_2, while down quarks get masses from couplings to H_1 (realized in MSSM).

Exclusive decays — $B \to K^*\gamma$

Very clean $K^*\gamma$ signal

$K^{*0} \to K^+\pi^-, K_S^0\pi^0$
$K^{*+} \to K_S^0\pi^+, K^+\pi^0$



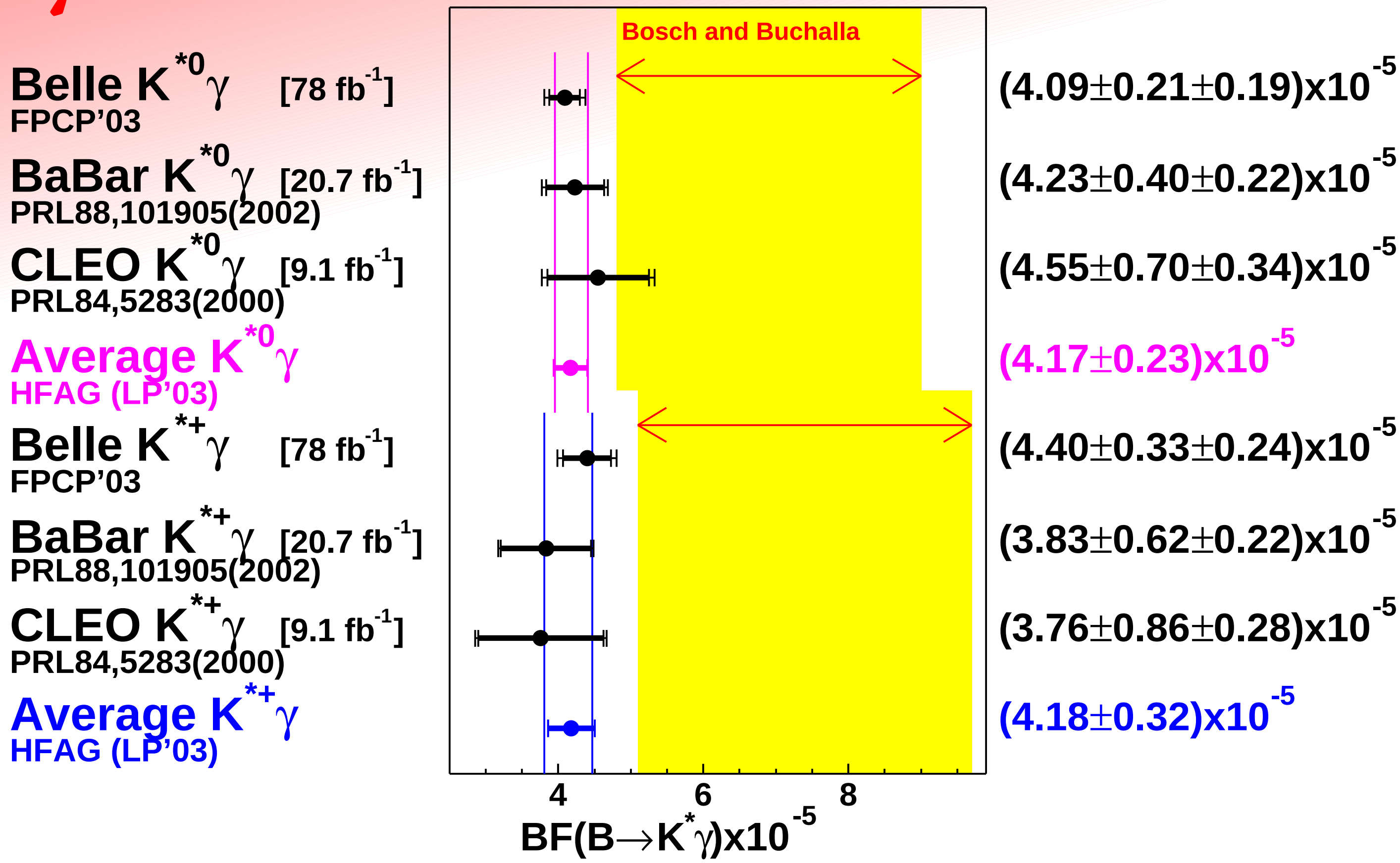
- Large theory errors for branching fractions
- Sign of isospin asymmetry tells the sign of C_6/C_7 ($\Delta_{0+}(\text{SM}) > 0$)
- Belle result [FPCP'03, 78 fb^{-1}]

$$\Delta_{0+} = \frac{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) - \mathcal{B}(B^+ \to K^{*+}\gamma)}{(\tau_{B^+}/\tau_{B^0})\mathcal{B}(B^0 \to K^{*0}\gamma) + \mathcal{B}(B^+ \to K^{*+}\gamma)} = +0.003 \pm 0.045 \pm 0.018$$

Using $\tau_{B^+}/\tau_{B^0} = 1.083 \pm 0.017$ [PDG2002], assuming $f_+/f_0 = 1$

- Need a precise f_+/f_0 before conclusion: Belle $f_+/f_0 = 1.01 \pm 0.03 \pm 0.09$ [PRD67,052004(2003)], PDG2002 $f_+/f_0 = 1.072 \pm 0.057$

$B \to K^{*}\gamma$ results

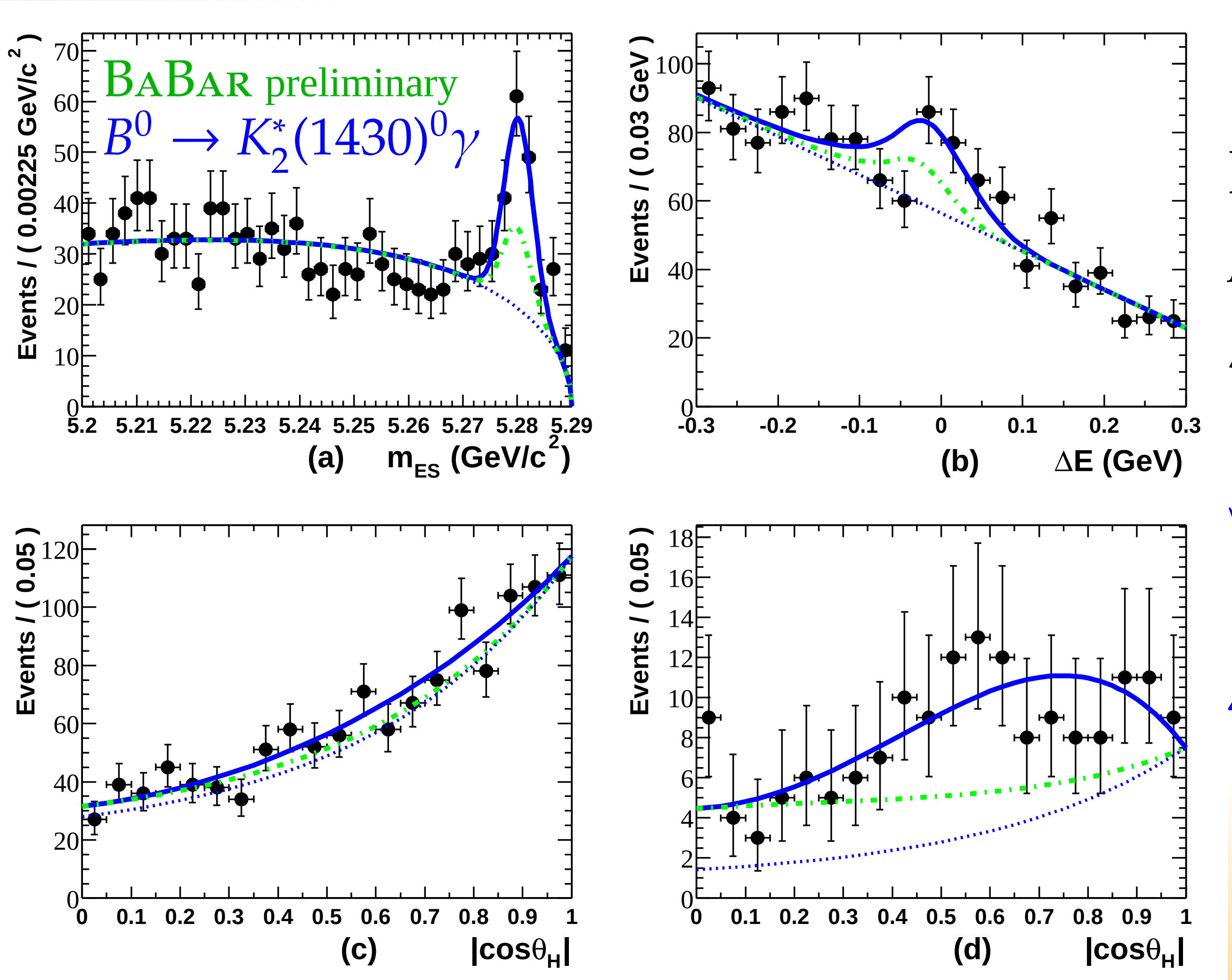


- All measurements agree
- Some theoretical debate on the $B \to K^{*}$ form factor
  - Light-cone sum rule (LCSR): $F_7^{B\to K^*}(0) = 0.38 \pm 0.05$
  - Extracted from measurements: $F_7^{B\to K^*}(0) = 0.27 \pm 0.04$
  - New preliminary Lattice: $F_7^{B\to K^*}(0) = 0.25 \pm 0.04$ (!?) [Becirevic et al.]

$B \to K_2^*(1430)\gamma$

CLEO, Belle have observed $B \to K_2^*(1430)\gamma$, and now BaBar has joined.

$K_2^*(1430) \to K\pi$ (50%), Helicity angle distribution: $\cos^2\theta_H - \cos^4\theta_H$



ML fit on M_{ES}, ΔE, $\cos\theta_H$

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

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

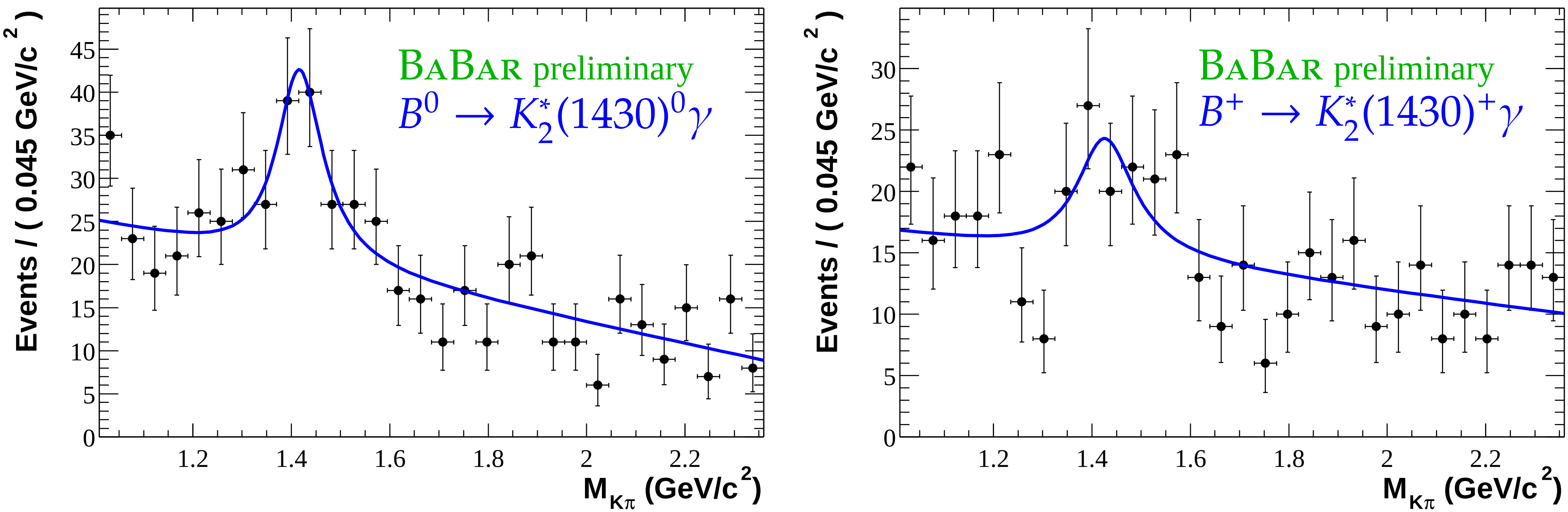
5.8σ for $K_2^*(1430)^0\gamma$, $K_2^{*0} \to K^+\pi^-$

4.1σ for $K_2^*(1430)^+\gamma$, $K_2^{*+} \to K^+\pi^0, K^0_S\pi^+$

$B \to K_2^*(1430)\gamma$ results

	$\mathcal{B}(B^0 \to K_2^*(1430)^0\gamma)$	$\mathcal{B}(B^+ \to K_2^*(1430)^+\gamma)$	
CLEO:	$(16.6^{+5.9}_{-5.3} \pm 1.3) \times 10^{-6}$ (combined)		[PRL84,5283(2000)]
Belle:	$(13 \pm 5 \pm 1) \times 10^{-6}$	—	[PRL89,231801(2002)]
BaBar:	$(12.2 \pm 2.5 \pm 1.1) \times 10^{-6}$	$(14.4 \pm 4.0 \pm 1.3) \times 10^{-6}$	[LP'03 new]

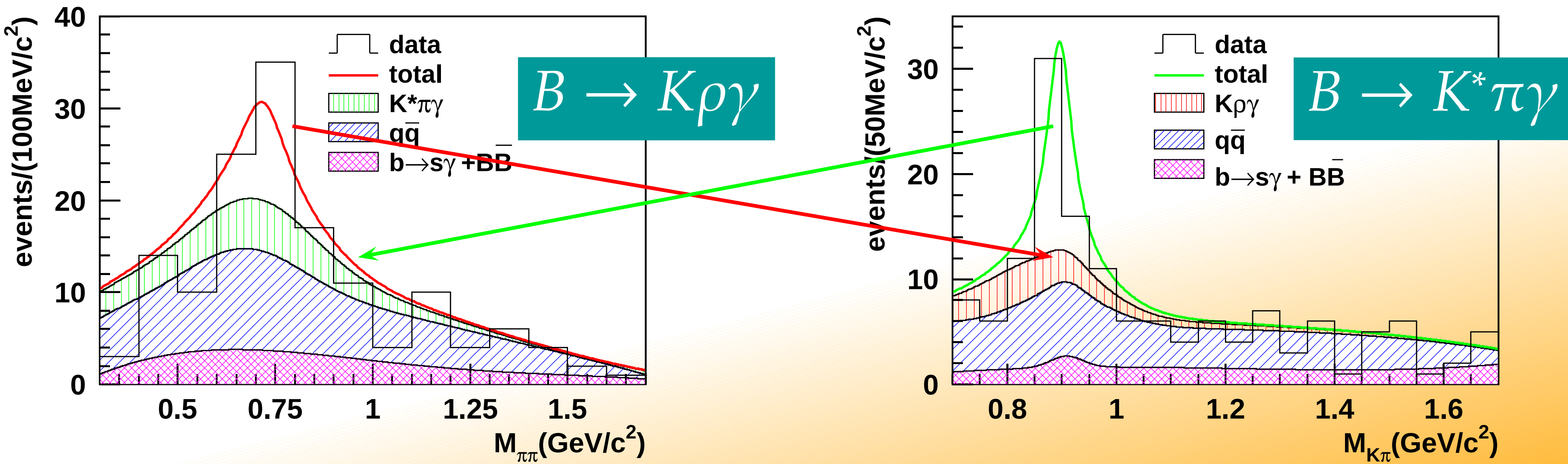
[SM: for example $\mathcal{B}(B \to K_2^*\gamma) = (17.3 \pm 8.0) \times 10^{-6}$, Veseli-Olsson PLB367,309(1996)]



More exclusive radiative decays

- $B \to K\pi\pi\gamma$ (Belle)
  $\mathcal{B}(B^+ \to K^+\pi^+\pi^-\gamma) = (24 \pm 5^{+4}_{-2}) \times 10^{-6}$
- $K^0_S\pi^+\pi^-\gamma$ for mixing-induced CPV for non-SM phase? (a la $B \to \phi K^0_S$)
  - $K^0_S\pi^0\gamma$ is challenging
  - Proposed: $B^0 \to K_1(1270)\gamma \to K^0_S\rho^0\gamma$ [D.Atwood et al., PRL79,185(1997)]
  - But hard to disentangle $K\rho$ (CP) and $K^*\pi$ (non-CP) states.

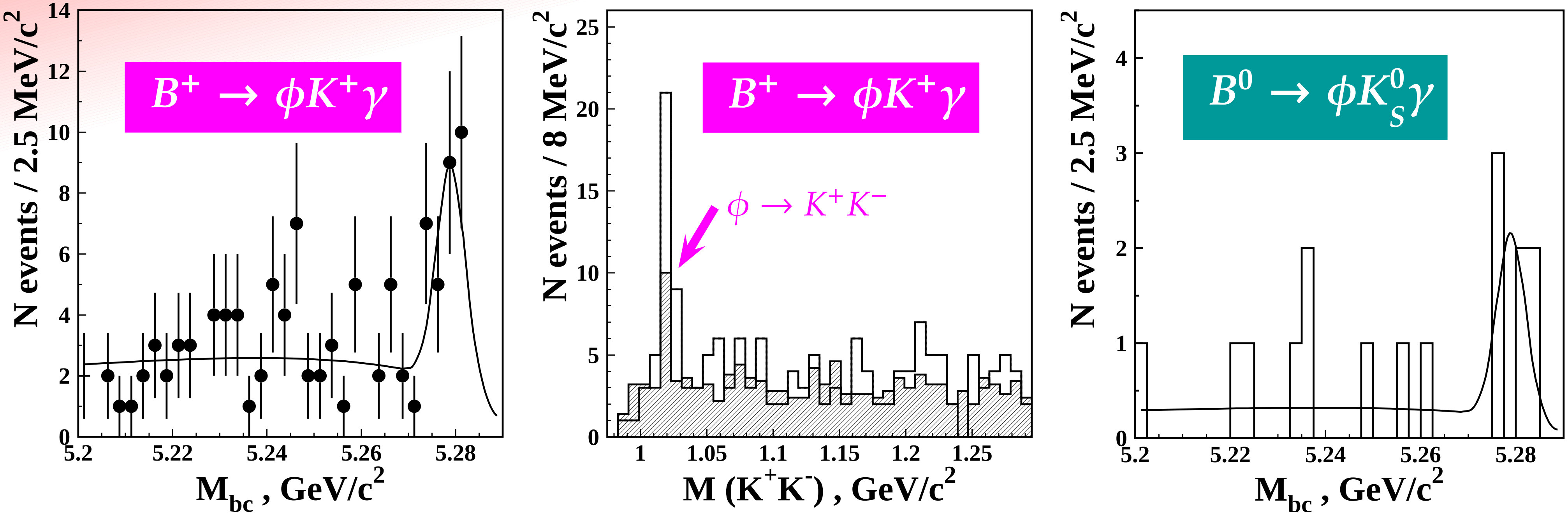
[Belle 29 fb^{-1}, PRL89,231801(2002)]



$B \to K\phi\gamma$ (Belle)

[Belle 90 fb^{-1} FPCP'03]

- New observation of $B^+ \to K^+\phi\gamma$ ($b \to s\bar{s}s\gamma$) — very clear signal!



$$\mathcal{B}(B^+ \to K^+\phi\gamma) = (3.4 \pm 0.9 \pm 0.4) \times 10^{-6}\ (5.5\sigma)$$

$$\mathcal{B}(B^0 \to K^0\phi\gamma) = (4.6 \pm 2.4 \pm 0.6) \times 10^{-6}\ (3.3\sigma)$$

$$< 8.3 \times 10^{-6}\ (90\%\ \text{C.L.})$$

- About 1% of total $b \to s\gamma$
- $B^0 \to K^0_S\phi\gamma$ will be useful for mixing-induced CPV search

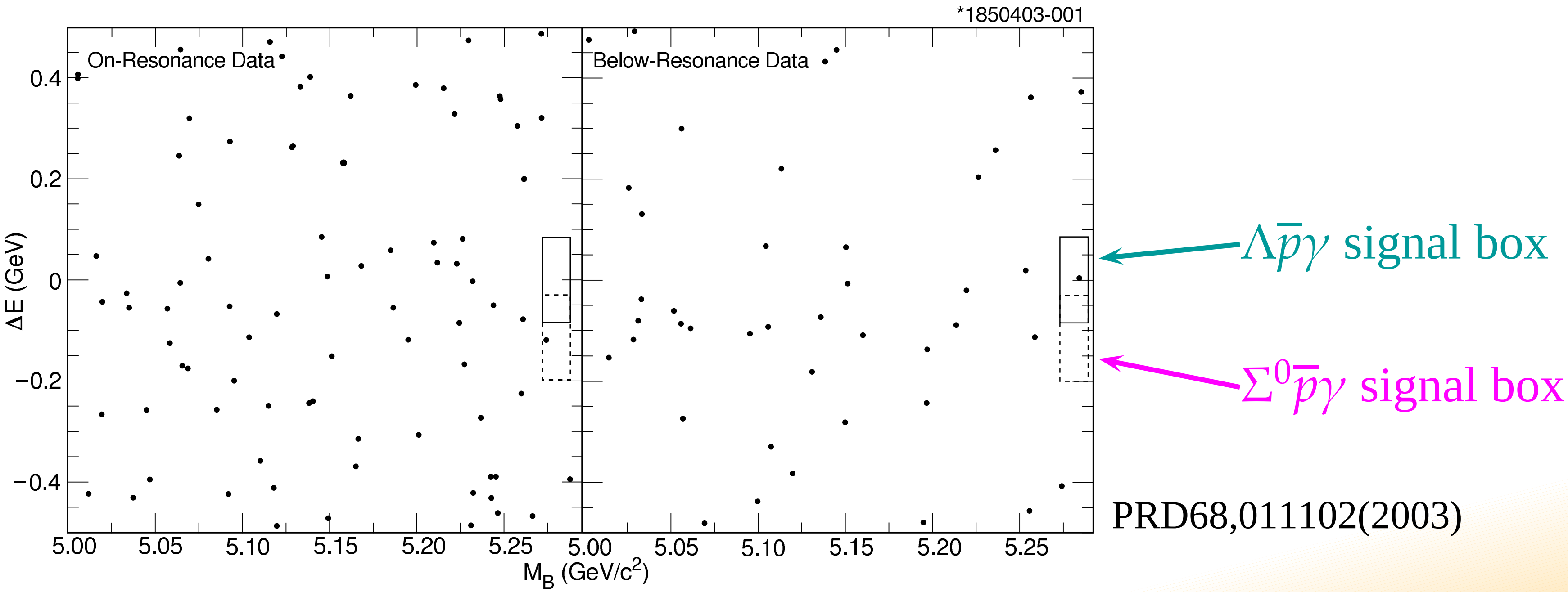
$B \to \Lambda\bar{p}\gamma$ search (CLEO)

$[\mathcal{B}(B \to \Lambda\bar{p}\gamma) + 0.3\mathcal{B}(B \to \Sigma^0\bar{p}\gamma)]_{E_\gamma > 2\,\text{GeV}} < 3.3 \times 10^{-6}$

$[\mathcal{B}(B \to \Sigma^0\bar{p}\gamma) + 0.4\mathcal{B}(B \to \Lambda\bar{p}\gamma)]_{E_\gamma > 2\,\text{GeV}} < 6.4 \times 10^{-6}$

considering isospin ($p \Leftrightarrow n$) and other resonances ($N(1232)\ldots$),

$Br(B \to \gamma + \text{any baryon})_{E_\gamma > 2.0\,\text{GeV}} < 3.8 \times 10^{-5}$ ($< 13\%$)

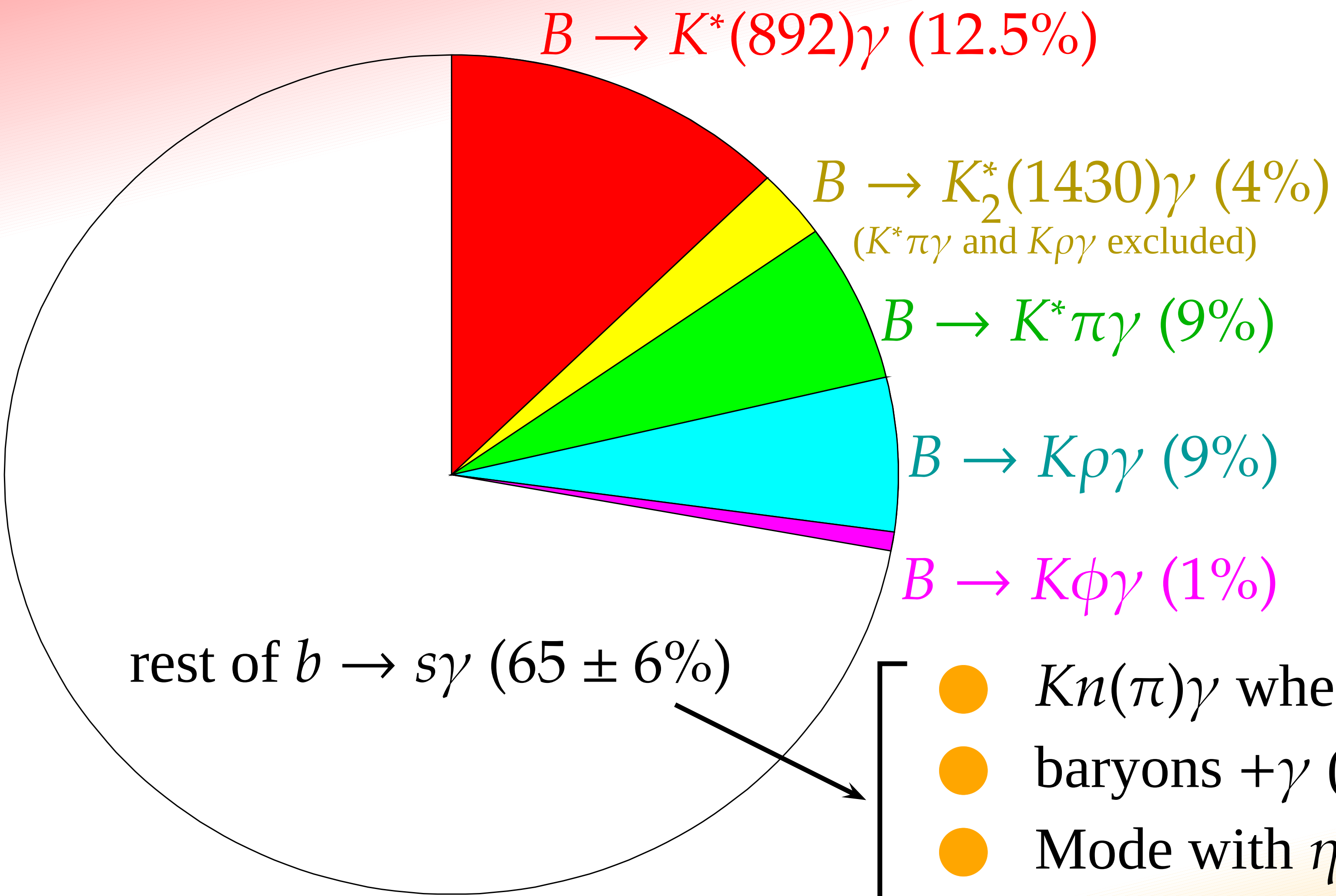


PRD68,011102(2003)

Uncertainty in baryonic $b \to s\gamma$ is within the quoted error by CLEO

Systematic error is less than 6.5%($\mathcal{B}$ and $\langle E_\gamma \rangle$), 36%($\langle E_\gamma^2 \rangle - \langle E_\gamma \rangle^2$)

$b \to s\gamma$ shareholders



- $Kn(\pi)\gamma$ where $n \geq 3$
- baryons $+\gamma$ ($< 13\%$)
- Mode with η or η',
- $KKKn(\pi)\gamma$ ($\neq K\phi\gamma$),
- or in $M(X_s) > 2$ GeV

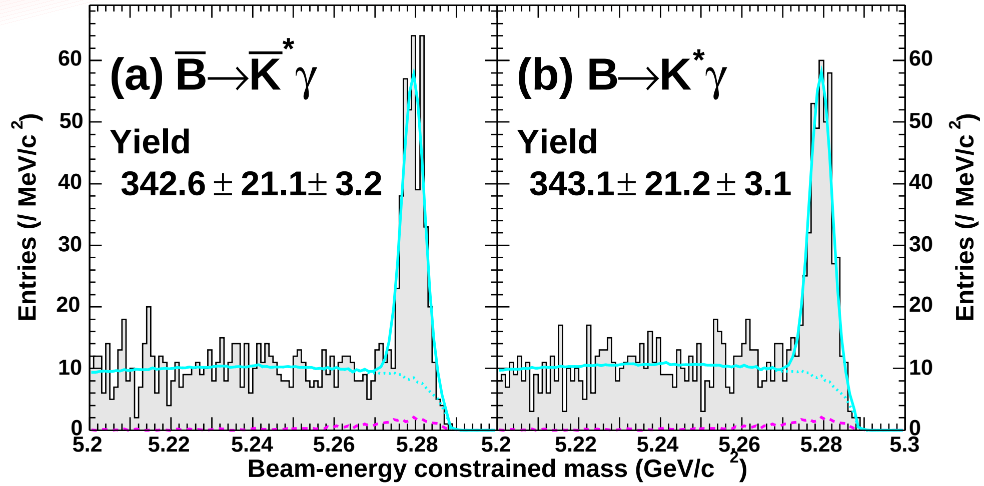
?

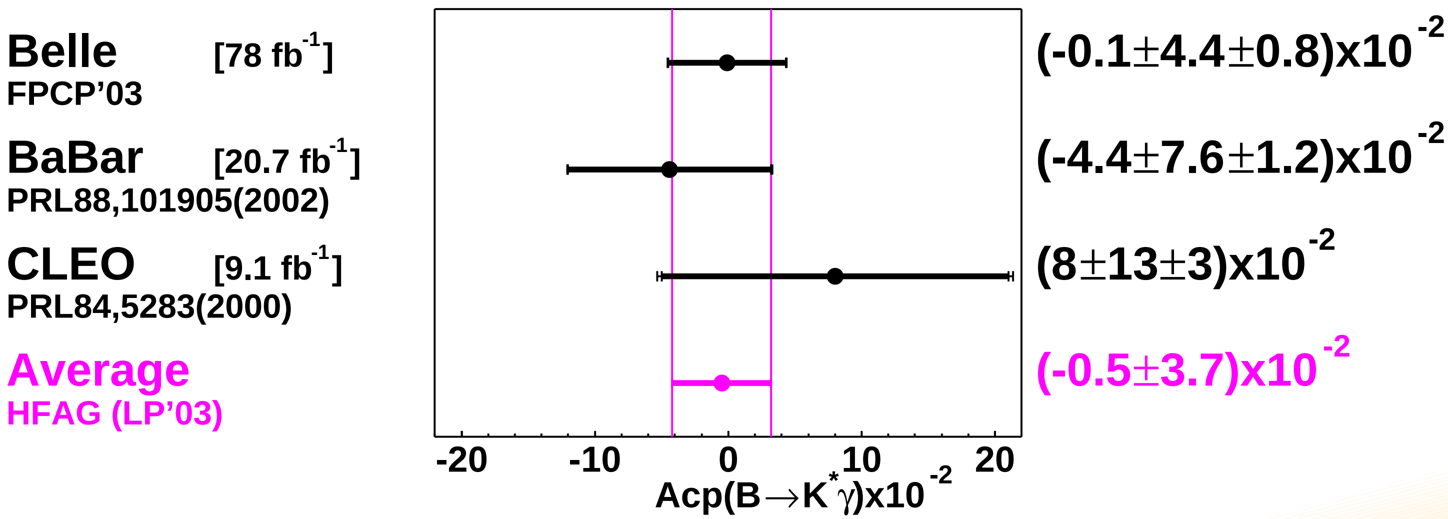
35 ± 6% of $b \to s\gamma$
has been measured exclusively.

Direct CP asymmetry in $B \to K^*\gamma$

[Belle FPCP'03 78 fb^{-1}]

- $B \to K^*\gamma$ is the easiest way to find a direct CP asymmetry in $B \to X_s\gamma$, if any exists
- Wrong-tag fraction is very small ($w = 0.9\%$ for Belle)





$$A_{CP} \equiv \frac{1}{1-2w}\frac{N(\overline{B})-N(B)}{N(\overline{B})+N(B)}$$

$$\overline{B} = \overline{B}^0 \text{ or } B^-$$

$$B = B^0 \text{ or } B^+$$

- No deviation from zero: $A_{CP}(B \to K^*\gamma) = (-0.5 \pm 3.7)\%$

Direct CP asymetry in inclusive $B \to X_s\gamma$

- There has been CLEO measurement only [PRL86, 5661, 2001, 9.1 fb^{-1}]

  $$A_{CP}^{\text{CLEO}} = 0.965 \times A_{CP}(B \to X_s\gamma) + 0.02 \times A_{CP}(B \to X_d\gamma)$$
  $$= (-0.079 \pm 0.108 \pm 0.022) \times (1 \pm 0.030)$$

  $A_{CP}(b \to d\gamma)$ can be large with a sign opposite to $A_{CP}(b \to s\gamma)$ in SM, even though $b \to d\gamma$ is very small

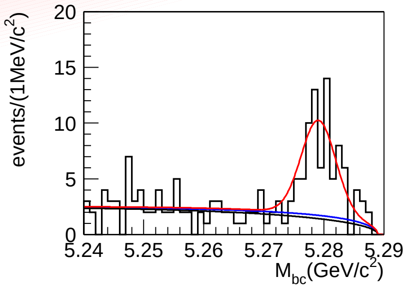
- New measurement by Belle (140 fb^{-1})
  with pseudo reconstruction a la previous Belle $B \to X_s\gamma$
  - $M(X_s) < 2.1$ GeV (almost equivalent to $E_\gamma > 2.2$ GeV)
  - Self-tagged if X_s is charged or odd number of $K^\pm$
    ambiguous only if X_s is neutral and even number of $K^\pm$
  - Three wrong-tag fractions: w_1 ($\pm\Rightarrow\mp$), w_2 ($0\Rightarrow\pm$), w_3 ($\pm\Rightarrow 0$)

$$A_{CP} \equiv \frac{1 - w_2 - w_3}{(1 - w_2)(1 - 2w_1 - w_3)} \times \frac{N_- - N_+}{N_- + N_+ + (w_2/1 - w_2)N_0}$$

$X_s\gamma$ breakdown (Belle)

X_s: K^+ or K^0_S + up to 4 pions (up to 1 π^0) or $K_{(S)}K^+K^-(\pi^+)$ combinations

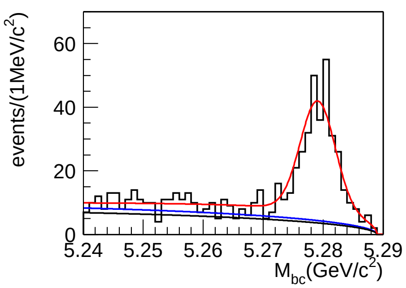
$K\pi\gamma$



63 ± 10 event

13% of data

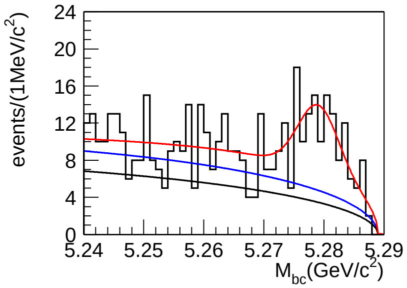
$K\pi\pi\gamma$



306 ± 21 event

63% of data

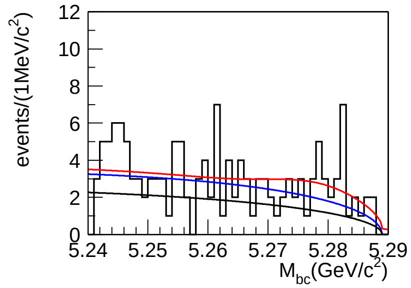
$K\pi\pi\pi\gamma$



96 ± 17 event

20% of data

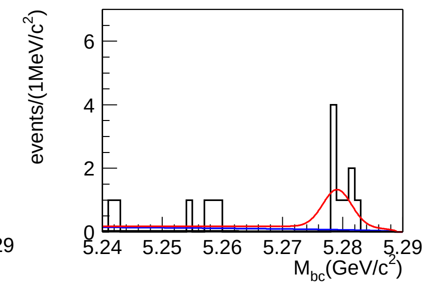
$K\pi\pi\pi\pi\gamma$



16 ± 11 event

3% of data

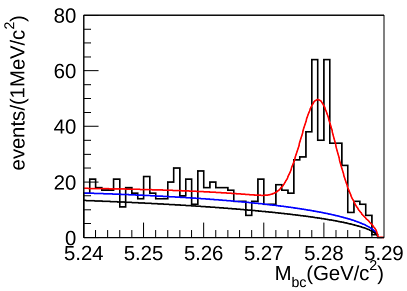
$KKK(\pi)\gamma$



9 ± 4 event

2% of data

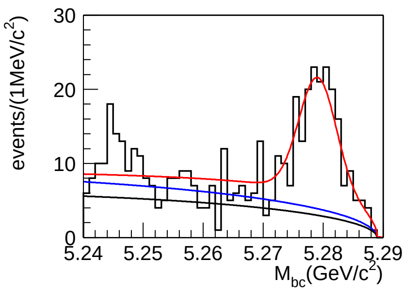
without π^0



322 ± 24 event

67% of data

with π^0



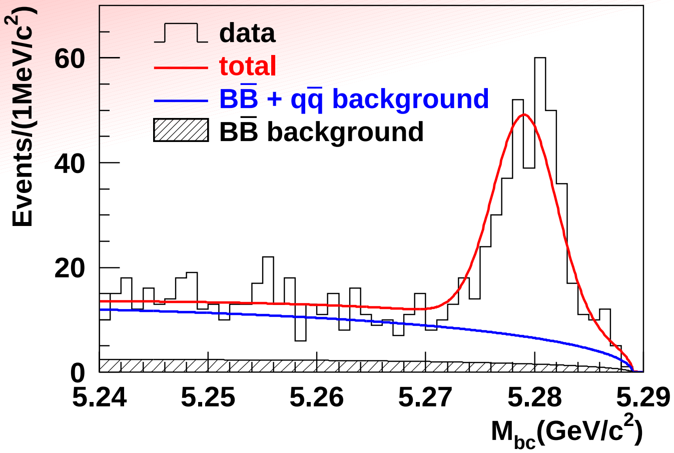
160 ± 17 event

33% of data

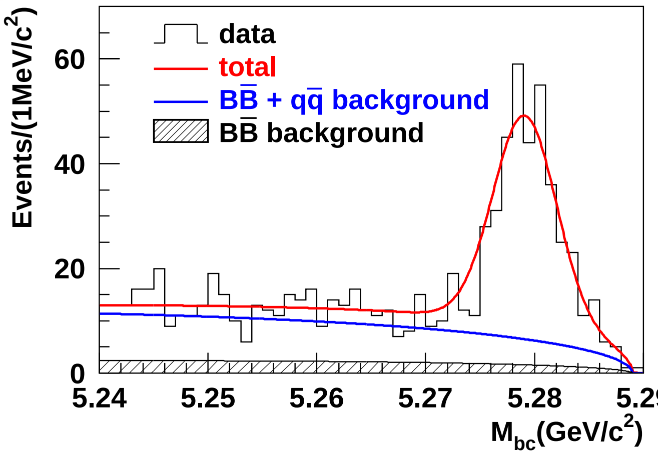
- Breakdown measured for $M(X_s) > 1.15$ GeV (excluding $K^*\gamma$)
- Measured relative fractions are used to evaluate the efficiency and wrong-tag fraction.

$A_{CP}(B \to X_s\gamma)$ results (Belle)

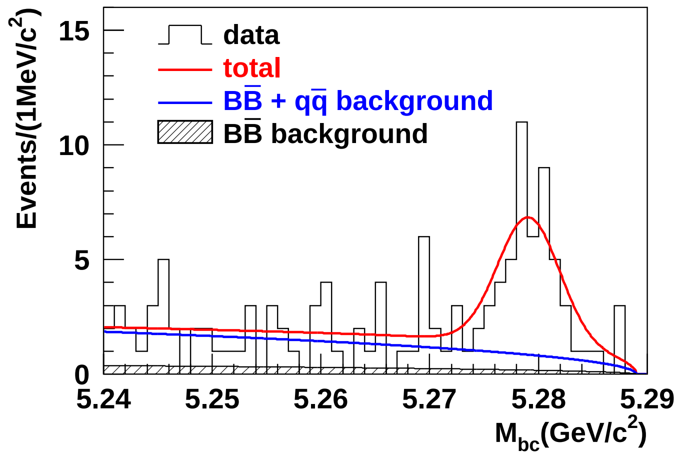
$\overline{B} \to \overline{X}_s\gamma$



$B \to X_s\gamma$



ambiguous



$342 \pm 23\,^{+7}_{-14}$ event

$349 \pm 23\,^{+7}_{-14}$ event

$47.8 \pm 8.7\,^{+1.4}_{-1.8}$ event

$w_1 = 0.019 \pm 0.014$

$w_2 = 0.240 \pm 0.192$

$w_3 = 0.0075 \pm 0.0079$

$$A_{CP}(B \to X_s\gamma)_{M(X_s)>2.1\text{ GeV}} = -0.004 \pm 0.051(\text{stat}) \pm 0.038(\text{syst})$$

$$-0.107 < A_{CP}(B \to X_s\gamma) < 0.099 \text{ (90\% CL)}$$

$A_{CP}(B \to X_s\gamma)$ and SUSY

[Baek-Ko, PRL83,488]

HFAG (if no $A_{CP}(B \to X_d\gamma)$ in CLEO)

$$A_{CP}(B \to X_s\gamma) = -0.023 \pm 0.055$$

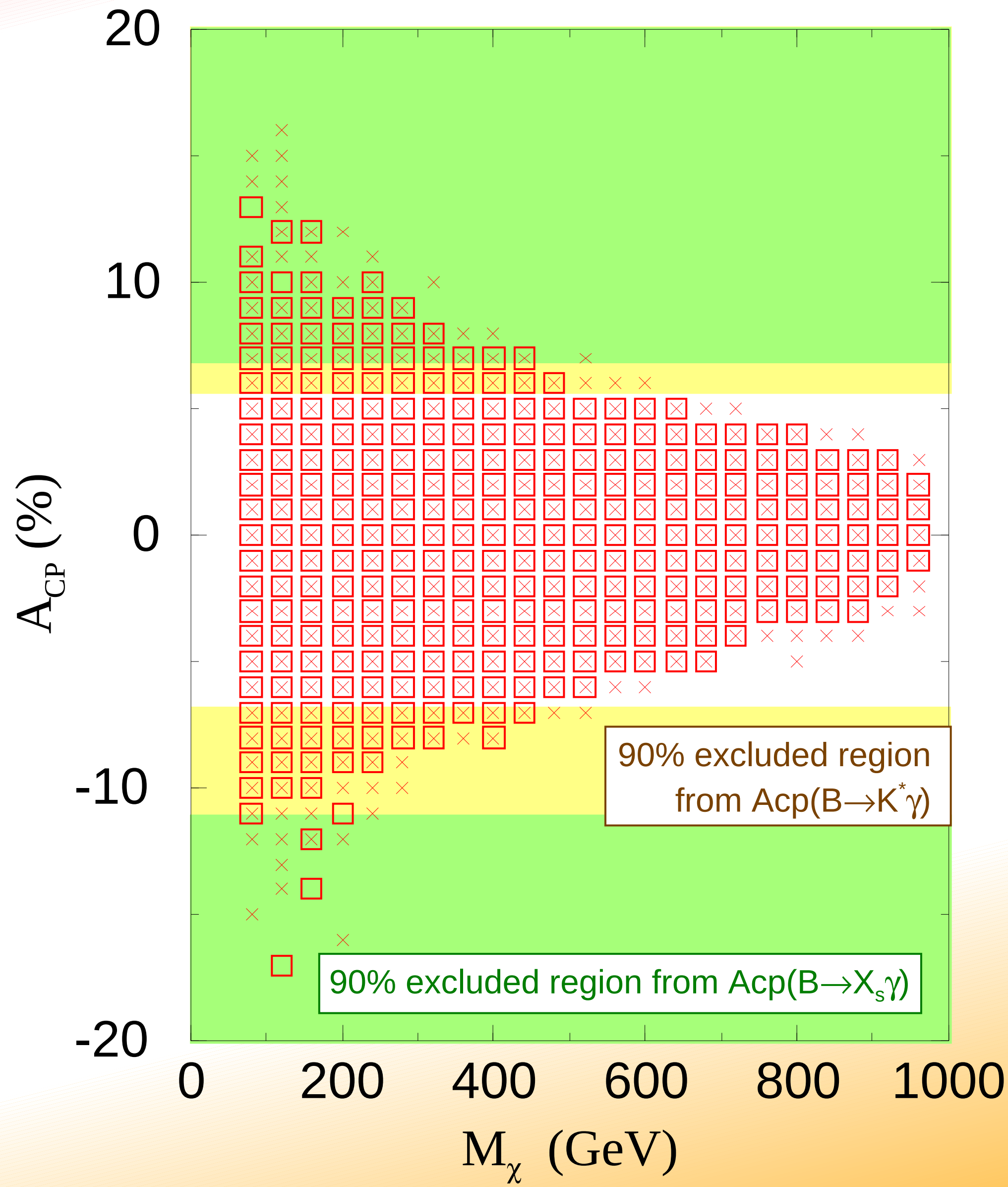
$$-0.113 < A_{CP}(B \to X_s\gamma) < 0.067 \text{ (90\% CL)}$$

Cutting into the SUSY (MSSM) parameter space, especially for the light chargino case.

[CPV phase from mass matrix of χ^+ and $\tilde{t}$]

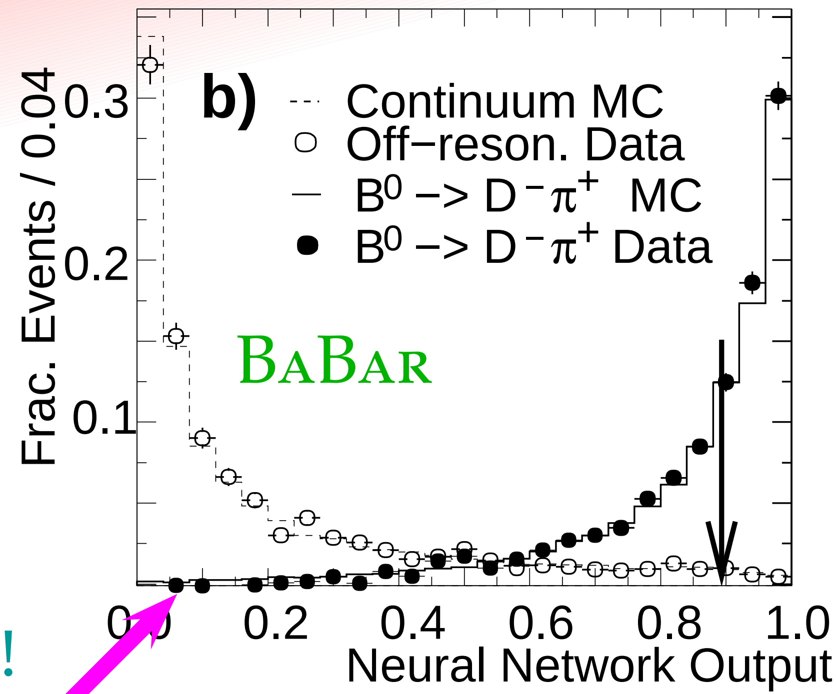
$A_{CP}(B \to K^*\gamma)$ band may be model dependent

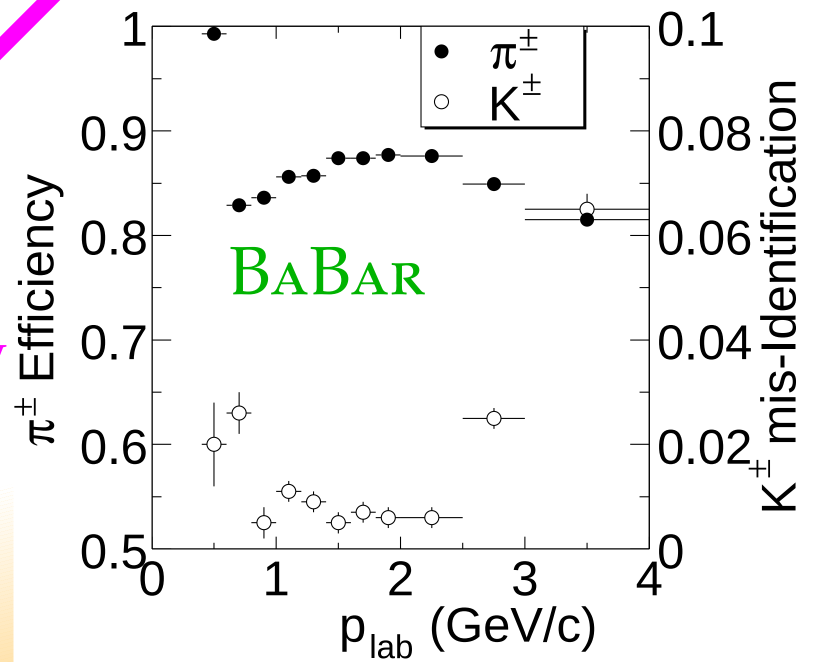
$$-0.066 < A_{CP}(B \to K^*\gamma) < 0.056 \text{ (90\% CL)}$$



$B \to \rho\gamma, \omega\gamma$

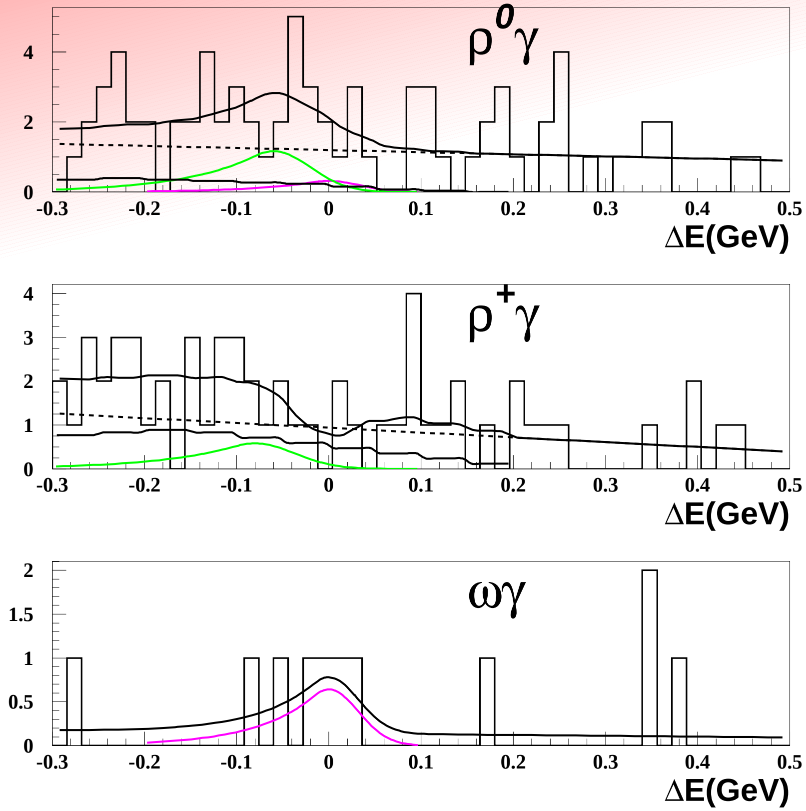
- $b \to d\gamma$ mode
  - Branching fraction $\sim 1 \times 10^{-6}$
  - Mode to measure $|V_{td}/V_{ts}|$ Independently from $\Delta m_d/\Delta m_s$
  - Direct CPV could be large
- More continuum background than $K^*\gamma$! (more ρ, wider ρ mass, more pions) Optimized neural net of event shape, helicity, z vertex displacement
- $B \to K^*\gamma$ — kaon rejection is essential 1–2% kaon fake at 80% pion efficiency



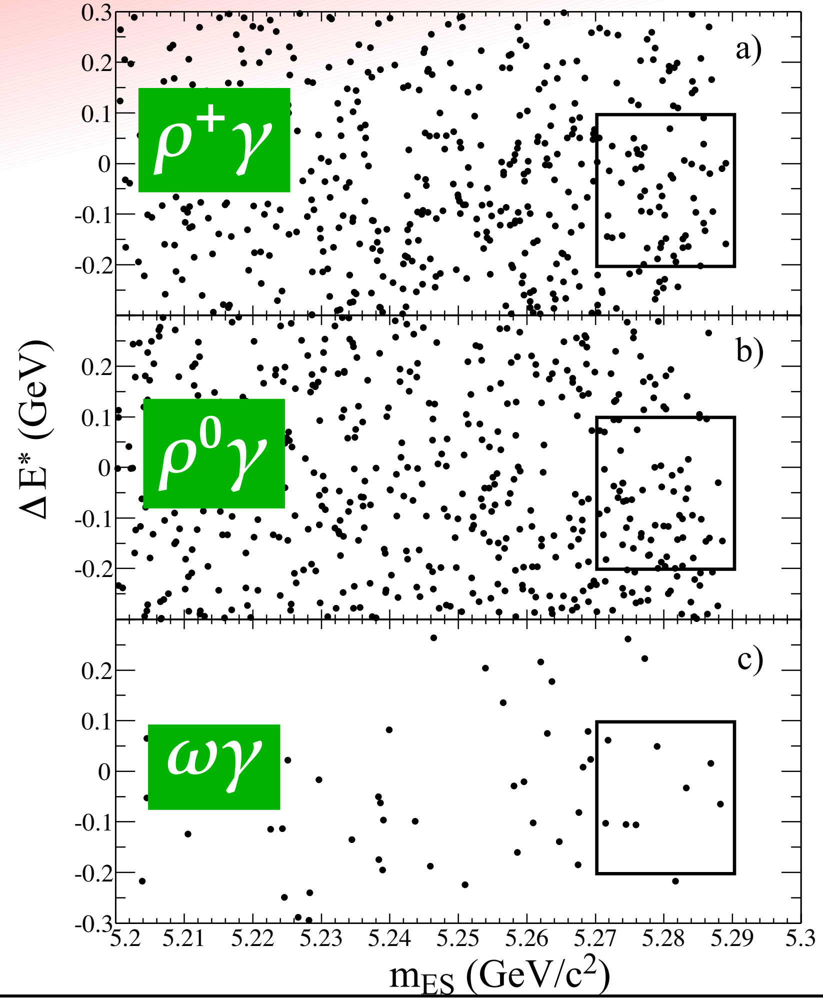


No $B \to \rho\gamma, \omega\gamma$ yet

[Belle Moriond'03 78 fb^{-1}]



[BaBar hep-ex/0306038 78 fb^{-1}]



mode	Belle	BaBar	CLEO	LCSR [Ali-Parkhomenko]
$B^+ \to \rho^+\gamma$	$< 2.7 \times 10^{-6}$	$< 2.1 \times 10^{-6}$	$< 13 \times 10^{-6}$	$(0.90 \pm 0.34) \times 10^{-6}$
$B^0 \to \rho^0\gamma$	$< 2.6 \times 10^{-6}$	$< 1.2 \times 10^{-6}$	$< 17 \times 10^{-6}$	$(0.49 \pm 0.18) \times 10^{-6}$
$B^0 \to \omega\gamma$	$< 4.4 \times 10^{-6}$	$< 1.0 \times 10^{-6}$	$< 9.2 \times 10^{-6}$	$(0.49 \pm 0.18) \times 10^{-6}$

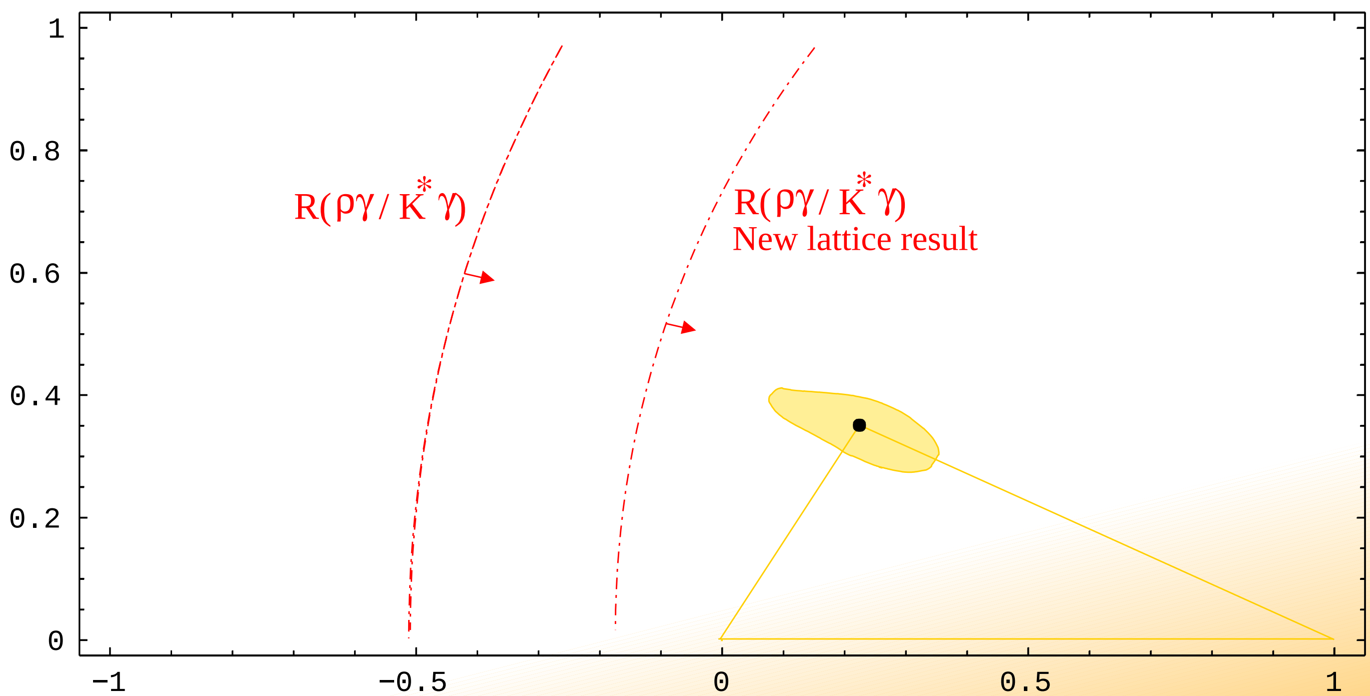
$B \to \rho\gamma$ towards V_{td} (BaBar)

Using isospin relation ($\Gamma(\rho\gamma) = \Gamma(\rho^+\gamma) = 2\Gamma(\rho^0\gamma)$), $\mathcal{B}(B \to \rho\gamma) < 1.9 \times 10^{-6}$

$$\frac{\mathcal{B}(B \to \rho\gamma)}{\mathcal{B}(B \to K^*\gamma)} = \left|\frac{V_{td}}{V_{ts}}\right|^2 \left(\frac{1 - m_\rho^2/m_B^2}{1 - m_{K^*}^2/m_B^2}\right)^3 \zeta^2[1 + \Delta R] < 0.047 \text{ (90\%C.L.)}$$

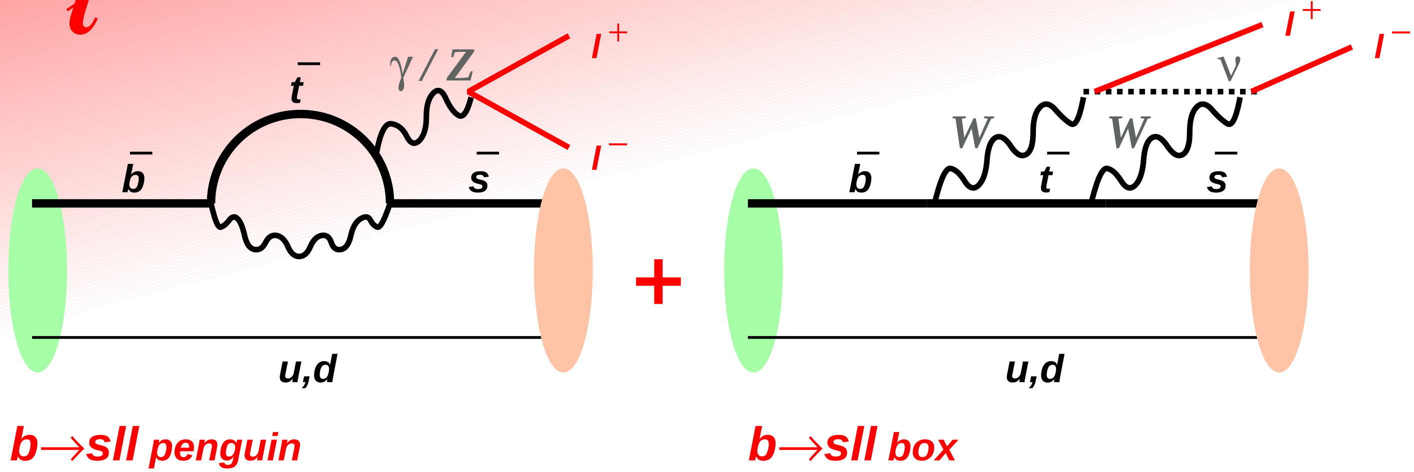
Using LCSR: $\zeta = 0.76 \pm 0.10$, $\Delta R = 0.0 \pm 0.2 \Rightarrow |V_{td}/V_{ts}| < 0.34$
However, form factor debate again: new lattice gives $\zeta = 0.91 \pm 0.08$!

[Becirevic et al, preliminary]



[Lunghi, hep-ph.0307142]

$b \to s\ell^+\ell^-$



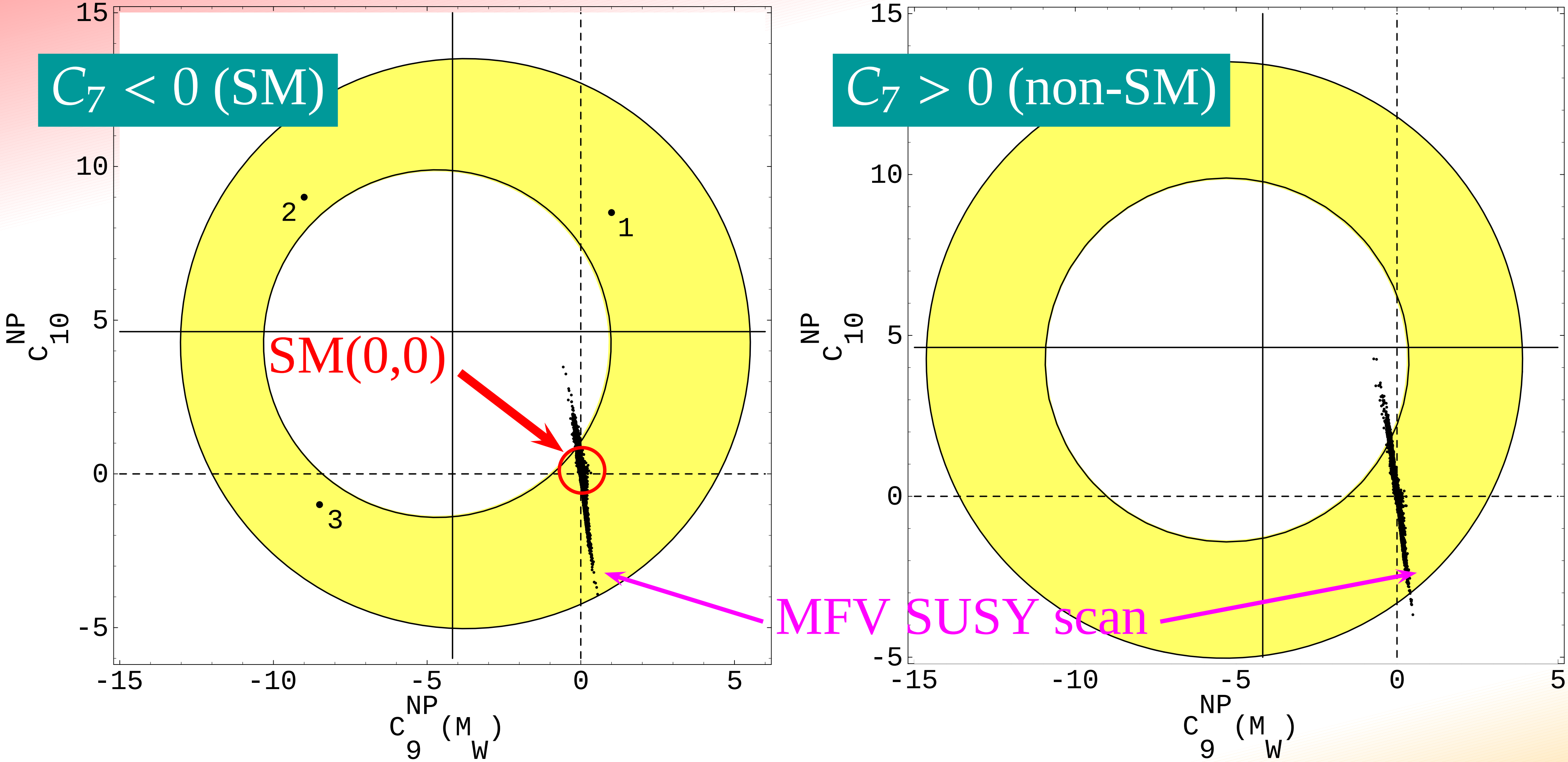
Formulated as a function of $\hat{s} = q^2/m_b^2 = (M(\ell^+\ell^-)/m_b)^2$

$$\frac{d\Gamma(b \to s\ell^+\ell^-)}{d\hat{s}} = \left(\frac{\alpha_{\rm em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3}(1-\hat{s})^2$$
$$\times\left[(1+2\hat{s})\left(|C_9^{\rm eff}|^2 + |C_{10}^{\rm eff}|^2\right) + 4\left(1+\frac{2}{\hat{s}}\right)|C_7^{\rm eff}|^2 + 12{\rm Re}\left(C_7^{\rm eff} C_9^{\rm eff}\right)\right] + \text{corr.}$$

- NNLO calculations (up to $c\bar{c}$ threshold)
- Sensitive to C_9, C_{10} and sgn(C_7), ($|C_7|$ from $b \to s\gamma$)
- q^2 distribution, Forward-backward asymmetry (A_{FB})

Constraints on C_9 and C_{10} (summer 2002 data)

[Lunghi hep-ph/0210379]



- Cutting out some non-SM C_9 and C_{10} space from $b \to s\ell^+\ell^-$ with a $|C_7|$ constraint from $b \to s\gamma$
- But sign of C_7 is not determined yet

$B \to K\ell^+\ell^-$ and $B \to K^*\ell^+\ell^-$

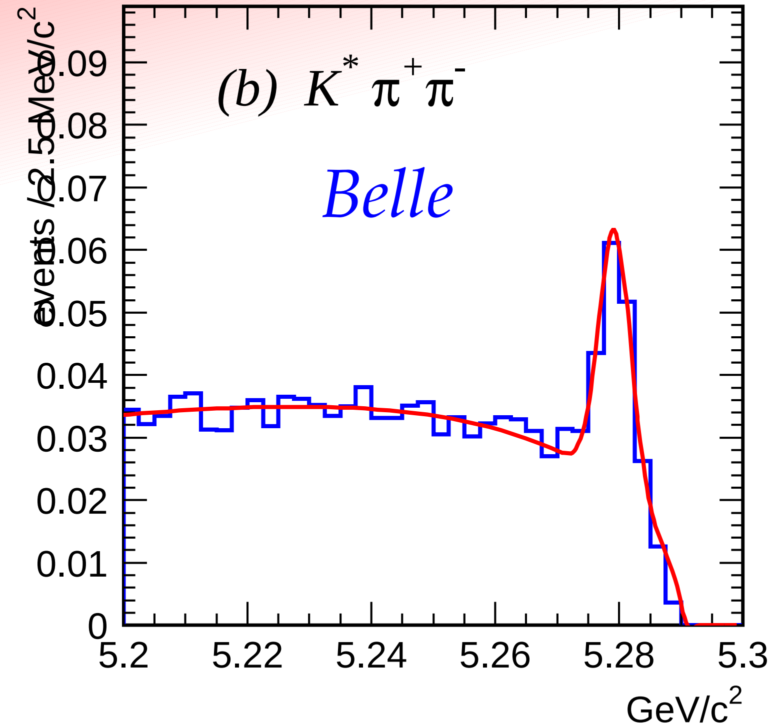
- First $B \to K\ell^+\ell^-$ signal was observed by Belle in 2001 with 29 fb^{-1}
  First $B \to K^*\ell^+\ell^-$ 3.0σ evidence was reported by BaBar with 81 fb^{-1}
  (EPS'03, less than a month ago!)

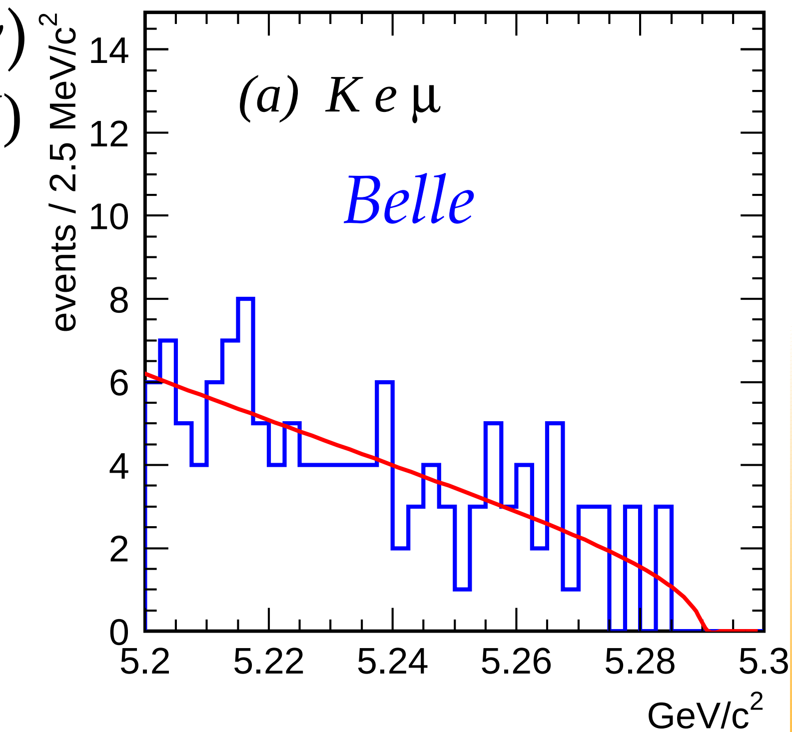
Today, both Belle and BaBar update with 140 fb^{-1}/113 fb^{-1} data!

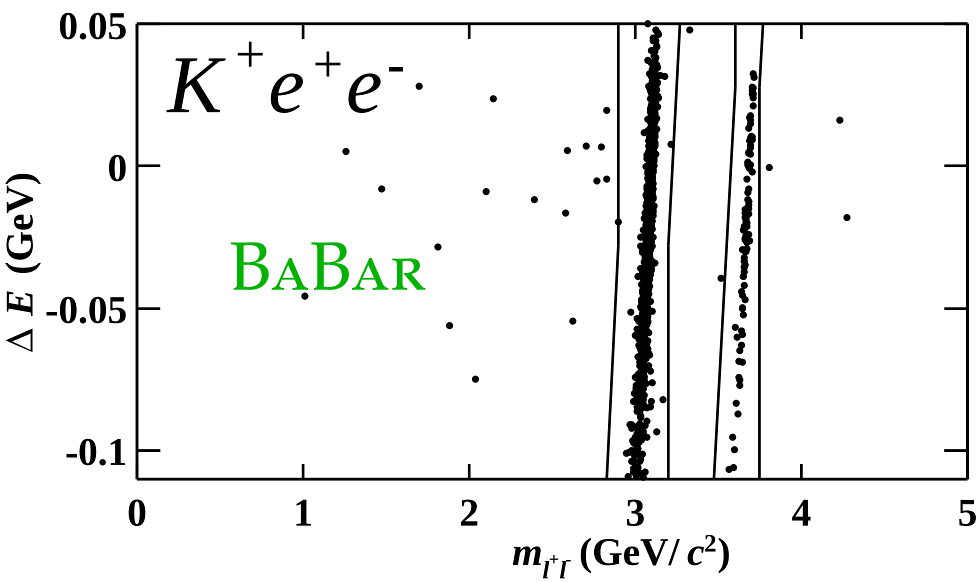
- Analysis improvements (analysis is straightforward as $J/\psi K^0_S$ reconstruction)
  - Belle
    Lower electron cut — $p(e) > 0.4$ GeV (was 0.5 GeV), 7% gain
    Lower muon cut — $p(\mu) > 0.7$ GeV (was 1.0 GeV), 12% gain
    New $J/\psi K$ veto: $(K\pi)\ell^+\ell^- \Leftrightarrow K(\ell^+\ell^-\gamma)$
  - BaBar
    Entire fit region was reblinded the data after last summer
    $M(K\pi)$ in the ML fit
    Photon bremsstrahlung recovery for $K^{(*)}e^+e^-$

$B \to K^{(*)}\ell^+\ell^-$ backgrounds

- $B \to J/\psi K^{(*)}$, $J/\psi \to \ell^+\ell^-(\gamma)$; also ψ'
  [$J/\psi K$ veto for $K^*\ell^+\ell^- - \pi + \gamma$ (Belle)]
- $B \to K^{(*)}\pi^+\pi^-$ ($\pi \Rightarrow \mu$ fake $\sim 2\%)^2$
- Semileptonic] (random comb.)
- Continuum]
- $B \to K^*\gamma$ (conversion), $K^{(*)}\pi^0(\to e^+e^-\gamma)$
  (BaBar only, Belle cuts $M(e^+e^-) > 0.14$ GeV)

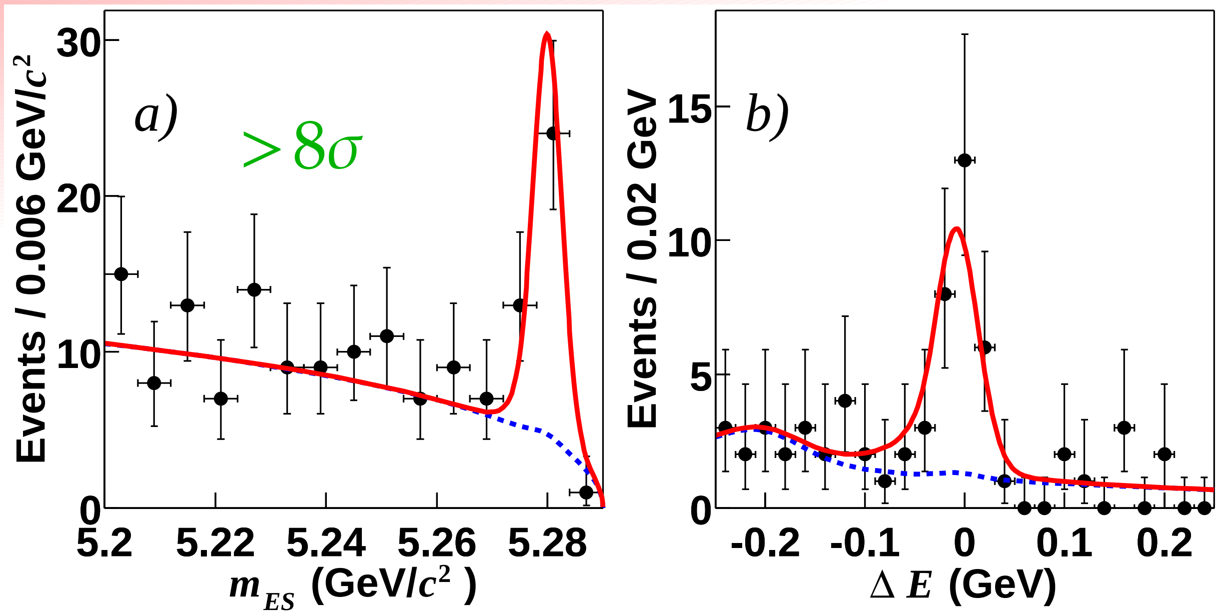




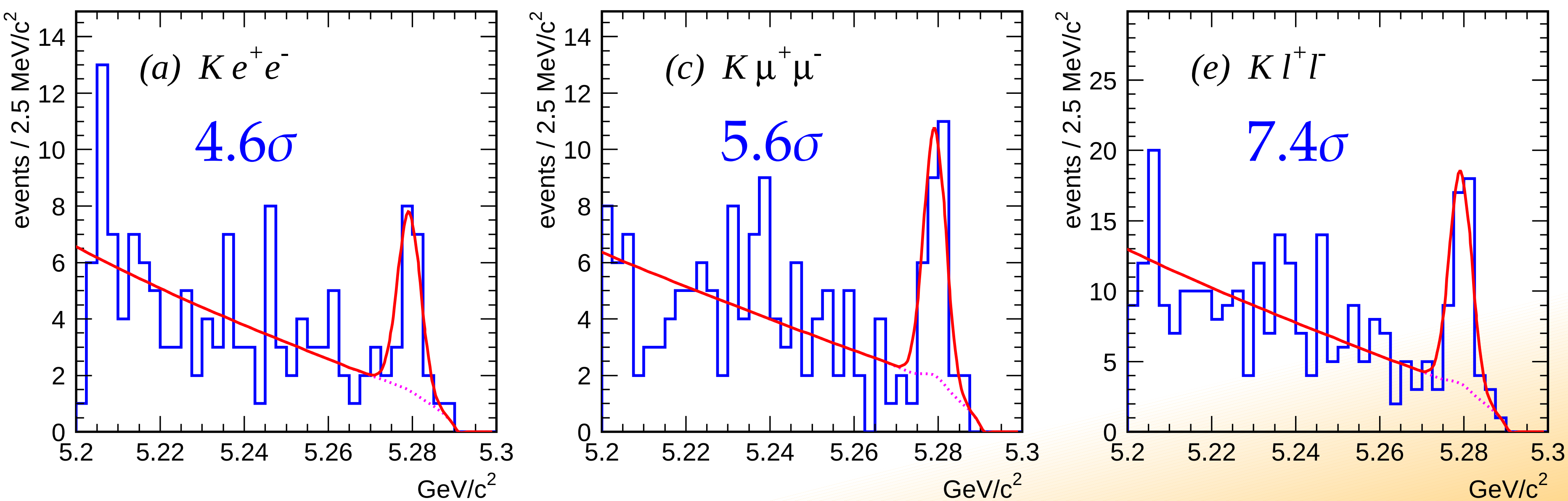


$B \to K\ell^+\ell^-$ signal

BaBar: 2-D fit (M_{ES}, ΔE), float background shape



Belle: 1-D fit (M_{bc}), background shape from MC

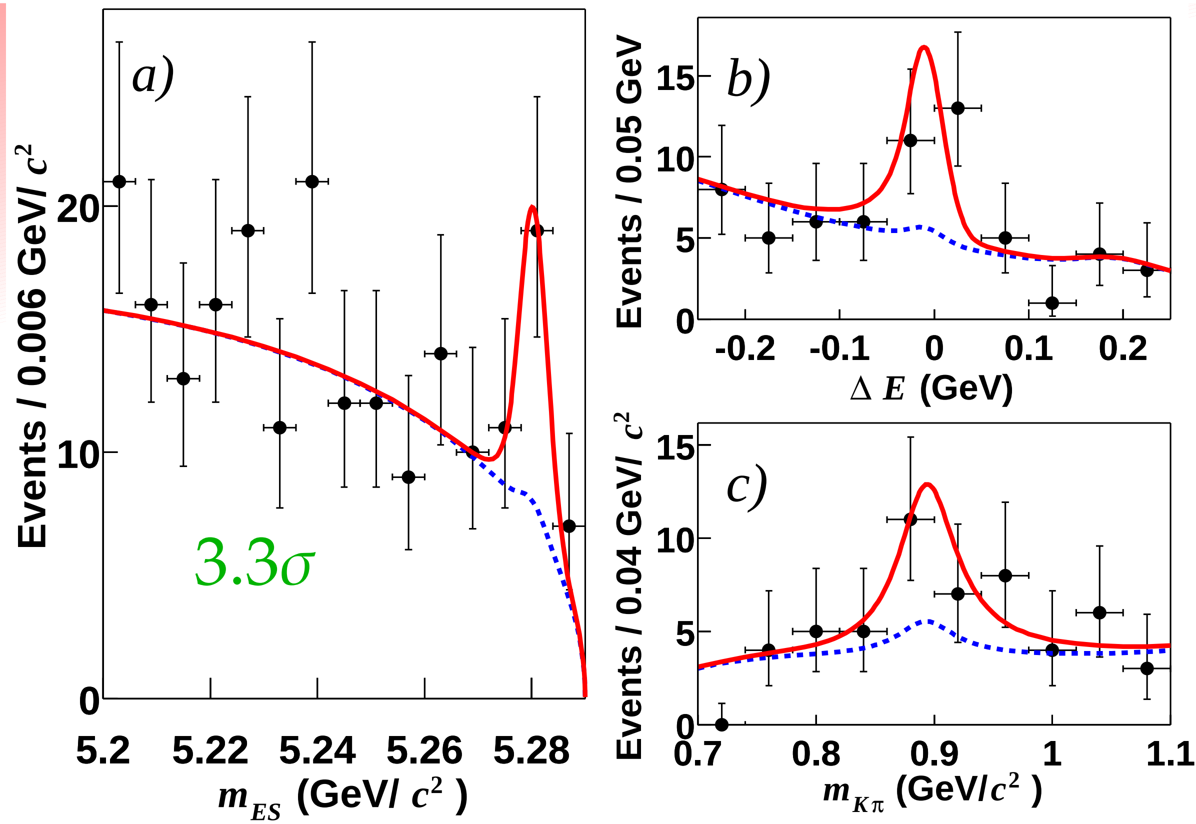


Very clear signals, from both Belle and BaBar!

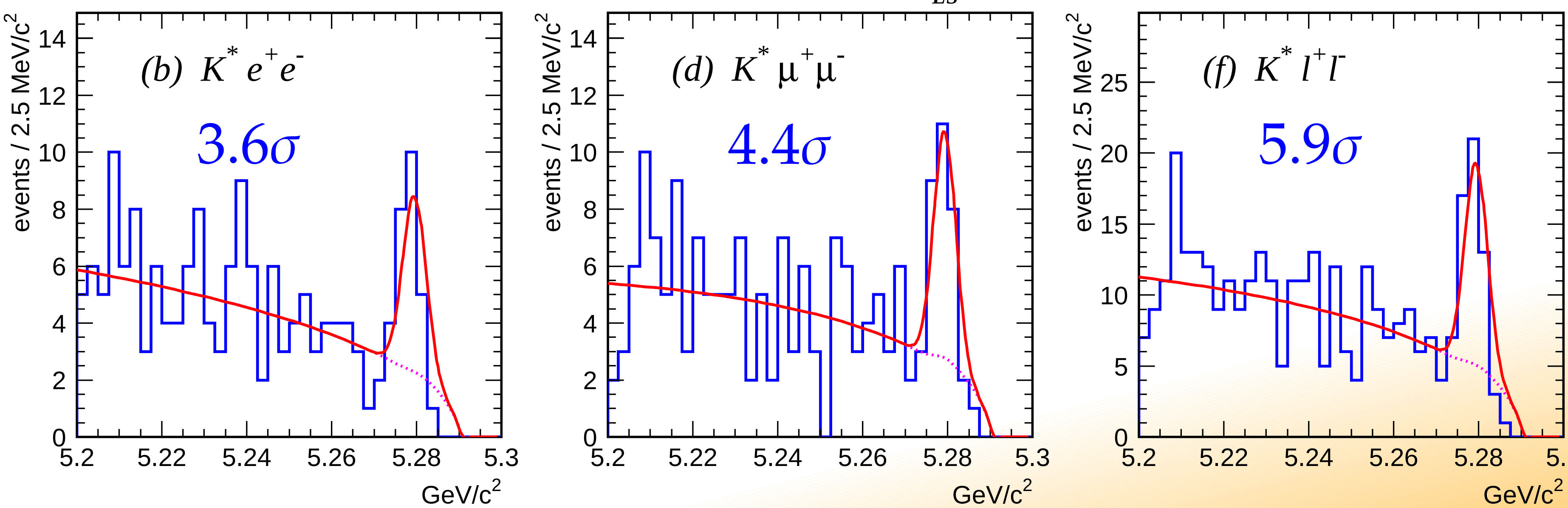
(systematic errors are taken into account in the signifi cances)

$B \to K^* \ell^+ \ell^-$ signal

BaBar: 3-D fit
(M_{ES}, ΔE, $M(K\pi)$),
float background shape



Belle: 1-D fit (M_{bc}),
background shape from MC



First $>5\sigma$ observation by Belle! / also $>3\sigma$ evidence by BaBar

$B \to K^{(*)}\ell^+\ell^-$ branching fractions

Mode	Belle $\mathcal{B} \pm$ stat $\pm$ syst $\pm$ model	BaBar $\mathcal{B} \pm$ stat $\pm$ syst
$B \to K e^+e^-$	$(4.8\,^{+1.5}_{-1.3} \pm 0.3 \pm 0.1) \times 10^{-7}$	$(7.9\,^{+1.9}_{-1.7} \pm 0.7) \times 10^{-7}$
$B \to K \mu^+\mu^-$	$(4.8\,^{+1.3}_{-1.1} \pm 0.3 \pm 0.2) \times 10^{-7}$	$(4.8\,^{+2.5}_{-2.0} \pm 0.4) \times 10^{-7}$
$B \to K \ell^+\ell^-$	$(4.8\,^{+1.0}_{-0.9} \pm 0.3 \pm 0.1) \times 10^{-7}$	$(6.9\,^{+1.5}_{-1.3} \pm 0.6) \times 10^{-7}$

SM: $\mathcal{B}(B \to K\ell^+\ell^-) = (3.5 \pm 1.2) \times 10^{-7}$

$B \to K^* e^+e^-$	$(14.9\,^{+5.2}_{-4.6}\,^{+1.1}_{-1.3} \pm 0.3) \times 10^{-7}$	$(10.0\,^{+5.0}_{-4.2} \pm 1.3) \times 10^{-7}$
$B \to K^* \mu^+\mu^-$	$(11.7\,^{+3.6}_{-3.1} \pm 0.8 \pm 0.6) \times 10^{-7}$	$(12.8\,^{+7.8}_{-6.2} \pm 1.7) \times 10^{-7}$
$B \to K^* \ell^+\ell^-$	$(11.5\,^{+2.6}_{-2.4} \pm 0.7 \pm 0.4) \times 10^{-7}$	$(8.9\,^{+3.4}_{-2.9} \pm 1.1) \times 10^{-7}$

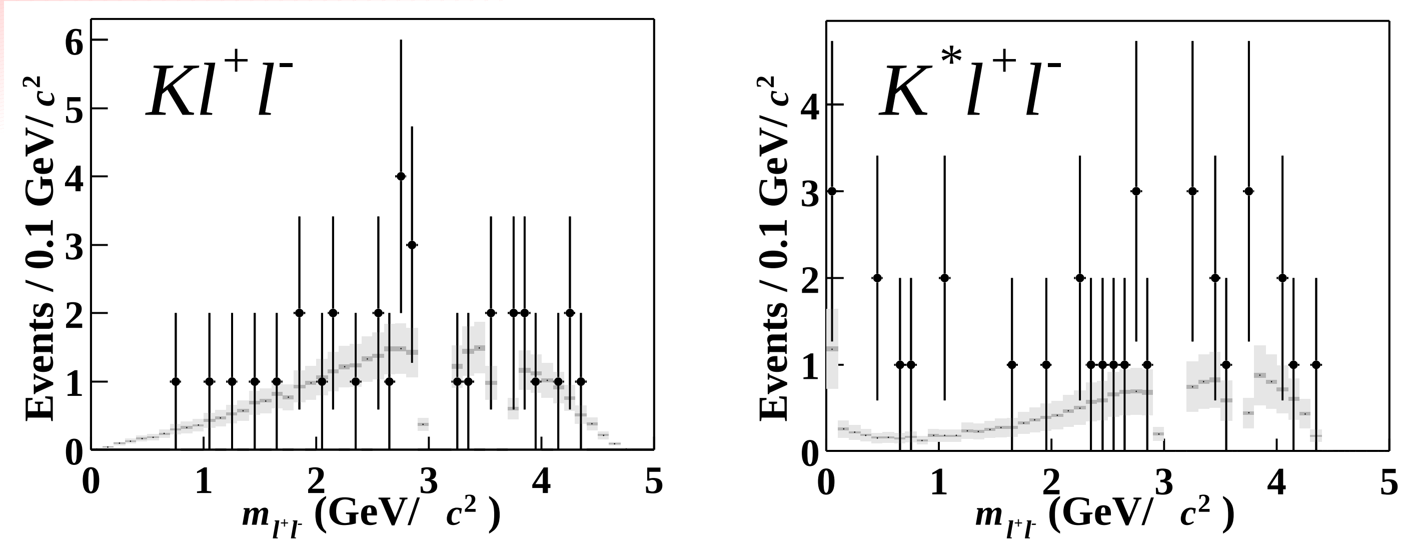
SM: $\mathcal{B}(B \to K^*\ell^+\ell^-) = (11.9 \pm 3.9) \times 10^{-7}$

- $\mathcal{B}(B \to K^*\ell^+\ell^-) \equiv \mathcal{B}(B \to K^*\mu^+\mu^-) = 0.75 \times \mathcal{B}(B \to K^*e^+e^-)$ is assumed to compensate $q^2 = 0$ pole in e^+e^-
  (Factor 0.75, and all SM numbers are from Ali et al.)

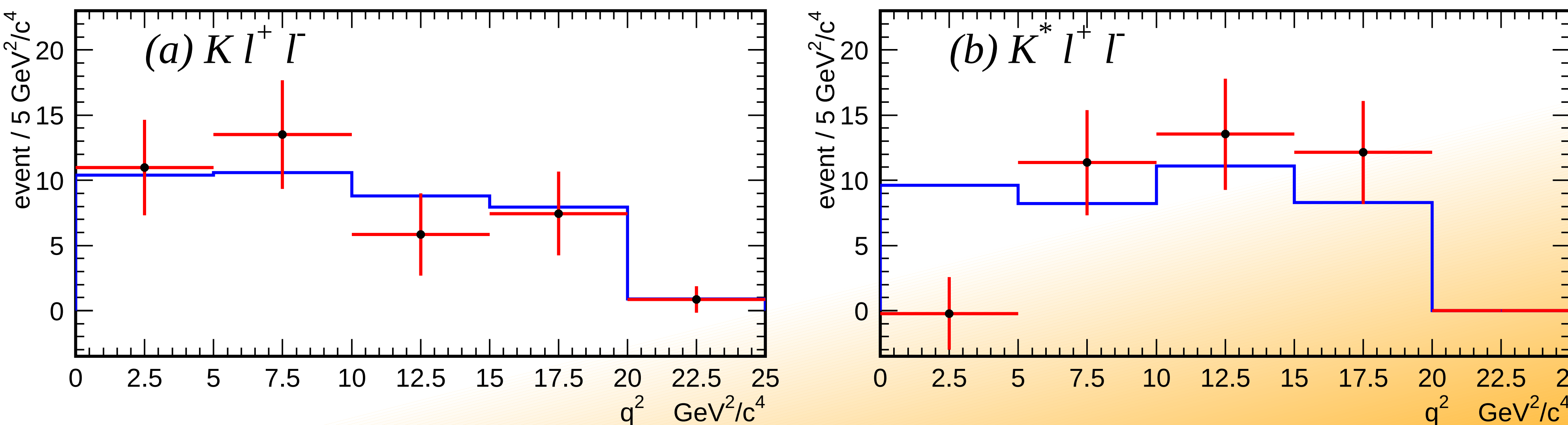
Caution: available exclusive predictions vary by a factor of ~ 2

$B \to K^{(*)}\ell^+\ell^-$ distributions

BaBar's $M(\ell^+\ell^-)$, compared with SM



Belle's q^2 distributions from bin-by-bin fit to $M_{\rm bc}$ ($q^2 = M(\ell^+\ell^-)^2$)



$B \to X_s \ell^+ \ell^-$ analysis (Belle/BaBar)

Pseudo-reconstruction has been tried by Belle and BaBar
Predictions are less model dependent

Belle

- X_s = a kaon + 0 to 4 pion
  (covers $(82 \pm 2)\%$ of signal)
  kaon = $K^\pm$ or K^0_S ($K^0_L = K^0_S$ assumed)
  pion = $\pi^\pm$ or π^0 (up to 1 π^0)
  $M(X_s) < 2.1$ GeV
- lepton = e or μ
  $p(e) > 0.5$ GeV
  $p(\mu) > 1.0$ GeV
  $M(\ell^+\ell^-) > 0.2$ GeV

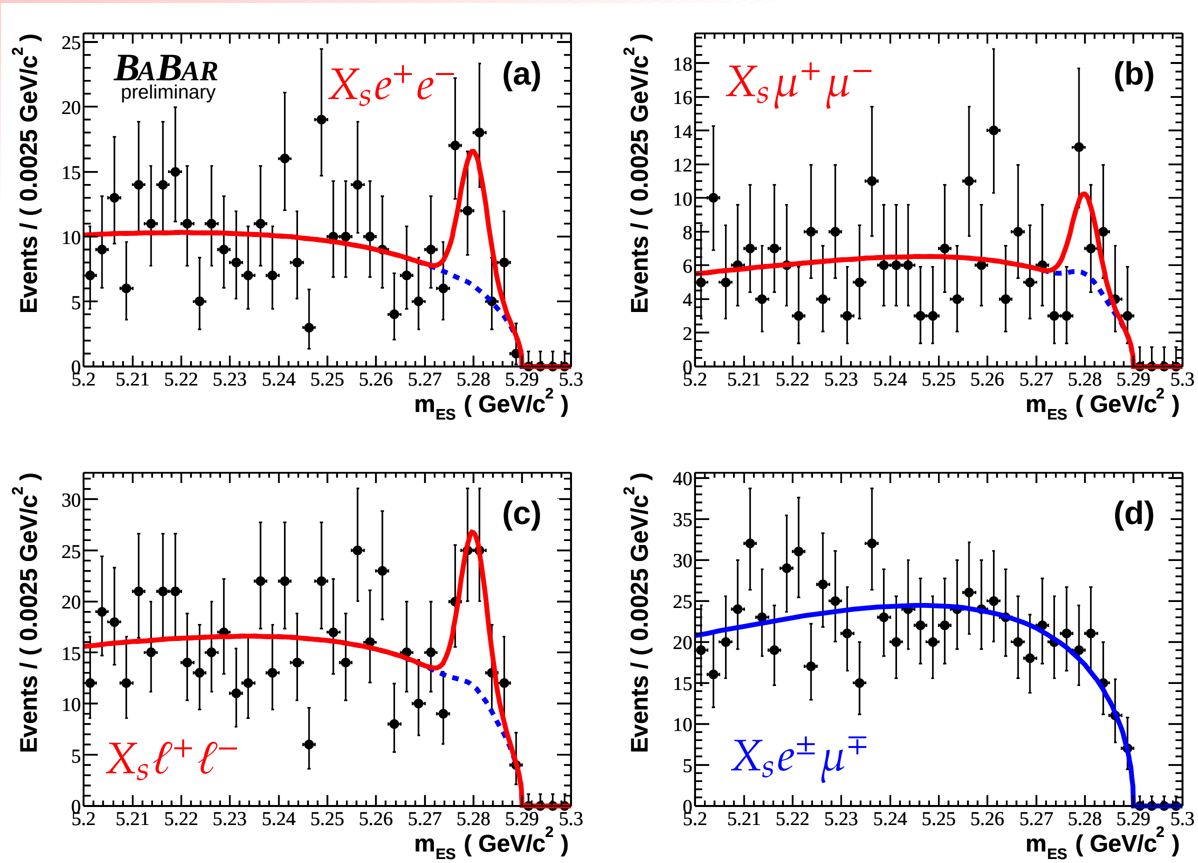
BaBar (new!)

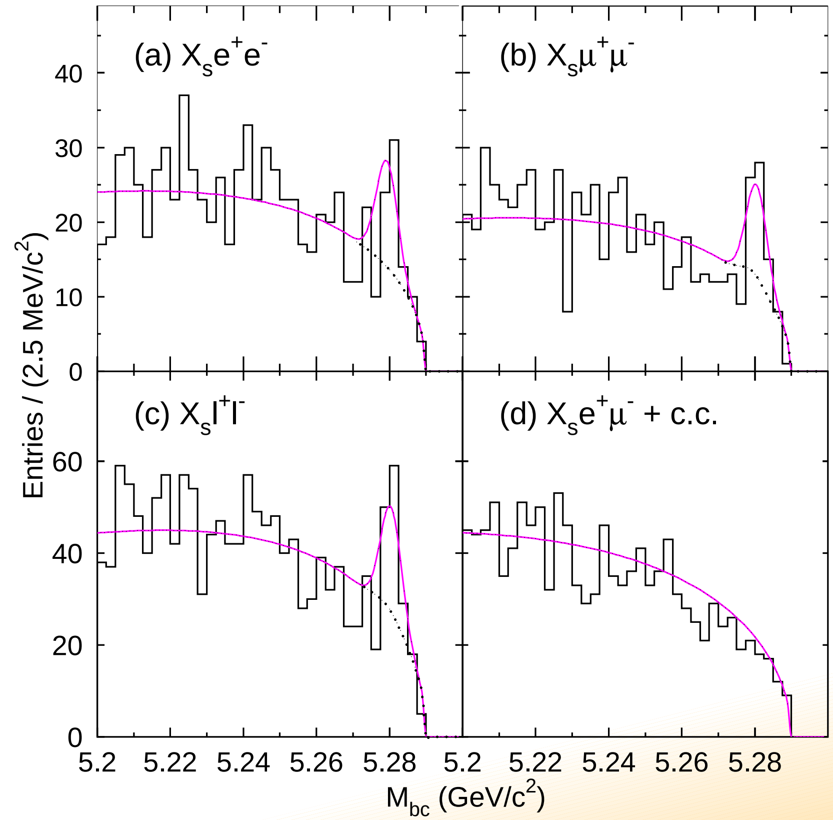
- X_s = a kaon + 0 to 2 pion
  (covers $\sim 75\%$ of signal)
  kaon = $K^\pm$ or K^0_S ($K^0_L = K^0_S$ assumed)
  pion = $\pi^\pm$ or π^0 (up to 1 π^0)
  $M(X_s) < 1.8$ GeV
- lepton = e or μ
  $p(e) > 0.5$ GeV
  $p(\mu) > 0.8$ GeV
  $M(\ell^+\ell^-) > 0.2$ GeV

- Backgrounds are similar to $B \to K^{(*)}\ell^+\ell^-$, just much more severe in the inclusive analysis

$B \to X_s \ell^+ \ell^-$ signal

Unbinned ML fit to $M_{\rm bc/ES}$ with signal + peaking + combinatorial





BaBar 82 fb^{-1} New! [hep-ex/0308016]

41 ± 10 $X_s \ell^+ \ell^-$ events, 4.6σ

Belle 60 fb^{-1} [PRL90,021801(2003)]

60 ± 14 $X_s \ell^+ \ell^-$ events, 5.4σ

$B \to X_s \ell^+ \ell^-$ branching fraction

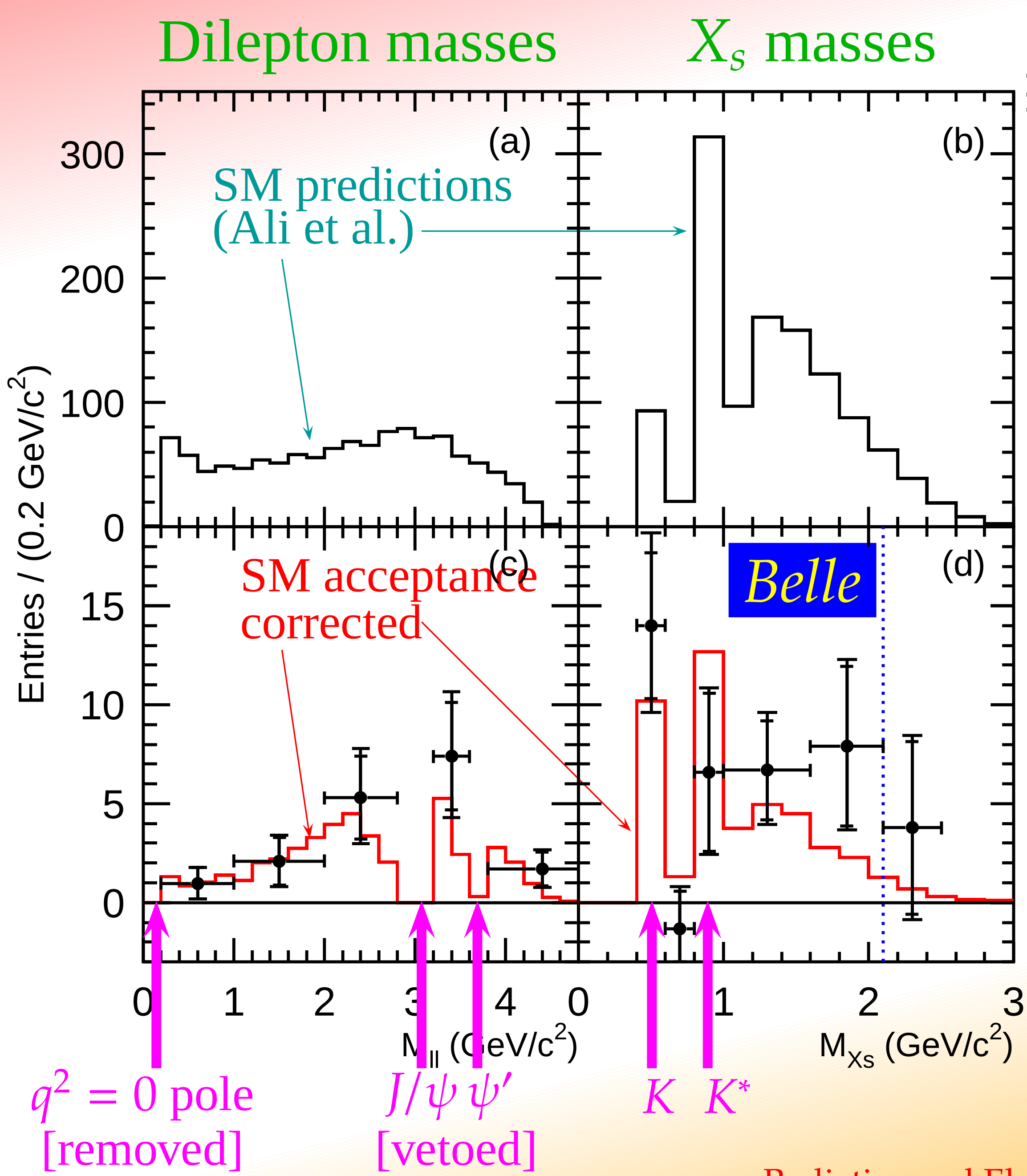
	$B \to X_s \ell^+ \ell^-$ combined
Belle	$(6.1 \pm 1.4\,^{+1.4}_{-1.1}) \times 10^{-6}$ (5.4σ)
BaBar	$(6.3 \pm 1.6\,^{+1.8}_{-1.5}) \times 10^{-6}$ (4.6σ)
Average [MN]	$(6.2 \pm 1.1\,^{+1.6}_{-1.3}) \times 10^{-6}$

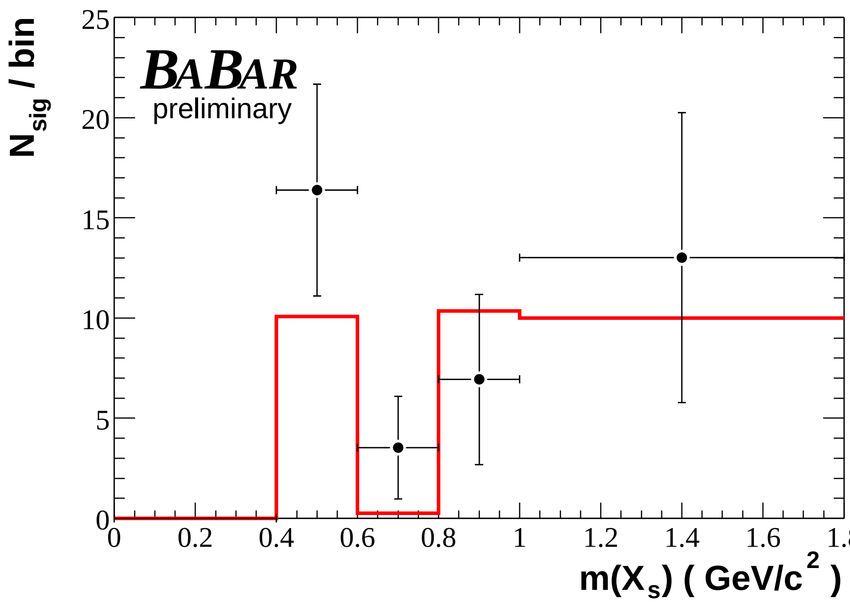
(MN: simple systematic error average assuming 100% correlation)

- SM predicts $\mathcal{B} = (4.2 \pm 0.7) \times 10^{-6}$ for both $B \to X_s e^+ e^-$ and $B \to X_s \mu^+ \mu^-$ when the $q^2 = 0$ pole is removed ($M(\ell^+\ell^-) > 0.2$ GeV)
- Reasonable agreement with SM (only 1σ off, error is still large)
  New result will further constrain the Wilson coefficients C_9 and C_{10}

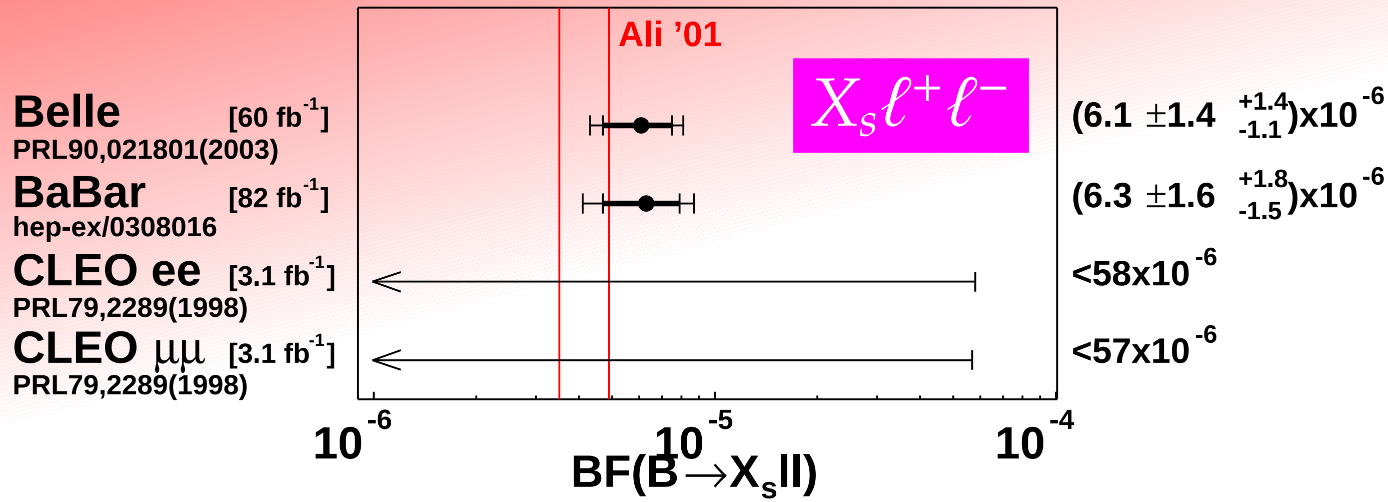
Breakdown	$B \to X_s e^+ e^-$	$B \to X_s \mu^+ \mu^-$
Belle	$(5.0 \pm 2.3\,^{+1.3}_{-1.1}) \times 10^{-6}$ (3.4σ)	$(7.9 \pm 2.1\,^{+2.1}_{-1.5}) \times 10^{-6}$ (4.7σ)
BaBar	$(6.6 \pm 1.9\,^{+1.9}_{-1.6}) \times 10^{-6}$ (4.0σ)	$(5.7 \pm 2.8\,^{+1.7}_{-1.4}) \times 10^{-6}$ (2.2σ)

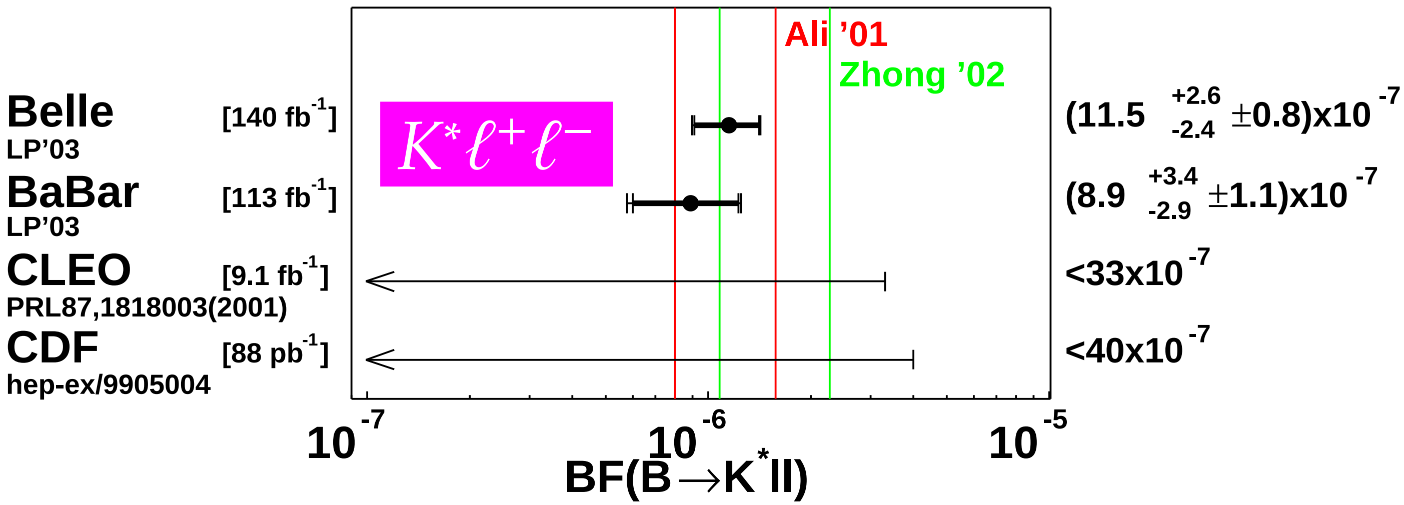
$B \to X_s \ell^+ \ell^-$ distributions

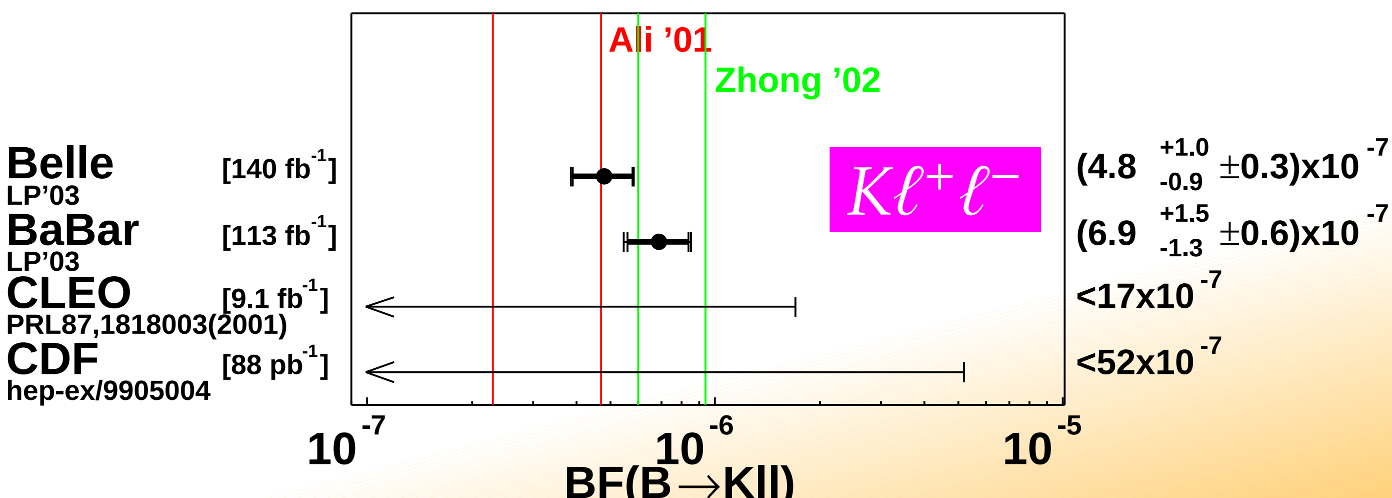




- From bin-by-bin fit to M_{bc}
- No deviation from expectation so far
- With more data, one can perform A_{FB} measuremts







Mission completed!

$K^{(*)}\ell^+\ell^-$ and $X_s\ell^+\ell^-$ are all measured

next target:
Precise $X_s\ell^+\ell^-$,
q^2 and A_{FB}

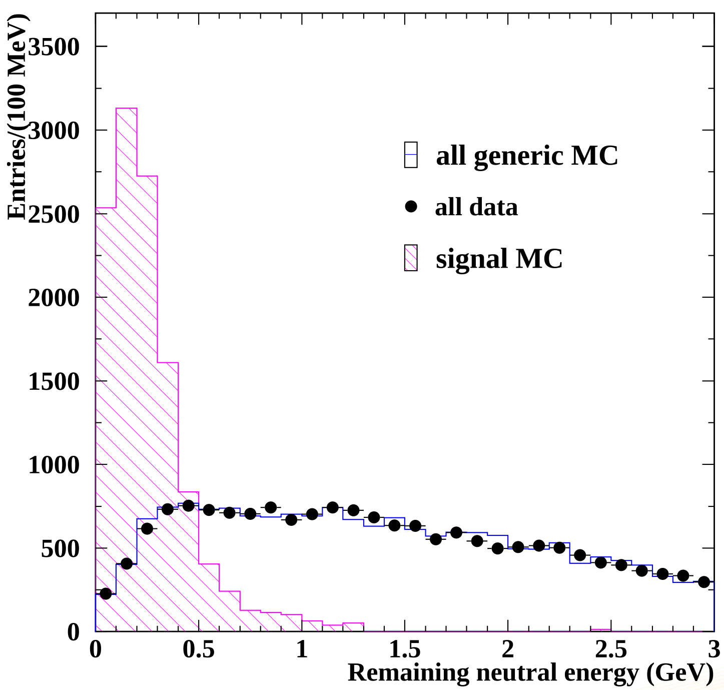
$B \to K\nu\bar{\nu}$ analysis (BaBar)

- Theoretically cleaner than $B \to K\ell^+\ell^-$, because of no $(c\bar{c})$ effects
- Signal: only one track as K (require $p^* > 1.5$ GeV)
- Two unmeasureable neutrinos! $\Rightarrow$ Need to tag the other side B

Semileptonic tag (D^0 and ℓ^-)

0.5% tagging efficiency

$E_{\rm left} < 0.5$ GeV

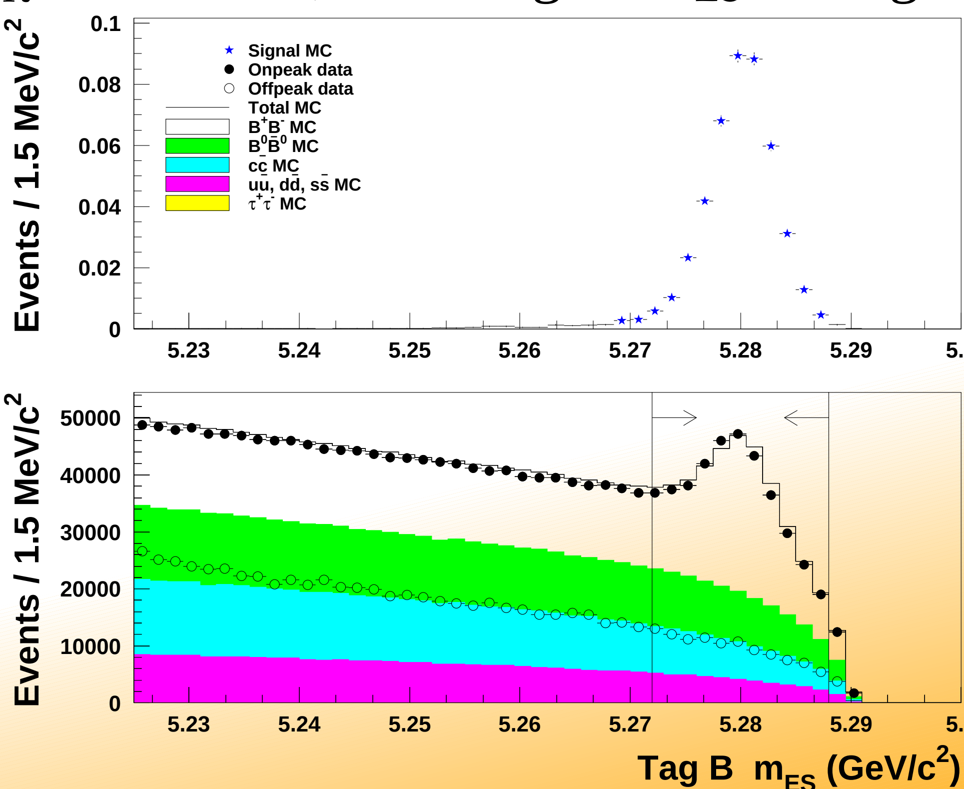


(remaining π^0, γ from D^{*0} decays)

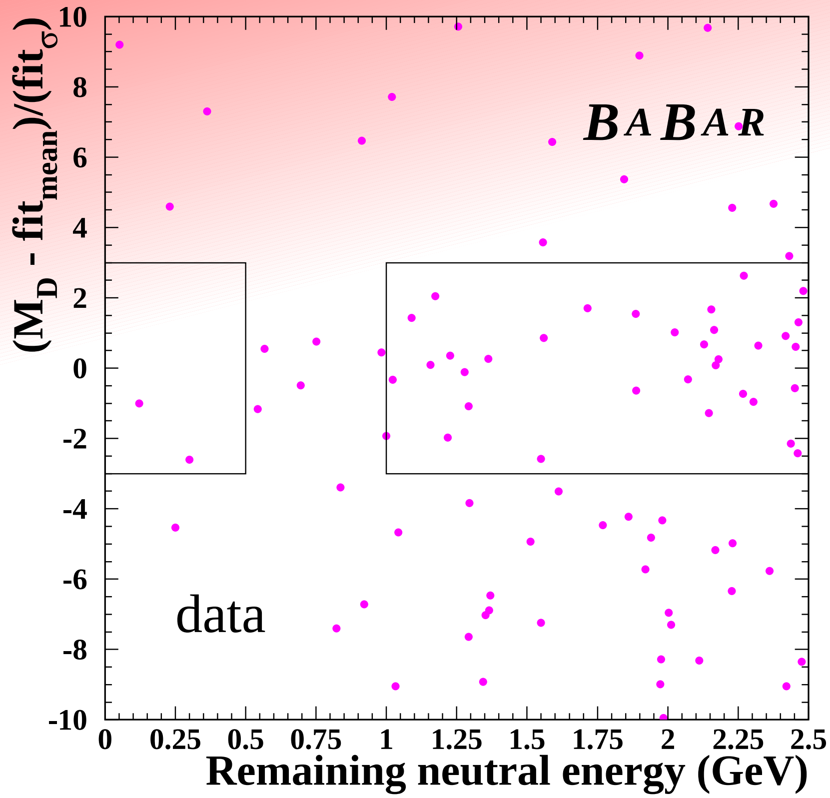
Hadronic tag ($D^0(n(\pi))^-$)

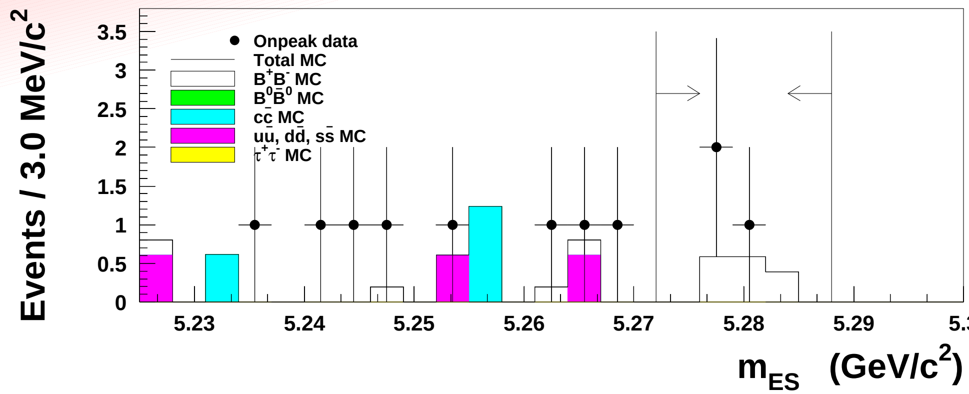
0.13% tagging efficiency

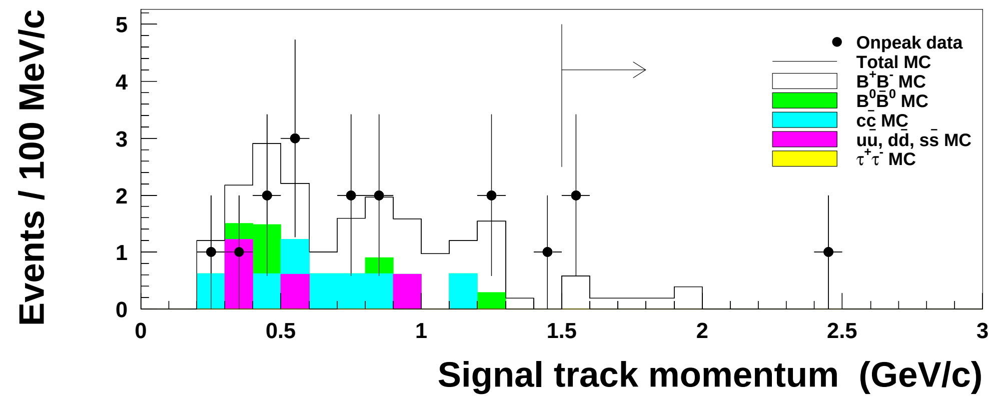
$E_{\rm left} < 0.3$ GeV, Clear tag-B M_{ES} for signal



$B \to K\nu\bar{\nu}$ results (BaBar)







Semileptonic tag (D^0 and ℓ^-)

51 fb^{-1}, 2 candidates

2.2 background expected

$\mathcal{B}(B \to K\nu\bar{\nu}) < 9.4 \times 10^{-5}$

Hadronic tag ($D(n(\pi))^-$)

80 fb^{-1}, 3 candidates

2.7 ± 0.8 background expected

$\mathcal{B}(B \to K\nu\bar{\nu}) < 10.5 \times 10^{-5}$

combined: $\mathcal{B}(B \to K\nu\bar{\nu}) < 7.0 \times 10^{-5}$ (90% C.L.)

SM: $\mathcal{B}(B \to K\nu\bar{\nu}) = (3.8\,^{+1.2}_{-0.6}) \times 10^{-6}$ [Buchalla,Hiller,Isidori 2000]

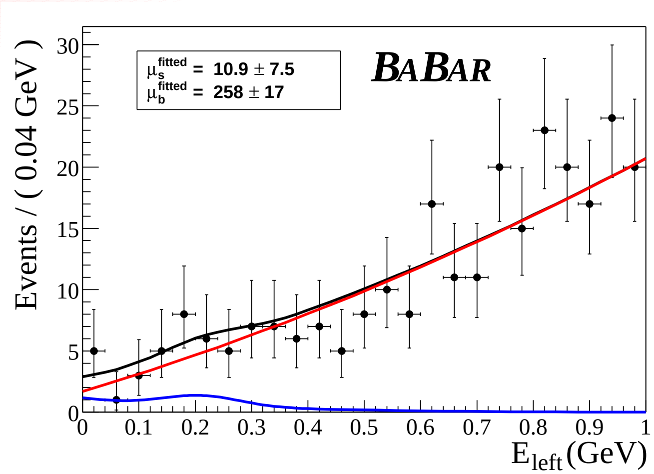
$B^+ \to \ell\nu$ and $B^0_{d,s} \to \ell^+\ell^-$

- Helicity suppressed two-body decay in SM, chances for new physics
- $B^+ \to \ell\nu$: tree diagram in SM
  - Sensitive to charged Higgs, leptoquarks (exchange diagram)
  - Experimental challenge because of the missing neutrino
- $B^0_{d,s} \to \ell^+\ell^-$: yet another Z-penguin
  - SM branching fractions are too small for B-factories / Tevatron
  - Sensitive to chirarity flipping interaction in 2HDM/MSSM, up to three orders of magnitude larger than SM at large $\tan\beta$ (and may not enhance $B \to K\ell^+\ell^-$)
  - Might be reachable by B-factories and Tevatron RunII

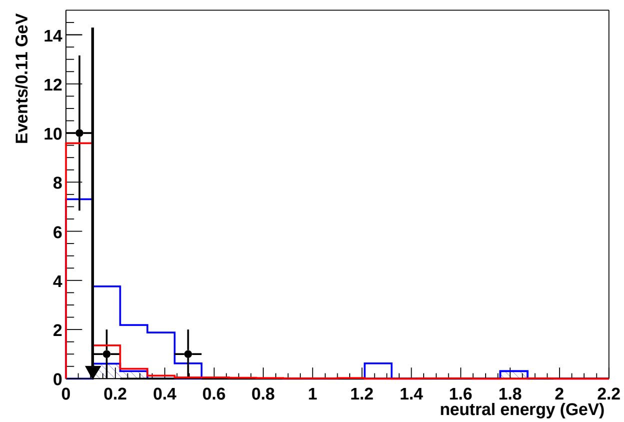
	SM predictions	Previous limit (PDG2002)
$B^0_s \to \mu^+\mu^-$	$(3.8 \pm 1.0) \times 10^{-9}$	$< 2.6 \times 10^{-6}$ (CDF)
$B^0_d \to \mu^+\mu^-$	$(1.0 \pm 0.3 \pm 0.3) \times 10^{-10}$	$< 6.1 \times 10^{-7}$ (CLEO)

$B \to \tau\nu, \mu\nu$ (BaBar)

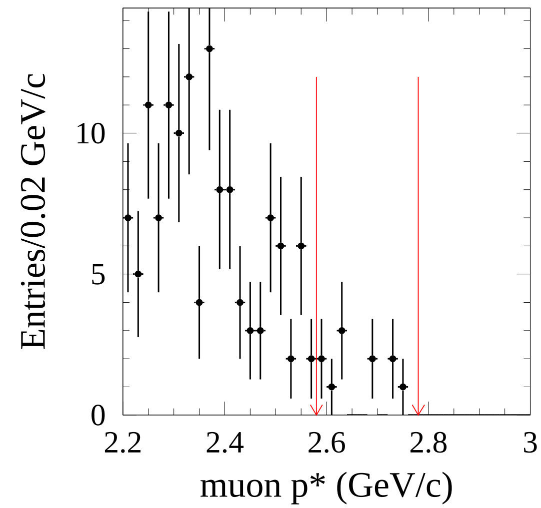
- $B \to \tau\nu$ with semileptonic/hadronic tag (a la $B \to K\nu\overline{\nu}$)
  $B \to \mu\nu$ with neutrino reconstruction (a la $b \to u\ell\nu$)
- $\tau \to e\nu\overline{\nu}$, $\mu\nu\overline{\nu}$, (+ $\pi^-\nu$, $\pi^-\pi^0\nu$, $\pi^-\pi^+\pi^-\nu$ for hadronic tag)



$\tau\nu$ semileptonic



$\tau\nu$ hadronic ($\tau \to e\nu\nu$)



$\mu\nu$

$\mathcal{B}(B \to \mu\nu) < 6.6 \times 10^{-6}$ [BaBar 81 fb^{-1} hep-ex/0307047]

$\Leftrightarrow$ Belle $\mathcal{B}(B \to \mu\nu) < 6.8 \times 10^{-6}$ [ICHEP'02]

$\mathcal{B}(B \to \tau\nu) < 4.1 \times 10^{-4}$ (combined)

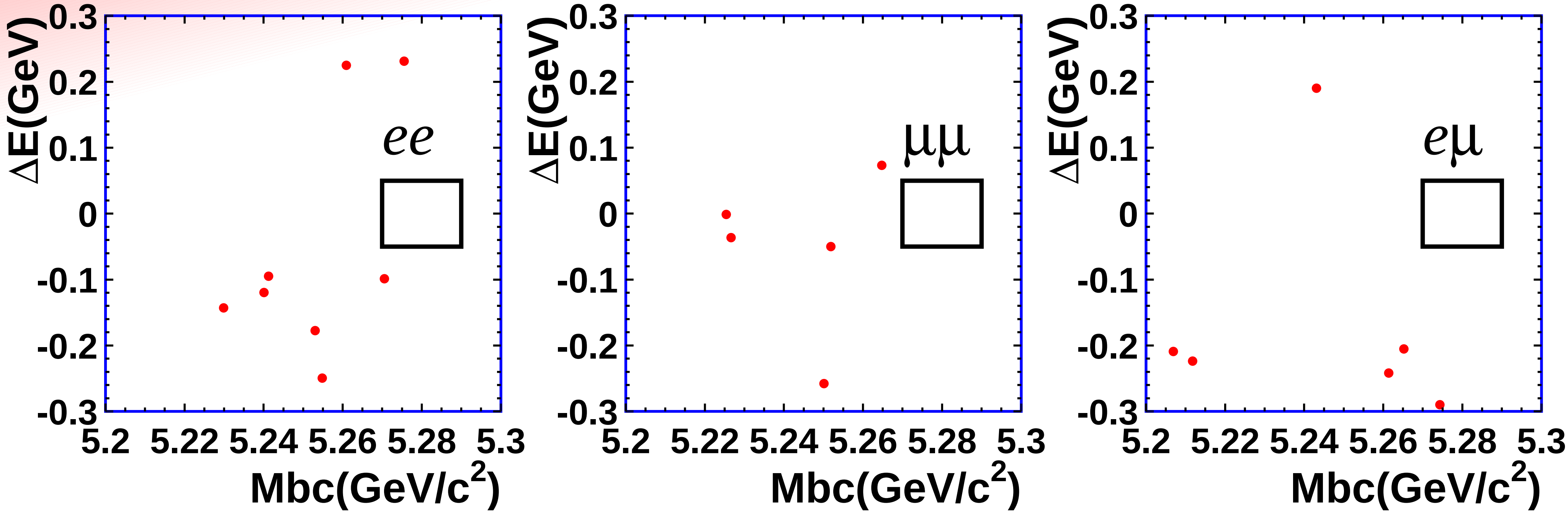
$\mathcal{B}(B \to \tau\nu) < 4.9 \times 10^{-4}$ (hadronic-tag) [BaBar 81 fb^{-1} hep-ex/0304030]

$\mathcal{B}(B \to \tau\nu) < 7.7 \times 10^{-4}$ (semileptonic-tag) [BaBar 81 fb^{-1} hep-ex/0303034]

$\Leftrightarrow$ L3 $\mathcal{B}(B \to \tau\nu) < 5.7 \times 10^{-4}$ [PLB396,327(1997)]

$B \to \ell^+\ell^-$ results (Belle)

- New results based on 78 fb^{-1} (supersedes FPCP'03 Belle results)

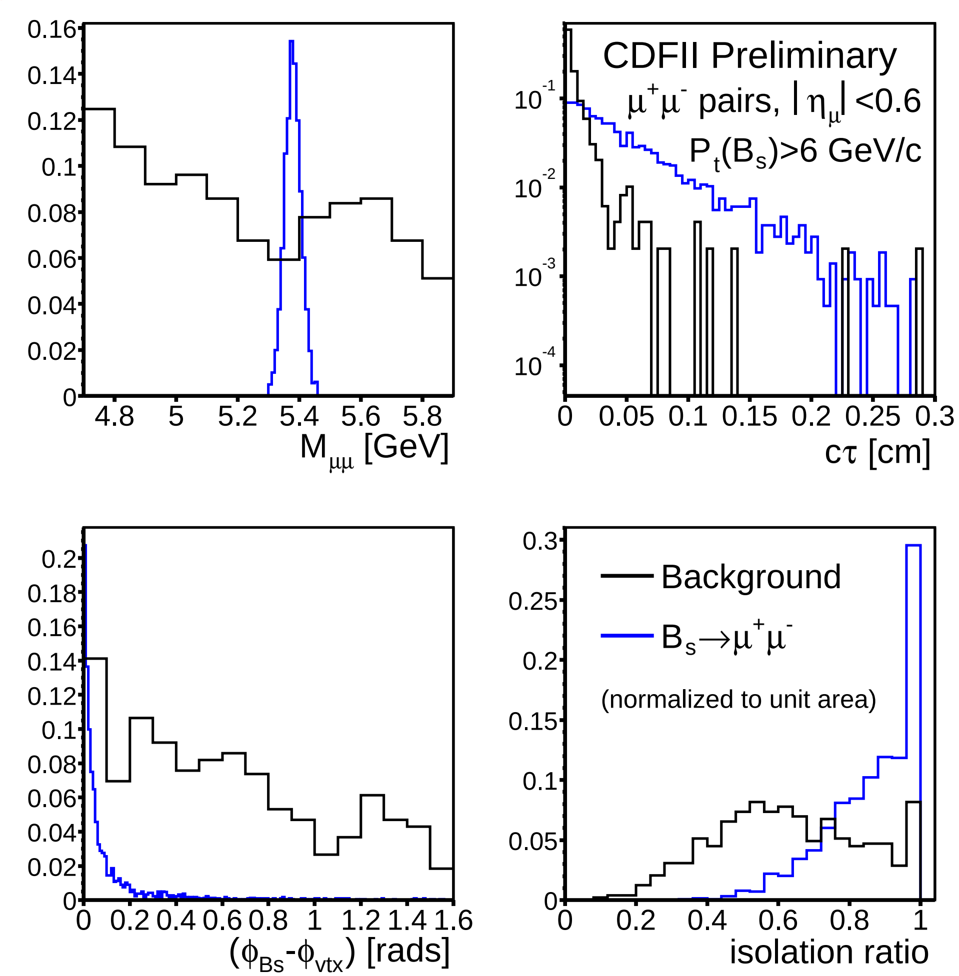


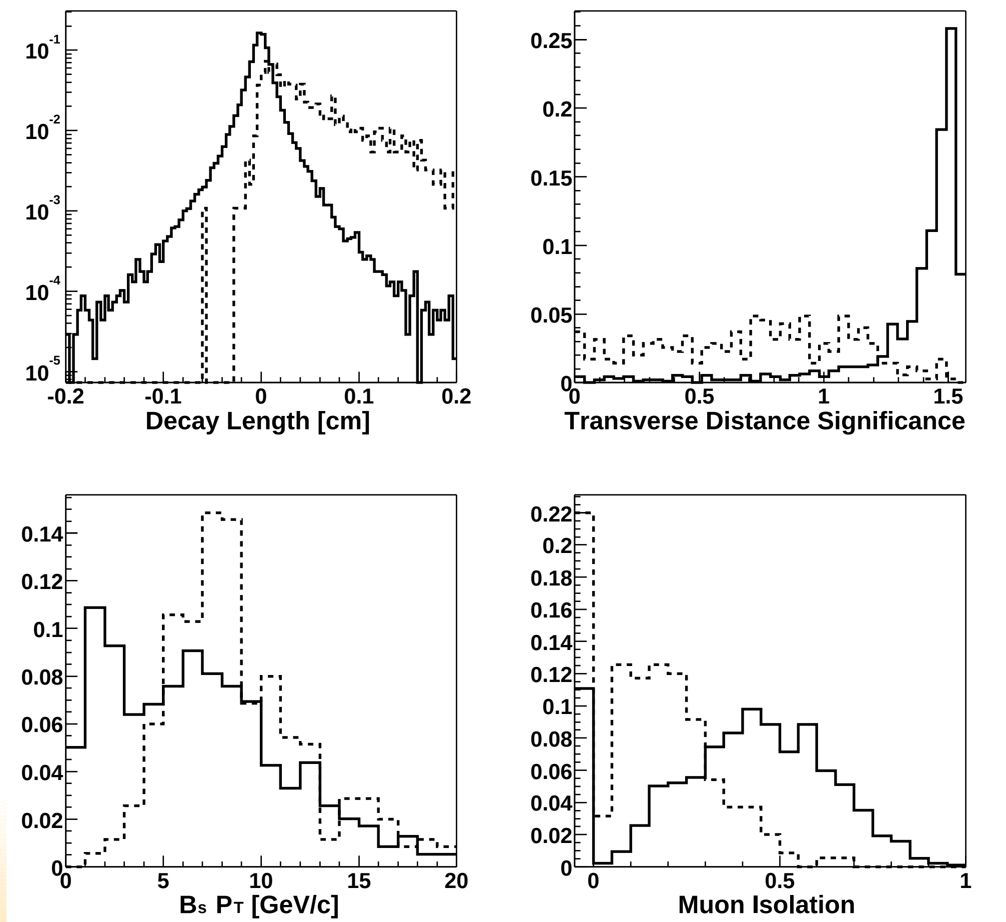
	efficiency	Observed ev.	Expected b.g.	BF (90% C.L.)
$B_d^0 \to e^+e^-$	14.3%	0	0.30 ± 0.12	$< 1.9 \times 10^{-7}$
$B_d^0 \to \mu^+\mu^-$	16.9%	0	0.19 ± 0.10	$< 1.6 \times 10^{-7}$
$B_d^0 \to e^\pm\mu^\mp$	15.8%	0	0.22 ± 0.10	$< 1.7 \times 10^{-7}$

CDF/D0 $B \to \mu^+\mu^-$ analysis

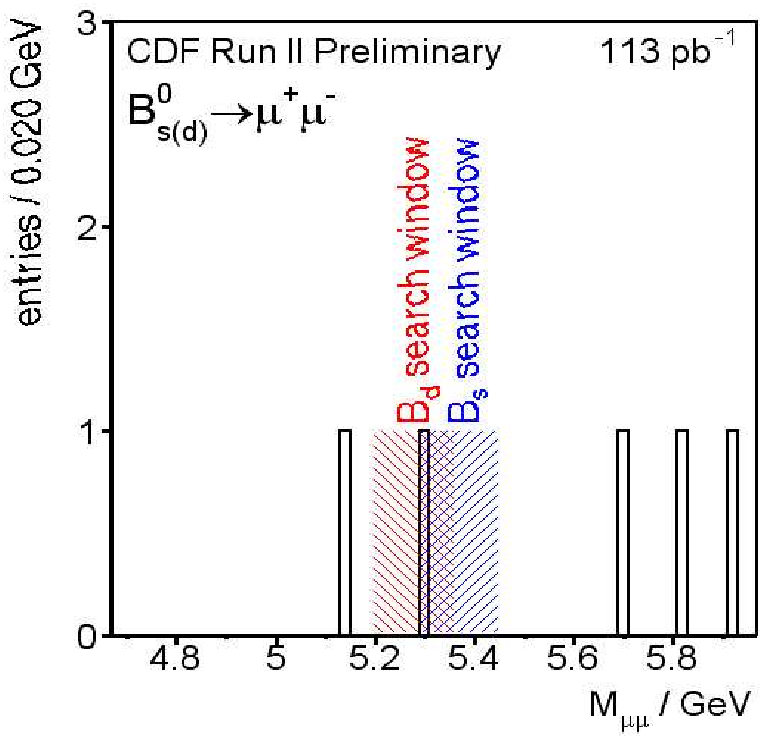
- CDF RunII 113 pb^{-1} data
  (supersedes RunI 98 pb^{-1} results)
- 3 variables to kill backgrounds

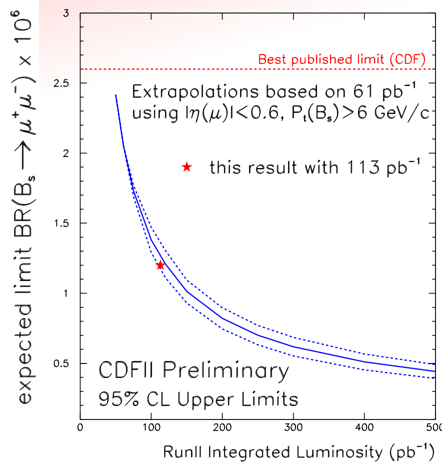
- D0 RunII 100 pb^{-1} data
- 3 variables to kill backgrounds





CDF/D0 $B \to \mu^+\mu^-$ result

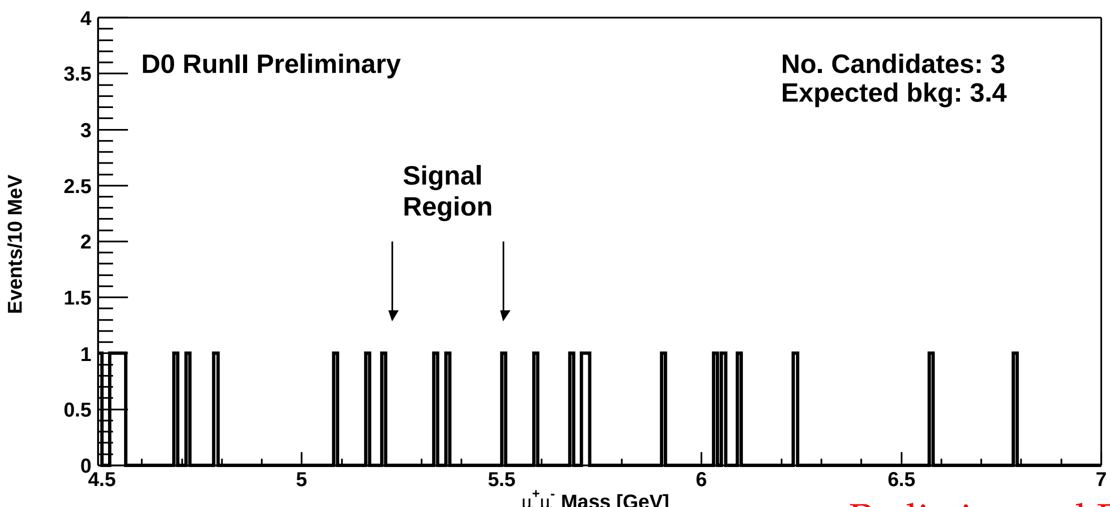




- CDF RunII 113 pb^{-1}

$$\mathcal{B}(B_s \to \mu^+\mu^-) < 9.5 \times 10^{-7}$$
$$\mathcal{B}(B_d \to \mu^+\mu^-) < 2.5 \times 10^{-7}$$
(90% C.L.)

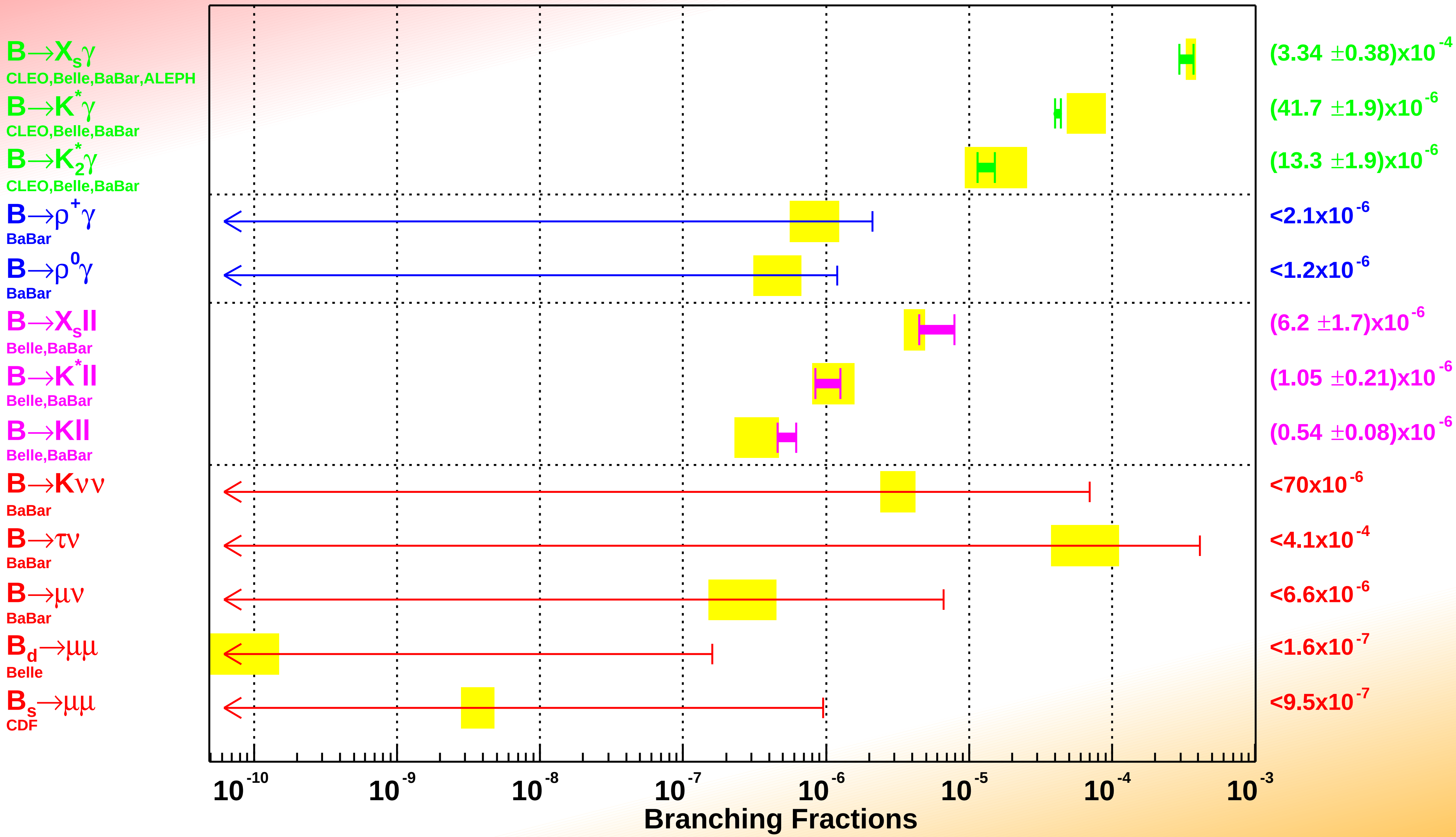
$$\left[\begin{array}{l} \mathcal{B}(B_s \to \mu^+\mu^-) < 12 \times 10^{-7} \\ \mathcal{B}(B_s \to \mu^+\mu^-) < 3.1 \times 10^{-7} \\ \text{(95\% C.L.)} \end{array} \right]$$



- D0 RunII 100 pb^{-1}

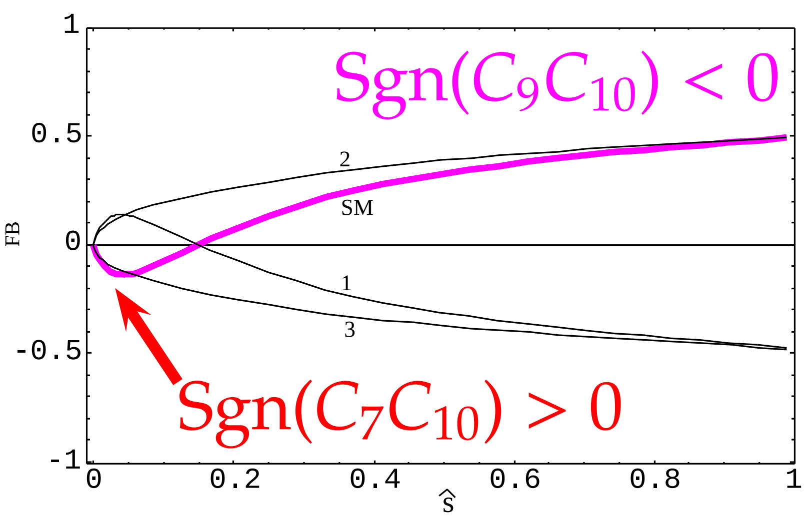
$$\mathcal{B}(B_s \to \mu^+\mu^-) < 16 \times 10^{-7}$$
(90% C.L.)

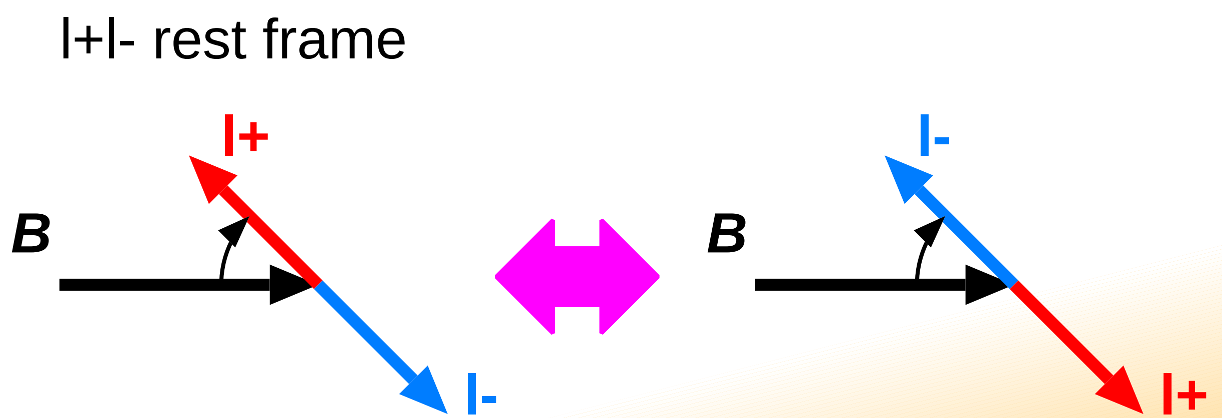
Summary of new results



Demand for more data

- Direct CP asymmetry in $b \to s\gamma$ can be nailed down to 1% with 20–50 times more data
- Mixing-induced CP asymmetry in $b \to s\gamma$ will be a clue to understand $b \to s$ transition with many ab^{-1}
- First $B \to K^*\ell^+\ell^-$ is just found, time to start A_{FB} and q^2 dependence 10–100 times more data will be helpful





A_{FB} in $B \to K^*\ell^+\ell^-$, $B \to X_s\ell^+\ell^-$

Huge dataset will certainly help for other challenging searches, too

Conclusion

- Many new results at LP'03, and within the past one year, including:
  - New modes/measurements in exclusive $b \to s\gamma$
  - Direct CPV search in $b \to s\gamma$
  - First observation of $B \to K^* \ell^+ \ell^-$ by Belle (evidence by BaBar)
  - New results for $B \to X_s \ell^+ \ell^-$ (BaBar), in agreement with Belle
  - Limits on $B \to K\nu\bar{\nu}$ and two-body leptonic decays
- All of new results are in good agreement with the SM.
  (No surprise yet. . . leptons and photons are our friends, aren't they?)
- CDF is back in the rare B decay business, D0 has also joined!
  Belle and BaBar will keep going. . . to meet the demands for more!!

End

Belle $B \to K^*\gamma$

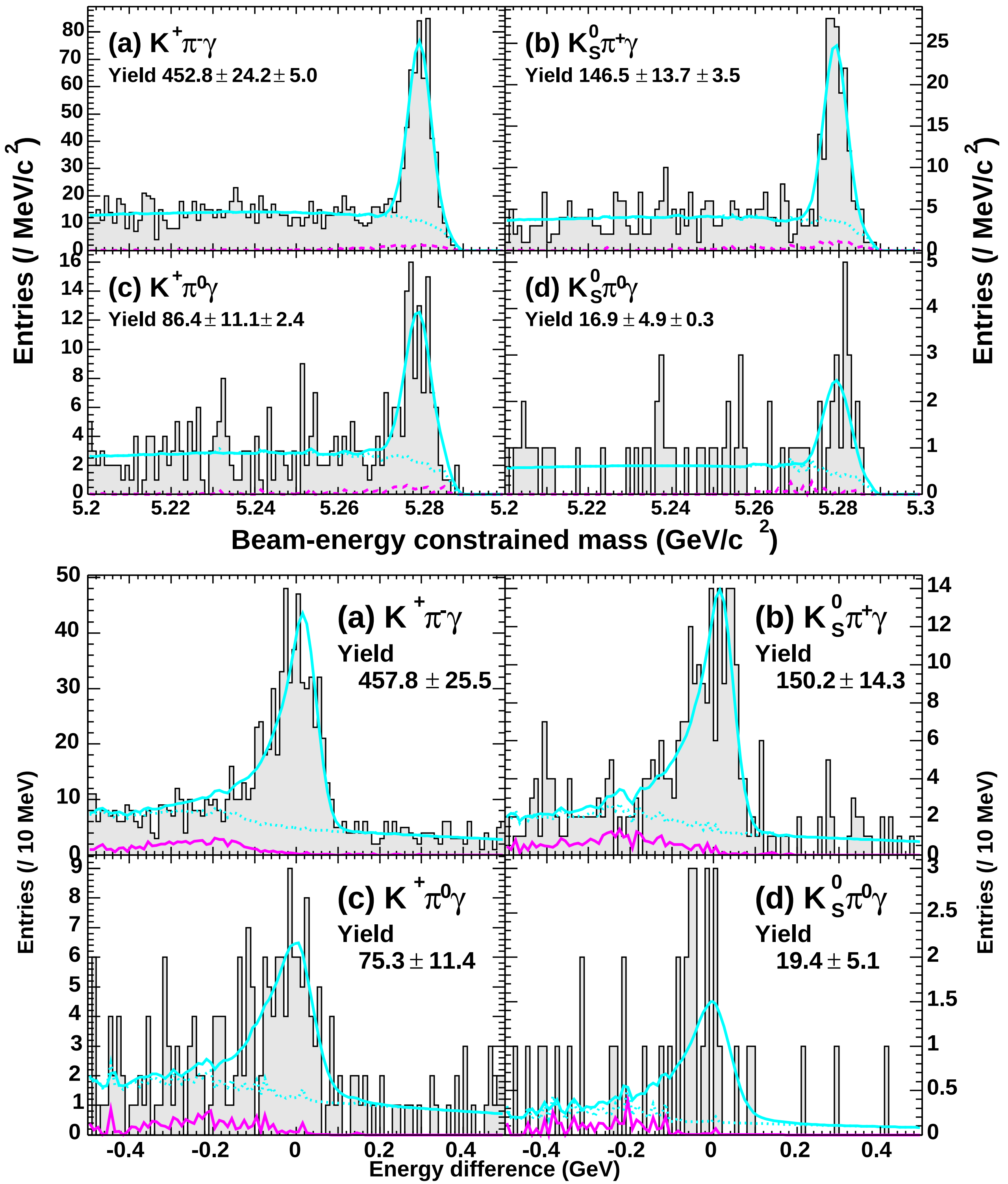
Belle 78 fb^{-1}

Solid: signal+background

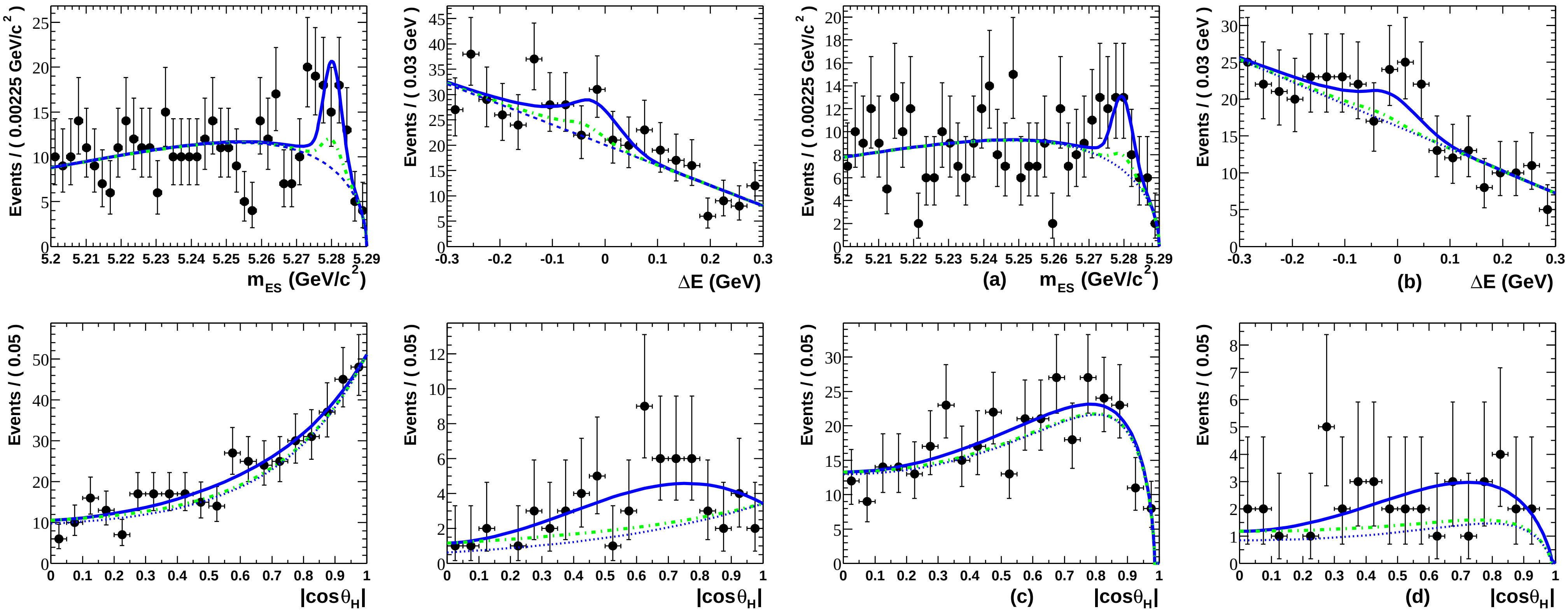
Dotted: total background

Dashed: B background

($K^*\pi^0$, $K^*\eta$, $K^*\pi\gamma$, etc



BaBar $B^+ \to K_2^*(1430)^+\gamma$



$K_2^* \to K_S^0\pi^+$ $\qquad\qquad$ $K_2^* \to K^+\pi^0$

$B \to K^{(*)}\ell^+\ell^-$ Predictions

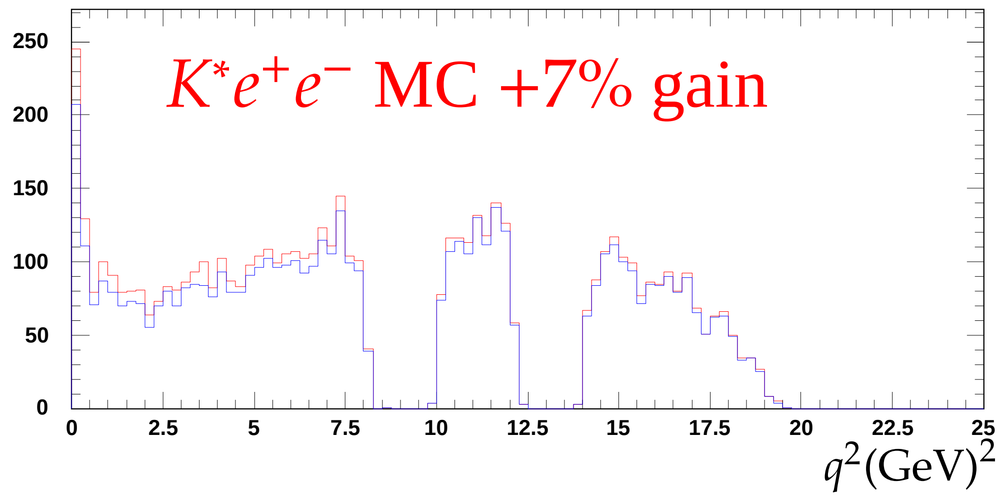
Predictions	$\mathcal{B}(B \to K\ell^+\ell^-)$	$\mathcal{B}(B \to K^*\mu^+\mu^-)$	$\mathcal{B}(B \to K^*e^+e$
Ali *et al.* (2000)	$(0.57^{+0.17}_{-0.10}) \times 10^{-6}$	$(1.9^{+0.5}_{-0.4}) \times 10^{-6}$	$(2.3^{+0.7}_{-0.5}) \times 10$
Ali *et al.* (2001) [NNLO]	$(0.35 \pm 0.12) \times 10^{-6}$	$(1.19 \pm 0.39) \times 10^{-6}$	$(1.58 \pm 0.49) \times$
Aliev *et al.* (1997)	$(0.31 \pm 0.09) \times 10^{-6}$	1.4×10^{-6}	
Colangelo *et al.* (1996)	0.3×10^{-6}	1.0×10^{-6}	
Faessler *et al.* (2002)	0.55×10^{-6}	0.81×10^{-6}	
Geng and Kao (1996)	0.5×10^{-6}	1.4×10^{-6}	
Melikhov *et al.* (1998)	0.44×10^{-6}	1.15×10^{-6}	1.50×10^{-6}
Zhong *et al.* (2002)	$(0.69^{+0.28}_{-0.25}) \times 10^{-6}$	$(1.98^{+0.66}_{-0.71}) \times 10^{-6}$	$(2.01^{+0.65}_{-0.73}) \times 1$

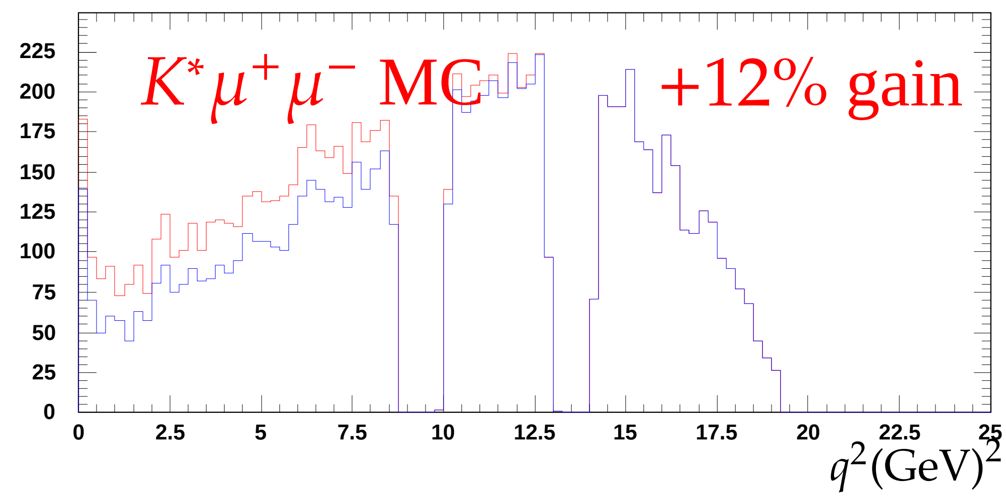
Ali et al. (2001) adjusted form factors to measured $B \to K^*\gamma$

[table compiled by A.Ryd, EPS'03]

$B \to K^{(*)}\ell^+\ell^-$ analysis (Belle)

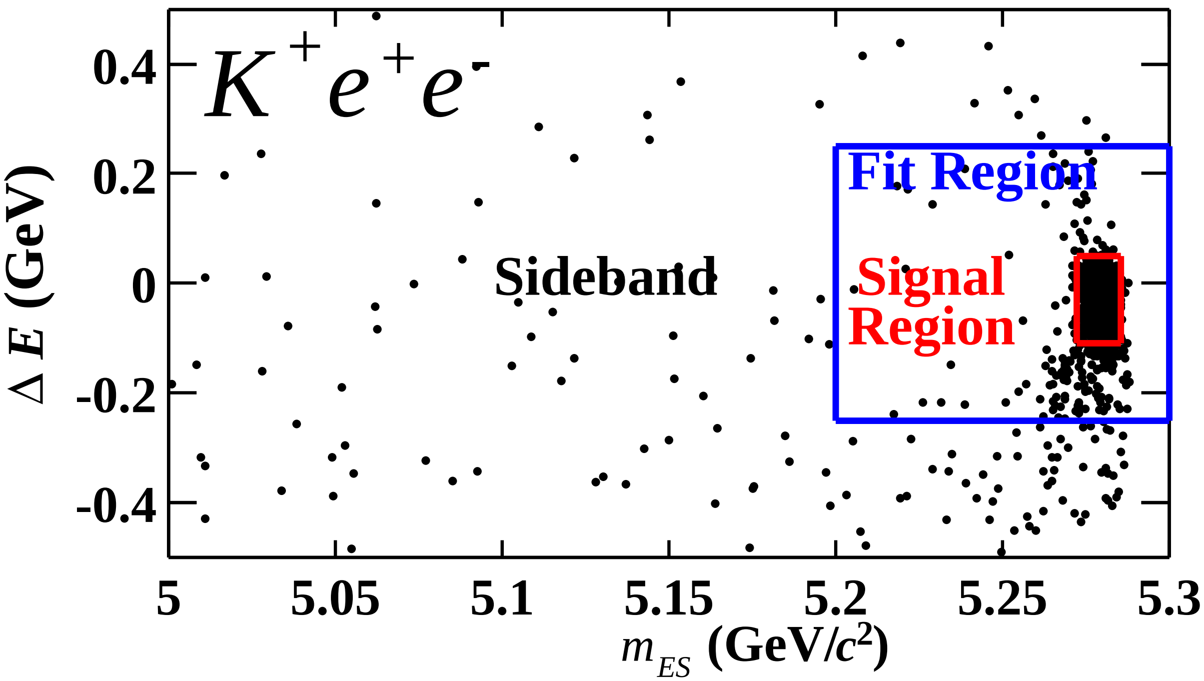
- Five × two modes: $[K^+,\ K_S^0,\ K^{*0} \to K^+\pi^-,\ K^{*+} \to K_S^0\pi^+,\ K^{*+} \to K^+\pi^0] \times [e^+e^-,\ \mu^+\mu^-]$
- Electron: $p > 0.4$ GeV (was 0.5 GeV), fake ~ 0.2%
- Muon: $p > 0.7$ GeV (was 1.0 GeV), momentum dep. μ-id, fake ~ 1.5%
- Huge di-lepton background MC: 4.3 times equiv. of data
- Best candidate based on ΔE, ±75 MeV cut for $M(K^*)$





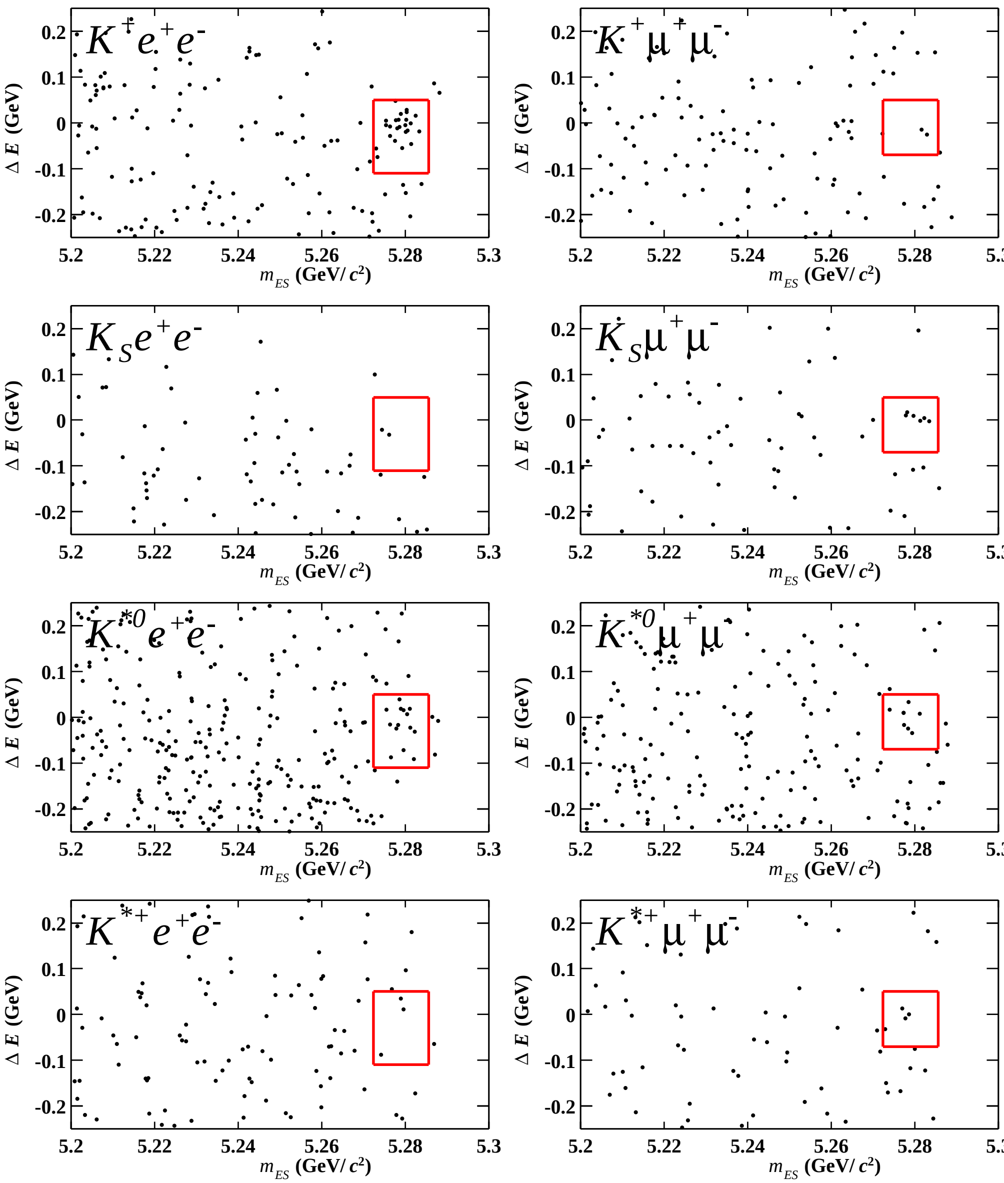
$B \to K^{(*)}\ell^+\ell^-$ analysis (BaBar)

- Charged track only: $B^+ \to K^+\ell^+\ell^-$, $B^0 \to K^0_S\ell^+\ell^-$, $B^0 \to K^{*0}(\to K^+\pi^-)\ell^+\ell^-$, $B^+ \to K^{*+}(\to K^0_S\pi+)\ell^+\ell^-$
- Electron: $p > 0.5$ GeV, fake $\sim 0.2\%$, brems. photon recovery
- Muon: $p > 1$ GeV, fake $\sim 2\%$
- Generic background MC: three times equiv. of data

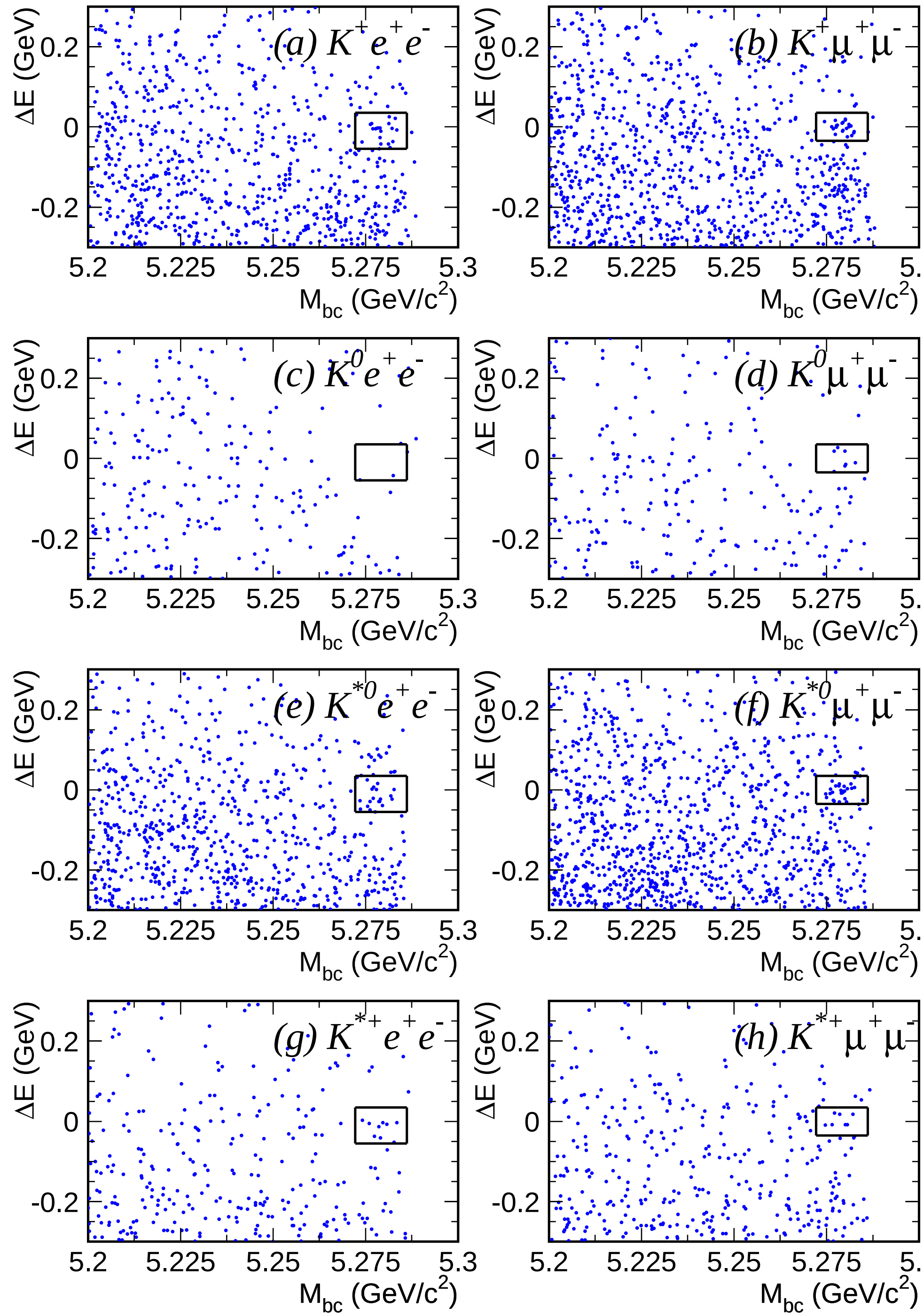


- Reblinded the data after last summer, "fit region" is blinded.
- 2- (3-) dim. ML fit on M_{ES}, ΔE (and $M(K\pi)$)

$B \to K^{(*)}\ell^+\ell^-$ events



BaBar 113 fb^{-1}



Belle 140 fb^{-1}

Significance calculation ($B \to K^{(*)}\ell^+\ell^-$)

- Systematic uncertainties from the fit affect the significance.
- Checklist:
  - Background shape parametrization
    - Belle fixes the parameters from MC, and varies for their errors
    - BaBar floats the parameters, so they will not contribute to systematics. But 2-d correlation is considered in addition
  - Peaking backgrounds (dominant)
  - Signal shape parameters (mean and width)
  - ΔE radiative tail in electron modes (BaBar only)
- The significance was evaluated by combining the variations that lead to decrease in the signal significance.
  - Belle $K^*\ell^+\ell^-$: 6.3σ (stat. only) $\Rightarrow$ 5.9σ
  - BaBar $K^*\ell^+\ell^-$: 3.8σ (stat. only) $\Rightarrow$ 3.3σ

$B \to X_s\ell^+\ell^-$ backgrounds (Belle/BaBar)

[Peaking backgrounds]
$B \to J/\psi X_s$
$B \to X_s\pi^+\pi^-$ (small but irreducible)
…These are good control samples, too

[Combinatorial backgrounds]
Semileptonic decays ($\ell^+\ell^- + 2\times\nu$)
Continuum background
Mis-combination within signal event

Belle

- Best candidate selection based on ΔE and $\cos\theta_B$
- Very wide $M(\ell^+\ell^-)$ veto window for J/ψ, ψ'
- Three-step cuts on
  Fisher of modified
  Fox-Wolfram moments,
  Fisher of E_{visible}, P_{miss},
  LR of ΔE, $\cos\theta_B$

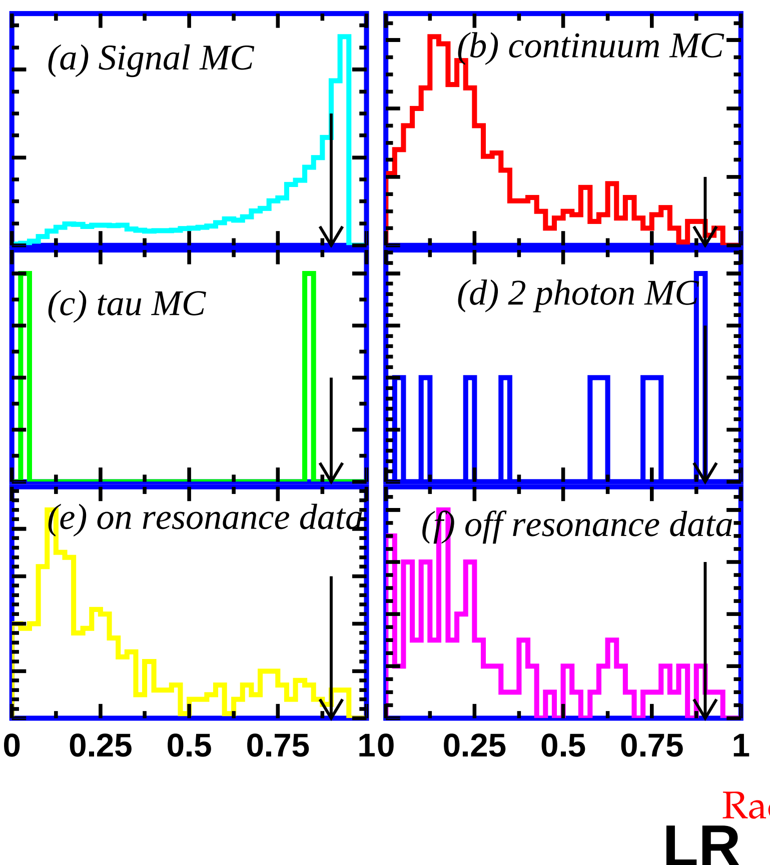
BaBar

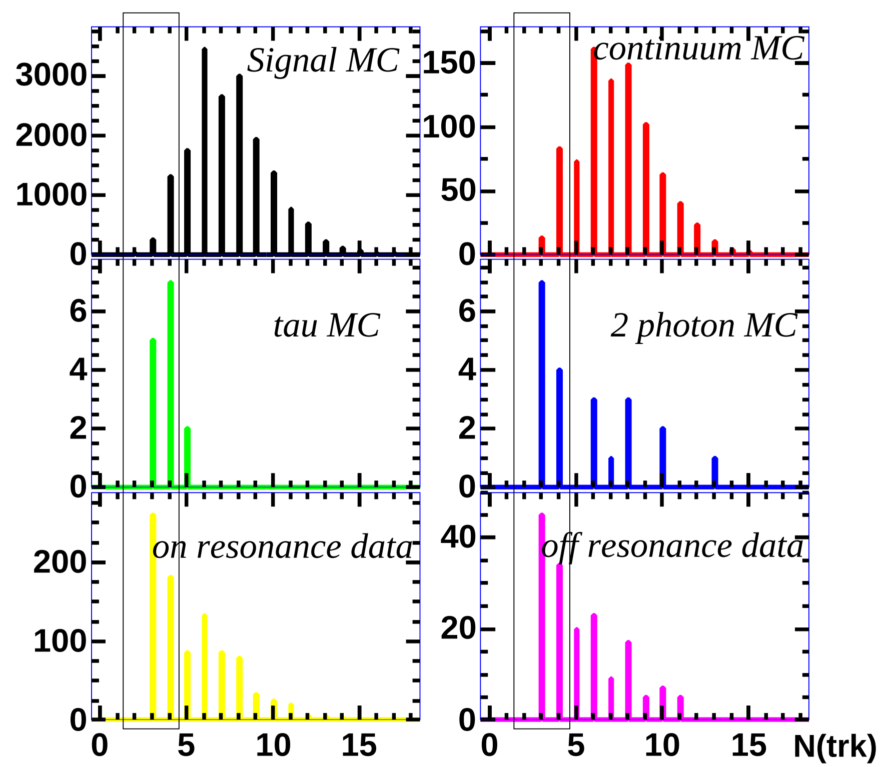
- Best candidate based on ΔE, $\cos\theta_B$ and $\log(\text{Prob}_{B-\text{vtx}})$
- $M(\ell^+\ell^-)$ veto for J/ψ, ψ' before/after Brems. recovery
- Single LR of nine variables:
  R_2, $\cos\theta_{\text{thrust}}$,
  ΔE^{ROE}, $M_{\text{ES}}^{\text{ROE}}$, $\cos\theta_{\text{miss}}$,
  ΔE, $\cos\theta_B$,
  $\Delta z_{\ell^+\ell^-}$ and $\log(\text{Prob}_{B-\text{vtx}})$

(ROE: rest of the event)

$B \to \ell^+\ell^-$ analysis (Belle)

- 2-body ($M_{\rm bc}$, ΔE), $B \to K\pi$ control sample ($\sim$ 100 events)
- Analysis: Lepton-id, Shape variable, $N_{trk} > 4$
  - Fisher (shape variables, $E_{\rm miss}$, $P_{\rm miss}$, $\cos\theta_{pl}$, $\cos\theta_{pb}$)
    θ_{pl}: angle between $P_{\rm miss}$ and thrust axis of leptons
    θ_{pb}: angle between $P_{\rm miss}$ and thrust axis of rest
  - Fisher + $\cos\theta_B$ $\Rightarrow$ Likelihood Ratio





$B \to \tau\nu, \mu\nu$

- SM: $\mathcal{B}(B \to \ell\nu) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$
- Helicity suppressed, SM:
  $\mathcal{B}(B \to \mu\nu) = 3.0 \times 10^{-7} < \mathcal{B}(B \to \tau\nu) = 7.5 \times 10^{-5}$
- Sensitive to f_B, or sensitive to charged Higgs, leptoquarks
- B-tag analysis for $B \to \tau\nu$ (same as $B \to K\nu\overline{\nu}$)

End of backup slides