Rare B Decays

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Introduction, Motivation and History

Trees and Penguins/ Experimental Techniques

Gluonic, Photonic and Electroweak Penguins

Mysteries and Open questions.

(Examples taken from CLEO, Belle and BaBar)

Motivation/History

Experiment: The decay $K_L \rightarrow \mu^+ \mu^-$ not observed. But in a world with three quarks, (u, s, and d) with Cabibbo mixing, there are large s→d transitions.

$$
\begin{aligned}
d_c &= d\cos\theta_c + s\sin\theta_c \\
J^0_{NC} &= u\bar{u} + d_c\overline{d_c} + s_c\overline{s_c} \\
&= u\bar{u} + d\bar{d}\cos^2\theta_c + s\bar{s}\sin^2\theta_c \\
&\quad +(s\bar{d} + \bar{s}d)\cos\theta_c\sin\theta_c
\end{aligned}
$$

⬅

In 1970 Glashow, Iliopoulos and Maiani (GIM) introduced the c quark to cancel the s→d transitions.

$$\begin{pmatrix} u \\ d_c \end{pmatrix}, \begin{pmatrix} c \\ s_c \end{pmatrix}$$

$$d_c = d\cos\theta_c + s\sin\theta_c$$
$$s_c = -d\sin\theta_c + s\cos\theta_c$$

$$\begin{aligned} J_{NC}^0 &= u\bar{u} + d_c\bar{d_c} + s_c\bar{s_c} + c\bar{c} \\ &= u\bar{u} + c\bar{c} + (d\bar{d} + s\bar{s})(\cos^2\theta_c + \sin^2\theta_c) \\ &\quad +(s\bar{d} + \bar{s}d - s\bar{d} - \bar{s}d)\cos\theta_c \sin\theta_c \\ &= u\bar{u} + c\bar{c} + d\bar{d} + s\bar{s} \end{aligned}$$

No FCNC at first order, but possible as higher order corrections! For example, $K^0 - K^0$bar mixing:

•Measured rate of transition allowed prediction of m_c!

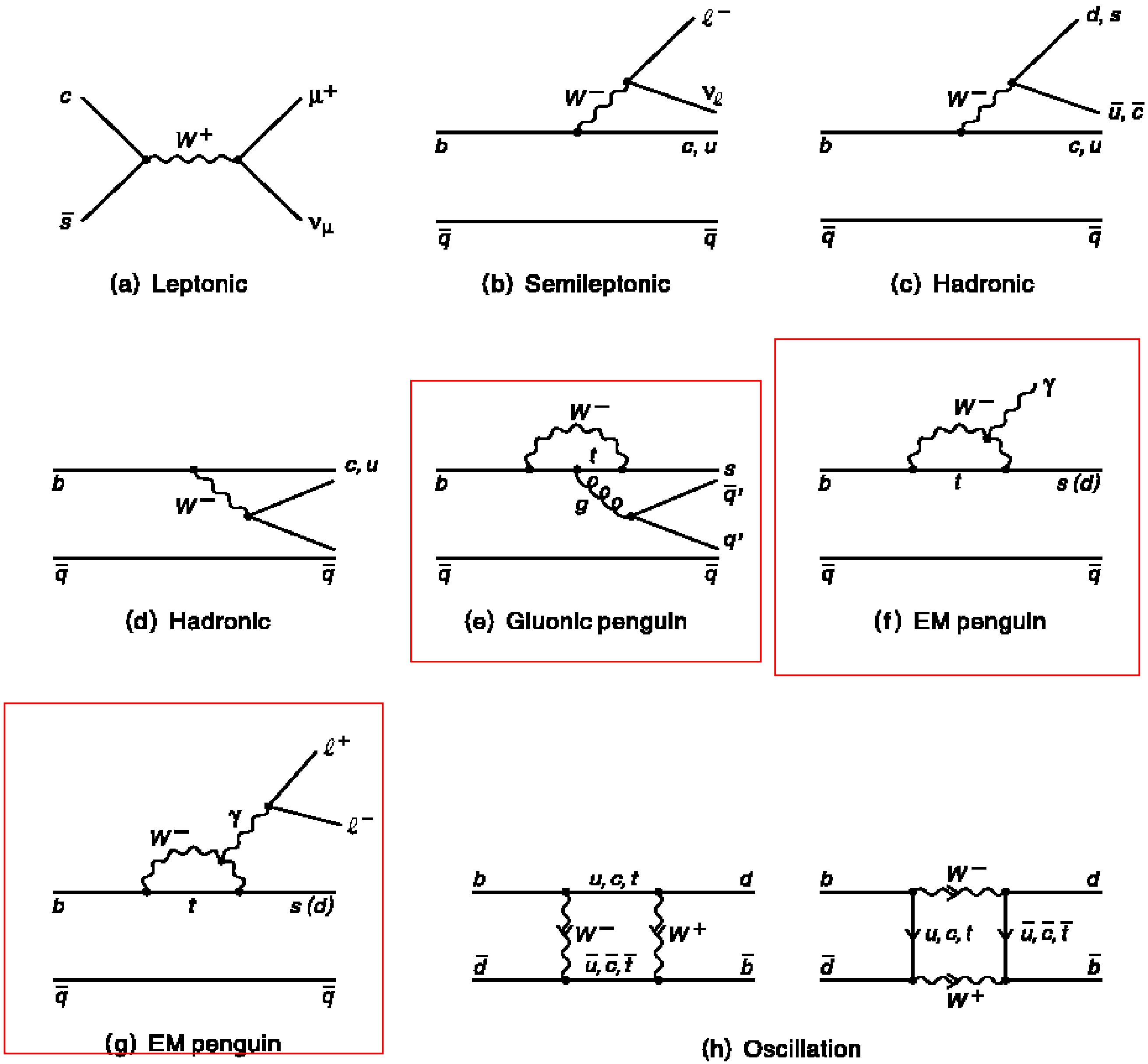
Later, accelerators and experimenters were able to directly produce the charm quark. In 1974 Richter and Ting observed the J/ψ, a (c cbar) bound state.

Rare decays at low energies led the way to ***new physics*** *of higher energies.*

Is this an anomalous example ?

Other examples: The absence of large FCNC in B decays. Ruled out "topless" models (with no t quark). Large B^0 mixing from ARGUS ➔ *m_t large*

Feynman diagrams for B decay



"Rare" means not b→c

Dominant Feynman diagrams for $B^0 \rightarrow K^- \pi^+$, $\pi^- \pi^+$ decays

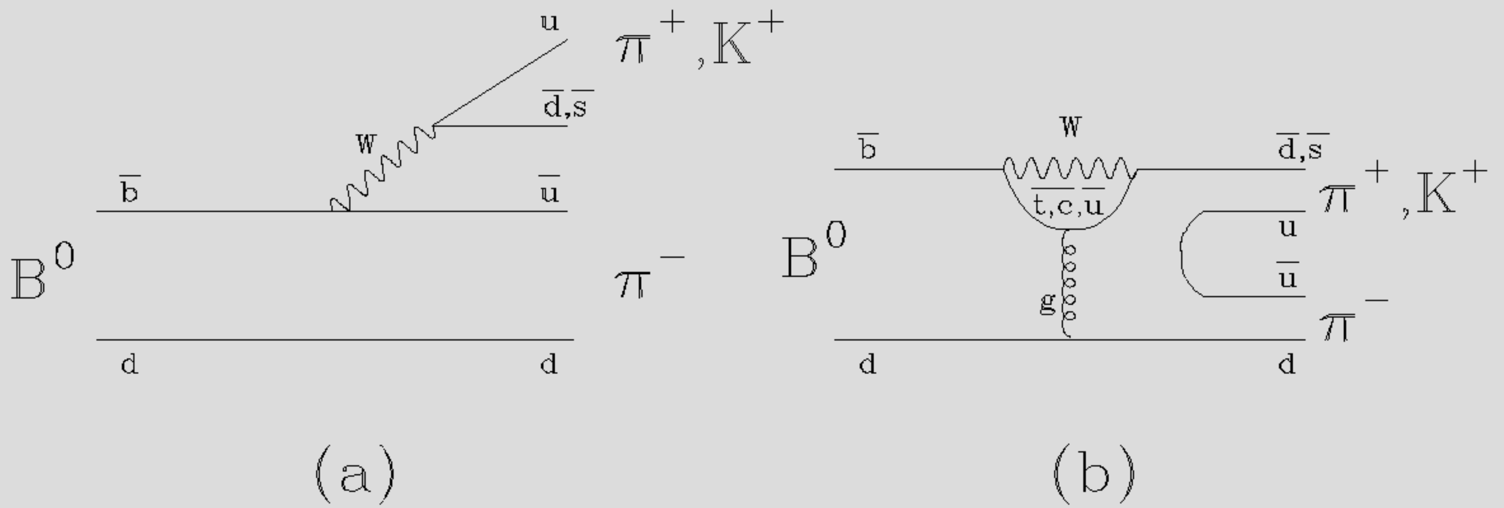
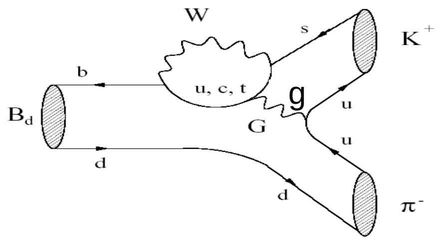


FIG. 1. (a) Spectator diagrams for $B^0 \to \pi^+\pi^-$ and $B^0 \to K^+\pi^-$ and (b) penguin diagrams for the same modes.

Warning: EWP(electroweak penguins) and FSI (final state interactions) may greatly complicate this simple picture.



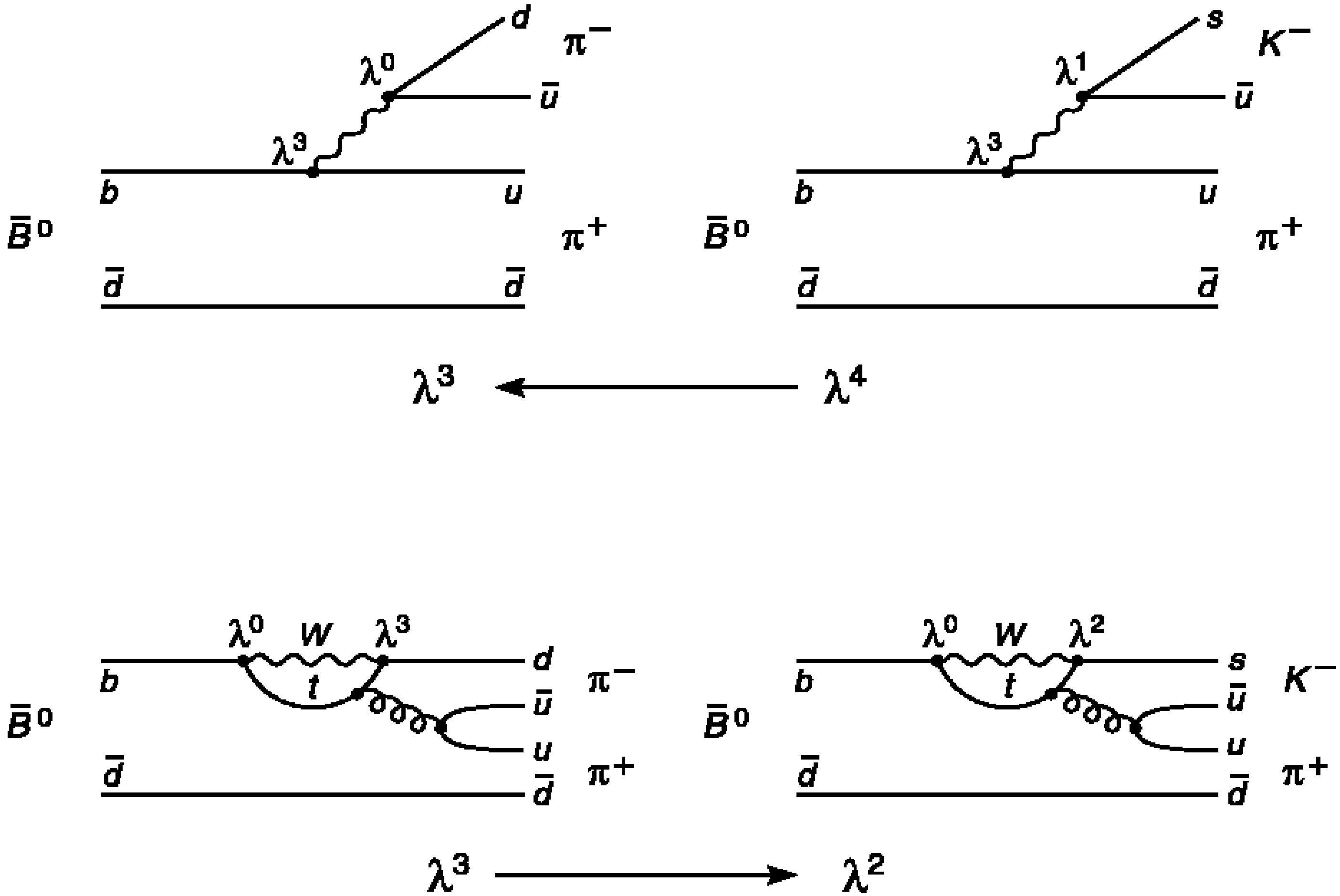
History of "Penguins"

Ref: Preface to Shifman's 1999 book, ITEP Lectures on Particle Physics and Field Theory, John Ellis recalls how the gluon interference diagram came to be called a penguin diagram.

One night in spring 1977, Ellis lost a bet during a game of darts. His penalty required that he use the word "penguin" in a journal article. "For some time, it was not clear to me how to get the word into this b quark paper that we were writing at the time," Ellis wrote.

"Then, one evening I stopped on my way back to my apartment to visit some friends living in Meyrin, where I smoked some illegal substance. *Later, when I got back to my apartment and continued working on our paper, I had a sudden flash that the famous diagrams looked like penguins.*
So we put the name into our paper, and the rest, as they say, is history."

Hierarchy of diagrams for B→K π, π π decays



Possibility of tree-penguin interference.

Direct CPV asymmetries

- Asymmetry in B decay rates

$$A_{dir} \equiv \frac{\Gamma(\overline{B} \to \bar{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \bar{f}) + \Gamma(B \to f)}$$

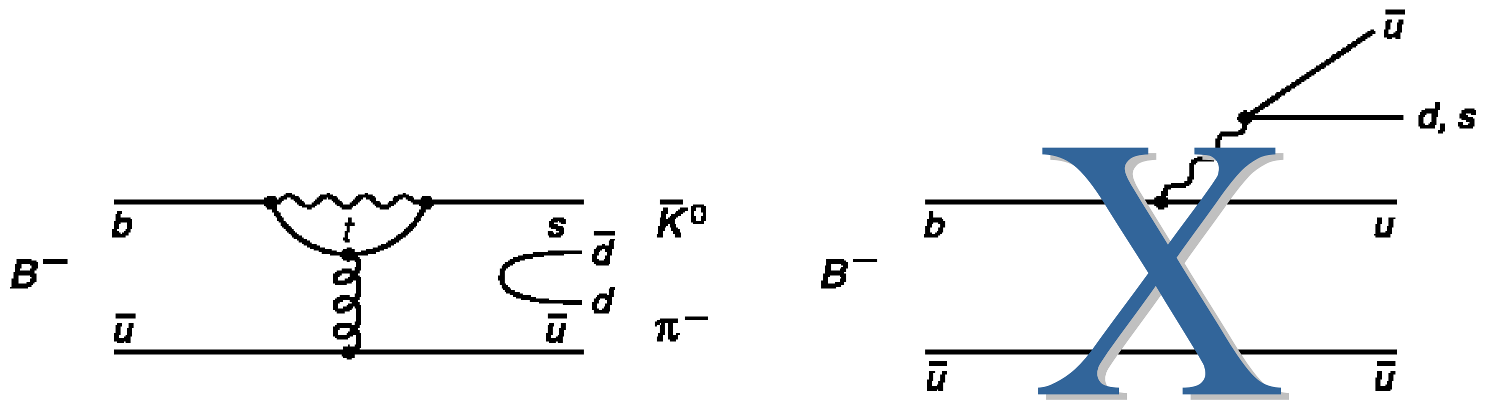
$$= \frac{2r \sin\phi \sin\delta}{1 + r^2 + 2r\cos\phi\cos\delta}$$

$$r = |P|/|T|, \phi = weak\ \ phase\ diff$$

$$\delta = strong\ \ phase\ diff$$

- *The direct CP asymmetry (A_{dir}) can be significant if the penguin (P) and tree(T) amplitudes are comparable and if both strong (CP conserving) and weak phase differences (CPV) are present.*

Another example: The penguin decay $B^{\pm} \rightarrow K_s\ \pi^{\pm}$



Expect little or no CPV asymmetry in the SM.

Use measurements of this mode to determine |P|

Overview of experimental techniques used for measurements of $B \rightarrow h\ h$ decay modes.

Kinematic variables

Continuum suppression

Particle Identification

Yield extraction and fitting

Examples of signals and results.

$$\Delta E \equiv E_{\pi} + E_{\pi} - E_{CM}/2$$

$$m_{bc} = \sqrt{(E_{CM}/2)^2 - (\vec{p}_{\pi} + \vec{p}_{\pi})^2}$$

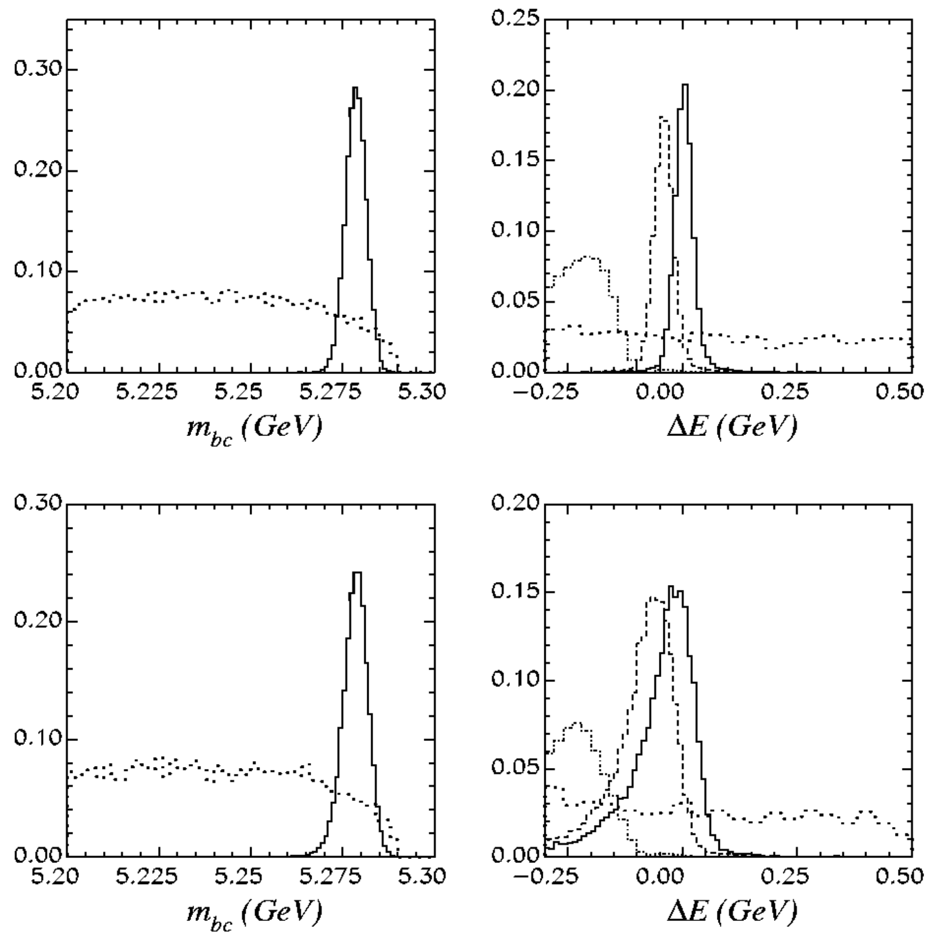
Shown For Monte Carlo

$B^0 \rightarrow h^+ h^-$ modes:

$(K^+ \pi^-, \pi^- \pi^+)$

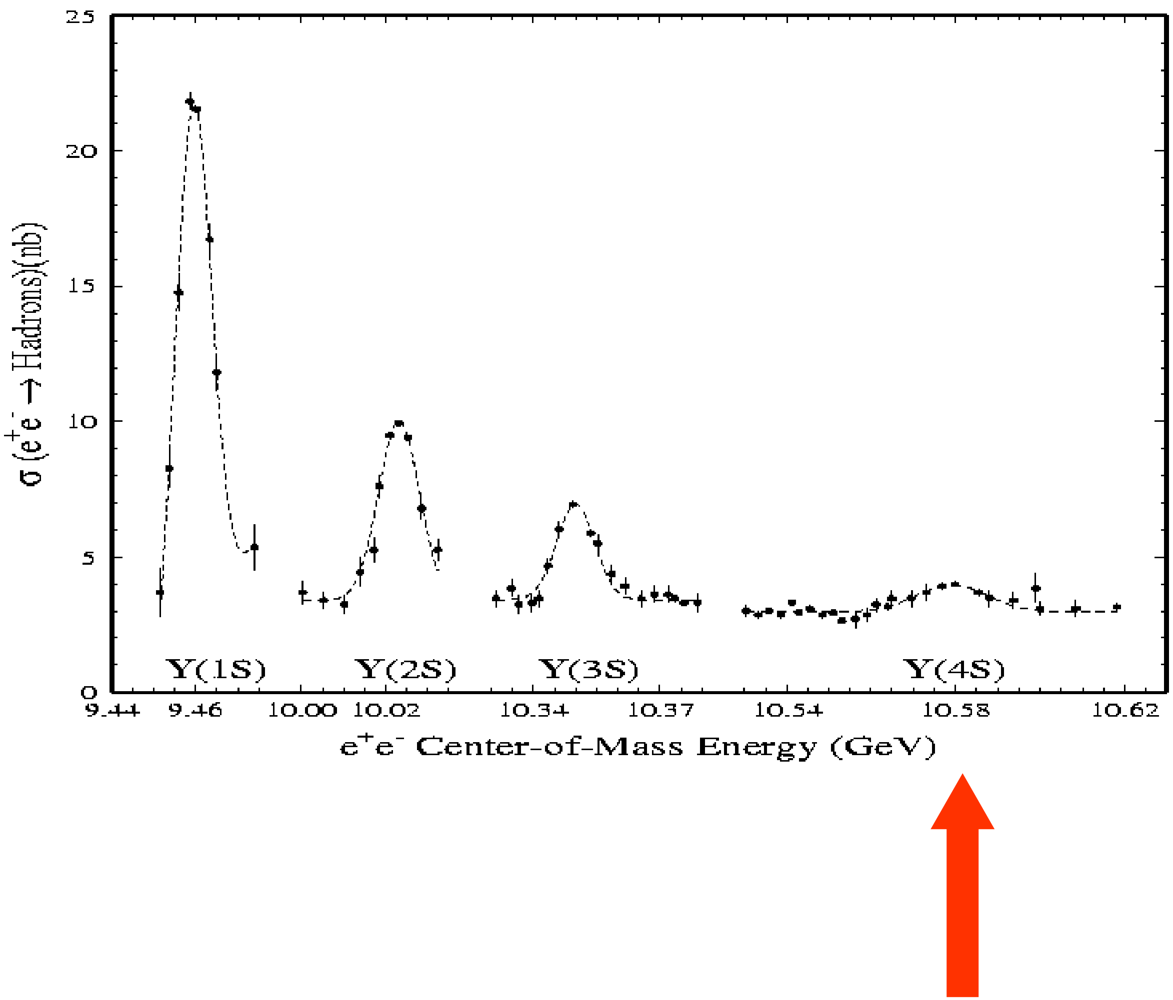
$B^{\pm} \rightarrow h^{\pm} \pi^0$ modes:

$(K^{\pm} \pi^0, \pi^{\pm} \pi^0)$

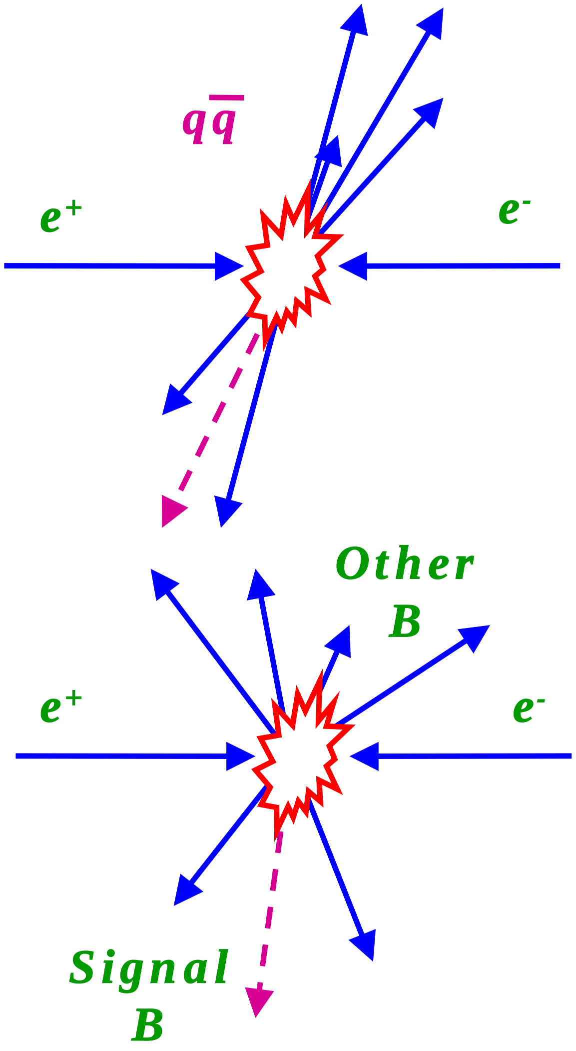


Continuum background problem

continuum means $e^+ e^- \rightarrow q\ \bar{q}$ *with q=u,d,s,c*



Continuum suppression (Idea)



Collimated, jetlike

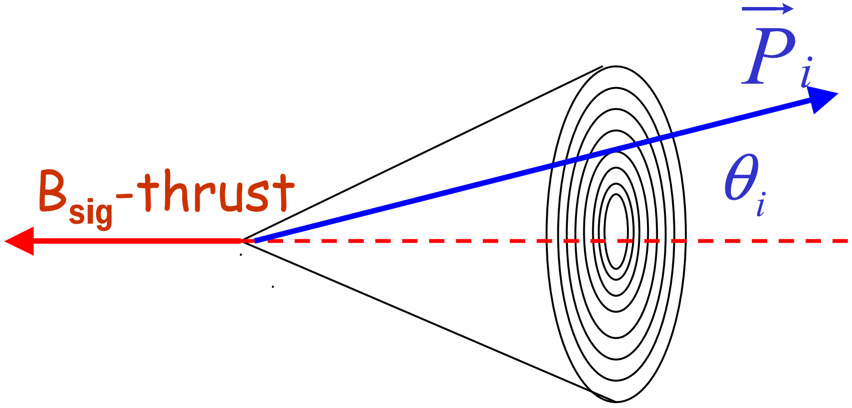
$e^+e^- \to \Upsilon(4S) \to B\bar{B}$

Small energy release

spherical

Variables for continuum suppression

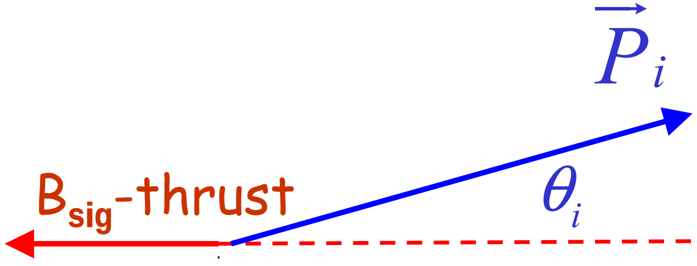
Fisher Discriminant



$$I_j^{CONE} = \sum_{i=1}^{\text{unused tracks,bumps}} P^i$$

$$F = \sum_{j=1}^{9} \alpha_j I^j$$

cos θ_s, Super Fox-Wolfram

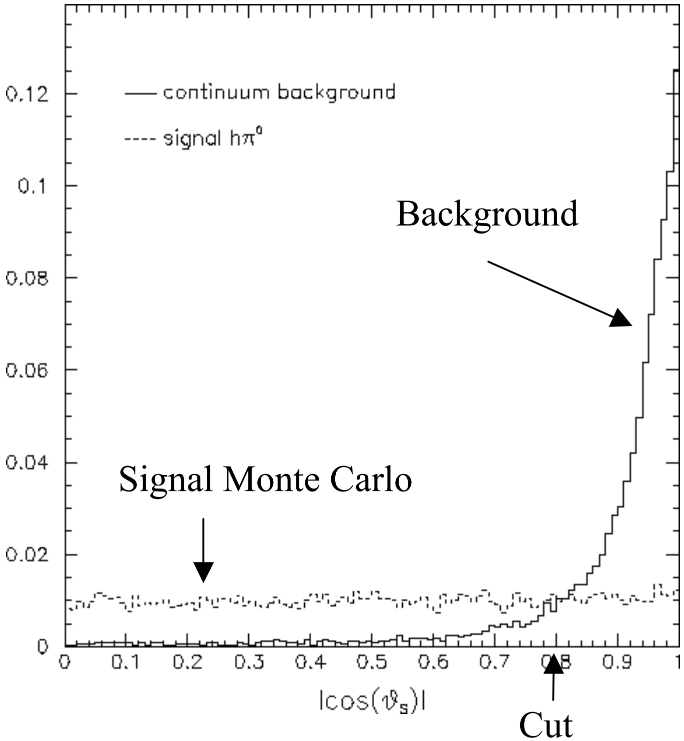


$$F = \sum_{i=1}^{\text{unused tracks,bumps}} (\alpha \cdot L_0(\theta_i) + \beta \cdot L_2(\theta_i) + \ldots) P^i$$

Ln - Legendre polynomial of n^{th} power

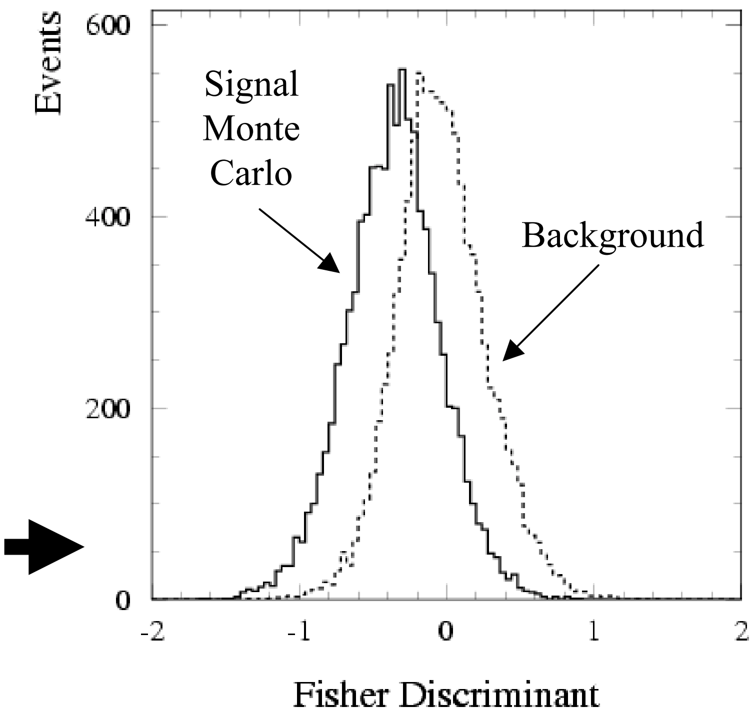
(e.g. $L_2(\theta_i) = 3\cos^2\theta_i - 1$)

Continuum suppression (Babar)



Cut on angle between B candidate and sphericity of the other tracks in the event e.g. $|\cos\theta_s| < 0.8$

F - optimized linear combination of energy flow into nine cones around candidate (CLEO Fisher discriminant).

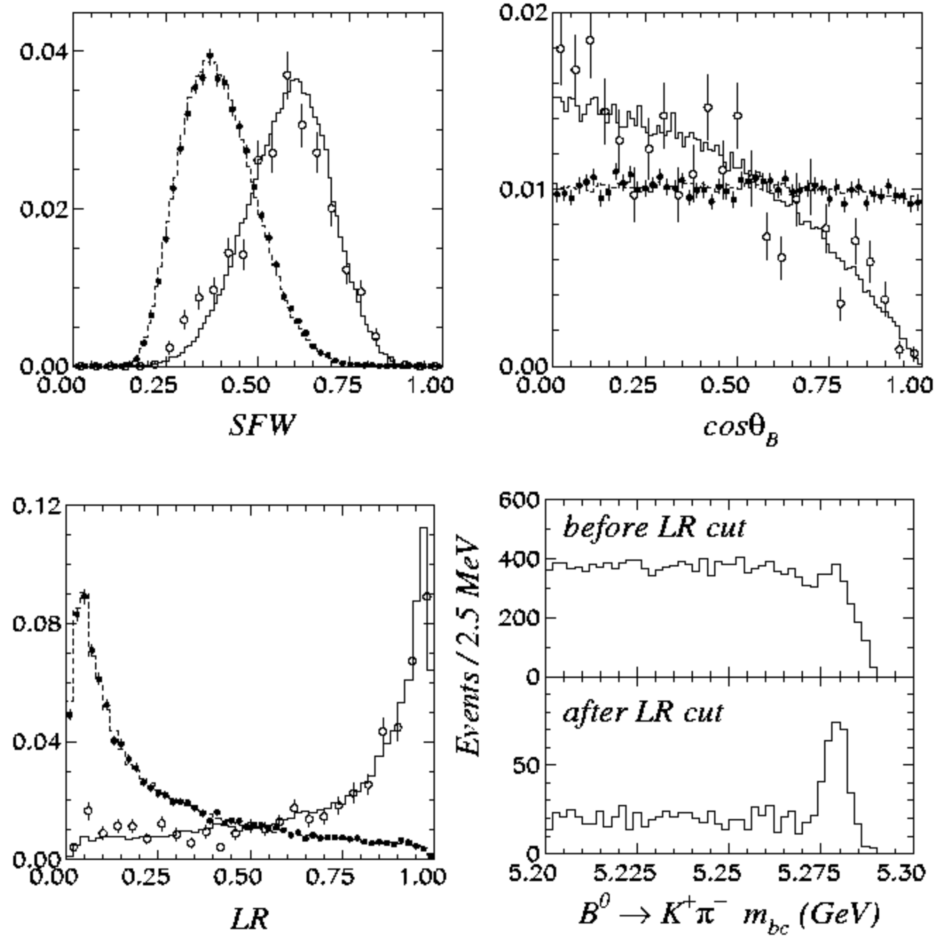


Continuum suppression (Belle)

SFW

Cos θ_B

$L_S/(L_S + L_B)$



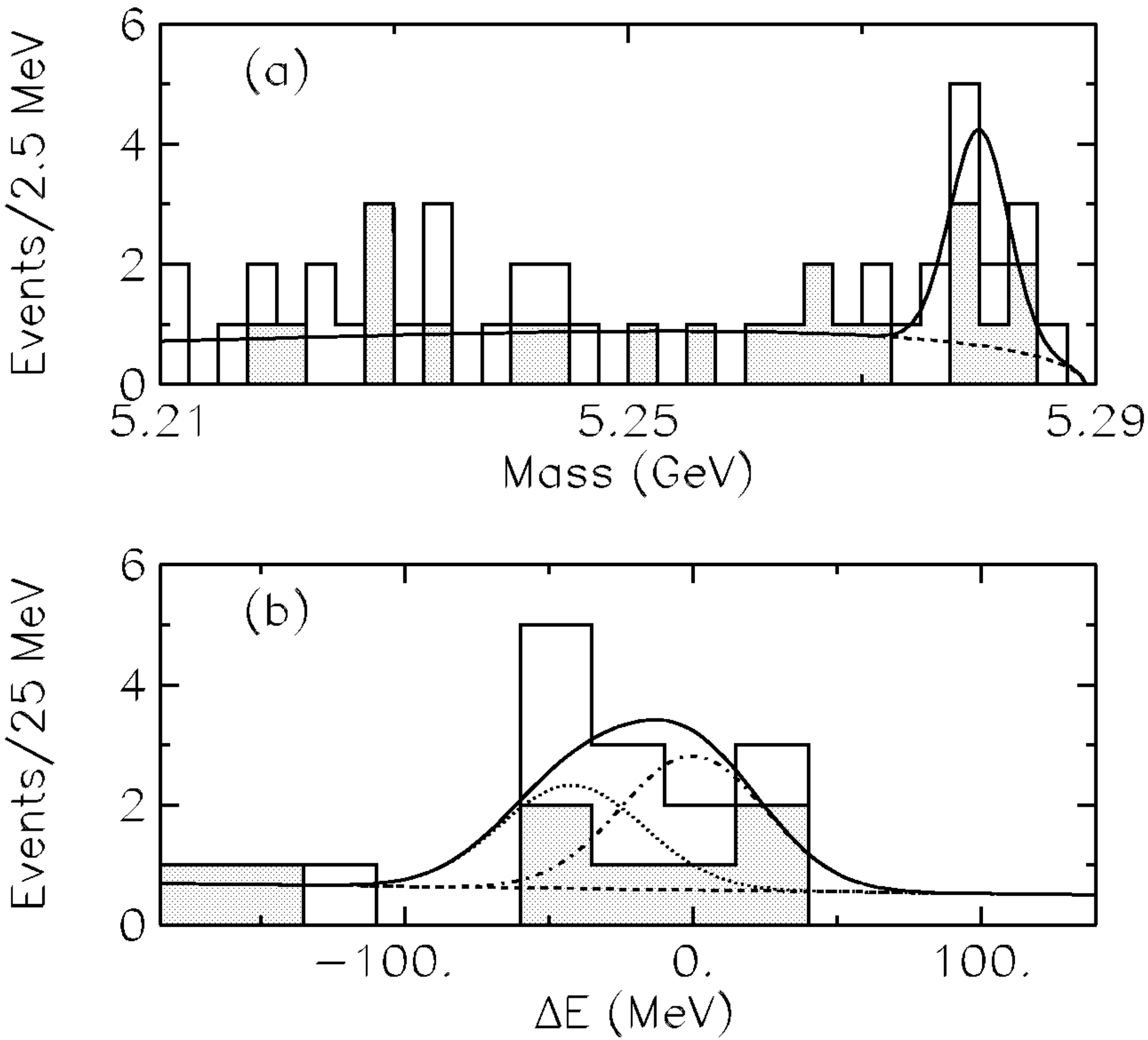
Yield Extraction and Fitting

Fit ΔE distribution or M_{bc} distribution or 2-d fit to ΔE and M_{bc}.

Multidimensional likelihood fit to ΔE , M_{bc} , shape variables, PID variables.

B Bbar backgrounds that peak in M_B and correlations require special care.

1993: CLEO II Signal for combined $K^- \pi^+ + \pi^- \pi^+$

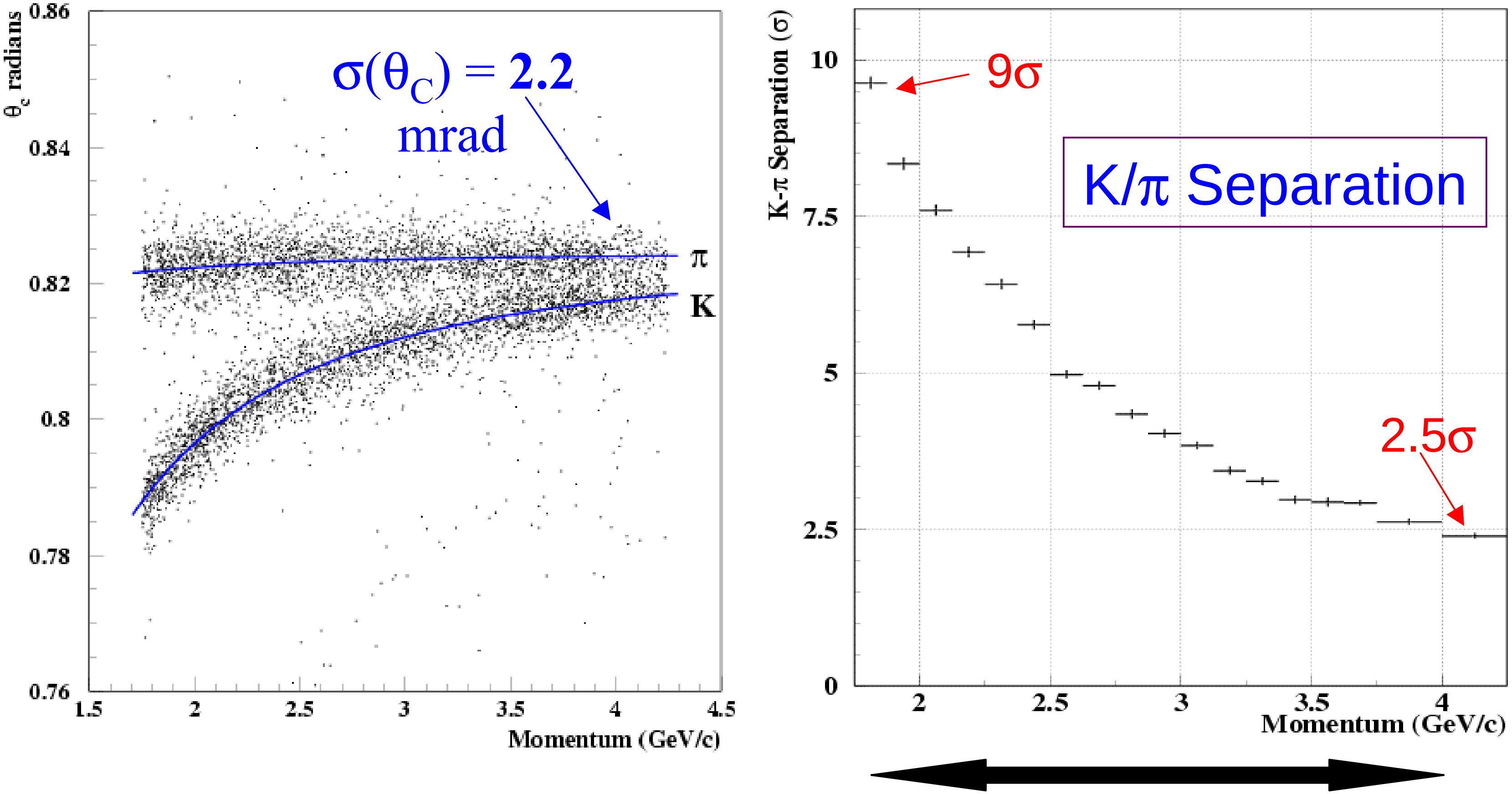


PID: dE/dx 1.7σ at 2.5GeV

Indicates that $BF(B^0 \rightarrow K^- \pi^+) = BF(B^0 \rightarrow \pi^+ \pi^-)$

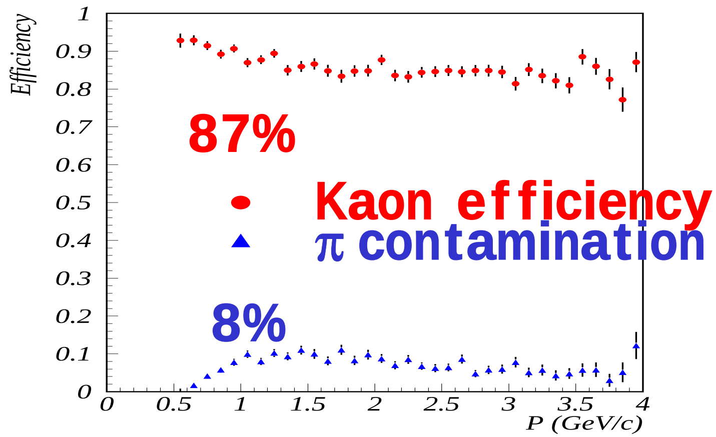
Particle identification - θ_c(Babar)

DIRC θ_c mean and resolution parameterized from data using $D^{*+} \to D^0\pi^+ \to (K^-\pi^+)\pi^+$ decays

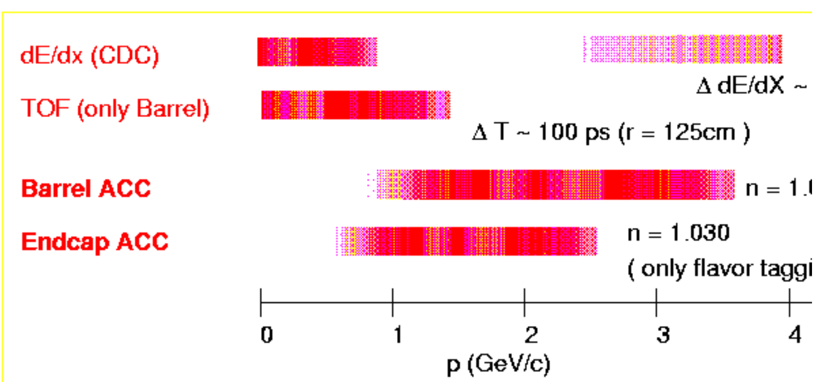


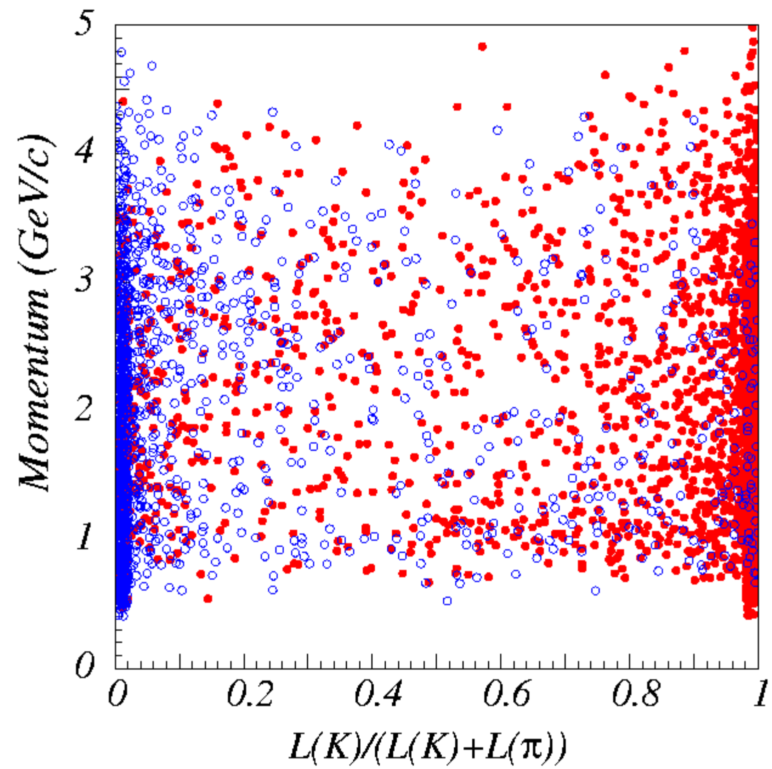
Momentum range of decays

Particle Identification (Belle)



PID(K)>0.6

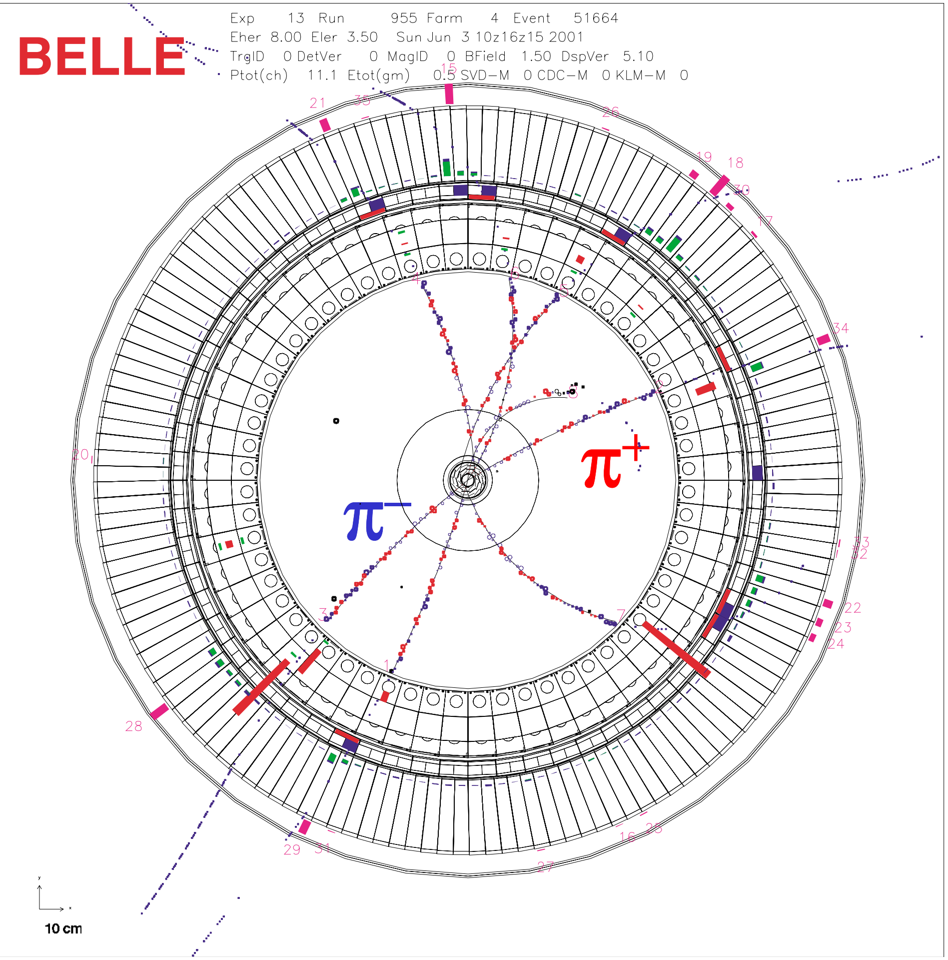


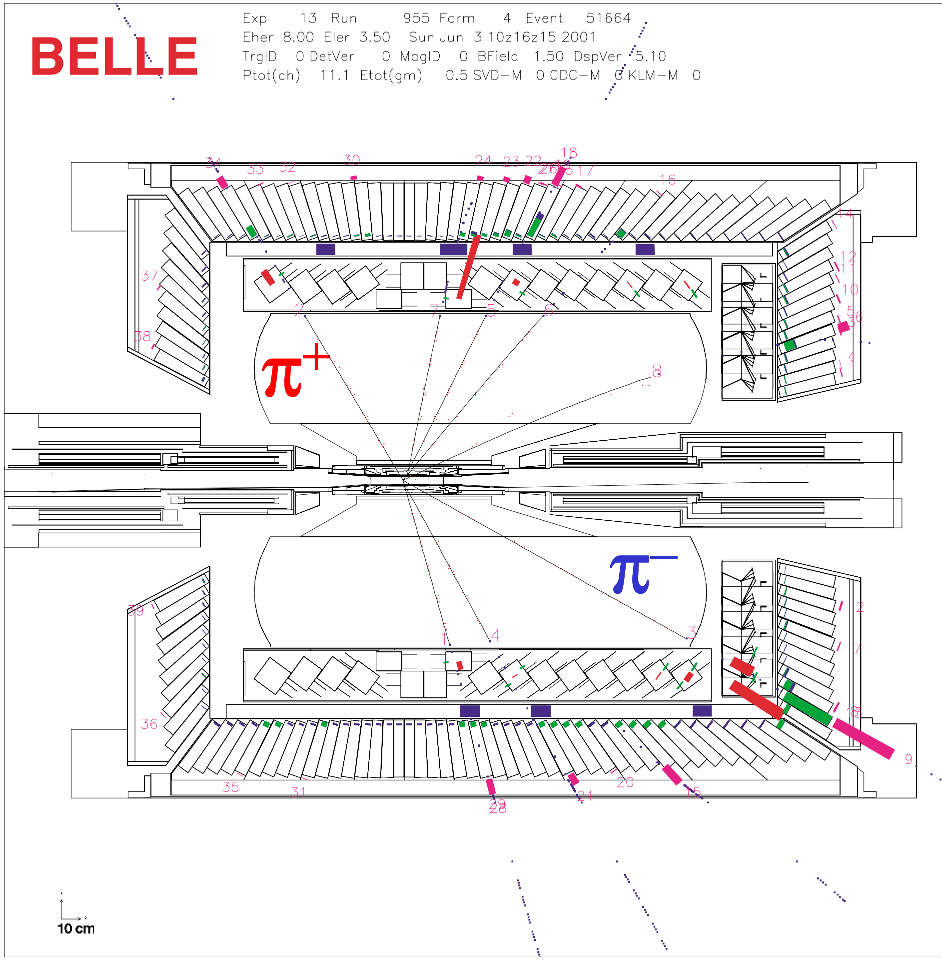


Verified using a tagged sample of K/π from $D^{*+} \to D^0\pi^+$ decays

$\quad\quad\quad\quad\quad\quad\quad\quad \hookrightarrow K^-\pi^+$

Example of a $B^0 \to \pi^+\pi^-$ event (Belle)

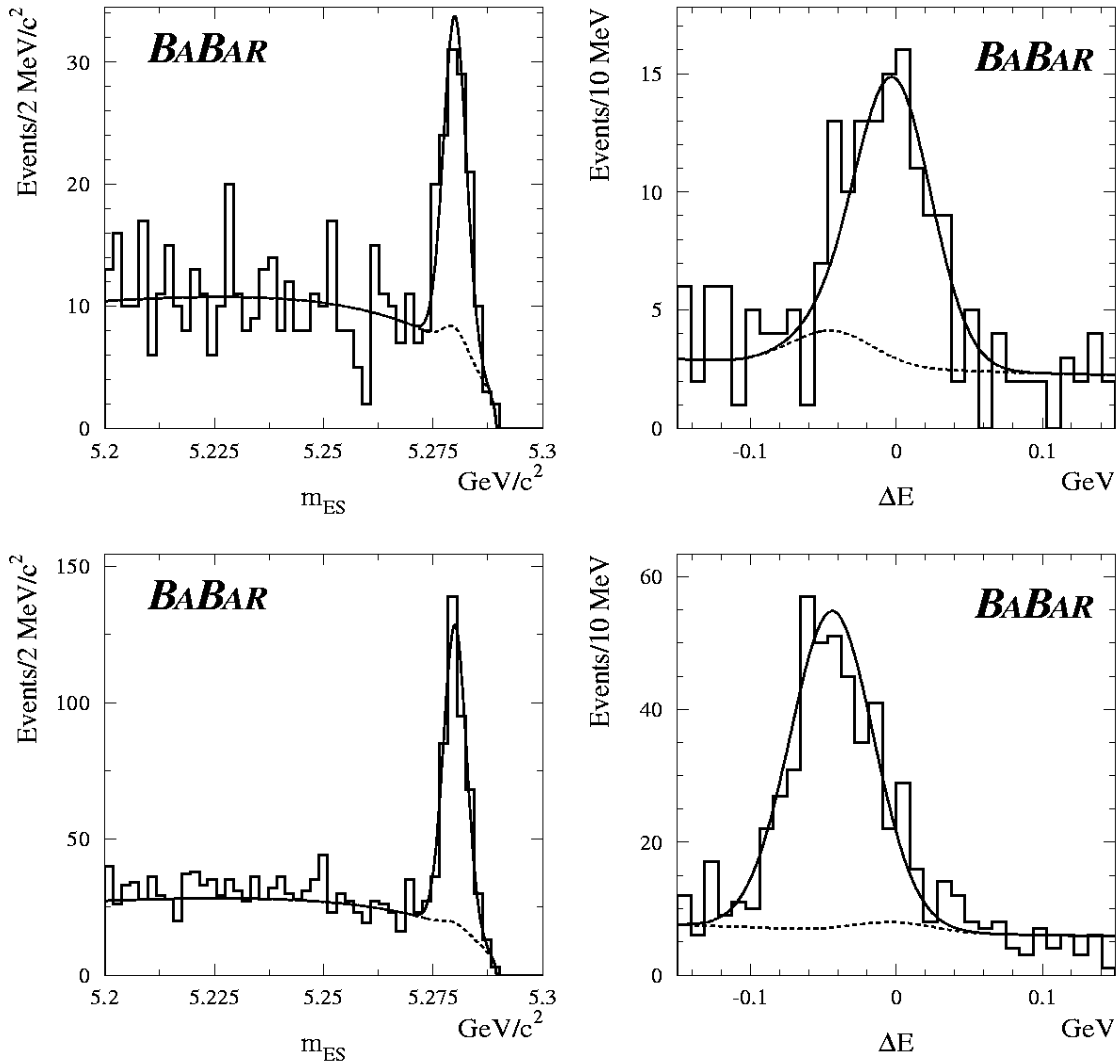




2002 BaBar: Exclusive B→$\pi^+ \pi^-$ and $K^+ \pi^-$ data

157±19

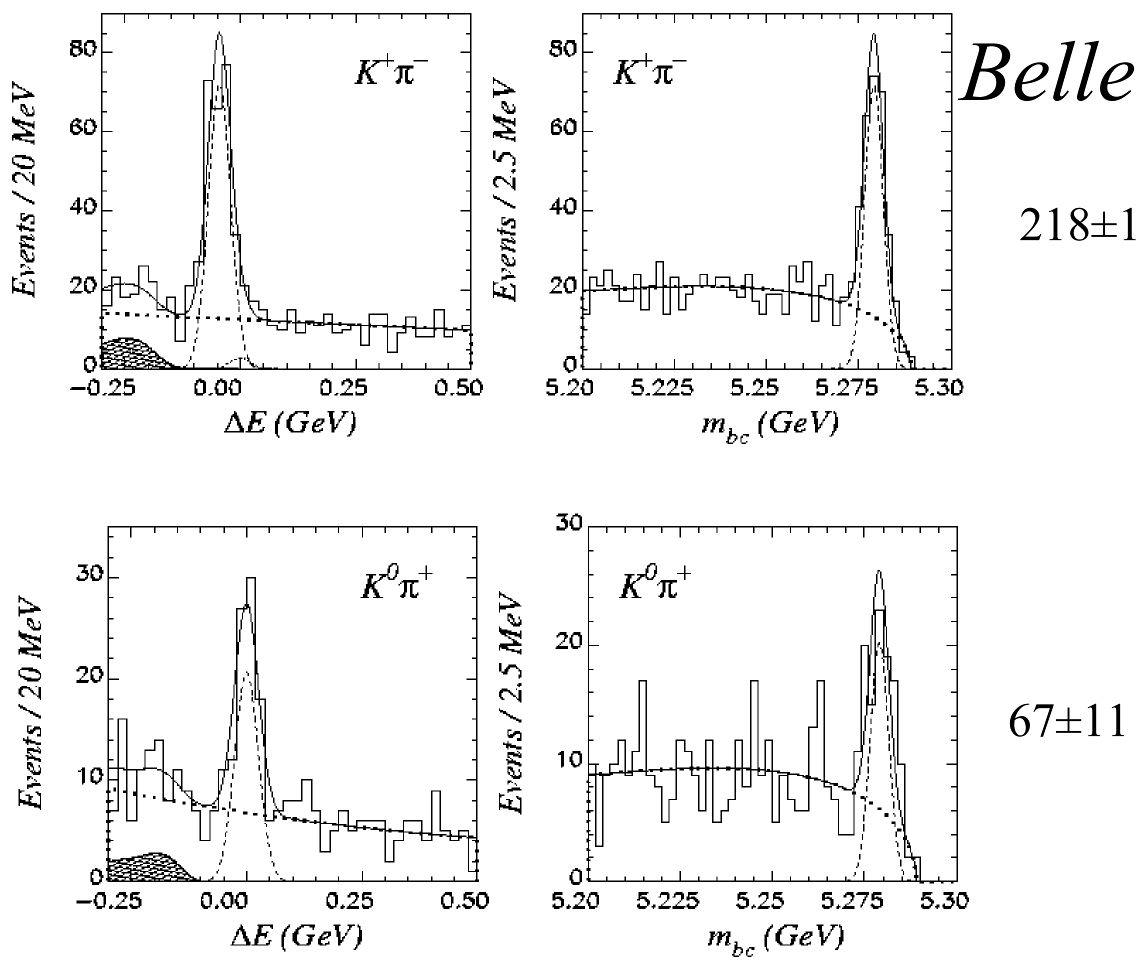
589±30



BF(B^0 → $K^+ \pi^-$) =(17.9±0.9±0.7) x 10^{-6} ;BF(B^0 → $\pi^+ \pi^-$) =(4.7±0.6±0.2) x 10^{-6}

Compare rare decay rates to determine φ_3 (γ)

$A_{K\pi} \propto P + \lambda^2 e^{i\gamma} T$



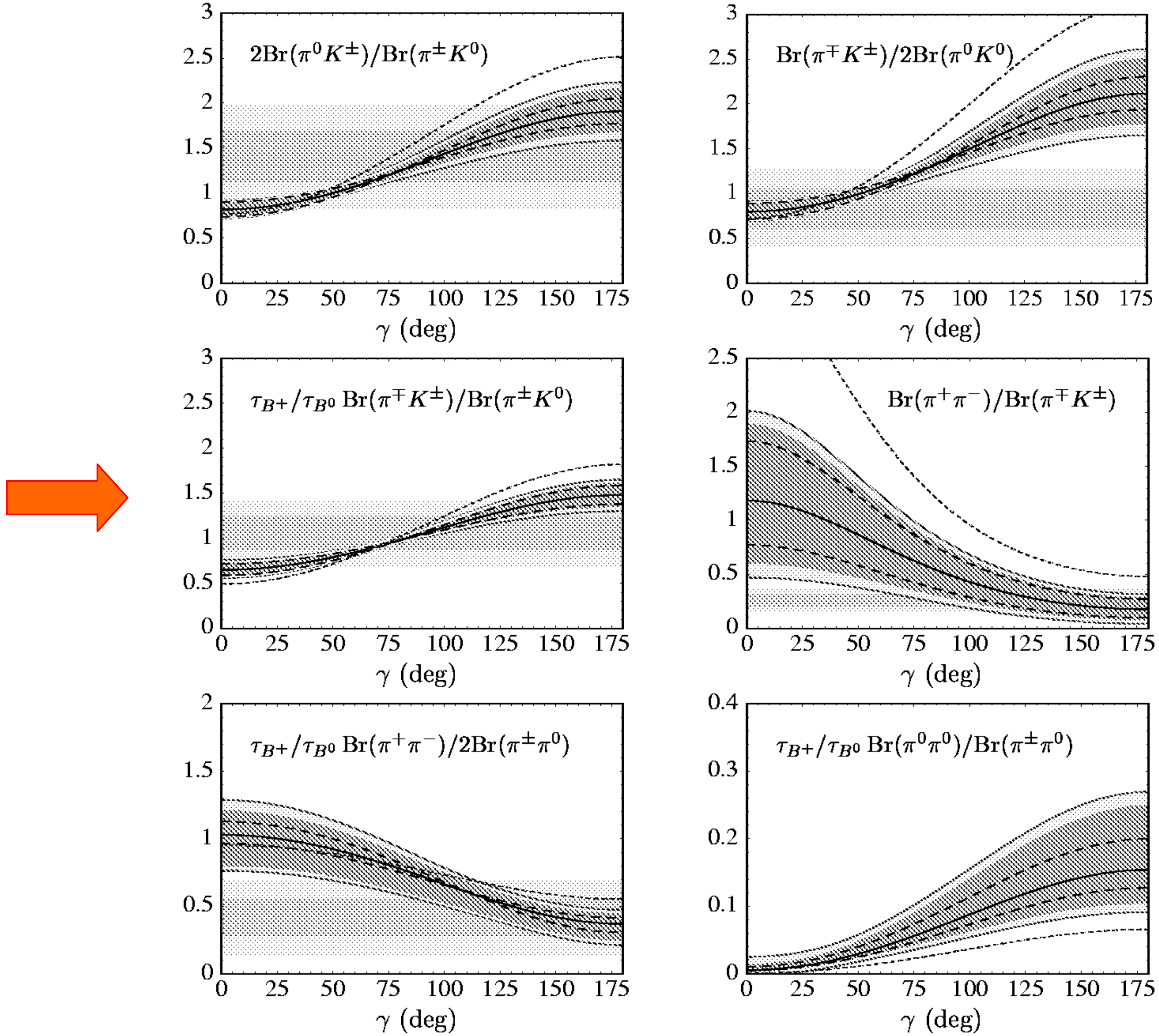
218±18

$A_{K\pi} \propto P$

67±11

The ratio of widths τ^+ / τ^0 $K^+ \pi^- / K^0 \pi^+ = 1.27 \pm 0.22 \pm 0.11$ (Belle)

Example of theory expectations for BFs vs φ_3 (γ)



Determination of φ_3 (γ) from B→h h

Fleischer, Mannel (98)
Gronau, Rosner, London (94, 98)
Neubert, Rosner (98)
Buras, Fleischer (98)
Beneke, Buchalla, Neubert, Sachrajda (01)
Keum, Li, Sanda (01)
Ciuchini et al. (01)
...and many more!

Theoretical issues (lectures by Ligeti and Kagan):

- SU(3) breaking
- Rescattering (FSI) !!!
- EW penguins
- Corrections to Factorization...

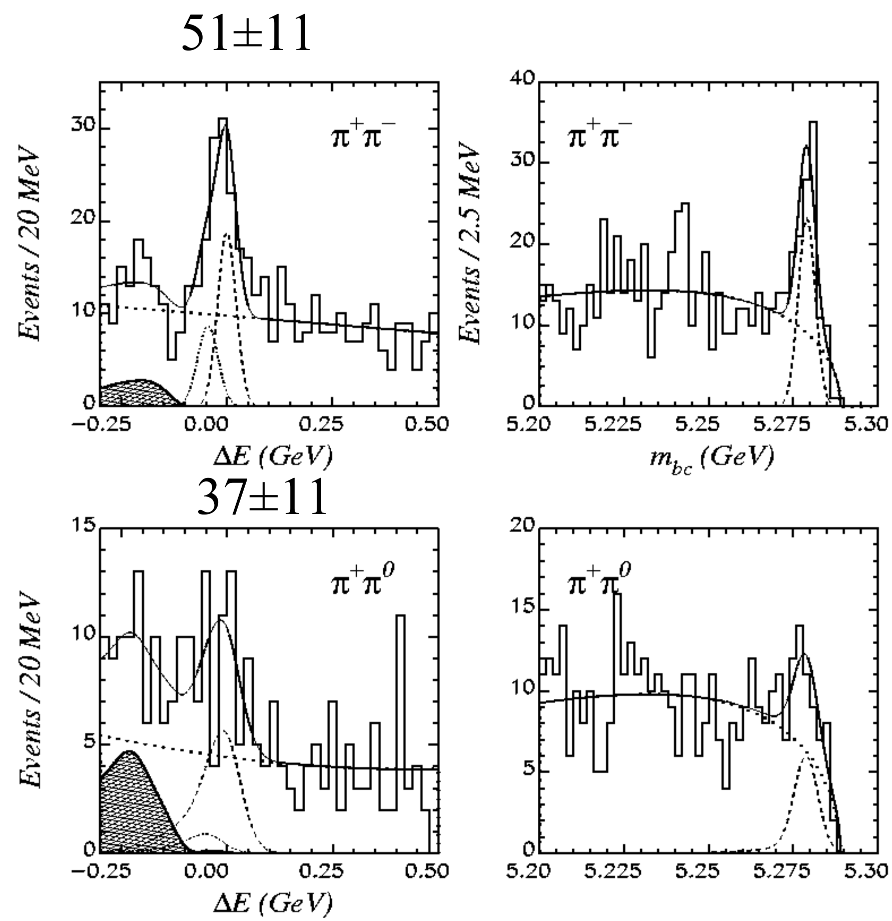
2002: B→$\pi^+ \pi^-$ and $B^\pm$→$\pi^\pm \pi^0$ (Belle)

τ^+/τ^0 BF($\pi^+ \pi^-$) /2BF($\pi^+ \pi^0$)

= 0.40±0.15±0.05 <<1

Interference

Possible sources: φ_3 (γ)>90;
FSI, or other diagrams



{BaBar (prelim): 0.42 ± 0.10}

CLEO 1993: Observation of B→K* γ

First evidence for b→s γ

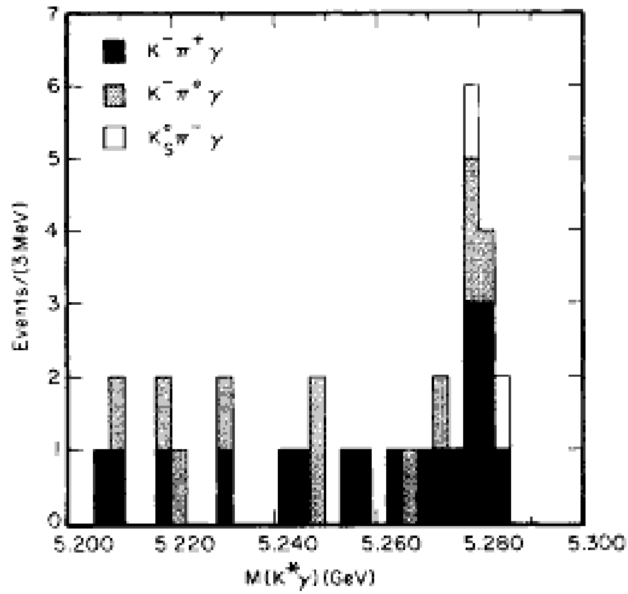


FIG. 2. The $K^*\gamma$ mass distributions for $B^0 \to K^{*0}\gamma$; $B^- \to K^{*-}\gamma$, $K^{*-} \to K^0_S\pi^-$; and $B^- \to K^{*-}\gamma$, $K^{*-} \to K^-\pi^0$ candidates.

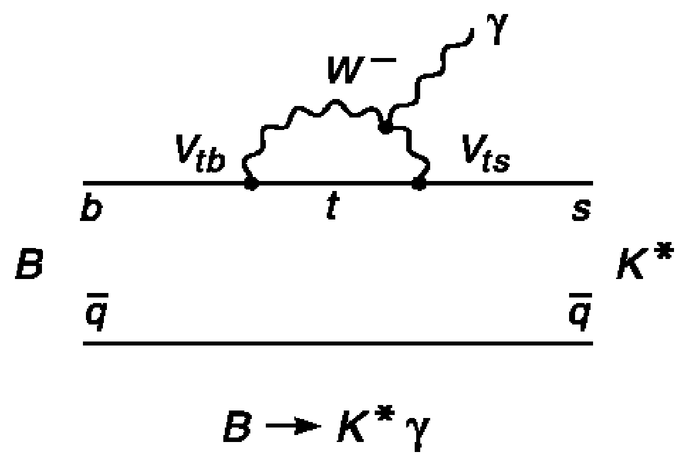


TABLE I. Summary of results for $B \to K^*\gamma$.

	$B^0 \to K^{*0}\gamma$	$B^- \to K^{*-}\gamma$	
	$K^{*0} \to K^+\pi^-$	$K^{*-} \to K^0_S\pi^-$	$K^{*-} \to K^-\pi^0$
Signal events	8	2	3
Sideband events	41	2	10
Sideband scale factor	37.6	40	12
Sideband background	1.1±0.2	0.05±0.03	0.8±0.3
Binomial probability	3.5×10^{-5}	3.7×10^{-3}	7.3×10^{-2}
Residual $B\overline{B}$ background	0.30±0.15	0.01±0.01	0.10±0.05
Efficiency	(11.9±1.8)%	(2.0±0.3)%	(3.1±0.5)%
Branching ratio	$(4.0\pm1.7\pm0.8)\times10^{-5}$	$(5.7\pm3.1\pm1.1)\times10^{-5}$	

Babar 2001

Exp: (BaBar) $B \rightarrow K^* \gamma$ $=(4.4 \pm 0.4 \pm 0.3) \times 10^{-5}$

Theory (Bosch et al) $B \rightarrow K^* \gamma$ ~ 7.1×10^{-5}

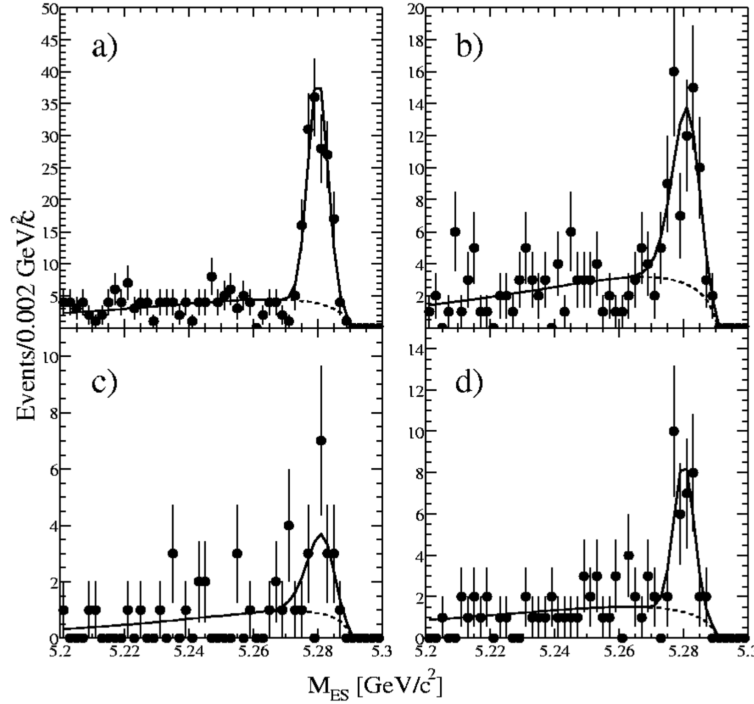


FIGURE 3. Signals in the $B \rightarrow K^*\gamma$ analysis where the K^* is reconstructed in the modes a) $K^+\pi^-$, b) $K^+\pi^0$, c) $K_S^0\pi^0$, and d) $K_S^0\pi^+$.

Note calorimeter energy leakage in dE distribution.

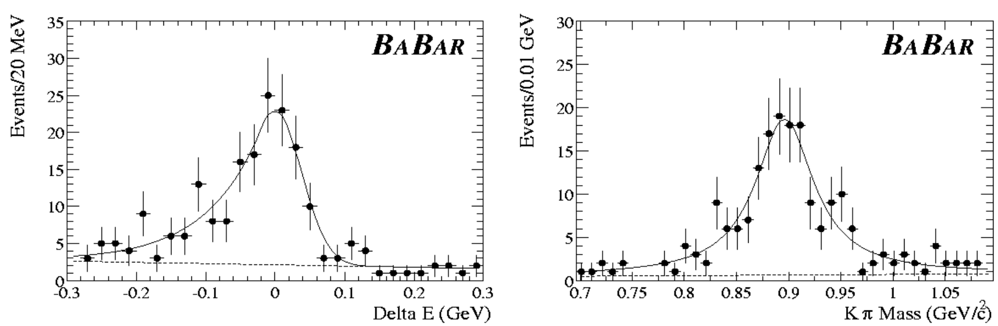


FIGURE 4. The ΔE (left) and $m_{K\pi}$ (right) distributions in the $K^+\pi^-$ mode in the $B \rightarrow K^*\gamma$ analysis.

Backgrounds for inclusive b→s γ

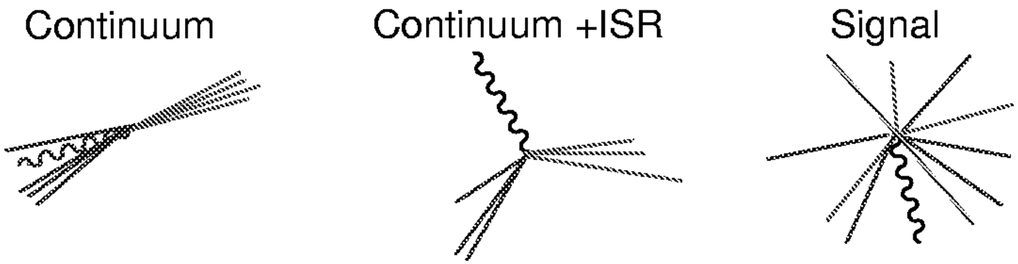
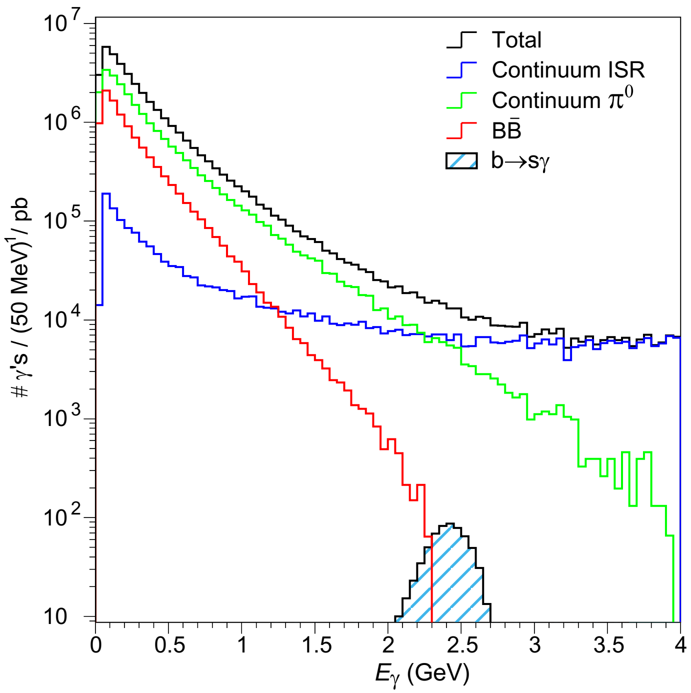


Figure 34. *Examples of idealized event shapes. The straight lines indicate hadrons and the wavy lines photons.*



- ❖MUST suppress continuum.
- ❖MUST subtract continuum.
- ❖To push spectrum down below 2.2 GeV, must handle backgrounds from other B decay processes.

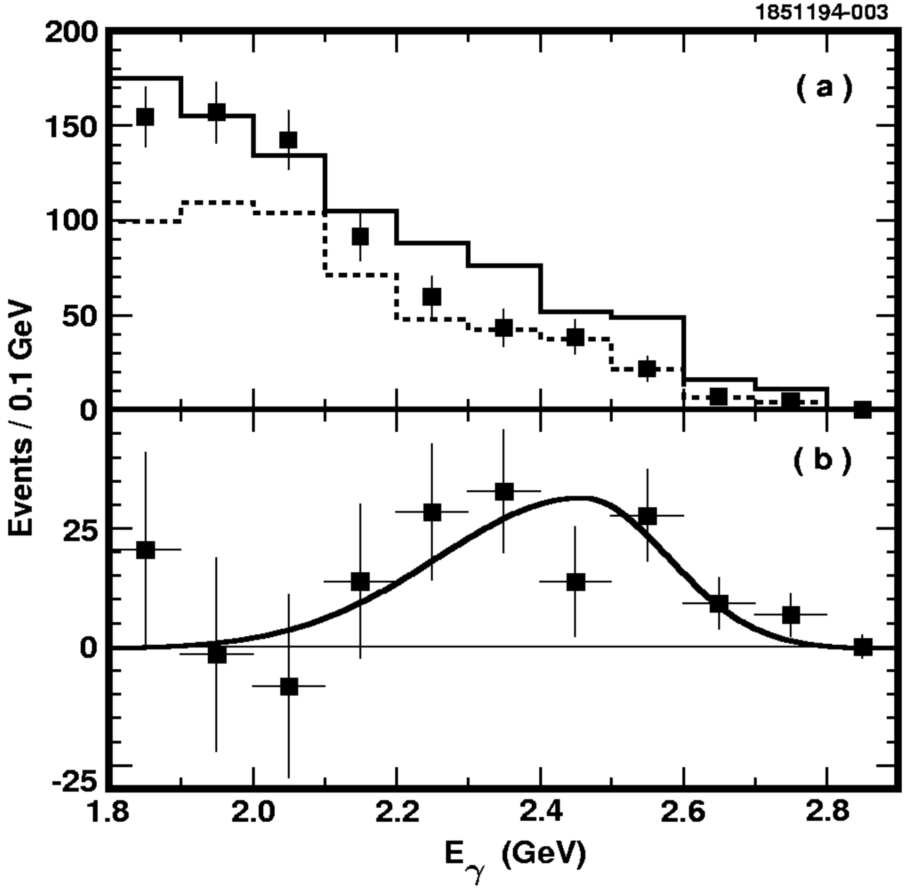
Large theory uncertainties in exclusive modes; inclusive modes can be calculated.
How to suppress backgrounds in inclusive $b \rightarrow s\,\gamma$ decay ?

B reconstruction method: K^- $(n\,\pi)$ γ where $n <= 4$ and at most 1 π^0. Resolve multiple entries.

Event shape: Neural net or Fisher discriminant from event shape variables e.g. energies in cones.

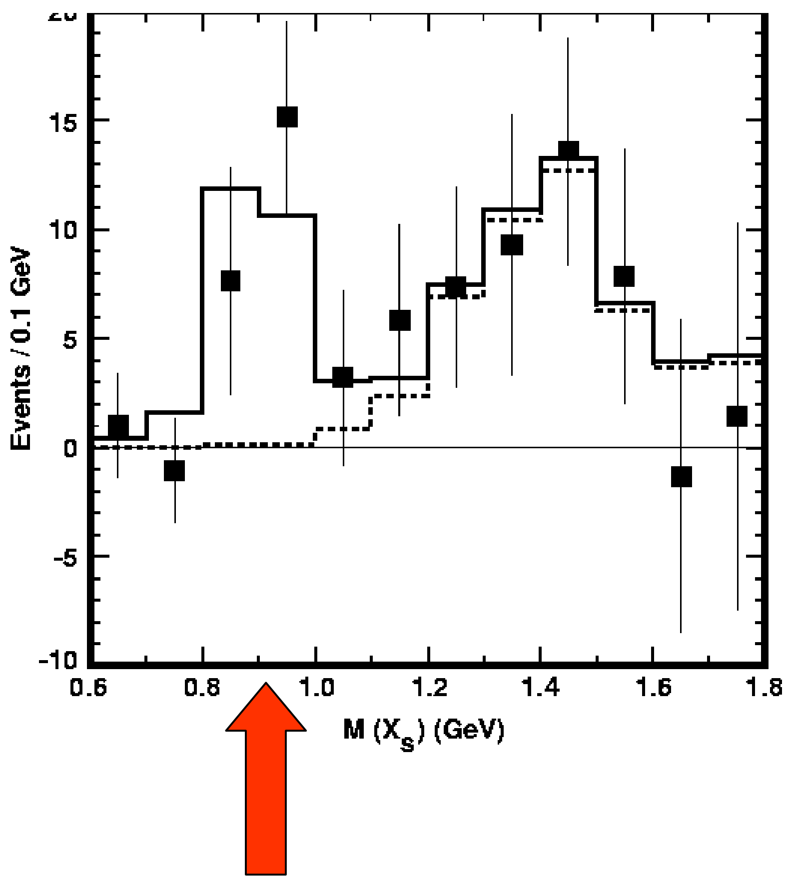
Event shape+lepton tag.

CLEO 1994: Inclusive b→s γ from the B reconstruction method. (3 fb^{-1})



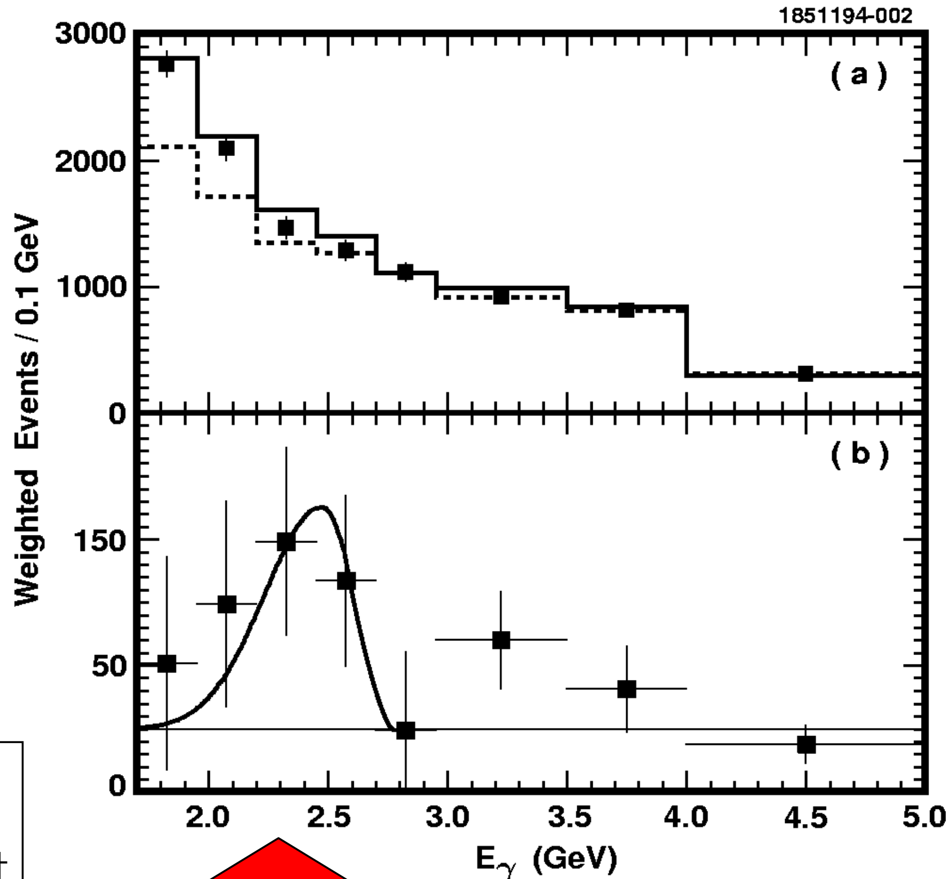
110±26

CLEO 1994: M_{X_s} spectrum for inclusive $b \rightarrow s\gamma$ from the B reconstruction method.



$B \rightarrow K^* \gamma$ (consistent)

CLEO 1994: Inclusive b→s γ from the neural net method.



263± 104

Quasi-two body in b rest frame.

BABAR 2002: Inclusive b→s γ with a high momentum lepton tag

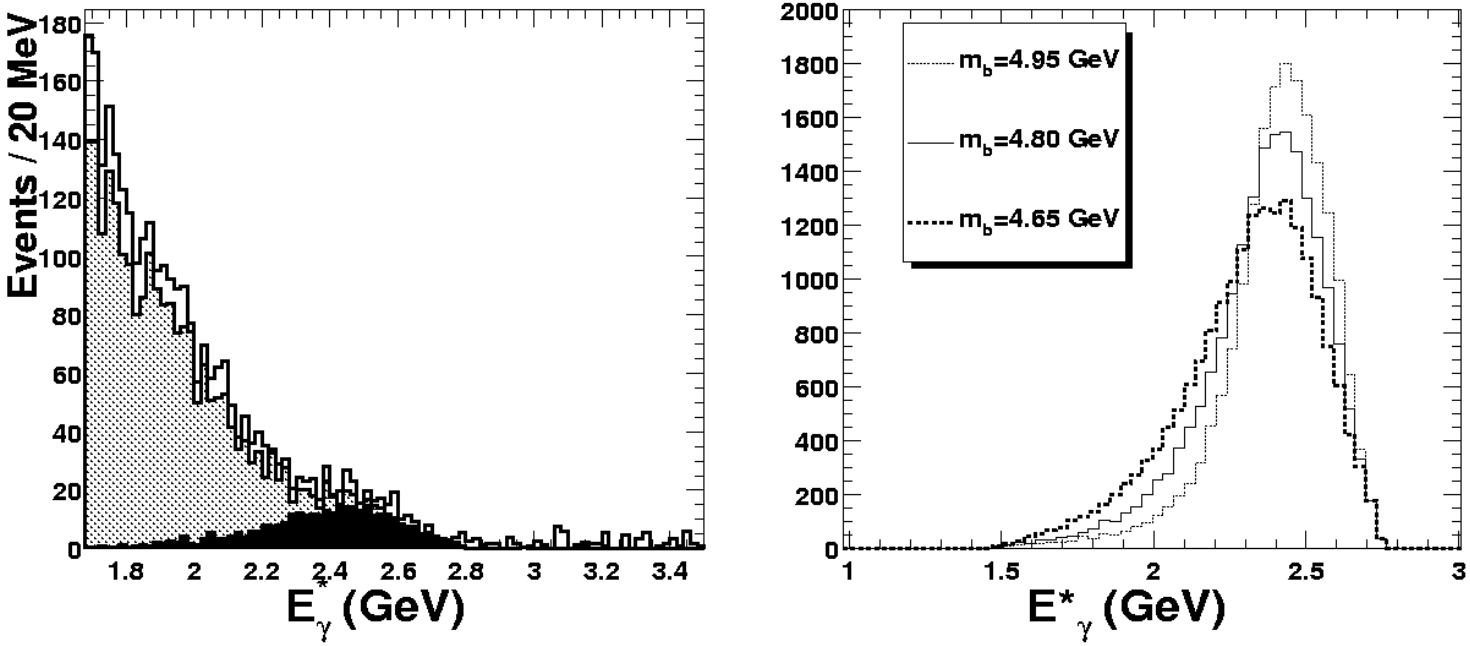
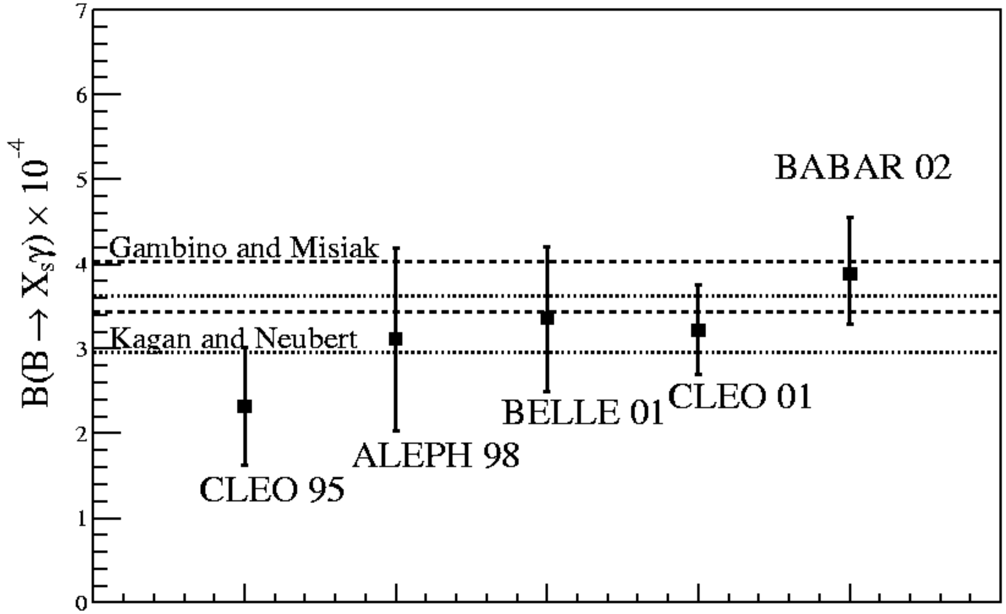


Figure 2: Left: The reconstructed E^*_γ distribution expected from Monte Carlo simulation after the selection criteria. The $B \to X_s\gamma$ signal assuming $\mathcal{B}(B \to X_s\gamma) = 3.45 \times 10^{-4}$ (dark shading), $B\overline{B}$ background (grey shading) and continuum background (unshaded) are normalized to $54.6\,\text{fb}^{-1}$. Right: The generated E^*_γ spectrum before cuts (arbitrary normalization) for different values of the b quark mass m_b, using the model of Kagan and Neubert [1]. Our signal region is defined for the corresponding reconstructed quantity as $2.1 < E^*_\gamma < 2.7$ GeV.

Over 500 SPIRES references to constraints on extensions of the SM from $b \rightarrow s\ \gamma$ e.g. limits on charged Higgs mass

Agreement ➡



In the SM since dominant diagrams have the same weak phase, $A_{cp}<0.5\%$ is expected

$-0.27<A_{cp}(b \rightarrow s\ \gamma)<0.10$ (CLEO)

Feynman diagrams for B→X_s $l^+ l^-$

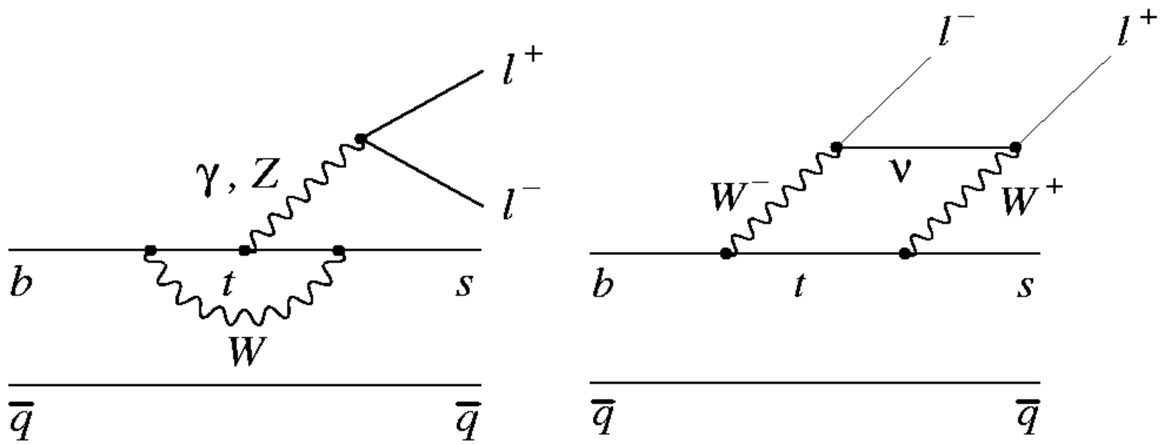
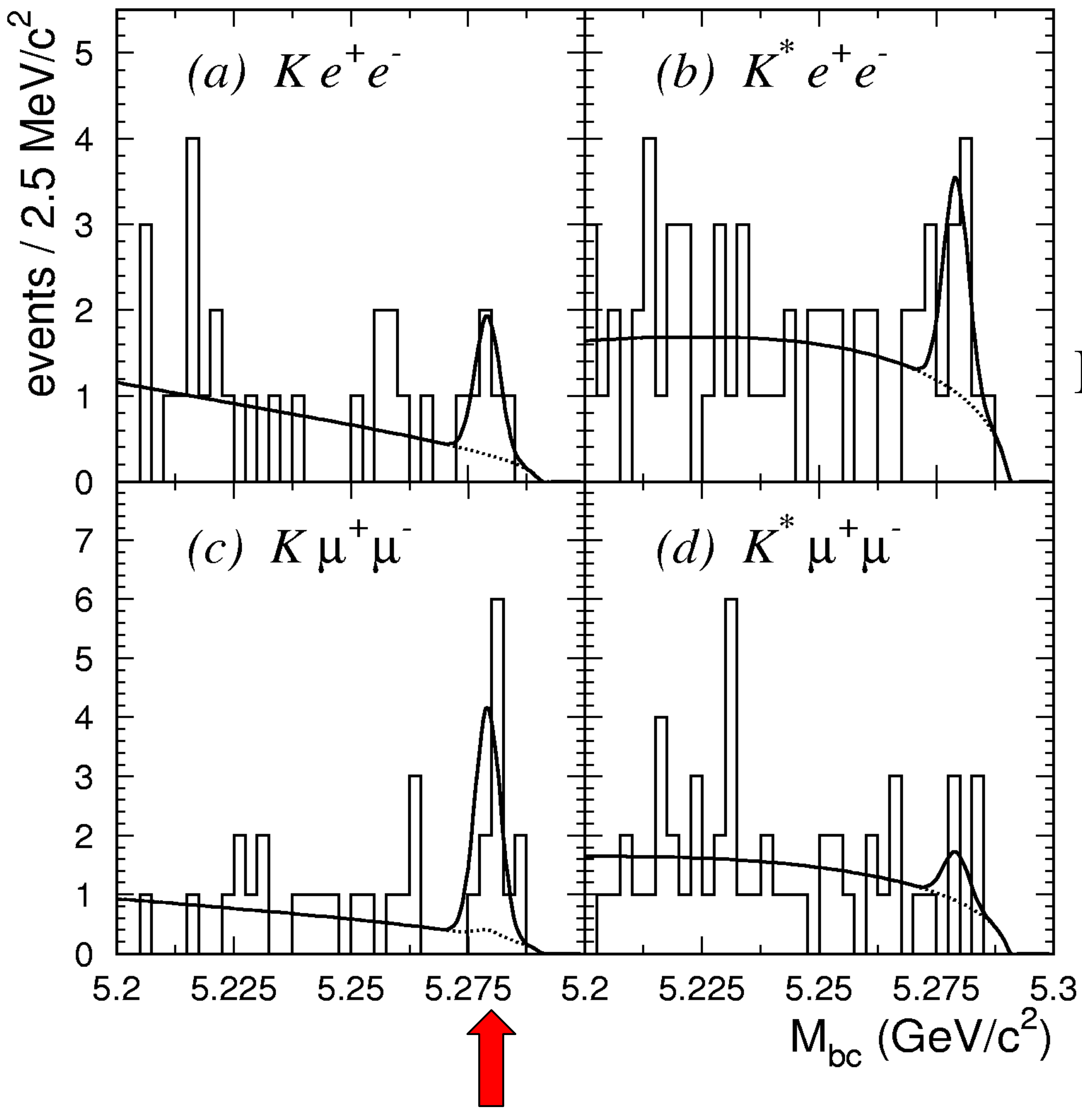


Figure 1: Standard Model diagrams for the decays $B \to K^{(*)}\ell^+\ell^-$.

As in b→s γ, heavy particles in the loops can be replaced with NP particles (e.g. $W^+ \to H^+$)

Note contributions from virtual γ , W, Z* and internal t quark.*

Belle 2001: Observation of $B \rightarrow K l^+ l^-$

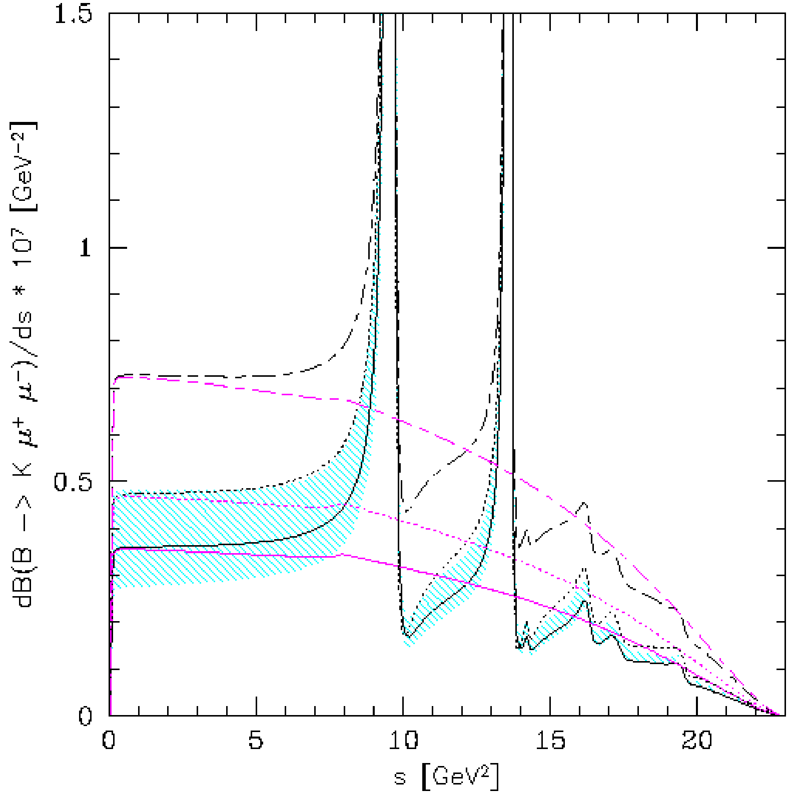


$$BF = (0.75\,^{0.25}_{-0.21} \pm 0.09) \times 10^{-6}$$

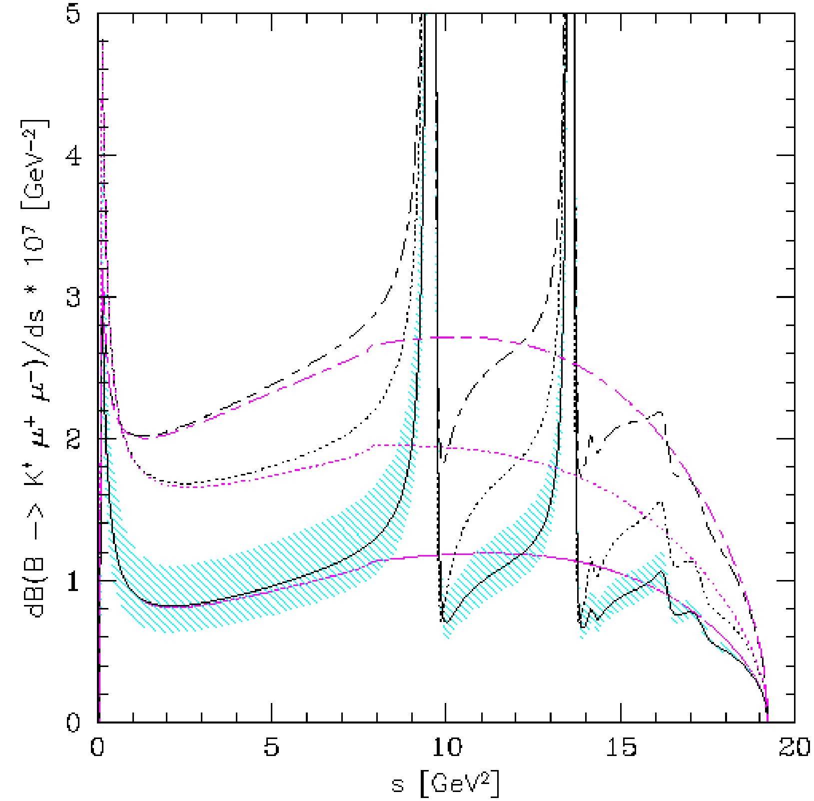
PRL 88, 052002 (2002)

Predicted distributions for $q^2 = M^2_{l+l-}$

$B \to K \mu^+\mu^-$:



$B \to K^{*0} \mu^+\mu^-$ (pole at $q^2 = 0$):



- Solid line + blue bands: SM range (± 35%); Ali et al. form factors
- Dotted line: SUGRA model (R_7 = -1.2, R_9 = 1.03, R_{10} = 1)
- Long-short dashed line: SUSY model (R_7 = -0.83, R_9 = 0.92, R_{10} = 1.61)

m_{l+l-} distributions for B→K l^+ l^-

Belle 2002

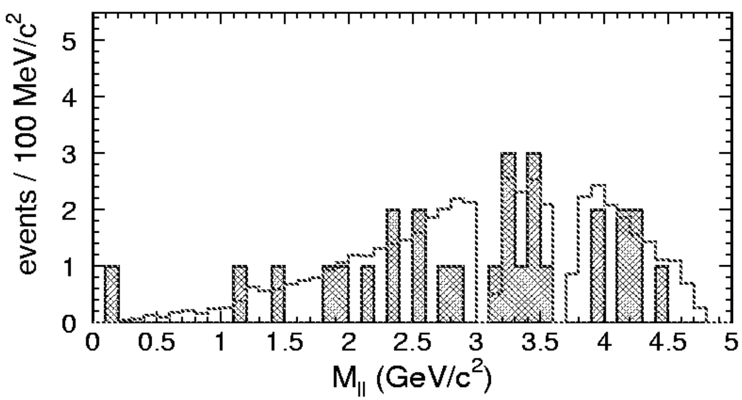
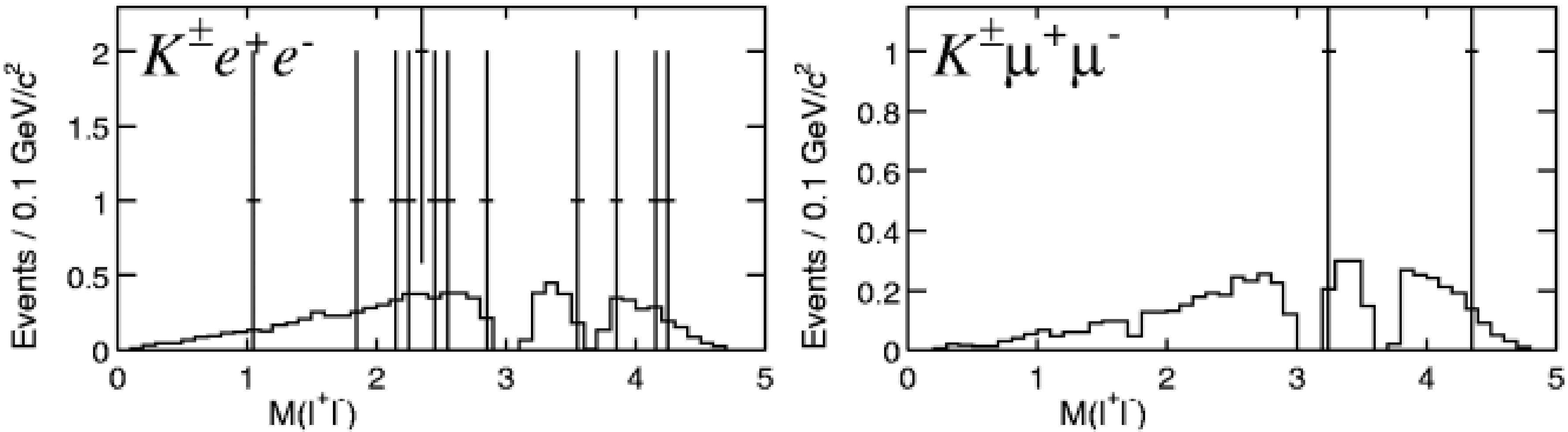


FIG. 5. The dilepton mass distributions for $B \to K\ell^+\ell^-$ candidates. The hatched histogram shows the data distribution while the open histogram shows the MC signal distribution.

BaBar 2002



Theoretical predictions: exclusive b→s l l modes

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

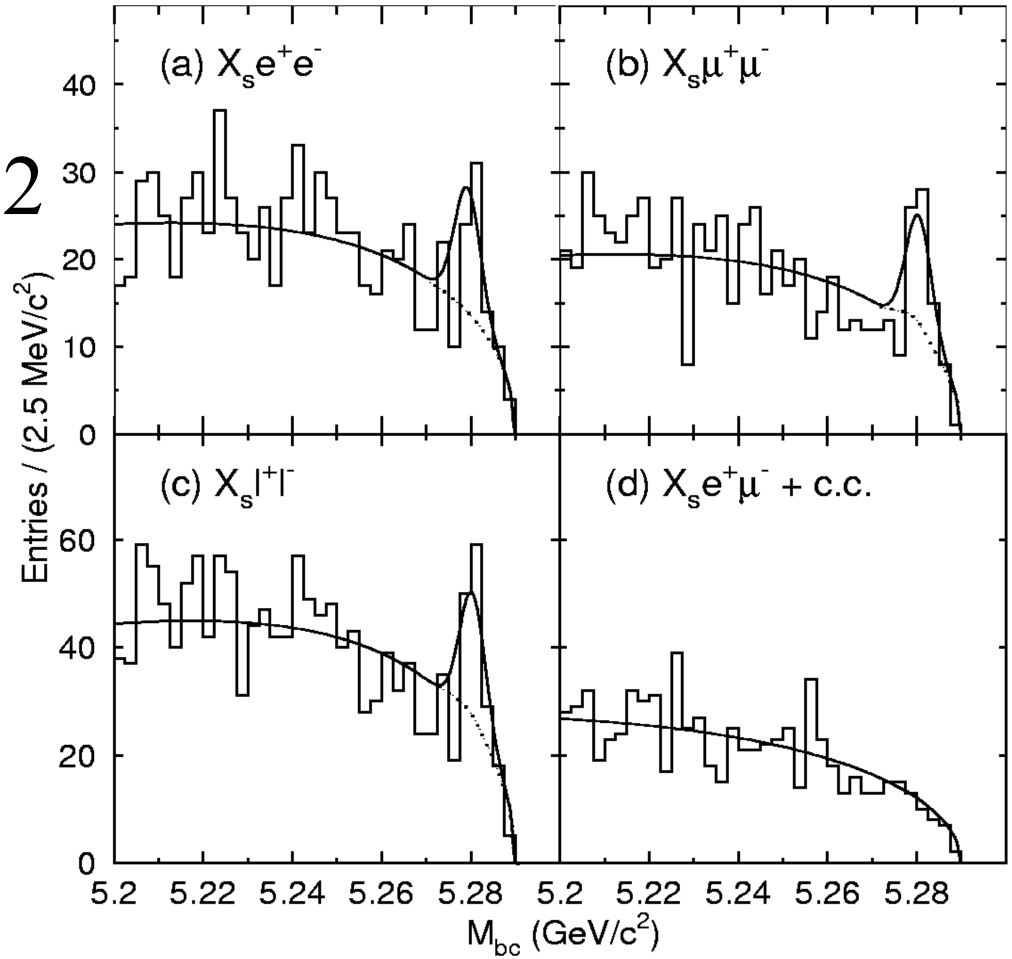
- $\mathcal{B}(B\to K\ell^+\ell^-) =$ $(0.35 \pm 0.11(\text{form fac.}) \pm 0.04(\mu_b) \pm 0.02(m_{t,\text{pole}}) \pm 0.0005(m_c/m_b)) \times 10^{-6}$ [Ali, Lunghi, Greub, Hiller, hep-ph/0112300, 2001]

dominant uncertainty: form factors

New calculations of QCD corrections predict too high a rate for B->K*γ; the necessary adjustment of T_1 form factor lowers the prediction for $B\to K^* l^+ l^-$.

Belle 2002: Observation of inclusive $B \rightarrow X_s l^+ l^-$

25.5±11.2

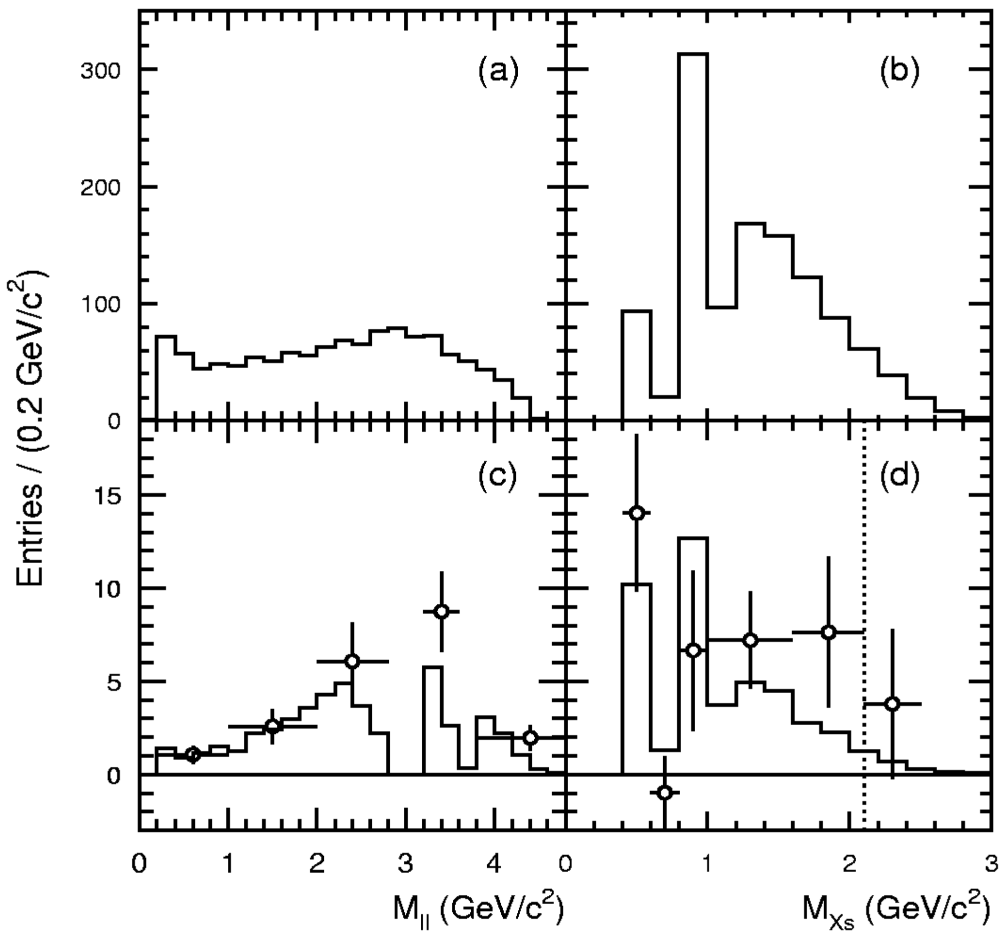


37.3±9.7

Control sample

$$BF(B \rightarrow X_s l^+ l^-) = (6.1 \pm 1.4 {}^{+1.3}_{-1.1}) \times 10^{-6}$$

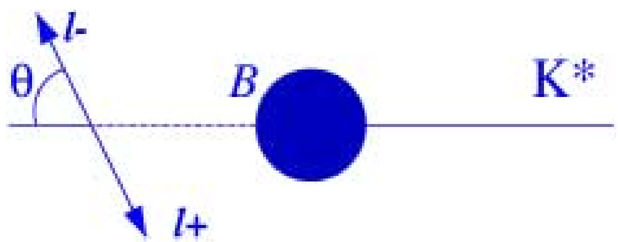
Belle 2002: M_{X_s} and $M_{l l}$ distributions for $B \rightarrow X_s\, l^+ l^-$



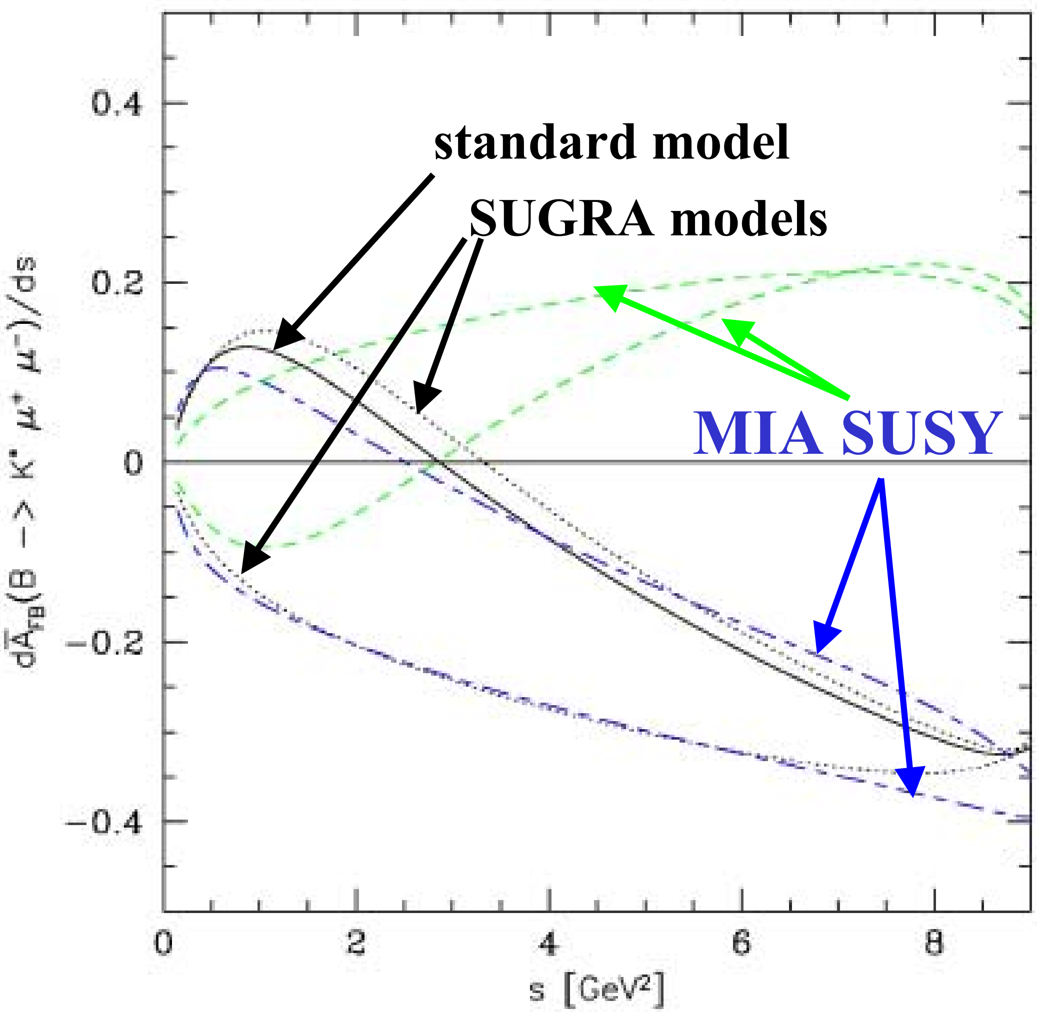
MC generator

Data vs MC

Sensitivity to new physics in A_{FB} ($B \to K^* l^+ l^-$)



Polar angle of lepton in dilepton rest frame.



q^2 (GeV^2)

A. Ali *et al.*, PRD 61, 074024 (2000).

Mysteries of Rare B Decay

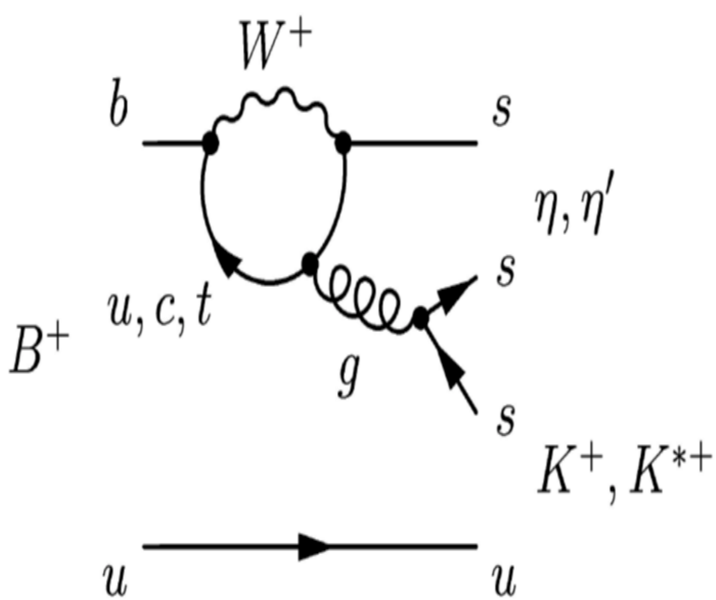
Diagrams for $B \to \eta^{(\prime)}K^{(*)}$ decays

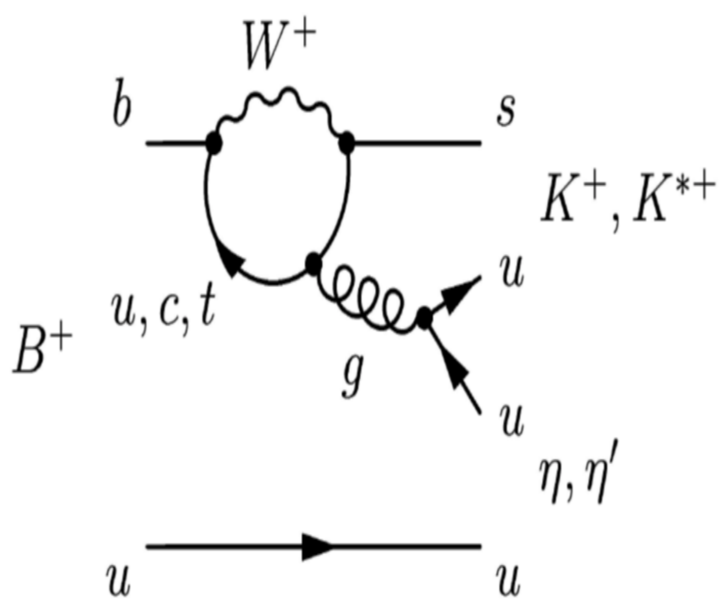
Interference between "penguins":

enhance: $B \to \eta K^*$ $B \to \eta' K$

suppress: $B \to \eta K$ $B \to \eta' K^*$

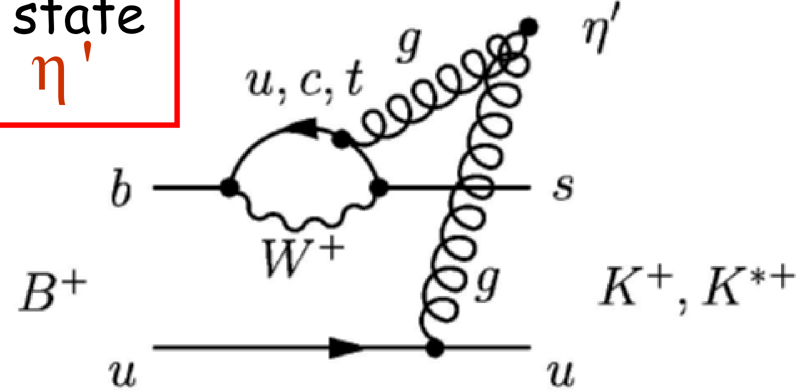
First seen by CLEO PRL 80:3710, (98)





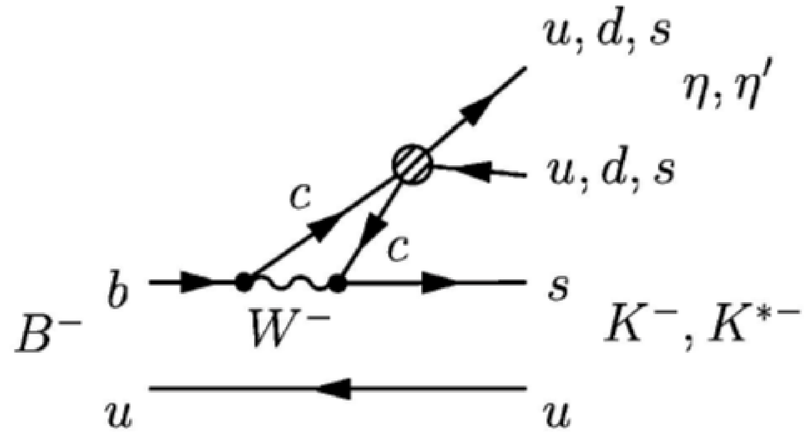
Large rate for B→η' X_s decays

η' approximates a flavor singlet state
QCD anomaly, gluonic coupling to η'



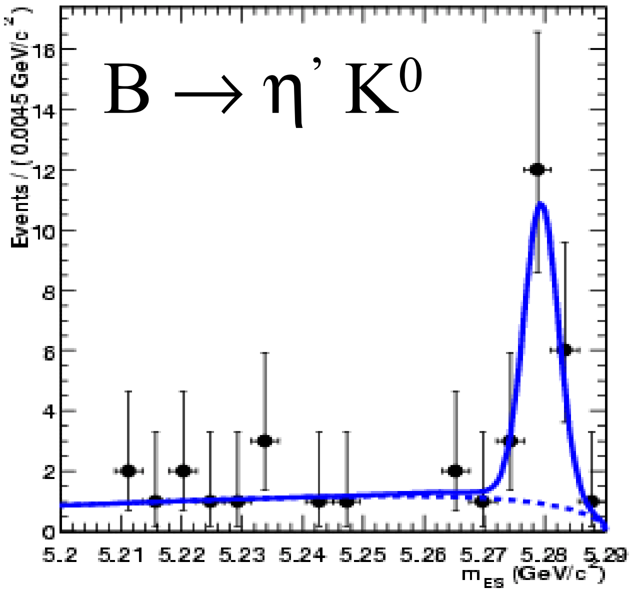
$B \to \eta' X_s = (6.2 \pm 1.6 \pm 1.3 {}^{+0.0}_{-1.5}) \times 10^{-4}$

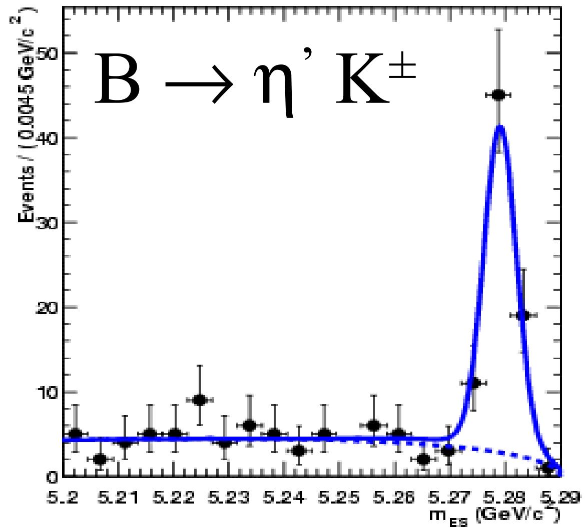
CLEO, PRL 81, 1786 (98)



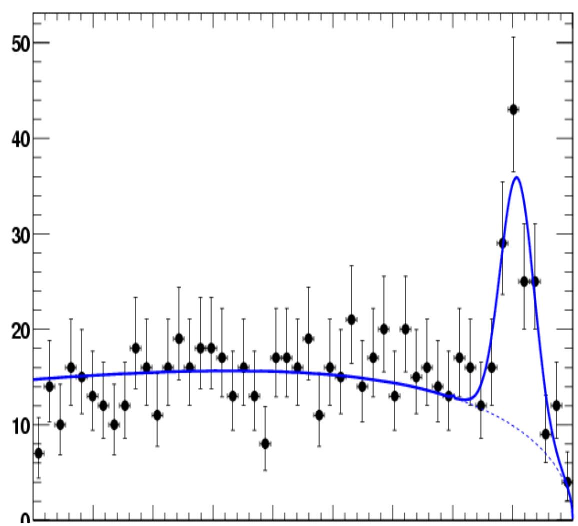
"charming" penguins – c enhanced in loop

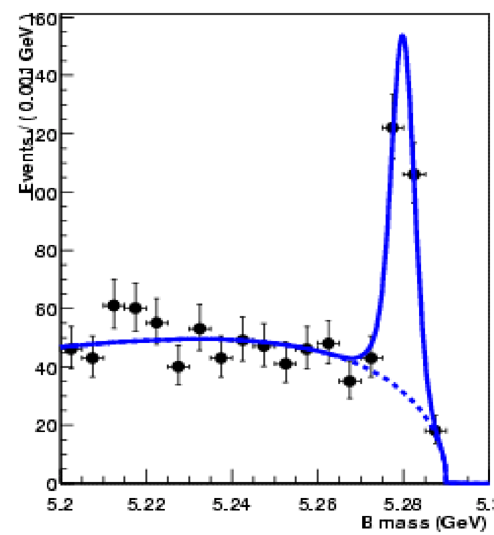
$B \rightarrow \eta' K^0, \eta' K^{\pm}$ (BaBar)





$\eta' \rightarrow \eta\pi\pi$

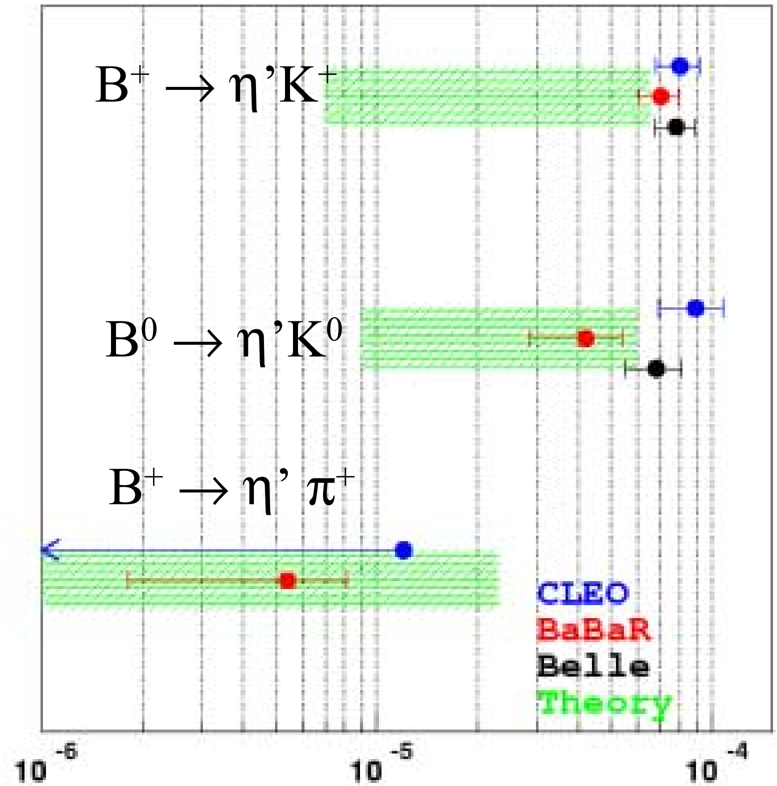




$\eta' \rightarrow \rho\gamma$

Summary of B → η` h data/theory

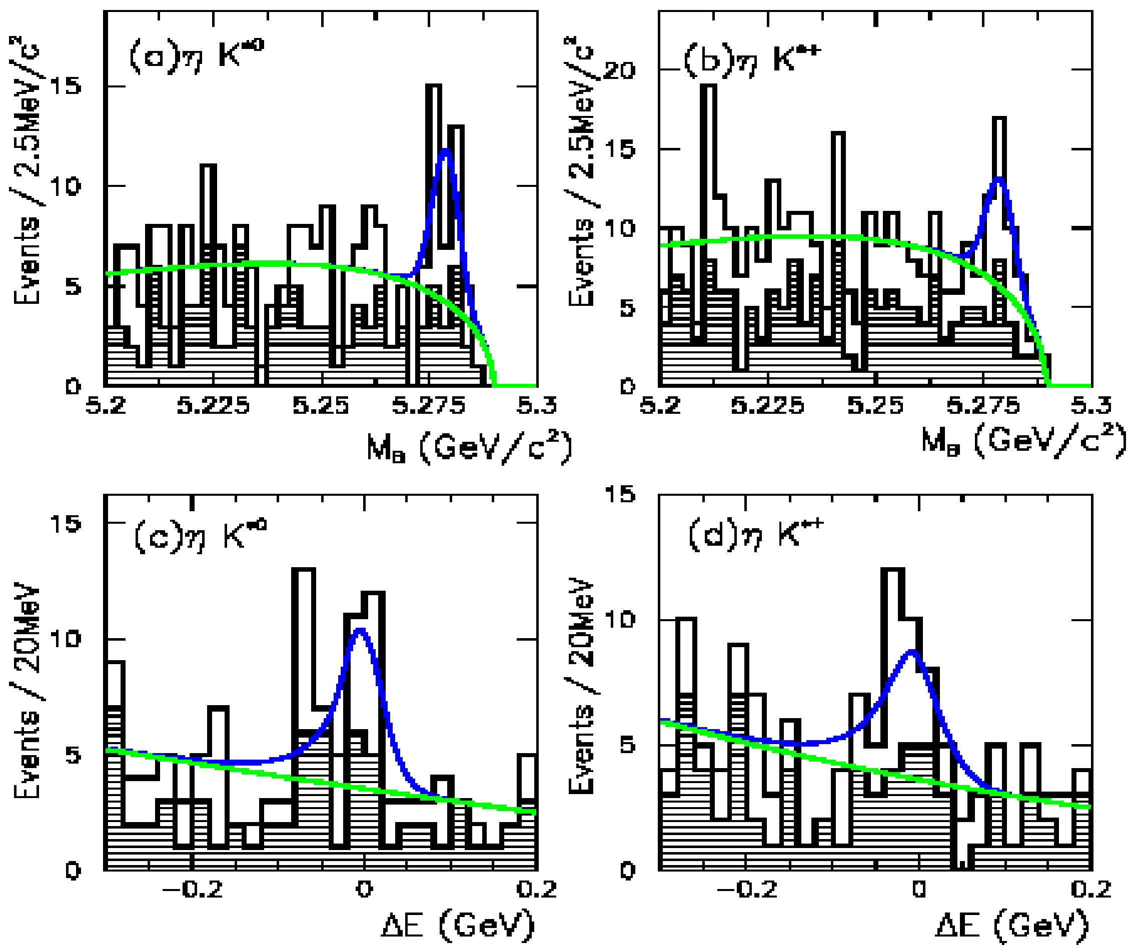
Mode	CLEO	BaBar	Belle
$\eta\prime K^+$	$80^{+10}_{-9} \pm 7$	$70 \pm 8 \pm 5$	$77.9^{+6.2}_{-5.9} \pm 9.0$
$\eta\prime K^0$	$89^{+18}_{-16} \pm 9$	$42^{+13}_{-11} \pm 4$	$68.0^{+10.4}_{-9.6} \pm 8.0$
$\eta\prime\pi^+$	< 12	$5.4^{+3.5}_{-2.6} \pm 0.8$	—



BFs in data are above theory predictions and (post)dictions.

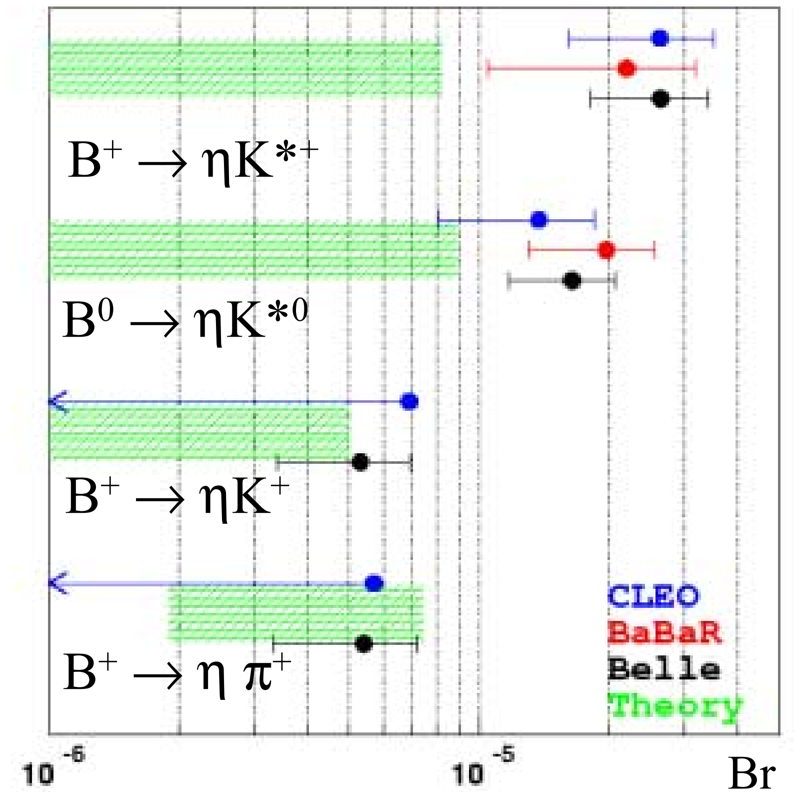
Signals for B → ηK* (Belle)

$B^0 \to \eta K^{*0}$ $B^+ \to \eta K^{*+}$



$B \to \eta\, h$, $\eta\, K^*$ summary

Mode	CLEO	BaBar	Belle
ηK^{*+}	$26.4^{+9.6}_{-8.2} \pm 3.3$	$22.1^{+11.1}_{-9.2} \pm 3.3$	$26.5^{+7.8}_{-7.0} \pm 3.0$
ηK^{*0}	$13.8^{+5.5}_{-4.6} \pm 1.6$	$19.8^{+6.5}_{-5.6} \pm 1.7$	$16.5^{+4.6}_{-4.2} \pm 1.2$
ηK^{+}	< 6.9	—	$5.3^{+1.8}_{-1.5} \pm 0.6$
$\eta \pi^{+}$	< 5.7	—	$5.4^{+2.0}_{-1.7} \pm 0.6$



Data BFs for B → η K modes are above theory predictions.*

Example from Beneke et al (2002)

Mode	Naive Fact.	QCD Fact.	Exp. average
$B^- \to K^-\eta'$	13	47^{+40}_{-19}	75.1 ± 6.2
$\overline{B}^0 \to \overline{K}^0\eta'$	14	47^{+38}_{-19}	61.0 ± 12.5
$B^- \to K^-\eta$	0.7	$1.3^{+1.4}_{-0.8}$	5.3 ± 1.8
$\overline{B}^0 \to \overline{K}^0\eta$	0.1	$0.5^{+1.0}_{-0.5}$	< 9.3
$B^- \to K^-\pi^0$	4.4	$9.4^{+7.3}_{-3.4}$	11.5 ± 1.3
$\overline{B}^0 \to \overline{K}^0\pi^0$	2.2	$6.4^{+6.1}_{-2.8}$	8.8 ± 2.2
$B^- \to K^{*-}\eta'$	2.9	$3.3^{+8.7}_{-3.3}$	< 35
$\overline{B}^0 \to \overline{K}^{*0}\eta'$	1.6	$2.1^{+7.4}_{-2.1}$	< 24
$B^- \to K^{*-}\eta$	3.8	$9.3^{+16.6}_{-6.1}$	25.4 ± 5.3
$\overline{B}^0 \to \overline{K}^{*0}\eta$	4.3	$10.4^{+17.3}_{-6.5}$	16.4 ± 3.0
$B^- \to K^{*-}\pi^0$	1.7	$3.0^{+4.0}_{-1.4}$	–
$\overline{B}^0 \to \overline{K}^{*0}\pi^0$	0.2	$0.8^{+2.5}_{-0.6}$	–

Table 3: CP-averaged $B \to K^{(*)}(\eta^{(\prime)}, \pi^0)$ branching fractions in units of 10^{-6} in naive factorization and QCD factorization compared to experimental averages. Theoretical results are preliminary as explained in the text. All theoretical errors are strongly correlated.

BABAR: Confirmation of Large Inclusive $B \rightarrow \eta' X_s$

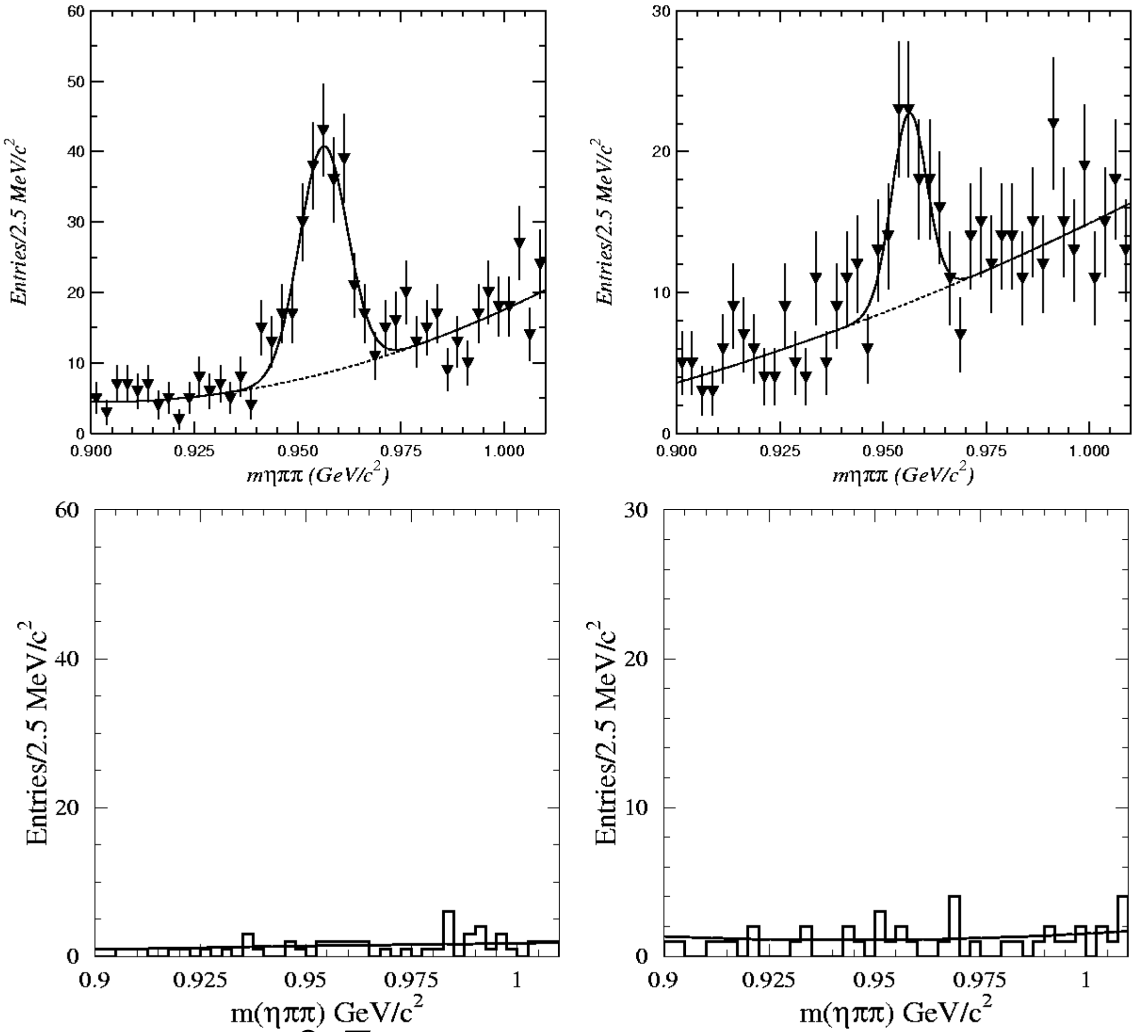
On 4S

188.5±21.5

57.1±14.7

2.0<$P_{\eta'}$<2.7

Below 4S



$$B \rightarrow \eta' X_s = (6.8^{+0.7}_{-1.0} \pm 1.0^{}_{-0.5}) \times 10^{-4}$$

Ref: hep-ex/0109034

BaBar: B→η' X_s inclusive

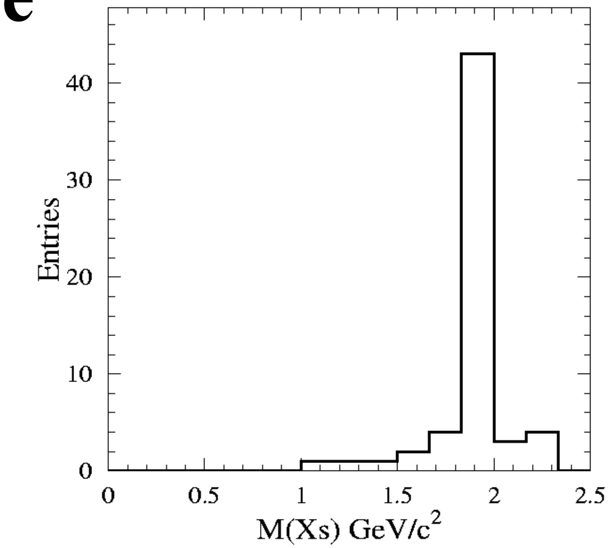
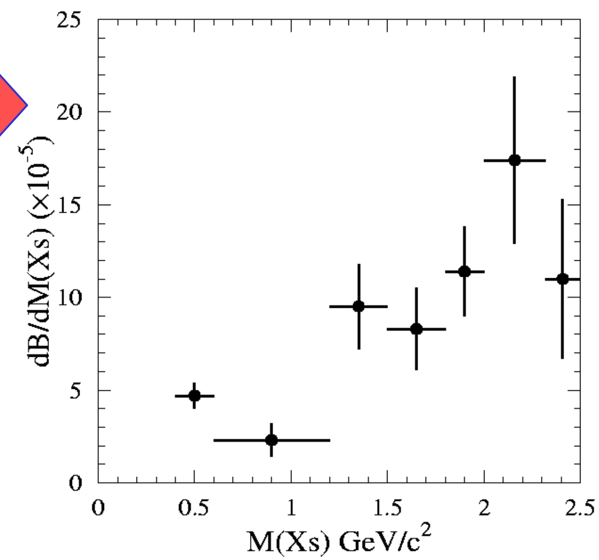


Figure 3: $M(X_s)$ spectrum predicted from simulation of $\overline{B}^0 \to \eta' D^0$ decays

QCD anomaly: **e.g**
D.Atwood and A.Soni,
W.S. Hou and Tseng



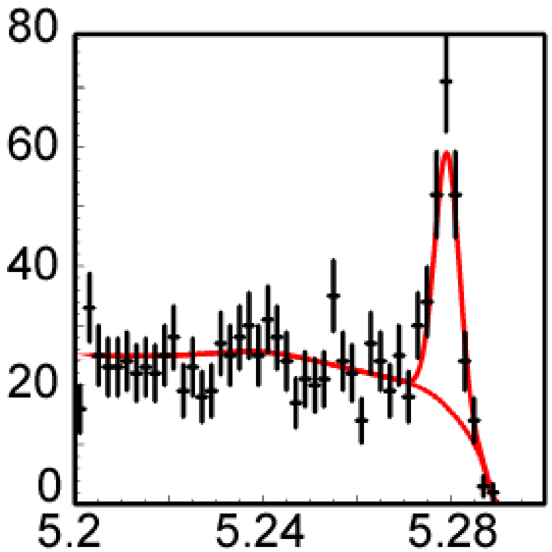
"3-body"

A. Kagan: Y(1S) data show that the η' gg form factor is much too small.

$B \rightarrow \eta' K_s$ and $B \rightarrow \eta' K^{\pm}$ (Belle)

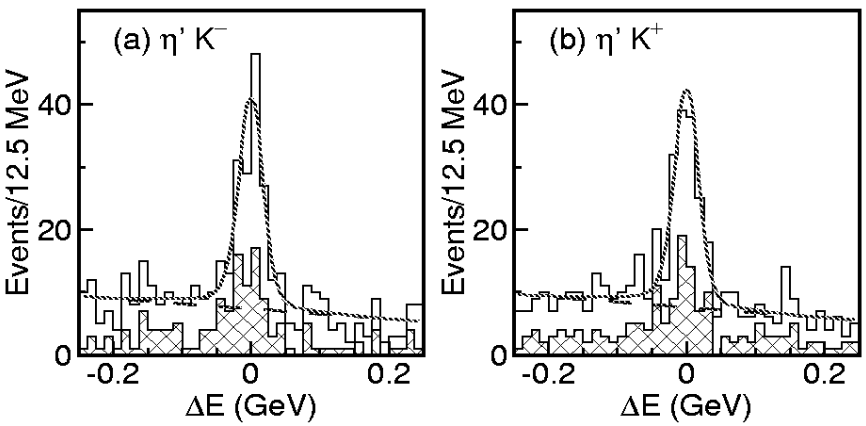
CP eigenstate: $B \rightarrow \eta' K_s$

128± 14 events

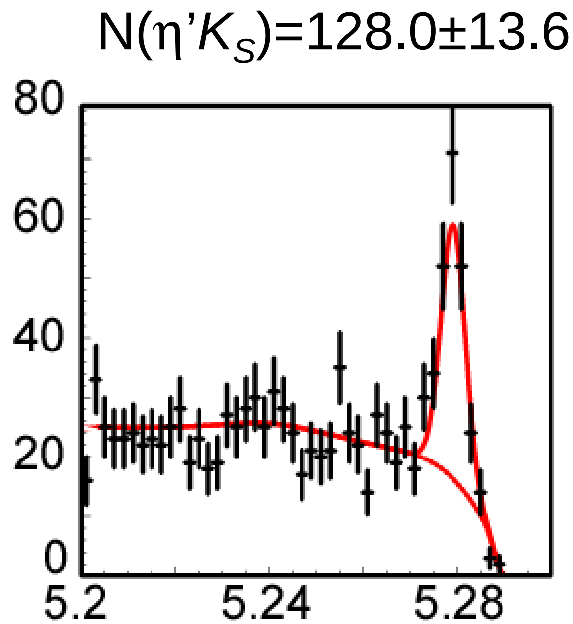


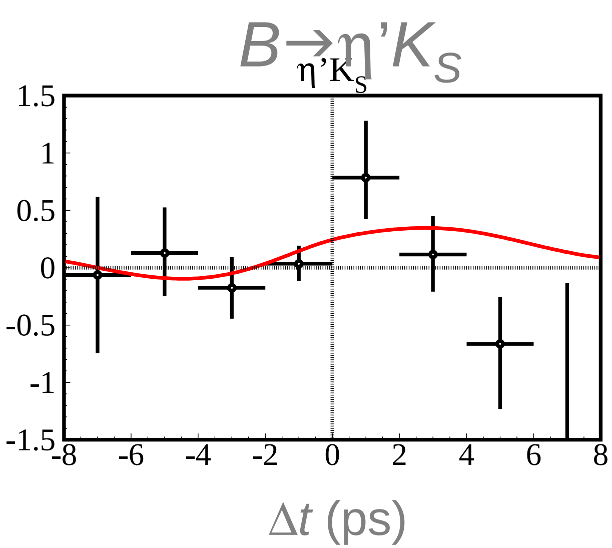
Self tagged $B^{\pm} \rightarrow \eta' K^{\pm}$ (29 fb^{-1})

~284 signal events



$$A_{\eta' K\pm} = (-1.5 {}^{+7.2}_{-6.8} \pm 0.9)\ \%$$





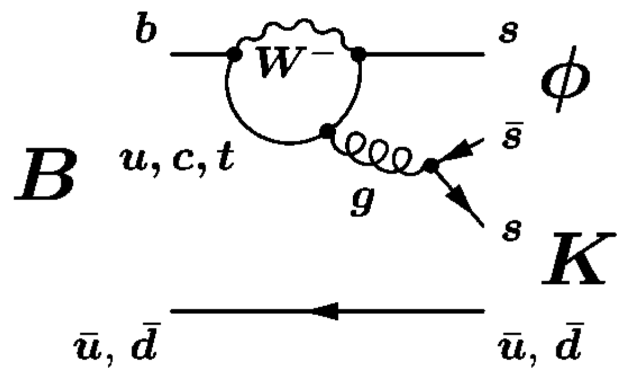
Search for phases from New Physics in a b→s penguin loop decay.

$$S_{\eta' K_s} = 0.76 \pm 0.36 \,{}^{+0.05}_{-0.06}$$

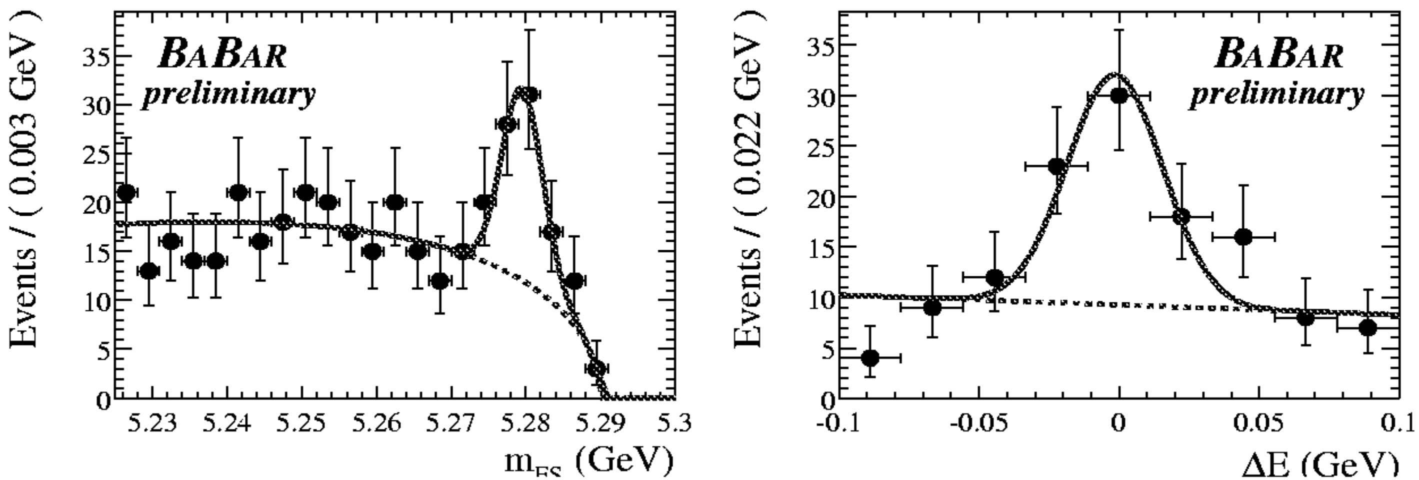
In the absence of New Physics, $S_{\eta' K_s} = \sin(2\varphi_1)$ (a.k.a. $\sin(2\beta)$)

Current WA: $\sin(2\varphi_1) = 0.731 \pm 0.055$

Hunting for new physics phases in b→s penguins

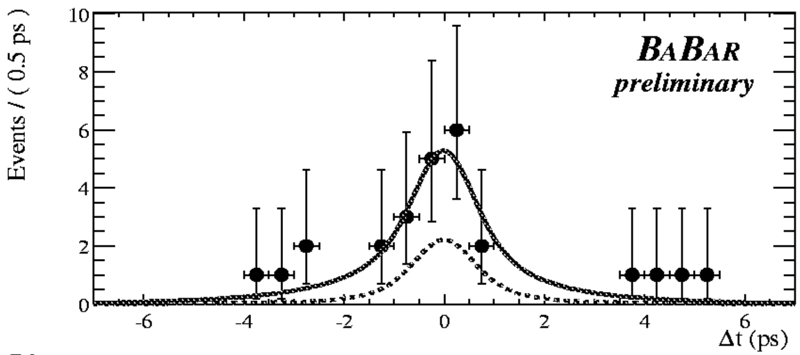


(a)

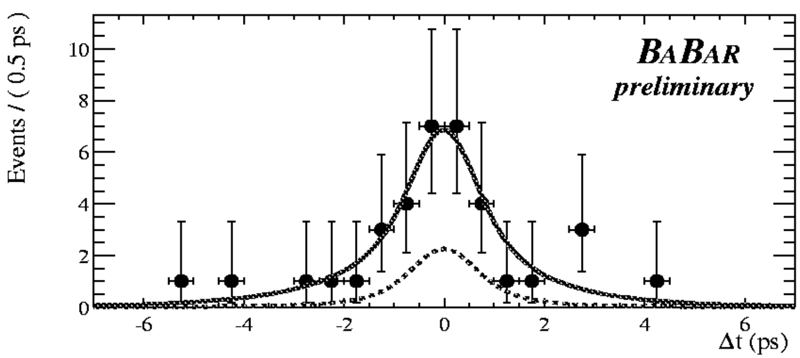


Hunting for new phases in b→s penguins

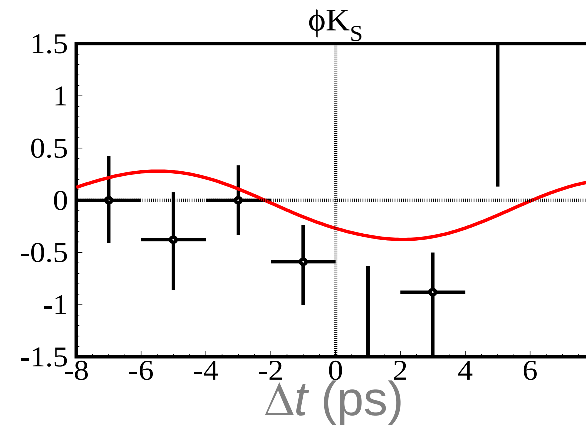
B^0 tags:



$\bar{B}^0$ tags:



$B \to \phi K_S$



Belle

BABAR: $\sin 2\beta_{eff} = -0.19 \pm 0.51 \pm 0.09$

Belle: $\sin 2\beta_{eff} = -0.73 \pm 0.64 \pm 0.18$

WA $\sin 2\beta_{eff}\,(\varphi\ K_S) = -0.39 \pm 0.41$

Example: new physics from SUSY with R parity violation

Alkabha Datta

(hep-ph/0208016)

Other examples given in Grossman, Isidori, and Worah.

Also discussed by Kagan

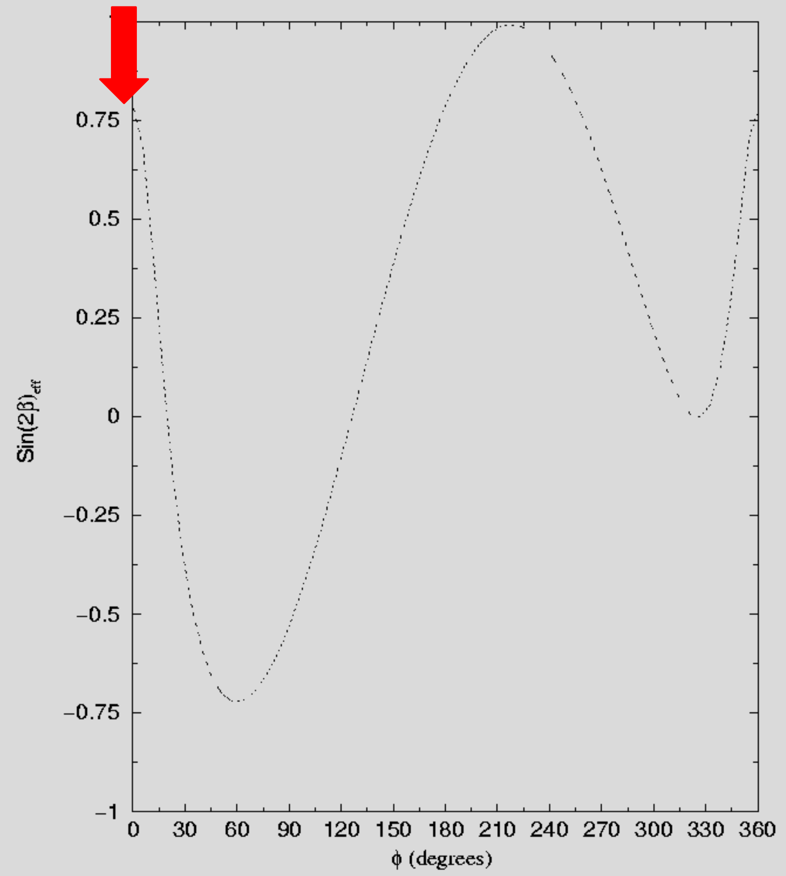
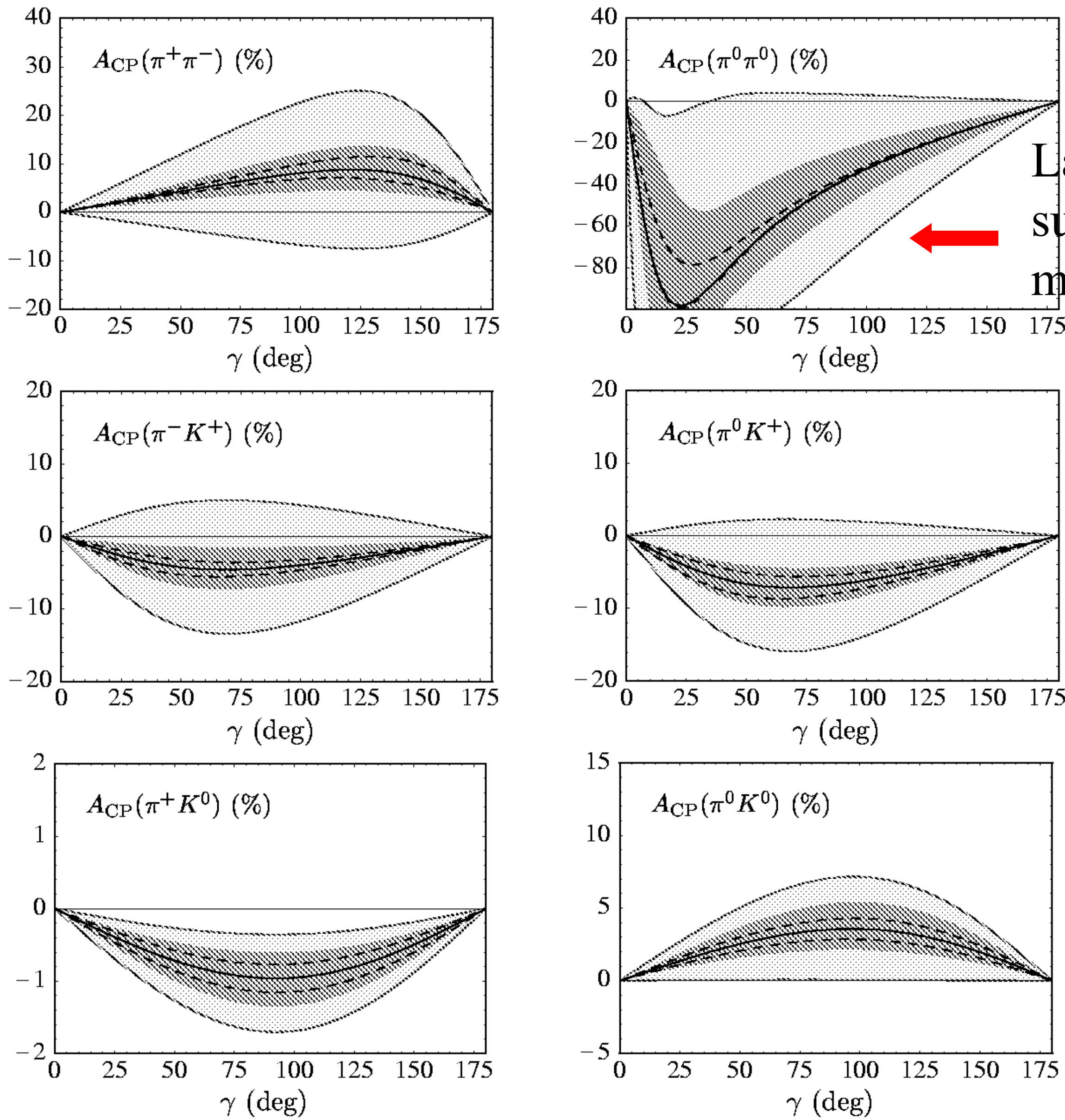


Figure 1: $Sin(2\beta)_{eff}$ versus ϕ

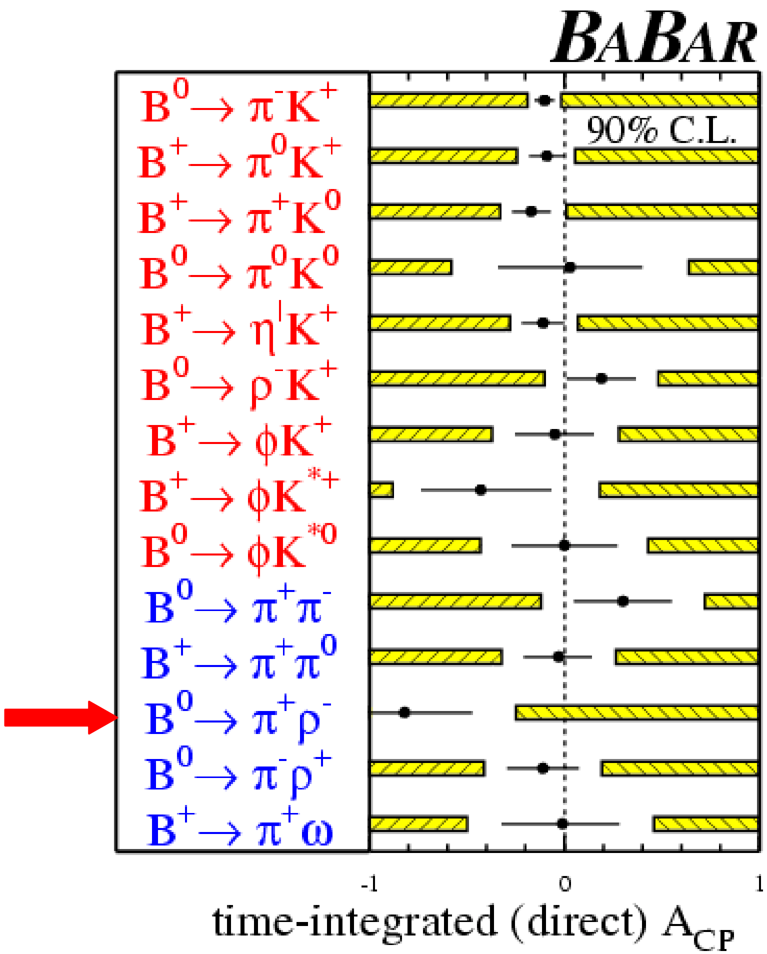
Example of theory expectations for direct CPV

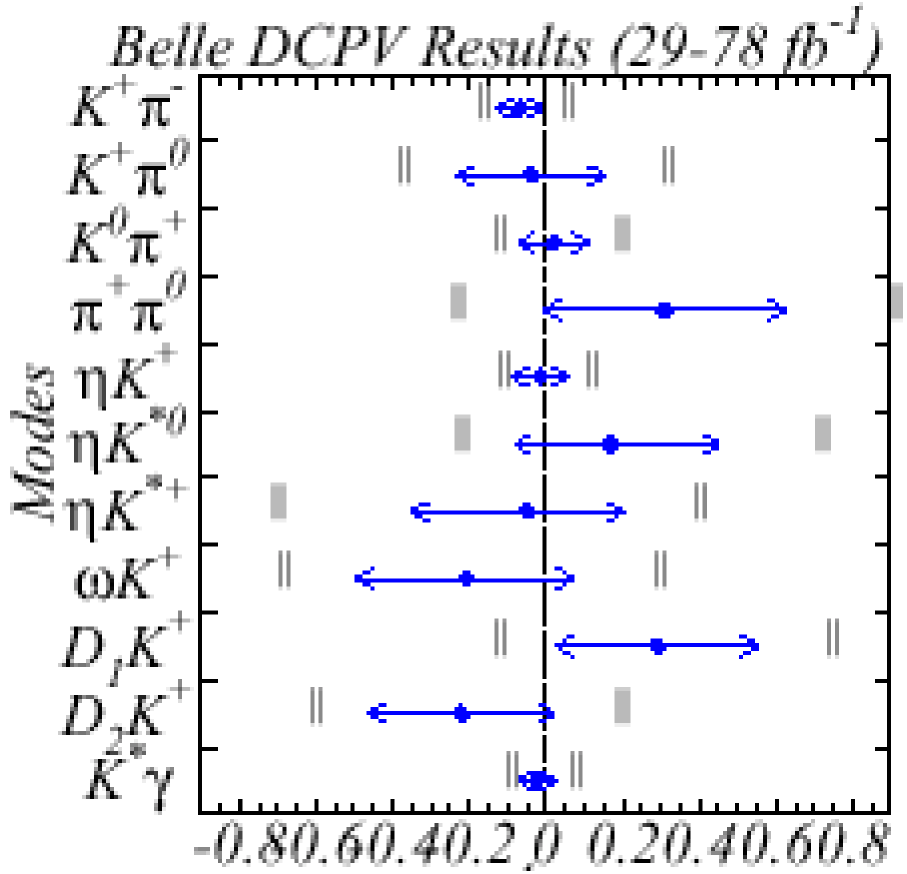
Beneke et al.
NPB 2001



Large CPV in suppressed modes

The Hunt for Direct CP violation





So far only seen in K decay at the $O(10^{-6})$ level

Mysteries and future work

Are there new physics effects in $b \rightarrow s\, l^+ l^-$

Modes with η and η' mesons. Why are they anomalously large ? Do they also include anomalous CP violation ?

Are there new sources of CPV in penguins ?

How large is direct CP violation in B decay ?