(Time-Independent)

Measurements of Rare B Meson Decays at Belle

Brendan Casey, Hawaii/Belle → Brown/D0

- B physics at KEK:
  - KEKB factory,
  - Belle experiment.
    - particle ID,
    - continuum suppression.
- Searching for NP with penguins
  - radiative,
  - leptonic,
  - hadronic.
- Even more info on $|V_{ub}|$
  - new modes, old tricks: $\omega l \nu$
  - new modes, new tricks $D_s \pi$

KEKB

$\sqrt{s} = 10.58$ GeV: $\Upsilon(4S)$

8 GeV e^-

3.5 GeV e^+

$\gamma\beta = 0.45$

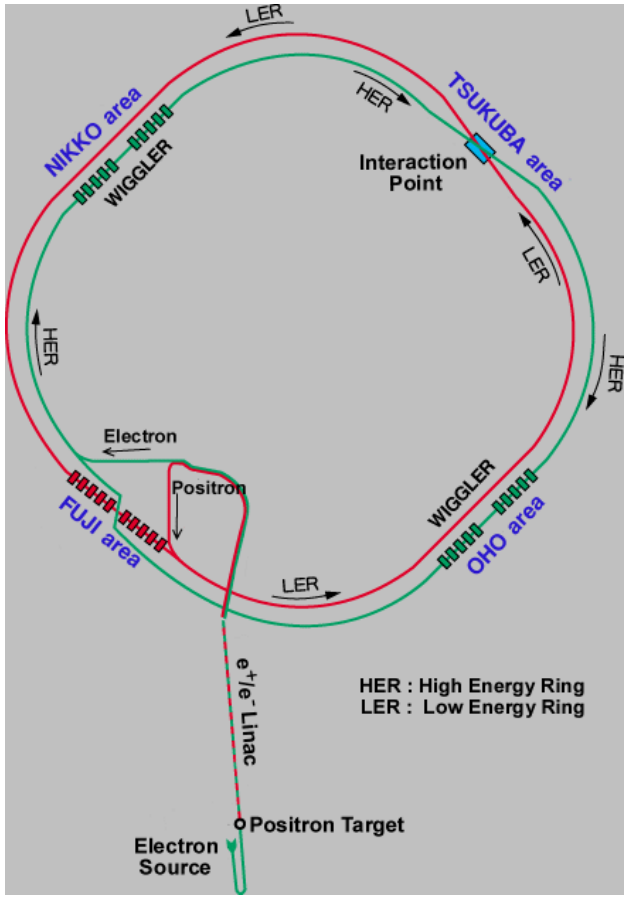
peak $\mathcal{L} = 7.348 \times 10^{33}/\text{cm/sec}$

Highest luminosity ever achieved!

$\int \mathcal{L}dt = 78.1$ fb^{-1} @ 10.58 GeV

8.8 fb^{-1} @ 10.52 GeV

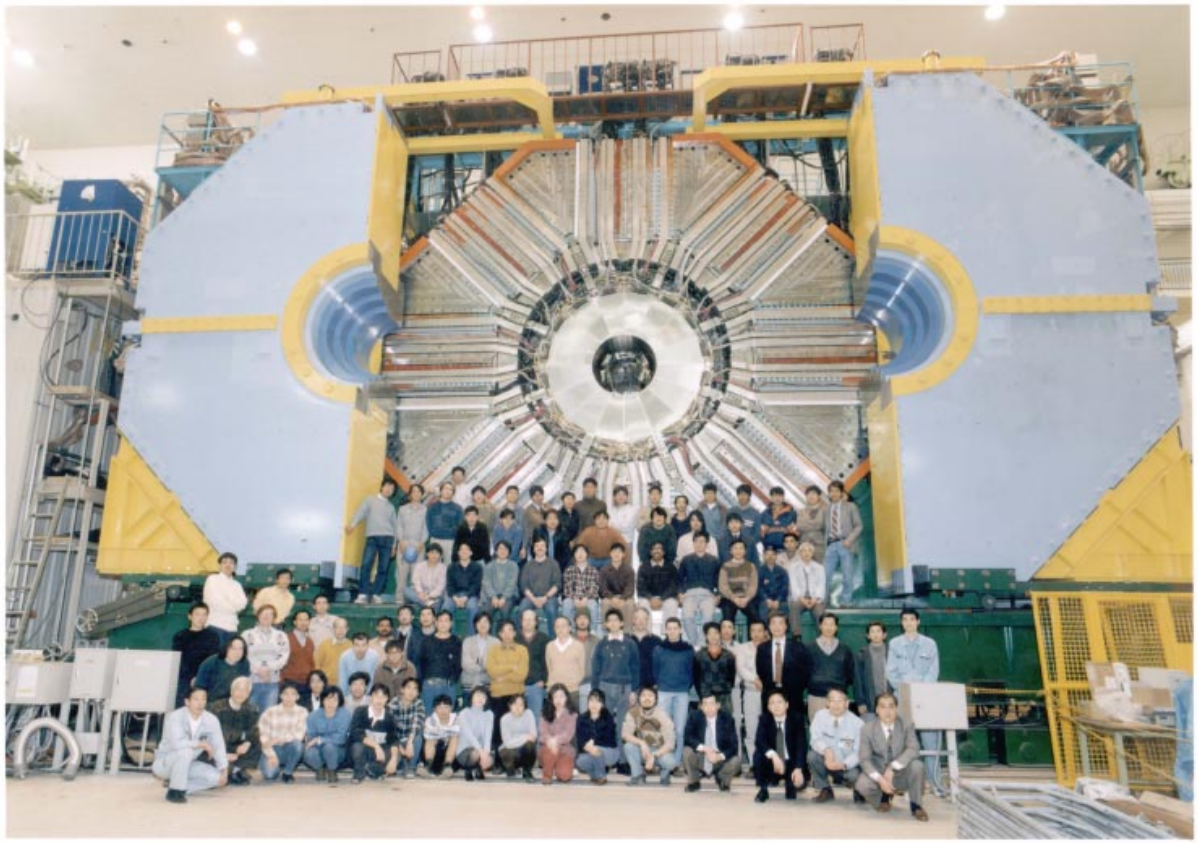
Best day: $\int \mathcal{L}dt = 0.4$ fb^{-1}



http://www-acc.kek.jp/WWW-ACC-exp/KEKB/KEKB-home.html

Belle Collaboration

250 – 350 scientists, 54 institutions, 13 countries, 4 continents



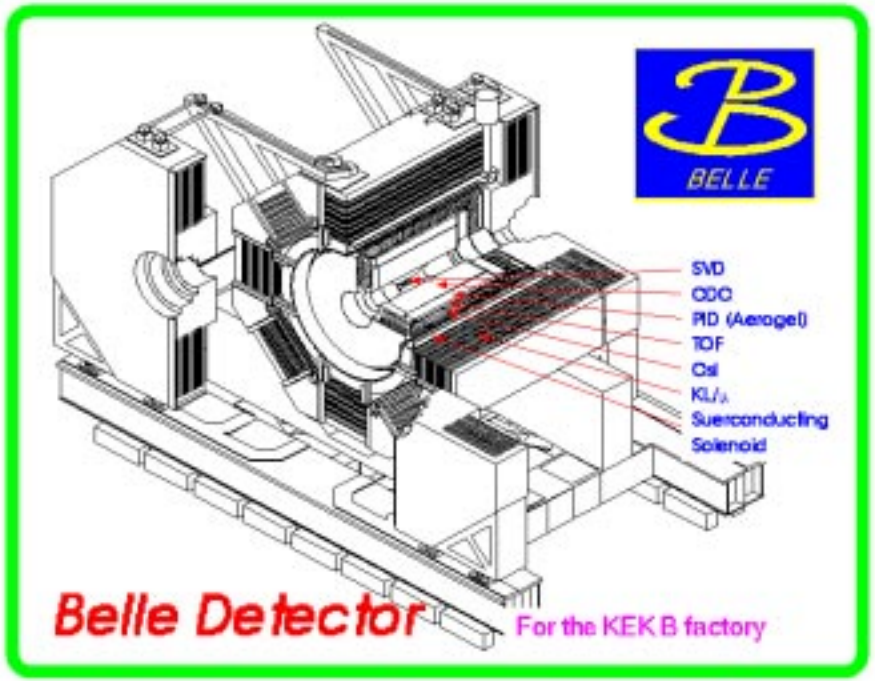
http://belle.kek.jp

Belle Experiment

tracking $< 1\%$ momentum res.

vertexing $\sim 100\ \mu$m Δz res.

calorimetry $< 2\%$ energy res.

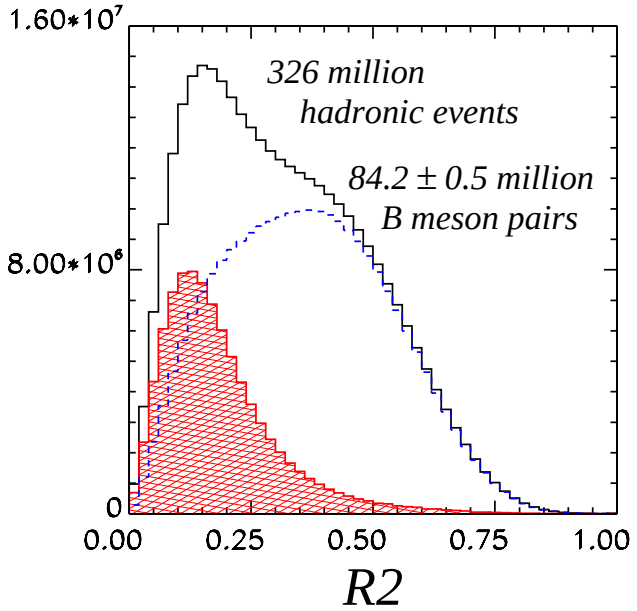


Data sample contains

326 million hadronic events on-resonace

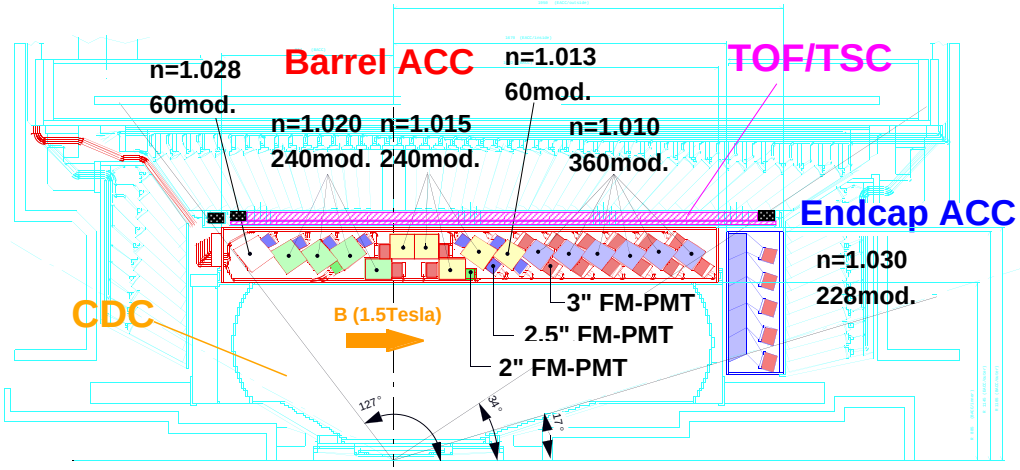
including

84.2 ± 0.5 million $B\bar{B}$ pairs

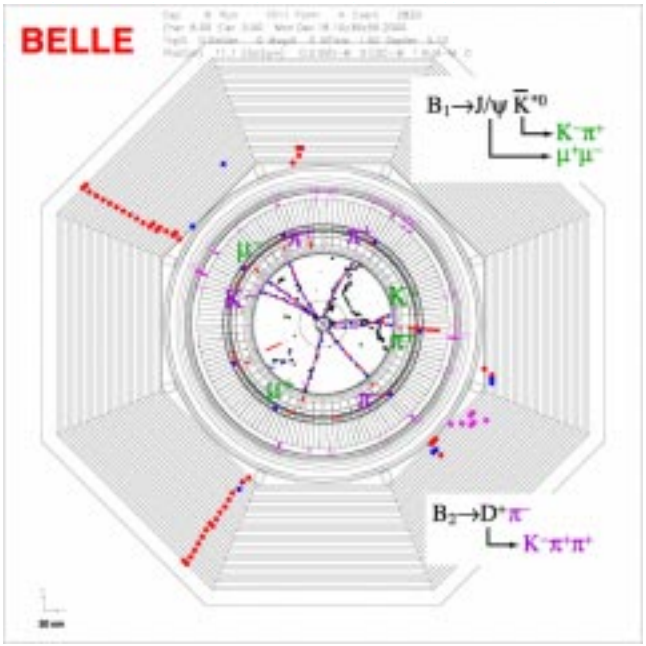


Belle Particle Identification

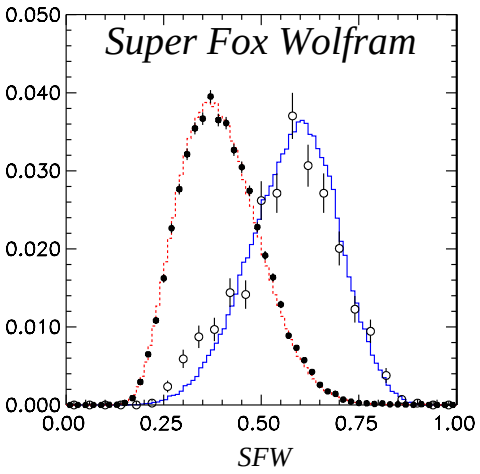
hadrons	dE/dx
	Aerogel
	Time of flight
electrons	E/p
	shower shape
	dE/dx
	Aerogel
muons	penetration depth

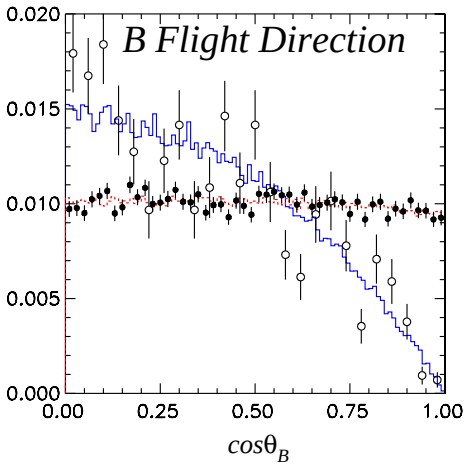


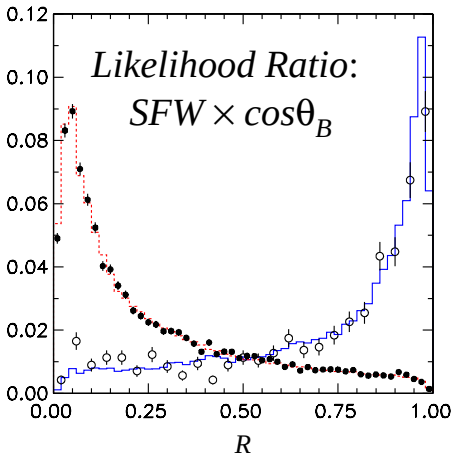
	ϵ	fake
K/π	$\sim 90\%$	$< 10\%$
e	$> 90\%$	$< 0.5\%$
μ	$> 90\%$	$< 2\%$



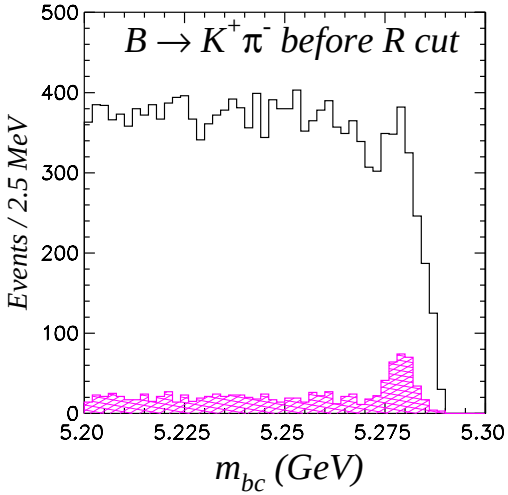
Belle Continuum Suppression

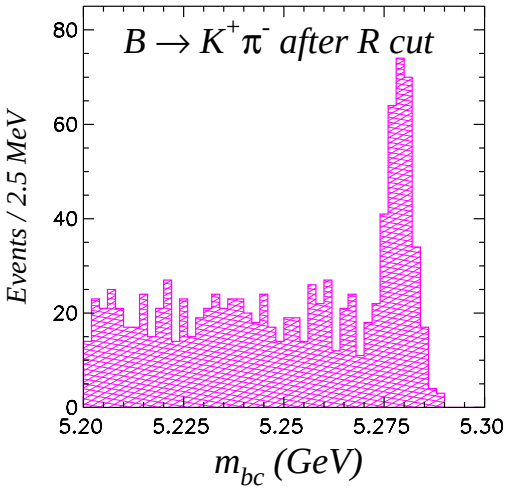






Small variations on Fisher and # of variables in the likelihood ratio for each analysis.





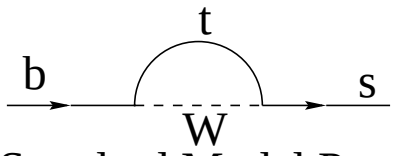
$B^0 \to K^+\pi^-$ data before and after likelihood ratio cut.

FCNC $b \to s$ Penguins

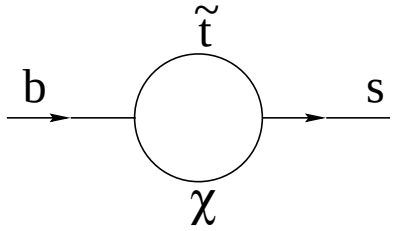
- No $b \to s$ tree in the SM
- Higher order penguins
- SM or new physics

		$\mathcal{B}$
radiative	$b \to s\gamma$	$10^{-5} \leftrightarrow 10^{-4}$
hadronic	$b \to sq\bar{q}$	$10^{-5} \leftrightarrow 10^{-4}$
leptonic	$b \to sl^+l^-$	$10^{-7} \leftrightarrow 10^{-6}$

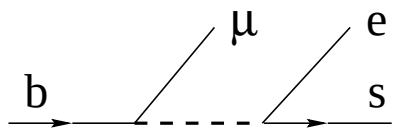
- Search for new physics by:
  - comparing exp. meas. to SM predictions,
  - CPV in 'pure' penguins.



Standard Model Penguin



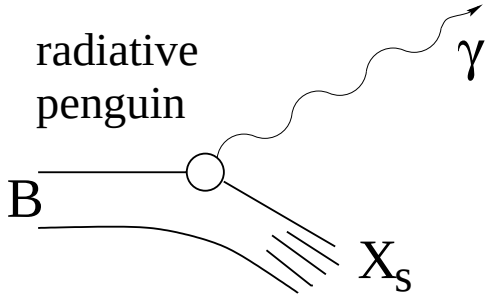
New Physics Penguin

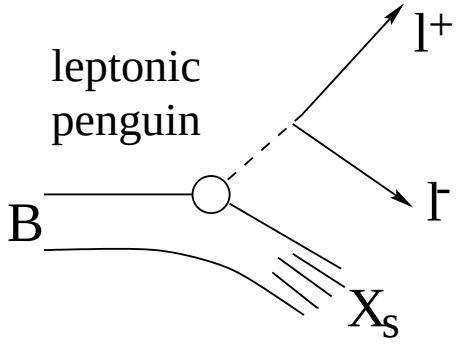


New Physics Tree

Inclusive Radiative and Leptonic $b \to s$ Penguins

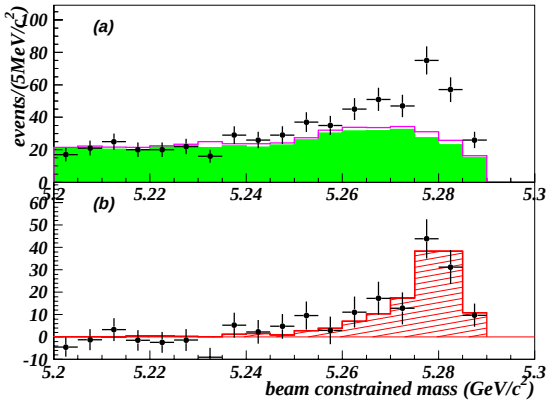
- Hadronic uncertainties minimized by summing over all states
- NLO and partial NNL0 calculation available
- Several observables sensitive to new physics
  - branching fractions,
  - di-lepton mass spectra,
  - hadronic mass spectra,
  - partial rate asymmetries between $b \to s$ and $\bar{b} \to \bar{s}$,
  - forward-backward asymmetries...

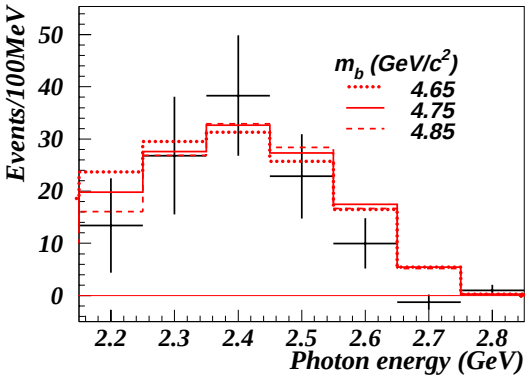


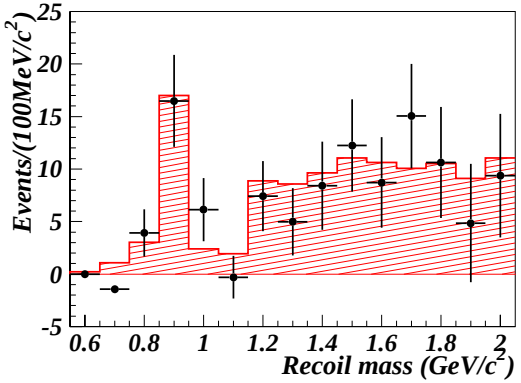


Inclusive $B \to X_s\gamma$

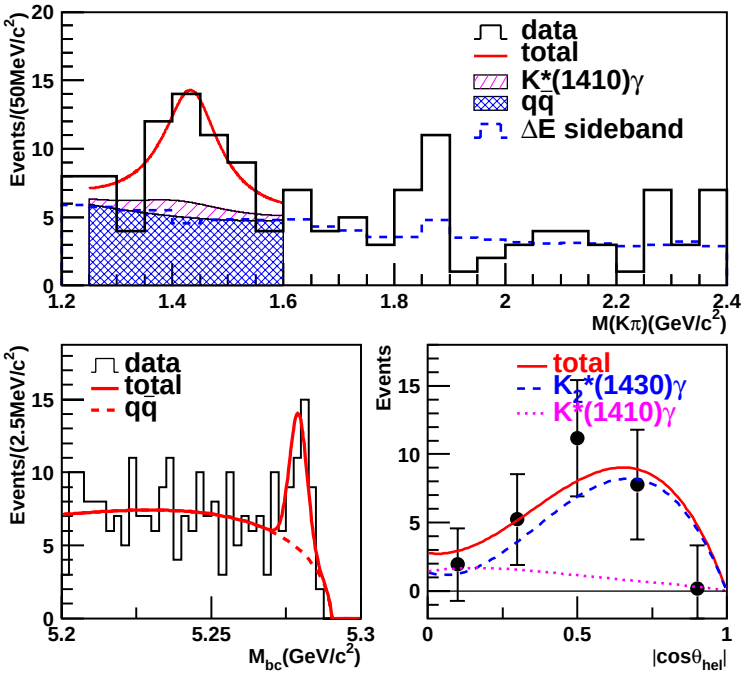
- First published by CLEO (1995), confirmed by ALEPH (1998) and Belle (2001) publications.
- Belle:
  - $\mathcal{B}(B \to X_s\gamma) = (3.36 \pm 0.53 \pm 0.42^{+0.50}_{-0.54}) \times 10^{-4}$.
  - based on first 6 million $B\bar{B}$ events.
  - K. Abe et al., PLB 511, 151 (2001).
- World average: $\mathcal{B}(B \to X_s\gamma) = (3.22 \pm 0.40) \times 10^{-4}$.
- SM (NLO) $= (3.35 \pm 0.30) \times 10^{-4}$.

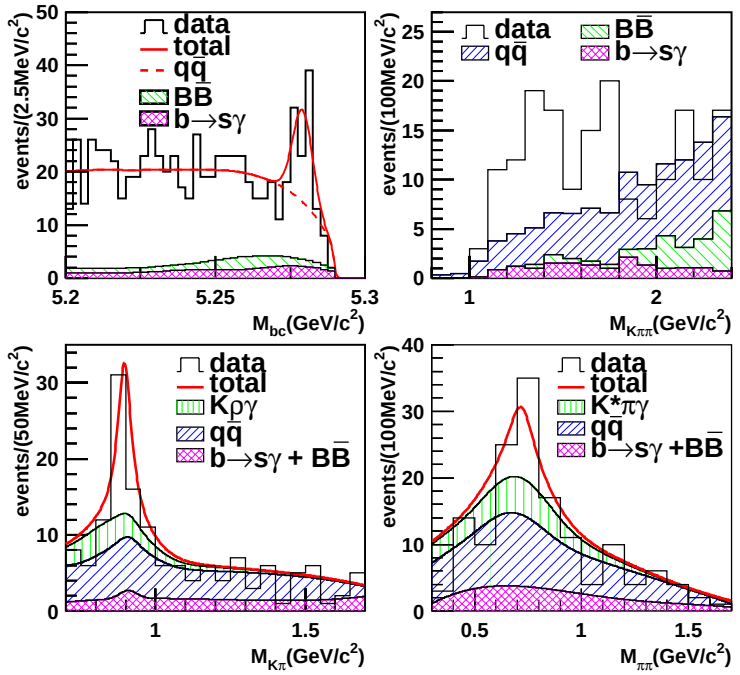






Exclusive $B \to K_X\gamma$





$K\pi$	$\mathcal{B}(10^{-5})$
$K^{*0}(892)\gamma$	$3.91 \pm 0.23 \pm 0.25$
$K^{*+}(892)\gamma$	$4.21 \pm 0.35 \pm 0.3$
$K_2^{*0}(1430)\gamma$	$1.5^{+0.6}_{-0.5}$

$K\pi\pi$	$\mathcal{B}(10^{-5})$
$K^+\pi^-\pi^+\gamma$	$2.4 \pm 0.23 \pm 0.25$
dominated by $K^*\pi$ and $K\rho$	

sum $= (35 \pm 8)\%$ of total $b \to s\gamma$

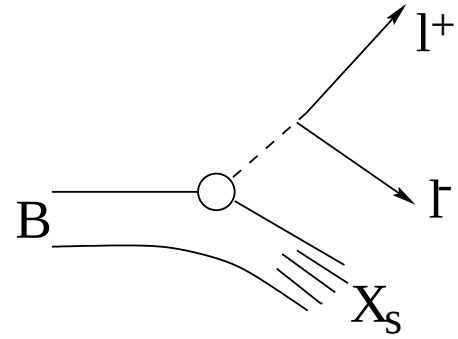
S. Nishida et al. hep-ex/0205025, submitted to PRL.

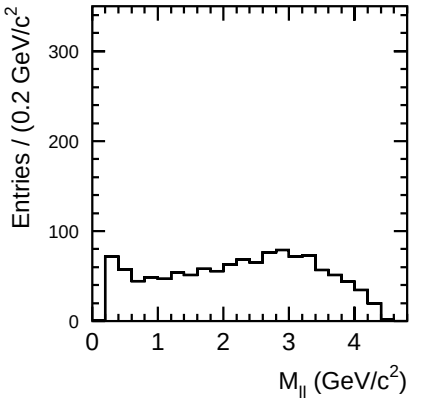
Radiative versus Leptonic Penguins

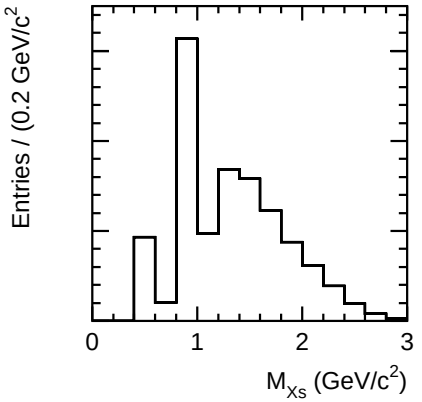
- Very good agreement between exp. and SM for $b \to s\gamma$.
- Already strong constraints on NP.
  - Kagen, Neubert hep-ph/9805303
  - Ali, Lunghi, Greub, Hiller hep-ph/0112300
- New Physics not accessible in FCNC B decays? Or is it hiding?
  - $\mathcal{A}(\mathrm{NP1}) = -\mathcal{A}(\mathrm{NP2})$?
  - $\mathcal{A}(\mathrm{NP}) = -2\mathcal{A}(\mathrm{SM})$: $\mathcal{A}(\mathrm{total}) = -\mathcal{A}(\mathrm{SM})$?
- Many ambiguities can be solved with leptonic penguins:
  - rate,
  - $m(l^+l^-)$,
  - Forward-backward asymmetry.
- Remove HQET dependence with $b \to s\gamma$.
- Chances for really exotic things like $b \to s\ e^+\mu^-$

$B \to X_s l^+ l^-$ Reconstruction

- di-lepton system:
  - e^+e^-, $\mu^+\mu^-$, and $e^+\mu^-$ combinations
  - $p(e) > 0.5$ GeV, $p(\mu) > 1$ GeV
  - $m(l^+l^-) > 200$ MeV $\Rightarrow e^+e^- = \mu^+\mu^-$
- Recoil system X_s:
  - one K^+ or K^0_S + up to 4 π, only 1 π^0 allowed
  - $m(X_s) < 2.1$ GeV
- best candidate/event based on ΔE and $\cos\theta_B$.
- model:
  - sum of K, K^*, $X_s(> 1.1$ GeV)
  - Ali, Ball, Greub, Handoko, Hiller, Lunghi
  - Large part of model dependence removed by $b \to s\gamma$ E_γ spectrum. (Thank you CLEO!)

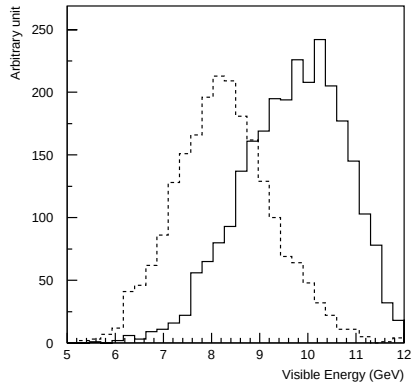


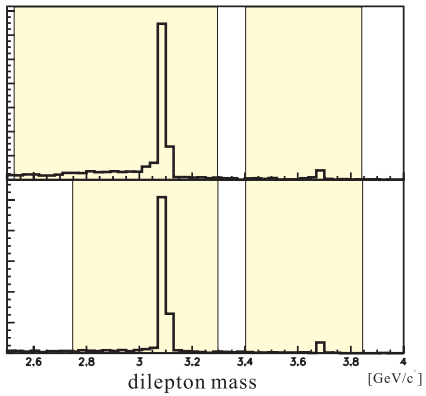


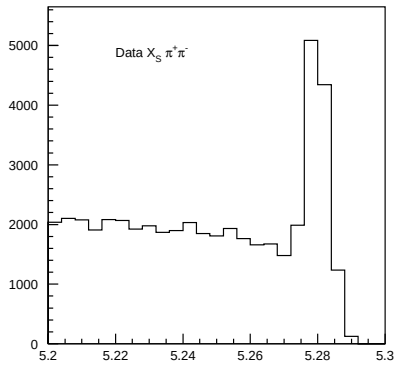


$B \to X_s l^+ l^-$ Backgrounds

- $q\bar{q} \Rightarrow$ shape variables
- double-semileptonic decay:
  - $B \to X l^+ \nu$, $\bar{B} \to \bar{X} l^- \bar{\nu}$
  - $B \to X_c l^+ \nu$, $X_c \to X_s l^- \bar{\nu}$
    - $2\nu =$ small E_{vis}
- $B \to \psi^{(')} X_s$:
  - veto $m(l^+ l^-)$
- double mis-id $\pi^+\pi^- \to l^+ l^-$
  - # background = $f^2(\pi \to l) \times N(B \to X_s \pi^+ \pi^-)$.

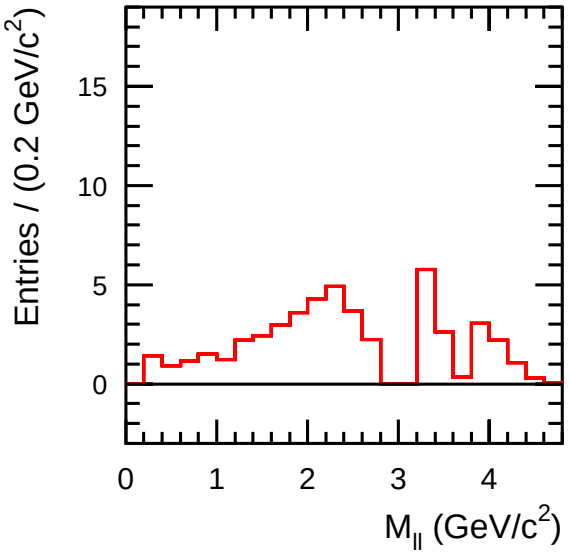






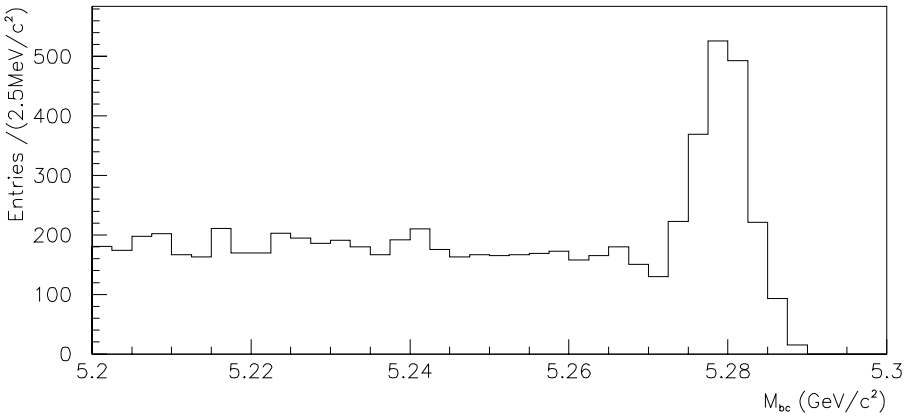
$B \to X_s l^+ l^-$ After Cuts

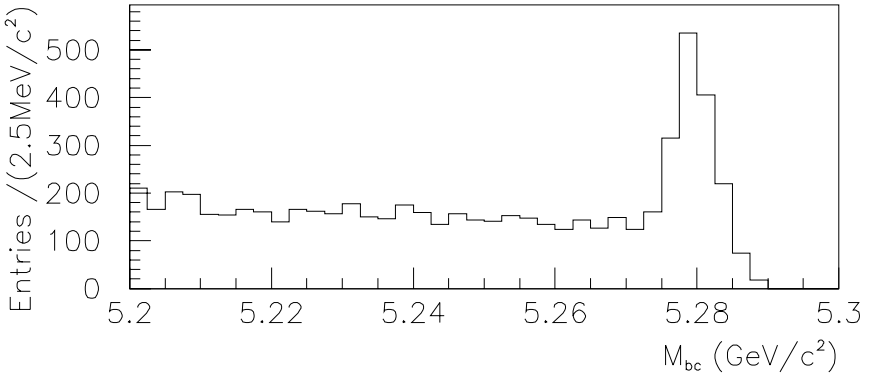
Signal $X_s l^+ l^-$	$\epsilon = 0.039$ e^+e^-,
	0.036 $\mu^+\mu^-$
	$\sim 14\%$ model error
$B \to X_s \pi^+ \pi^-$	2.6 expected for $\mu^+\mu^-$,
	~ 0.1 for e^+e^-
$B \to X_s J/\psi^{(\prime)}$	< 1 event expected
	in signal region.
Combinatorial	70% S.L.,
	30% $q\bar{q}$



$B \to J/\psi X_s$

- remove J/ψ veto
- use for:
  - PDF tuning,
  - cross-checks



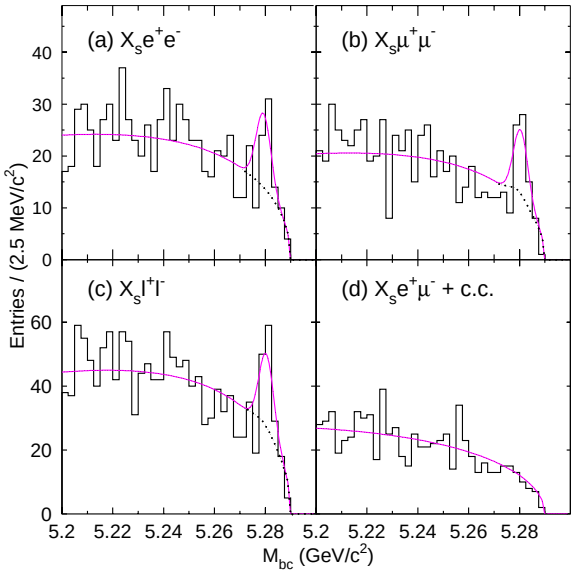


First Observation

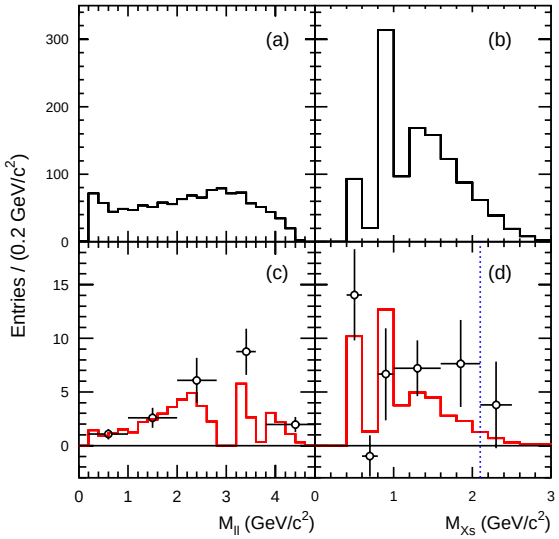
$B \to X_s l^+ l^-$

- Signal shape determined from $J/\psi X_s$
- background shape from MC

65.4 million $B\bar{B}$ events



	$\mathcal{B}(\times 10^{-6})$ $m(l^+l^-) > 0.2$ GeV
$X_s e^+ e^-$	$5.0 \pm 2.3^{+1.2}_{-1.1}$
$X_s \mu^+ \mu^-$	$7.9 \pm 2.1^{+2.0}_{-1.5}$
$X_s l^+ l^-$	$6.1 \pm 1.4^{+1.3}_{-1.1}$



5.4 σ sig. above background

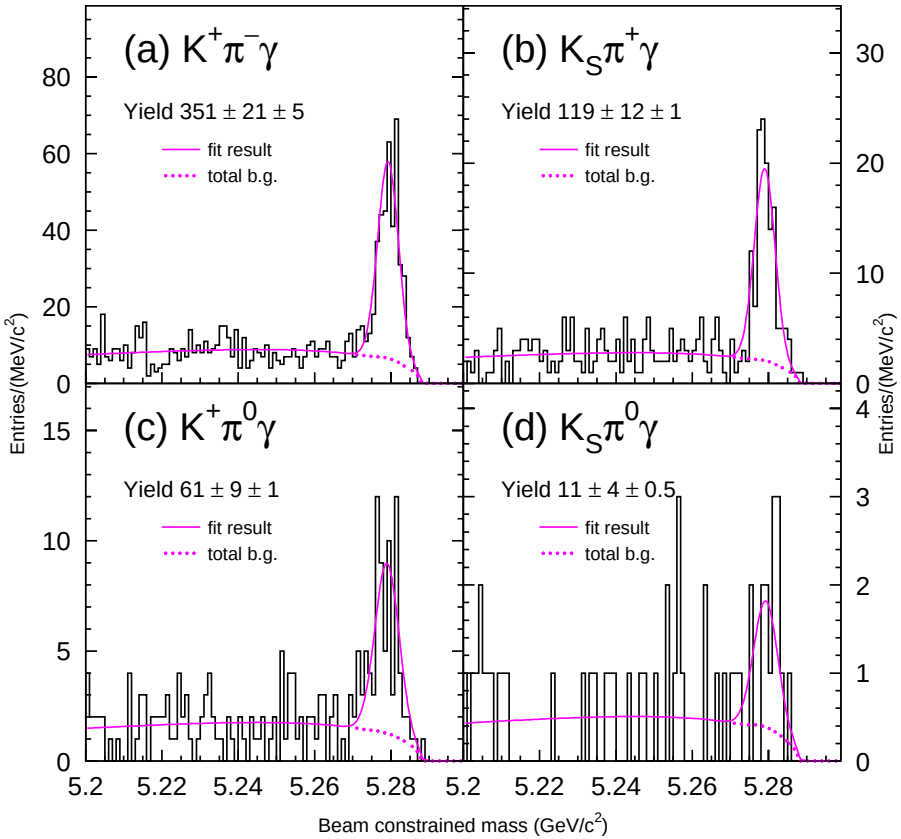
J. Kaneko et al. Belle-Conf-0258

SM NNLO $m(l^+l^-) > 0.2$ GeV:
$4.2 \pm 0.7 \times 10^{-6}$

Exclusive $B \to K^{(*)} l^+ l^-$

65.4 million $B\bar{B}$ events

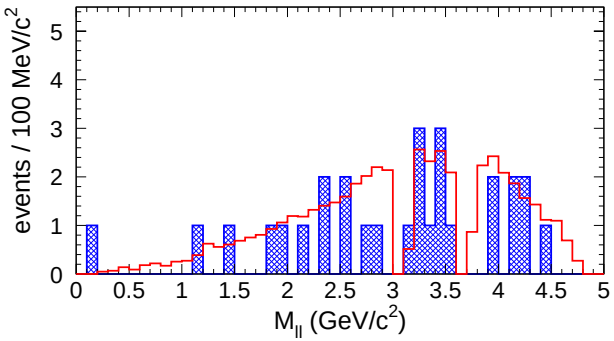
	$\mathcal{B}(\times 10^{-7})$
Ke^+e^-	$3.8^{+2.1}_{-1.7}\ ^{+0.5}_{-0.6}$
$K\mu^+\mu^-$	$8.0^{+2.8}_{-2.3} \pm 0.8$
Kl^+l^-	$5.8^{+1.7}_{-1.5} \pm 0.6$
$K^*l^+l^-$	$< 1.4 \times 10^{-6}$ @ 90% C.L.



Kl^+l^-: 5.4 σ sig. above background!

SM NNLO: $Kl^+l^- = 3.5 \pm 1.2 \times 10^{-7}$

$K^*l^+l^- = 1.4 \pm 0.4 \times 10^{-6}$

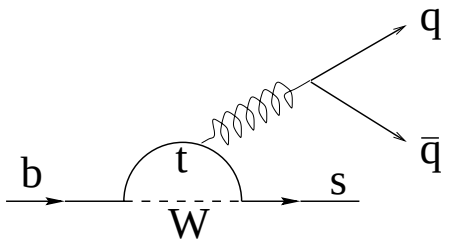


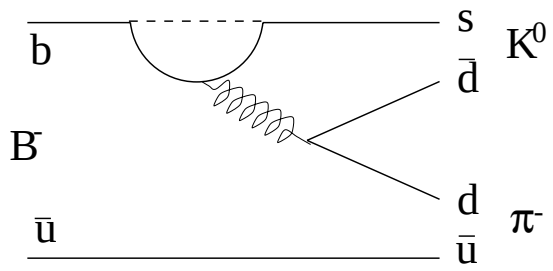
K. Abe et al., PRL 88, 052002 (2002)

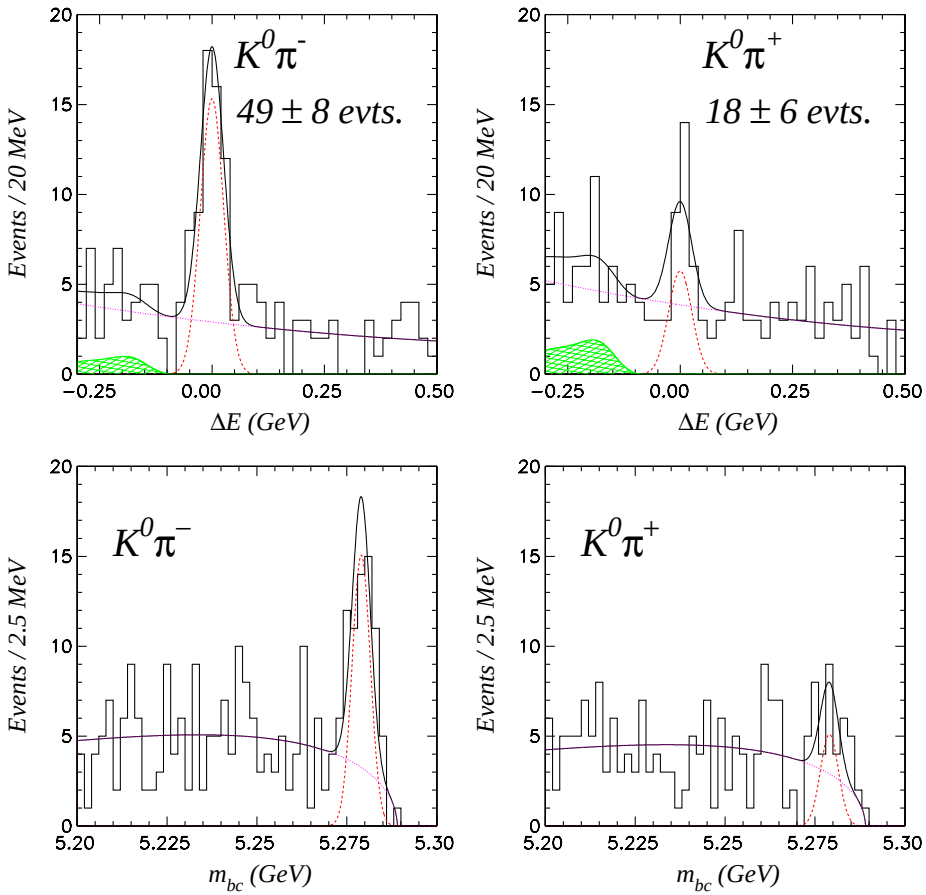
A. Ishikawa et al., Belle-Conf-0241

Hadronic Penguins

- Difficult to calculate in SM due to hadronic uncertainties....
- Still a great candidate for NP in 'pure' penguin modes
- Any measurement of (large) interference = NP.
- $B^{\mp} \to K_S \pi^{\mp}$:
  - nearly pure penguin
  - factorization based expectation: $< 3\%$ asymmetry between $K_S\pi^-$ and $K_S\pi^+$
  - SU(3) rescattering: $\mathcal{A}_{CP}(K_S\pi^{\mp}) \leq \mathcal{A}_{CP}(K^{\mp}\pi^{\pm,0})$
    - $-0.15 < \mathcal{A}_{CP}(K^{\mp}\pi^{\pm}) < -0.2$ @ 90% C.L. (Belle + BaBar + CLEO)







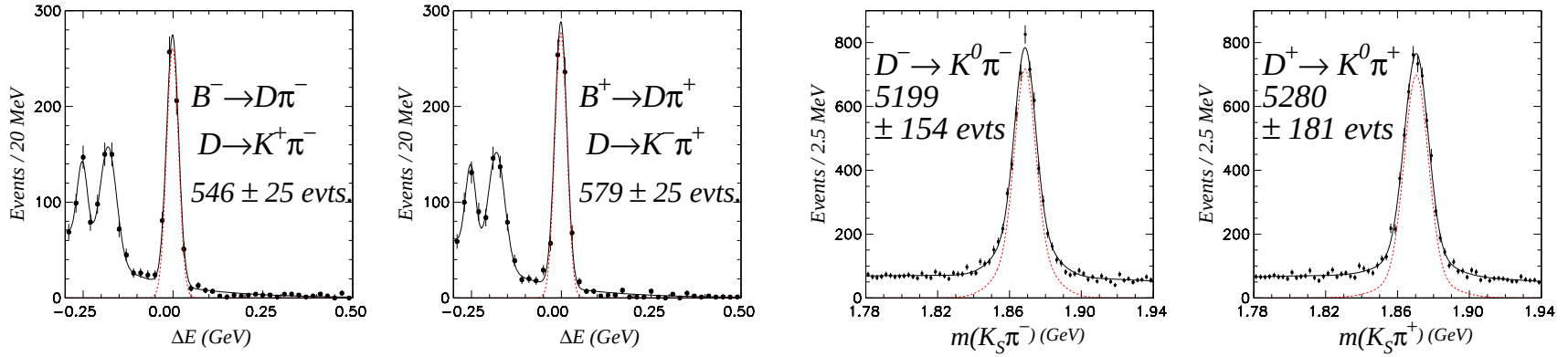
$K_S\pi^-$ versus $K_S\pi^+$

First 33 million $B\bar{B}$

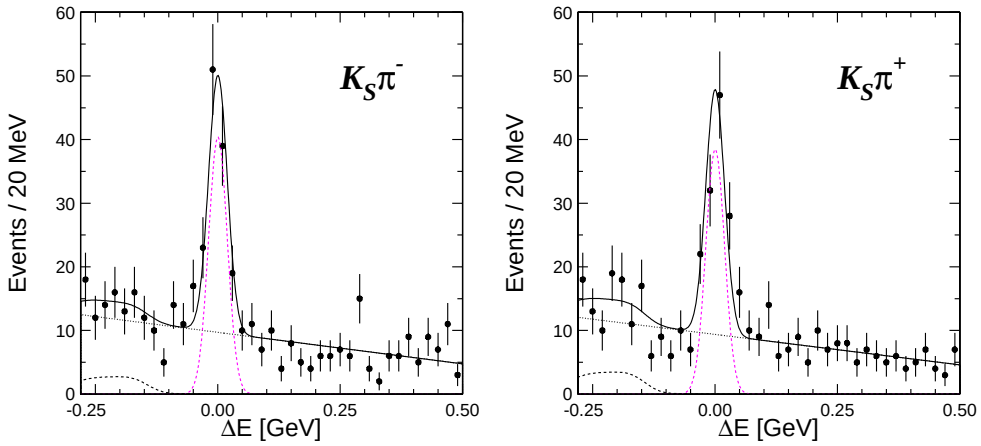
$\mathcal{A}_{CP} = 0.46 \pm 0.15 \pm 0.02$

$B \to K^0\pi^\mp$ (m_{bc})	0.49 ± 0.16
$B \to D\pi^\mp$; $D \to K^\pm\pi^\mp$	-0.03 ± 0.03
$D \to K^0\pi^\mp$	-0.01 ± 0.02

B. C. K Casey et al.,
hep-ex/0207090, submitted to PRD



$B^{\mp} \to K_S\pi^{\mp}$ with 85 million $B\bar{B}$ events



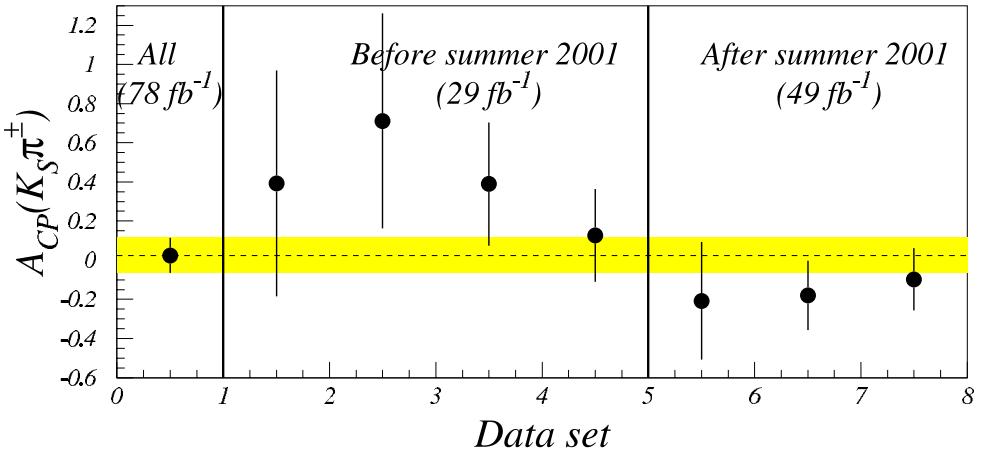
$$N(B^-) = 96 \pm 12$$

$$N(B^+) = 92 \pm 12$$

$$\mathcal{A}_{CP}(K_S\pi^{\mp}) = 0.02 \pm 0.09 \pm 0.01$$

$$0.14 < \mathcal{A}_{CP}(K_S\pi^{\mp}) < 0.18 \ \ @90\% \text{ C.L.}$$

New seasonal variation in B physics:

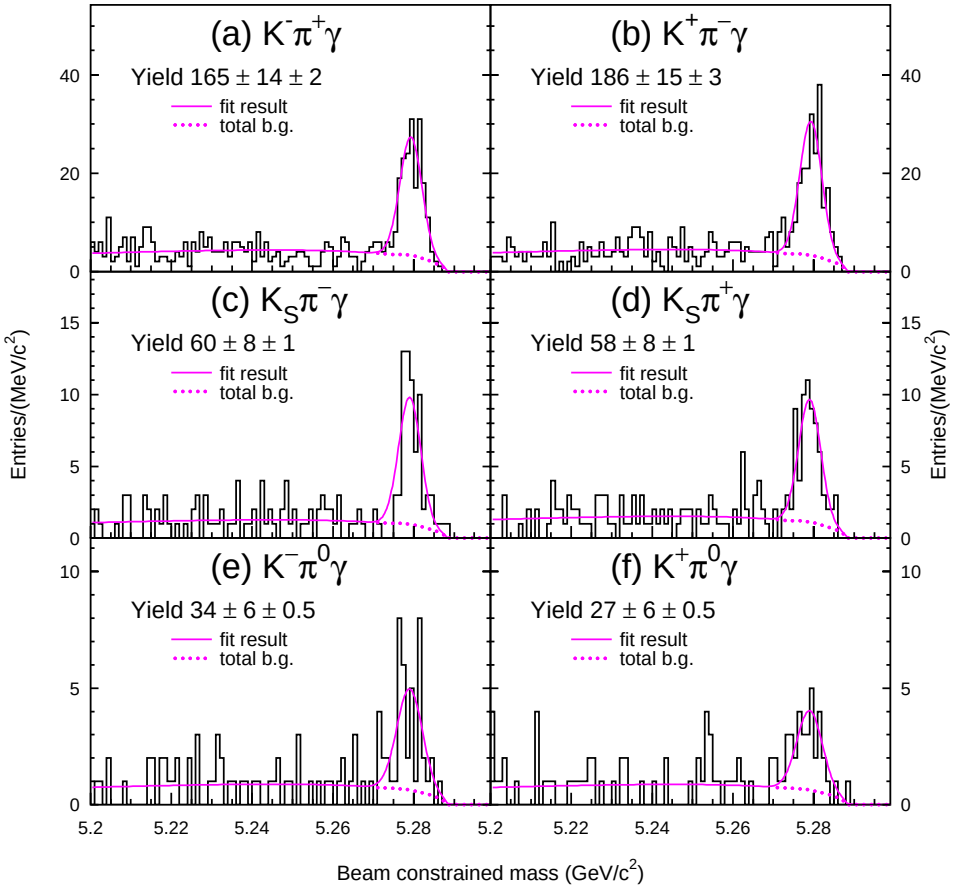


Other Pure Penguin Asymmetries

	$\mathcal{A}_{CP}$ (90% C.L.)
$K^*\gamma$	$-0.022 \pm 0.048 \pm 0.017$
	$-0.106 < \mathcal{A} < 0.062$
$\phi K^\mp$	$-0.007 \pm 0.090 \pm 0.050$
	$-0.18 < \mathcal{A} < 0.16$

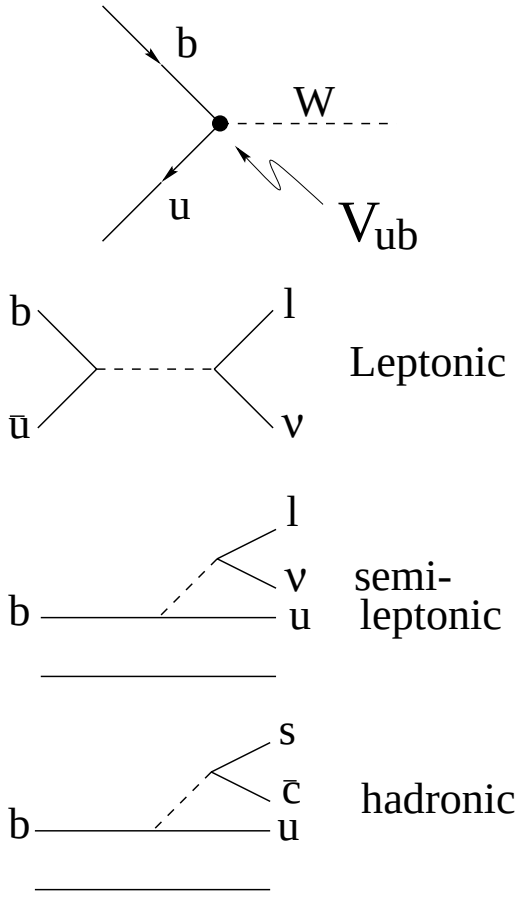
strongest bounds on DCPV in 'pure' penguin modes

M. Nakao et al., Belle-Conf-0239



Measuring V_{ub}

- Leptonic:
  - not there yet
- Semi-leptonic:
  - exclusive and inclusive
  - theory problems
  - background problems
- Exclusive hadronic:
  - similar theory problems
  - experimentally easy!

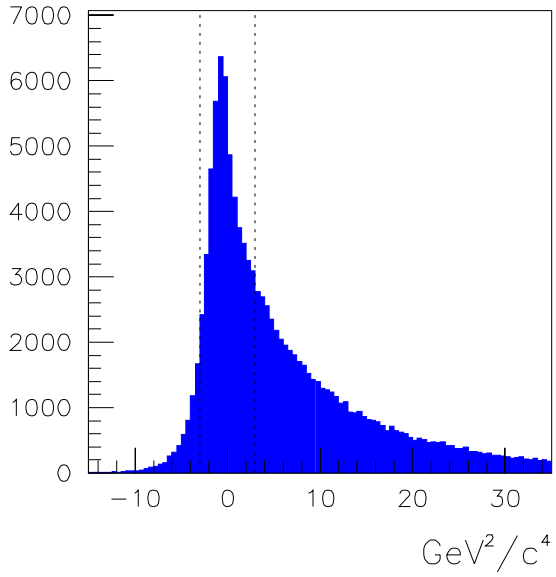


Need several measurements and iterations

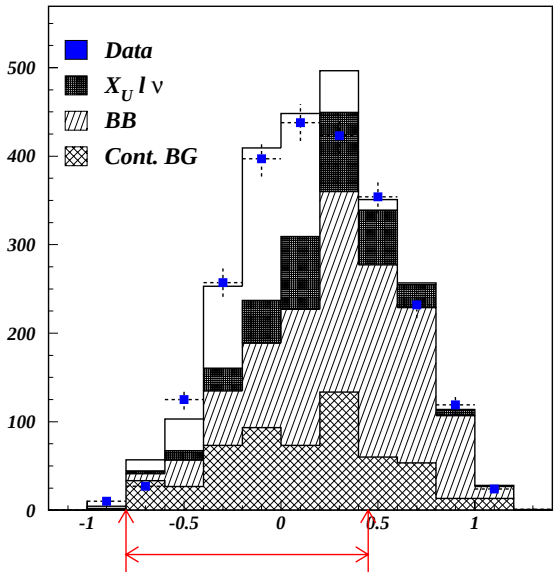
Exclusive

Semi-leptonic Decays

- neutrino reconstruction:
  - $E_{miss} = E_{beam} - E_{rec}$
  - $\vec{p}_{miss} = \vec{p}_{beam} - \vec{p}_{rec}$
- consistency cuts:
  - single lepton
  - event charge
  - missing mass
  - direction of missing momentum
- signal yield from:
  - ΔE, p_l, intermediate resonance...



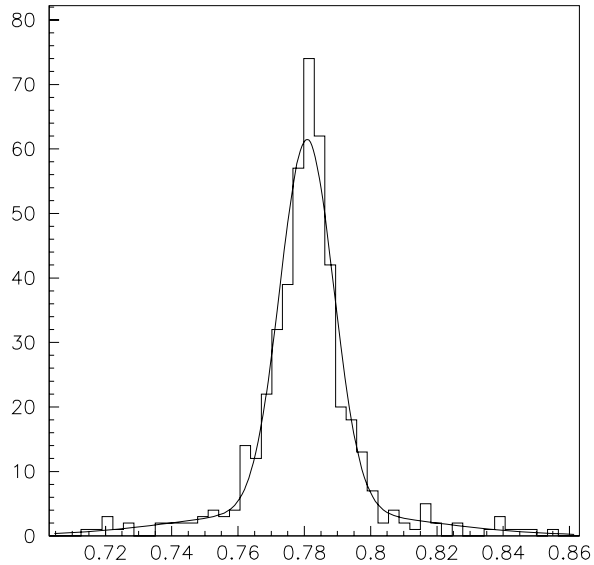
m^2_{miss}



ΔE for $\pi l \nu$

$B^+ \to \omega l^+ \nu$

- narrow resonance, clean channel
  - , $(\rho) = 150$ MeV; , $(\omega) = 8.4$ MeV
- easier on the lattice
- yet another cross check



$B^+ \to \omega l^+ \nu$

make cuts on ΔE and m_{bc}

then fit the ω peak

73 ± 15 ω candidates

19% from continuum ω determined from sideband studies

59 ± 15 $B^+ \to \omega e^+ \nu$ events

(Only electrons for now)

$\mathcal{B}(B^+ \to \omega e^+ \nu) = (1.4 \pm 0.4 \pm 0.3) \times 10^{-4}$

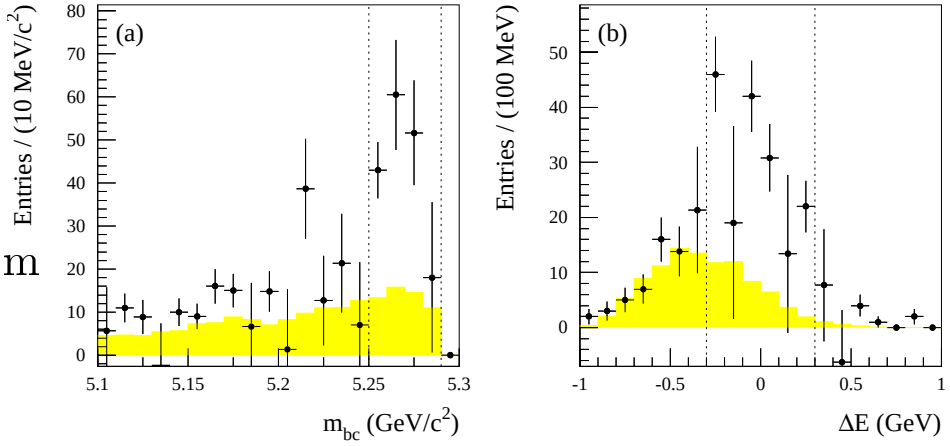
Other semi-leptonic:

$\mathcal{B}(B^0 \to \pi^- l^+ \nu) =$
$(1.35 \pm 0.11 \pm 0.21) \times 10^{-4}$

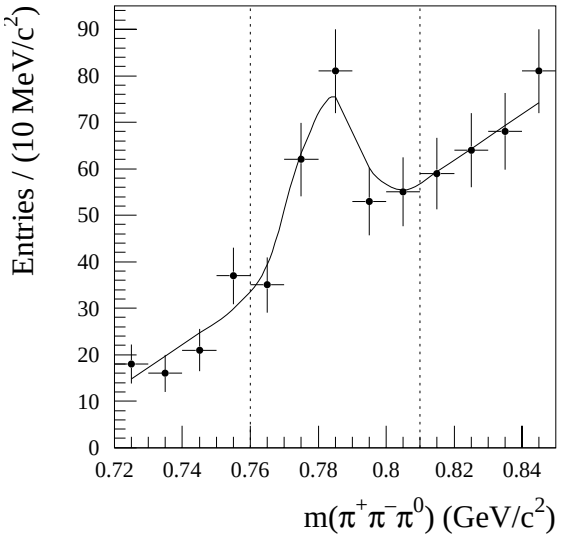
$\mathcal{B}(B^+ \to \rho^0 e^+ \nu) =$
$(1.44 \pm 0.18 \pm 0.23) \times 10^{-4}$

C. Schwanda et al., Belle-Conf-0240

BELLE

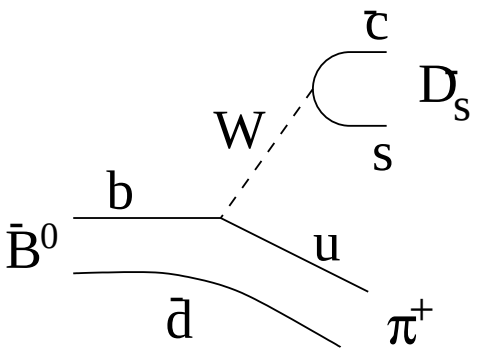


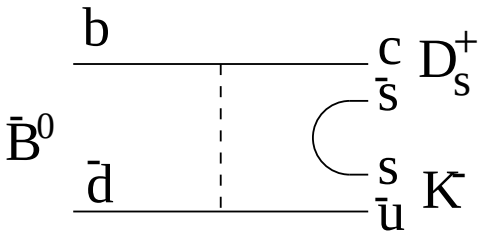
BELLE



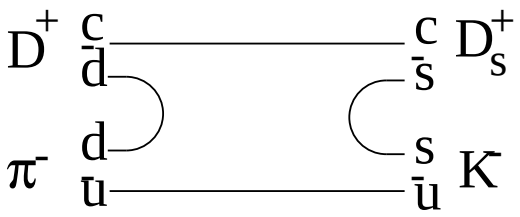
$B \to D_s\pi,\ D_sK$

- $D_s\pi$:
  - single amplitude prop. to $|V_{ub}|$
  - same theory problems as exclusive S.L. plus factorization
  - orders of magnitude easier measurement.





- D_sK:
  - Exchange only
  - possible SU(3) rescattering

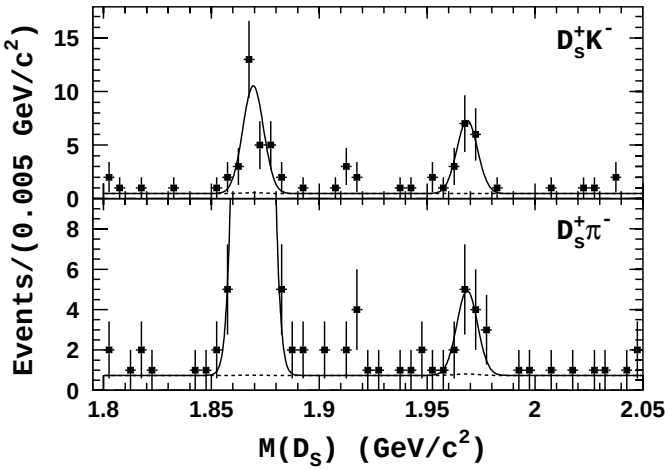


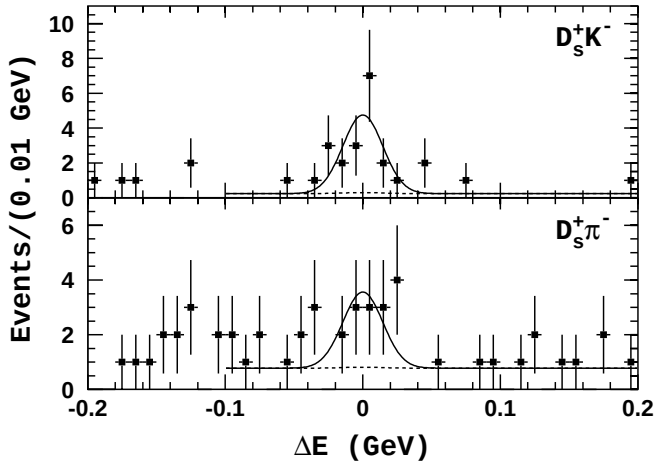
$B \to D_s\pi$, D_sK Reconstruction/Backgrounds

- $Ds \to \phi\pi$, K^*K, K_sK
- combine with π or K to form B
- standard shape cuts for $q\bar{q}$ suppression
- backgrounds:
  - real D_s: $q\bar{q} \leftarrow$ flat in ΔE
  - real charmless $B \to hhh$; $h = \pi$ or K: $\leftarrow$ flat in $m(D_s)$
  - mis-id: $D^+ \to K_s\pi^+$, $K^-\pi + \pi+$: $\leftarrow$ veto
- 2-D fit to ΔE and $m(D_s)$

$B \to D_s\pi$, D_sK Results

- $D_s^+\pi^-$:
  - $10.1^{+4.4}_{-3.7}$ events
  - $\mathcal{B}(B^0 \to D_s^+\pi^-) = (2.4^{+1.0}_{-0.8} \pm 0.7) \times 10^{-5}$
  - 3.6 σ
- $D_s^-K^+$:
  - $16.4^{+4.6}_{-3.9}$ events
  - $\mathcal{B}(\bar{B}^0 \to D_s^-K^+) = (4.6^{+1.2}_{-1.1} \pm 1.3) \times 10^{-5}$
  - 6.4 σ
- Cross check:
  - $\mathcal{B}(\bar{B}^0 \to D^+\pi^-) = (2.8 \pm 0.2) \times 10^{-3}$
    PDG: $(3.0 \pm 0.4) \times 10^{-3}$
  - $\mathcal{B}(\bar{B}^0 \to D^+K^-) = (3.0 \pm 0.7) \times 10^{-4}$
    PDG: $(2.0 \pm 0.6) \times 10^{-4}$





P. Krokovny et. al., hep-ex/0207077, submitted to PRL

$B^0 \to D_s^+\pi^-$ and V_{ub}

Ratio of $b \to u$ tree to $b \to c$ tree:

$$R = \frac{, (D_s^+\pi^-)}{, (D_s^+D^-)} = (0.424 \pm 0.041)\left|\frac{V_{ub}}{V_{cb}}\right|^2$$

Belle $D_s^+\pi^-$ and PDG $D_s^+D^-$:

$$R = (3.0^{+1.8}_{-1.6}) \times 10^{-3}$$

using $|V_{cb}| = (41.2 \pm 2.0) \times 10^{-3}$ gives

$$|V_{ub}| = (3.5^{+1.0}_{-0.9}) \times 10^{-3}$$

Good agreement with semi-leptonic modes but error is still large

Good new challenge to theorists working on $|V_{ub}|$

(Already enough info to do an SU(3) analysis? $D\pi$, DK, $D_s\pi$, D_sK...)

Other Interesting Rare Things

42 Papers sent to ICHEP2002:

- Charmless:
  - First observation of $B^+ \to \rho^+\rho^0$; $\mathcal{B} = (38.5 \pm 10.9^{+5.9\ +2.7}_{-5.4\ -7.5}) \times 10^{-6}$
- Charmed:
  - several signals in $D^{0(*)}\pi^+\pi^-$: $D^{**}\pi$, $D^0\rho^0$...
- Charmonium:
  - Several color suppressed measurements: $J/\psi\pi^0$, $J/\psi\eta$....
- Baryonic:
  - Chamless + baryons, charmed + baryons, charmed baryons...
- plus charm, two-photon, and tau physics

Conclusions for Time-independent Studies

- Belle and new physics:
  - Belle is leading the way into a new era of precision SM testing and searches for NP with leptonic penguin decays.
    - Now measuring modes at the 6×10^{-7} level.
  - strongest limits on $DCPV$ in 'pure' penguin modes.
- Belle and $|V_{ub}|$
  - New measurement of $|V_{ub}|$ from $D_s\pi$
    - experimental feasibility (and simplicity) demonstrated
    - now its up to the theorists
  - New semi-leptonic mode $\omega l\nu$
    - narrow ω resonance may reduce the sensitivity to large model-dependent backgrounds