Charmless Multi-Body B Decays

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- Introduction
- Belle $K^+h^+h^-, K^0h^+h^-$ - 29.4 fb^{-1}
- Belle KKK - 78 fb^{-1}
- Belle $K^+\pi^-\pi^0$ - 29.4 fb^{-1}
- CLEO $K^0h^+\pi^+, K^+h^-\pi^0, K^0h^+\pi^0$ - 13.5 fb^{-1}
- Summary

Introduction

- Understand B decays and search for CPV.
- Good technique to search for intermediate quasi 2-body states.
  Non-resonant contribution and possible interferences between states
- Large branching fractions of $B^+ \to K^+\pi^-\pi^+$ and $K^+K^-K^+$ have been observed by Belle. [PRD 65, 092005]

$$\begin{aligned} \mathcal{B}(B^+ \to K^+\pi^-\pi^+) &= (55.6 \pm 5.8 \pm 7.7) \times 10^{-6} \\ \mathcal{B}(B^+ \to K^+K^+K^-) &= (35.3 \pm 3.7 \pm 4.5) \times 10^{-6} \end{aligned}$$

  - First observations of $K^{*0}\pi^+$, $\chi_{c0}K^+$, $f_0(980)K^+$ (SP) decays
  - See excess in high mass regions, $K^+\pi^-(1400)$, $\pi^+\pi^-(1300)$, $K^+K^-(1500)$

- Similar 3-body studies have been performed by CLEO and BaBar.

Analysis Technique

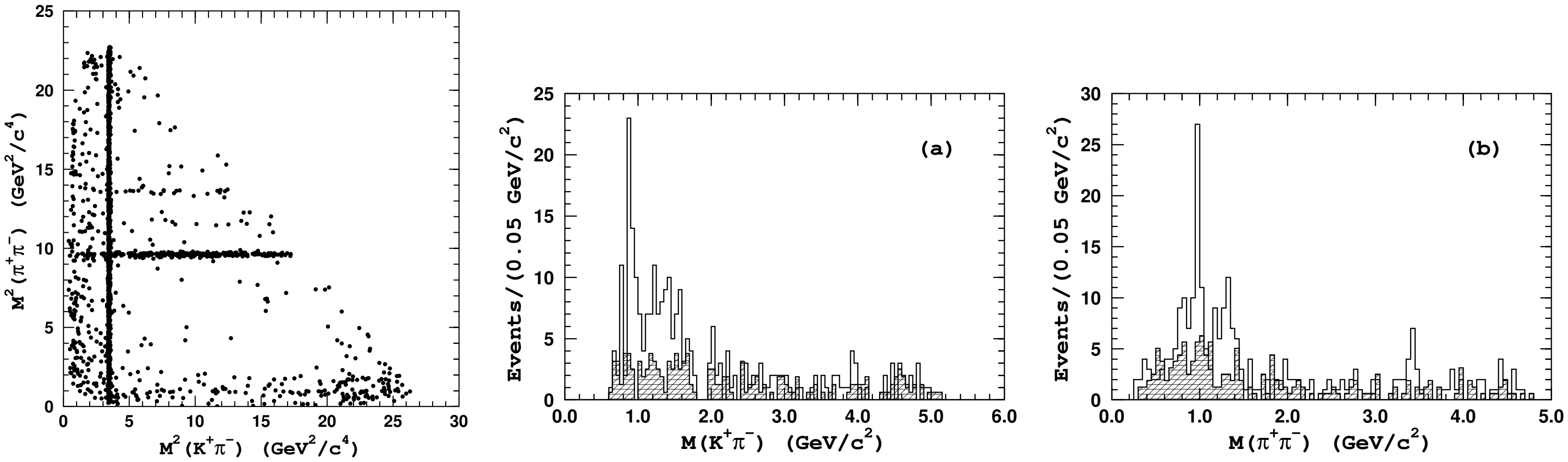
- Belle

1. Perform particle identification to select candidates
2. Suppressed continuum background by LR cut. $\Rightarrow$ Gordon's talk.
3. Identify B candidates by cutting M_{bc} and fitting ΔE (signal, continuum and $B\bar{B}$) $\Rightarrow$ Gordon's talk.
4. Examine the Dalitz plot and remove known charm content
5. Search for intermediate 2-body states
6. Consider cross-feed from different channels

- CLEO

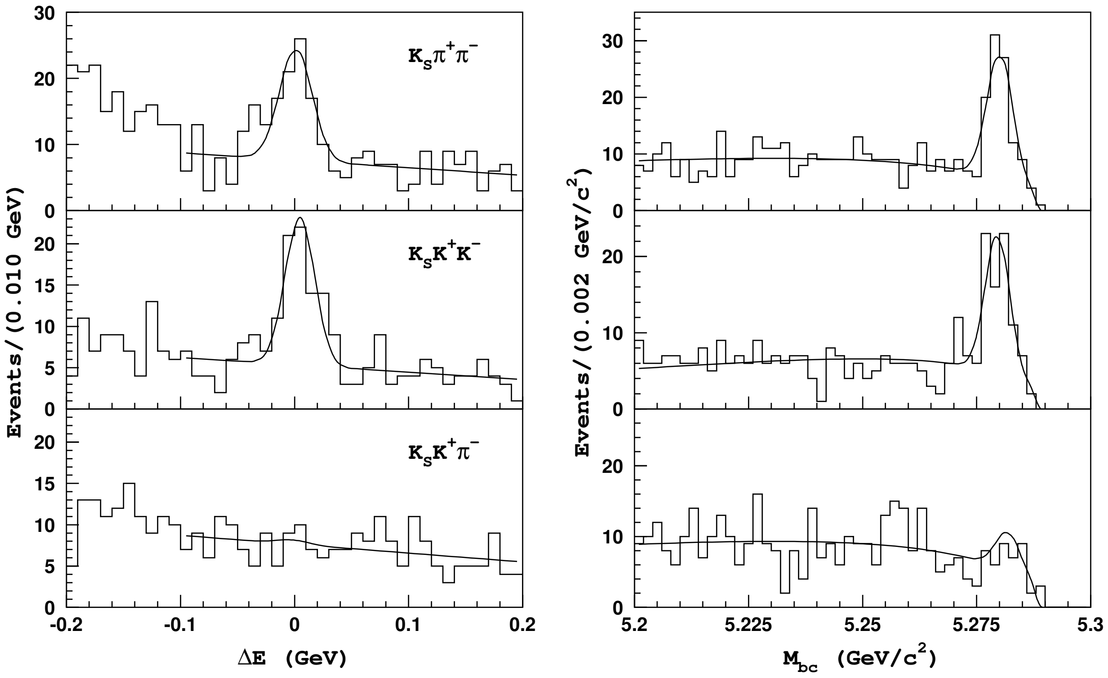
1. Loose cut on continuum suppression
2. Simultaneous fit on $M_{bc}, \Delta E, dE/dx, \mathcal{F}$
3. Search for intermediate 2-body states by adding the Dalitz plot in the multi-dimensional fit. $\Rightarrow$ Assume no interference

$B^+ \to K^+\pi^-\pi^-$, Belle



Two-body mode	Efficiency (%)	Yield (events)	Significance (σ)	$\mathcal{B}_{B^+\to Rh^+} \times \mathcal{B}_{R\to h^+h^-}$ (10^{-6})
$K^*(892)^0\pi^+$	18.9	60^{+13}_{-12}	6.2	$12.9^{+2.8+1.4+2.3}_{-2.6-1.4-4.5}$
$K_X(1400)\pi^+$	16.2	58^{+14}_{-13}	4.9	$14.5^{+3.5+1.8+3.3}_{-3.3-1.8-6.5}$
$\rho^0(770)K^+$	15.1	9^{+13}_{-12}	0.8	< 12
$f_0(980)K^+$	17.8	42^{+11}_{-10}	5.0	$9.6^{+2.5+1.5+3.4}_{-2.3-1.5-0.8}$
$f_X(1300)K^+$	16.9	46^{+14}_{-13}	3.9	$11.1^{+3.4+1.4+7.2}_{-3.1-1.4-2.9}$

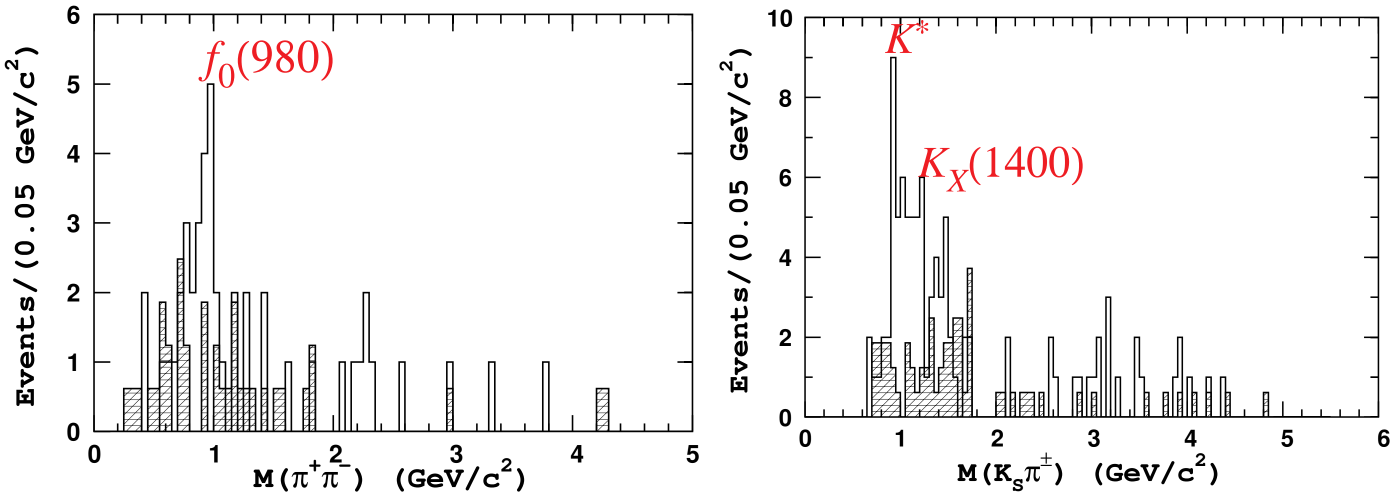
Observation of $B^0 \to K_S^0\pi^+\pi^-$ and $K_S^0K^+K^-$, Belle



Mode	Eff. (%)	Yield, events	Sig., σ	$\mathcal{B}$ $(\times 10^{-6})$	$\mathcal{B}(B^+)$ (10^{-6})
$K^0\pi^+\pi^-$	4.4	60.3 ± 11.0	6.6	$53.2 \pm 11.3 \pm 9.7$	$55.6 \pm 5.8 \pm 7.7$
$K^0K^+K^-$	6.3	57.9 ± 10.0	7.4	$34.8 \pm 6.7 \pm 6.5$	$35.3 \pm 3.7 \pm 4.3$
$K^0K^\pm\pi^\mp$	3.7	$1.7^{+7.3}_{-6.7}$, < 8.6 $(90\%CL)$	0.3	< 9.3 $(90\%CL)$	< 12 $(90\%CL)$

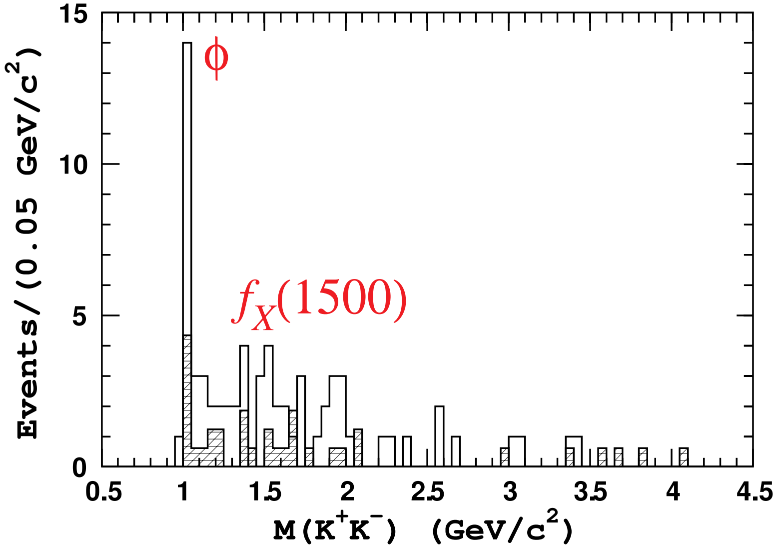
$B^+ \to K^+h^+h^-$: PRD65, 092005

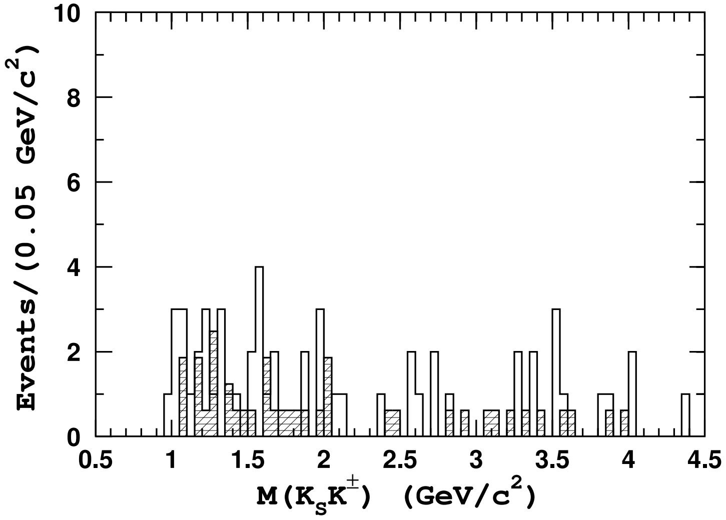
Results for $K_S^0\pi^+\pi^-$



Two body mode	Yield, events	Sig., σ	$\mathcal{B}(B^0\to Rh)\times\mathcal{B}(R\to hh)$, 10^{-6}	$\mathcal{B}(B^+\to Rh^+)\times\mathcal{B}(R\to h^+h^-)$, 10^{-6}
$K^*(892)^\pm\pi^\mp$	$16.9^{+6.0}_{-5.2}$	3.9	$13.5^{+5.0}_{-4.4}\pm 2.9$	$12.9^{+2.8+1.4+2.3}_{-2.6-1.4-4.5}$
$K_X(1400)^\pm\pi^\mp$	$24.9^{+9.0}_{-8.3}$	3.3	$22.9^{+8.7}_{-8.0}\pm 6.0$	$14.5^{+3.5+1.8+3.3}_{-3.3-1.8-6.5}$
$\rho^0(770)K^0$	$1.4^{+6.4}_{-5.7}$, < 12.3	0.2	< 12.4	< 12
$f_0(980)K^0$	$9.4^{+6.0}_{-4.9}$, < 18.4	2.1	< 14.2	$9.6^{+2.5+1.5+3.4}_{-2.3-1.5-0.8}$
$f_X(1300)K^0$	$8.0^{+6.0}_{-5.0}$, < 17.3	1.7	< 13.7	$11.1^{+3.4+1.4+7.2}_{-3.1-1.4-2.9}$

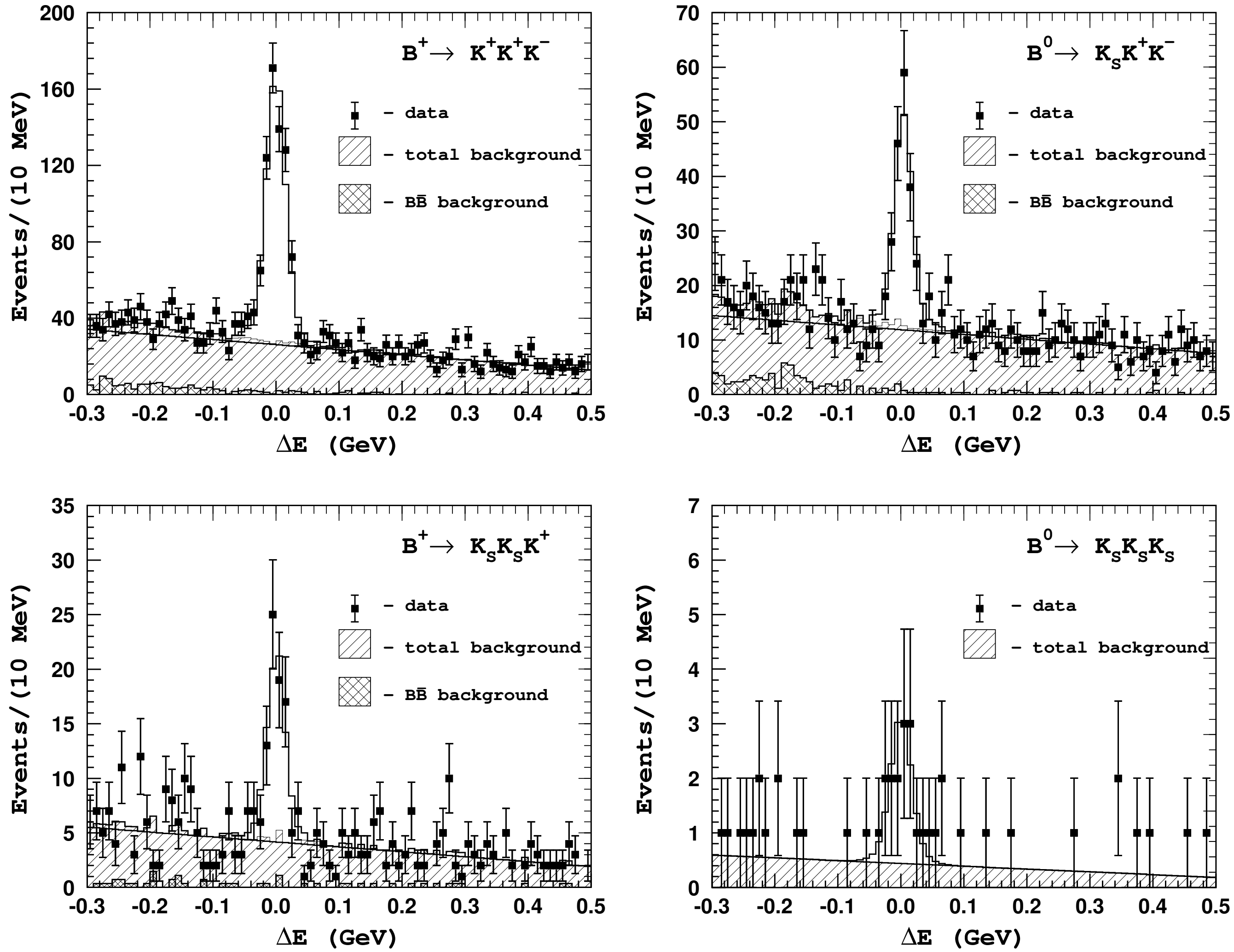
Results for $K_S^0 K^+ K^-$





Two body mode	Yield, events	Sig., σ	$\mathcal{B}(B^0 \to Rh) \times \mathcal{B}(R \to hh)$, 10^{-6}	$\mathcal{B}(B^+ \to Rh^+) \times \mathcal{B}(R \to h^+h^-)$, 10^{-6}
$\phi(1020)K^0$	$11.7^{+5.5}_{-4.6}$	3.0	$6.4^{+3.0}_{-2.6} \pm 1.3$	$7.2^{+1.5+0.9+0.4}_{-1.4-0.9-0.4}$
$f_X(1500)K^0$	$33.5^{+8.1}_{-7.5}$	5.3	$20.4^{+5.3}_{-4.9} \pm 3.8$	$27.6^{+3.2+3.5+1.4}_{-3.2-3.5-1.4}$
$a_0(980)^\pm K^\mp$	$3.4^{+3.0}_{-2.4}$, $< 8.3\ (90\%CL)$	1.5	$< 12.1\ (90\%CL)$	—
$a_X(1300)^\pm K^\mp$	$4.0^{+4.7}_{-4.1}$, $< 11.5\ (90\%CL)$	1.0	$< 10.0\ (90\%CL)$	—

$B \to KKK$, 78 fb^{-1}

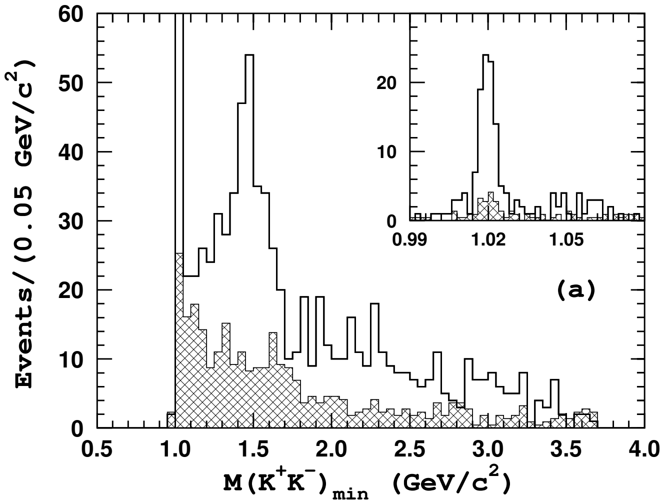


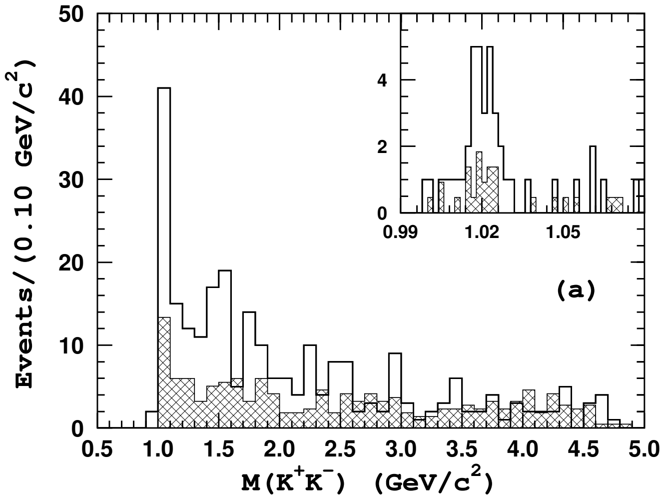
- Veto $D^0 \to K^+K^-, D^0 \to K^-\pi^+, D^+ \to \overline{K}^0\pi^+, \chi_c^0 \to K^+K^-$

$B \to KKK, cont$

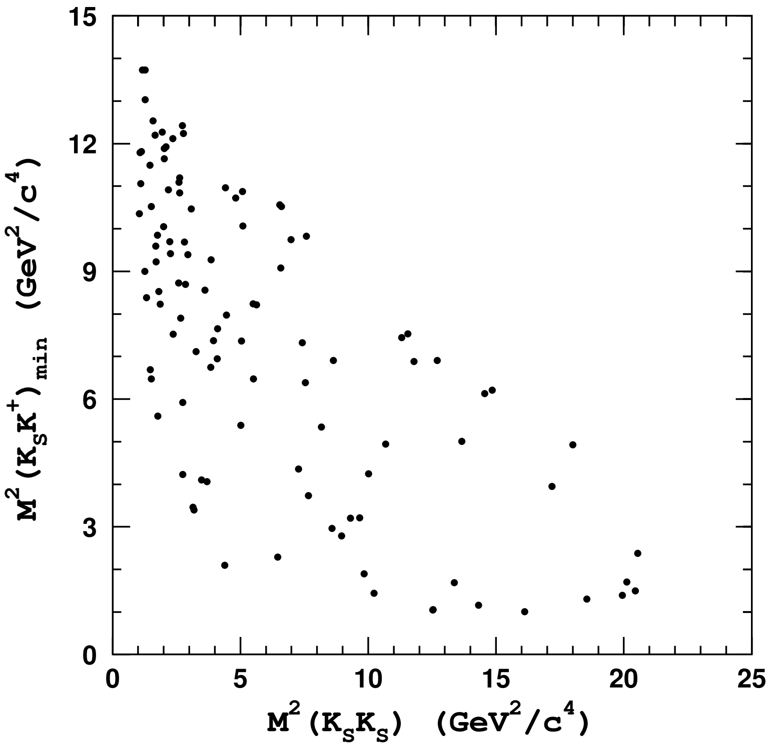
Three-body mode	Efficiency (%)	Signal Yield (events)	$\mathcal{B}$ or 90% CL UL (10^{-6})	Reference	Results from PRD
$K^+K^+K^-$	23.5 ± 0.50	565 ± 30	$33.0 \pm 1.8 \pm 3.0$	BC 225	$35.3 \pm 3.7 \pm 4.5$
$K^0K^+K^-$	7.20 ± 0.17	149 ± 15	$29.3 \pm 3.4 \pm 4.0$	BC 225	-
$K_SK_SK^+$	6.78 ± 0.19	66.5 ± 9.3	$13.4 \pm 1.9 \pm 1.4$	BC 225	-
$K_SK_SK_S$	3.98 ± 0.17	$12.2^{+4.5}_{-3.8}$	$4.3^{+1.6}_{-1.4} \pm 0.7$	BC 225	-
$K^+K^-\pi^+$	13.8	93.7 ± 23.2	$9.3 \pm 2.3 (< 13)$	BC 226	< 12
$K^0K^+\pi^-$	4.53	$26.8 \pm 16.6 (< 48)$	$8.4 \pm 5.2 (< 15)$	BC 226	-

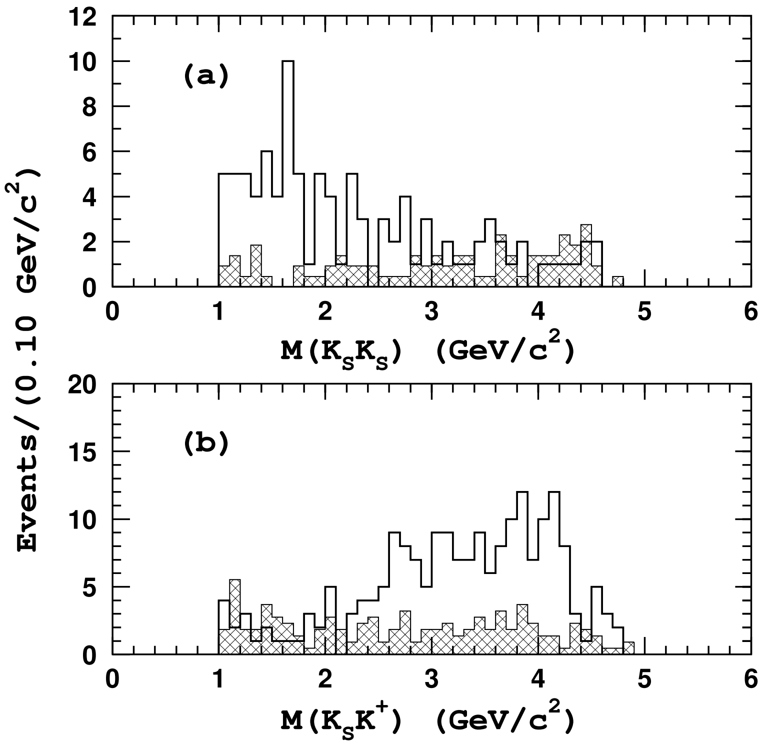
- Update results of $B^+ \to K^+K^-\pi^+$ and $B^0 \to K^0K^+\pi^-$
- Similar K^+K^- mass spectrum for $K^+K^+K^-$ and $K_SK^+K^-$





Intermediate states in $K_S K_S K^-$





- Similar $M(K_S K_S)$ to $M(K^+K^-)$ except for ϕ
- Low $M(K_S K^+)$ consistent with background.

CP content of $K_S K^+ K^-$

- CP eigenstate ($b \to sg$); relatively small fraction from ϕK. But
  - CP-parity of $K_S K^+ K^-$? $\phi(K^+K^-)K_S$ is CP-odd
  - $b \to u$ contr. may introduce an additional weak phase.
- Detailed description in BELLE-CONF-0225
- Check $b \to u$ contribution to the $K^+K^-\pi^+$ final state.

  $F \equiv \frac{|A^{KKK}_{b\to u}|^2}{|A^{KKK}_{total}|^2} \sim \frac{\mathcal{B}(B^+\to K^+K^-\pi^+)}{\mathcal{B}(B^+\to K^+K^+K^-)} \times (\frac{f_K}{f_\pi})^2 \times \tan^2\theta_c$, $f_{K,\pi}$ decay constants

  - $F = 0.022 \pm 0.005$ using $B^+ \to K^+K^-\pi^+$ and $B^+ \to K^+K^+K^-$
  - $F = 0.023 \pm 0.013$ using $B^+ \to K^0K^+K^-$ and $B^0 \to K^0K^+\pi^-$
- Neglect $b \to u$ contribution and perform isospin analysis

$$\mathcal{B}(B^0 \to K^0K^+K^-) = \mathcal{B}(B^+ \to K^+K^+K^-) \times \frac{\tau_{B^0}}{\tau_{B^+}} \quad (1)$$

$$\mathcal{B}(B^0 \to K^0K^+K^-) = \mathcal{B}(B^+ \to K^+K^0\overline{K}^0) \times \frac{\tau_{B^0}}{\tau_{B^+}} \quad (2)$$

CP Content cont.

- Check isospin violating contribution (Eq. 1) in data

$$R \equiv \frac{\mathcal{B}(B^0 \to K^0 K^+ K^-)}{\mathcal{B}(B^+ \to K^+ K^+ K^-)} \times \frac{\tau_{B^+}}{\tau_{B^0}} = 0.95 \pm 0.11 \pm 0.06$$

- Express $K^+ K^0 \overline{K}^0$ wave function as

$$|K^+ K^0 \overline{K}^0 >= \alpha \frac{|K^+ K_S K_S> + |K^+ K_L K_L>}{\sqrt{2}} + \beta |K^+ K_S K_L >$$

$$\alpha^2 = 2\frac{\mathcal{B}(B^+ \to K^+ K_S K_S)}{\mathcal{B}(B^0 \to K^0 K^+ K^-)} \times \frac{\tau_{B^0}}{\tau_{B^+}}; \ \alpha : \text{CP even}$$

or $$= 2\frac{\mathcal{B}(B^+ \to K^+ K_S K_S)}{\mathcal{B}(B^+ \to K^+ K^+ K^-)}$$

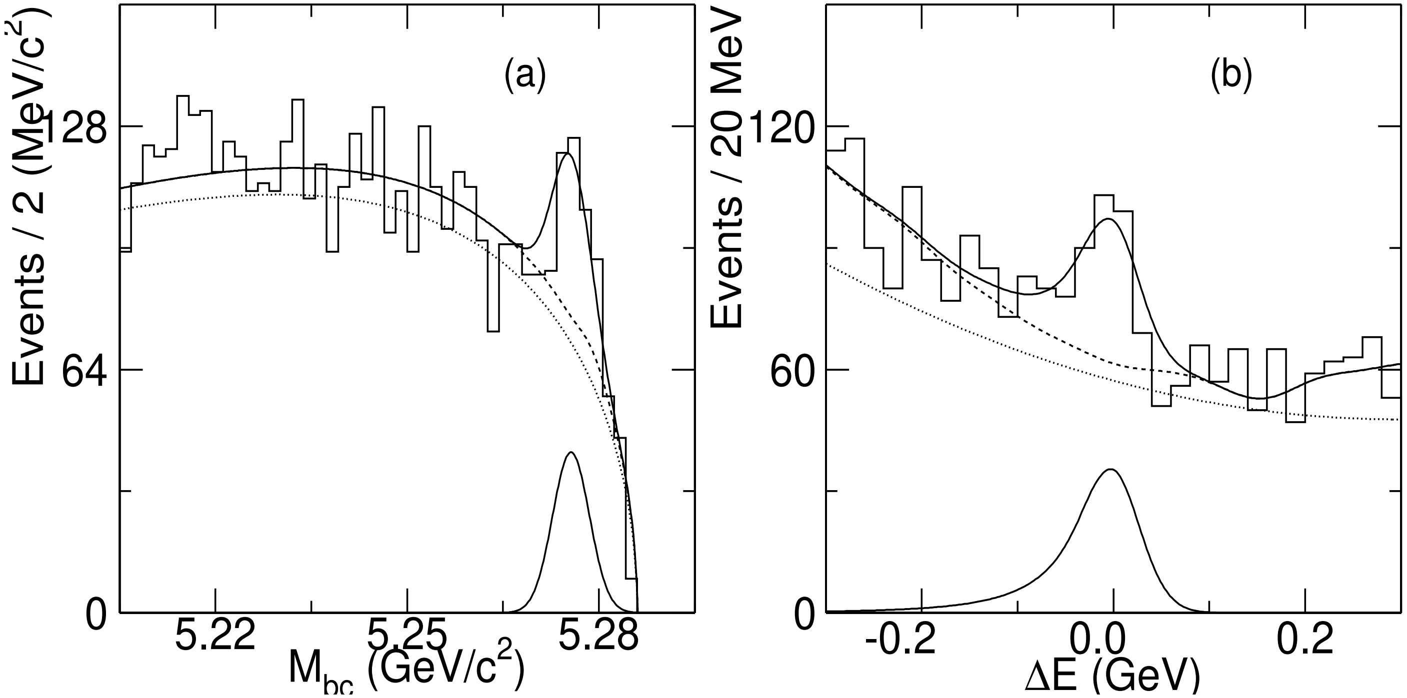
- $\alpha^2 = 0.86 \pm 0.15 \pm 0.05;\ \alpha^2_{non\ \phi} = 1.04 \pm 0.10 \pm 0.06$
  or $\alpha^2 = 0.82 \pm 0.12 \pm 0.06;\ \alpha^2_{non\ \phi} = 0.97 \pm 0.15 \pm 0.07$

- Evidence of dominant CP-even component in non-ϕ $K_S K^+ K^-$ state.

- Sample can be used for CP fit

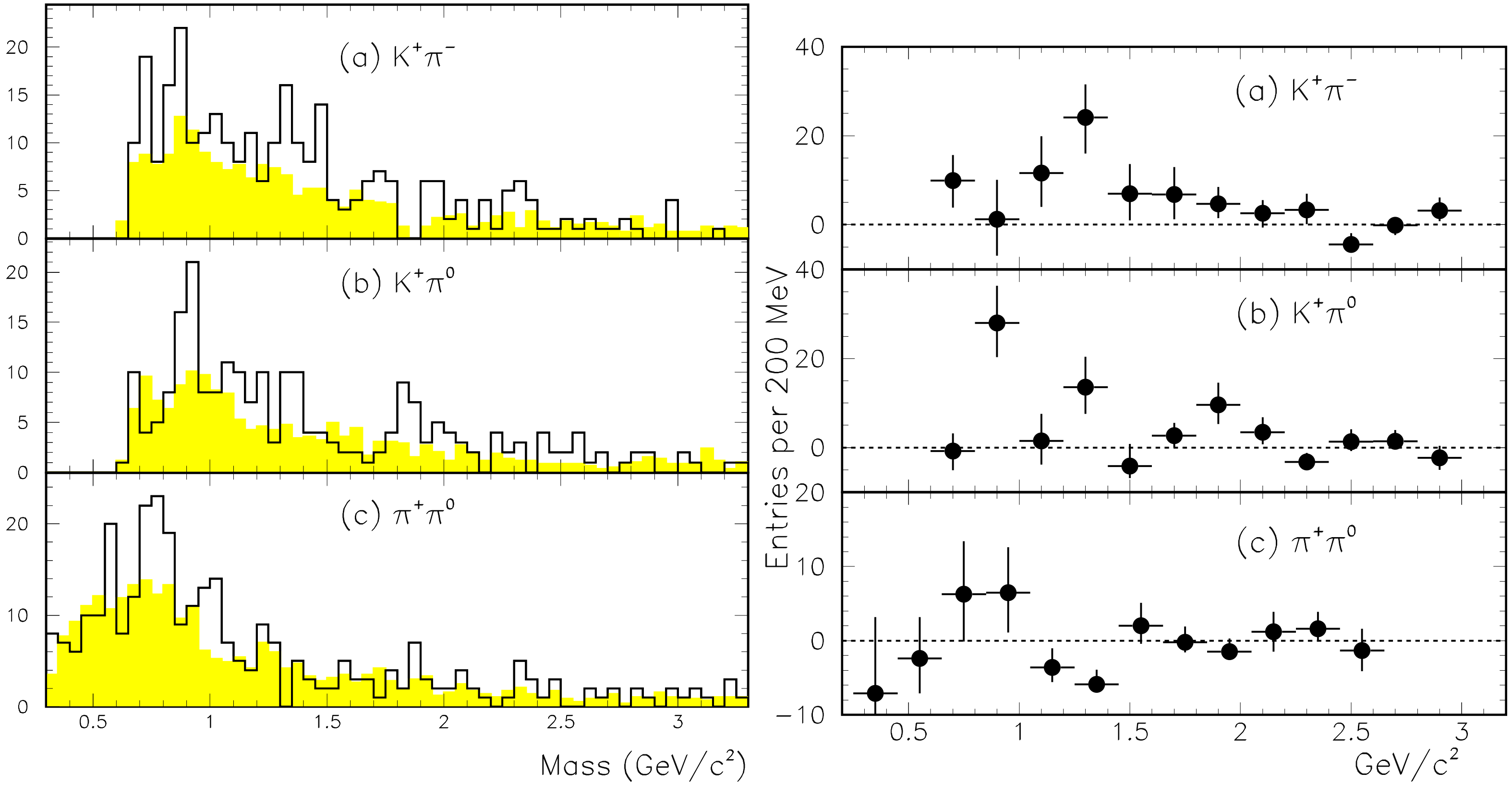
$B^0 \to K^+\pi^-\pi^0$ from Belle

Data Sample	π^0 momentum	Signal Yield	Sig.
M_b fit	No Requirement	$169.4^{+26.2}_{-25.5}$	7.3
ΔE fit	$p < 0.5$	$9.5^{+9.1}_{-8.4}$	1.1
	$0.5 < p < 1.5$	$40.2^{+14.2}_{-13.6}$	3.1
	$p > 1.5$	$123.1^{+25.5}_{-24.9}$	5.2
Sum		$172.8^{+30.5}_{-29.6}$	6.1



$$\mathcal{B}(B^0 \to K^+\pi^-\pi^0) = (47.1^{+8.3}_{-8.1}(stat.)^{+6.4}_{-6.3}(Syst.)) \times 10^{-6}$$

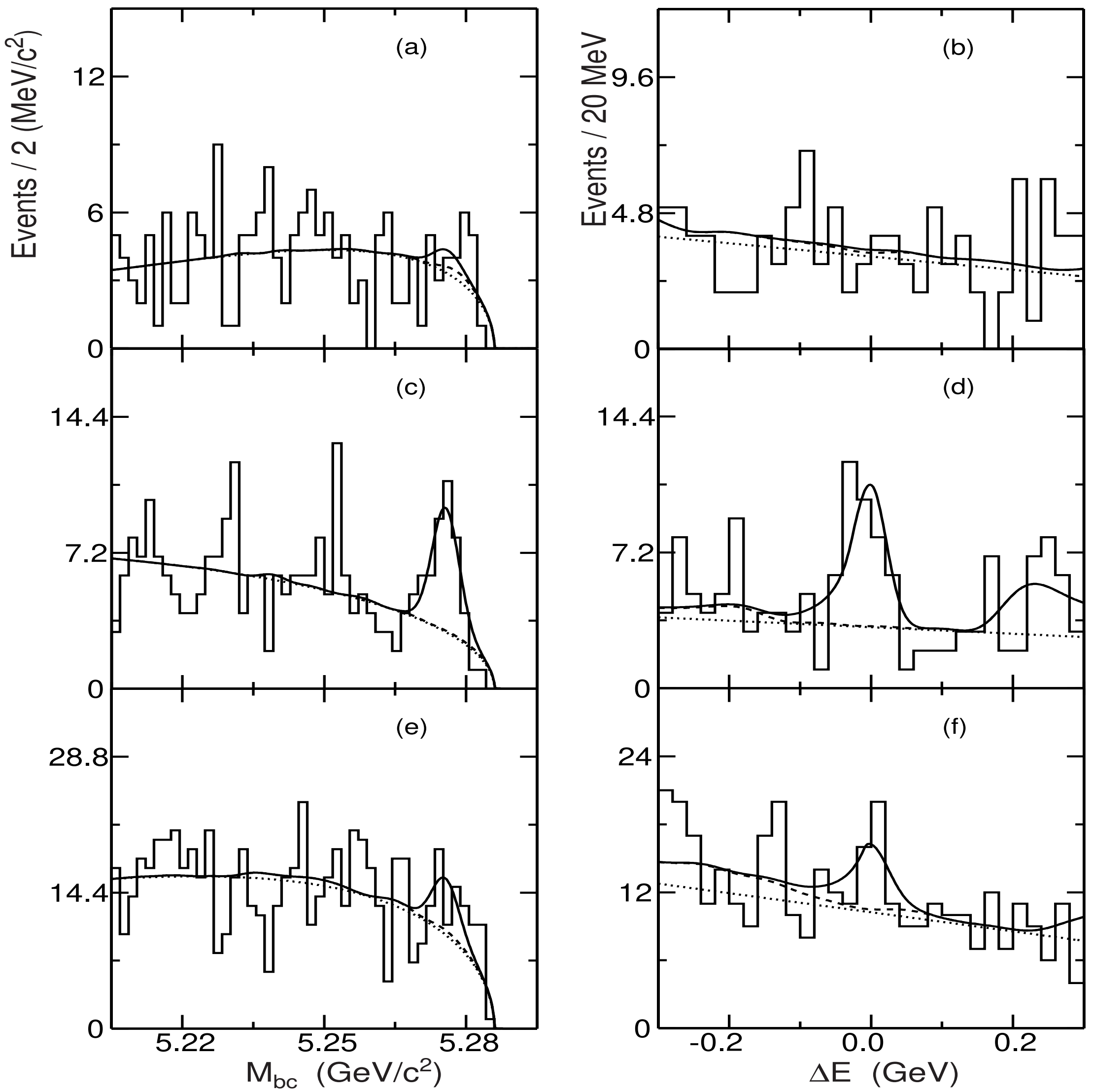
Two-body mass spectra



- Cut out the interference region to avoid cross talk.
- Observe excess in high mass $K^+\pi^-$ region (1.1-1.8 GeV/c^2).
- More structures in the $K^+\pi^0$ mass spectrum: $K^*(892)^+, K_x^*$
- Observe $(K^-)\rho^+ \to \pi^+\pi^0$

PV decays

- $K^*(892)^0\pi^0$ (a,b)
- $K^*(892)^+\pi^-$ (c,d)
- $\rho(770)^+K^-$ (e,f)

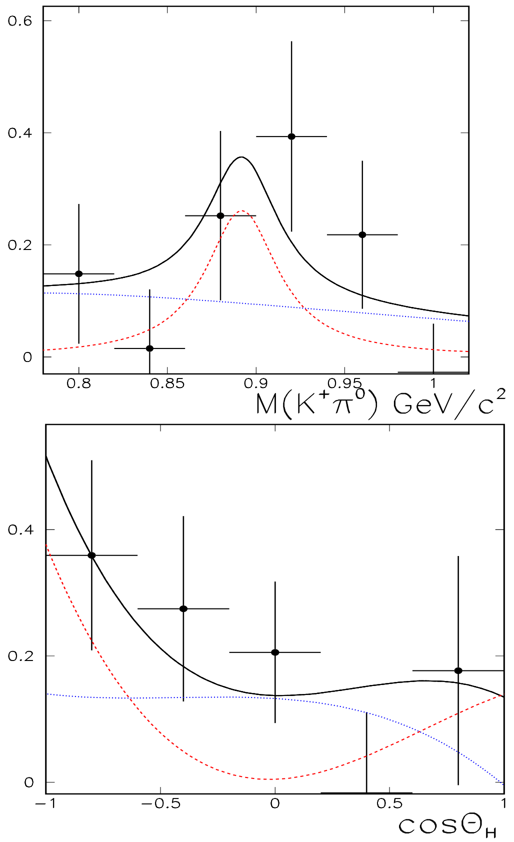


PV decays, cont (BELLE-CONF-0227)

Channel	Yield	Eff.(%)	Sig.	Frac.	BF (10^{-6})	U.L. (10^{-6})
$K^+\pi^-\pi^0$	$172.8^{+30.5}_{-29.6}$	11.6	6.1	-	$47.6^{+8.3}_{-7.7} \pm 5.2$	-
$K^{*0}(892)\pi^0$	$0.6^{+7.6}_{-6.5}$	10.3	-	-	-	7.0
$K^{*+}(892)\pi^-$	$26.6^{+8.0}_{-7.3}$	8.6	4.2	$0.45^{+0.24}_{-0.23}$	$13.0^{+3.9+2.0+6.9}_{-3.6-1.8-6.1}$	30.4
ρ^+K^-	$22.5^{+11.8}_{-11.2}$	6.4	2.1	-	$11.2^{+5.9+1.9}_{-5.6-1.8}$	22.7

- $\mathcal{B}(K^{+*}\pi^-) = (29.2^{+8.8+4.6}_{-8.1-4.0}) \times 10^{-6}$
  Assume only $K^*(892)^+$ state
- K^{*+} are not polarized.
- Assume a scalar contribution

  "$\kappa^+(797)$" or phase-space model
- Fit $M(K^+\pi^0)$ and $\cos\theta_H$.
  K^* Frac.: $0.45^{+0.24}_{-0.23}(\kappa^+\pi^-)$
  or $0.50^{+0.23}_{-0.22}$ (phase-space)
- Upper limit for $K^*(892)^+\pi^-$
- Need more data to clarify

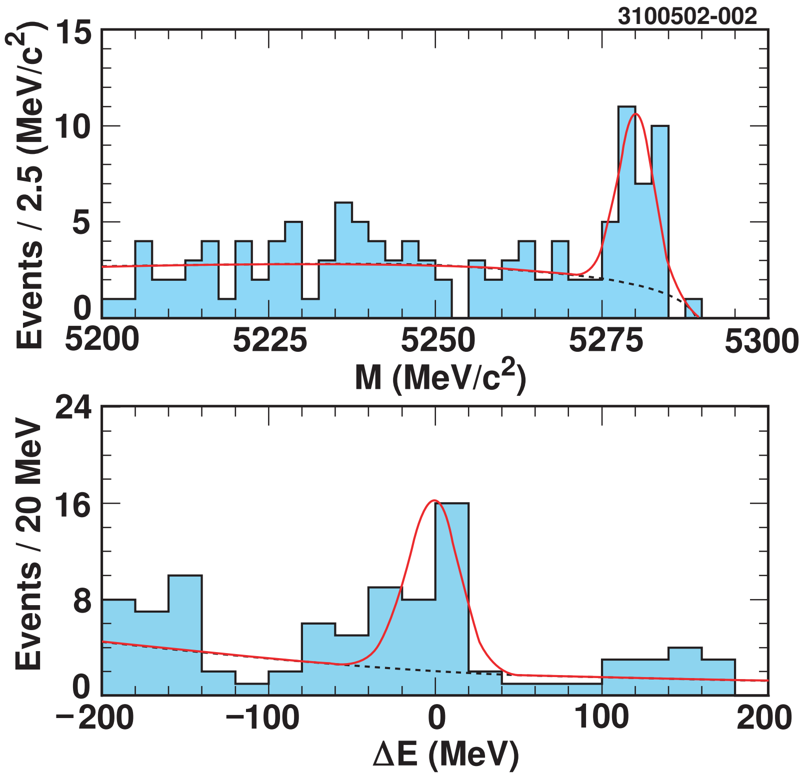


Three-body Analysis from CLEO, 9.12 fb^{-1} on-res.

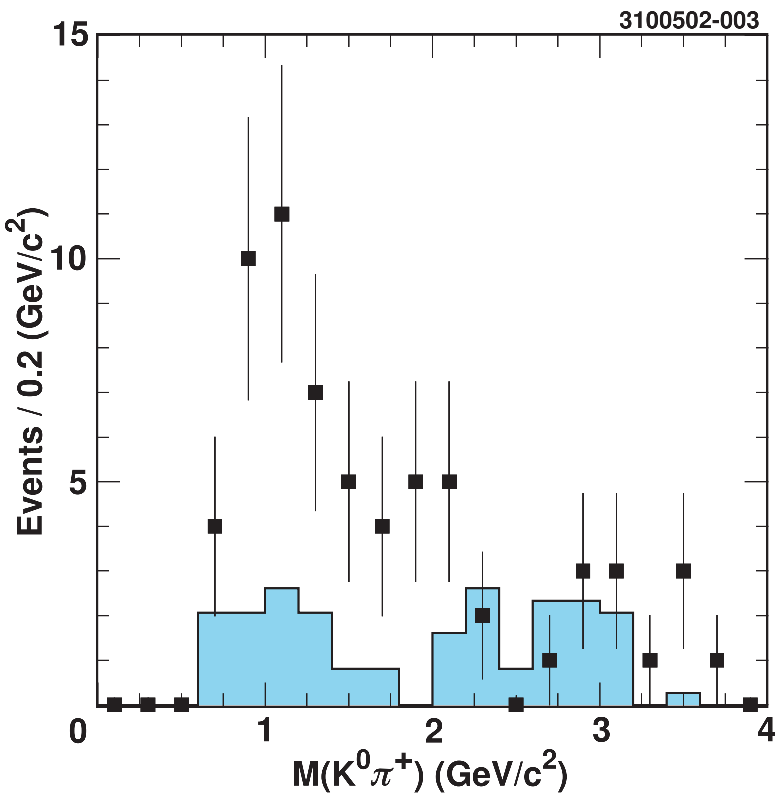
- Study $K^0_S h^+\pi^-, K^+h^-\pi^0, K^0_S h^+\pi^0$ with $p(\pi^0) > 1$ GeV/c

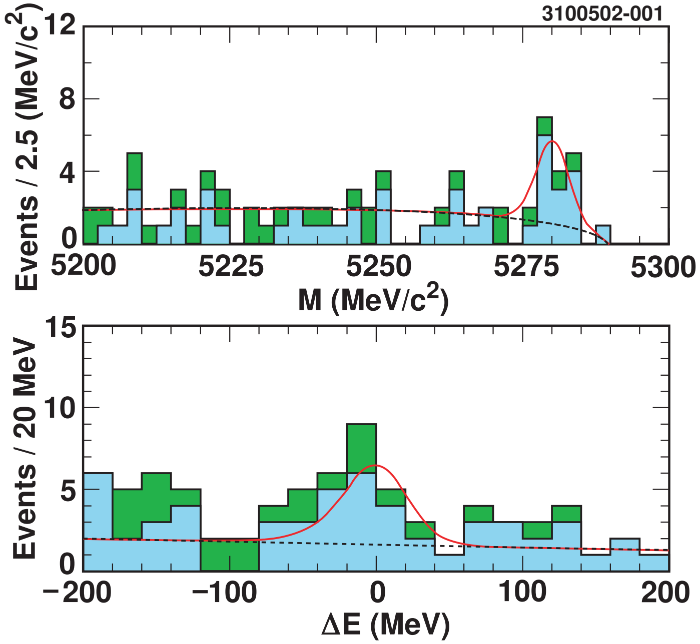
Mode	Raw Yield	Significance	ϵ (%)	$\mathcal{B} \times 10^{-6}$
$K^0\pi^+\pi^-$	$60.2^{+11.5}_{-10.6}$	8.1σ	12	$50^{+10}_{-9} \pm 7$
$K^+\pi^-\pi^0$	$43.0^{+14.5}_{-13.5}$	3.7σ	19	< 40

- $K^0\pi^+\pi^-$ is statistically significant. Consistent with Belle $\mathcal{B} = (53.2 \pm 11.3 \pm 9.7) \times 10^{-6}$
- Cannot directly compare the Belle $K^+\pi^-\pi^0$ results CLEO requires $p(\pi^0) > 1$ GeV/c
- hep-ex/0206024



CLEO $B \to K^{*+}(892)\pi^-$





- Observe $K^*(892)^+$ and $K_0^*(1430)^+$ enhancements.
- Perform Dalitz plot fits by constraining equal BR. for each $K^+(X)h^-$
- $12.6^{+4.6}_{-3.9}$ $K^* \to K^0\pi^+$ and $6.1^{+2.2}_{-1.9}$ $K^* \to K^+\pi^0$ events
- $\mathcal{B}(B^0 \to K^*(892)^+\pi^-) = (16^{+6}_{-5} \pm 2) \times 10^{-6}$, Sig. $= 4.6\sigma$.

Summary

- Lots of three-body decay studies have been performed.
- In $K^+h^+h^-$ decays, Belle observed $K^{*0}\pi^+, \chi_{c0}K^+$ and $f_0(980)K^+$
- Intermediate two-body decays for $K^0\pi^+\pi^-$ and $K^+\pi^-\pi^0$
  - CLEO measured $\mathcal{B}(B^0 \to K^{*+}\pi^-) = (16^{+6}_{-5} \pm 2) \times 10^{-6}$
  - Hint for signals for $K^{*+}\pi^-$ and upper limits for $K^{*0}\pi^0, \rho^+K^-, \rho^0K^0, f_0K^0$
  - Perform Dalitz analysis with more statistics.
- All branching KKK fractions are measured by Belle
  - Besides $\phi \to K^+K^-$, observe a broad KK mass spectrum
  - Small $b \to u$ contri.; Predominant CP-even for non-ϕ $K^0_SK^+K^-$
  - Use $K^0_SK^+K^-$ candidates for time-dependent CP fit.

    $\Rightarrow$ Aushev's talk in CP-3.

    $\Rightarrow$ Yamauchi's talk in the plenary session.

CP fit on $K_S K^+ K^-$