[919] $b \to d$ and other charmless B decays at Belle

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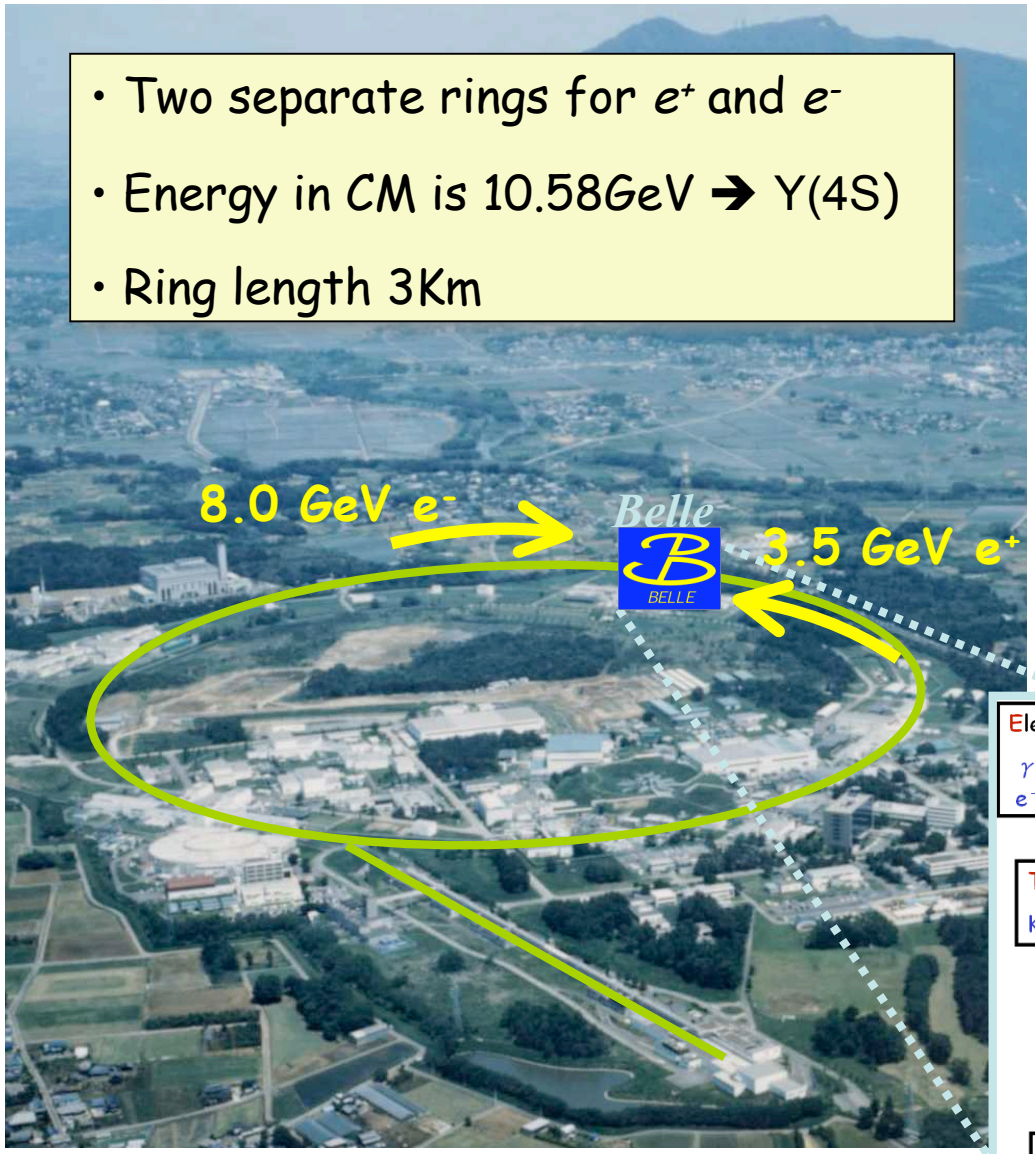
Outline

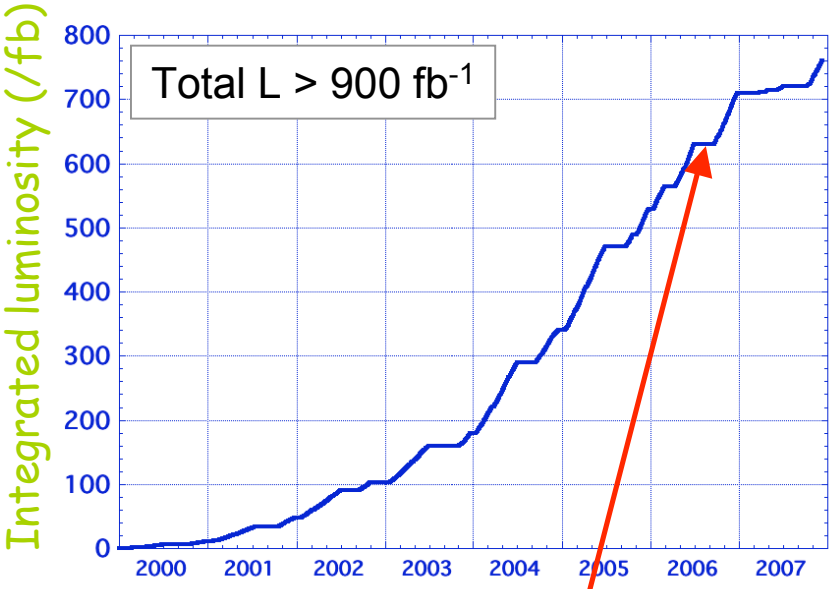
- The KEKB and Belle Detector
- $B^- \to K^{*0} K^-$ Decay

  (Preliminary result)
- $B^0 \to K^{*0} \overline{K}^{*0}$ and $B^0 \to K^{*0} K^{*0}$ Decays

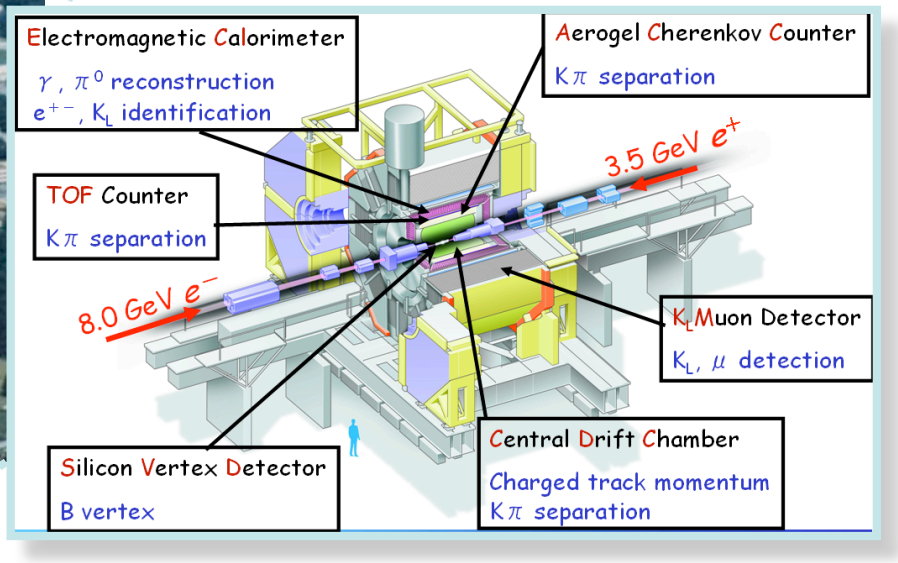
  (Preliminary results)
- Summary

KEKB e^+e^- Collider



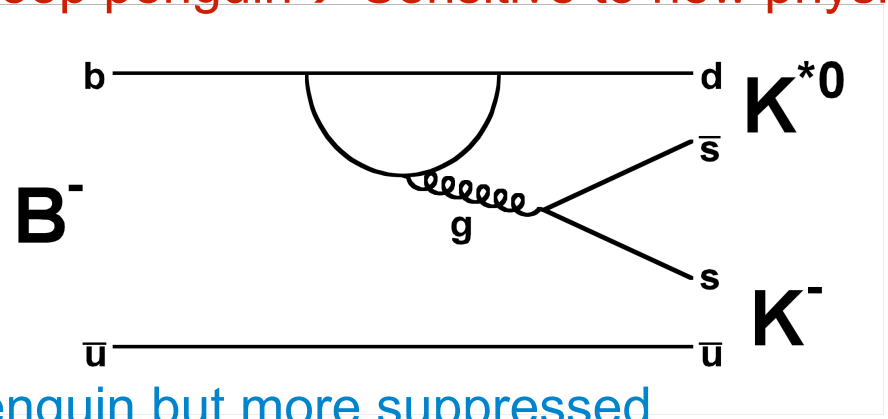


Results are based on 657 $M\bar{B}\bar{B}$ pairs



$b \to d$ FCNC process: $B^- \to K^{*0} K^-$ decay

- $b \to dg$ process: One-loop penguin→ Sensitive to new physics



- Analogous to $b \to s$ penguin but more suppressed

$\Gamma(b \to d)/\Gamma(b \to s) \sim |V_{td}|^2/|V_{ts}|^2 \sim 4\%$

- Currently, only a few $b \to dg$ modes are observed

$B^0 \to K^0 K^0$ BaBar [PRL 97, 171805 (2006)], Belle [PRL 98, 181804 (2007)]

$B^0 \to K^{*0} \bar{K}^{*0}$ BaBar [PRL 100, 081801 (2008)]

- Current status of the of $B^- \to K^*(892)^0 K^-$ measurements : UL only

- Exp. CLEO BF <5.3 x10^{-6} [PRL 85, 2881 (2000)]

Exp. BaBar BF = [0.6±0.3±0.2(<1.1)] x10^{-6} (1.6σ) [PRD 76, 071103 (2007)]

- Theoretical predictions

~0.5 x10^{-6} Flavour SU(3) +exp. [PRD 71, 051501 (2005); PRD 69, 034001 (2004)]

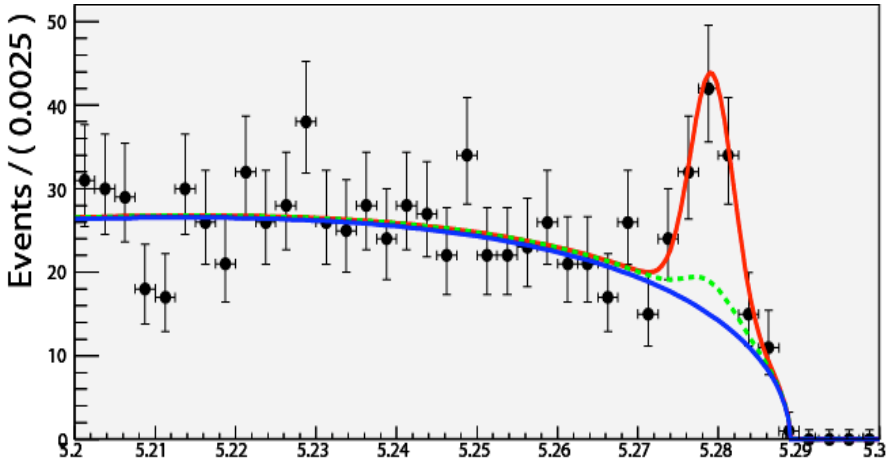
~0.3 x10^{-6} Perturbative QCD factorization [PRD 75, 014019 (2007)]

Measurement of $B^- \to K^{*0} K^-$ decay

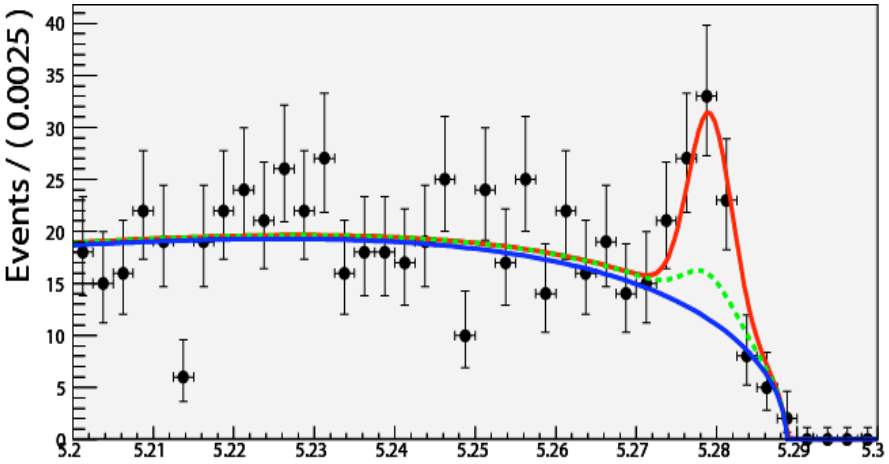
Belle 657M BB
Preliminary

M_{bc} for $|\Delta E|<0.043$

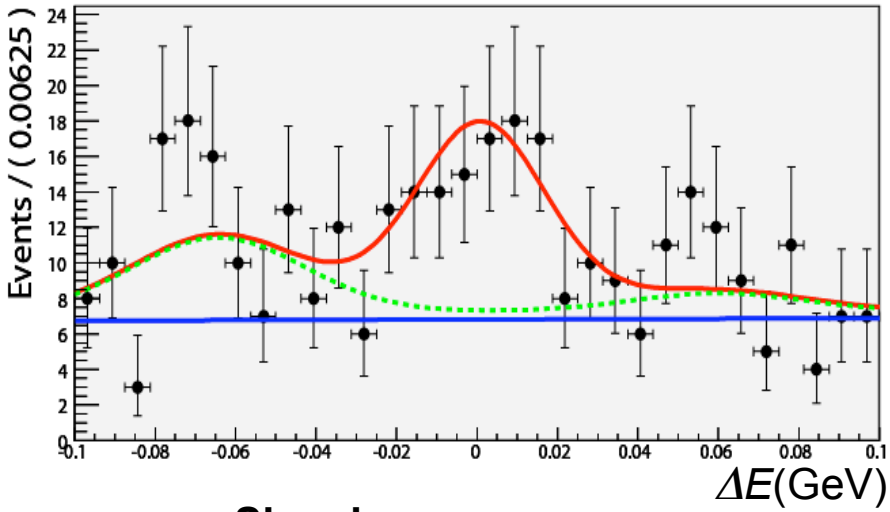
$B^- \to K^*(892)^0 K^-$

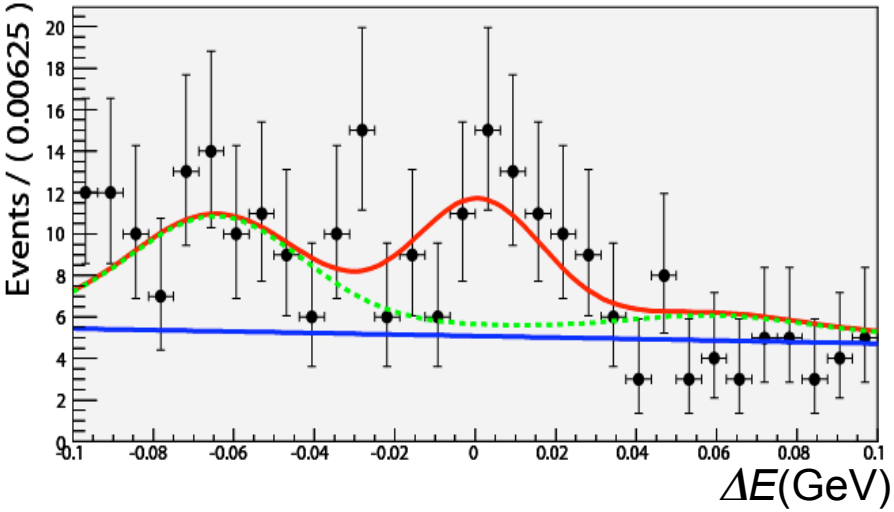


$B^- \to K^*(1430)^0 K^-$



ΔE for $|M_{bc}-5.279|<0.0081$

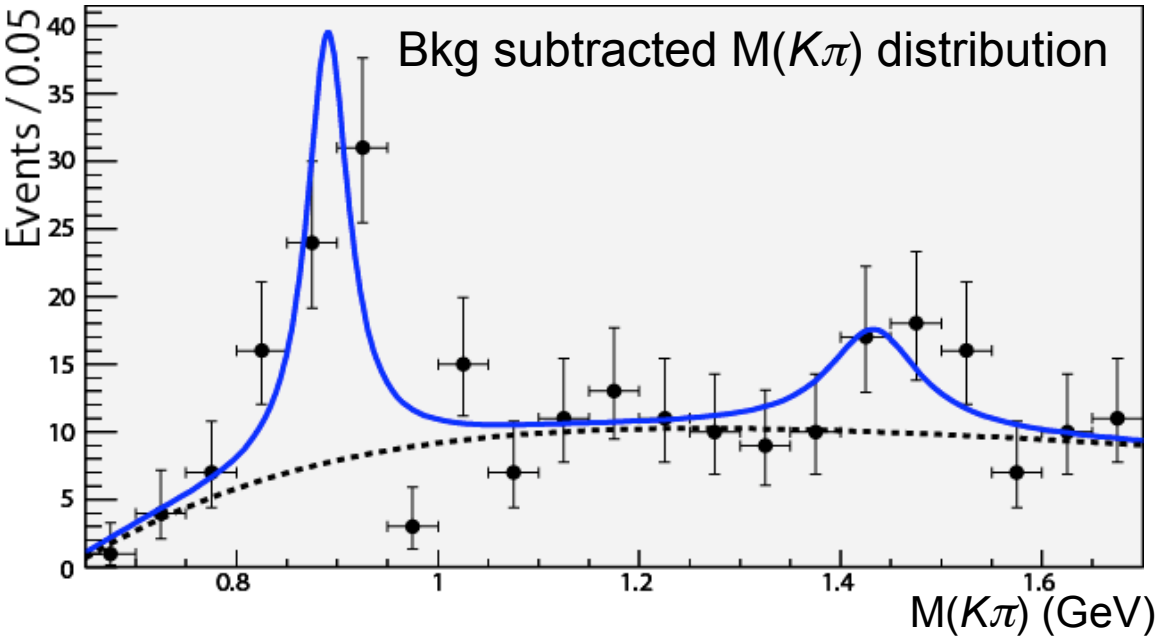




Signal
qq BG
rare-B BG

(at this page the signal includes also $B \to KK\pi$ component)

Evidence of $B^- \to K^*(892)^0 K^-$



Belle 657M BB
Preliminary

Yield of the $K^*(892)^0 K$, $K^*_{0/2}(1430)^0 K$, and non-resonant $KK\pi$ are determined by M($K\pi$) fitting

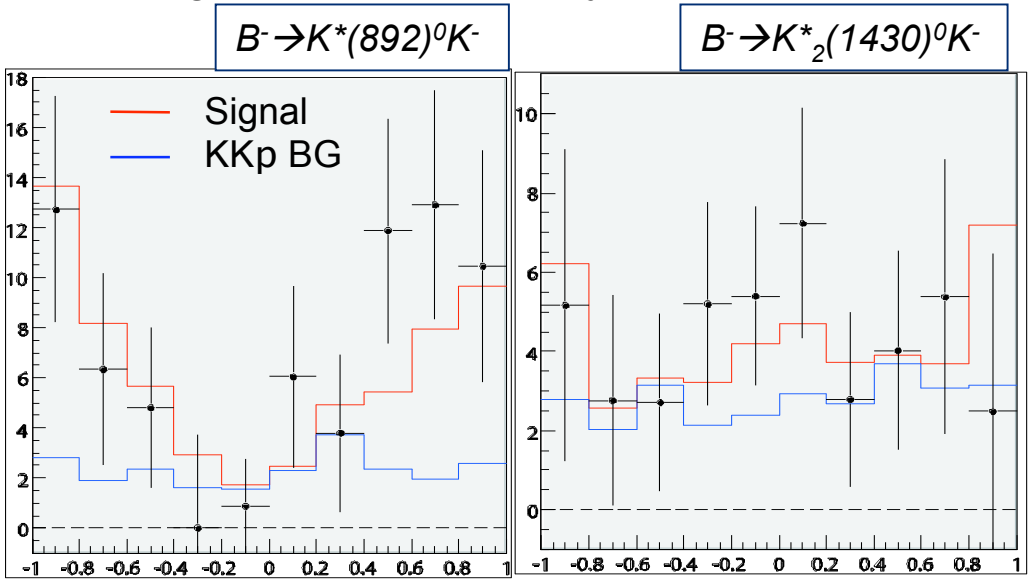
$B^- \to K^*(892)^0 K^-$
Yield : 47.72 ± 11.13

BF : [0.68±0.16±0.10] x10^{-6} (4.4σ)

First evidence of $B^- \to K^*(892)^0 K^-$

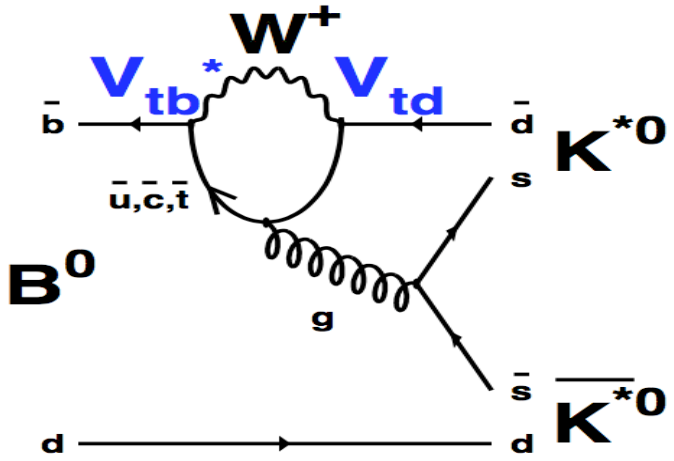
$B^- \to K^*_{0/2}(1430)^0 K^-$
Yield : 23.35 ± 12.13
BF : [0.63±0.33±0.12(<1.10)] x10^{-6}
(1.5σ)

Bkg subtracted helicity distributions



$B^0 \to K^{*0}\overline{K}^{*0}$ Decay

- This is a *B→VV* decay with *b→d* process:



- The longitudinal polarization fraction f_L of $K^{*0}\overline{K}^{*0}$ can verify a theoretical explanation for $B^0 \to \phi K^{*0}$ puzzle (f_L ~0.5). [Phys. Lett. B 622, 63 (2005)]
- A method for clean determination of the CKM phase angles ϕ_2 (α) and ϕ_3 (γ) using only direct CP violation of decays $B_{u,d,s} \to VV$, such as $B_{d,s} \to K^{*0}\overline{K}^{*0}$. [PRD 65, 073018 (2002); PRD 76, 074005 (2007)]
- The current status:
  - BaBar: $BF = (1.28^{+0.35}_{-0.30} \pm 0.11) \times 10^{-6}$ (6σ), $f_L = 0.80^{+0.10}_{-0.12} \pm 0.06$ [PRL 100, 081801 (2008)]
  - Theoretical predictions: $BF = (0.17 \sim 0.92) \times 10^{-6}$, $f_L = 0.04 \sim 1.0$ [PRD 72, 094026 (2005); Nucl. Phys. B774, 64 (2007); PRD 78, 094001 (2008)]

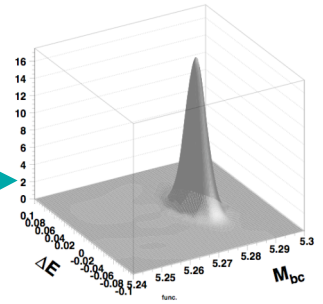
$B^0 \to K^{*0}\overline{K}^{*0}$ Decay

Analysis method:

- Reconstruct B^0 with four charged tracks (2 Kaons, 2 pions) :

  $B^0 \to K^{*0}\overline{K}^{*0} \to (K^+\pi^-)(K^-\pi^+)$

- Reconstructed variables :
  - Beam-energy constrained mass: $M_{bc} = \sqrt{E_{beam}^2 - P_B^2}$
  - Energy difference : $\Delta E = E_B - E_{beam}$
  - Two $K\pi$ invariant masses : $M_{K\pi} = \sqrt{E_{K\pi}^2 - P_{K\pi}^2}$



For *B* decays

$B^0 \to K^{*0}\overline{K}^{*0} \to K^+\pi^-K^-\pi^+$

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

$B^0 \to K_0^*(1430)\overline{K}_0^*(1430) \to K^+\pi^-K^-\pi^+$

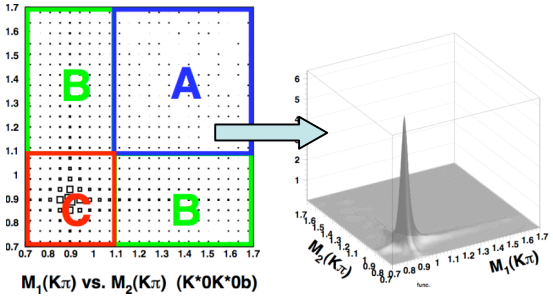
$B^0 \to K_0^*(1430)\overline{K}^{*0} \to K^+\pi^-K^-\pi^+$

$B^0 \to K_0^*(1430)K^-\pi^+ \to K^+\pi^-K^-\pi^+$

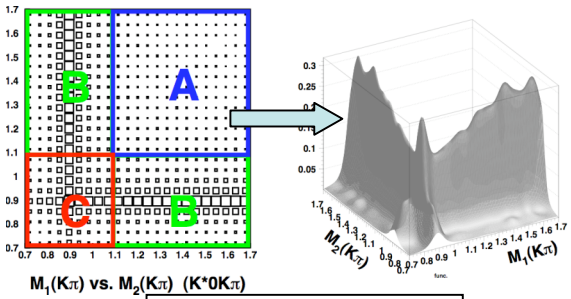
$B^0 \to K^+\pi^-K^-\pi^+$

We can distinguish and measure these decays from $M_{K+\pi-}$ vs. $M_{K-\pi+}$ distributions.

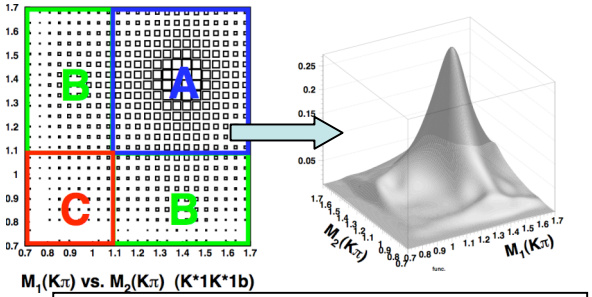
$M_{1(K\pi)}$ vs. $M_{2(K\pi)}$ distributions for different B decays



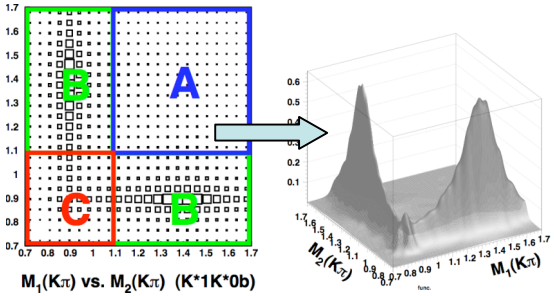
$B \to K^{*0}\overline{K}^{*0}$ (MC)



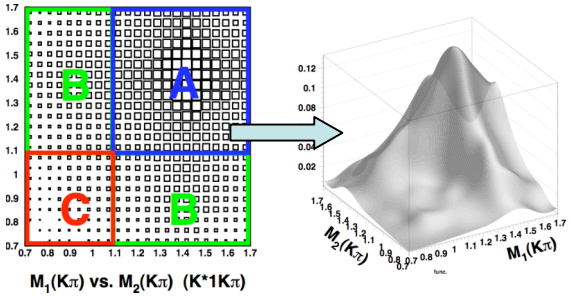
$B \to K^{*0}K\pi$ (MC)



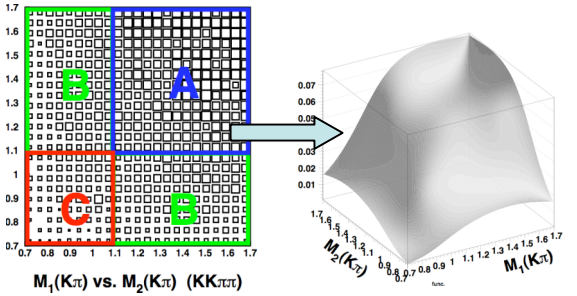
$B \to K_0^*(1430)\overline{K}_0^*(1430)$ (MC)



$B \to K_0^*(1430)\overline{K}^{*0}$ (MC)

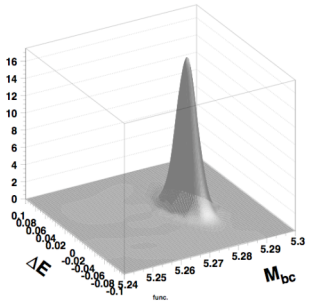


$B \to K_0^*(1430)K\pi$ (MC)



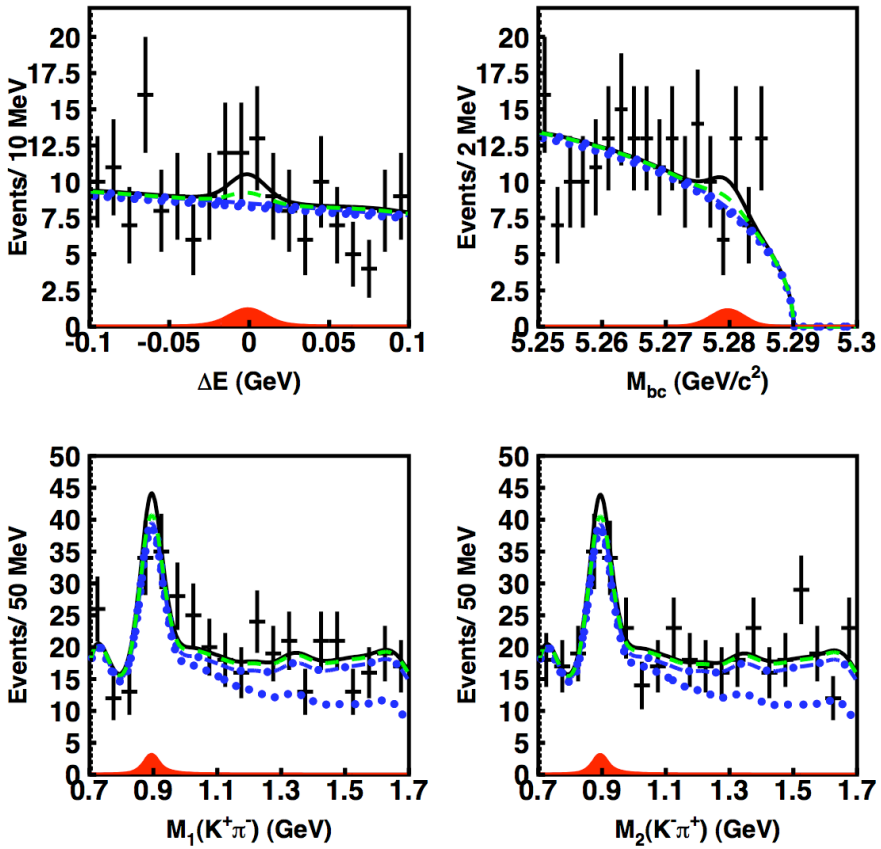
non-resonant $B \to K^+K^-\pi^+\pi^-$ (MC)

ps: Their $(\Delta E, M_{bc})$ distributions are the same:



$B^0 \to K^{*0}\overline{K}^{*0}$ Decay

657M BB sample



Preliminary

- These plots are projected in $K^{*0}\overline{K}^{*0}$ signal region: $5.27<M_{bc}<5.29$ (GeV), $|\Delta E|<0.045$ (GeV) and $0.826<M_{1,2}(K\pi)<0.966$ (GeV)

: $B^0 \to K^{*0}\overline{K}^{*0}$
: Continuum
: $b \to c$ decays
: Other charmless B decays

$B^0 \to K^{*0}\overline{K}^{*0}$ Decay

Final state: ($K^+\pi^-$)($K^-\pi^+$)

Preliminary

Mode	Yield	Eff.(%)	Σ	BF (x10^{-6})	UL (x10^{-6})
$K^{*0}\overline{K}^{*0}$	$7.7^{+9.7+2.8}_{-8.4-2.0}$	4.43 (f_L=1)	0.9	$0.3 \pm 0.3 \pm 0.1$	< 0.8 (f_L=1)
$K^{*0}K\pi$	$18.2^{+48.4+41.6}_{-45.3-40.7}$	1.31*	0.3	$2.1^{+5.6+4.8}_{-5.3-4.7}$	< 13.9
$K_0^*(1430)\overline{K}_0^*(1430)$	$78.5^{+70.6+56.1}_{-69.6-56.6}$	3.72*	0.8	$3.2^{+2.9}_{-2.8} \pm 2.3$	< 8.4
$K_0^*(1430)\overline{K}^{*0}$	$19.6^{+31.1+40.0}_{-31.0-42.9}$	4.38*	0.4	$0.7 \pm 1.1^{+1.4}_{-1.5}$	< 3.3
$K_0^*(1430)K\pi$	$-222.8^{+171.5+159.5}_{-170.8-168.6}$	1.34*	…	…	< 31.8
Non-resonant $K^+K^-\pi^+\pi^-$	$158.4^{+120.6+103.9}_{-117.8-104.9}$	0.82*	1.0	$29.4^{+22.4+19.3}_{-21.9-19.5}$	< 71.1
Non-resonant $K^+\pi^-\pi^+\pi^-$ & $K^-\pi^+\pi^+\pi^-$	$150.1^{+44.1+14.6}_{-42.9-15.7}$	0.06*	3.5	$380.8^{+111.9+37.0}_{-108.8-39.9}$	…

* Partial Efficiency

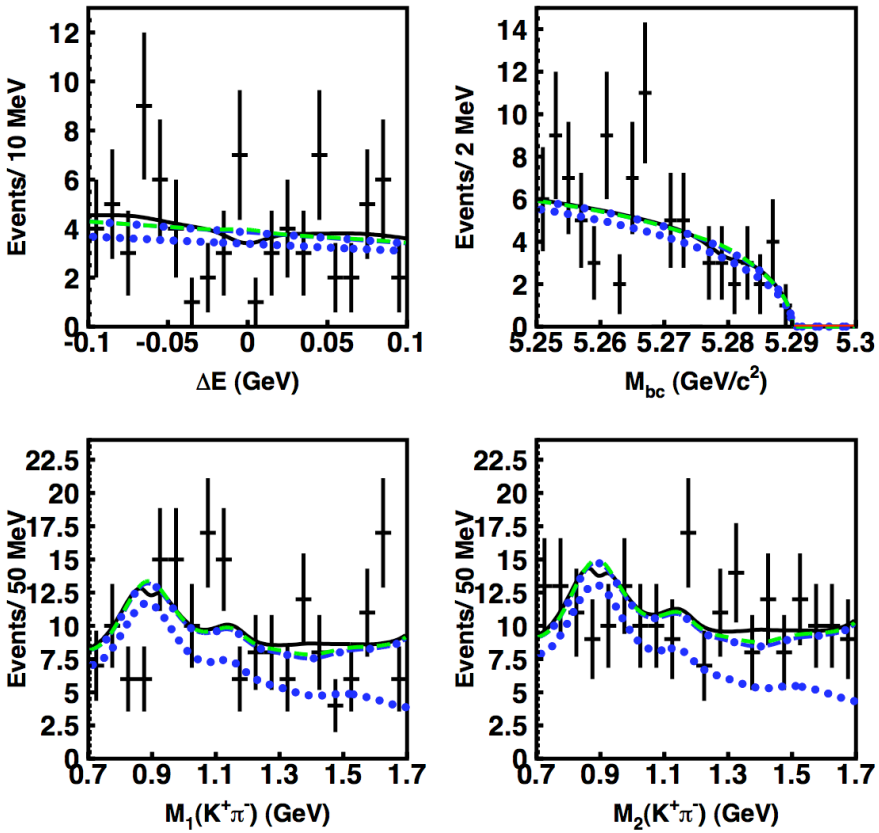
Assume: $K^{*0} \to K^+\pi^-(66.51\%)$

$K_0^*(1430) \to K^+\pi^-(66.67\%)$

$B^0 \to K^{*0}K^{*0}$ Decay

657M BB sample

Preliminary



- This mode has a different charge final state: **(*K*+π-)(*K*+π-)**.
- The standard model forbidden decay $B^0 \to K^{*0}K^{*0}$ is not expected to be found unless there is a new process that we do not find yet.

: $B^0 \to K^{*0}K^{*0}$
: Continuum
: $b \to c$ decays
: Other charmless B decays

$B^0 \to K^{*0}K^{*0}$ Decay

Final state: ($K^+\pi^-$)($K^+\pi^-$)

Preliminary

Mode	Yield	Eff.(%)	Σ	BF (x10^{-6})	UL (x10^{-6})
$K^{*0}K^{*0}$	$-3.7 \pm 3.3^{+2.4}_{-2.7}$	5.74 (f_L=1)	…	…	< 0.2 (f_L=1)
$K^{*0}K\pi$	$0.4 \pm 32.3^{+43.4}_{-40.0}$	1.93*	0.0	$0.0 \pm 2.5^{+3.4}_{-3.2}$	< 7.6
$K_0^*(1430)K_0^*(1430)$	$-28.4 \pm 16.1^{+87.6}_{-21.1}$	4.28*	…	…	< 4.7
$K_0^*(1430)K^{*0}$	$8.0 \pm 18.7^{+23.9}_{-30.3}$	5.14*	0.3	$0.2 \pm 0.6^{+0.7}_{-0.9}$	< 1.7
Non-resonant $K^+K^+\pi^-\pi^-$	$10.8 \pm 28.3^{+31.4}_{-101.4}$	1.98*	0.3	$0.8 \pm 2.2^{+2.4}_{-7.8}$	< 6.0
Non-resonant $K^+\pi^-\pi^+\pi^-$	$24.1 \pm 29.1^{+8.2}_{-5.2}$	0.03*	0.8	$61.2 \pm 73.8^{+20.7}_{-13.3}$	< 177.6

* Partial Efficiency

Assume: $K^{*0} \to K^+\pi^-(66.51\%)$

$K_0^*(1430) \to K^+\pi^-(66.67\%)$

Control samples with same final states

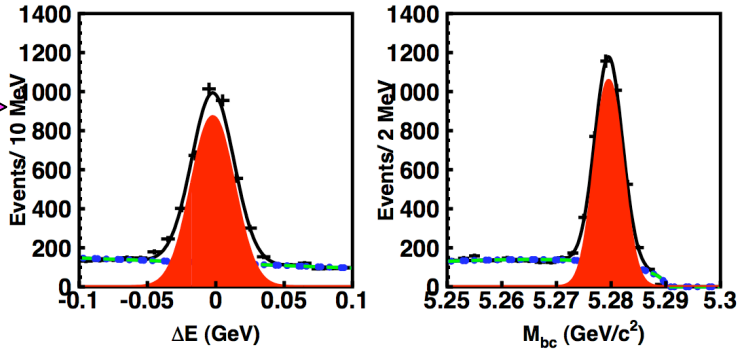
ΔE-M_{bc} fit with tighter mass cut on M($KK\pi$).

657M BB sample

$$B^0 \to D^-\pi^+ \to (K^+K^-\pi^-)\pi^+,$$

$$\overline{B}^0 \to D^+\pi^- \to (K^+K^-\pi^+)\pi^-$$

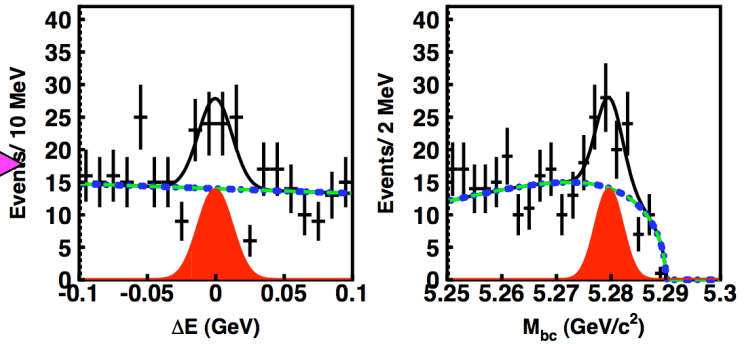
ps: $B^0 \to K^{*0}\overline{K}^{*0} \to (K^+\pi^-)(K^-\pi^+)$



ΔE-M_{bc} fit with tighter mass cut on M($K\pi$).

$$B^0 \to \overline{D}^0 K^{*0} \to (K^+\pi^-)(K^+\pi^-)$$

ps: $B^0 \to K^{*0}K^{*0} \to (K^+\pi^-)(K^+\pi^-)$



Mode	Eff. (%)	Estimated no. (657M BB Data)	Fit no. (ΔE-M_{bc} Fit) (657M BB Data)	Difference (%)
$B^0 \to D^{\pm}\pi^{\mp}$	19.0	3214.9 ± 155.9	3401.6 ± 68.4	+5.8 ± 5.8
$B^0 \to \overline{D}^0 K^{*0}$	11.4	40.8 ± 5.8	43.1 ± 9.3	+5.6 ± 27.8

Summary

$B^- \to K^*(892)^0 K^-$:

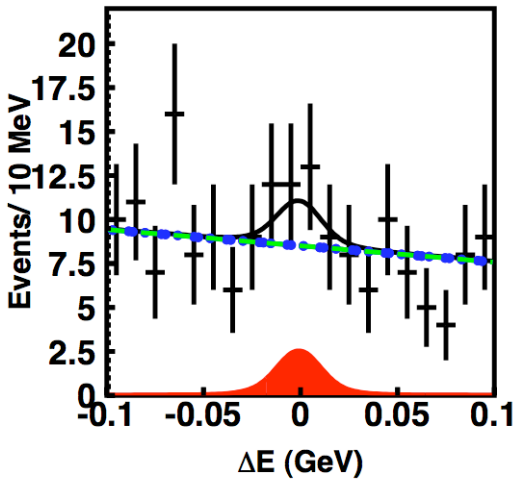
- We find evidence (4.4σ) of this mode with the branching fraction $(0.68 \pm 0.16 \pm 0.10) \times 10^{-6}$.

$B^0 \to K^{*0}\overline{K}^{*0}$:

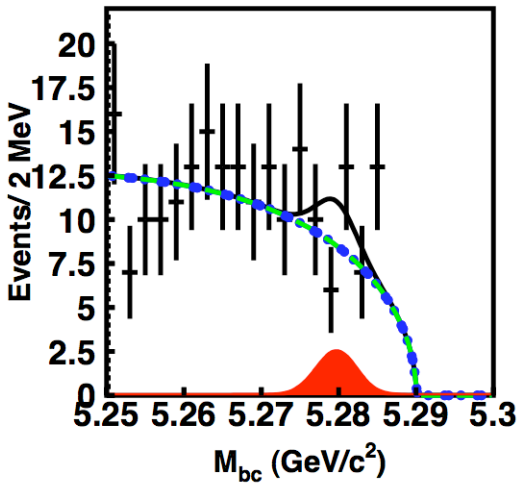
- We measure the branching fraction of $B^0 \to K^{*0}\overline{K}^{*0}$ to be $(0.3 \pm 0.3 \pm 0.1) \times 10^{-6}$ with 0.9σ significance, assuming $f_L = 1$, the 90% confidence level upper limit is $< 0.8 \times 10^{-6}$, which is within the theoretical prediction.
- The branching fraction from BaBar measurement is $(1.28^{+0.35}_{-0.30} \pm 0.11) \times 10^{-6}$, the difference of the mean branching fraction between BaBar and Belle is about 1.4σ.
- For possible feeddown decays, such as non-resonant $B^0 \to KK\pi\pi$ and $B^0 \to K_0^*(1430)X$, their yields from the simultaneous fit are not significant, so we set the corresponding upper limits.

Backup

2-D (M_{bc}-ΔE) fit in $B^0 \to K^{*0}\overline{K}^{*0}$ Signal Region



5.27<M_{bc}<5.29 (GeV) and
0.826<$M_{1,2}(K\pi)$<0.966 (GeV)

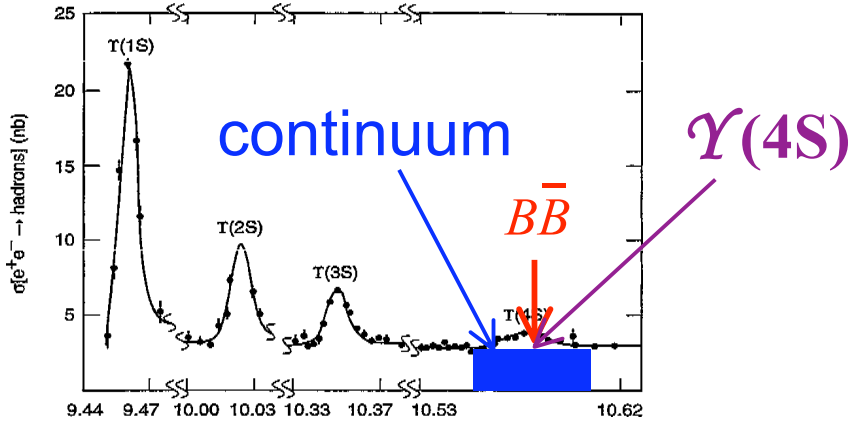


|ΔE|<0.045 (GeV) and
0.826<$M_{1,2}(K\pi)$<0.966 (GeV)

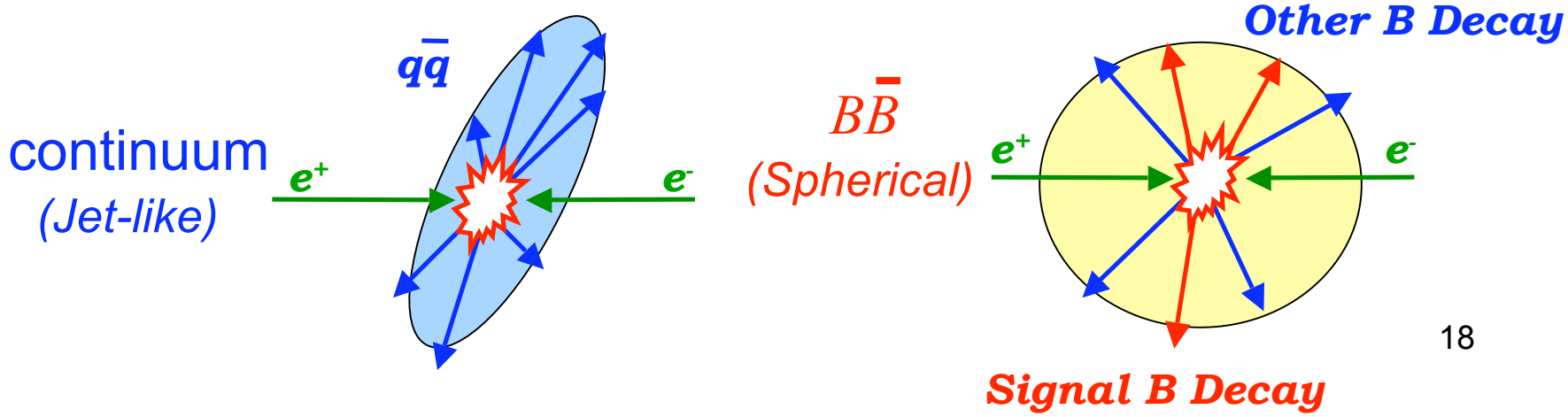
Mode	Yield	Eff. (%)	BF (x 10^{-6})
$K^{*0}\overline{K}^{*0}$	8.7 ± 6.3	2.78 (f_L = 1.0)	0.5 ± 0.3

$e^+e^- \to q\bar{q}$ (q=u,d,s,c) Background Suppression

- The dominant background in B analysis is $e^+e^- \to q\bar{q}$ (q=u,d,s,c), we called "continuum" (~ 3x $B\bar{B}$).



- To suppress continuum background, we use event shape variables and flavor tagging information.



Fit Bias Study (for 4-D Fit)

- The correlations between (ΔE, M_{bc}) and (M_1, M_2) would cause fit bias, we study this effect by MC with full detector simulation.
- We very the input number of signal events in MC ensemble data, and then check the output number of signal events from 4-D fit **(Fig. 1)**.
- To correct this fit bias we substitute the fit bias correction equations into 4-D fit likelihood function **(Fig. 2)**.
- The **MC ensemble fit** can be also used to check the correctness of statistical error of the signal yields. We define **PULL = (fit no. - Input no. of MC) / (Stat. error from the fit)**, and check its distribution from MC ensemble fit **(Fig. 3)**.

Before fit bias correction

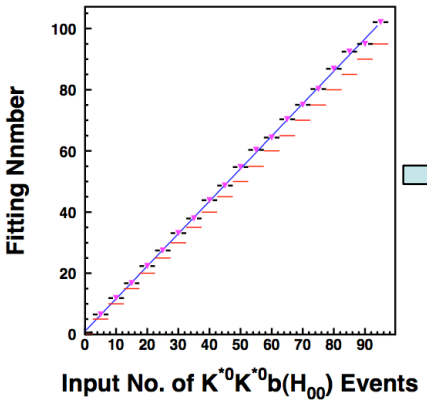


Fig. 1

After fit bias correction

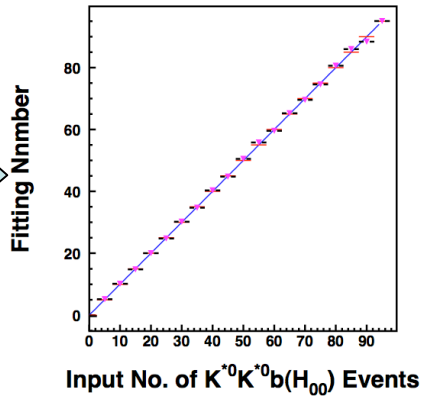


Fig. 2

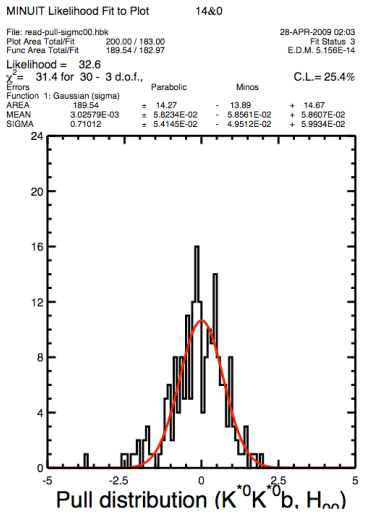


Fig. 3

The width of PULL distribution should be equal or less than 1.

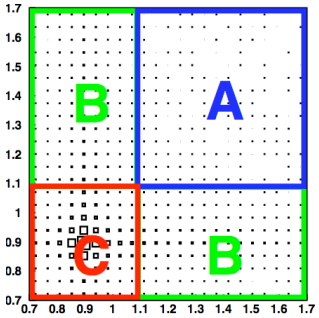
Systematic Uncertainties ($B^0 \to K^{*0}\overline{K}^{*0}$ analysis)

Source \ Mode	$K^{*0}(892)$ $K^{*0}(892)$	$K^{*0}(892)$ $K\pi$	$K_0^*(1430)$ $K_0^*(1430)$	$K_0^*(1430)$ $K^{*0}(892)b$	$K_0^*(1430)$ $K\pi$	Non-Resonant $K^+K^-\pi^+\pi^-$	Non-Resonant $K^+\pi^-\pi^+\pi^-$ & $K^-\pi^+\pi^+\pi^-$
Fitting PDF	± 0.234	± 2.22	± 0.708	± 1.92	± 0.709	± 0.646	± 0.028
N[$B^0 \to K_2^*(1430)X$]	+ 0.148	+ 0.56	- 0.09	- 1.04	- 0.237	- 0.066	- 0.037
N(Rare B)	± 0.004	± 0.003	± 0.002	± 0.004	± 0.003	± 0.006	± 0.01
f_L	- 0.007	…	…	…	…	…	…
f_{SCF}	± 0.097	± 0.076	± 0.071	± 0.113	± 0.077	± 0.092	± 0.067
Fit Bias	+ 0.201	- 0.299	+ 0.027	+ 0.678	- 0.066	- 0.068	- 0.013
Tracking	± 0.051	± 0.045	± 0.044	± 0.045	± 0.043	± 0.043	± 0.044
PID	± 0.05	± 0.037	± 0.037	± 0.037	± 0.037	± 0.038	± 0.039
LR cut	± 0.02	± 0.02	± 0.02	± 0.02	± 0.02	± 0.02	± 0.02
N(BBar)	± 0.014	± 0.014	± 0.014	± 0.014	± 0.014	± 0.014	± 0.014
Sum (fraction)	+0.364 -0.264	+2.29 -2.24	+0.715 -0.72	+2.04 -2.19	+0.716 -0.757	+0.656 -0.662	+0.097 -0.105

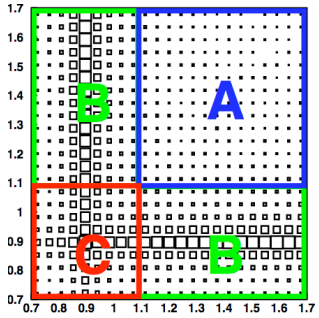
Systematic Uncertainties ($B^0 \to K^{*0}K^{*0}$ analysis)

Source \ Mode	$K^{*0}(892)$ $K^{*0}(892)$	$K^{*0}(892)$ $K\pi$	$K_0^*(1430)$ $K_0^*(1430)$	$K_0^*(1430)$ $K^{*0}(892)$	Non-Resonant $K^+K^-\pi^+\pi^-$	Non-Resonant $K^+\pi^-\pi^+\pi^-$
Fitting PDF	± 0.646	± 89.7	± 0.073	± 2.82	± 2.83	± 0.187
N[$B^0 \to K_2^*(1430)X$]	- 0.091	+ 37.8	+ 3.0	- 2.54	- 8.99	- 0.04
N[$B^0 \to K_0^*(1430)K\pi$]						
N(Rare B)	± 0.0	± 0.909	± 0.004	± 0.041	± 0.03	± 0.064
f_L	-0.182	…	…	…	…	…
f_{SCF}	± 0.039	± 0.544	± 0.028	± 0.06	± 0.023	± 0.05
Fit Bias	- 0.273	- 5.53	- 0.12	+ 1.03	+ 0.713	+ 0.262
Tracking	± 0.05	± 0.045	± 0.044	± 0.045	± 0.043	± 0.043
PID	± 0.045	± 0.038	± 0.036	± 0.036	± 0.036	± 0.04
LR cut	± 0.02	± 0.02	± 0.02	± 0.02	± 0.02	± 0.02
N(BBar)	± 0.014	± 0.014	± 0.014	± 0.014	± 0.014	± 0.014
Sum (fraction)	+0.651 -0.735	+97.3 -89.9	+3.09 -0.74	+3.0 -3.8	+2.92 -9.43	+0.338 -0.217

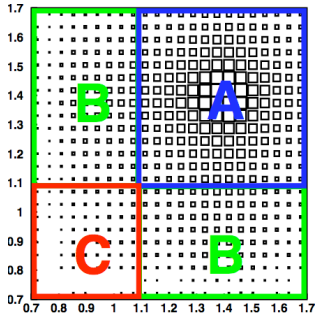
Make Projections in Three $M_{1(K\pi)}$ vs. $M_{2(K\pi)}$ Areas



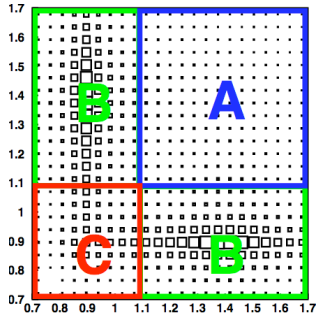
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*0K*0b)



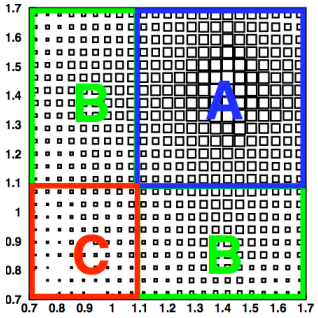
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*0Kπ)



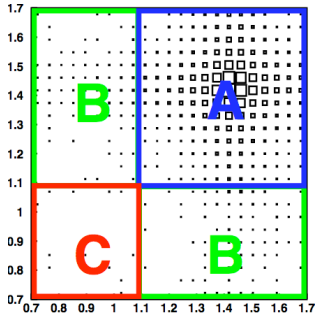
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*1K*1b)



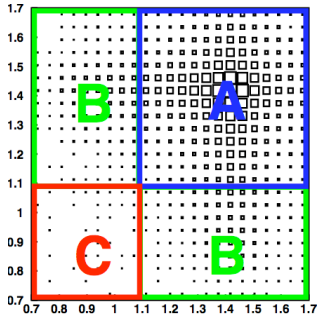
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*1K*0b)



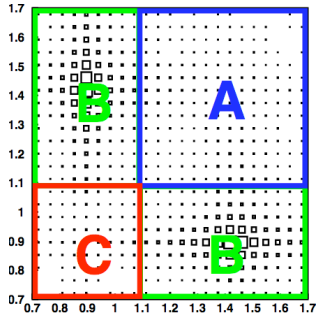
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*1Kπ)



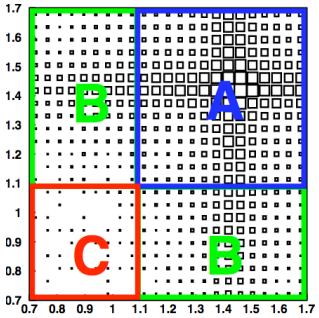
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*2K*2b)



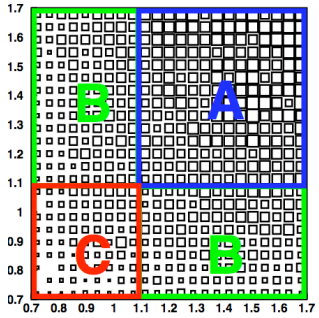
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*2K*1b)



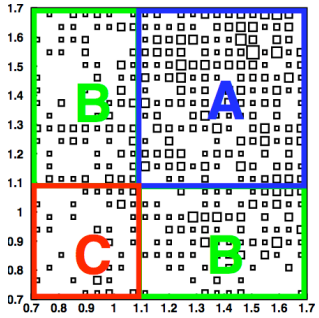
$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*2K*0b)

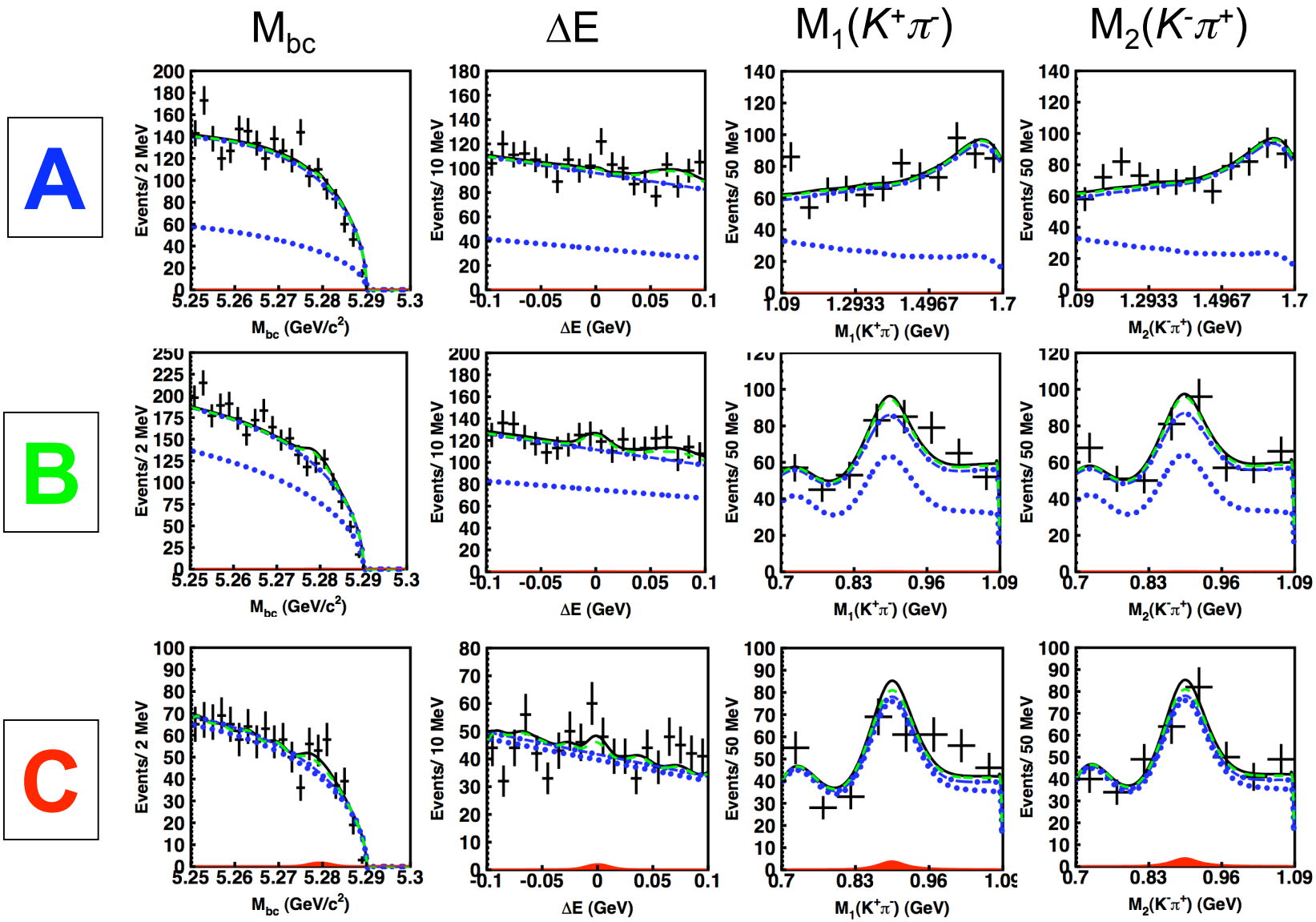


$M_1(K\pi)$ vs. $M_2(K\pi)$ (K*2Kπ)



$M_1(K\pi)$ vs. $M_2(K\pi)$ (KK$\pi\pi$)



$M_1(K\pi)$ vs. $M_2(K\pi)$ (K$\pi\pi\pi$)

Make Projections in Three $M_{1(K\pi)}$ vs. $M_{2(K\pi)}$ Areas