Hadronic B decays related to QCD at Belle

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representing the Belle Collaboration

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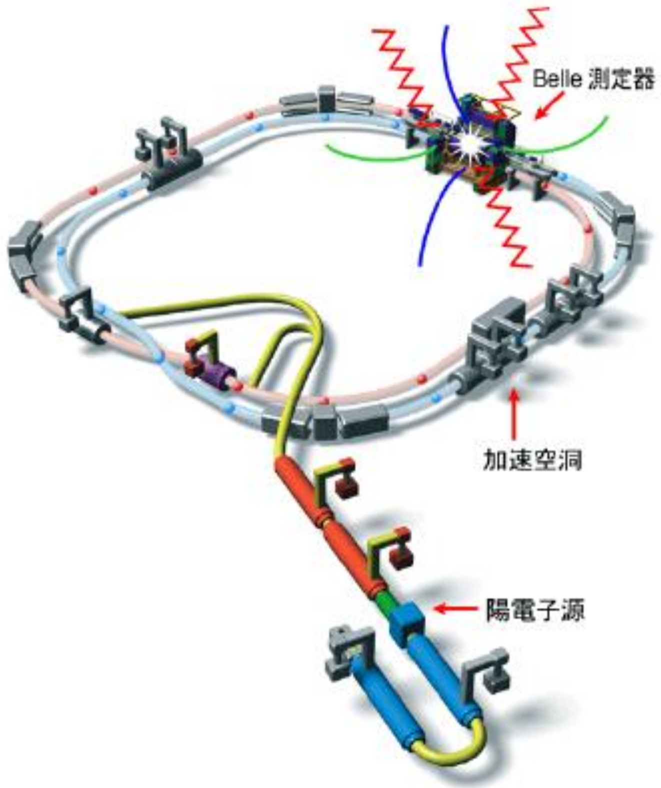
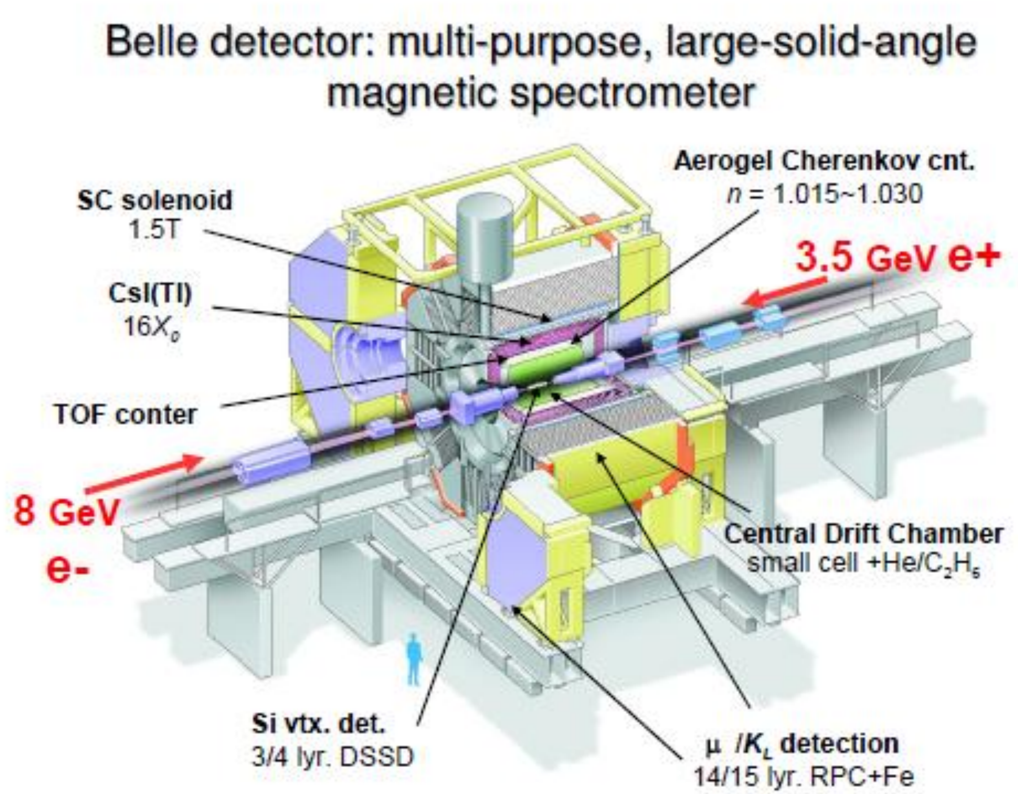
Outline:

- introduction
- Inclusive $B \to X_s \eta$
- $B \to VV$
- $B \to D_s^{(*)} K \pi$
- conclusions

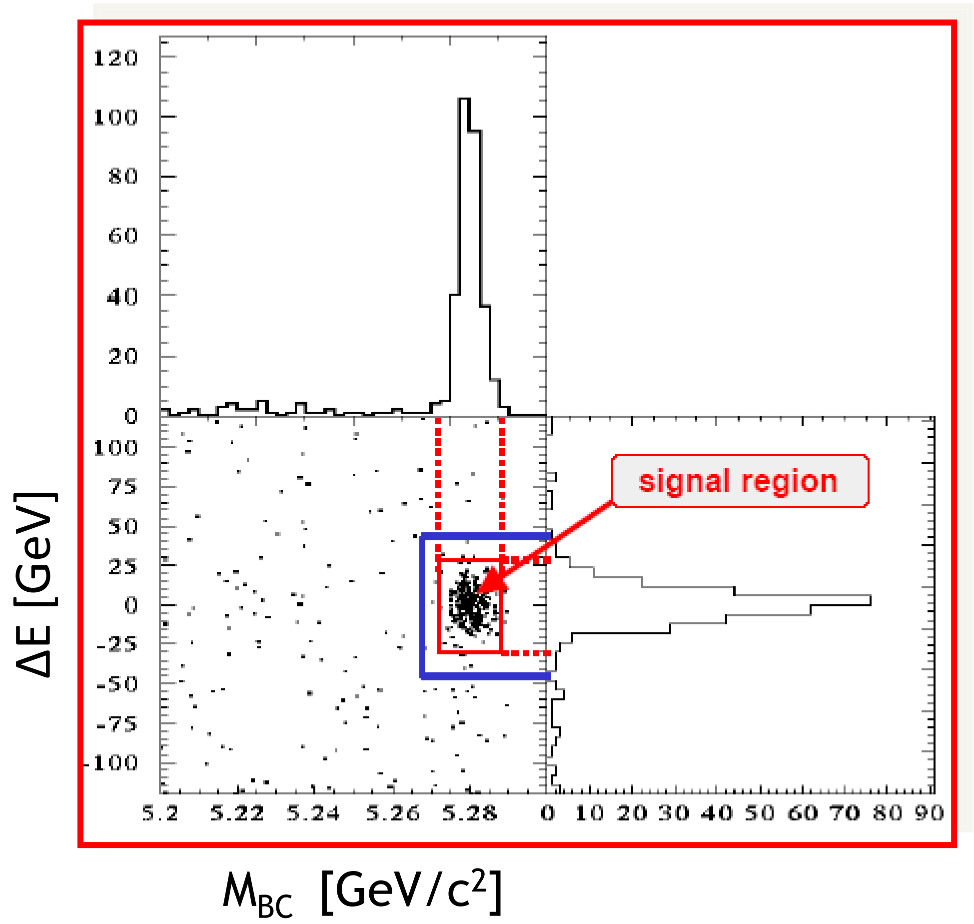
KEKB B-factory and Belle detector





$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$ clean source of exclusive B meson pairs

Belle kinematic variables ΔE and M_{BC}



$$\Delta E = \sum_i E_i^* - E_{beam}^*$$

$$M_{bc} = \sqrt{E_{beam}^{*2} - (\sum_i p_i^*)^2}$$

E_{beam} - beam energy in the CM frame

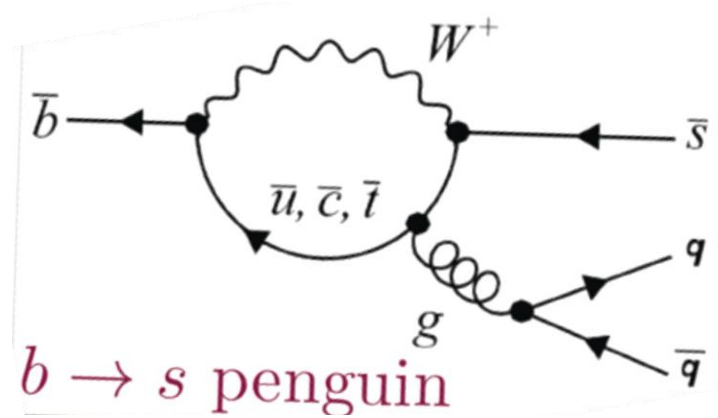
$\Sigma_i E_i$ - total energy of the B products

$\Sigma_i p_i$ - total momentum of the B products

Inclusive $B \to X_s\eta$ decays

Motivation:

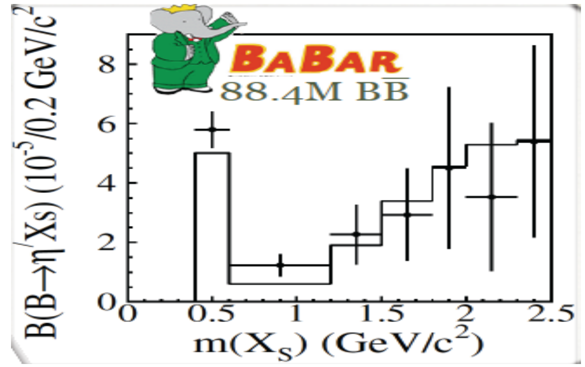
- Charmless B decays ($b \to s$ penguins) - precise tests of the Standard Model and possible indications of the new physics



- Interesting properties of the decays that involve η and η' due to interference effects between the underlaying pseudoscalar octet and singlet components
  - $\to$ well understood in the exclusive $B \to K^{(*)}\eta^{(\prime)}$ (arXiv:1005.1968)
  - $\to$ less clear in the inclusive $B \to X_s\eta^{(\prime)}$ modes

Unexpected features for $B \to X_S \eta'$ measured by CLEO and BaBar :

Phys. Rev. D **68**, 011101 (2003)   Phys. Rev. Lett. **93**, 061801 (2004)



$\to$ large branching fraction

$\to$ peak at high X_S mass spectrum

Possible theoretical explanations:

- QCD anomaly mechanism – couples two gluons to the singlet components of η'

- The η' contains an intrinsic charm component

Disfravored by existing data (CLEO):

Phys. Rev. D 67, 052003 (2003)
(η' energy spectra in $\Upsilon(1S)$ *decays compared* with models of the η' g^*g *form factor)*
Phys. Rev. Lett. 86, 30 (2001)
$B \to \eta_c K$

- Large contributions from non-perturbative charming penguin amplitudes
  $\to$ needs further confirmation !

Studies on $B \to X_S \eta$ can clarify the situation !

$B \to X_s\eta$: 18 channels involved

semi-inclusive method

arXiv: 0910.4751

$$B^+ \to K^+(\pi^0)\eta \qquad B^0 \to K^0_S(\pi^0)\eta$$
$$B^+ \to K^0_S\pi^+(\pi^0)\eta \qquad B^0 \to K^+\pi^-(\pi^0)\eta$$
$$B^+ \to K^+\pi^+\pi^-(\pi^0)\eta \qquad B^0 \to K^0_S\pi^+\pi^-(\pi^0)\eta$$
$$B^+ \to K^0_S\pi^+\pi^-\pi^+(\pi^0)\eta \qquad B^0 \to K^+\pi^-\pi^+\pi^-(\pi^0)\eta$$
$$B^+ \to K^+\pi^+\pi^-\pi^+\pi^-\eta \qquad B^0 \to K^0_S\pi^+\pi^-\pi^+\pi^-\eta$$

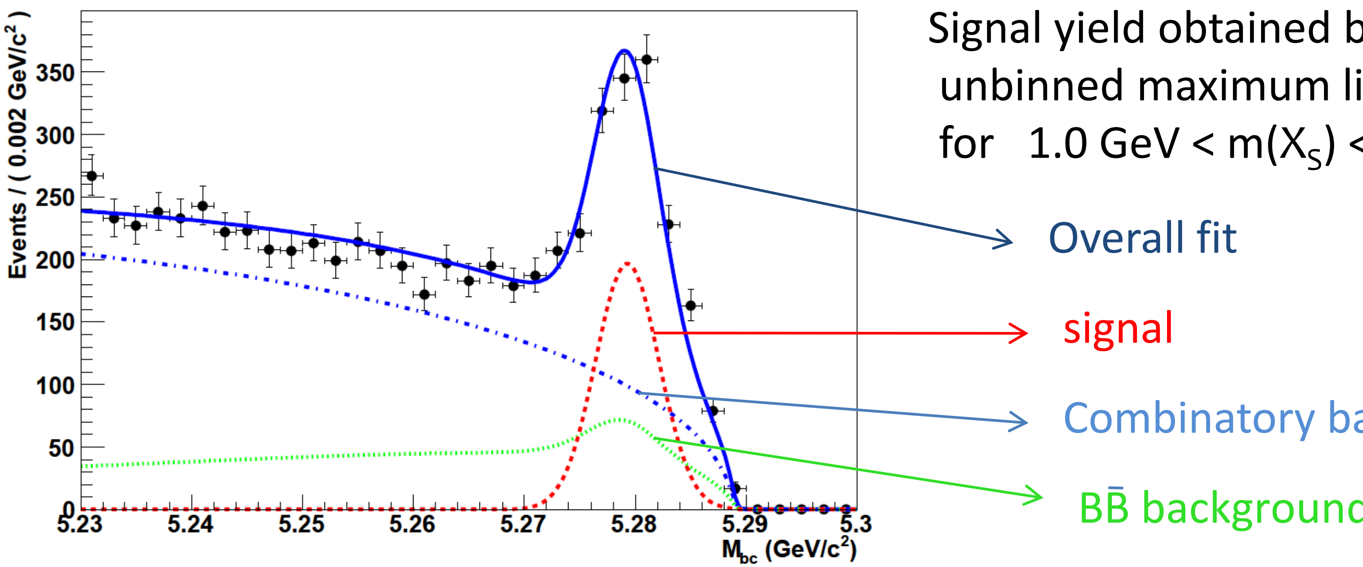
where η is reconstructed from 2γ.

Belle measurement

Data sample:

657×10^6 $B\bar{B}$ pairs

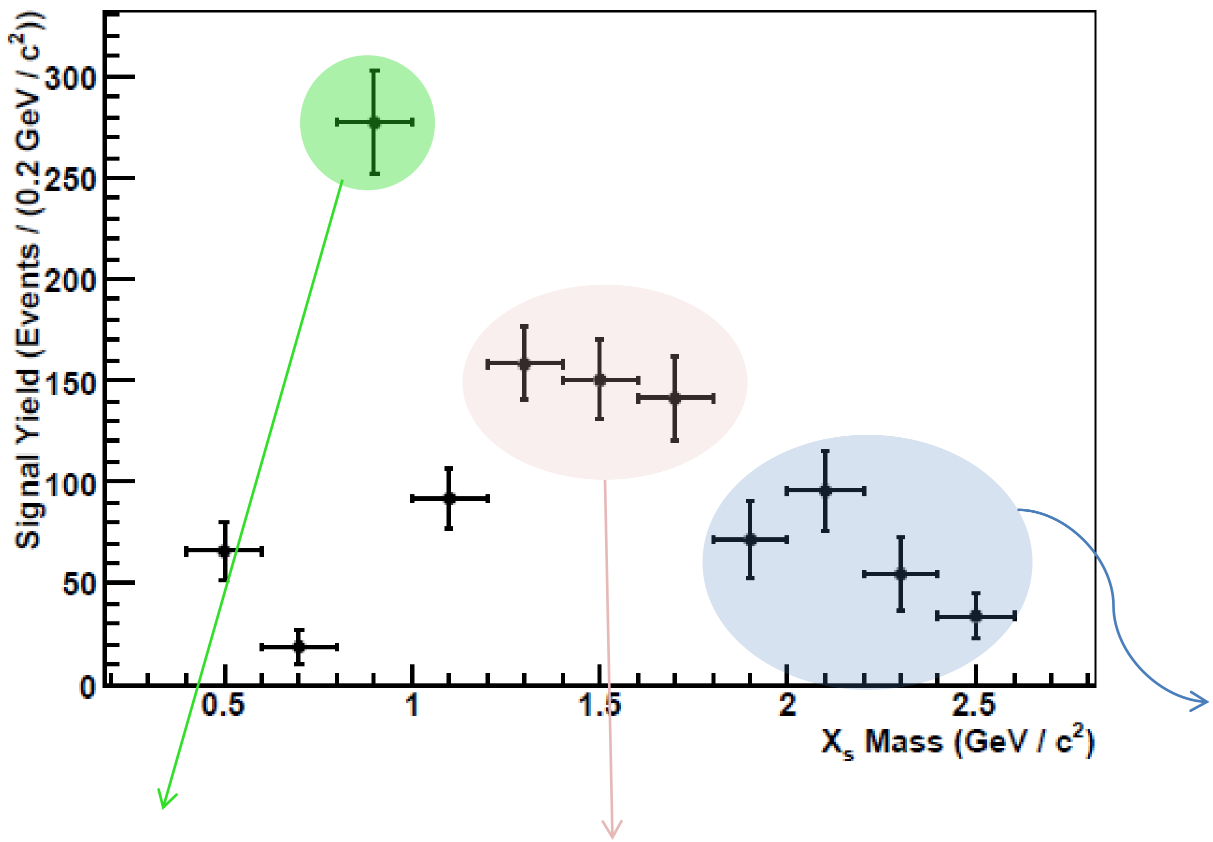
- veto on charm contribution (D^0, D^+, η_c)
- veto on $\eta' \to \eta\, \pi^+\pi^-$



Signal yield obtained by extended unbinned maximum likelihood fit to M_{bc} for 1.0 GeV $< m(X_S) <$ 2.6 GeV

$B \rightarrow X_s\eta$

- Signal yields were fitted in bins of X_s mass:



Not yet explained

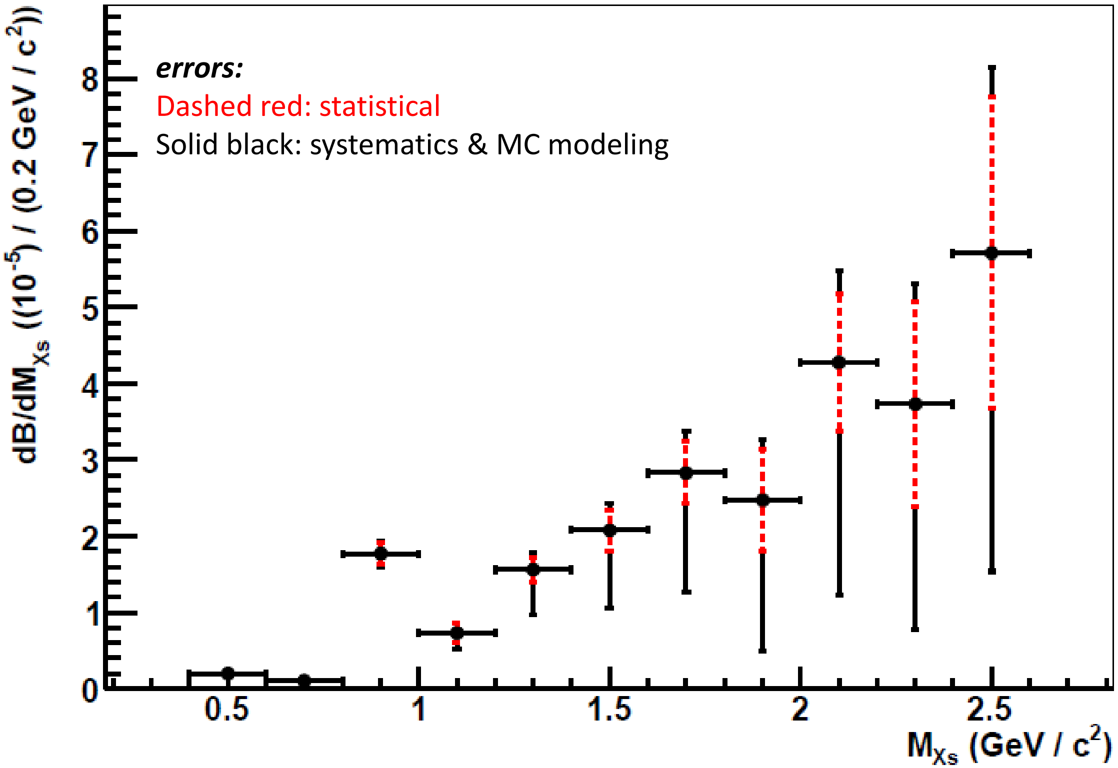
$B \rightarrow K^*(892)\eta$

$B \rightarrow K^*(1430)\eta$

$B \rightarrow K\pi....\eta$

$B \to X_S\eta$

Partial branching fraction in the range of
0.4 GeV < $m(X_S)$ < 2.6 GeV:



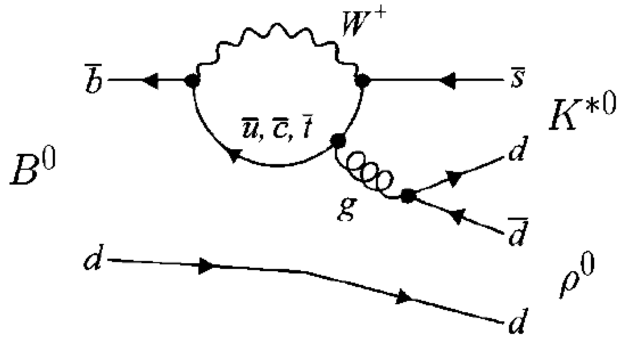
$$\mathcal{B}(B \to X_s\eta) = (25.5 \pm 2.7 \pm 1.6^{+3.8}_{-14.1}) \times 10^{-5}$$

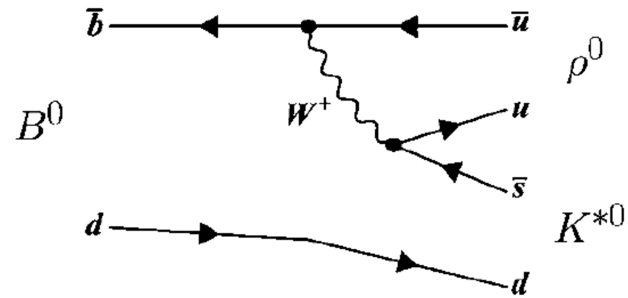
High branching fraction for $m(X_S)$ > 2 GeV
⟹ comparable to respective $B \to X_S\eta'$ result from BaBar ! (Phys. Rev. Lett. 93, 061801 (2004))

$B \to V\,V$ decays

proceed mainly via $b \to s\bar{q}q$ penguins (dominating) and $B \to uW$ tree diagrams.

$B \to \rho^0 K^*$

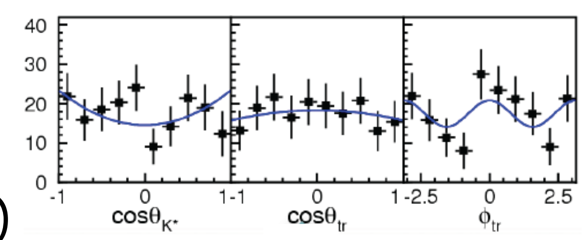




Suppressed → sensitive to non-SM contributions

- Puzzling results on $B \to \phi K^*$: large transverse polarizations found:

$\boxed{F_l \sim 0.5}$



→ disagreement with naive SM prediction which says: *longitudinal component should dominate* ($F_l \sim 95\,\%$)

- measurements of other penguin modes ($B \to \rho^0 K^{*0}$, $B \to K^{*0}\overline{K}^{*0}$) should shine some light on the situation

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

- ρ^0 reconstructed from $\pi^+\pi^-$
- K^* reconstructed from $K^+\pi^-$

PRD 80:051103 (2009)

In addition, 5 more channels sharing the same final state were taken into account:

$f_0(980)K^{*0}$
$\pi^+\pi^- K^{*0}$
$\rho^0 K^+\pi^-$
$f_0(980)K^+\pi^-$
$\pi^+\pi^- K^+\pi^-$

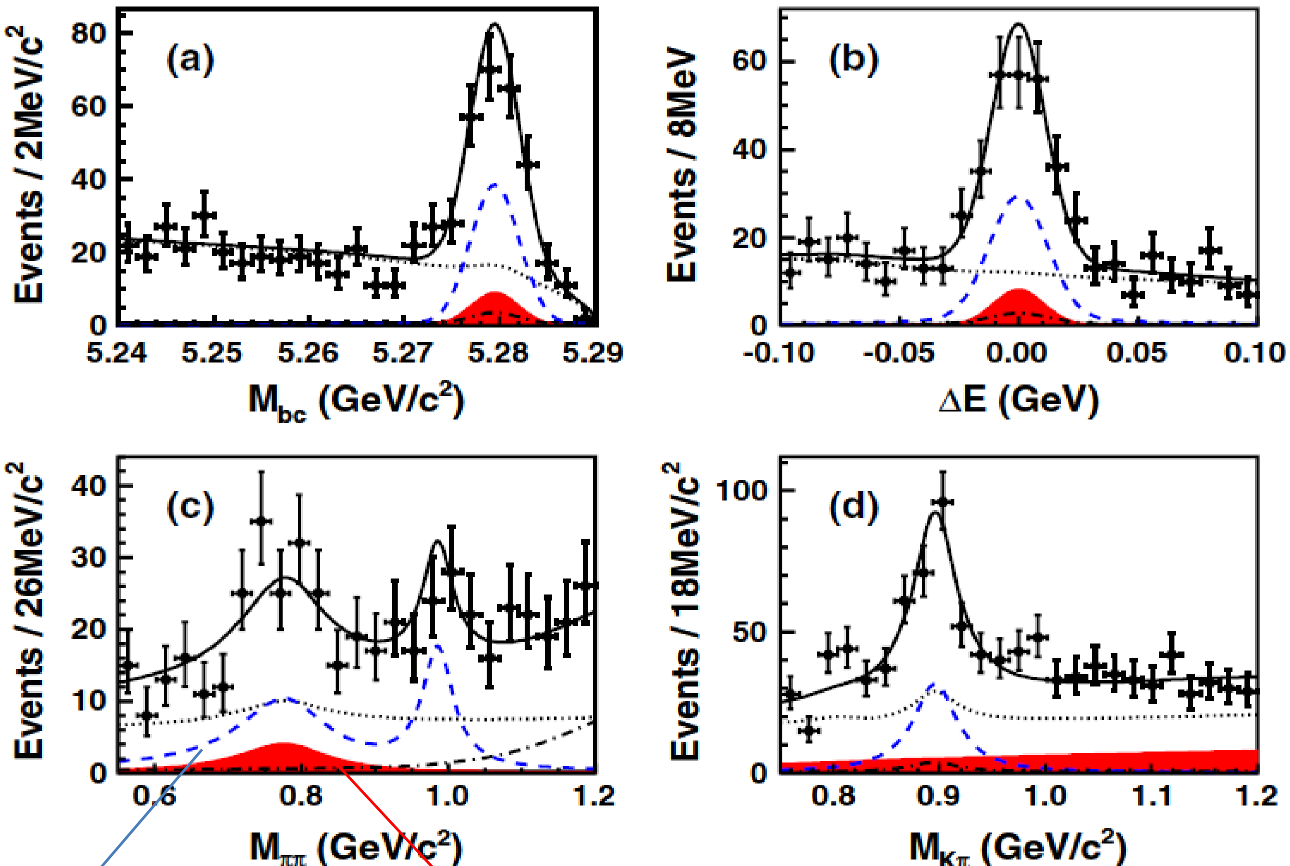
Challenging measurement due to large non-resonant contribution

⇩

Understanding of these processes and clear distinction between $B \to V\,V$ and non-resonant decays could enhance our understanding of strong and weak interaction dynamics.

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

Results from the 4D extended unbinned maximum-likelihood fit to ΔE, M_{bc}, $m(\pi\pi)$, $m(K\pi)$



$\rho^0 K^{*0} + f_0\,(980) K^{*0}$

$\rho^0 K^+ \pi^-$

$B \to \rho^0 K^{*0}$ results

Mode	Y (events)	ε (%)	$\mathcal{S}$ (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}_{\rm UL}$ (10^{-6})
$\rho^0 K^{*0}$	$77.6^{+28.6}_{-27.9}$	5.73	2.7	$2.1^{+0.8+0.9}_{-0.7-0.5}$	<3.4
$f_0(980)K^{*0}$	$51.2^{+20.4}_{-19.3}$	5.56	2.5	$1.4^{+0.6+0.6}_{-0.5-0.4}$	<2.2
$\rho^0 K^+ \pi^-$	$207.8^{+39.8}_{-39.2}$	11.15	5.0	$2.8 \pm 0.5 \pm 0.5$	$\cdots$
$f_0(980)K^+\pi^-$	$106.9^{+31.6}_{-29.9}$	11.43	3.5	$1.4 \pm 0.4^{+0.3}_{-0.4}$	<2.1
$\pi^+\pi^- K^{*0}$	$200.7^{+46.7}_{-44.9}$	6.74	4.5	$4.5^{+1.1+0.9}_{-1.0-1.6}$	$\cdots$
$\pi^+\pi^- K^+\pi^-$	$-5.4^{+54.9}_{-44.9}$	6.84	0.0	$-0.1^{+1.2+1.4}_{-1.1-0.8}$	<2.1

first observation !

not seen by Belle !

BaBar result:

PRL 97, 201801, 2006

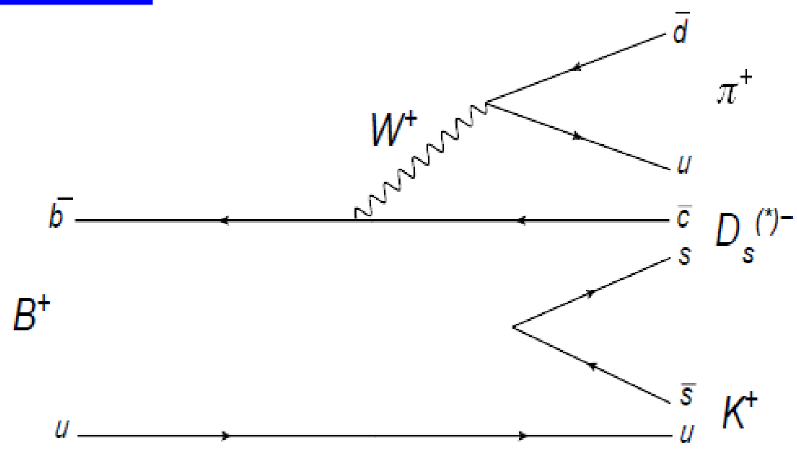
$$\mathcal{B}(B \to \rho^0 K^{*0}) = 5.6 \pm 0.9 \pm 1.3 \times 10^{-6}$$

$S(\sigma)$: 5.3

f_L~0.57

$\to$ Needs further investigation

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



Phys. Rev.D 80, 052005 (2009)

Data sample: 657×10^6 $B\bar{B}$ pairs

$B^+ \to D_s^{(*)-} K^+\pi^+$ process mediated by the $b \to c$ quark transition and includes the production of an additional $\bar{s}s$ pair

Reconstructed in three D_s channels:

$D_s \to \phi\pi$

$D_s \to K^{*0}K$

$D_s \to K^0_s K$

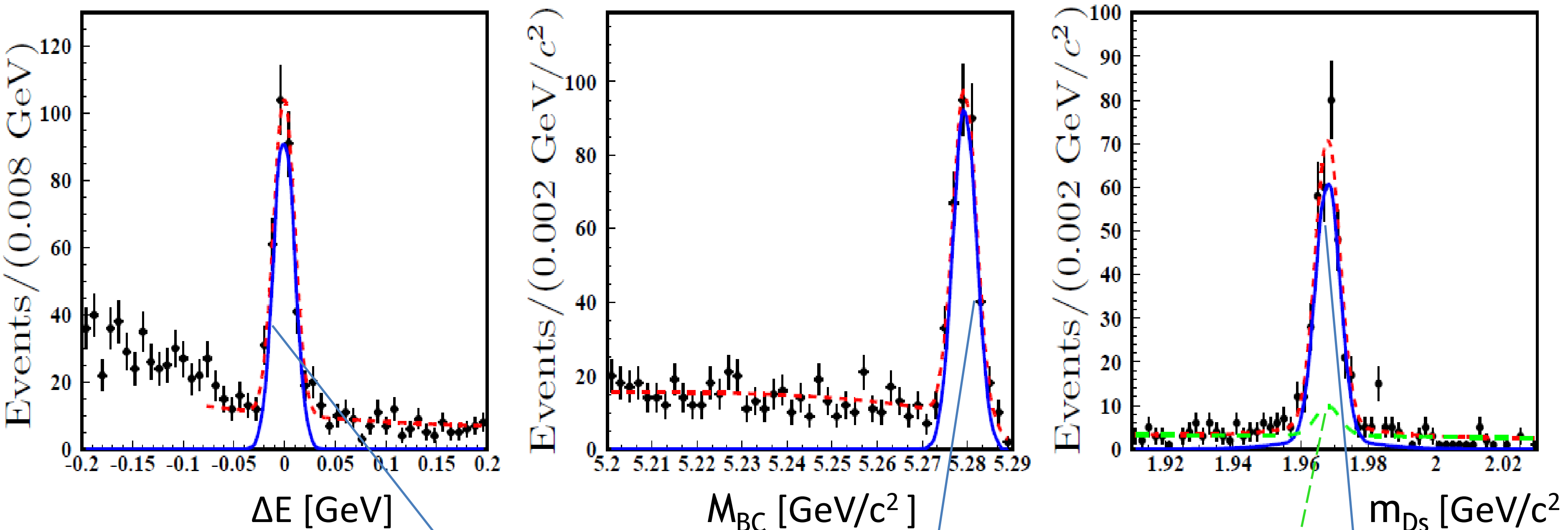
$D_s^* \to D_s \gamma$

The intermediate resonances could be formed from the three final-state particles

Possible studies of the invariant mass distributions for the two-body subsystems to search for new resonances.

$B^+ \to D_s^{(*)-} K^+ \pi^+$ - fit parametrization

3D unbinned extended maximum likelihood fit to the (ΔE, M_{BC}, $m_{Ds^{(*)}}$) variables



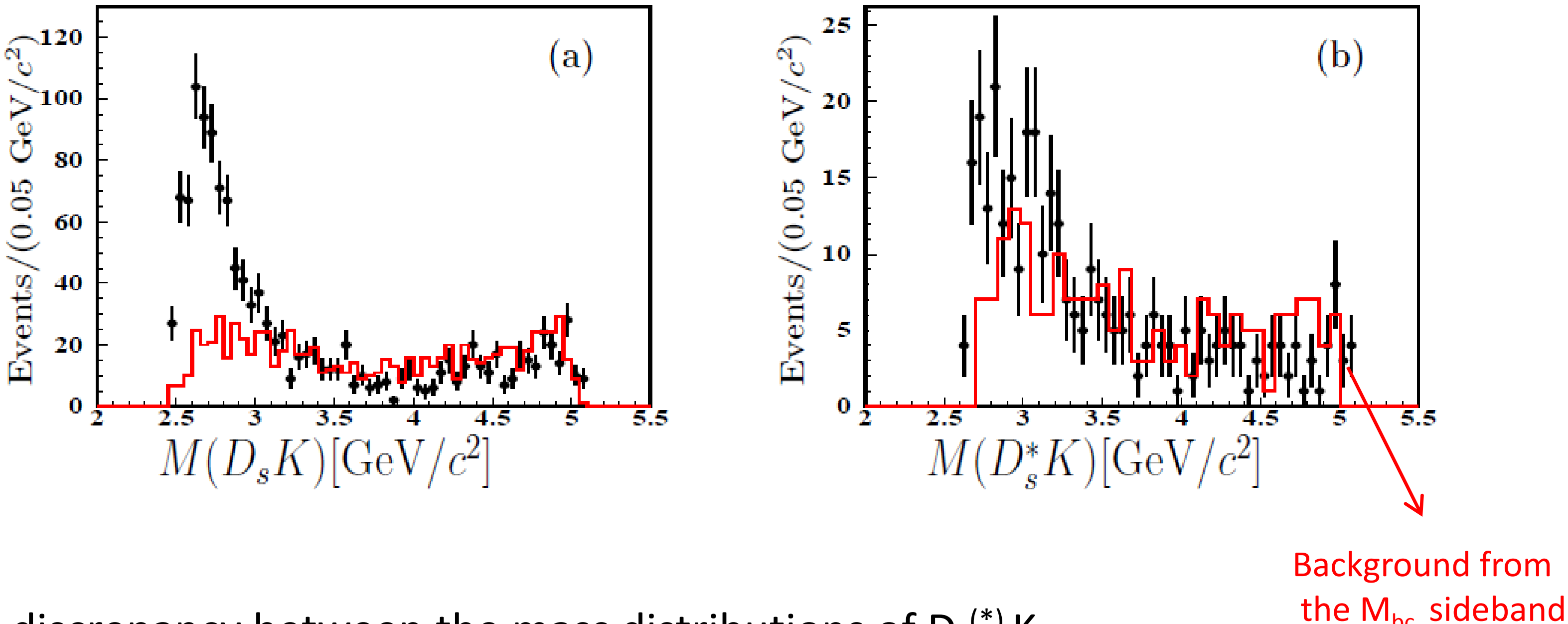
Signal parametrization: Gaussian Gaussian Double Gaussian

Peeking background in $M(D_s^{(*)})$ - $D_s^{(*)}$ randomly combined with K, π -- Double Gaussian

Comb. background parametrization: 2nd order polynomials (ΔE, m_{Ds}) and Argus function (M_{BC})

$B \rightarrow D_s^{(*)} K \pi$

Clear enhancement near the threshold in the invariant mass of the two-body subsystem D_sK and D_s^*K



→ discrepancy between the mass distributions of $D_s^{(*)}K$ and the distribution expected for the three-body phase space production

→ efficiency variation across $M(D_s^{(*)}K)$ distribution taken into account!

Results for $B \to D_s^{(*)} K \pi$

Branching fractions for separate D_s decay modes consistent with each other

Simultaneous fit to three D_s modes:

$$\mathcal{B}(B^+ \to D_s^- K^+ \pi^+) = (1.71^{+0.08}_{-0.07}(\mathrm{stat})\ ^{+0.20}_{-0.20}(\mathrm{syst}) \pm 0.15(\mathcal{B}_{int})) \times 10^{-4}$$

$$\mathcal{B}(B^+ \to D_s^{*-} K^+ \pi^+) = (1.31^{+0.13}_{-0.12}(\mathrm{stat})\ ^{+0.25}_{-0.25}(\mathrm{syst}) \pm 0.12(\mathcal{B}_{int})) \times 10^{-4}$$

BaBar results:
$BF(B^+ \to D_s^- K^+ \pi^+) = 2.02 \pm 0.13 \pm 0.38 \times 10^{-4}$
$BF(B^+ \to D_s^{*-} K^+ \pi^+) = 1.67 \pm 0.16 \pm 0.35 \times 10^{-4}$

B. Aubert *et al.* (BaBar Collaboration), Phys. Rev. Lett. **100**, 171803 (2008)

Preliminary studies of two-body subsystems show no evidence for the existence of any new resonance !

conclusions

- $B \to X_S\eta$ measured using semi-inclusive method. Large branching fraction is found for $m(X_S) > 2$ GeV following similar observation in the channel with η'.

- penguin dominated $B \to \rho^0 K^{*0}$ channel and the associated decays are studied. Disagreement between Belle and BaBar $\to$ perhaps three body decays contribution should be studied more carefully.
The first measurement of $B \to \rho^0 K^+ \pi^-$ is performed.

- $B \to D_s^{(*)} K \pi$

Respective branching fractions are measured.
No evidence for any new states found in studied data sample.
However : peak near the threshold in the invariant mass of the two - body subsystems $D_s K$ and $D_s^* K$ - deviation from the phase space model!

BACKUP

Decay	Signal yield	Efficiency [%]	Statistical Signif. [σ]	Branching fraction [(10^{-4})]
$B^+ \to D_s^-(\to \phi\pi^-)K^+\pi^+$	$306.0^{+19.7}_{-19.1}$	13.09 ± 1.00	31.5	$1.63^{+0.11}_{-0.10}\ ^{+0.18}_{-0.18} \pm 0.25$
$B^+ \to D_s^-(\to K^{*0}K^-)K^+\pi^+$	$281.7^{+24.7}_{-23.6}$	9.48 ± 0.67	26.5	$1.74^{+0.15}_{-0.15}\ ^{+0.20}_{-0.20} \pm 0.27$
$B^+ \to D_s^-(\to K^0_S K^-)K^+\pi^+$	$179.4^{+16.7}_{-16.0}$	14.49 ± 1.11	20.4	$1.82^{+0.17}_{-0.16}\ ^{+0.24}_{-0.25} \pm 0.11$
$B^+ \to D_s^{*-}(\to \phi\pi^-)K^+\pi^+$	$59.0^{+9.3}_{-8.6}$	3.51 ± 0.52	11.0	$1.24^{+0.20}_{-0.18}\ ^{+0.23}_{-0.23} \pm 0.19$
$B^+ \to D_s^{*-}(\to K^{*0}K^-)K^+\pi^+$	$61.7^{+10.6}_{-9.8}$	2.88 ± 0.42	9.3	$1.33^{+0.23}_{-0.21}\ ^{+0.25}_{-0.25} \pm 0.21$
$B^+ \to D_s^{*-}(\to K^0_S K^-)K^+\pi^+$	$35.7^{+7.7}_{-6.9}$	4.02 ± 0.59	8.0	$1.39^{+0.30}_{-0.27}\ ^{+0.29}_{-0.28} \pm 0.08$