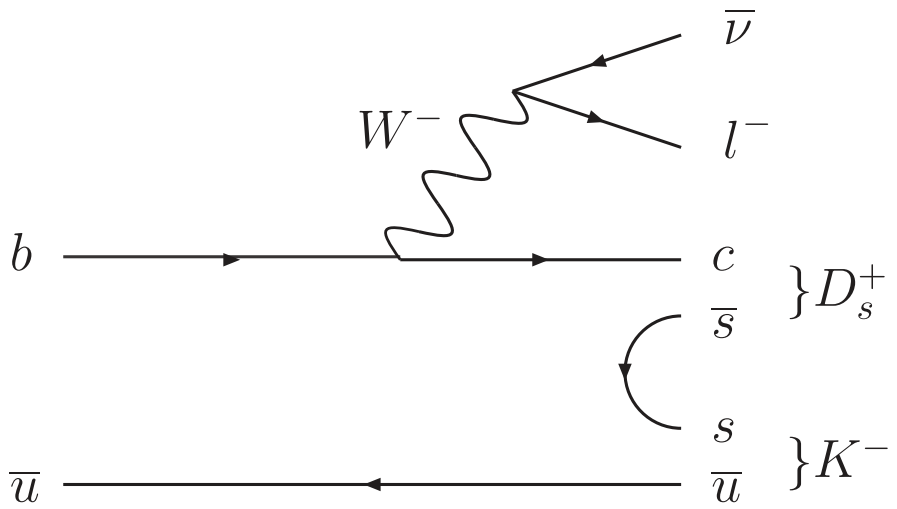
Study of the $B^- \to D_s^{(*)+} K^- \ell^- \overline{\nu}_\ell$ decays at Belle



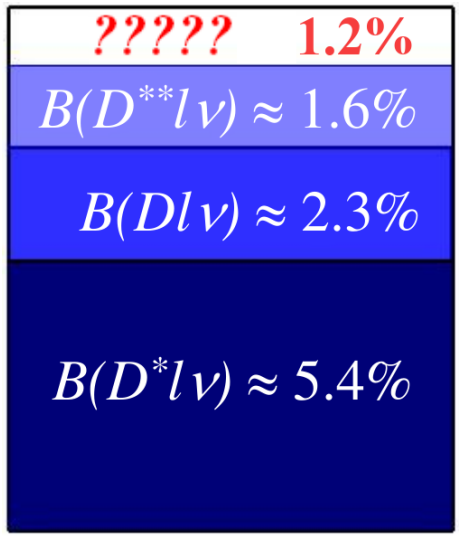
The inclusion of the charge-conjugate modes is implied

Motivation

Open questions in semileptonic B decays with $b \to c\ell\nu$

- Known exclusive decays don't sum up to total inclusive branching fraction $B \to X_c \ell\nu$
- Discrepancies between measurements and theoretical expectations for semileptonic B decays to excited charmed resonances

$$\Rightarrow |V_{ub}|, |V_{cb}| \text{ accuracy depends on it}$$



- Exploration of masses $m(D_s K) > 2.46$ GeV where resonant and non-resonant contributions are expected
- Impact on background description for many important processes, *e.g.* $B_s \to D_s X \ell\nu$.

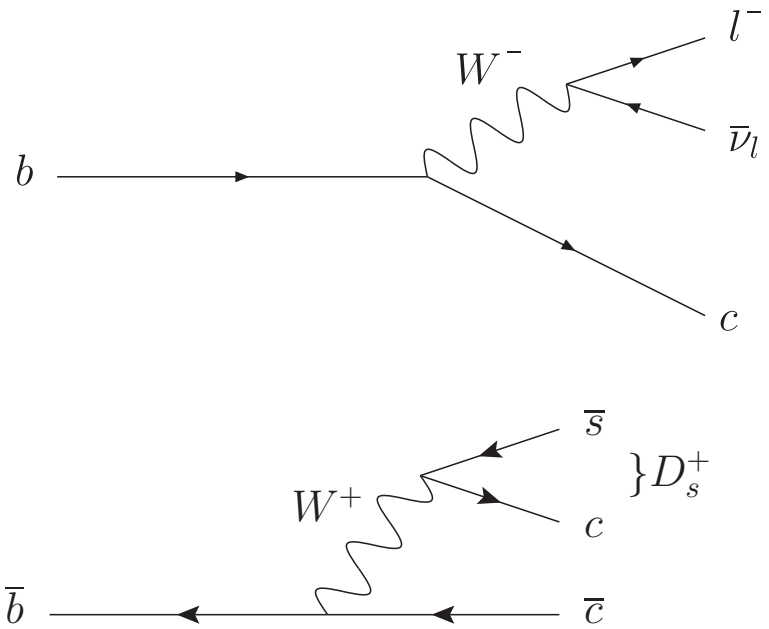
Recently measured by BaBar[1]:
$\mathcal{B}(B^- \to D_s^{(*)+} K^- \ell_- \nu) = [6.13 \pm {}^{+1.04}_{-1.03}(stat.) \pm 0.43(syst.) \pm 0.51(\mathcal{B}(D_s))] \cdot 10^{-4}$.
The analysis did not distinguish between D_s and D_s^* final states.

[1] PRL 107, 041804 2011

Experimental challenges

- Final state contains undetected neutrino $\Rightarrow$ cannot be fully reconstructed

- Large background (all particles in final state are copiously produced in B decays)
  - semileptonic $\sim 11\%$
  - $B^+ \to D_s^+ X \sim 8\%$



- Four-body decay with unknown dynamics
  - avoid selection requirements involving signal characteristics to limit model dependence[2]

[2] different from the BaBar analysis

Data

- Analysis based on data sample of **656M** $B\overline{B}$ collected at Belle detector in clean environment of KEKB collider: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$

- Signal efficiencies and background contributions evaluated from MC generated samples:
  - signal $\rightarrow$ MC generated with the EvtGen package, $\approx$ 60 times the expected signal (with PS model and ISGW2 model including the resonances that can decay to $D_s^{(*)}K$)
  - $B\overline{B}$ background $\rightarrow$ MC with generic B decays equivalent to about 10 times the accumulated data used to evaluate the background from $B\overline{B}$
  - continuum($q\overline{q}$, $q = u, d, s, c$) background $\rightarrow$ MC equivalent to about 6 times the accumulated data

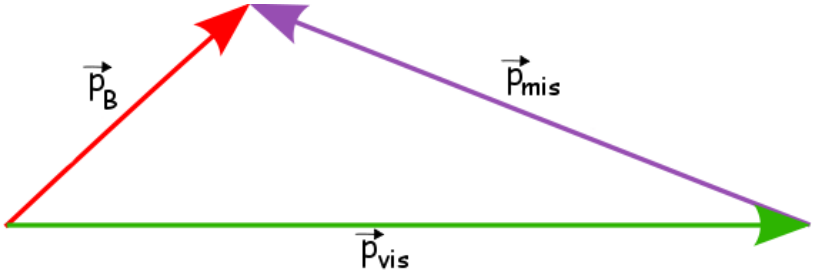
Event reconstruction

- Use the cleanest channels for secondary decays:

$$B^- \to D_s^+ K^- \ell^- \overline{\nu}_\ell$$

$$B^- \to D_s^{*+} K^- \ell^- \overline{\nu}_\ell, \quad D_s^{*+} \to D_s^+ \gamma, \quad D_s^+ \to \phi\pi^+, \quad \phi \to K^+ K^-$$

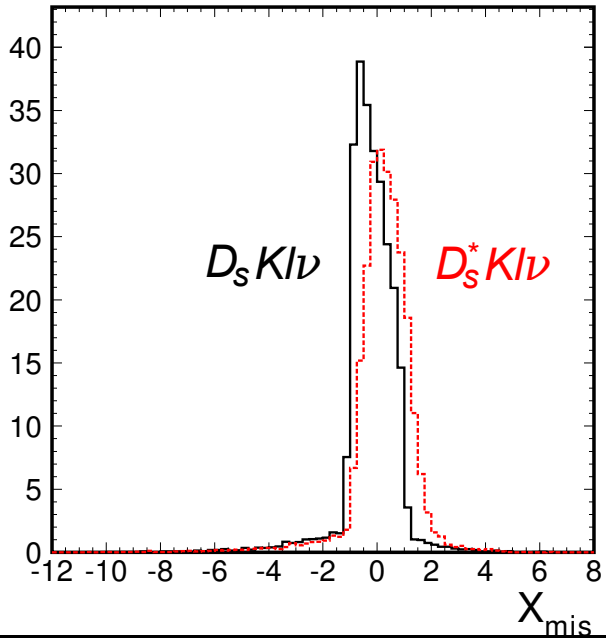
- "Neutrino reconstruction": at B-factories we can check if a single neutrino is missing in B decay



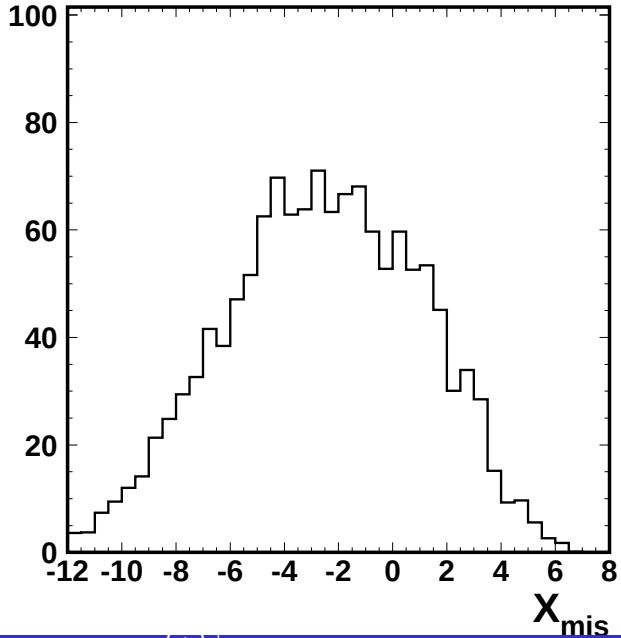
$$|\vec{p}_{mis}| = E_{mis} = E_{beam} - E_{vis}$$

$$\left| X_{\text{mis}} = \frac{|\vec{p}_{mis}| - |\vec{p}_{vis}|}{|\vec{p}_B|} \right| \leqslant 1$$

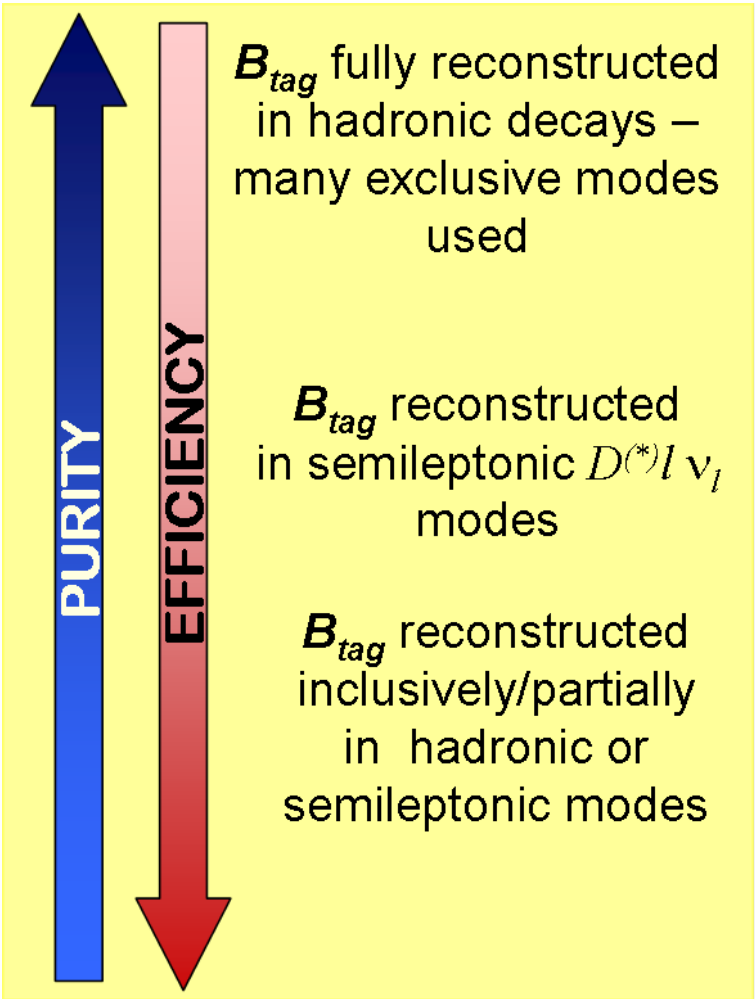
Signal

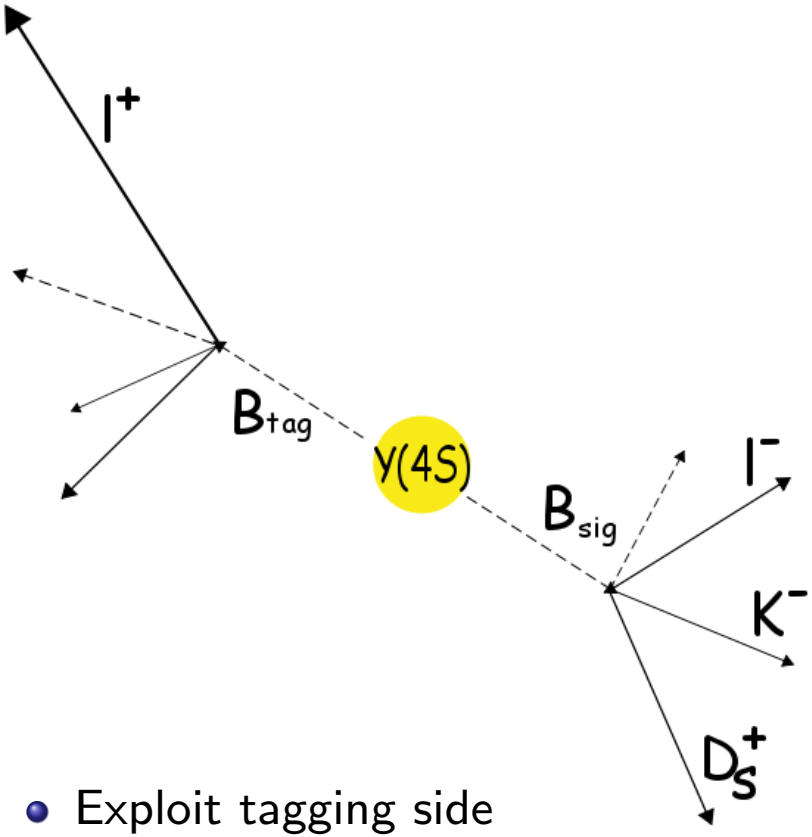


Background



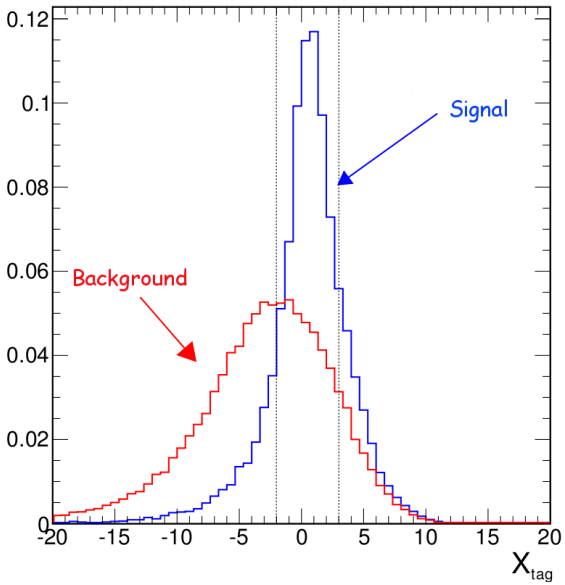
Background suppression

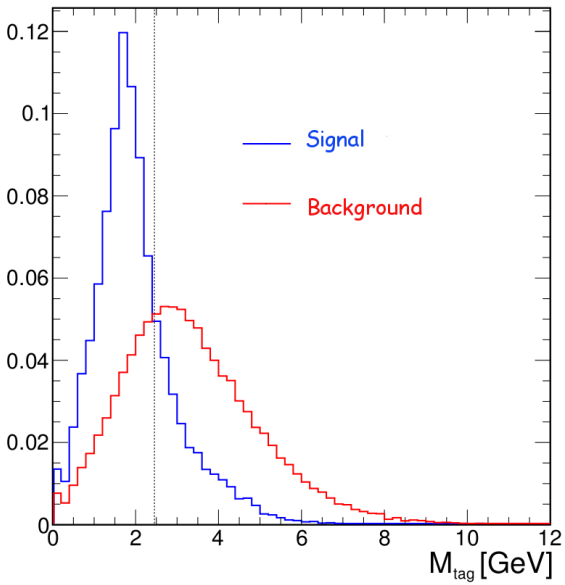




- Exploit tagging side
- Requirement of properly charged: prompt lepton ($p_{\ell\text{-tag}} > 0{,}5$ GeV) on the tag side suppresses the main background from mixed up decay products: $B^-(\overline{B}^0) \to \ell^- X$ and $B^+(B^0) \to D_s^+ X'$
- S/B : before 2%, after 12%

Background suppression





$X_{tag} \rightarrow X_{mis}$ of the tagging side

$$X_{tag} = \frac{|\vec{p}^{tag}_{mis}| - |\vec{p}^{tag}_{vis}|}{|\vec{p}^{tag}_{B}|}$$

$$-2 < X_{\text{tag}} < 3$$

$M^c_{tag} \rightarrow$ inclusively reconstructed effective mass of the hadronic system produced in B_{tag} decay

$$M^c_{tag} = \sqrt{(E_{tag} - E_{\ell\text{-tag}})^2 - (\vec{p}^{tag}_{vis} - \vec{p}_{\ell\text{-tag}})^2}$$

$$M^c_{\text{tag}} < 2.4\text{GeV}$$

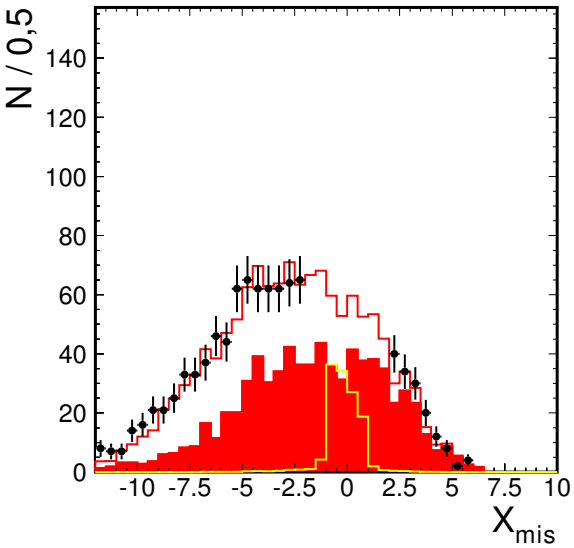
Optimization

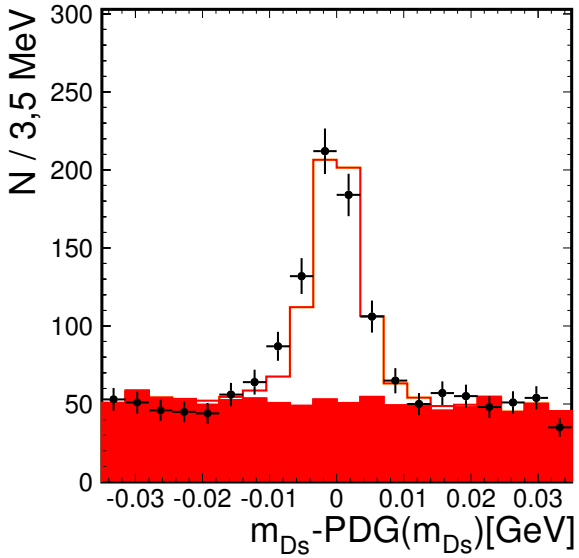
Maximize $\mathcal{F}.\mathcal{O}.\mathcal{M} = \frac{N_S}{\sqrt{N_S+N_B}}$

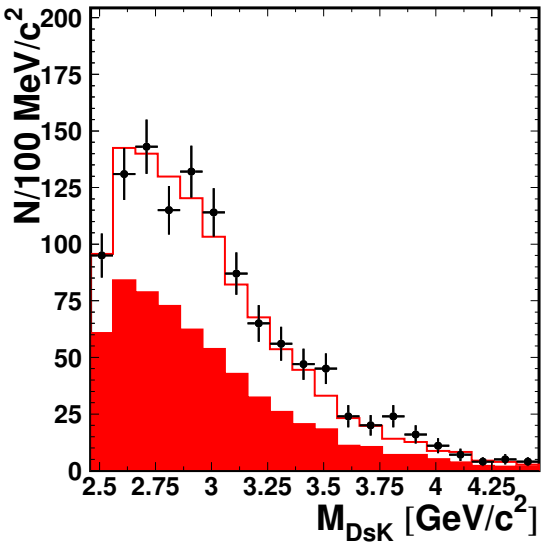
assuming that $\mathcal{B}(B \rightarrow D_s^{(*)} K \ell \nu) = 5.0 \cdot 10^{-4}$

Background model

- true D_s background $\rightarrow$ MC-generic scaled to the luminosity in data
- fake D_s background $\rightarrow$ m_{D_s} side-bands in data





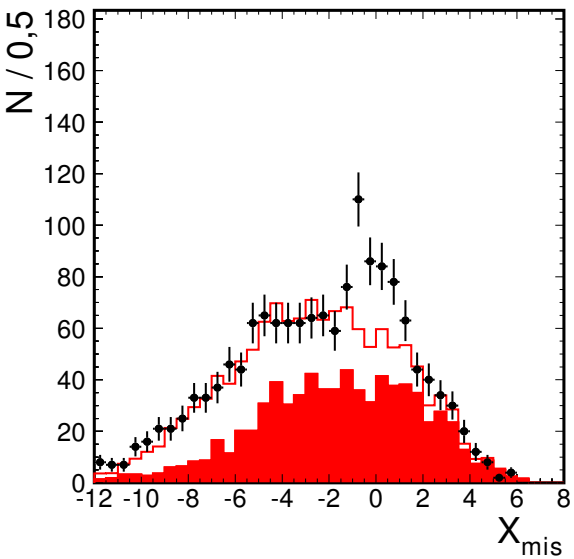


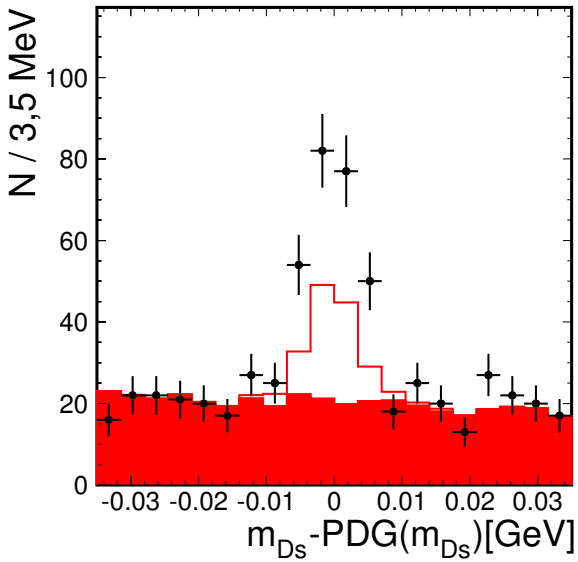
Background model was tested for many variables in side-band regions

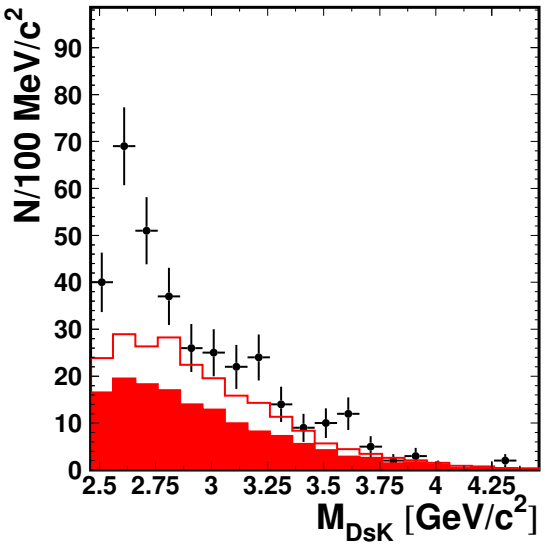
Signal in data

Unblind the signal box

Excess is visible





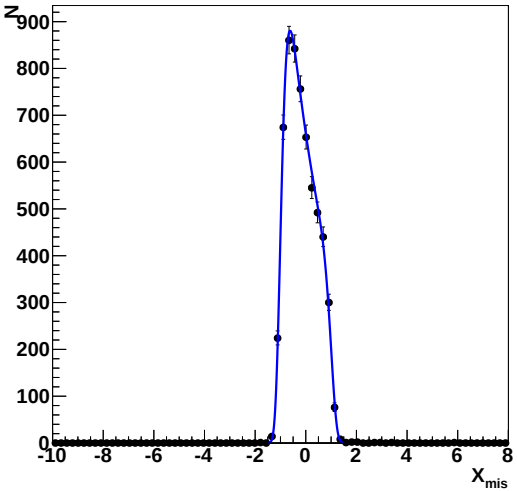


Signal extraction

- Signal yields extracted from an extended unnbinned maximum likelihood fit
- Simultaneous fit to non-overlapping samples: $D_s^+ K^- \ell^-$ and $D_s^{*+} K^- \ell^-$ (events with accepted $D_s^* K \ell$ candidates are removed from the set of $D_s K \ell$ candidates)
- Fit in 2D: $(X_{\mathrm{mis}},\ m_{D_s})$ for the D_s sample, and in 3D: $(X_{\mathrm{mis}},\ m_{D_s},\ m_{D_s^*})$ for the D_s^* sample taking into account cross-feeds
- X_{mis} PDF for signal X_{mis} was parametrized by:

$$C e^{-\left|\frac{X_{mis}-\mu}{\sigma}\right|^n} e^{-\alpha(X_{mis}-\mu)}$$

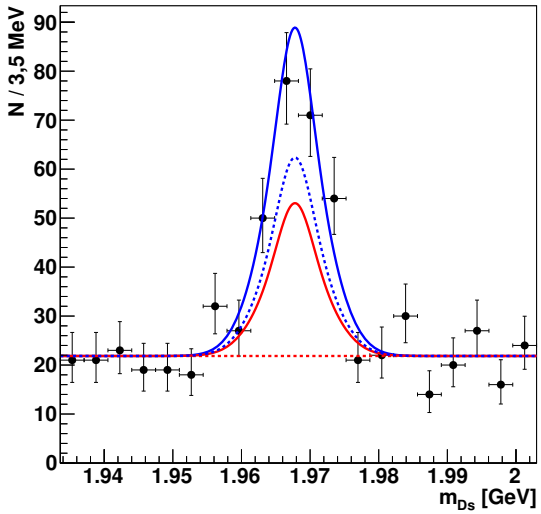
where μ (mean), σ (width), α (slope), n (steepness) fixed from the signal MC.

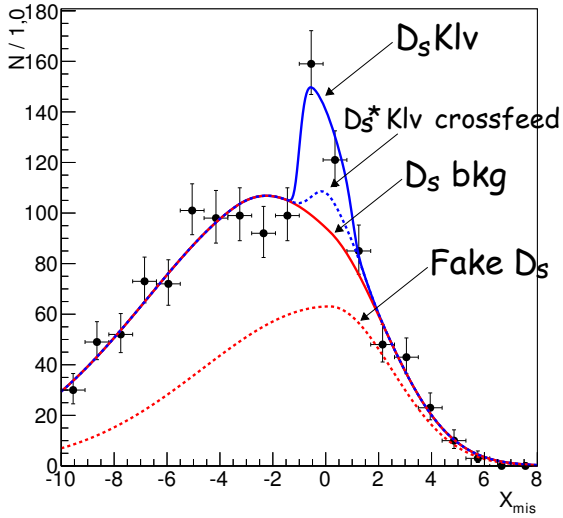


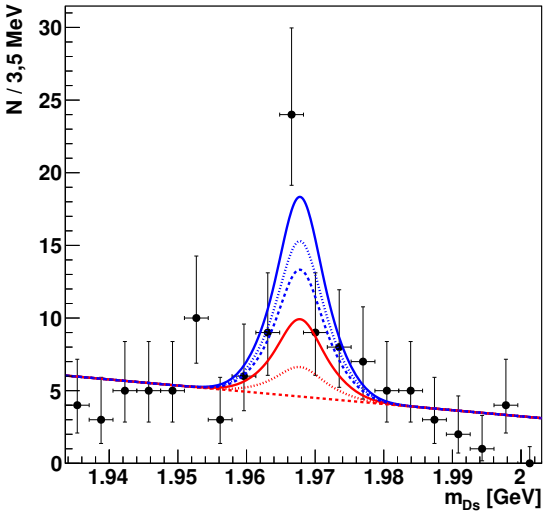
D_s

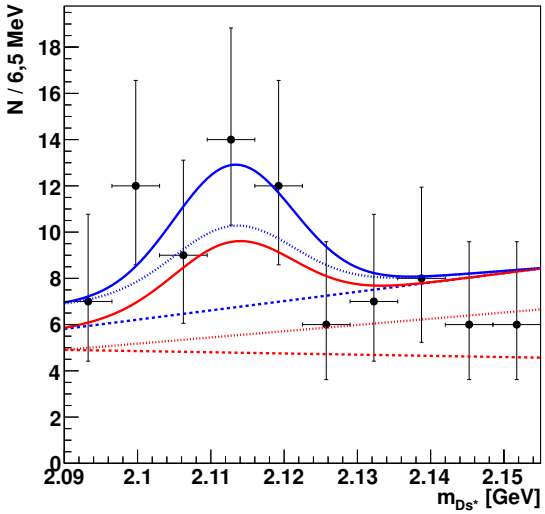
Fit projections

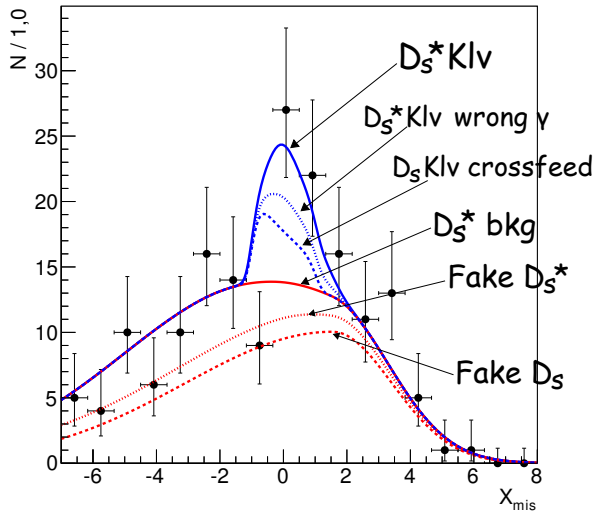
Fit projections for each variables are plotted in signal windows of the other variables.











Results

preliminary

Decay channel	$N_{D_s^{(*)}}$	Branching fraction	Significance
$D_s K\ell\nu$	84 ± 24	$[3.0 \pm 1.2(\text{stat})^{+1.1}_{-0.8}(\text{syst})] \cdot 10^{-4}$	3.4σ
$D_s^* K\ell\nu$	41 ± 22	$[2.9 \pm 1.6(\text{stat})^{+1.1}_{-1.0}(\text{syst})] \cdot 10^{-4}$	1.8σ
		$< 5.4 \cdot 10^{-4}$ $CL = 90\%$	
combined $D_s^{(*)} K\ell\nu$			6σ

Consistent with the BaBar result

Systematic uncertainties

Source	$\Delta\mathcal{B}(D_s)\%$	$\Delta\mathcal{B}(D_s^*)\%$
Tracking, KID, LeptID	8	
$\mathcal{B}(D_s \to \phi\pi)$	6	
signal efficiency	21	
N(B^+B^-)	2	
signal PDF (MC)	+27,-7	+17,-22
BKG PDF (MC)	+6,-8	+20,-17
BKG PDF (Data)	+5,-1	3
cross feed	1	2

$\Longleftarrow$ Efficiency determined with data $-$ reduced model dependence

Summary

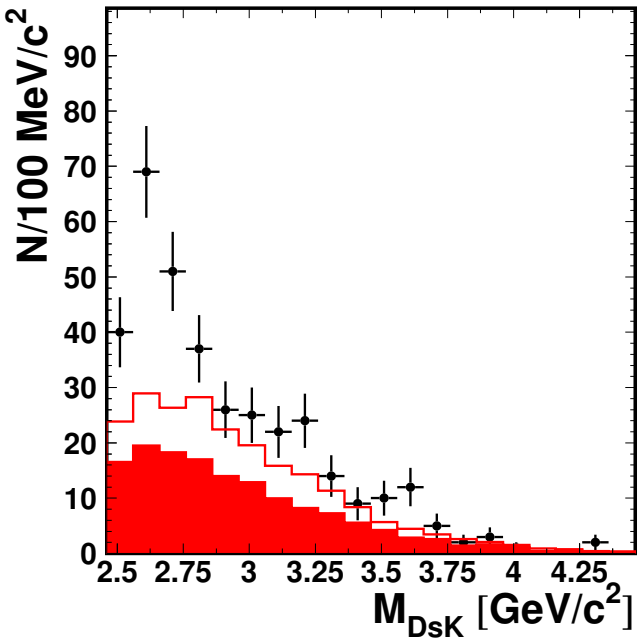
- Observation of combined $B \to D_s^{(*)} K \ell \nu_\ell$ modes with significance of 6 σ
- First time measured separately:
  $\mathcal{B}(B \to D_s K \ell \nu_\ell) = [3.0 \pm 1.2(\text{stat})^{+1.1}_{-0.8}(\text{syst})] \cdot 10^{-4}$ (3.4 σ, first evidence)
  $\mathcal{B}(B \to D_s^* K \ell \nu_\ell) < 5.4 \cdot 10^{-4}$ $CL = 90\%$
  (only a small part of $B \to X_c \ell \nu$)
- Model-independent analysis $\Rightarrow$ first measurement of the $m(D_s K)$ spectrum - pronounced peak at $\approx 2.6 GeV/c^2$

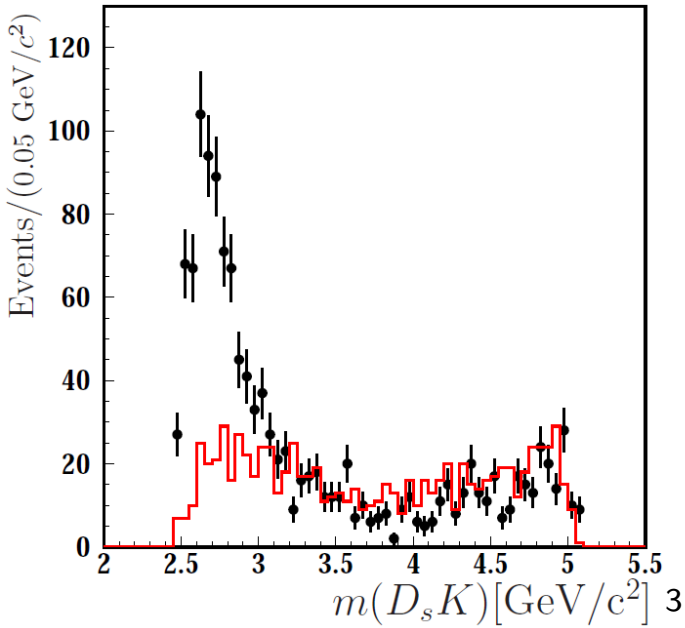
The results are still preliminary.

BACKUP

Signal window for:

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





[3]

- Both distributions are dominated by a pronounced peak at $\approx 2.6 GeV/c^2$

[3] J. Wiechczyński *et al.* Phys. Rev. D 80, 052005 (2009)