



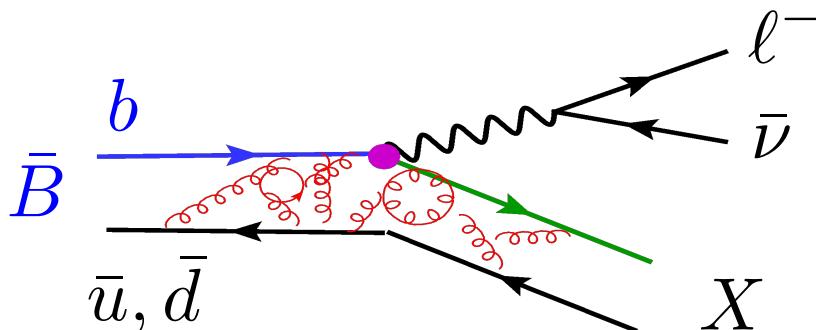
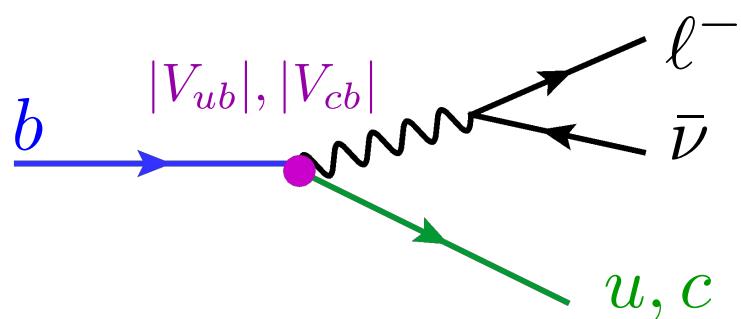
Semileptonic B and B_s decays at Belle



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ICHEP
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Semileptonic B decays



- Extraction of the CKM matrix elements $|V_{ub}|, |V_{cb}|$
- Described at first order by a transition at quark level $b \rightarrow c, u$

Inclusive vs. Exclusive puzzle

Exclusive branching ratios do not sum up to the inclusive branching ratio

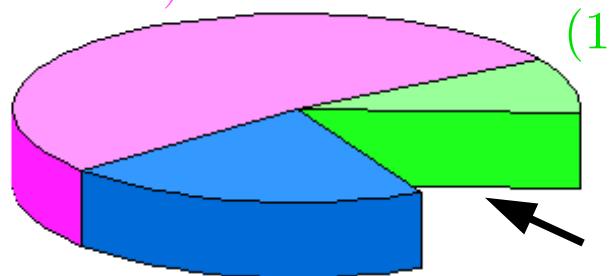
Decays modes with an η are challenging
→ semi-inclusive measurement instead

D^{**} = all observed modes besides D^- and D^*

$$B^- \rightarrow X_c \ell \nu : (10.9 \pm 0.2)\%$$

$$D^* : (5.6 \pm 0.2)\%$$

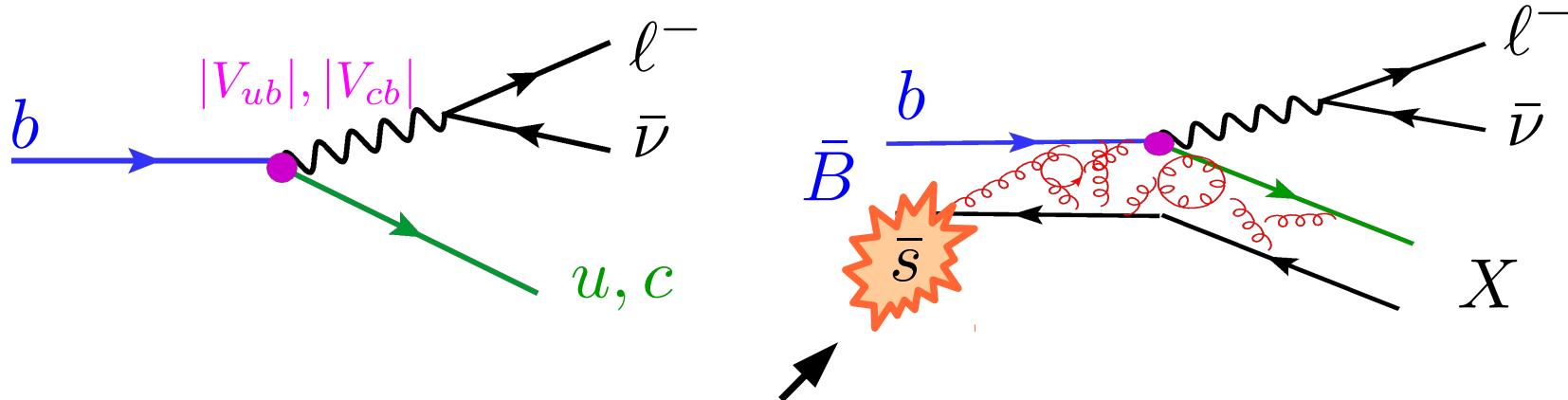
$$D^{**} : (1.7 \pm 0.1)\%$$



$$D : (2.3 \pm 0.1)\%$$

[HFAG, PDG]

SU(3) symmetry?



What happens when the **up** or **down** quark is replaced by a **strange** quark?

Experiment:

$$\frac{\Gamma_{\text{sl}}(B_u^+)}{\Gamma_{\text{sl}}(B_d^0)} = (0.99 \pm 0.04)$$

$$\frac{\Gamma_{\text{sl}}(D_s^+)}{\Gamma_{\text{sl}}(D^+)} = (0.83 \pm 0.05)$$

[PDG 2012]

Theory:

$$\frac{\Gamma_{\text{sl}}(B_s^0)}{\Gamma_{\text{sl}}(B_d^0)} \approx 0.99$$

[Bigi et al., JHEP 1109 (2011) 012]

$\mathcal{B}(B_{u,d,s} \rightarrow X \ell^+ \nu_\ell)$ extensively used as normalisation in other measurements

$\mathcal{B}(B_s^0 \rightarrow X \ell^+ \nu_\ell)$: Method

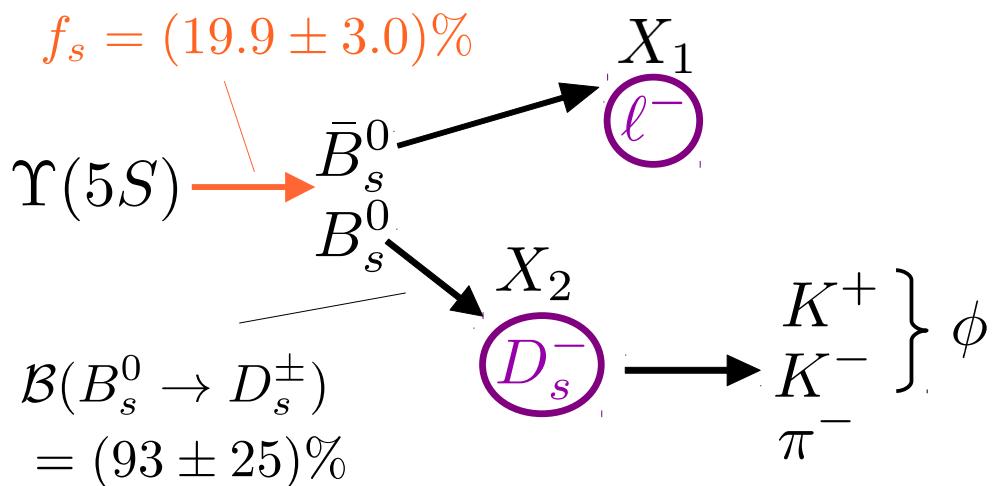


Measurement

121 fb⁻¹ $\Upsilon(5S)$ data

B_s^0 events contain a D_s^- with high probability

Same sign $D_s^- \ell^-$ come from different B_s^0



Extraction of $\mathcal{B}(B_s^0 \rightarrow X \ell^+ \nu_\ell)$

[PDG 2012]

our measurement

$$\frac{N(D_s^- \ell^-)}{N(D_s^-)} = \frac{N_s(D_s^- \ell^-) + N_{u,d}(D_s^- \ell^-)}{N_s(D_s^-) + N_{u,d}(D_s^-)}$$

external parameters

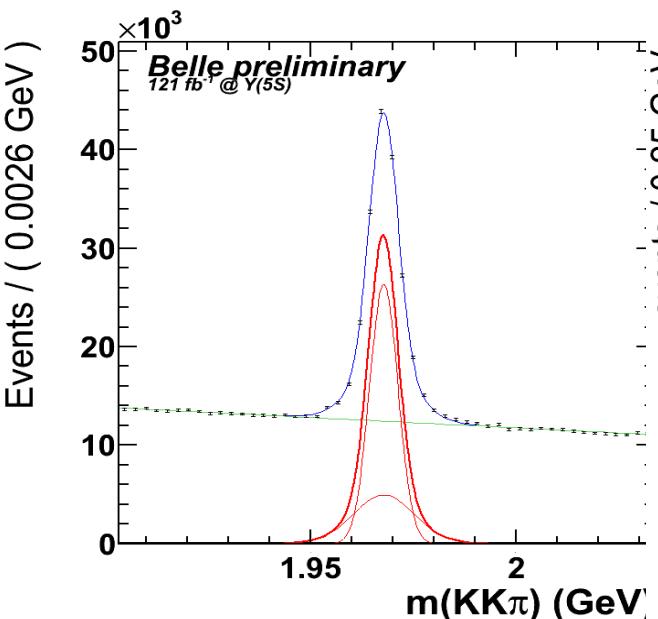
$$N(D_s^- \ell^-) \propto f_s \cdot \mathcal{B}(B_s^0 \rightarrow X \ell^+ \nu_\ell)$$

Background from $B_{u,d}$ decays

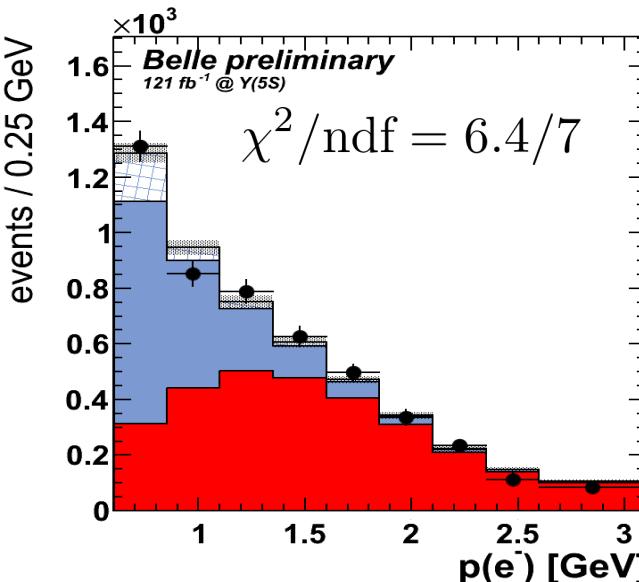
Systematic uncertainties:

External parameter	$\Delta \mathcal{B}/\mathcal{B}$
f_s/f_{ud}	3.2 %
$\mathcal{B}(B_s^0 \rightarrow D_s^\pm X)$	4.4 %
$B_{u,d} \rightarrow D_s$ branching fractions	3.2 %
other external parameters	0.7 %

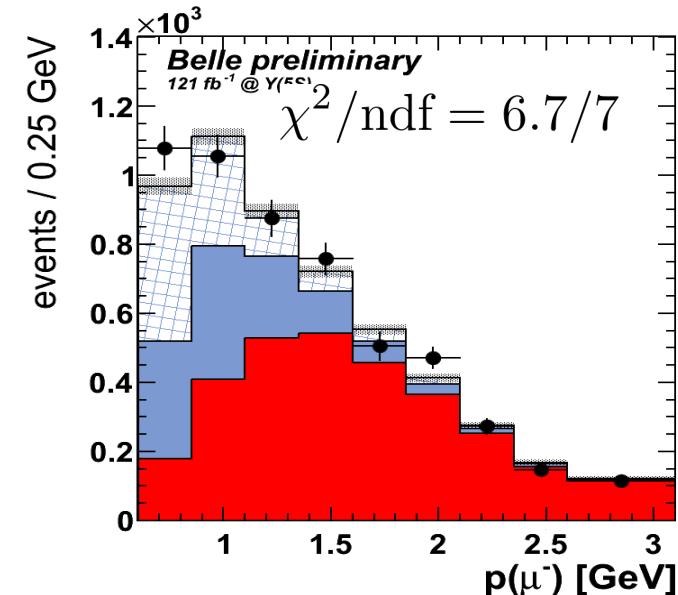
Extraction of leptons from B decays



D_s⁻ counted in fits to m(KKπ)
Continuum bkg. subtracted
with off resonance data



Two component fraction fit:
prompt leptons and **secondary+fake** leptons

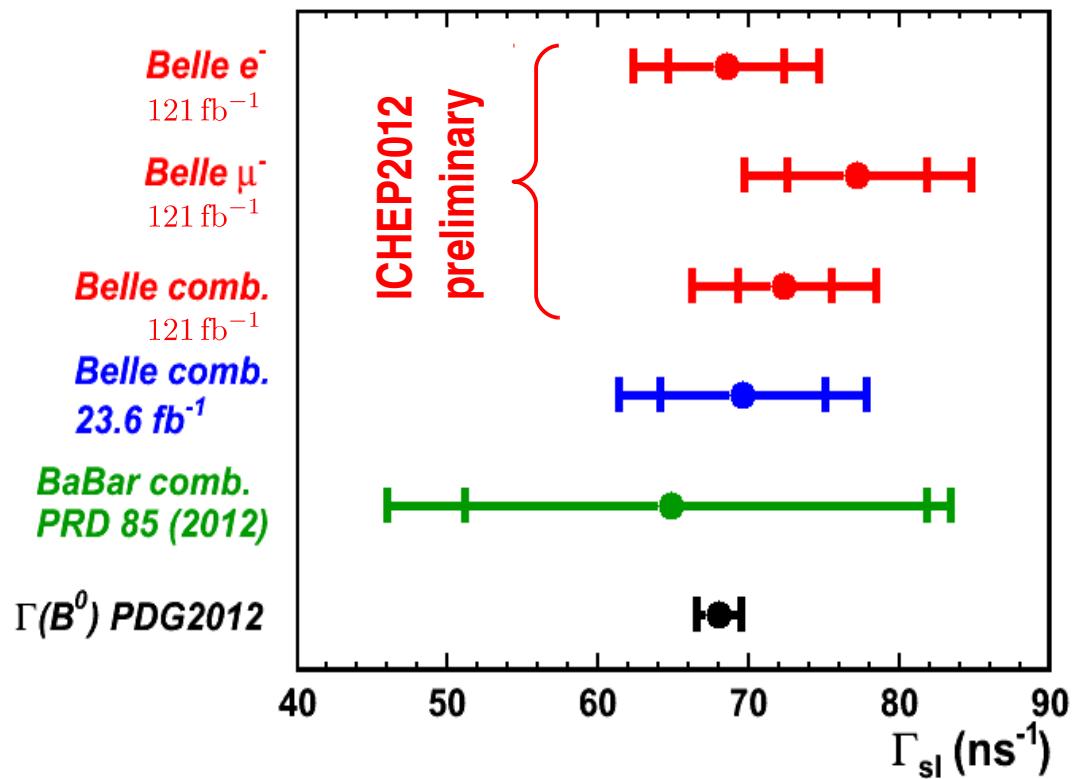


$$\frac{N(D_s^- e^-)}{N(D_s^-)} = 0.0426 \pm 0.0020 \pm 0.0013$$

$$\frac{N(D_s^- μ^-)}{N(D_s^-)} = 0.0471 \pm 0.0024 \pm 0.0016$$

Rel. Systematic uncertainty	e ⁻	μ ⁻
Lepton reconstruction, ID and fake rate	0.7 %	1.4 %
D _s reconstruction efficiency	0.8 %	0.8 %
KKπ mass shape	2.0 %	2.2 %
Estimation of continuum background		1.1%
Composition of the secondary and fake ℓ bkg.	1.0 %	1.5 %
Model of the semileptonic width		1.2 %

Results $\mathcal{B}(B_s^0 \rightarrow X \ell^+ \nu_\ell)$



$\mathcal{B}(B_s^0 \rightarrow X \ell^+ \nu_\ell)$ preliminary

		stat.	syst.	ext.
$\ell = e:$	(10.04 \pm 0.57)	\pm 0.37	\pm 0.61	%
$\ell = \mu:$	(11.32 \pm 0.68)	\pm 0.46	\pm 0.74	%
$\ell = e, \mu:$	(10.61 \pm 0.46)	\pm 0.37	\pm 0.67	%

Limit on SU(3) symmetry breaking (90 % CL): $92.8\% < \frac{\Gamma_{\text{sl}}^-(B_s^0)}{\Gamma_{\text{sl}}(B_d^0)} < 126.2\%$

Signal candidates: $D_s^{(*)+} K^+ \ell^-$

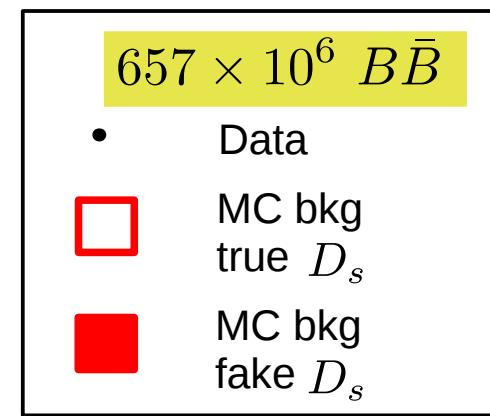
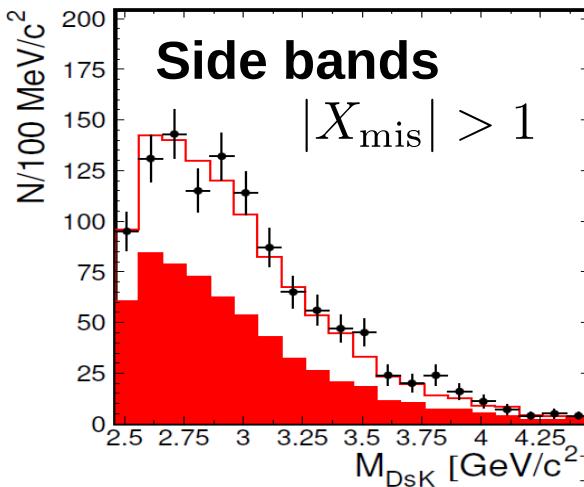
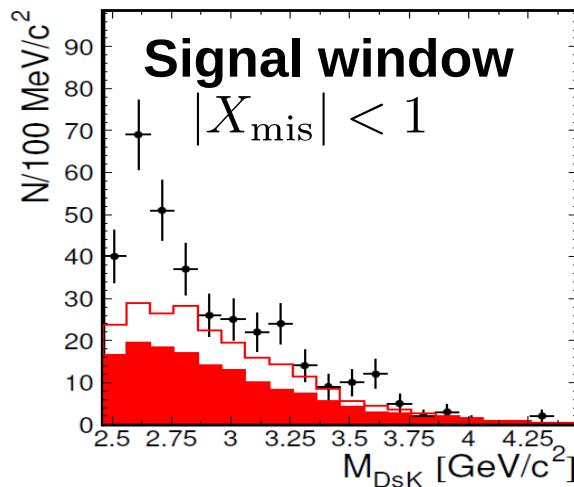
$$D_s^- \rightarrow \phi \pi^+, \phi \rightarrow K^+ K^-$$

$$D_s^{*+} \rightarrow D_s^+ \gamma \quad (E_\gamma > 125 MeV)$$

Challenge: missing neutrino

$$X_{\text{mis}} = \frac{(E_{\text{beam}} - E_{\text{vis}}) - p_{\text{vis}}}{\sqrt{E_{\text{beam}}^2 - M_B^2}}$$

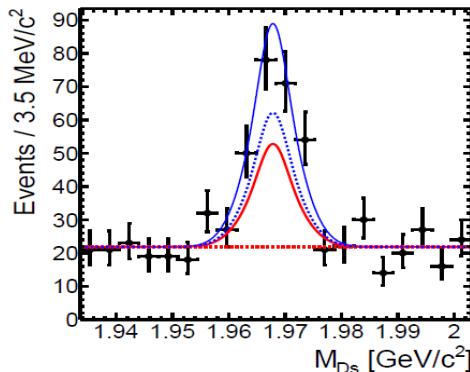
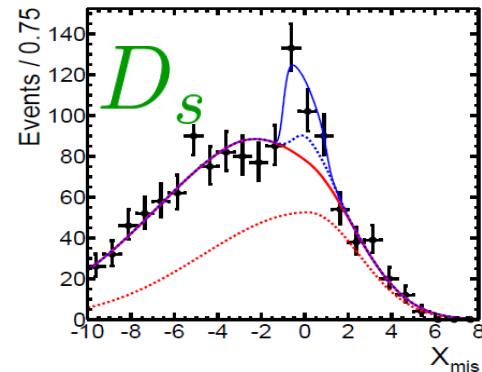
Remaining particles of the event for bkg. suppression: additional ℓ^- , M_{tag}^c , X_{tag}



Simultaneous unbinned max. likelihood fit in
 \rightarrow crossfeed $D_s \leftrightarrow D_s^*$ taken into account

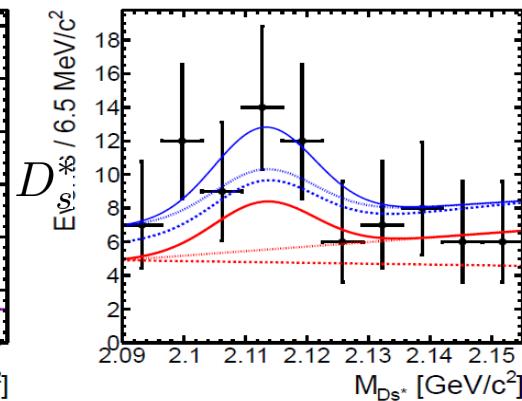
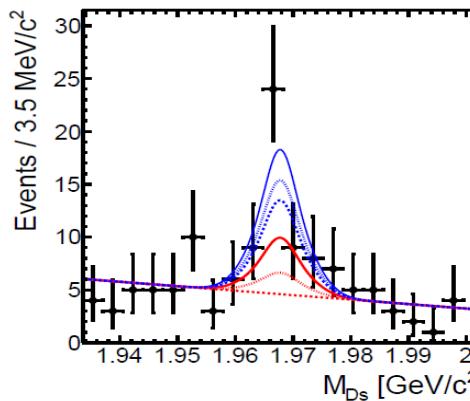
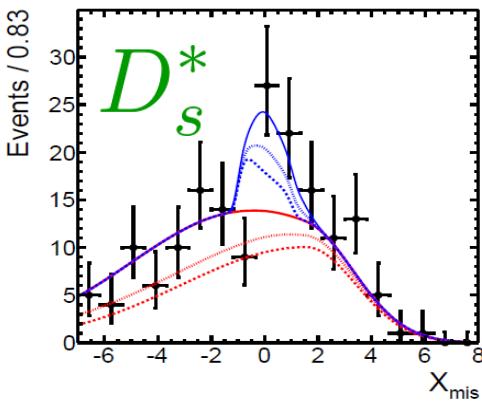
$\underbrace{X_{\text{mis}}, m(D_s)}_{D_s K}, \underbrace{X_{\text{mis}}, m(D_s), m(D_s^*)}_{D_s^* K}$

Results $B \rightarrow D_s^{(*)+} K \ell \nu_\ell$



true D_s (signal)
 true D_s^* (signal)
 true D_s (bkg)
 fake D_s (bkg)

$657 \times 10^6 B\bar{B}$



true D_s^* (signal)
 fake D_s^* (signal)
 true D_s (signal)
 true D_s^* (bkg)
 fake D_s^* (bkg)
 fake D_s (bkg)

Mode	Σ	$\mathcal{B} \times 10^{-3}$
$B^- \rightarrow D_s^+ K^- \ell^- \bar{\nu}_\ell$	3.9	$0.30 \pm 0.09 \pm 0.11$
$B^- \rightarrow D_s^{*+} K^- \ell^- \bar{\nu}_\ell$	1.9	$0.29 \pm 0.16 \pm 0.11$
$B^- \rightarrow D_s^{(*)+} K^- \ell^- \bar{\nu}_\ell$	6	$0.59 \pm 0.12 \pm 0.15$

} First (and only) separate measurement of $D_s K$, $D_s^* K$ in semilept. decays

Article is about to be submitted to PRD

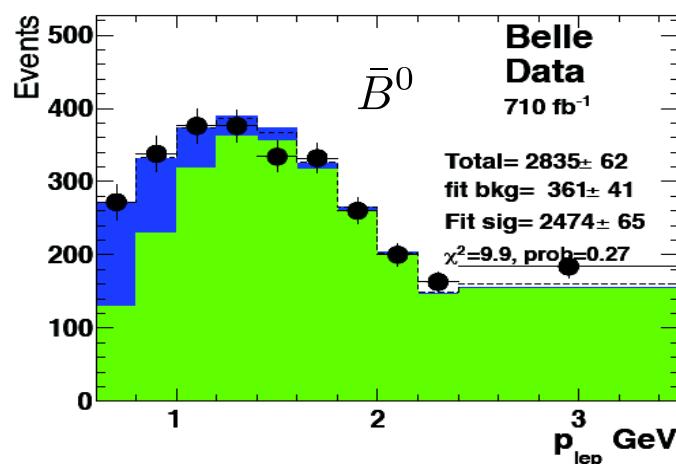
Semi-inclusive $B \rightarrow D^{(*)} X \ell \nu$

Full hadronic reconstruction of tag B with neural network

Reconstruction of signal:

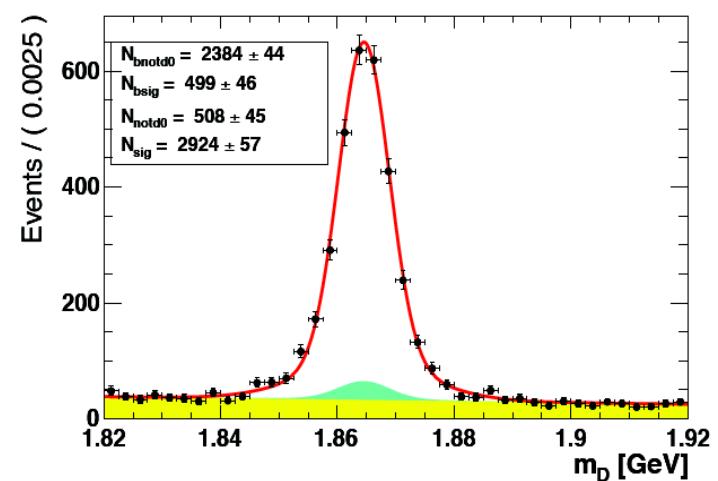
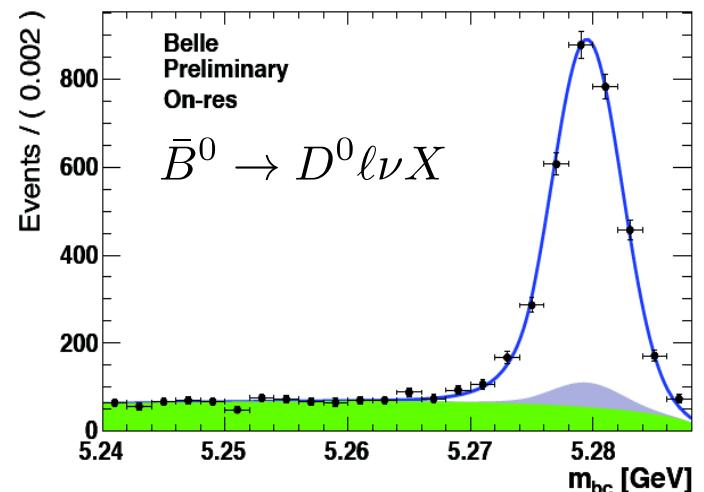
$$\left. \begin{array}{l} D^0 \rightarrow K^- \pi^+ (\pi^+ \pi^-) \\ D^- \rightarrow K^- \pi^- \pi^+ \\ D^{*0} \rightarrow D^0 \pi_{\text{slow}}^0 \\ D^{*+} \rightarrow D^0 \pi_{\text{slow}}^+ \end{array} \right\} \times 2 \text{ B flavours} = 8 \text{ different modes}$$

Secondary+fake lepton bkg subtracted from a χ^2 fit to the lepton momentum



$772 \times 10^6 B\bar{B}$

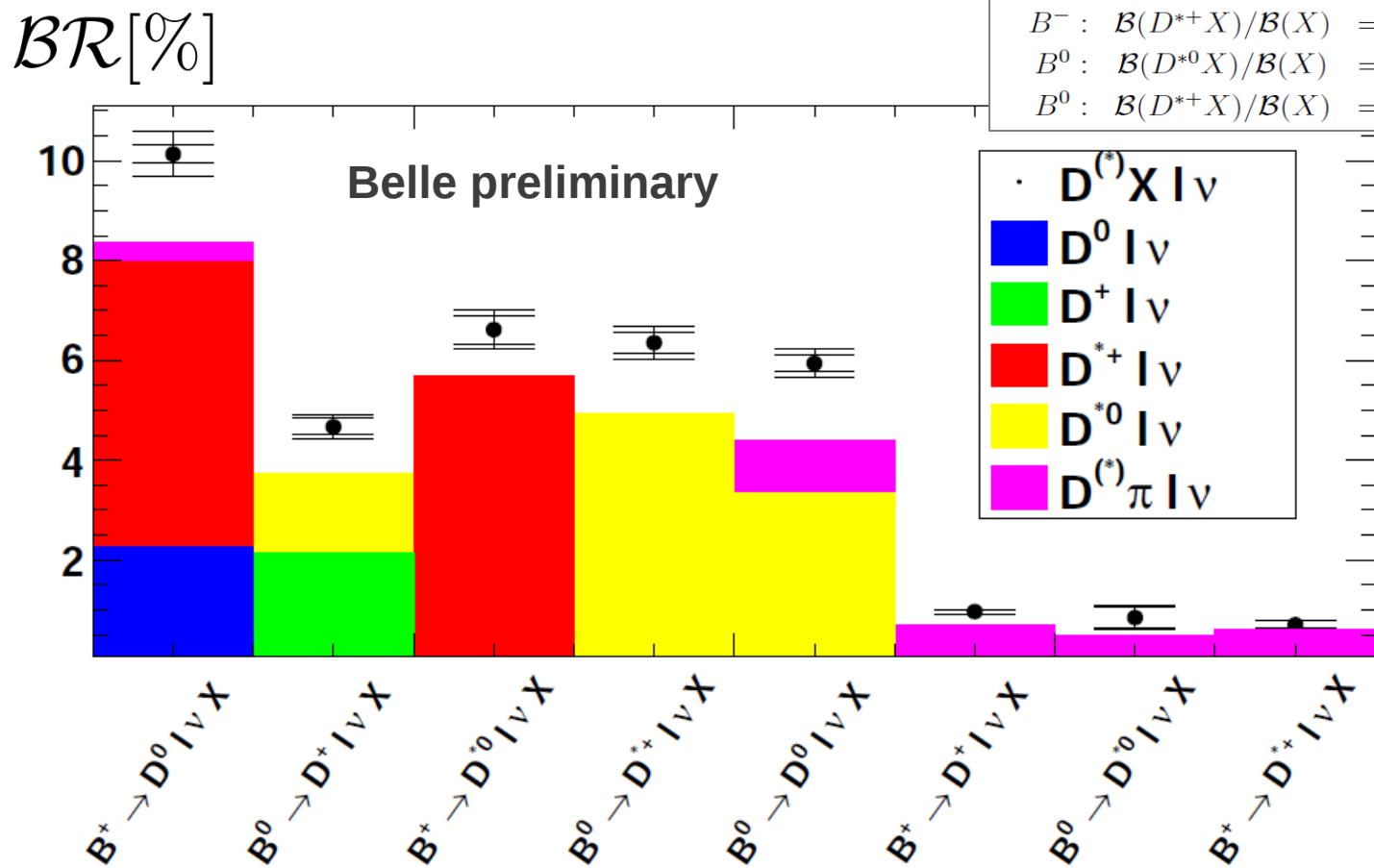
2D unbinned fit in m_{bc} and m_D
(D modes)
 $\Delta m = m_{D^*} - m_D$ (D^* modes)



Results $B \rightarrow D^{(*)} X \ell \nu$



Branching ratios given with respect to $\mathcal{B}(X) = \mathcal{B}(B \rightarrow X \ell \nu)$
(systematics cancel)



preliminary

$B^- : \mathcal{B}(D^0 X)/\mathcal{B}(X)$	$= 0.922 \pm 0.016_{\text{stat.}} \pm 0.011_{\mathcal{B}(D)} \pm 0.036_{\text{sys}}$
$B^- : \mathcal{B}(D^+ X)/\mathcal{B}(X)$	$= 0.088 \pm 0.004_{\text{stat.}} \pm 0.002_{\mathcal{B}(D)} \pm 0.005_{\text{sys}}$
$B^0 : \mathcal{B}(D^0 X)/\mathcal{B}(X)$	$= 0.575 \pm 0.016_{\text{stat.}} \pm 0.007_{\mathcal{B}(D)} \pm 0.022_{\text{sys}}$
$B^0 : \mathcal{B}(D^+ X)/\mathcal{B}(X)$	$= 0.452 \pm 0.007_{\text{stat.}} \pm 0.010_{\mathcal{B}(D)} \pm 0.021_{\text{sys}}$
$B^- : \mathcal{B}(D^{*0} X)/\mathcal{B}(X)$	$= 0.597 \pm 0.026_{\text{stat.}} \pm 0.007_{\mathcal{B}(D)} \pm 0.024_{\text{sys}}$
$B^- : \mathcal{B}(D^{*+} X)/\mathcal{B}(X)$	$= 0.064 \pm 0.007_{\text{stat.}} \pm 0.008_{\mathcal{B}(D)} \pm 0.004_{\text{sys}}$
$B^0 : \mathcal{B}(D^{*0} X)/\mathcal{B}(X)$	$= 0.081 \pm 0.020_{\text{stat.}} \pm 0.009_{\mathcal{B}(D)} \pm 0.006_{\text{sys}}$
$B^0 : \mathcal{B}(D^{*+} X)/\mathcal{B}(X)$	$= 0.615 \pm 0.021_{\text{stat.}} \pm 0.007_{\mathcal{B}(D)} \pm 0.024_{\text{sys}}$

Composition evaluated from current HFAG&PDG averages

Summary

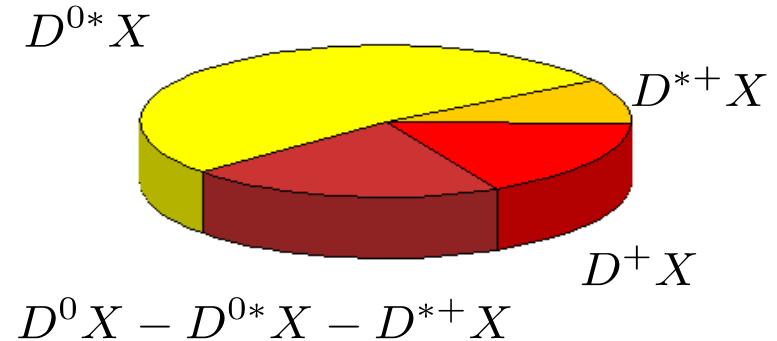
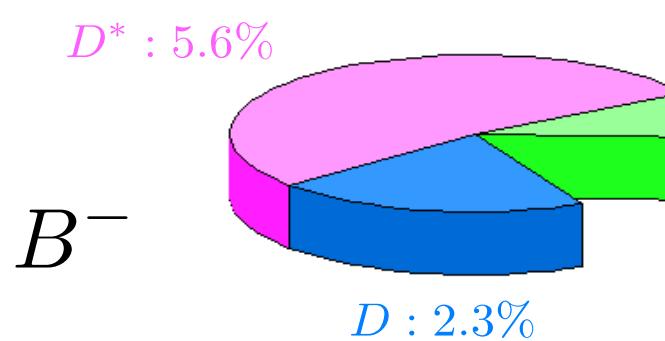


- Inclusive vs. Exclusive puzzle:**

- Full semilept. width described by semi-inclusive modes:

$$B^0 : \mathcal{B}(D^0 X + D^+ X) / \mathcal{B}(X) = 1.027 \pm 0.018_{\text{stat.}} \pm 0.012_{\mathcal{B}(D)} \pm 0.040_{\text{sys}}$$

$$B^- : \mathcal{B}(D^0 X + D^+ X) / \mathcal{B}(X) = 1.010 \pm 0.015_{\text{stat.}} \pm 0.011_{\mathcal{B}(D)} \pm 0.040_{\text{sys}}$$



$$\left. \begin{array}{l} \mathcal{B}(B^- \rightarrow D_s^+ K^- \ell^- \bar{\nu}_\ell) = (0.30 \pm 0.09 \pm 0.11) \times 10^{-3} \\ \mathcal{B}(B^- \rightarrow D_s^{*+} K^- \ell^- \bar{\nu}_\ell) = (0.29 \pm 0.16 \pm 0.11) \times 10^{-3} \end{array} \right\} \begin{array}{l} \text{first separate} \\ \text{measurement} \end{array}$$

$$\left. \begin{array}{l} \\ \end{array} \right\} \begin{array}{l} m(D_s K) \text{ study} \\ \text{above 2.4 GeV} \end{array}$$

- Study of inclusive semileptonic decays of the B_s^0**

$$\mathcal{B}(B_s^0 \rightarrow X \ell^+ \nu_\ell) = (10.61 \pm 0.46(\text{stat}) \pm 0.37(\text{syst}) \pm 0.67(\text{ext}))\%$$



BACKUP

Signal selection $B \rightarrow D_s^{(*)+} K \ell \nu_\ell$



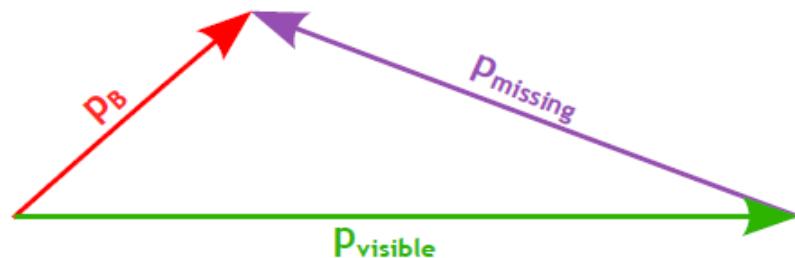
$657 \times 10^6 B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance

Signal candidates: $D_s^{(*)+} K^+ \ell^-$

$$D_s^- \rightarrow \phi \pi^+, \phi \rightarrow K^+ K^-$$

$$D_s^{*+} \rightarrow D_s^+ \gamma \quad (E_\gamma > 125 MeV)$$

Challenge: missing neutrino



$$|p_B - p_{vis}| \leq p_{mis} < p_B + p_{vis}$$

$$X_{mis} = \frac{(E_{beam} - E_{vis}) - p_{vis}}{\sqrt{E_{beam}^2 - M_B^2}}$$

for signal: $X_{mis} \in [-1, 1]$

Remaining particles ('tag') in the event used for bkg. suppression:

additional ℓ^- required with $p(\ell) > 0.5 \text{ GeV}$

$$M_{tag}^c = \sqrt{(E_{tag} - (E_{tag}^\ell))^2 - (\vec{p}_{tag} - \vec{p}_{tag}^\ell)^2} \quad M_{tag}^c < 2.4 \text{ GeV}$$

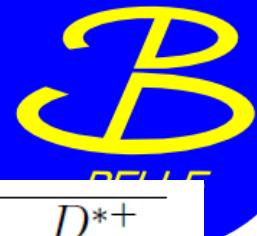
$$X_{tag} = (E_{beam} - E_{tag} - |\vec{p}_{tag}|) / \sqrt{E_{beam}^2 - m_{B^+}^2} \quad -2 < X_{tag} < 3$$

$$B \rightarrow D_s^{(*)+} \bar{D}^{(*)}$$

$$\bar{B} \rightarrow D^{(*)} \ell^- \bar{\nu}_\ell X$$

$$\downarrow K^+ X$$

Results and systematic uncertainties



	D_s^+	D_s^{*+}
Signal yield	84	41
Uncertainties		
Parametrisation of X_{mis} dependency of the signal	$\pm 6^{23}$	$\pm 9^7$
Modeling of the X_{mis} distributions of bkg. components with true D_s	$\pm 7^5$	$\pm 7^8$
Determination of fit parameters from sidebands	$\pm 2^4$	$\pm 1^0$
Estimation of the relative contributions of the signal components	± 1	± 1

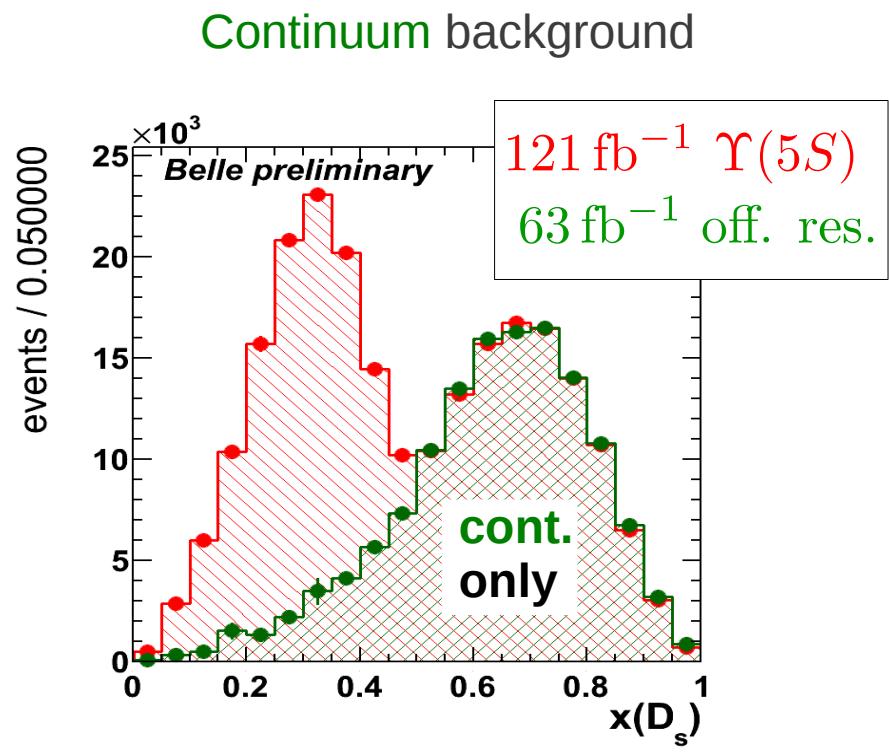
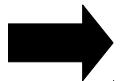
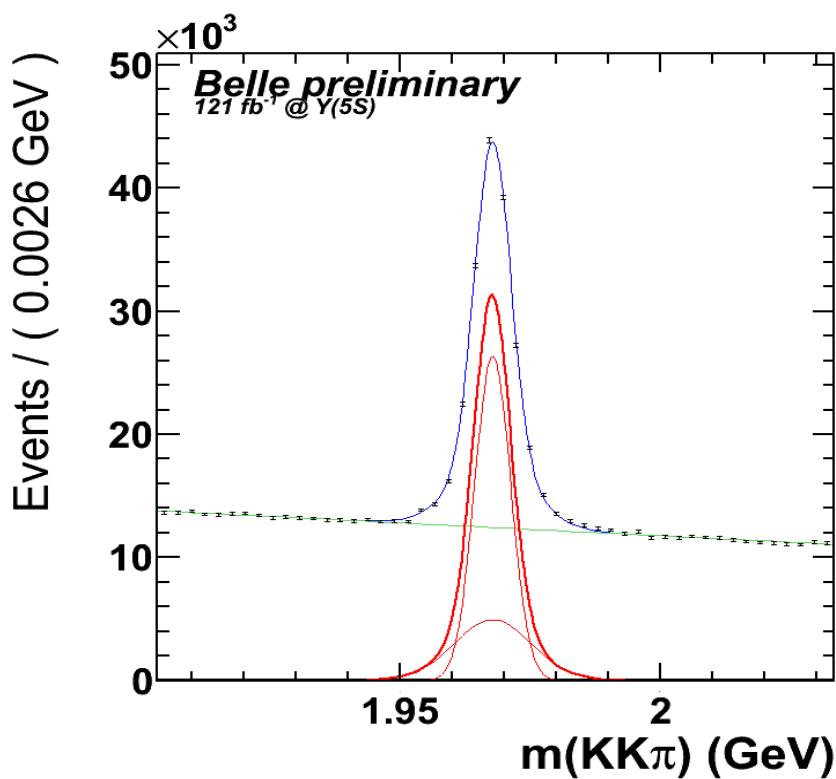
$$\mathcal{B}(B^- \rightarrow D_s^{(*)+} K^- \ell^- \bar{\nu}_\ell) = \frac{N_s^{(*)}}{2N_{B^+ B^-} \epsilon^{(*)} \mathcal{B}_{\text{int}}}$$

Mode	Σ	$\mathcal{B} \times 10^{-3}$
$B^- \rightarrow D_s^+ K^- \ell^- \bar{\nu}_\ell$	3.9	$0.30 \pm 0.09 \pm 0.11$
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$B^- \rightarrow D_s^{(*)+} K^- \ell^- \bar{\nu}_\ell$	6	$0.59 \pm 0.12 \pm 0.15$

Other systematic uncertainties

Charged track reconstruction efficiency	6.6 %
Particle identification efficiency	3.9 %
Intermediate branching fractions	6.1 %
Number of $B^+ B^-$ pairs	1.5 %
Reconstruction efficiency correction $\Delta \epsilon_{text{cor}}$	21 %

Determination of $N(D_s^-)$



$$x(D_s) = \frac{p(D_s)}{p_{\max}(D_s)} < 0.5$$

$$N(D_s^-) = N_{\Upsilon(5S)}(D_s^-) - N_{\text{off}}(D_s^-)$$