Branching Ratio Measurement

$$\mathrm{Br}(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)})$$

at the DØ Experiment

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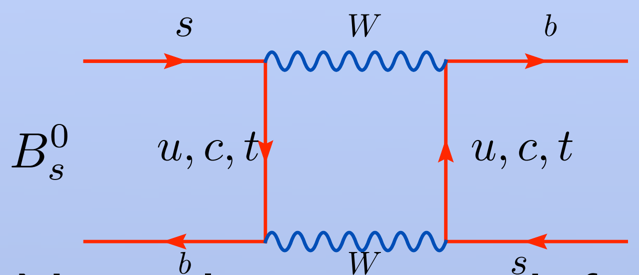
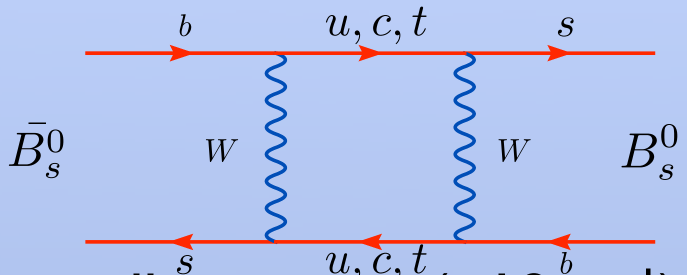
On behalf of the DØ Collaboration

Outline

- Bs meson sector
- The DØ detector
- Extracting $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$
- Normalisation channel
- Background contributions
- Results and Summary

Strange Properties of Beautiful Mesons





- Neutral mesons with fast oscillation rate (~18 ps^{-1})

$$i\frac{\mathrm{d}}{\mathrm{d}t}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i}{2}\Gamma & M_{12} - \frac{i}{2}\Gamma_{12} \\ M_{12}^* - \frac{i}{2}\Gamma_{12}^* & M - \frac{i}{2}\Gamma \end{pmatrix}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$

- Flavour $B_s^0, \bar{B}_s^0$ and mass B_L, B_H eigenstates different

5 observables

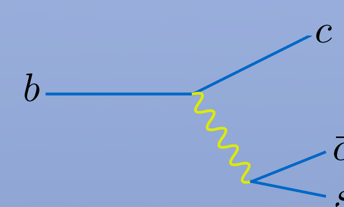
M$_{12}$ dominated by $b \longrightarrow t\bar{t}s$

$$M_s = \frac{M_H + M_L}{2}$$

$$\Delta m_s = M_H - M_L \sim 2|M_{12}|$$

$$\Gamma_s \equiv \frac{1}{\bar{\tau}_s} = \frac{\Gamma_L + \Gamma_H}{2}$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|\cos\phi_s$$



Γ$_{12}$ dominated by $b \longrightarrow c\bar{c}s$

$$\phi_s = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

Measuring Beyond SM effects

- M_{12} sensitive to effects of new physics, both through $|M_{12}|$ and $\arg(M_{12})$.
- $|M_{12}|$ measured from $\Delta m_s \sim 2|M_{12}|$
- $\arg(M_{12})$ can be obtained through $\phi_s = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$
- Γ_{12} from tree level processes; new physics unlikely, however NP can enter width difference through ϕ_s

  $$\Delta\Gamma_s = 2|\Gamma_{12}|\cos\phi_s \approx \Delta\Gamma_{\mathrm{SM}}\cos\phi_s$$

- leads to decrease in $\Delta\Gamma_s$.
- Gluinos and squarks in MSSM box diagrams can compete with SM contributions,

Width Difference $\Delta\Gamma_s$

- Width difference $\Delta\Gamma_s = \Delta\Gamma_s^{\mathrm{CP}} \cos\phi_s$, where $\Delta\Gamma_s^{\mathrm{CP}} \equiv 2|\Gamma_{12}| = \Gamma(\mathrm{even}) - \Gamma(\mathrm{odd})$ is the difference between the CP-even and CP-odd final-states.

- $\Delta\Gamma_s^{\mathrm{CP}}$ is independent to CP-violation, provides a further check on NP

- Effects from New Physics processes may reduce width difference

  CP - even final states $\Delta\Gamma_s \uparrow$

  CP - odd final states $\Delta\Gamma_s \downarrow$

- Width difference in Bs system predicted in SM as

$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.124 \pm 0.056$$

hep-ph/0612167v3

$B_s \to D_s^{(*)} D_s^{(*)}$

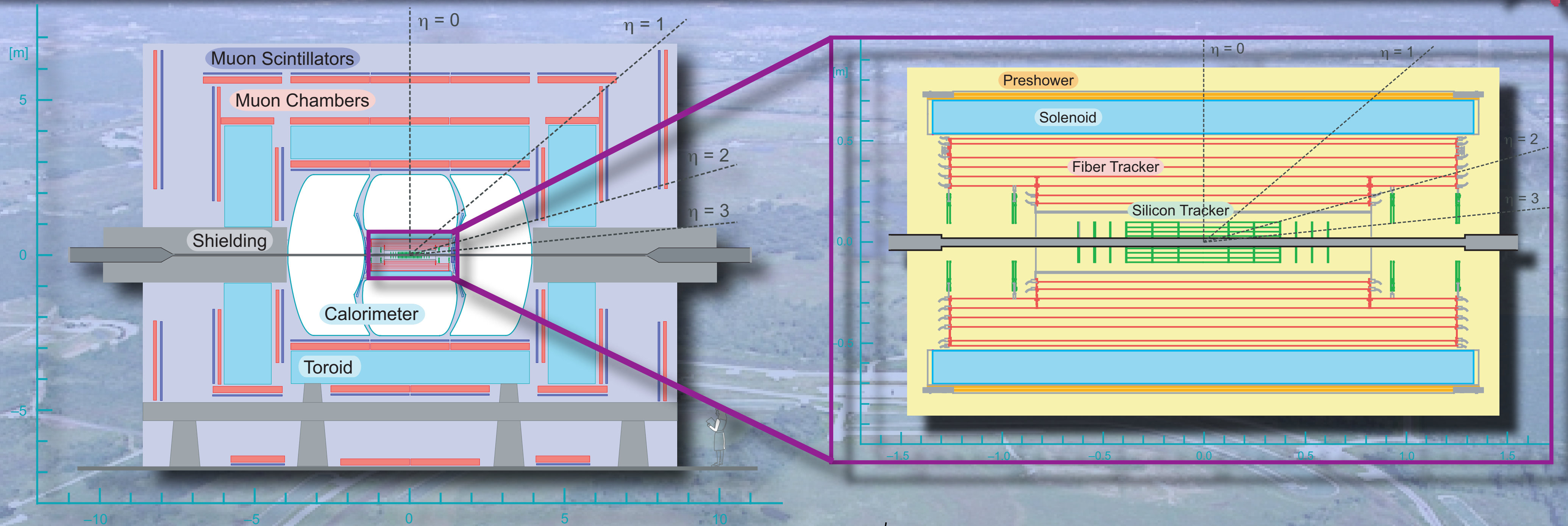
- Decay of $B_s \to D_s^+ D_s^-$ is pure CP-even
- Under certain theoretical assumptions $D_s^{(*)} D_s^{(*)}$ is mainly CP-even.
- Under these assumptions, measurement of branching fraction allows determination of the width difference $\Delta\Gamma_s^{CP}$

$$2\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)}) = \frac{\Delta\Gamma_s^{CP}}{\Gamma_s}\left\{1 + \mathcal{O}\left(\frac{\Delta\Gamma_s}{\Gamma_s}\right)\right\}$$

- Measurement of $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$ previously performed at ALEPH from study of correlated $\phi\phi$ production from Z decays

$$2 \cdot \mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)}) = (23^{+21}_{-13})\%$$

Measuring B_s mesons at DØ



- Tevatron: proton–antiproton collisions at $\sqrt{s}$=1.96 TeV.
- Most B physics analyses utilise excellent 3-layer muon system with large $|\eta|<2$ coverage.
- Vertexing and decay-length measurements using silicon and fiber-tracking systems, enclosed within 2T field.
- Over 3.5fb^{-1} delivered by accelerator division to DØ since 2002.
- This analysis used ~1fb^{-1} integrated luminosity.

Branching Fraction Determination

- Branching ratio is determined from expression:

Determined from Data/Simulation

$$\frac{N(\mu\phi D_s) - N_{bkg}(\mu\phi D_s)}{N(\mu D_s)\ f(B_s^0 \to \mu\nu D_s^{(*)})} = \frac{2\,\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)}) \cdot \mathrm{Br}(D_s \to \phi\mu\nu)}{\mathrm{Br}(B_s^0 \to \mu\nu D_s^{(*)})}\ \mathrm{Br}(\phi \to K^+K^-)\ \frac{\varepsilon(B_s^0 \to D_s^{(*)} D_s^{(*)})}{\varepsilon(B_s^0 \to \mu\nu D_s^{(*)})}$$

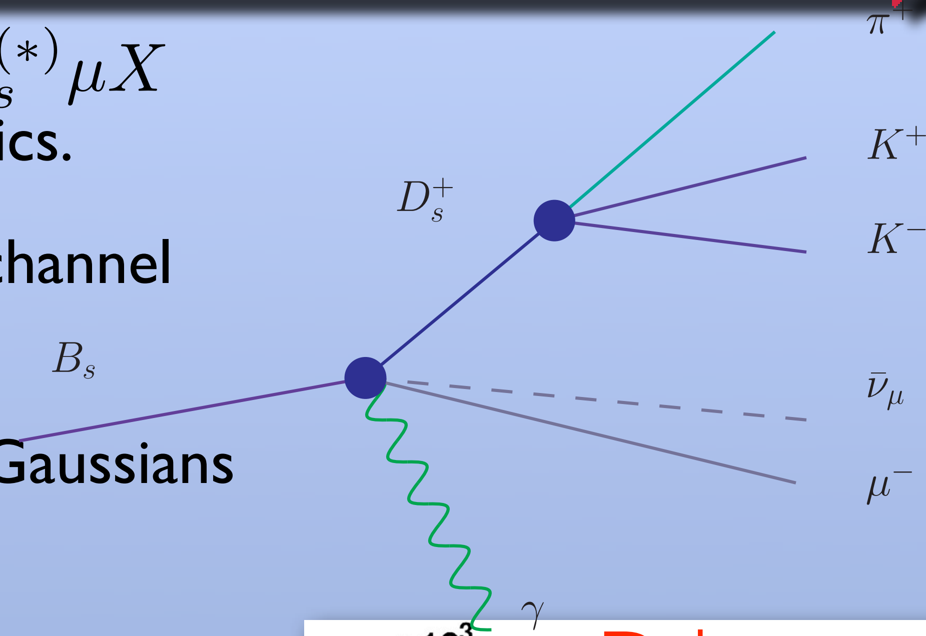
What we want

From PDG

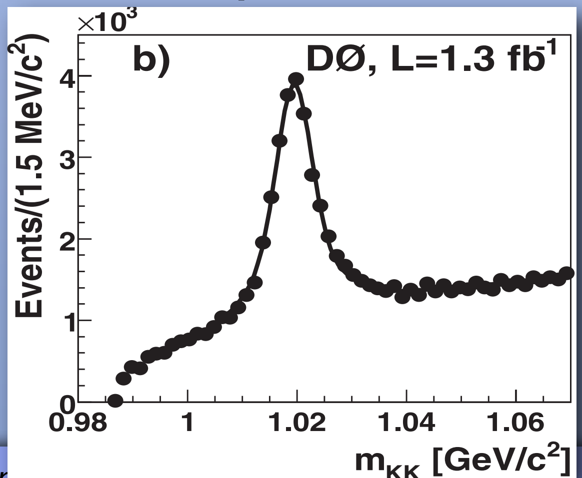
Reconstruction efficiencies (from MC)

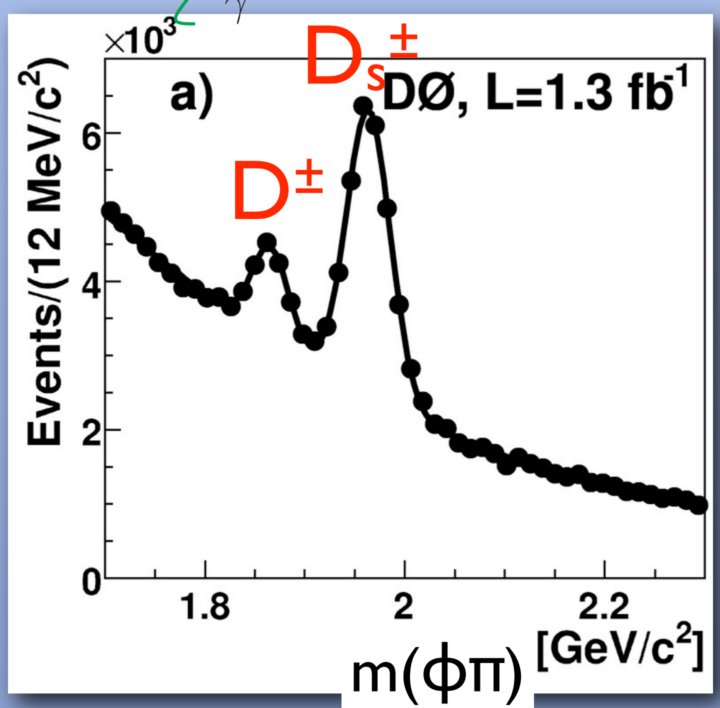
Normalisation Channel

- Normalise main decay to $B_s^0 \to D_s^{(*)} \mu X$ to reduce detector related systematics.
- Number of events in normalisation channel estimated from binned fit.
- Double Gaussian for φ peak, single Gaussians for Ds and D peaks.
- Background parameterised by 2nd-order polynomial.
- Extracted values used as fixed inputs in other fits.

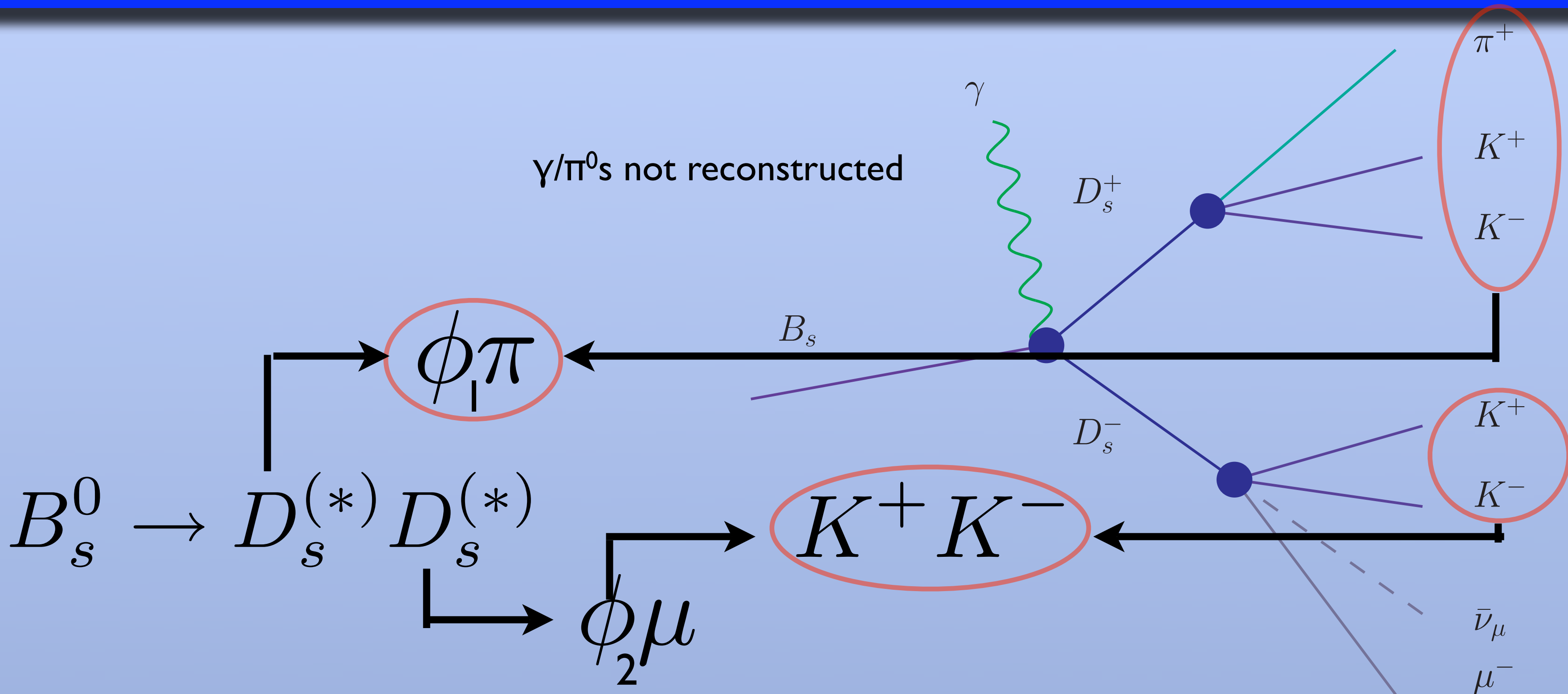


N(μD_s) = 17,700±230.





Extracting $N(\mu\phi D_s^{(*)})$



- Use 2-dimensional unbinned maximum log-likelihood technique to simultaneously fit:
  - $m(KK)$ from $D_s \to \phi_2\mu$,
  - and $m(\phi_1\pi)$.

Extracting $N(\mu\phi D_s^{(*)})$

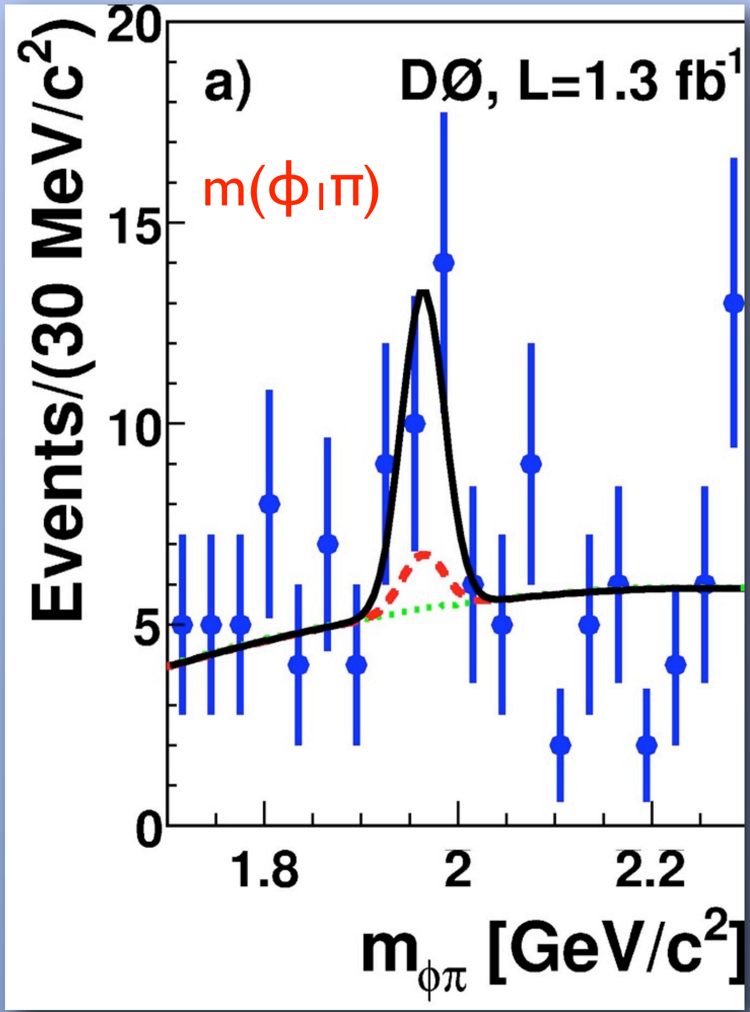
- Sample of $(\mu\phi D_s^{(*)})$ events contains contributions:
  - Combinatoric background,
  - Reconstructed $\phi\pi$ in mass peak of Ds, without joint production of φ from $\phi\mu$,
  - Reconstructed φ from $\phi\mu$, without joint production of $\phi\pi$ in mass peak of Ds,
  - Joint signal production of $\phi\pi$ and φ.
- Use event-by-event fitting procedure to extract fractions of each contribution.

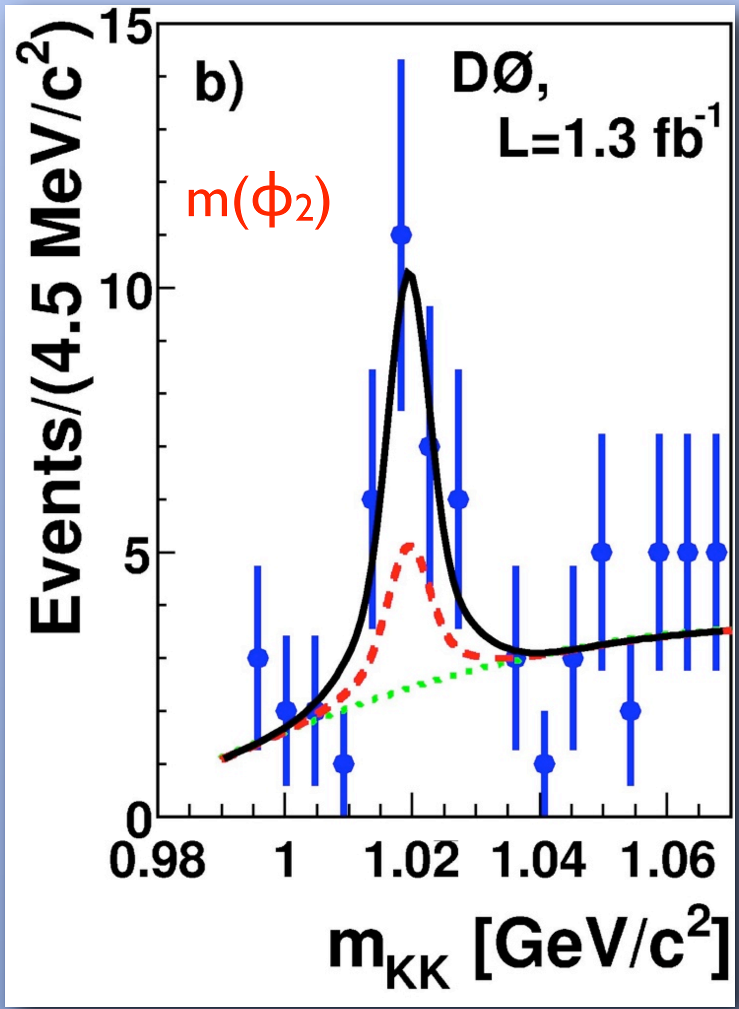
$$\mathcal{L} = \prod_i^N \mathcal{F}_i$$

$$\begin{aligned}\mathcal{F}(M_D, M_\phi) = {} & f_s \mathcal{S}_D(M_D)\mathcal{S}_\phi(M_\phi) \\ & + f_\phi \mathcal{B}(M_D, a_D, b_D)\mathcal{S}_\phi(M_\phi) \\ & + f_D \mathcal{S}_D(M_D)\mathcal{B}(M_\phi, a_\phi, b_\phi) \\ & + (1 - f_s - f_D - f_\phi)\,\mathcal{B}(M_D, a_D, b_D)\mathcal{B}(M_\phi, a_\phi, b_\phi),\end{aligned}$$

Results

- From fit estimate $N(\mu\phi D_s^{(*)}) = 13.4^{+6.6}_{-6.0}$ events.
- Plot projection of fit results in signal regions of the non-plotted mass.





Background Contributions

- From MC estimate contribution of the normalisation $B_s^0 \to D_s^{(*)} \mu X$ channel as $f(B_s^0 \to D_s^{(*)} \mu X) = 0.82 \pm 0.05$

- Using MC and data estimate the background component to the signal process $B_s^0 \to D_s^{(*)} D_s^{(*)}$

- Estimate $N_{bkg}(\mu \phi D_s^{(*)}) = 2 \pm 2$ background events.

- Efficiency of reconstruction is found from simulation.

  - Due to trigger effects and uncertainties in B meson production, MC is reweighted.

  - Ratio of efficiencies $$\frac{\varepsilon(B_s^0 \to D_s^{(*)} D_s^{(*)})}{\varepsilon(B_s^0 \to \mu\nu D_s^{(*)})} = (5.45 \pm 0.08 \text{ (stat)})\%,$$

Process
$B^0 \to D_s D^{(*)} X$
$B^{\pm} \to D_s D^{(*)} X$
$B_s^0 \to D_s^{(*)} D_s^{(*)}$
$B_s \to D_s D X$

Summary

- Branching fraction measured to be

$$\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)}) = 0.039^{+0.019}_{-0.017}\,(\mathrm{stat})^{+0.016}_{-0.015}\,(\mathrm{syst})$$

- Allows an indirect estimate of $\Delta\Gamma_s$ through

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} \approx 2\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$$

$$\frac{\Delta\Gamma_s^{CP}}{\Gamma_s} = 0.079^{+0.038}_{-0.035}(\mathrm{stat})^{+0.031}_{-0.030}(\mathrm{syst})$$

- Consistent with SM prediction $\frac{\Delta\Gamma_s}{\Gamma_s} = 0.124 \pm 0.056$ hep-ph/0612167v3

  UTfit recent result (hep-ph 0803.0659) $\frac{\Delta\Gamma_s}{\Gamma_s} = 0.105 \pm 0.049$

- Published in PRL **99**, 241801 (2007)

Backup

Systematic Uncertainties

Source	Uncertainty in $\mathrm{Br}(B_s^0 \to D_s^{(*)} D_s^{(*)})$
$\mathrm{Br}(D_s \to \phi\pi) = 0.044 \pm 0.006$	$^{+0.006}_{-0.005}$
$\mathrm{Br}(B_s^0 \to \mu\nu D_s^{(*)})\ \mathrm{Br}(D_s \to \phi\pi)$	0.007
$\mathrm{Br}(D_s \to \phi\mu\nu)/\mathrm{Br}(D_s \to \phi\pi)$	0.003
$f(B_s^0 \to \mu\nu D_s^{(*)}) = 0.82 \pm 0.05$	0.002
Background contribution in $N(\mu\phi D_s)$	0.007
Ratio of efficiencies	0.006
Reweighting of MC	0.006
Fitting procedure	0.006

Background Contributions I

- In both normalisation and signal channels additional contributions remain.

- Fit of $(\mu D_s^{(*)})$ sample gave ~18k events in Ds peak. Using MC estimate the fraction of $B_s^0 \to D_s^{(*)}\mu X$ in $(\mu D_s^{(*)})$ from composition

Process	$f(b \to B)$	Branching ratio (%)	r_i
$B^0 \to D_s D^{(*)} X$	0.397	10.5 ± 2.6	0.072 ± 0.018
$B^\pm \to D_s D^{(*)} X$	0.397	10.5 ± 2.6	0.076 ± 0.019
$B_s^0 \to D_s^{(*)} D_s^{(*)}$	0.107	12^{+11}_{-7}	0.023 ± 0.017
$B_s \to D_s D X$	0.107	15.4 ± 15.4	0.021 ± 0.021

$$r_i = \frac{\varepsilon(b\bar{b} \to BY \to D_s^{(*)} D_x Y')}{\varepsilon(b\bar{b} \to B_s^0 Y \to D_s^{(*)}\mu\nu Y')},$$

- Estimate fraction of $B_s^0 \to D_s^{(*)}\mu X$ in sample as

$$f(B_s^0 \to D_s^{(*)}\mu X) = 0.82 \pm 0.05$$

Background Contributions II

- Using MC and scaling to data estimate the background $(\mu\phi D_s^{(*)})$ contribution in the fit result of sample.

$$B_s^0 \to D_s^{(*)} D_s^{(*)} K \quad \frac{N_{\mathrm{MC}}(m(\mu\phi D_s) > 4.3)}{N_{\mathrm{MC}}(m(\mu\phi D_s) < 4.3)} \cdot N_{\mathrm{data}}(m(\mu\phi D_s) < 4.3) = 0.14 \pm 0.54$$

$$B_s^0 \to D_s^{(*)} \mu\phi \quad \frac{N_{\mathrm{MC}}(m(\mu\phi) < 1.85)}{N_{\mathrm{MC}}(m(\mu\phi) > 1.85)} \cdot N_{\mathrm{data}}(m(\mu\phi) > 1.85) = 1.8 \pm 1.5$$

- $N_{bkg}(\mu\phi D_s^{(*)}) = 2 \pm 2$ background events in sample.

Selection Criteria

- To reduce background apply number of kinematic and topological selection cuts.

Particle	Selection Criterion
All tracks:	Number of axial hits in SMT≥ 2
	Number of axial hits in CFT≥ 2
Muon:	$\mathrm{p_T} > 2$ GeV/c
	$\mathrm{p} > 3$ GeV/c
	nseg ≥ 2
Pion:	$\mathrm{p_T} > 1.0$ GeV/c
	Opposite charge combination $(\mu^{\pm}, \pi^{\mp})$
$K^{\pm}$:	$\mathrm{p_T} > 0.8$ GeV/c
ϕ:	Both kaons to have $S_K > 4$, as defined in Eq. (3)
	Opposite kaon charge combination
ϕ from $D_s \to \phi\pi$:	$1.01 < m(KK) < 1.03$ GeV/c^2
ϕ from $D_s \to \phi\mu$:	$0.99 < m(KK) < 1.07$ GeV/c^2
$D_s \to \phi\pi$:	$1.7 < m(\phi\pi) < 2.3$ GeV/c
	χ^2(vertex)< 16
	$d_T^D/\sigma(d_T^D) > 4$
	$\cos(\alpha_T^D) > 0.9$
	Helicity between D_s and K, $\lvert\cos(\theta)\rvert > 0.35$

$D_s \to \phi\mu\nu$	$1.2 < m(\phi\mu) < 1.85$ GeV/c^2
	χ^2(vertex)< 16
	$d_T^D/\sigma(d_T^D) > 1$
$B_s^0 \to \mu D_s$:	χ^2(B vertex)< 16
	$m(\mu D_s) < 5.2$ GeV/c^2
	$d_T^B < d_T^D$ or $d_T^{BD} < 2 \cdot \sigma(d_T^{BD})$
	$L(\mu D_s) = M(B_s) \cdot d_T^B / P_T(\mu D_s) > 150\mu$m
	$Iso > 0.6$
$B_s^0 \to \mu\phi D_s$:	χ^2(B vertex)< 16
	$4.3 < m(\mu\phi D_s) < 5.2$ GeV/c^2
	$d_T^B < d_T^D$ or $d_T^{BD} < 2 \cdot \sigma(d_T^{BD})$
	$L(\mu\phi D_s) = M(B_s) \cdot d_T^B / P_T(\mu\phi D_s) > 150\mu$m
	$Iso > 0.6$