Fermilab Users' Meeting

June 04-05 2008

$Br(B_s \rightarrow D_s^{(*)} D_s^{(*)})$ and Lifetime Difference

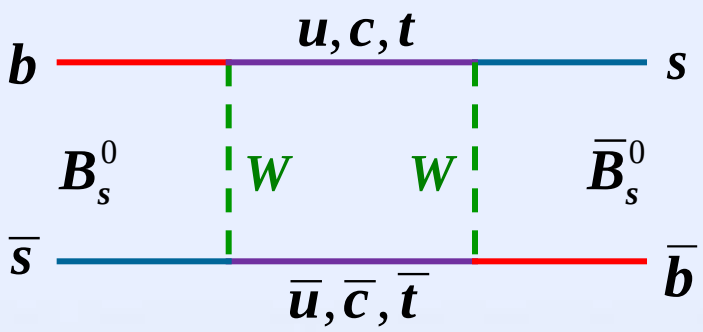
- $\Delta\Gamma$ in B_s Decays
- Motivation
- Analysis Procedure
- Result
- Conclusion

SungWoo YOUN
Northwestern University

$\Delta\Gamma$ in B_s Decays

B_s Decays

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle\\ |\bar{B}_s^0(t)\rangle\end{pmatrix}=\left(M-i\frac{\Gamma}{2}\right)\begin{pmatrix}|B_s^0(t)\rangle\\ |\bar{B}_s^0(t)\rangle\end{pmatrix}$$



M: mass matrix, Γ: decay matrix

$M_{12}=M_{21}^*$, $\Gamma_{12}=\Gamma_{21}^*$ → ***Mixing***

$$\text{Mass}:\begin{cases}|B_L\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle\\ |B_H\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle\end{cases},\quad p^2+q^2=1$$

$$CP:\begin{cases}|B_L\rangle = \frac{1}{\sqrt{2}}|B_s^0\rangle - \frac{1}{\sqrt{2}}|\bar{B}_s^0\rangle\\ |B_H\rangle = \frac{1}{\sqrt{2}}|B_s^0\rangle + \frac{1}{\sqrt{2}}|\bar{B}_s^0\rangle\end{cases}$$

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

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

$$\Delta\Gamma_s^{CP} = \Gamma_s^{even} - \Gamma_s^{odd} = 2|\Gamma_{12}|$$

$$\text{where, } \phi_s = \arg\left(\frac{M_{12}}{\Gamma_{12}}\right)$$

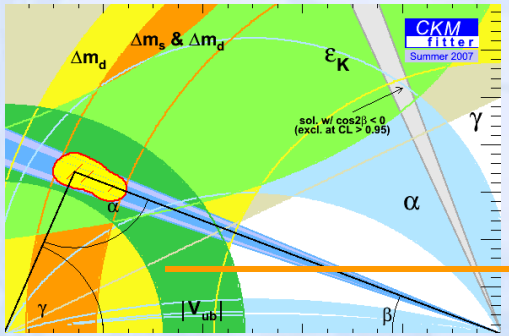
$$\Rightarrow \Delta\Gamma_s = \Delta\Gamma_s^{CP}\cos\phi_s$$

(SM) x (NP)

CPV & $\Delta\Gamma$ in B_s Decays

CKM Matrix: $V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$

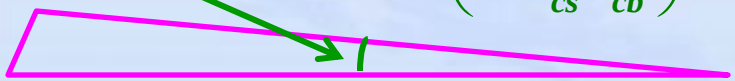
Unitary Triangle:



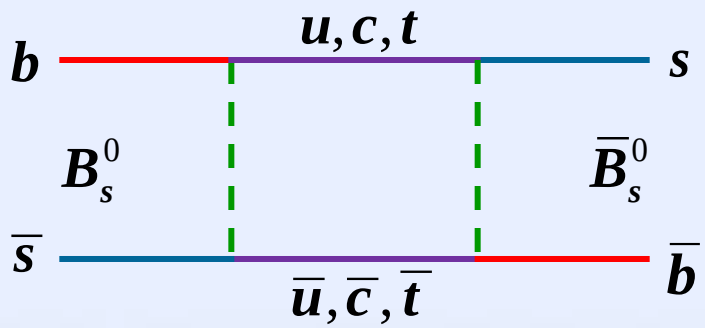
proportional to level of CPV

In B_S System:

$$\beta_s \equiv \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) \sim 0$$



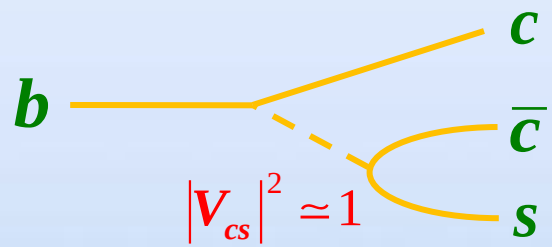
Squashed Unitary Triangle
CPV ~ 0



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

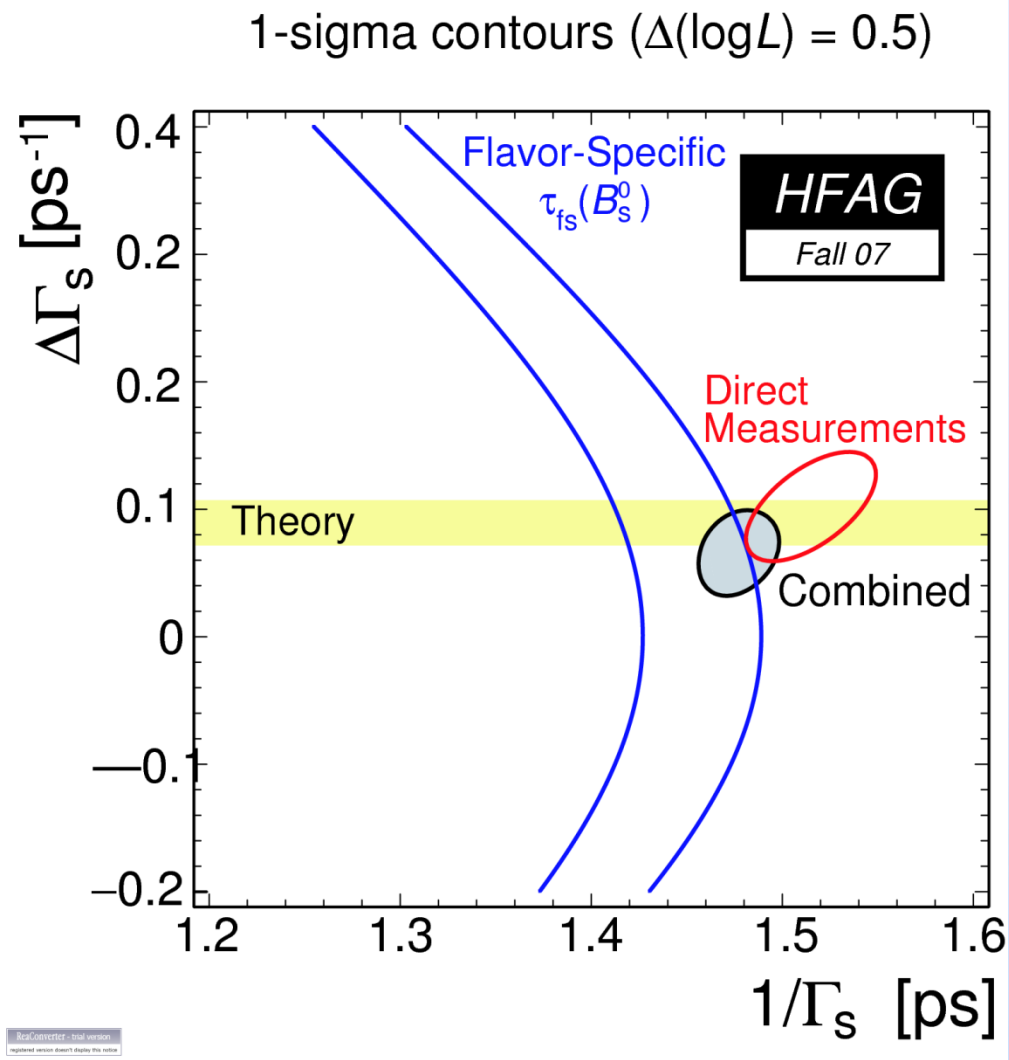
(SM) x (NP)

Γ_{12} is dominated by $b \to c\bar{c}s$



not suppressed !
$\Delta\Gamma_s$ sizable

Summary $\Delta\Gamma_s$ (as of 2007)



Flavor-Specific:
$B_s^0 \rightarrow D_s \mu \nu$
CP asymmetry: a^{fs}

Direct Measurements:
$B_s^0 \rightarrow J/\Psi \varphi$
angular analysis: $\Delta\Gamma_s$ & φ_s
(D0 & CDF)

Theory Prediction
$\Delta\Gamma_s = 0.096 \pm 0.039$
(J. HEP. 0706, 072)

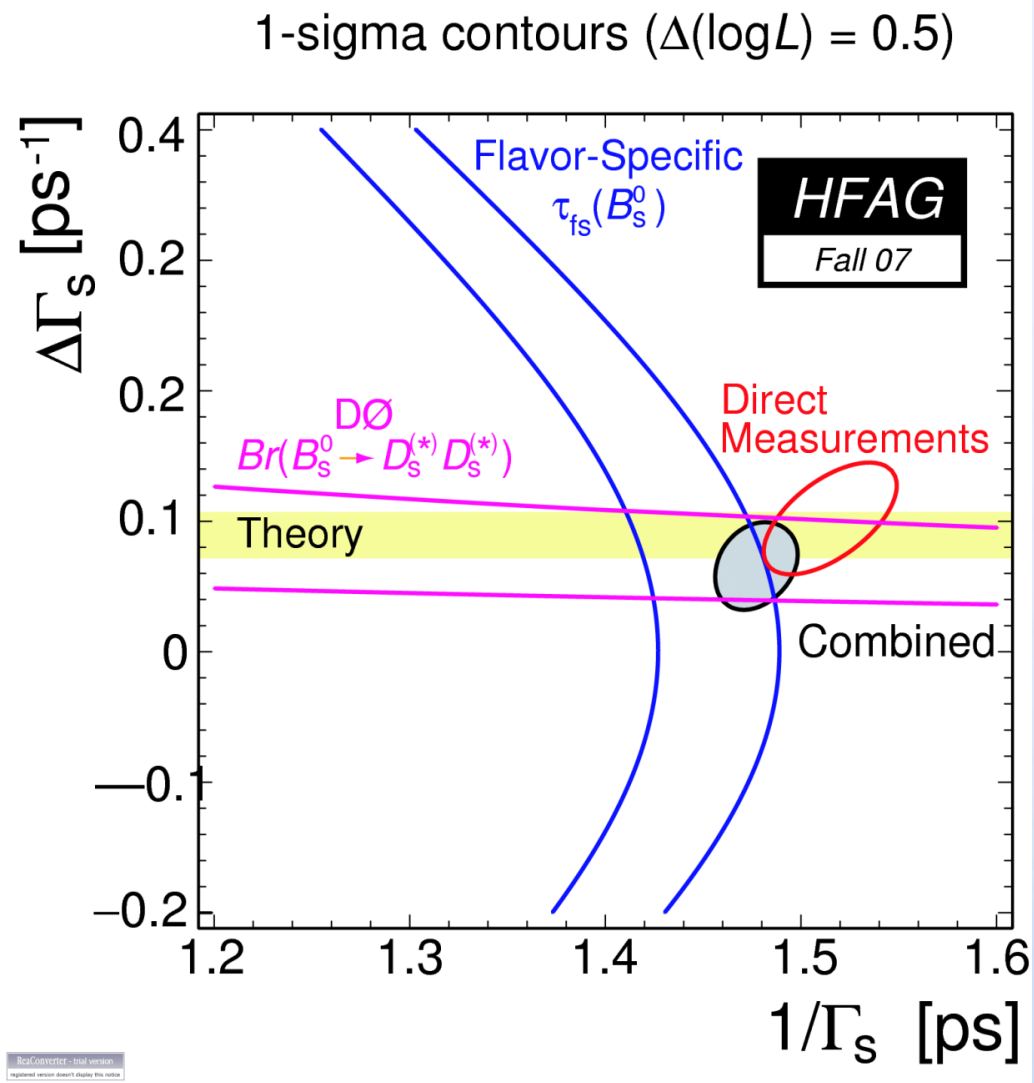
Motivation & Theory

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

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

- theory based analysis: CP even (5~30%)
- consistent with theory
- compatible error band
- untagged: efficiency, purity, acceptance
- simple measurement

Powerful constraint on mixing and CP violation !



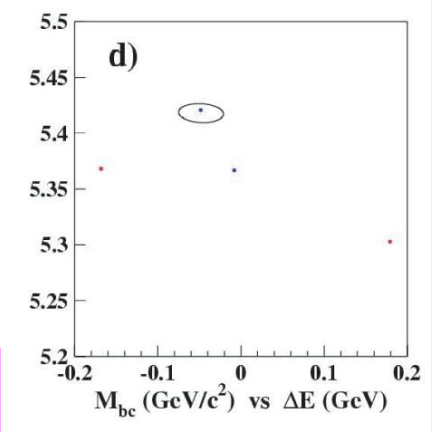
History of $Br(B_s \rightarrow D_s^{(*)} D_s^{(*)})$

NORTHWESTERN UNIVERSITY

ALEPH (2000)
φφ correlation in Z decays

$$N = 18.5 \pm 6.7$$
$$Br = 0.077 \pm 0.034^{+0.038}_{-0.026}$$

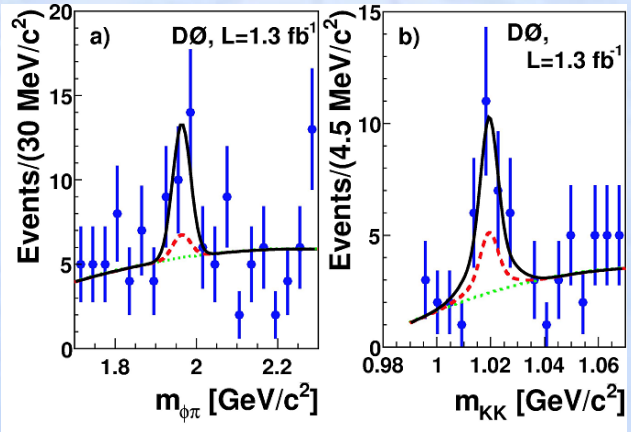
Belle (2006) – 1.86 fb^{-1}
at Υ(5S) resonance



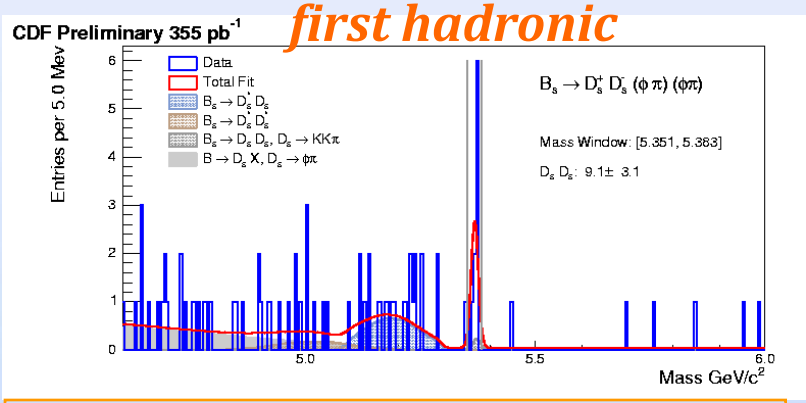
$$Br(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)}) < 27.3\ \%$$

D0 (2007) – 1.3 fb^{-1}
$D_s D_s$ correlation

$$N = 13.4^{+6.6}_{-6.0}$$
$$Br = 0.039^{+0.019+0.016}_{-0.017-0.015}$$



CDF (2006) – 355 pb^{-1}
first hadronic



$$N = 23.5 \pm 5.5$$
$$Br(B_s^0 \rightarrow D_s^+ D_s^-) / Br(B^0 \rightarrow D_s^+ D^-)$$

History of $Br(B_s \rightarrow D_s^{(*)} D_s^{(*)})$

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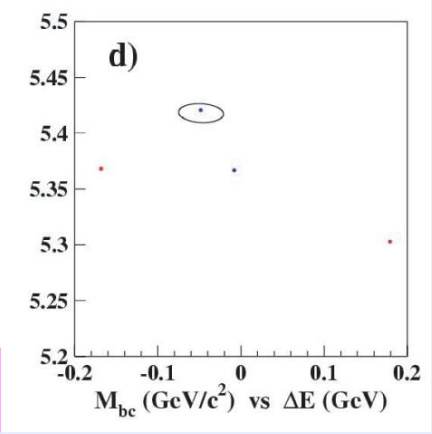

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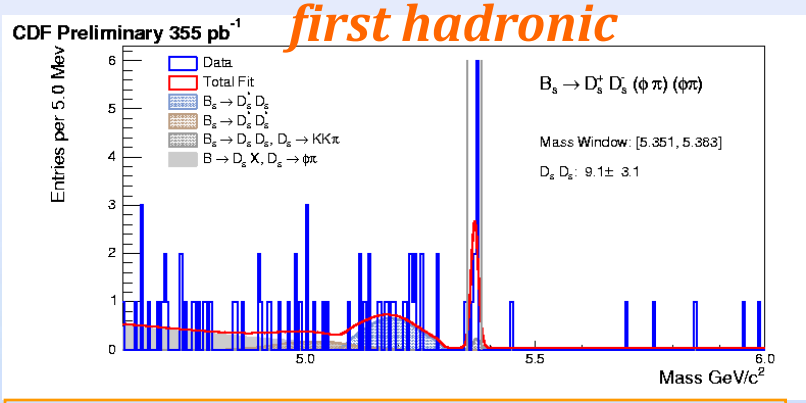


$$N = 23.5 \pm 5.5$$
$$Br(B_s^0 \rightarrow D_s^+ D_s^-) / Br(B^0 \rightarrow D_s^+ D^-)$$

Theory of Br & ΔΓ

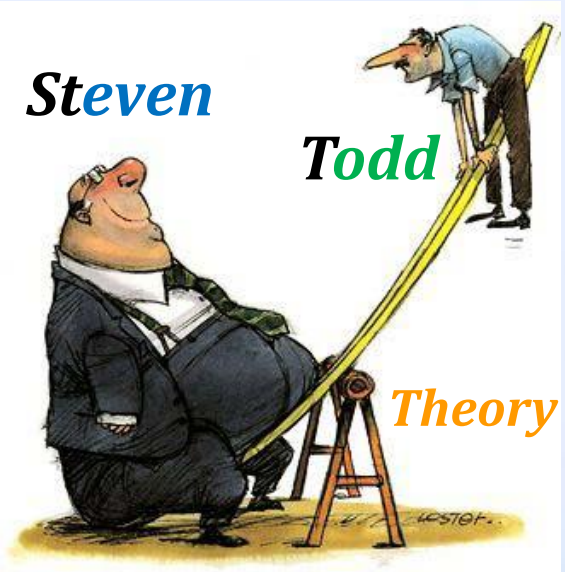
- $D_s^{(*)}D_s^{(*)}$ final state - inclusive

$D_s^+D_s^-$	S wave	CP even
$D_s^*D_s^*$	S,P,D wave	CP mixture
$D_sD_s^*$		CP mixture

+ heavy quark ($m_c \to \infty$)
+ factorization ($2m_c \to m_b$)

(Phys. Lett. B 316, 567 (1993))

$D_s^{(*)}D_s^{(*)} \Rightarrow$ Purely CP even!!!



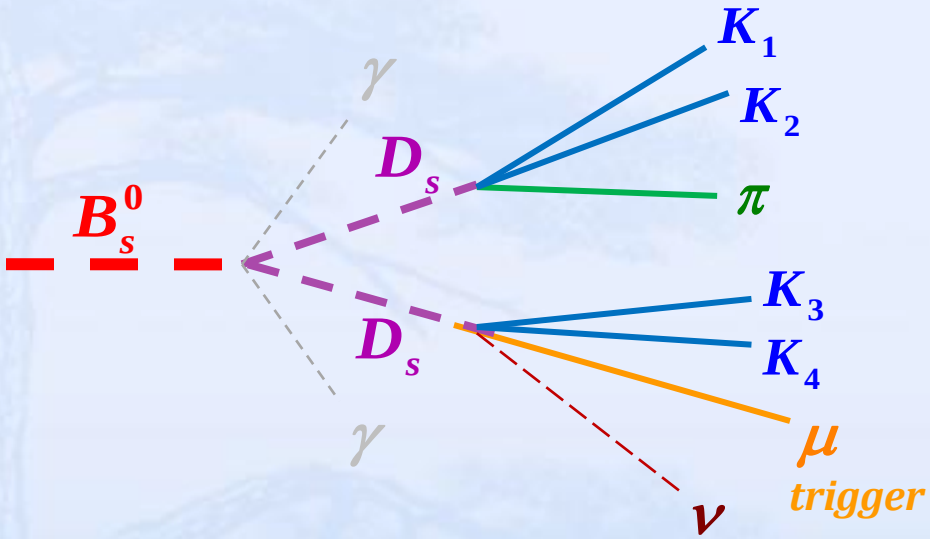
$$2Br(B_s^0 \to D_s^{(*)}D_s^{(*)}) \simeq \Delta\Gamma_s^{CP}\left[\frac{1+\cos\phi_s}{\Gamma_L} + \frac{1-\cos\phi_s}{\Gamma_H}\right]$$

$$\text{In SM } (\phi_s = 0) \quad : \quad \frac{\Delta\Gamma_s}{\Gamma_s} \simeq \frac{2Br(B_s^0 \to D_s^{(*)}D_s^{(*)})}{1 - Br(B_s^0 \to D_s^{(*)}D_s^{(*)})}$$

Analysis Procedure

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

- **Sampling: $D_s \varphi \mu$** vs. $D_s \mu$



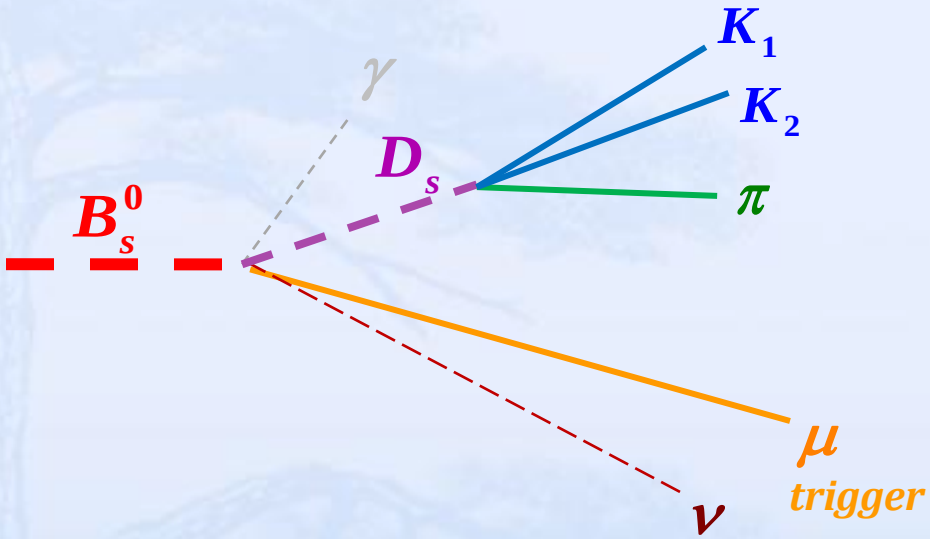
$$D_s \rightarrow \varphi(KK)\pi$$

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

$$D_s \rightarrow \varphi(KK)\mu\nu$$

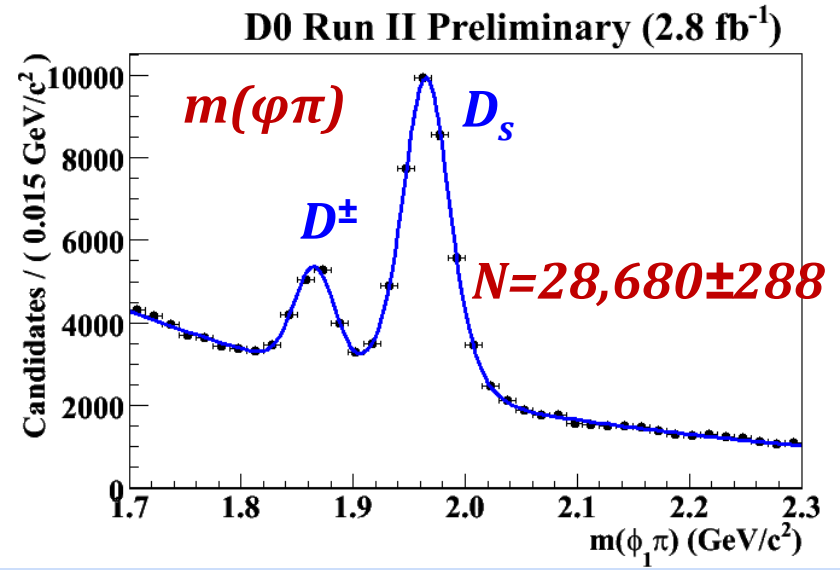
$Br(B_s \rightarrow D_s^{(*)} D_s^{(*)})$

- **Sampling: $D_s\varphi\mu$ vs. $D_s\mu$**



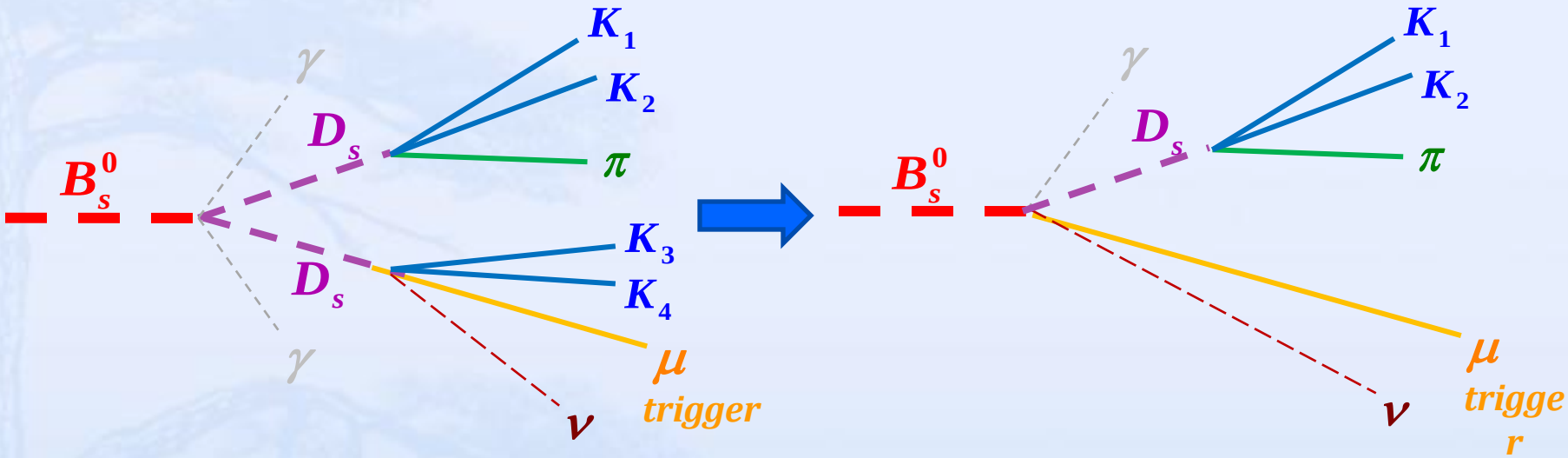
$$D_s \rightarrow \varphi(KK)\pi$$

$$B_s^0 \rightarrow D_s^{(*)}\mu\nu$$



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

Normalizing: $D_s\varphi\mu$ to $D_s\mu$



$$\frac{N(B_s \to D_s^{(*)} D_s^{(*)})}{N(B_s \to D_s^{(*)} \mu\nu)} = 2R \cdot \frac{\varepsilon(B_s \to D_s^{(*)} D_s^{(*)})}{\varepsilon(B_s \to D_s^{(*)} \mu\nu)}$$

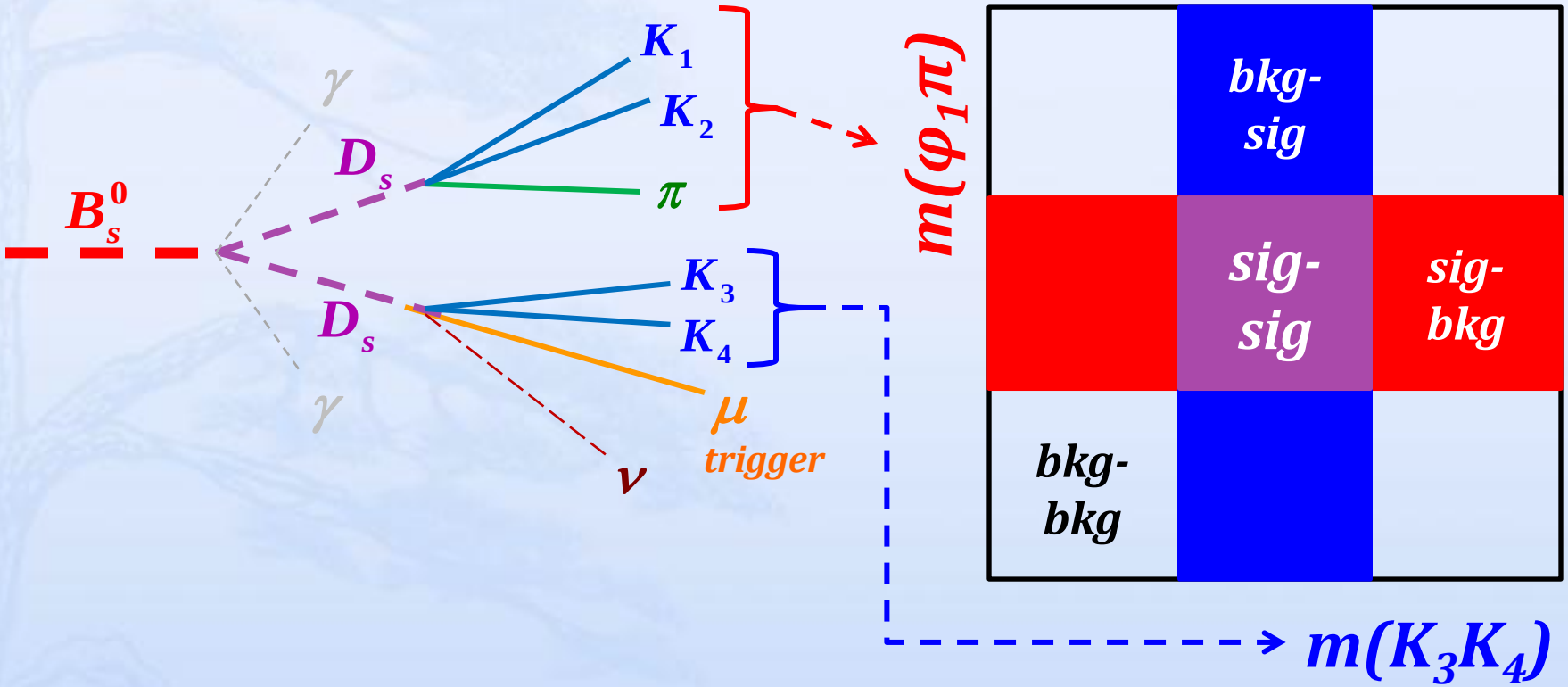
$$R \equiv \frac{Br(B_s \to D_s^{(*)} D_s^{(*)}) \cdot Br(D_s \to \varphi\mu\nu) \cdot Br(\varphi \to K^+K^-)}{Br(B_s \to D_s^{(*)} \mu\nu)}$$

(Many detector-related systematic effects cancel)

D_s-D_s Correlations

2-D Unbinned Loglikelihood Fit

$D_s(\varphi_1\pi)$ vs. $\varphi_2(K_3K_4)$



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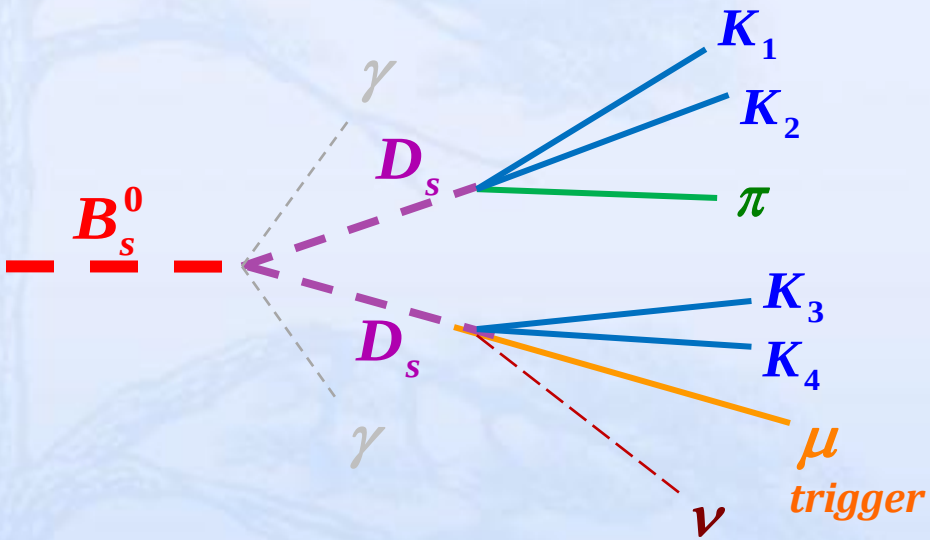
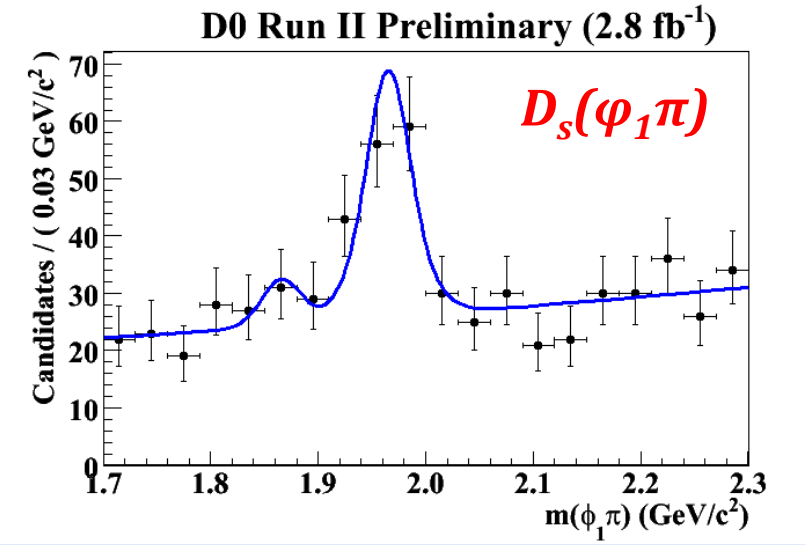
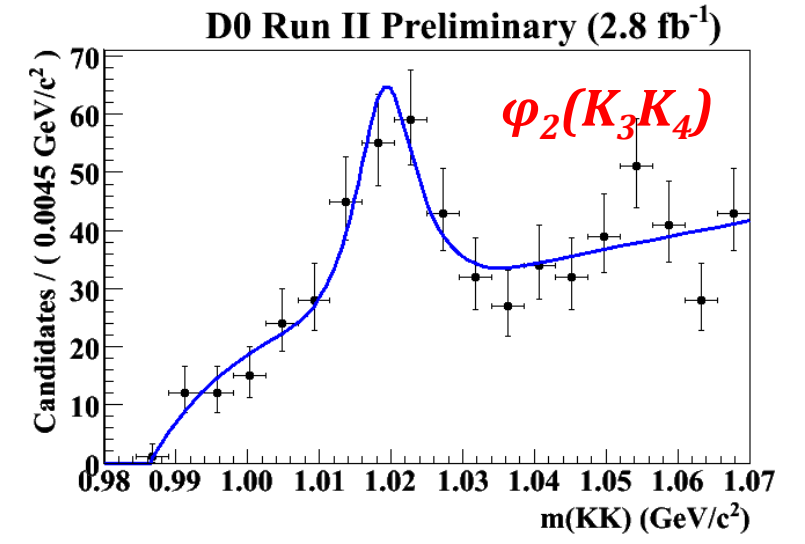






$N(D_s\varphi\mu) = 31.0 \pm 9.4$

significance: 3.7σ

Peaking Background

- **Physics-suppressed**

Process	Remark	Recipe	Contrib.
$B_s \to D_s^{(*)} D_s^{(*)} X$	two gluons required	negligible	~ 0 %

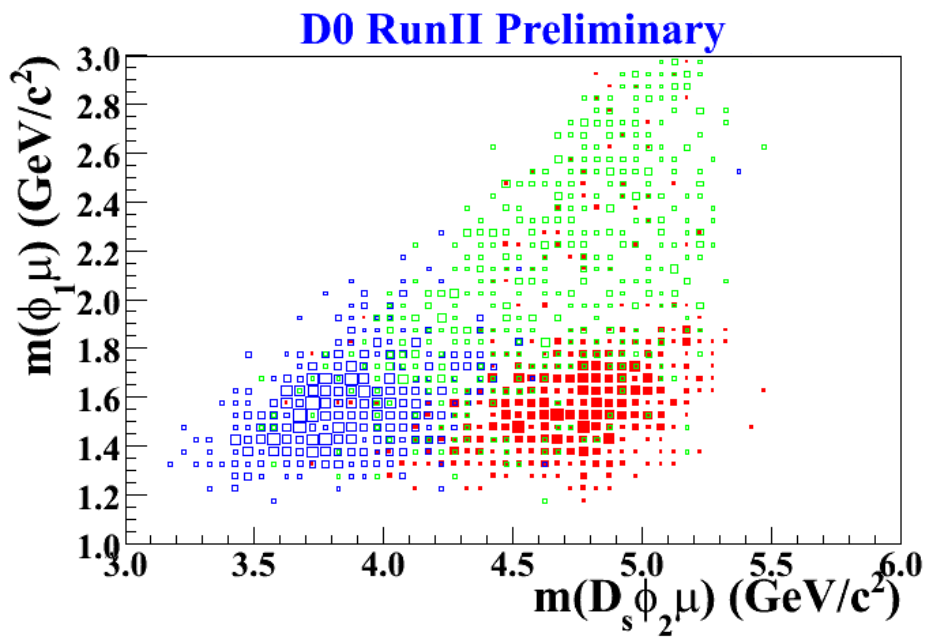
- **Kinematics-suppressed: Sample composition**

Process	Remark	Recipe	Contrib.
$B^{\pm,0} \to D_s^{(*)} D_s^{(*)} KX$	low mass ($D_s\varphi\mu$)	$m(D_s\varphi\mu) > 4.3$ GeV	5 ± 2 %
$B_s \to D_s^{(*)} \mu\nu\varphi$	high mass ($\varphi\mu$)	$m(\varphi\mu) > 1.85$ GeV	0 ± 3 %

- **ccbar(N_{cc}) contamination: $f_{cc}(B_s^0 \to D_s\mu\nu) = 10.3 \pm 2.5$ %**

Process	Comment	Recipe	Contrib.
ccbar $\to D_s^{(*)} \varphi\mu X$	short decay length	lifetime cut	2 ± 1 %

Sample Composition

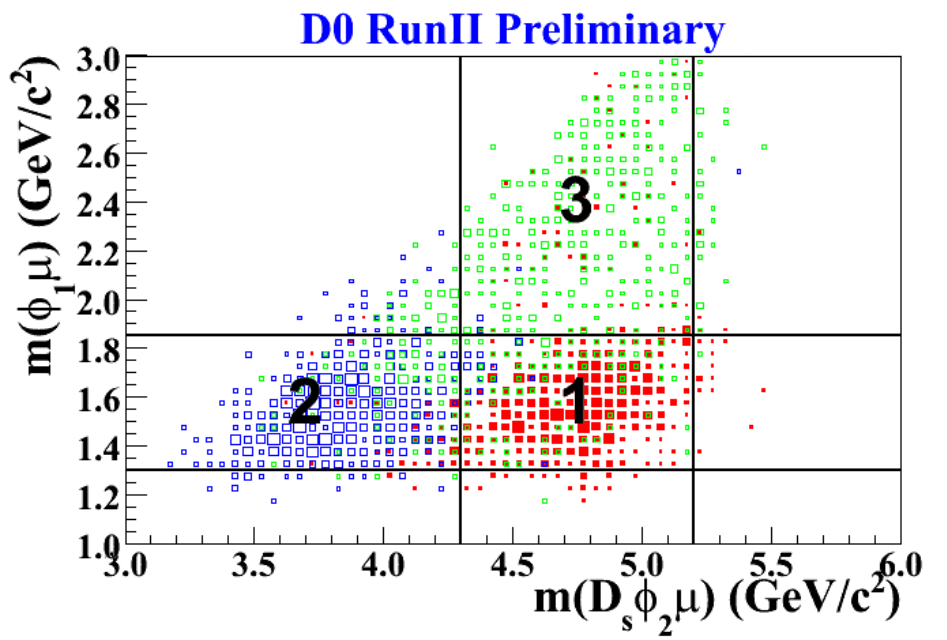


a: $B_s \rightarrow D_s^{(*)} D_s^{(*)}$

b: $B^{\pm,0} \rightarrow D_s^{(*)} D_s^{(*)} KX$

c: $B_s \rightarrow D_s^{(*)} \mu \nu \varphi$

Sample Composition



M_i: total # of events for channel i
n_j : total # of events in region j
$f_{i,j}$: frac. for channel i in region j

$$\Rightarrow \begin{pmatrix} f_{a,1} & f_{b,1} & f_{c,1} \\ f_{a,2} & f_{b,2} & f_{c,2} \\ f_{a,3} & f_{b,3} & f_{c,3} \end{pmatrix} \begin{pmatrix} M_a \\ M_b \\ M_c \end{pmatrix} = \begin{pmatrix} n_1 \\ n_2 \\ n_3 \end{pmatrix}$$

a: $B_s \to D_s^{(*)} D_s^{(*)}$
b: $B^{\pm,0} \to D_s^{(*)} D_s^{(*)} KX$
c: $B_s \to D_s^{(*)} \mu\nu\varphi$

$$N(D_s^{(*)} D_s^{(*)}) = f_{a,1} \cdot M_a$$

$$N_{c\bar{c}}(D_s^{(*)} D_s^{(*)}) = N_{c\bar{c}}(D_s \varphi \mu) \cdot \frac{f_{a,1} \cdot M_a}{\sum_i f_{i,1} \cdot M_i}$$

pure signal events: $N(B_s^0 \to D_s^{(*)} D_s^{(*)}) = 27.5 \pm 9.8$

Systematics

Sources	Uncertainty
$Br(B_s^0 \to D_s^{(*)}\mu\nu)$	0.0127
$Br(D_s \to \varphi\mu\nu)$	0.0047
$\varepsilon(D_s^{(*)}D_s^{(*)})/\varepsilon(D_s^{(*)}\mu\nu)$	0.0072
fitting procedure	0.0071
$N(D_s^{(*)}D_s^{(*)})$: Matrix	0.0041
ccbar	0.0011
$f(B_s^0 \to D_s^{(*)}\mu\nu)$	0.0006
$N(D_s\mu)$	0.0005
Total	0.0174

- poor measurement of branching ratios (≥ 60 %)
- large room for further improvement

- trigger efficiency model dependent calculation

- uncertainty by ccbar contamination is small

Result & Conclusion

Result

D0 Preliminary (2.8 fb^{-1})

$$Br(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)}) = 0.042 \pm 0.015\ (stat) \pm 0.017\ (syst)$$

$$\Delta\Gamma_s / \Gamma_s = 0.088 \pm 0.030\ (stat) \pm 0.036\ (syst)$$

	$Br(B_s^0 \rightarrow D_s^{(*)} D_s^{(*)})$	$\Delta\Gamma_s / \Gamma_s$
ALEPH (2000)	$0.077 \pm 0.034_{-0.026}^{+0.038}$	$0.167 \pm 0.070_{-0.053}^{+0.079}$
D0 (2007, 1.3 fb^{-1})	$0.039_{-0.017}^{+0.019}{}_{-0.015}^{+0.016}$	$0.081_{-0.035}^{+0.039}{}_{-0.030}^{+0.033}$
WA (end of 2006)	0.046 ± 0.022	0.096 ± 0.048
Theory		0.127 ± 0.024

Conclusion

- $Br(B_s \rightarrow D_s^{(*)} D_s^{(*)})$ promising method for $\Delta\Gamma_s$
  - Theory applicable
- $Br(B_s \rightarrow D_s^{(*)} D_s^{(*)})$ & $\Delta\Gamma_s$ (2.8 fb^{-1})
  - $Br(B_s \rightarrow D_s^{(*)} D_s^{(*)})$
    $= 0.042 \pm 0.015\ (stat) \pm 0.017\ (syst)$
  - $\Delta\Gamma_s^{CP} / \Gamma_s = 0.088 \pm 0.030\ (stat) \pm 0.036\ (syst)$
  - Consistent with SM
- Polarization study: pure even?
  - Experimental constraint on theory

Conclusion

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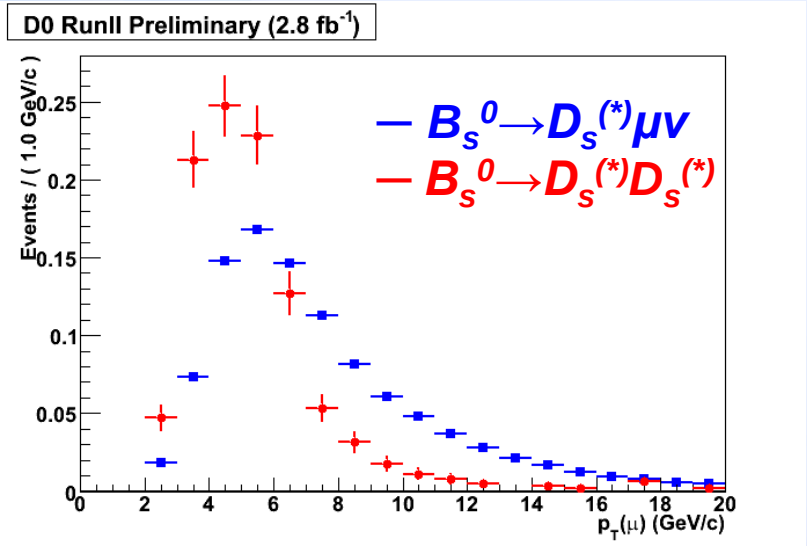
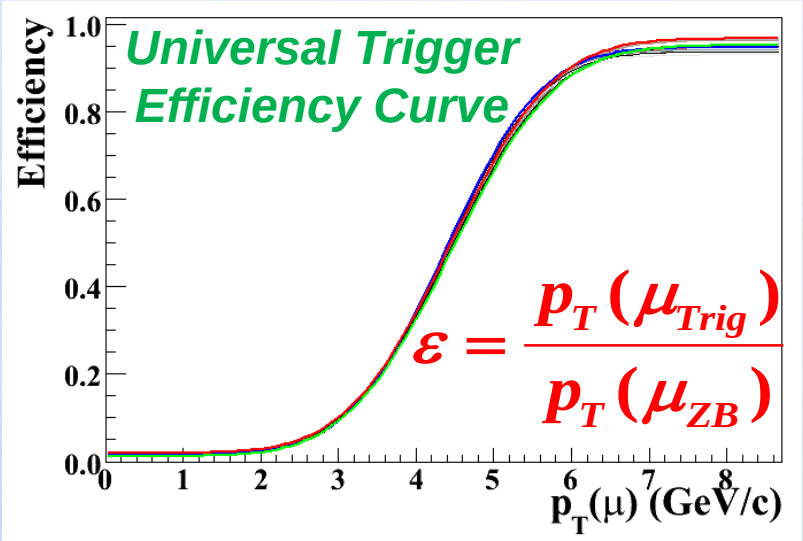
  - $\Delta\Gamma_s^{CP} / \Gamma_s = 0.088 \pm 0.030\ (stat) \pm 0.036\ (syst)$
  - Consistent with SM
- Polarization study: pure even?
  - Experimental constraint on theory
- **First experimental evident for $\Delta\Gamma_s \neq 0$ (significance > 3σ)**

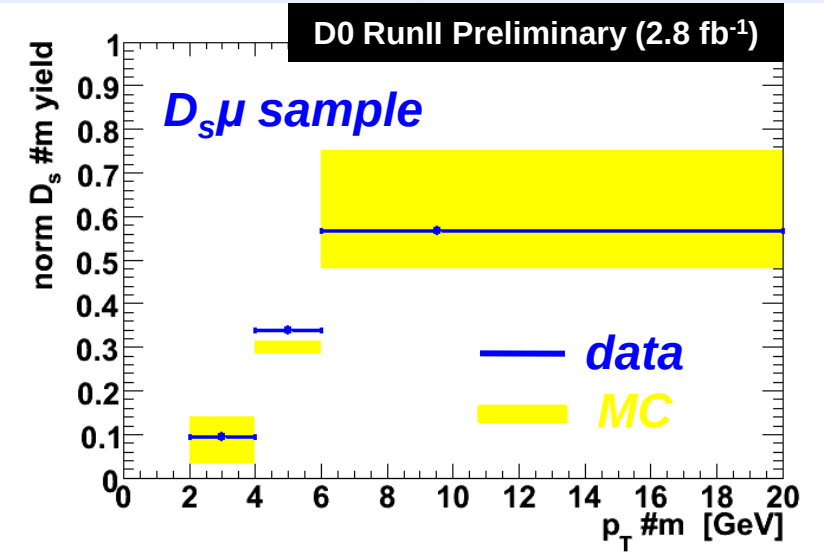
Backup

Efficiency Model





- *Different muon property*
  - *$B_s^0 \to D_s^{(*)}\mu\nu$: primary*
  - *$B_s^0 \to D_s^{(*)}D_s^{(*)}(D_s \to \varphi\mu\nu)$: secondary*



Normalized signal yield for data and model