HOT Topics @ D0

Flavor Physics & CP violation

Taipei, Taiwan

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Sungwoo YOUN

Northwestern University

on behalf of D0 Collaboration

D0 Results

- *Direct CP violation in B decays (M. Kreps)*
- *CPV in B_s System (D. Strom)*
- *Lifetime and mixing (C. Liu)*
- *Bs/b-Baryon decays (A. Warburton)*
- *Rare decays of B/Bs mesons from Tevatron (D. Tsybychev)*
- *Spectroscopy of hadrons with b quark (R. V. Kooten)*

- *This talk will cover the hottest topic…*

Outline

New Measurement of

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

$(1.3\ fb^{-1}$ to $2.8\ fb^{-1})$

$\Delta\Gamma$ in B_s Decays

Motivation

Tevatron & D0

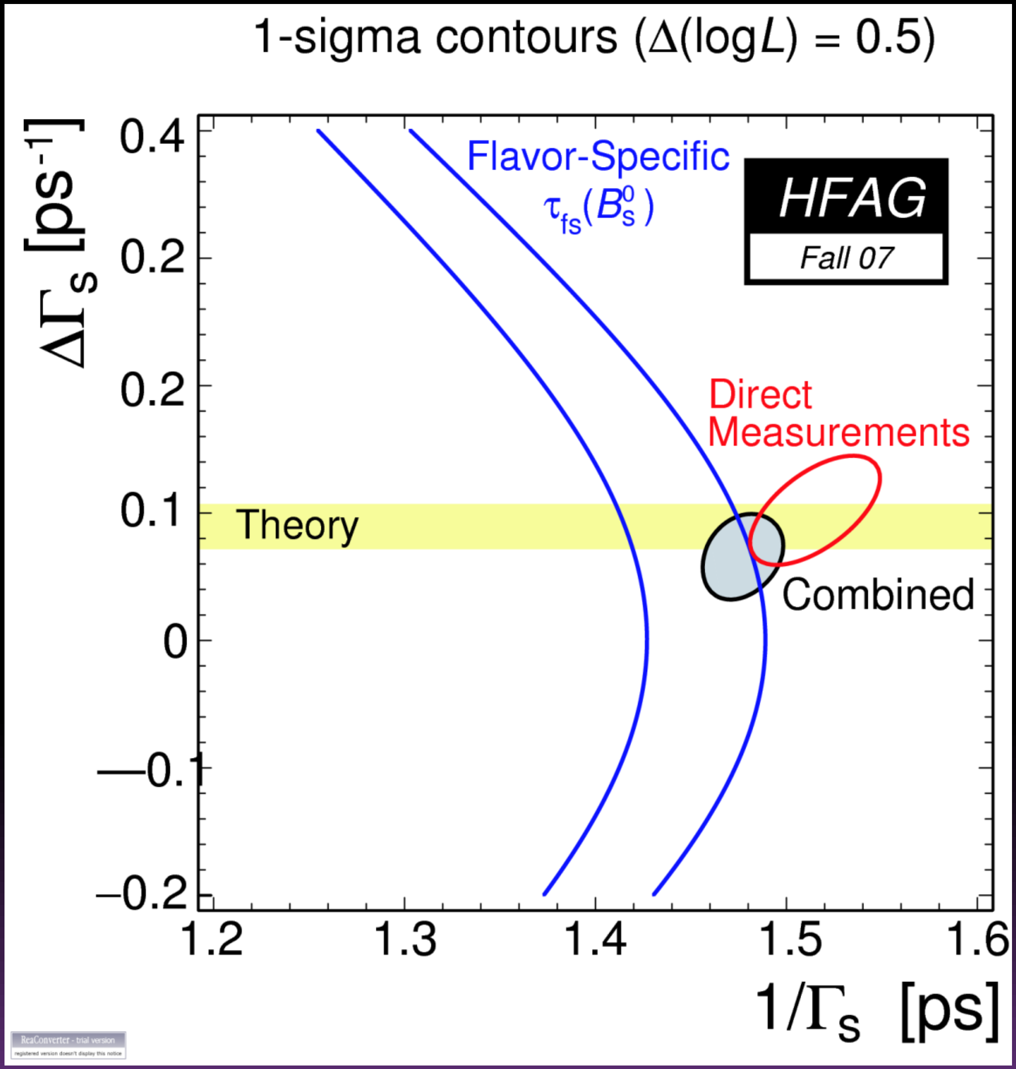
Analysis Procedure

New Result

Conclusion

ΔΓ in B_s Decays

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



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

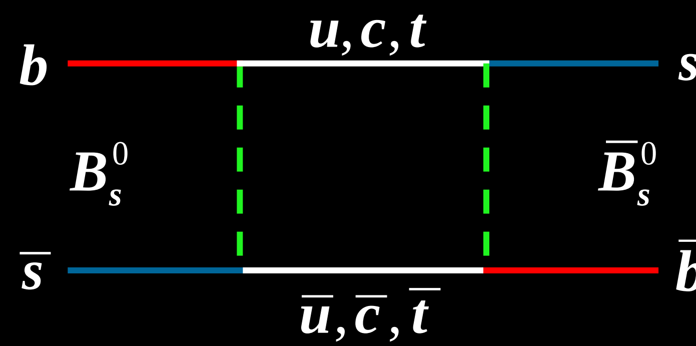
Direct Measurements:
$B_s^0 \rightarrow J/\Psi\varphi$
angular analysis : $\Delta\Gamma_s$ & φ_s
(D0 & CDF)
(talks in next session)

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

CPV & $\Delta\Gamma$ in B_s System

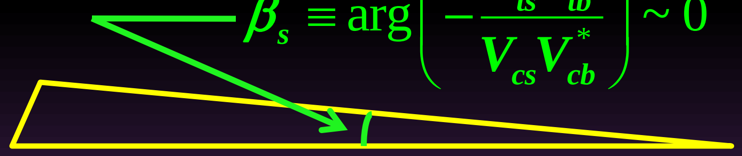
$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(M - i\frac{\Gamma}{2}\right)\begin{pmatrix}|B_s^0(0)\rangle \\ |\bar{B}_s^0(0)\rangle\end{pmatrix}$$

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



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

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

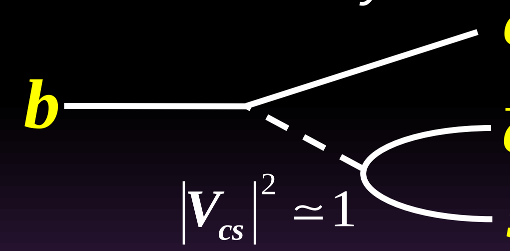


Squashed Unitary Triangle
CPV ~ 0

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

(SM) x (NP)

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



not suppressed !
$\Delta\Gamma_s$ sizable

Motivation & Theory

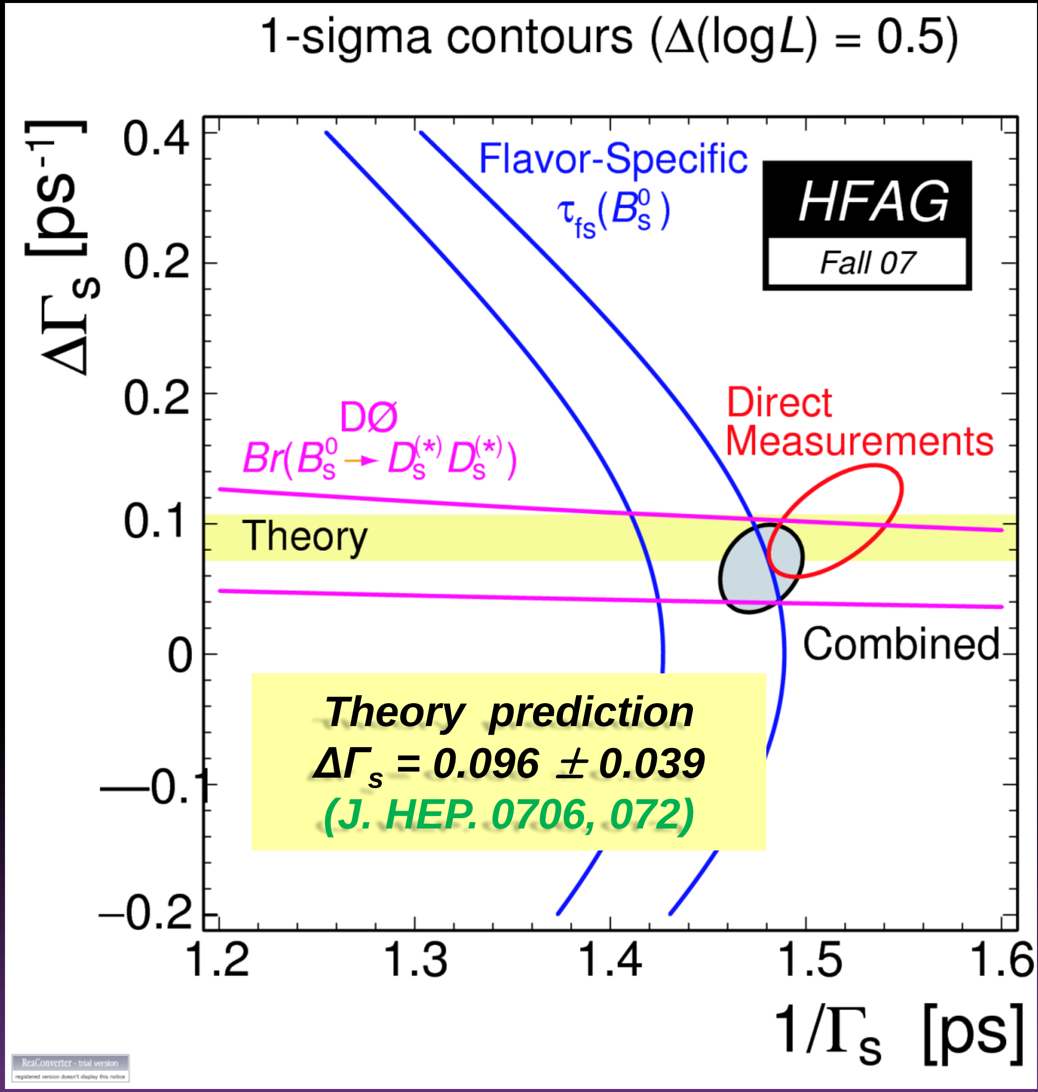
Why $B_s \to D_s^{(*)} D_s^{(*)}$?

Flavor -Specific:
$B_s^0 \to D_s \mu \nu$
50 % even / 50% odd

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

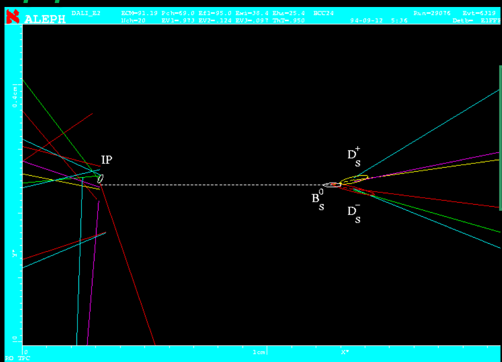
- *theory based analysis: CP even (5~30%)*
- *compatible error band*
- *consistent with theory*
- *untagged: efficiency, purity, acceptance*
- *simple measurement*

Direct Measurements:
$B_s^0 \to J/\Psi \varphi$
angular analysis: ΔΓ & φ
(D0 & CDF)
(talks in next session)



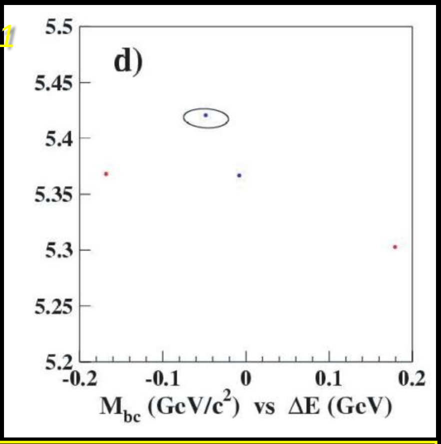
History of $Br(B_s \to D_s^{(*)} D_s^{(*)})$

ALEPH (2000)
$\varphi\varphi$ correlation in Z decays



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

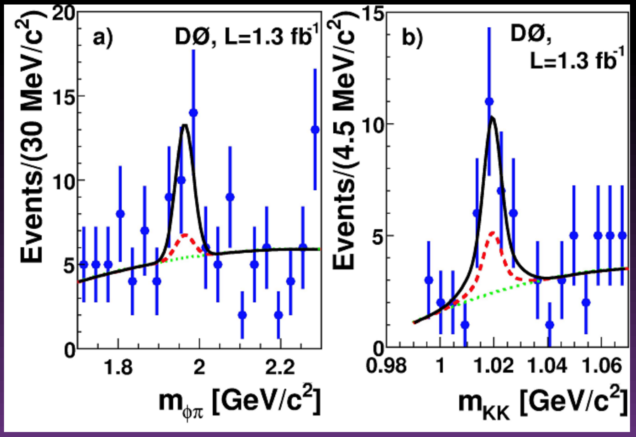
Belle (2006) – 1.86 fb^{-1}
at Y(5S) resonance



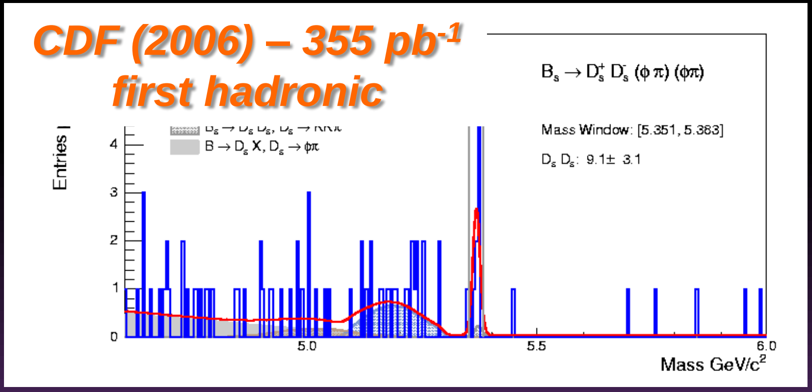
$$Br(B_0^s \to D_s^{(*)} D_s^{(*)}) < 27.3\%$$

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

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



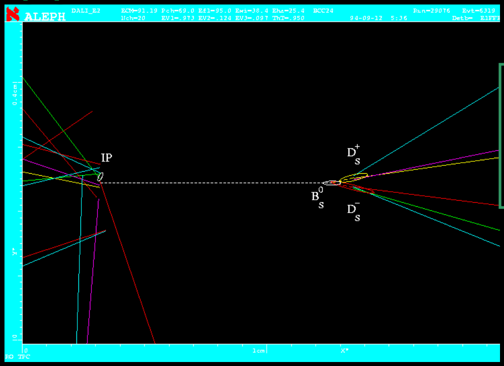
CDF (2006) – 355 pb^{-1}
first hadronic



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

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

ALEPH (2000)
φφ correlation in Z decays



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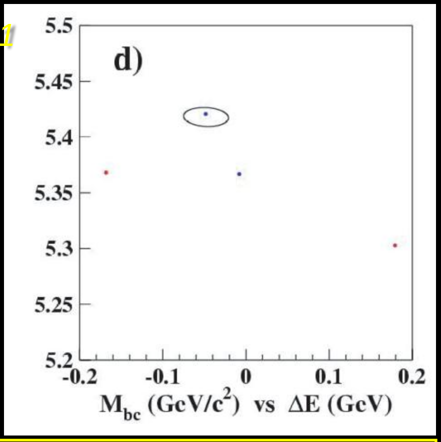

$$Br(B_0^s \to D_s^{(*)} D_s^{(*)}) < 27.3\%$$

D0 (2007) – 1.3 fb^{-1}
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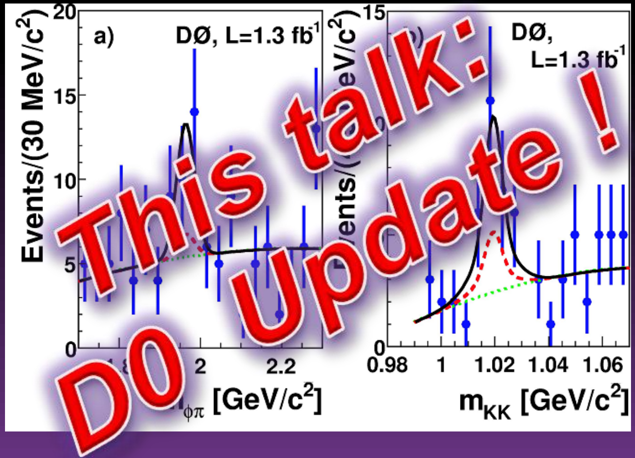

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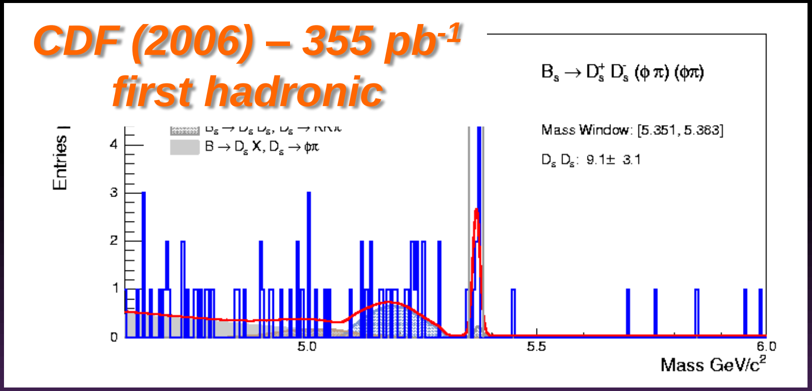


$$N = 23.5 \pm 5.5$$
$$Br(B_s^0 \to D_s^+ D_s^-) / Br(B^0 \to D_s^+ D^-)$$

Theory of *Br* & *ΔΓ*

- $D_s^{(*)}D_s^{(*)}$ ground states

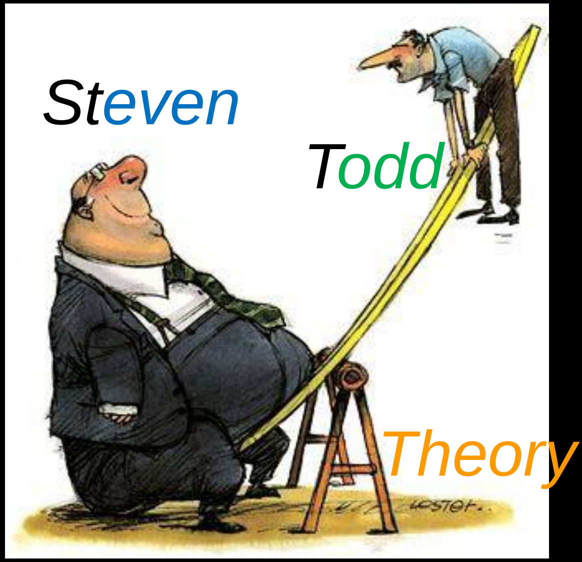
$D_s^+D_s^-$	S wave	CP even
$D_s^*D_s^*$	S,P,D wave	CP mixture
$D_sD_s^*\,(D_s^*D_s)$		CP mixture

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

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

$D_s^{(*)}D_s^{(*)}$	S wave	CP even

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



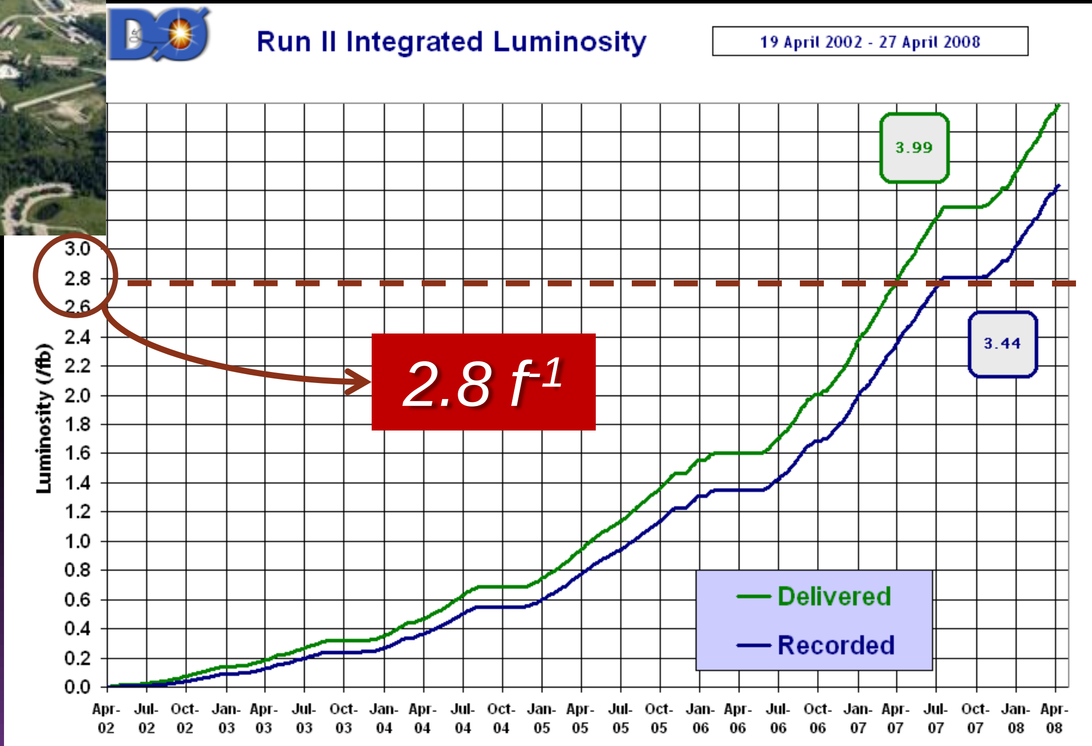
$$2Br(B_s^0 \to D_s^{(*)}D_s^{(*)}) \simeq \Delta\Gamma_s^{CP}\left[\frac{1+\cos\phi_s}{\Gamma_L} + \frac{1-\cos\phi_s}{\Gamma_H}\right]$$

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

Tevatron & D0

Tevatron

- *p-pbar at √s=1.96 TeV*
- *excellent performance*
- *4.0 fb^{-1} delivered (Apr/30/08)*

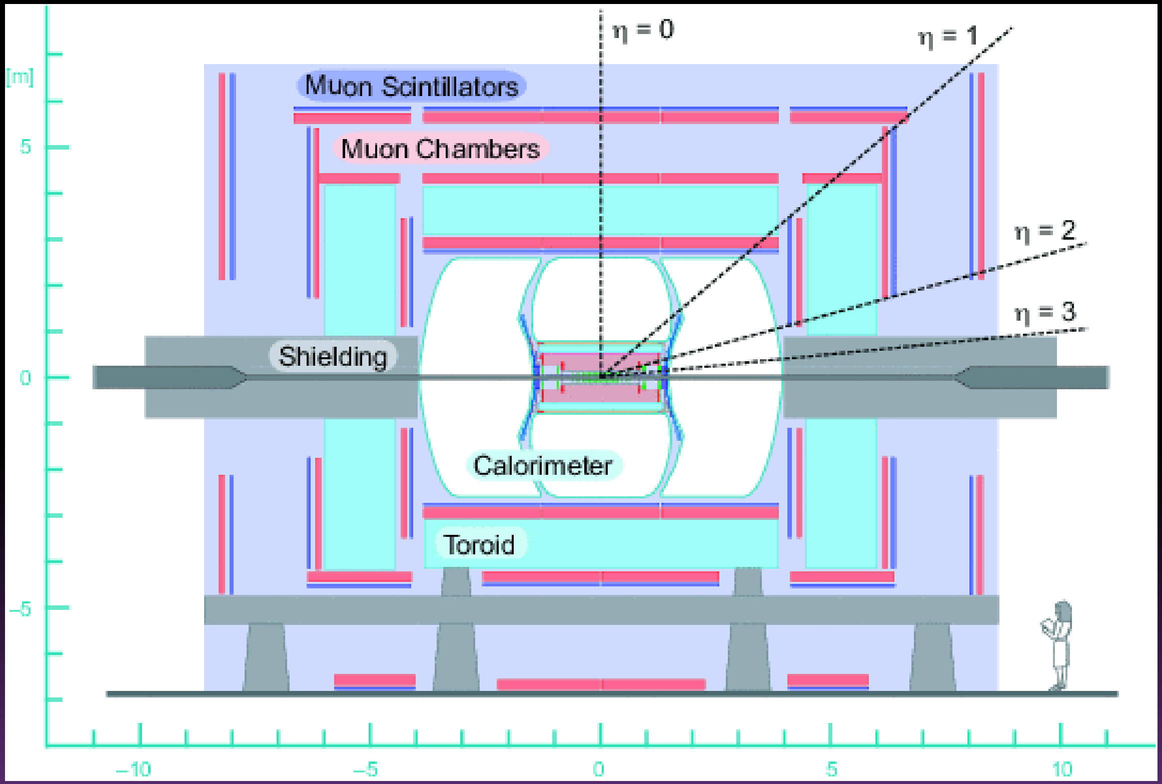


- *peak : 3.15 x 10^{32} $cm^{-2}sec^{-1}$*
- *> 85 % DAQ efficiency*
- *~ 45 pb^{-1}/week*
- *~ 8 fb^{-1} designed by 2009*

D0 Detector

- *Calorimeter*
  - *Uranium / Liquid Ar*

- *Muon system*
  - *drift tubes & scintillators*
  - *excellent muon trigger*
  - *1.8 T toroid*
  - *$|\eta| < 2.0$*

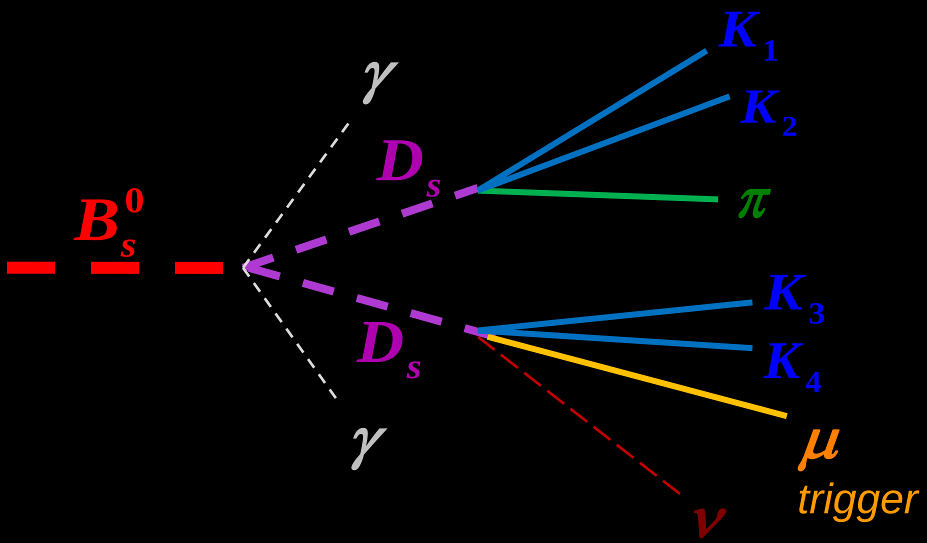


- *Tracking system*
  - *SMT, CFT*
  - *new layer in 2006*
  - *2 T solenoid*
  - *$|\eta| < 3.0$*

Analysis Procedure

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

- Sampling: $D_s \varphi \mu$



$D_s \to \varphi\pi$; $\varphi \to KK$

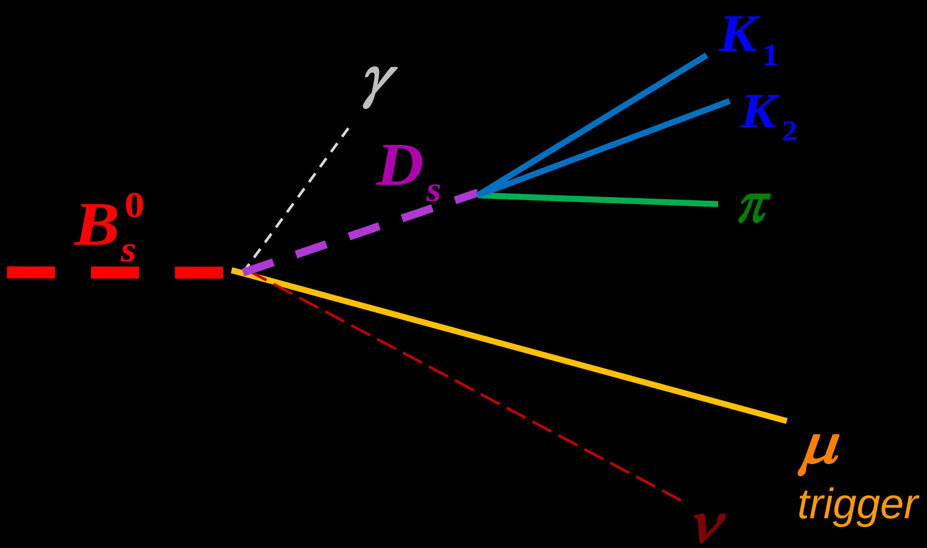
$B_s^0 \to D_s^{(*)} D_s^{(*)}$

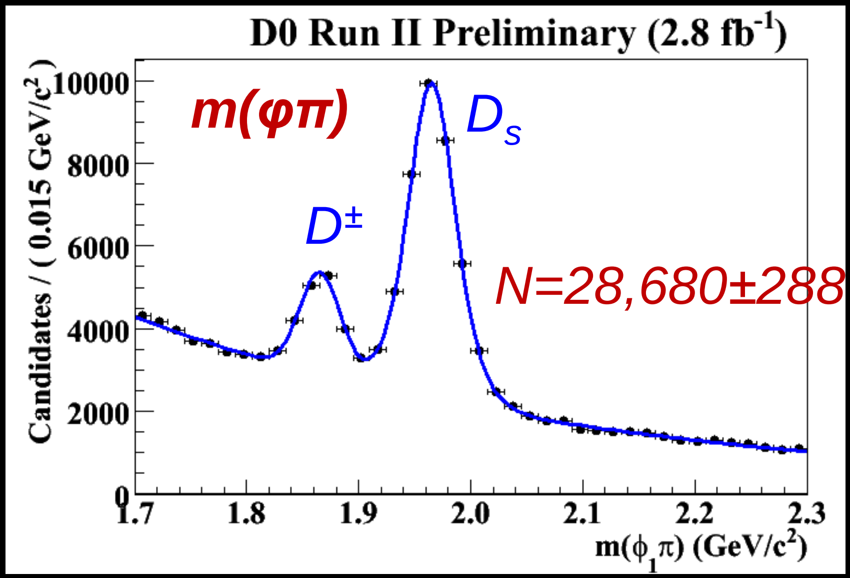
$D_s \to \varphi\mu\nu$; $\varphi \to KK$

Correlation between $D_s(\varphi\pi)$ and $D_s(\varphi\mu\nu)$

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

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



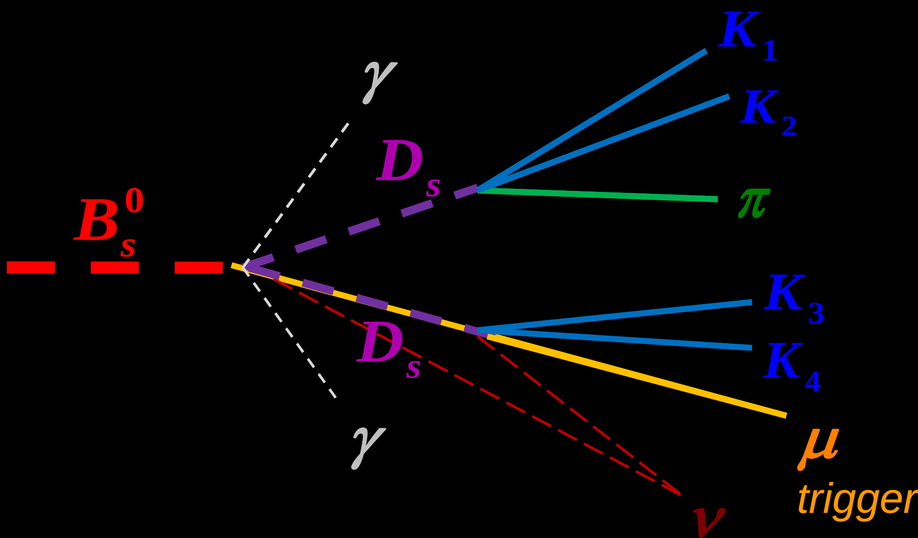


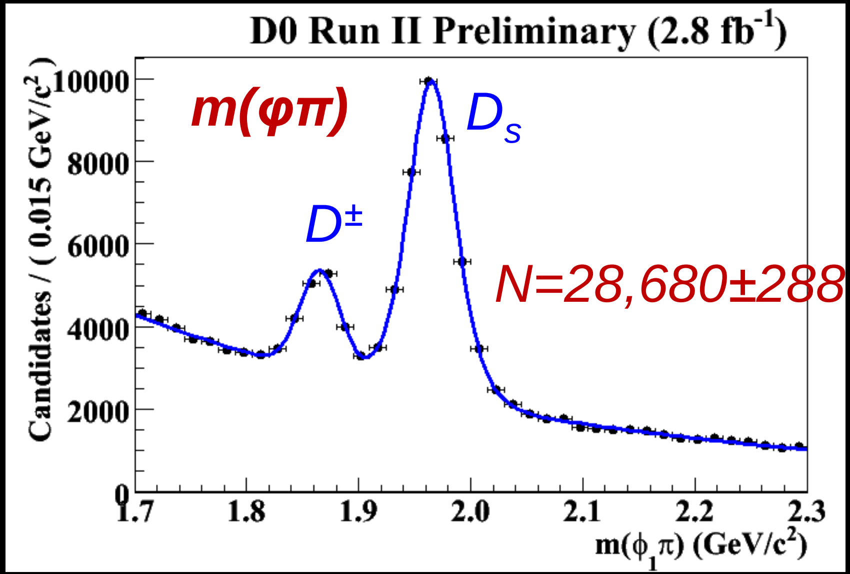
$D_s \to \varphi\pi$; $\varphi \to KK$

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

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

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





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

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

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

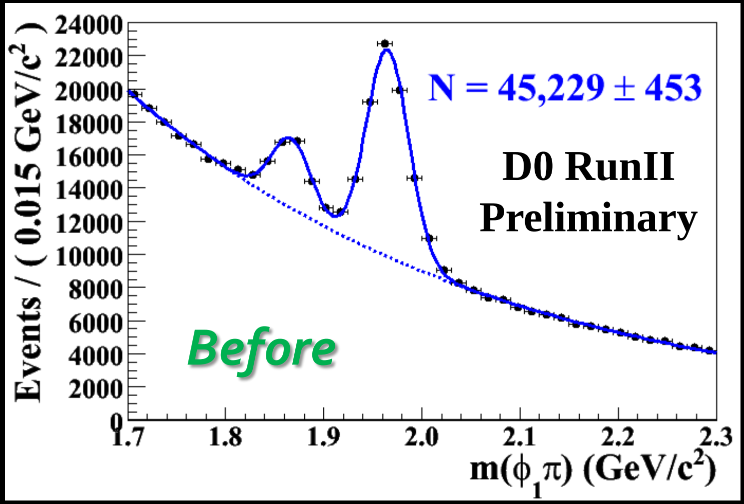
Likelihood Ratio Variable

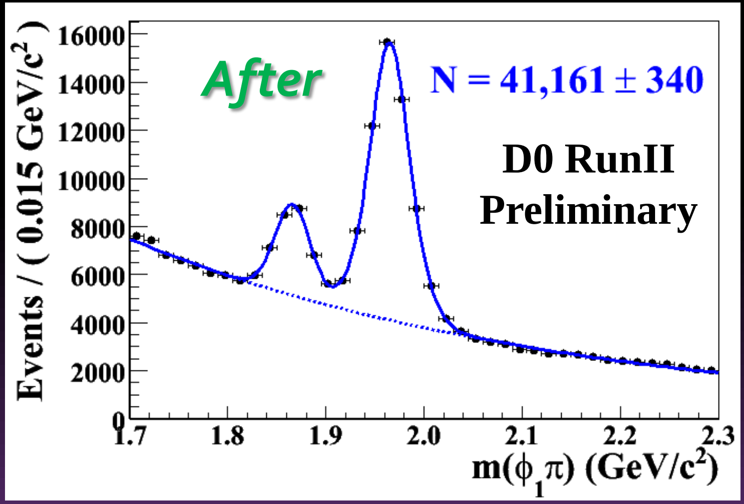
$$Y = \prod_i y_i; \quad y_i = \frac{PDF_{bkg}(x_i)}{PDF_{sgl}(x_i)}$$

$(x_i$: discriminating variable)

miximal $S / \sqrt{S+B}$

$D_s\mu$ Sample	$D_s\varphi\mu$ Sample
isolation(B_s)	isolation(B_s)
$\cos(\theta_{helicity})$	$\cos(\theta_{helicity})$
$p_T(K_1K_2)$	$p_T(K_1K_2)$
$m(B_s)$	$m(B_s)$
$\chi_{vtx}^2(D_s)$	$m(K_3K_4) - m(K_1K_2)$
$m(K_1K_2)$	$p_T(\varphi_2) - p_T(\varphi_1)$
	$p_T(D_{s,2}) - p_T(D_{s,1})$

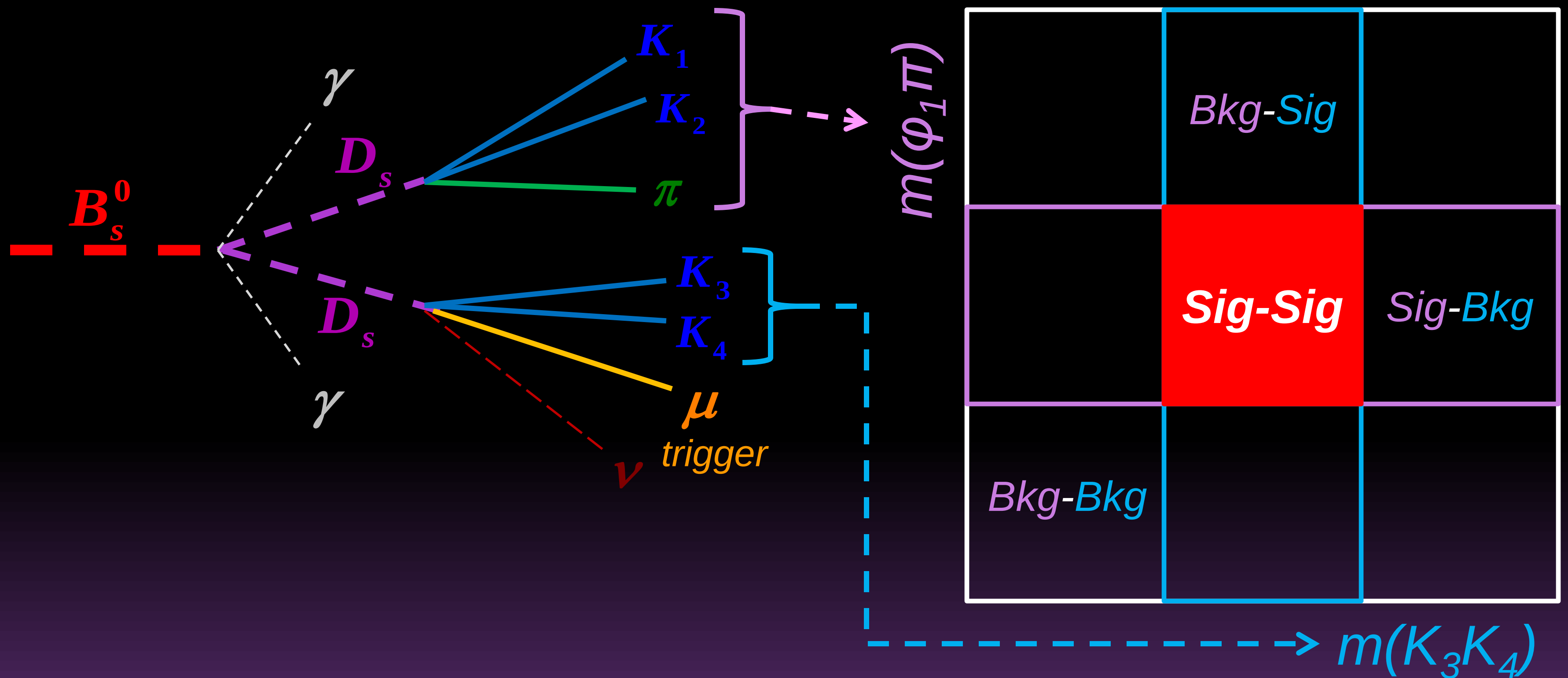




SIGNAL CLEAR-UP

Correlation D_s-D_s

2-D Unbinned Loglikelihood Fit
$D_s(\varphi_1\pi)$ vs. $\varphi(K_3K_4)$



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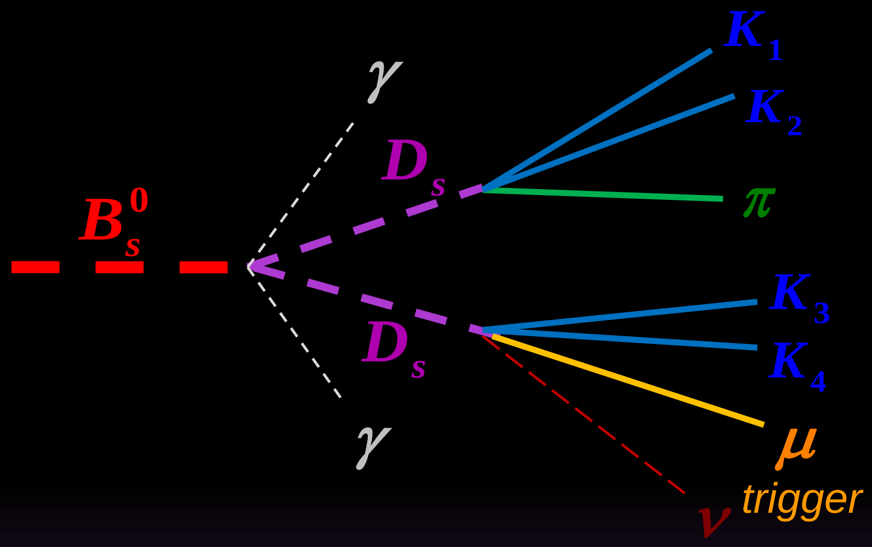
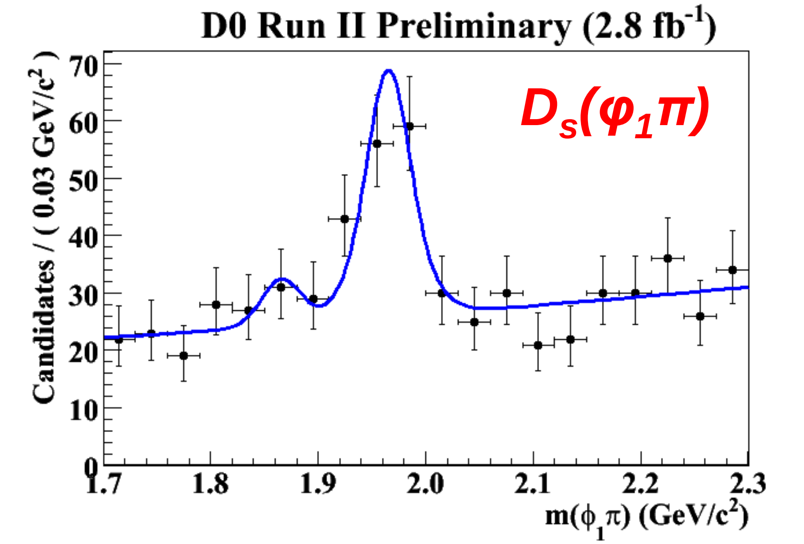
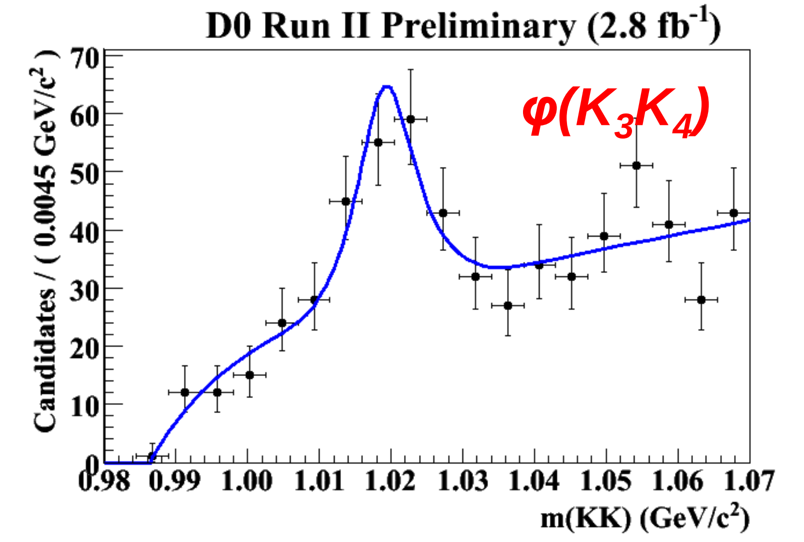






$N(D_s\varphi\mu) = 31.0 \pm 9.4$

significance: 3.7σ

Peaking Background

- Physics-suppressed

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

- Kinematics-suppressed: Matrix method

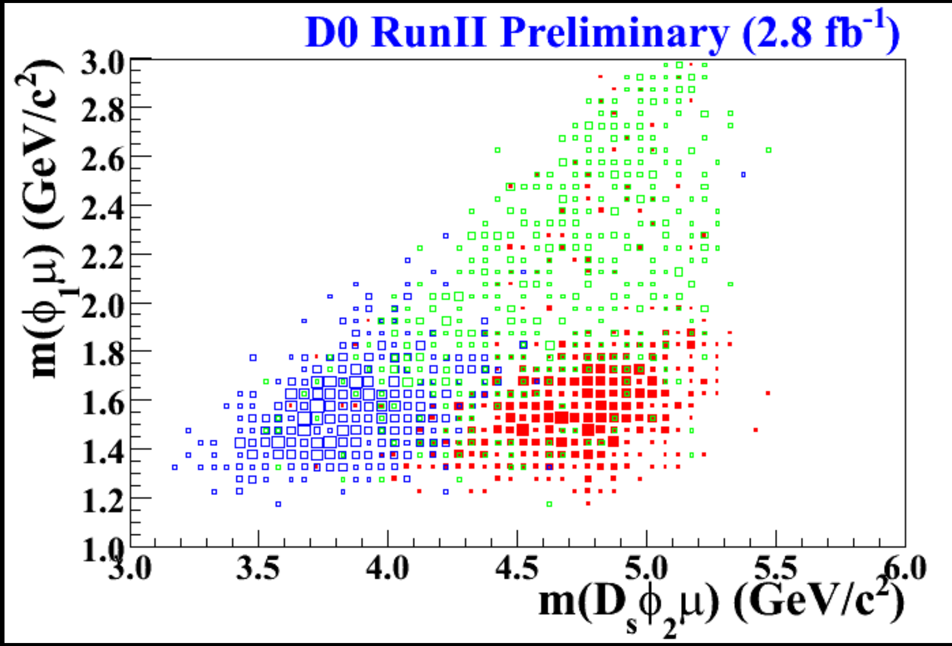
Process	Remark	Recipe	Contrib.
$B^{\pm,0} \rightarrow D_s^{(*)} D_s^{(*)} K X$	low mass ($D_s \varphi \mu$)	$m(D_s \varphi \mu) > 4.3$ GeV	5 ± 2 %
$B_s \rightarrow D_s^{(*)} \mu \nu \varphi$	high mass ($\varphi \mu$)	1.85 GeV $< m(\varphi \mu)$	0 ± 3 %

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

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

$$\frac{N_{c\bar{c}}(D_s \varphi \mu)}{N(D_s \mu) \cdot f_{c\bar{c}}(D_s \mu)} = \frac{Br(c\bar{c} \rightarrow D_s \varphi \mu)}{Br(c\bar{c} \rightarrow D_s \mu)} \cdot \frac{\varepsilon(c\bar{c} \rightarrow D_s \varphi \mu)}{\varepsilon(c\bar{c} \rightarrow D_s \mu)}$$

Sample Composition

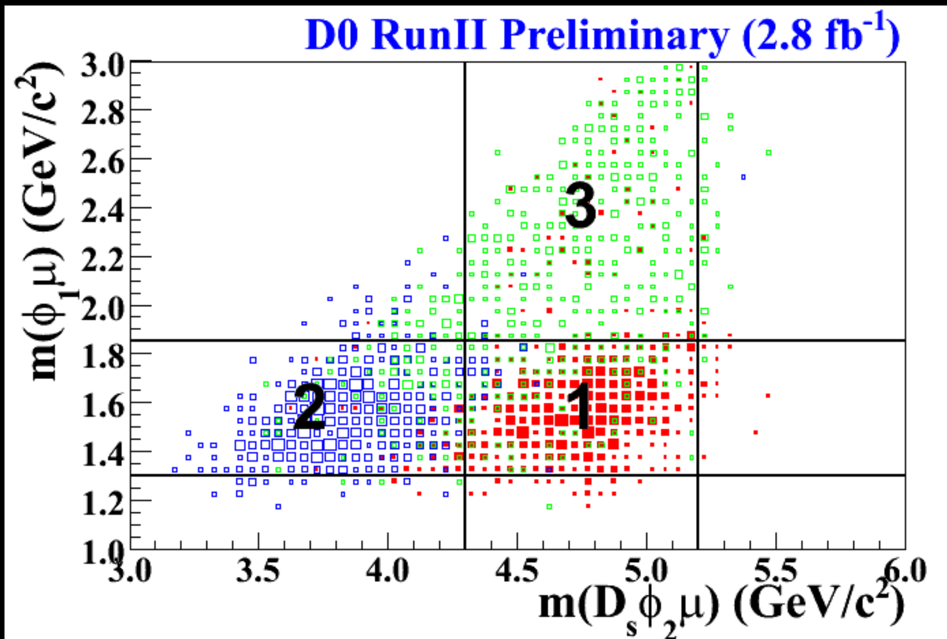


a: $B_s \rightarrow D_s^{(*)} D_s^{(*)}$

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 j region

$f_{i,j}$: fraction for channel i in region j

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

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

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

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

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

$$N_{c\bar{c}}(D_s^{(*)} D_s^{(*)}) = \frac{N_{c\bar{c}}(D_s \varphi \mu) \cdot f_{a,1} \cdot M_a}{f_{a,1} \cdot M_a + f_{b,1} \cdot M_b + f_{c,1} \cdot M_c}$$

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

Systematics

Sources	Uncertainty
$Br(B_s^0 \rightarrow D_s^{(*)}\mu\nu)$	0.0127
$Br(D_s \rightarrow \varphi\mu\nu)$	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
$f(B_s^0 \rightarrow D_s^{(*)}\mu\nu)$	0.0006
$N(D_s\mu)$	0.0005
Total	0.0174

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

- *trigger efficiency model dependent calculation*

- *uncertainty by ccbar contamination is small*

Result & Conclusion

New Result

D0 Preliminary (2.8 fb^{-1})

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

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

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

Conclusion

- D0 is productive in CPV sector in B_s physics
- $Br(B_s \to D_s^{(*)} D_s^{(*)})$ promising method for $\Delta\Gamma_s$
  - Theory applicable
- $Br(B_s \to D_s^{(*)} D_s^{(*)})$ & $\Delta\Gamma_s$ (2.8 fb^{-1})
  - $Br(B_s \to D_s^{(*)} D_s^{(*)})$
    $= 0.042 \pm 0.015$ (stat) ± 0.017 (syst)
  - $\Delta\Gamma_s^{CP} / \Gamma_s = 0.0.88 \pm 0.030$ (stat) ± 0.036 (syst)
- Polarization study: pure even?
  - Experimental correction to theory

Conclusion

- D0 is productive in CPV sector in B_s physics
- $Br(B_s \to D_s^{(*)} D_s^{(*)})$ promising method for $\Delta\Gamma_s$
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- $Br(B_s \to D_s^{(*)} D_s^{(*)})$ & $\Delta\Gamma_s$ (2.8 fb^{-1})
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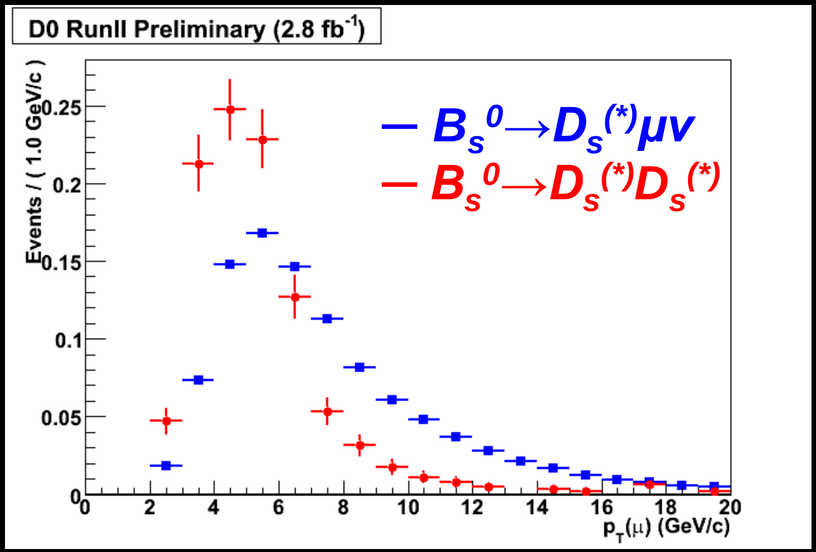
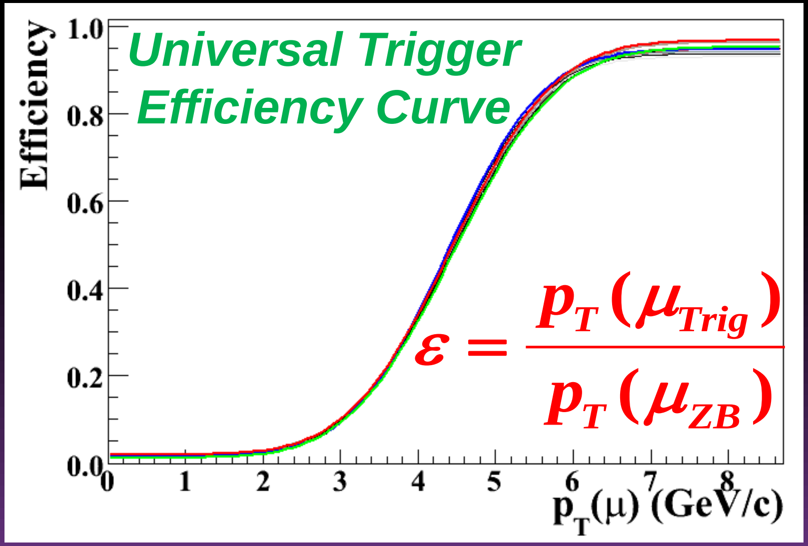
  - $\Delta\Gamma_s^{CP} / \Gamma_s$ = 0.0.88 ± 0.030 (stat) ±0.036 (syst)
- Polarization study: pure even?
  - Experimental correction to theory
- **First experimental evident for $\Delta\Gamma_s \neq 0$ (significance: 3.7 σ)**

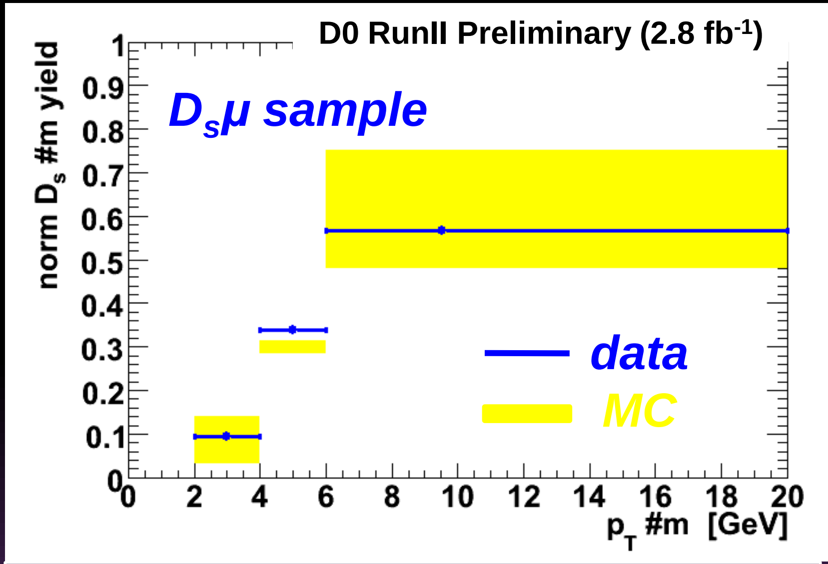
Backup

Efficiency Model



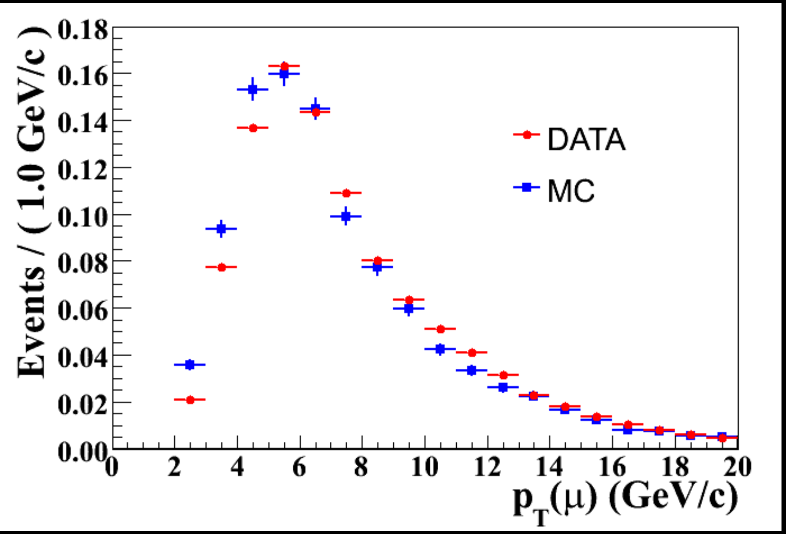


- *Different muon property*
  - $B_s^0 \to D_s^{(*)}\mu\nu$: *primary*
  - $B_s^0 \to D_s^{(*)} D_s^{(*)} (D_s \to \varphi\mu\nu)$: *secondary*

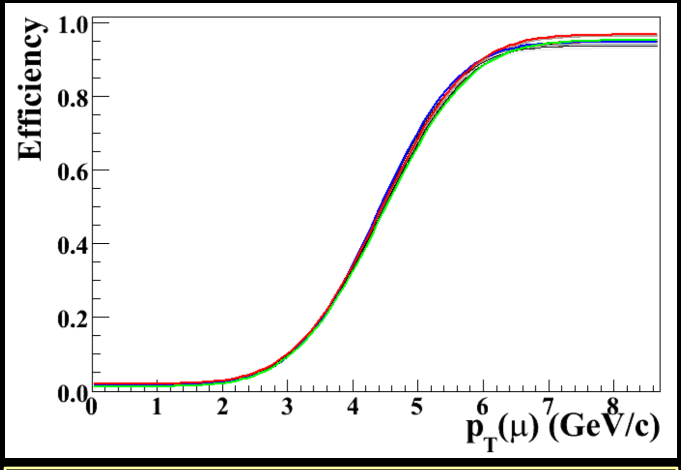


Normalized signal yield for data and model

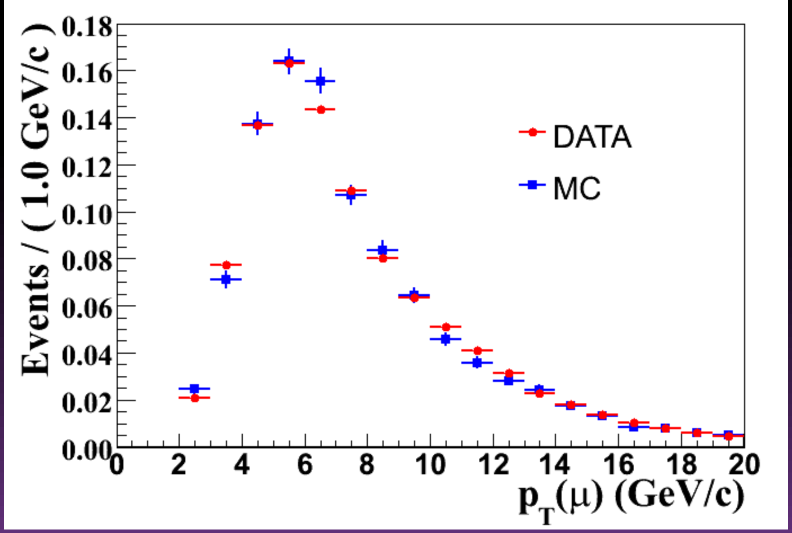
Trigger Effect



Trigger Efficiency Curve



$$Eff. = p_T(\mu_{trig}) / p_T(ZB)$$

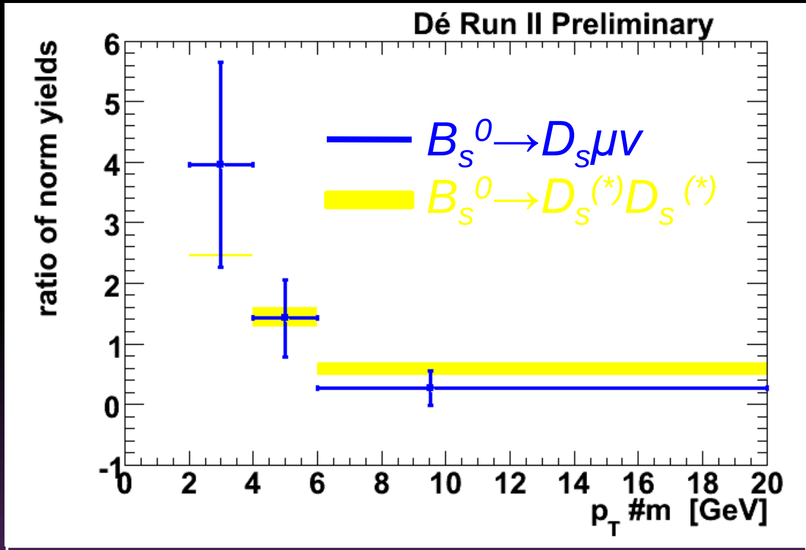


Universal weighting function for many B analyses at D0

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 precision of branching ratio
- Large room for further improvement (Exp.+Thy.)
- reconstruction efficiency



Ratio of normalized signal yield for $B_s^0 \to D_s\mu\nu$ and $B_s^0 \to D_s^{(*)}D_s^{(*)}$