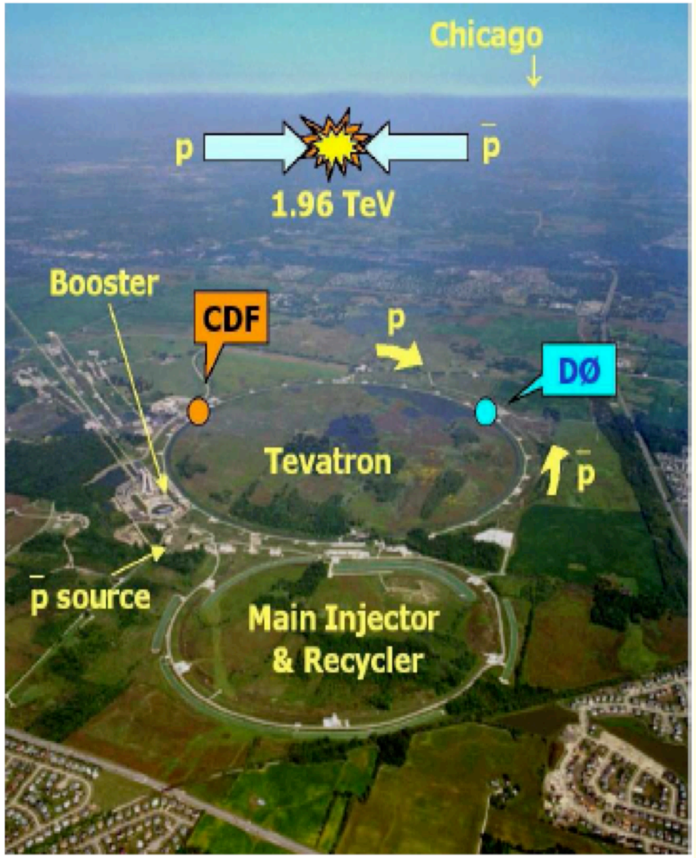
ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

Hot topics at DØ

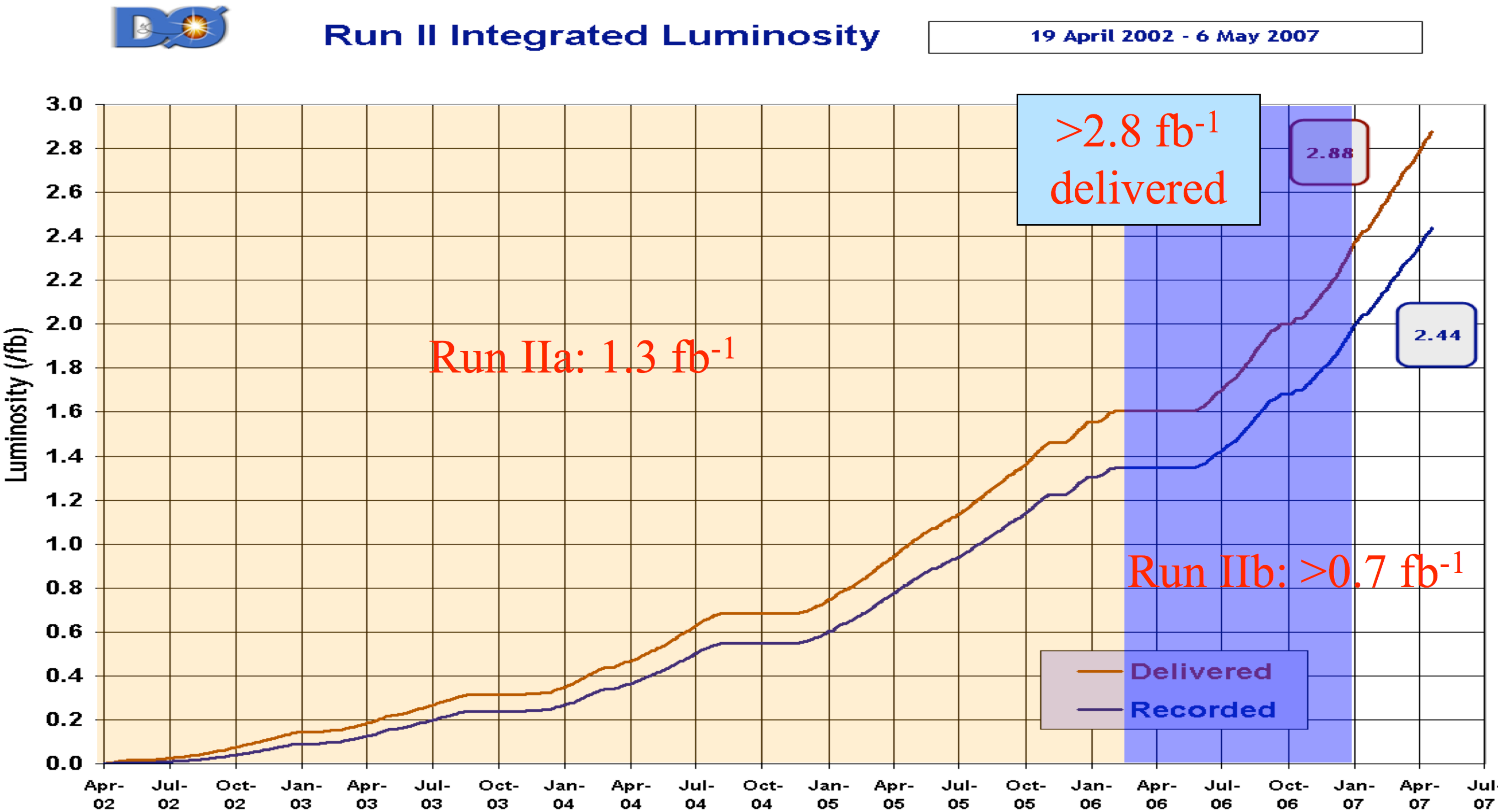


Ralf Bernhard
University of Freiburg
FPCP 2007

Focus on:

- CP Violation in B_s Mixing
  - Measurement of $\Delta\Gamma$
  - Measurement ϕ_s
  - Measurement of charge asymmetry
- Rare decay Bs -> $\mu^+\mu^-$

Dataset



Run II Integrated Luminosity
19 April 2002 - 6 May 2007
Luminosity (/fb)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Apr-02
Jul-02
Oct-02
Jan-03
Apr-03
Jul-03
Oct-03
Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07
Apr-07
Jul-07
>2.8 fb-1 delivered
2.88
2.44
Run IIa: 1.3 fb-1
Run IIb: >0.7 fb-1
Delivered
Recorded

Measurement of $\Delta\Gamma$

- $B_s \to D_s^{(*)} D_s^{(*)}$
  - Three channels
    - [$D_s D_s$ (PP), $D_s^* D_s$ (VP), $D_s^* D_s^*$ (VV)]
  - Heavy quark limit + factorization
    - $B_s^{odd} \to D_s^* D_s$ is forbidden
  - $D_s^* D_s^*$ in S-wave
  - $\Rightarrow$ $Ds^{(*)} Ds^{(*)}$ pure CP even

$$BF(B_s \to D_s^{(*)} D_s^{(*)}) = \left(\frac{\Delta\Gamma_{CP}}{2\Gamma}\right)\left(1 + O\left(\frac{\Delta\Gamma}{\Gamma}\right)\right)$$

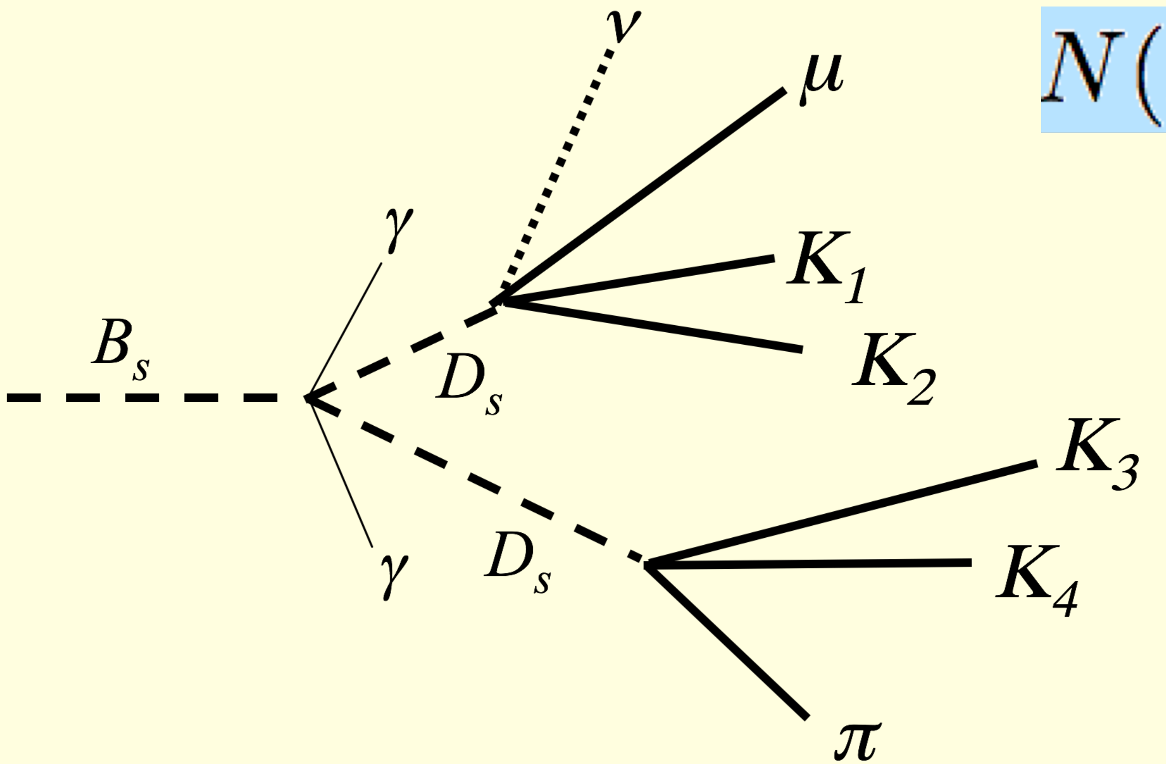
- Flavor specific B_s lifetime
  - *Flavor specific decays carry equal amounts of B_H and B_L*
  - *Get flavor specific lifetime if FS data with is fit w/ single exponential*

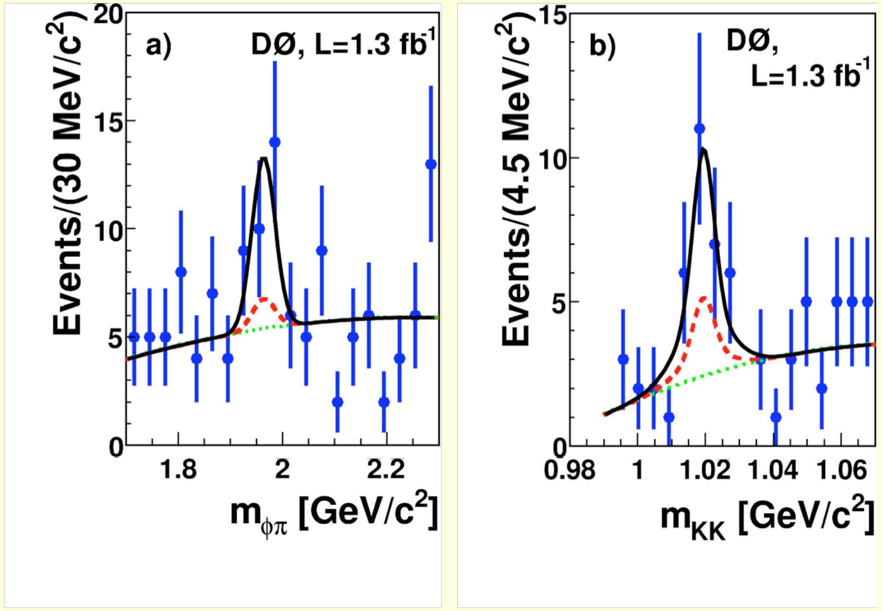
$$e^{-t/\tau_{FS}} = \frac{1}{2} \cdot \left(e^{-t/\tau_H} + e^{-t/\tau_L}\right)$$

- $B_s \to J/\psi\ \phi$: $P \to VV$
  - Even and odd paths distinguishable with angular analysis of final state particles

$\Delta\Gamma$ *from* $B_s \to D_s^{(*)} D_s^{(*)}$

$$N(D_s^{(*)} D_s^{(*)}) = 13.4\ ^{+6.6}_{-6.0}$$

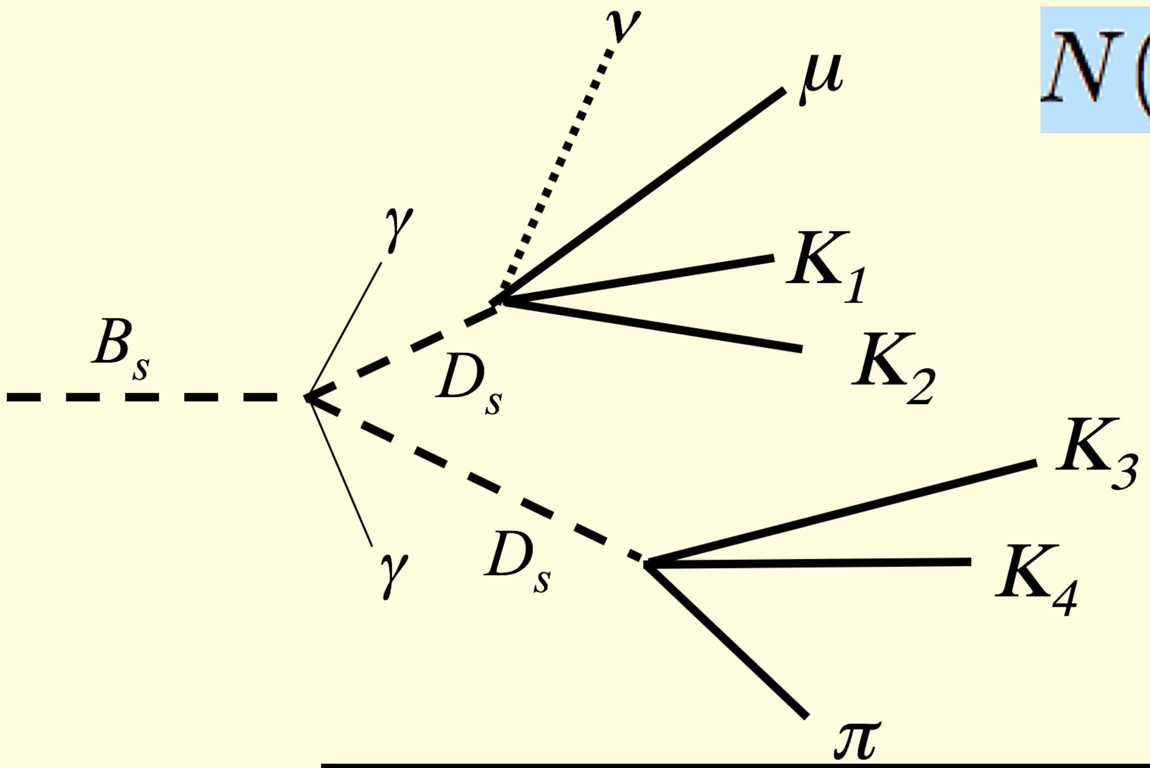




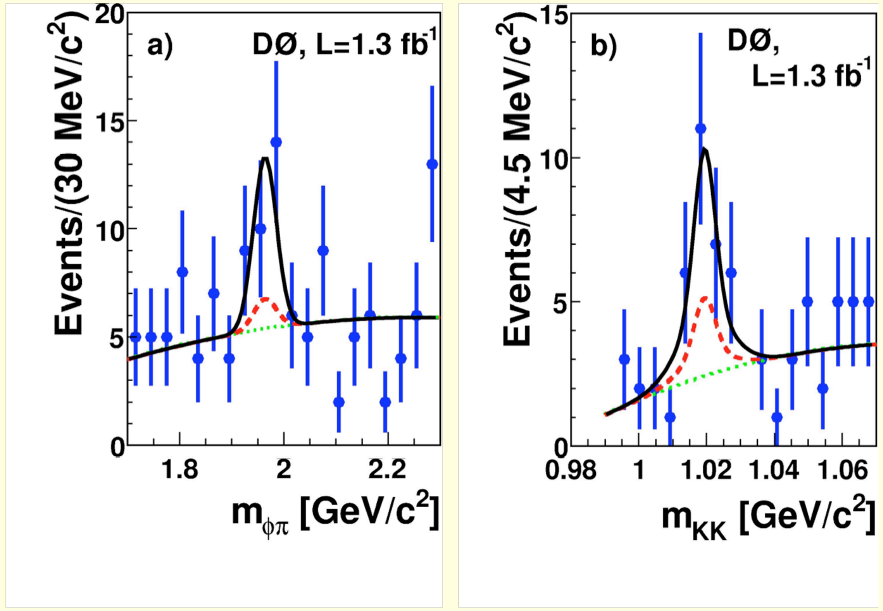
hep-ex/0702049, submitted to PRL

- Trigger on muon from semileptonic D_s decay
- Ignore any photons
- Look for correlated production of $D_s \to \phi\pi$ and $D_s \to \phi\mu$

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



$$N(D_s^{(*)} D_s^{(*)}) = 13.4\ ^{+6.6}_{-6.0}$$



hep-ex/0702049, submitted to PRL

$$BF(B_s \rightarrow D_s^{(*)} D_s^{(*)}) = 0.039^{+0.019}_{-0.017}\ ^{+0.016}_{-0.015}$$

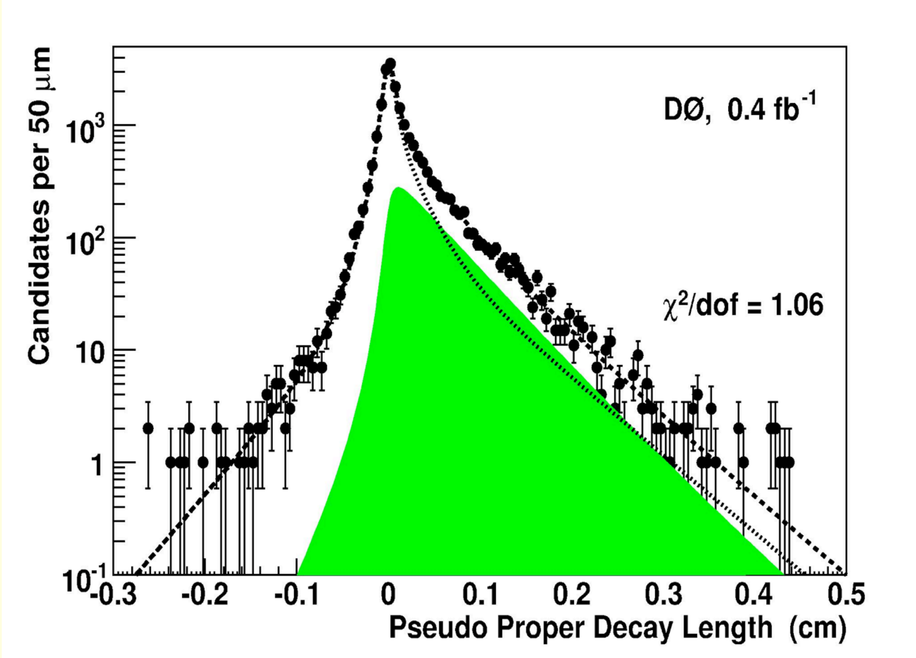
$$\frac{\Delta\Gamma_{CP}}{\Gamma} = 0.079^{+0.038}_{-0.035}\ ^{+0.031}_{-0.030}$$

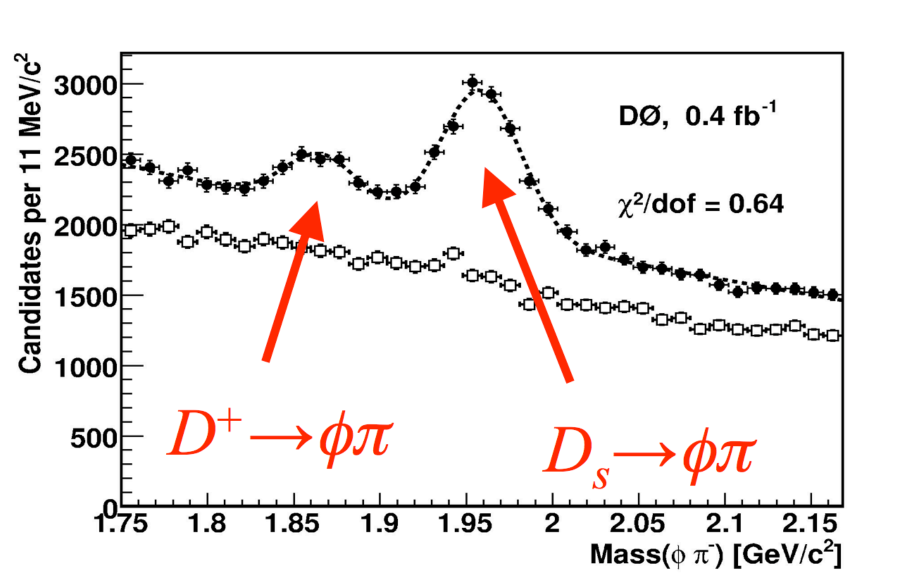
B_s Flavor Specific Lifetime

$$|B_s \to D_s \mu\nu\rangle = \frac{1}{\sqrt{2}}\left(|B_H\rangle + |B_L\rangle\right)$$

hep-ph/0201071

$$\tau_{FS} = \frac{1}{\bar{\Gamma}_s}\frac{1+y^2}{1-y^2} \text{ with } y = \frac{\Delta\Gamma}{2\Gamma}$$





$$\tau_{FS}(B_s) = 1.381 \pm 0.055^{+0.052}_{-0.046}\, ps$$

$$\tau_{FS}(B_s, WA) = 1.440 \pm 0.036\, ps$$

Phys.Rev.Lett.97:241801,2006

$B_s \rightarrow J/\psi\ \phi$

Time evolution: pure even case

$$\Gamma(t) \approx \left| A_{even}(\theta, \psi, \varphi, t) \right|^2$$

$$f(t, even) \approx e^{-\Gamma_L t}$$

Time evolution: even plus odd components

$$\Gamma(t) \approx \left| A_{even}(\theta, \psi, \varphi, t) \right|^2 + \left| A_{odd}(\theta, \psi, \varphi, t) \right|^2$$

$$+ A^* A(CPC)$$

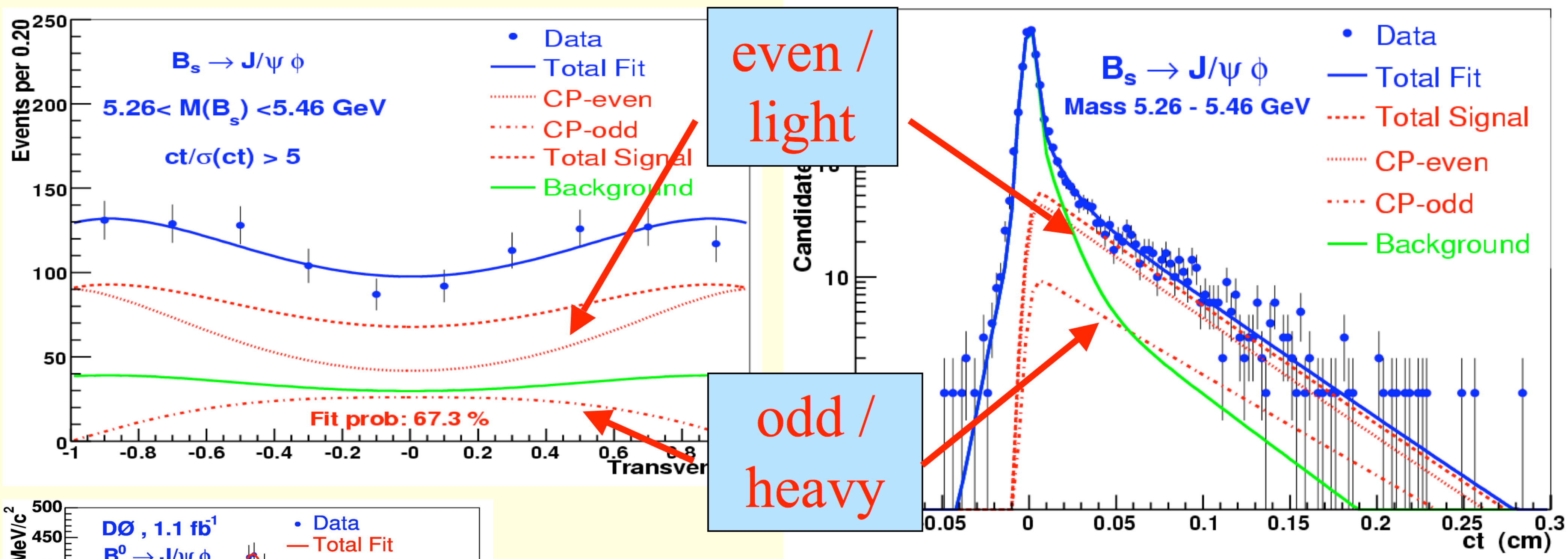
CP conserving interference

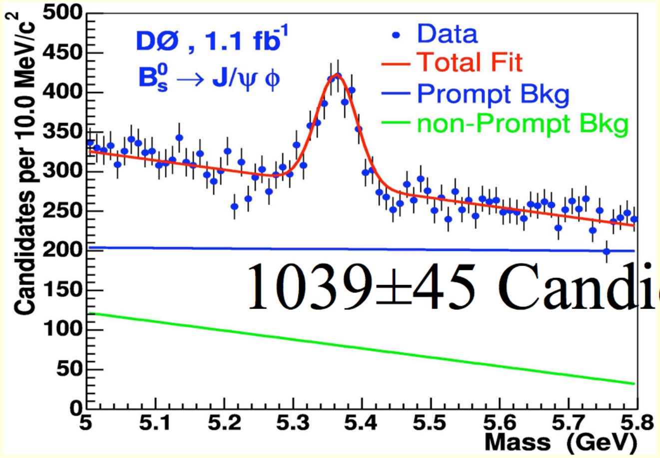
$$f(t, even) \approx e^{-\Gamma_L t}$$

$$f(t, odd) \approx e^{-\Gamma_H t}$$

CP states = heavy, light states

$B_s \rightarrow J/\psi\ \phi$





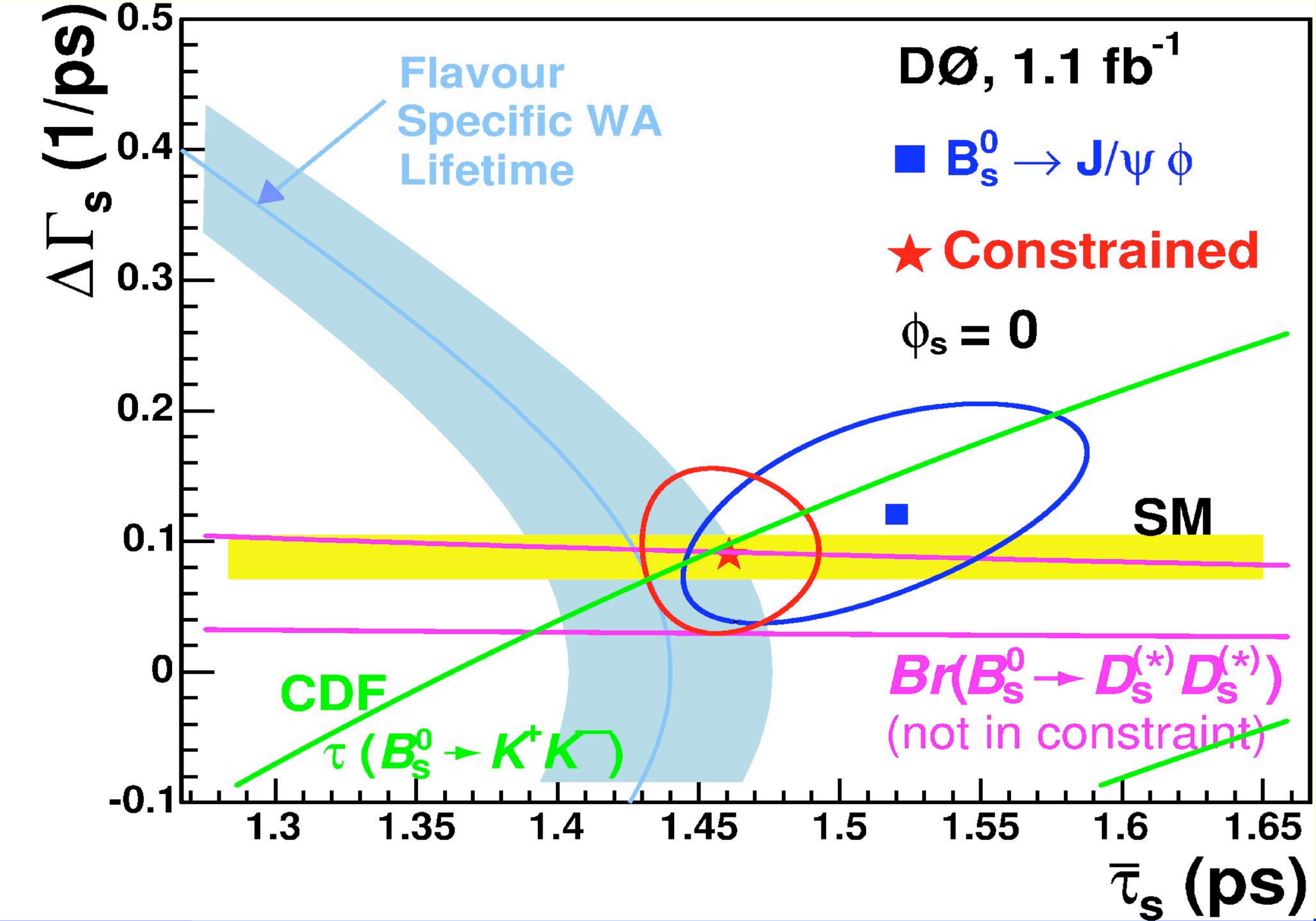
1039±45 Candidate B_S

$$\Delta\Gamma_s = 0.12^{+0.08}_{-0.10} \pm 0.02\,ps^{-1}$$

$$\bar{\tau}_s = 1/\Gamma_s = 1.52 \pm 0.08^{+0.01}_{-0.03}\,ps$$

Phys. Rev. Lett. 98, 121801 (2007)

Combined $\Delta\Gamma$ ($\cos\phi_s \equiv 1$)



ϕ_s Measurement

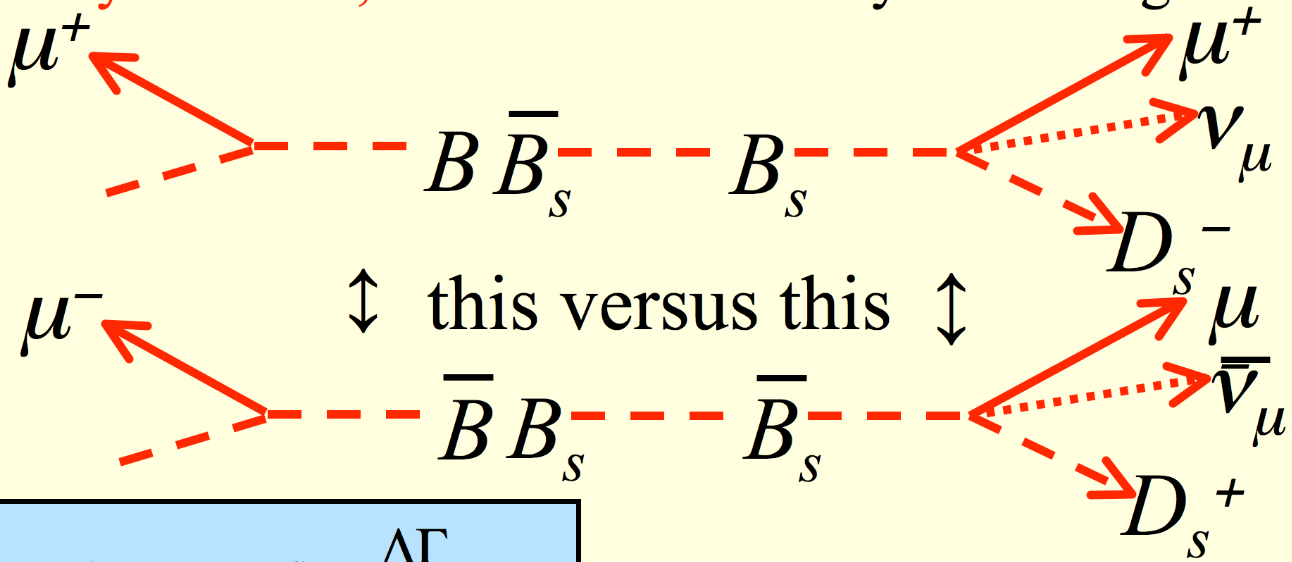
In Standard Model: $\phi_s \approx \arg(-V_{ts}) \approx 0.004$ rad.

Observables: Semileptonic asymmetries, interference in decays to CP eigenstates

<u>Two samples</u>

Exclusive untagged $D_s\mu$

Inclusive like-sign $\mu\mu$



$$\frac{N(D_s\mu^+) - N(D_s\mu^-)}{N(D_s\mu^+) + N(D_s\mu^-)} = A_{SL}(untagged) \approx \frac{\Delta\Gamma}{\Delta m}\tan\phi$$

$$\frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = A_{SL}(tagged) = 2A_{SL}(untagged)$$

A. Lenz, U. Nierste hep-ph/0612167

Same sign Dimuons

$$\frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = A_{SL}(tagged) = 2A_{SL}(untagged)$$

N(same sign) ≈ 310K

$$A_{SL} = -0.0092 \pm 0.0044 \pm 0.0032$$

~60/40 mix of B_d and B_s

$$A_{SL} = A_{SL}(B_d) + \frac{f_s Z_s}{f_d Z_d} A_{SL}(B_s) \quad Z \sim 2\chi$$

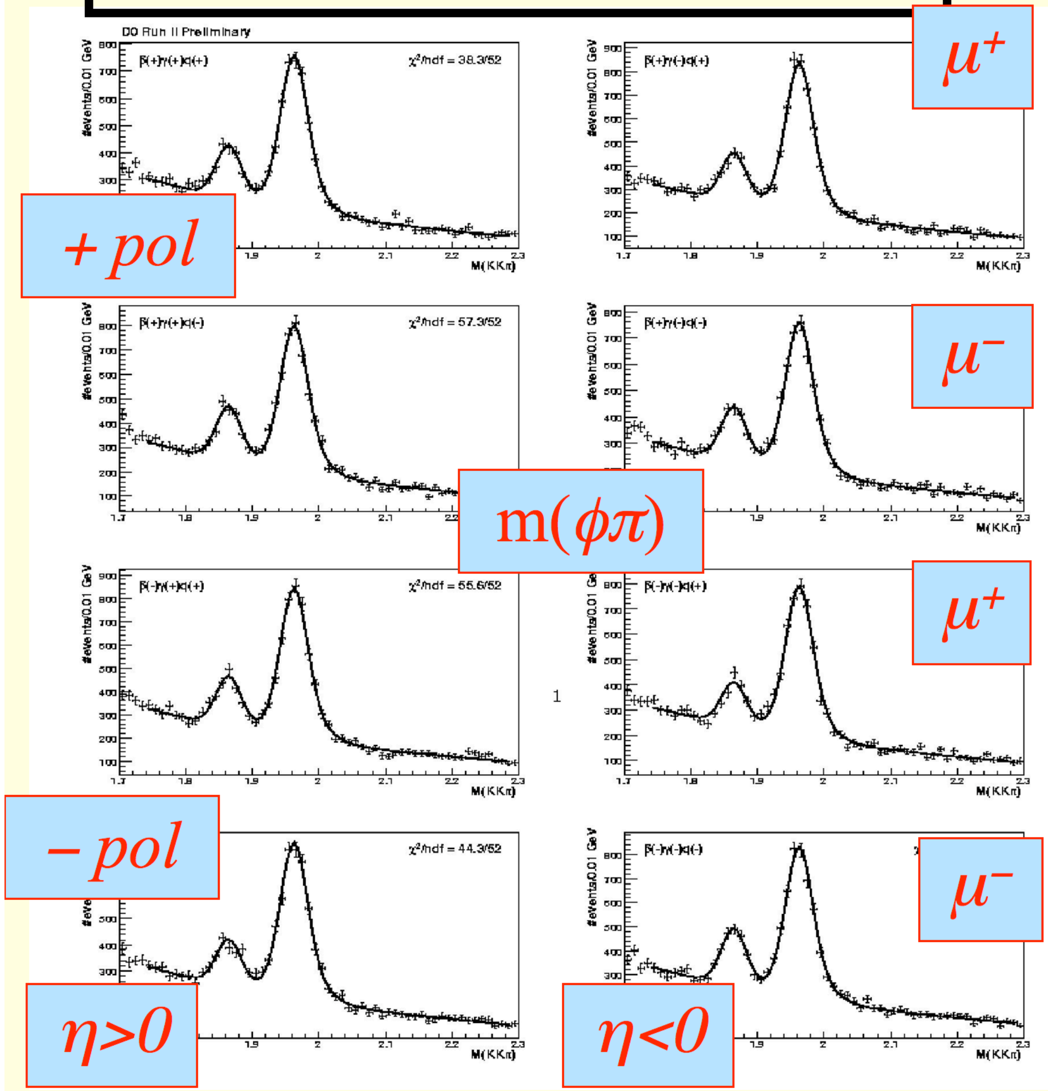
$A_{SL}(B_d)$=-0.0047±0.0046 (HFAG, B-factories)

$$A_{SL}(B_s, \mu\mu) = -0.0064 \pm 0.0101$$

Phys. Rev. D 74, 092001 (2006)

Exclusive $B_s \rightarrow D_s^{\pm}\mu\nu$ Results

Exclusive $D_s\mu$



$$\frac{N(D_s\mu^+) - N(D_s\mu^-)}{N(D_s\mu^+) + N(D_s\mu^-)} = A_{SL}(untagged) \approx \frac{\Delta\Gamma}{\Delta m}\tan\phi$$

$$A_{SL}(B_s, D_s\mu) =$$
$$0.0245 \pm 0.0193 \pm 0.0035$$

DØ Combined:

$$A_{SL}(B_s, \mu\mu + D_s\mu) =$$
$$0.0001 \pm 0.0090$$

Using Δm_s from CDF:

$$\Delta\Gamma_s \cdot \tan\phi_s = 0.02 \pm 0.16\, ps^{-1}$$

Phys. Rev. Lett. 98, 151801 (2007)

$B_s \rightarrow J/\psi\ \phi$

Time dependent angular analysis of untagged sample

Time evolution: even plus odd plus CPV

$$\Gamma(t) \approx \left|A_{even}(\theta,\psi,\varphi,t)\right|^2 + \left|A_{odd}(\theta,\psi,\varphi,t)\right|^2$$

$$+ A^* A(CPC)$$

CP conserving interference

$$+ A^* A(CPV)(e^{-\Gamma_L t} - e^{-\Gamma_H t})\sin\phi_s$$

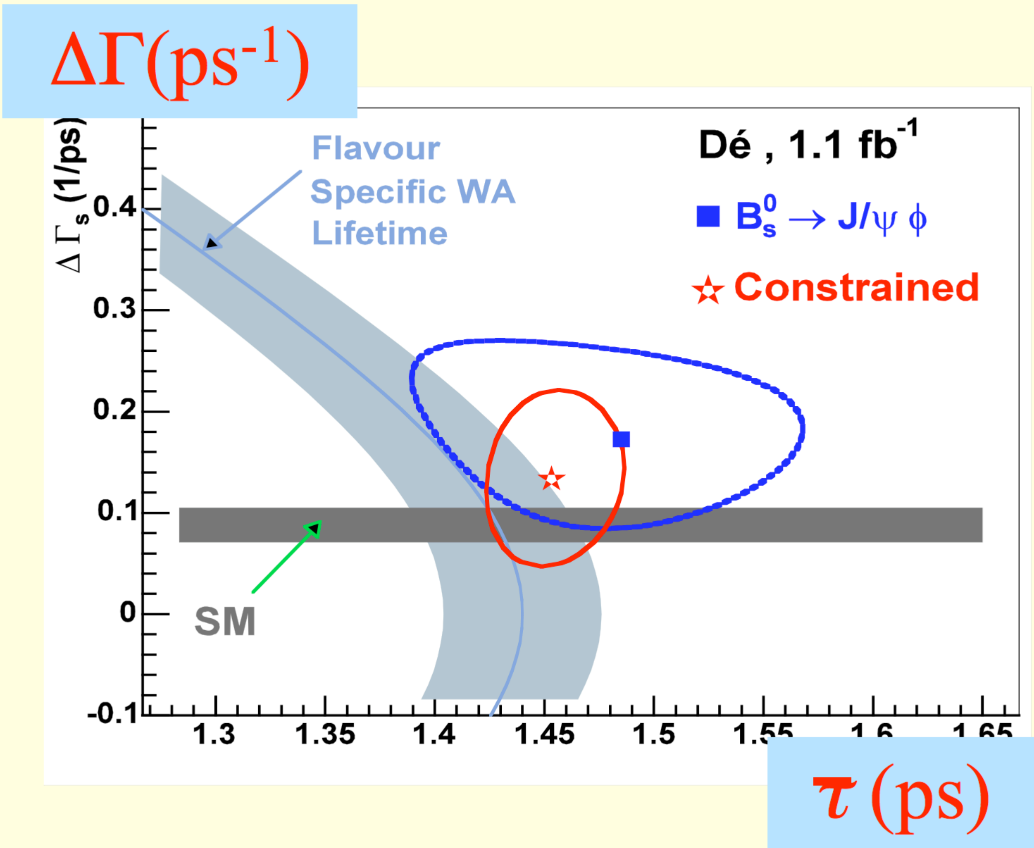
CP violating interference between two paths

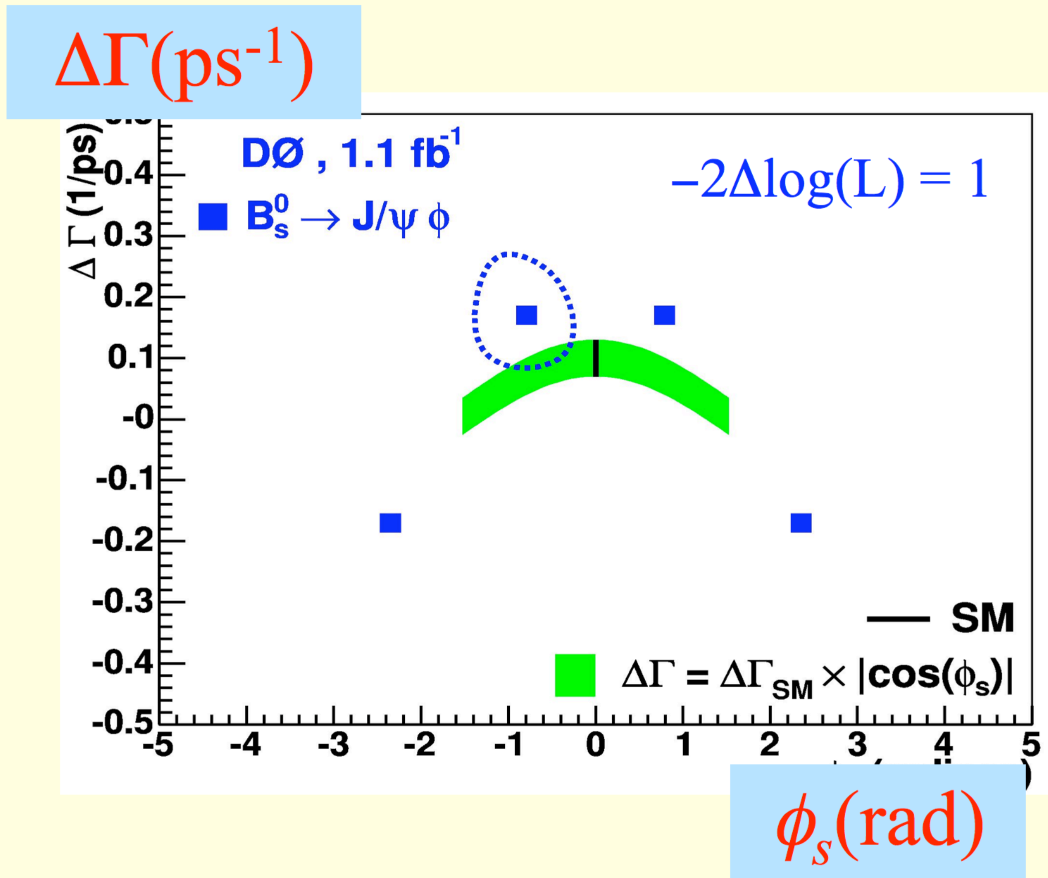
$$f(t,even) \approx (1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t}$$

$$f(t,odd) \approx (1+\cos\phi_s)e^{-\Gamma_H t} + (1-\cos\phi_s)e^{-\Gamma_L t}$$

Heavy and light states are mixed CP

$B_s \to J/\psi\,\phi$ Results





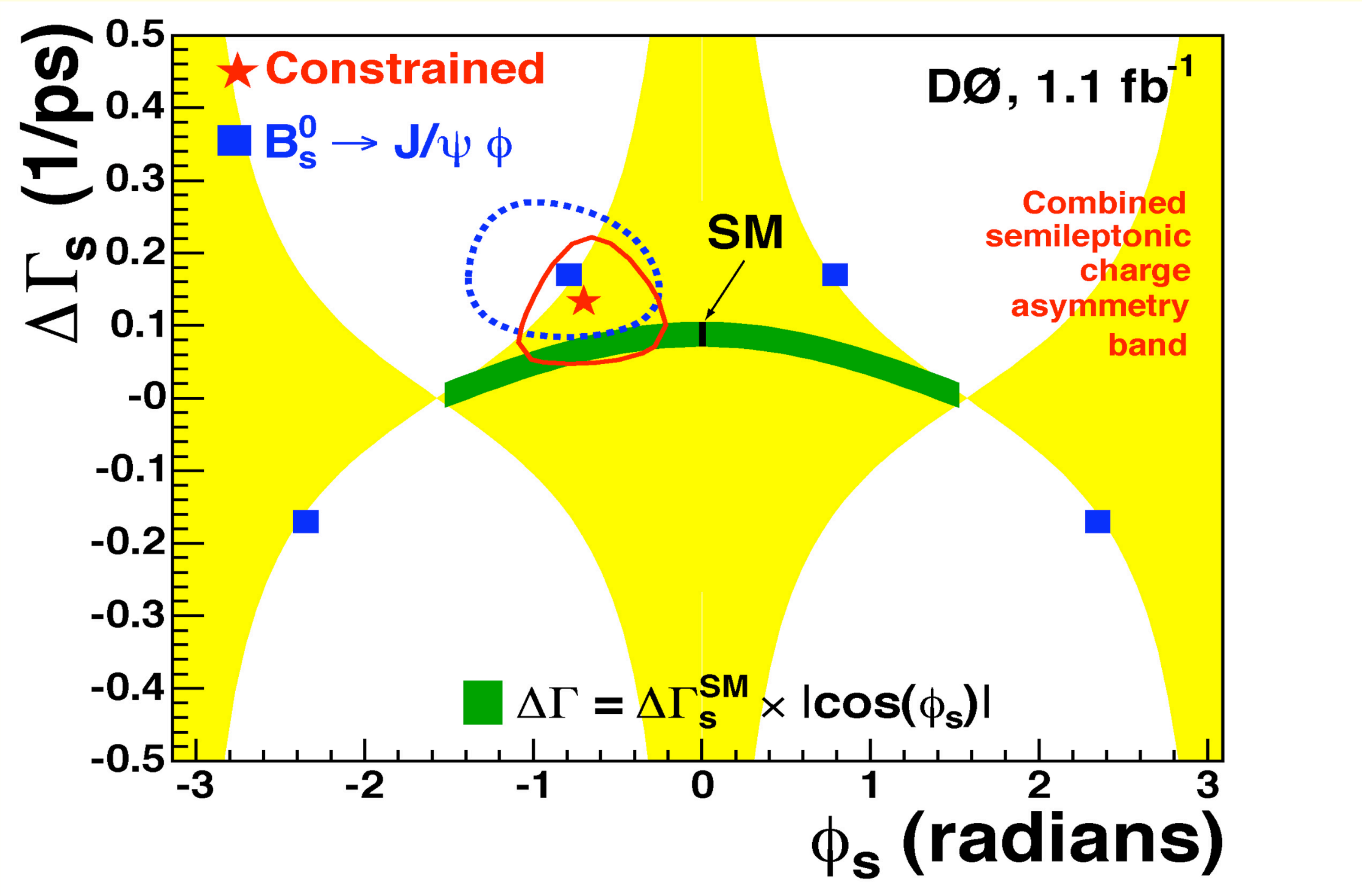
Likelihood invariant to simultaneous flip of sign of ΔΓ and even-odd strong phase difference ⇒ 4-fold ambiguity

$$\Delta\Gamma_s = 0.17 \pm 0.09 \pm 0.02\, ps^{-1}$$

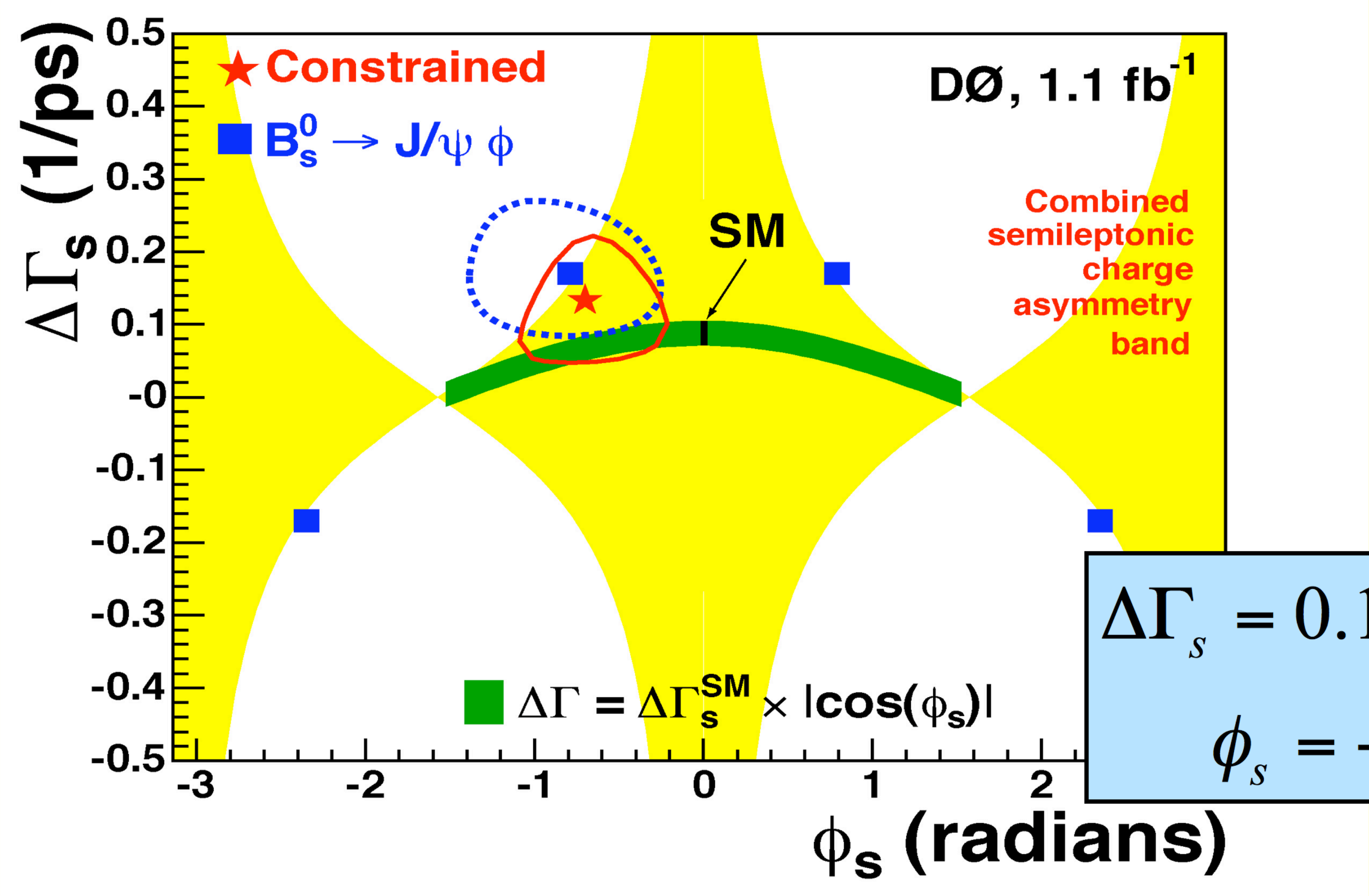
$$\phi_s = -0.79 \pm 0.56^{+0.14}_{-0.01}$$

Phys. Rev. Lett. 98, 121801 (2007)

ϕ_s Results



ϕ_s Results

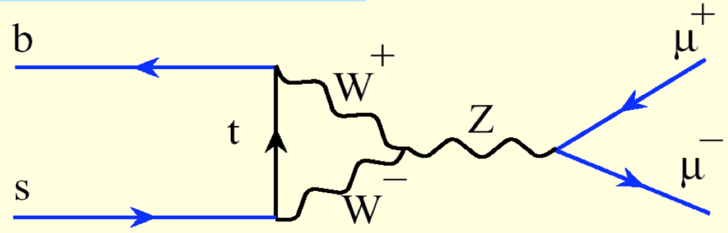


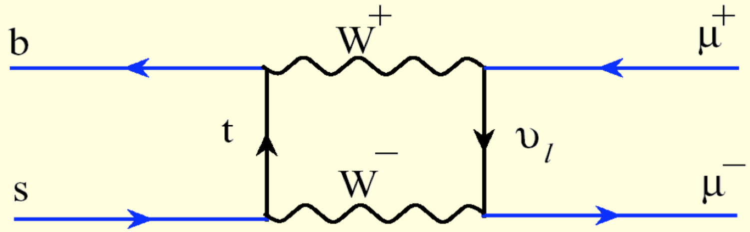
$$\Delta\Gamma_s = 0.13 \pm 0.09\, ps^{-1}$$

$$\phi_s = -0.70^{+0.47}_{-0.39}$$

Purely leptonic B decay

- **B->l^+ l^-** decay is helicity suppressed FCNC
- SM: BR(B_s->$\mu^+\mu^-$) ~ 3.4×10^{-9}
- depends only on one SM operator in effective Hamiltonian, hadronic uncertainties small
- B_d relative to B_s suppressed by $|V_{td}/V_{ts}|^2$ ~ 0.04 if no additional sources of flavor violation
- reaching SM sensitivity: present limit for B_s -> $\mu^+\mu^-$ comes closest to SM value





SM expectations:

	$Br(B_d \to l^+l^-)$	$Br(B_s \to l^+l^-)$
$l = e$	3.4×10^{-15}	8.0×10^{-14}
$l=\mu$	1.0×10^{-10}	**3.4×10^{-9}**
$l=\tau$	3.1×10^{-8}	7.4×10^{-7}

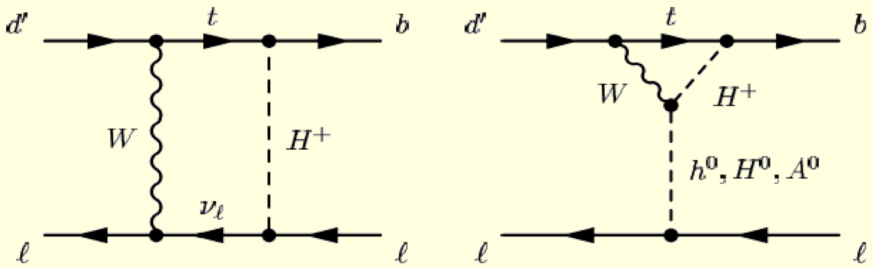
Current published limits:

	$Br(B_d \to l^+l^-)$	$Br(B_s \to l^+l^-)$
$l = e$	$< 6.1 \cdot 10^{-8}$	$< 5.4 \cdot 10^{-5}$
$l=\mu$	$< 8.3 \cdot 10^{-8}$	**$<1.5 \times 10^{-7}$**
$l=\tau$	< 2.5%	< 5.0%

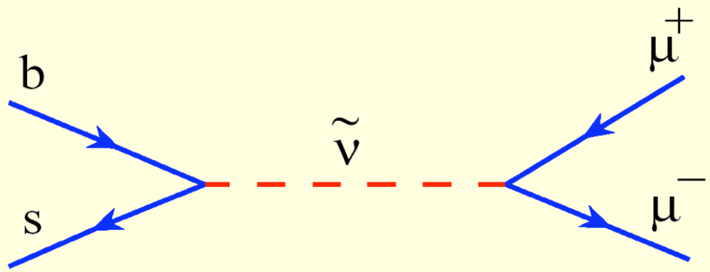
Purely leptonic B decay

- excellent probe for many new physics models
- particularly sensitive to models w/ extended Higgs sector
  - BR grows ~$\tan^6\beta$ in MSSM
  - 2HDM models ~ $\tan^4\beta$
  - mSUGRA: BR enhancement correlated with shift of $(g-2)_\mu$
- also, testing ground for
  - minimal SO(10) GUT models
  - R_p violating models, contributions at tree level
  - (neutralino) dark matter …

Two-Higgs Doublet models:



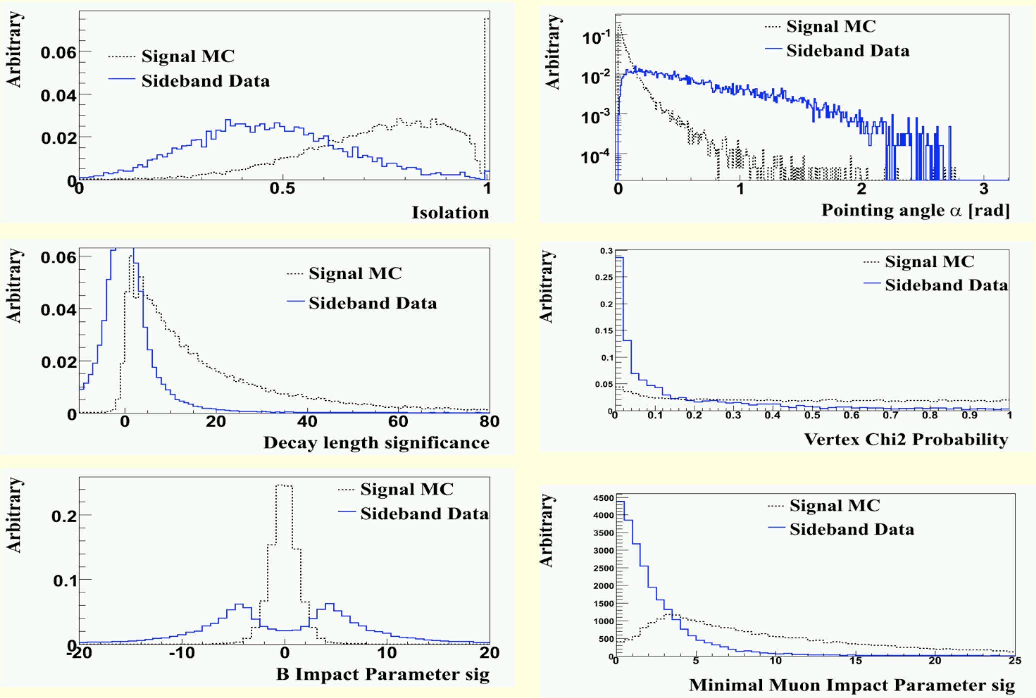
R_p violating:



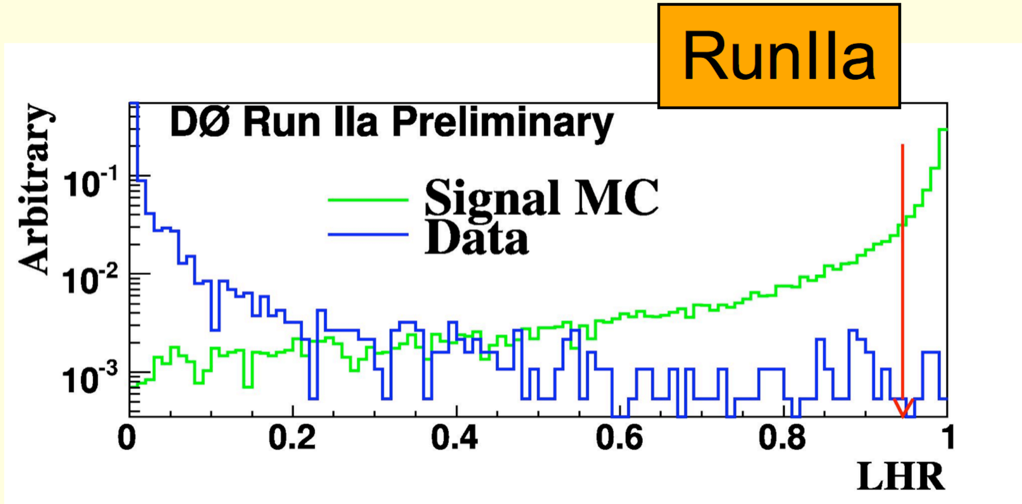
Strategy

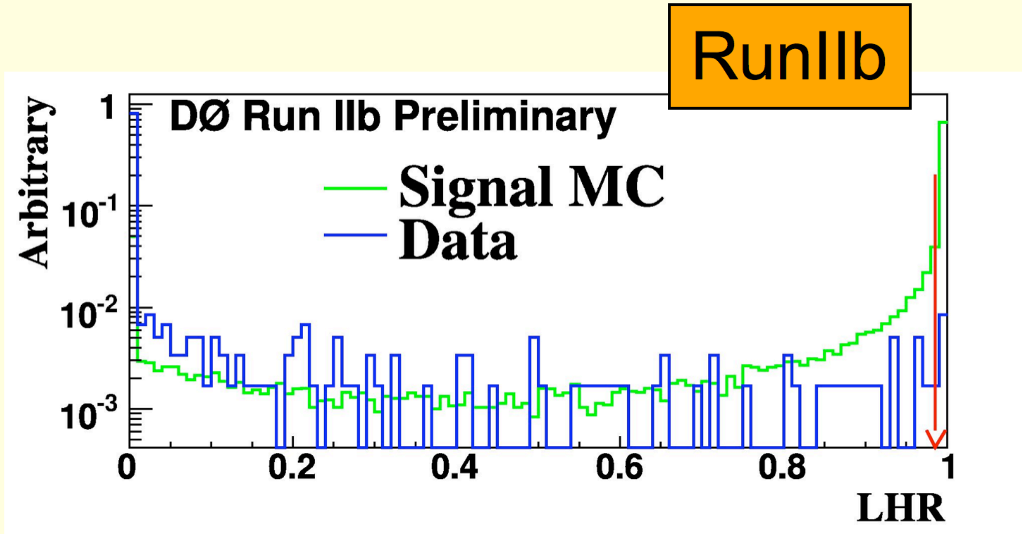
- Preselection of Di Muon events
- Normalization channel $B^+ \rightarrow J/\psi K^+$
  - Advantage of efficiency normalization
- Background estimation using sidebands
  - Blind analysis to avoid bias
- Background reduction using a LHR

Likelihood



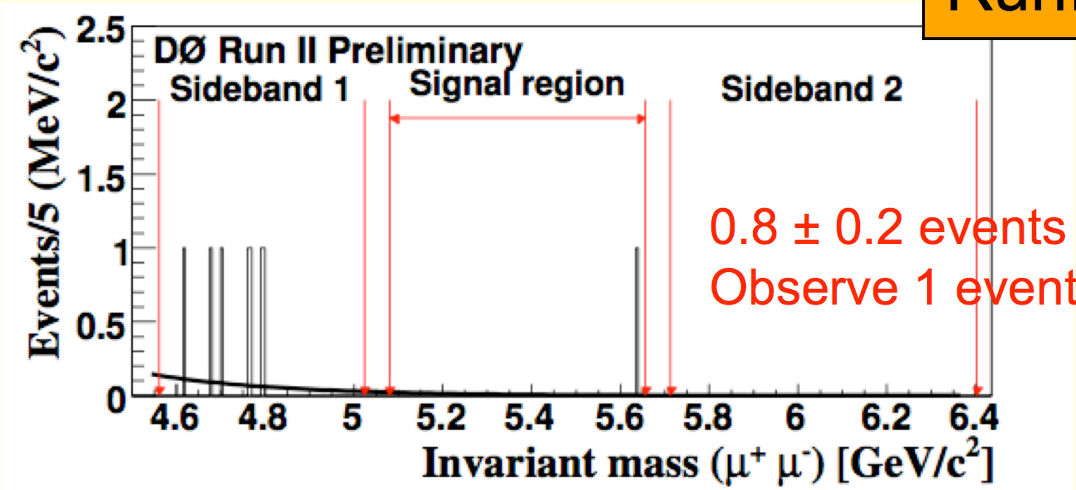
$$LHR = \frac{\prod_{i=0}^{6} s_i(x)}{\prod_{i=0}^{6} s_i(x) + \prod_{i=0}^{6} b_i(x)}$$



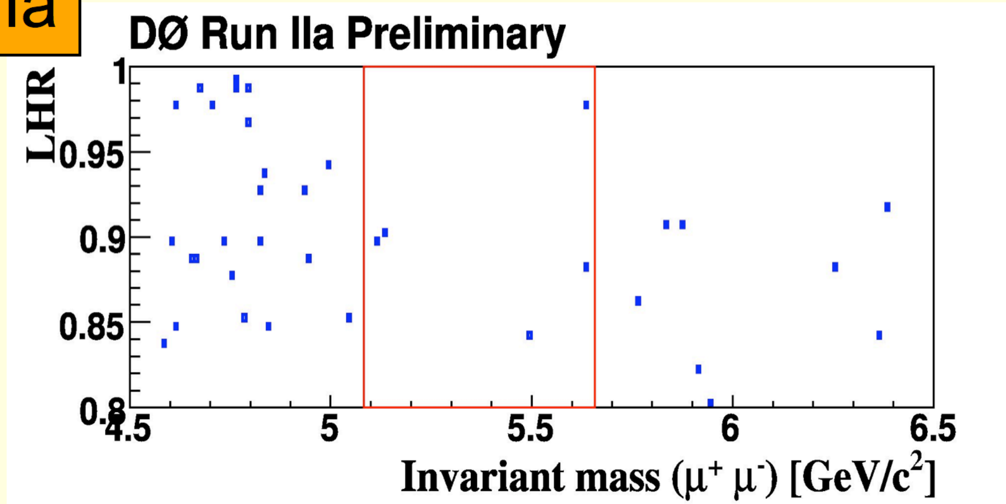


Mass Distributions

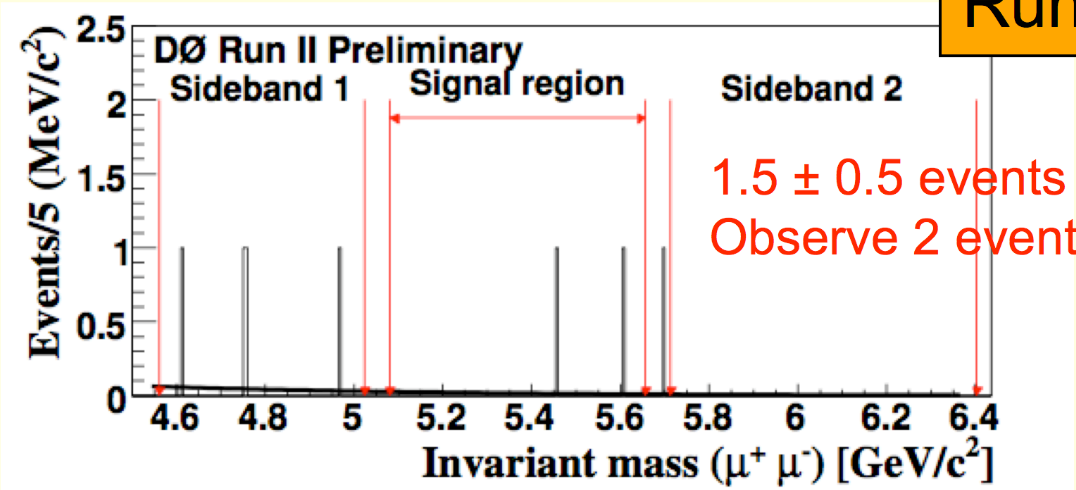
RunIIa



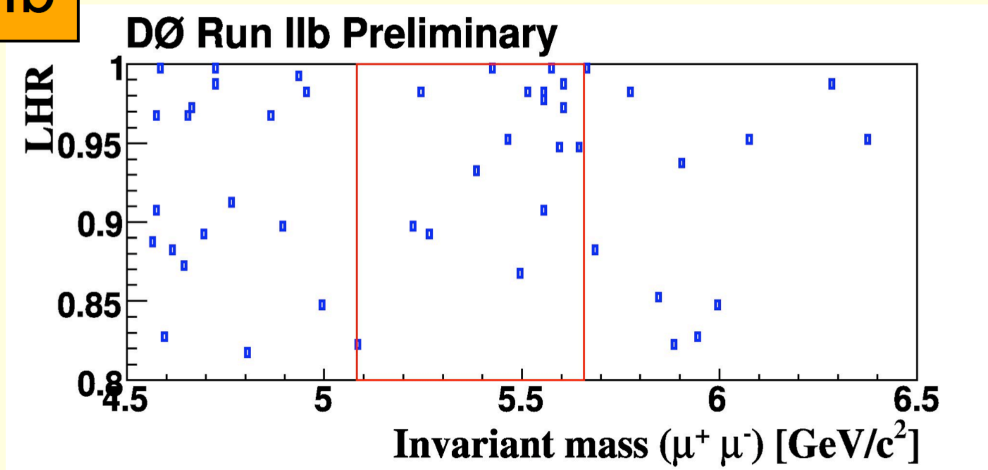
0.8 ± 0.2 events
Observe 1 event



RunIIb

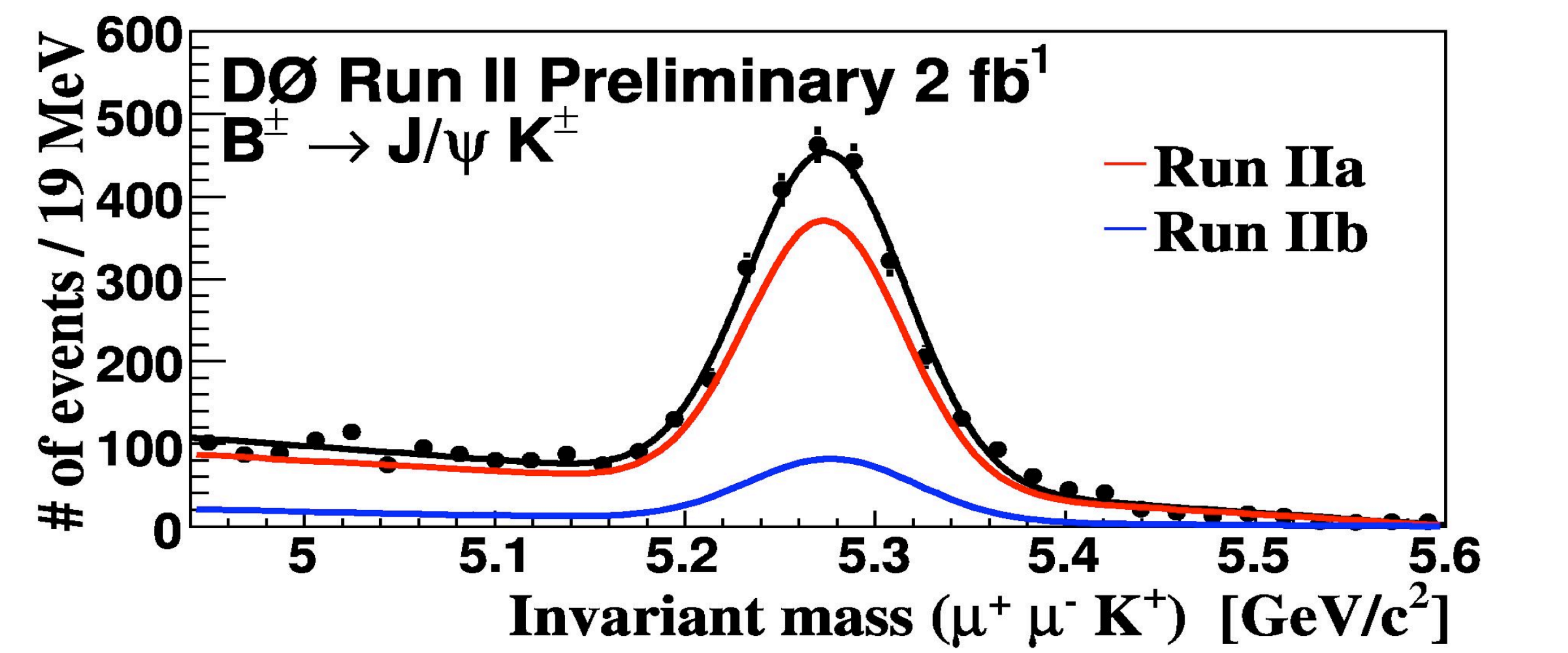


1.5 ± 0.5 events
Observe 2 events



Normalization

- Additional cuts on the Kaon and B candidate are:
  - Kaon p_T > 0.9 GeV/c
  - Collinearity of > 0.9 is required
  - χ^2 of the vertex fit contribution not more than 10, together < 20
  - Also cut on the LHR cut like the $B_s \to \mu^+\mu^-$ signal



Limit Calculation

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < \frac{N_{UL}}{N_{B^+}} \cdot \frac{\varepsilon^{B^+}_{\mu^+\mu^- K}}{\varepsilon^{B_s^0}_{\mu^+\mu^-}} \cdot \frac{\mathcal{B}(B^\pm \to J/\psi(\mu^+\mu^-)K^\pm)}{\frac{f_{b\to B_s}}{f_{b\to B_{u,d}}} + R \cdot \frac{\epsilon^{B_d^0}_{\mu^+\mu^-}}{\epsilon^{B_s^0}_{\mu^+\mu^-}}}$$

- Relative Normalization
- $\varepsilon_{B^+} / \varepsilon_{B_s}$ relative efficiency of normalization to signal channel
- f_s/f_u fragmentation ratio - use world average (3.71) with 15% uncertainty
- $\varepsilon_{Bd} / \varepsilon_{Bs}$ relative efficiency for $B_d \to \mu^+ \mu^-$ versus $B_s \to \mu^+ \mu^-$ events in B_s search channel (~0.95) $R = BR(B_d)/BR(B_s)$ is small due to $|V_{td}/V_{ts}|$^2

$Br(B_s \to \mu\mu)$	1.3 fb^{-1}	9.5×10^{-8}	Prelim.RunIIa
$Br(B_s \to \mu\mu)$	0.6 fb^{-1}	3.9×10^{-7}	Prelim.RunIIb
$Br(B_s \to \mu\mu)$	combined	9.3×10^{-8}	Prelim.RunII

at 95% CL

Wrap up

- Now have information on all B_s mixing parameters from DØ.
  - $\Delta\Gamma$ consistent with SM calculations
  - First attempt to measure ϕ_s parameter using angular analysis of $B_s \rightarrow J/\psi\phi$ and semileptonic asymmetries
- Limit on rare decay $B_s \rightarrow \mu^+\mu^-$ is getting more and more stringent, help constrain BSM physics
- Update on these analysis are expected this summer with even more statistics (2+fb^{-1})

Back up slides

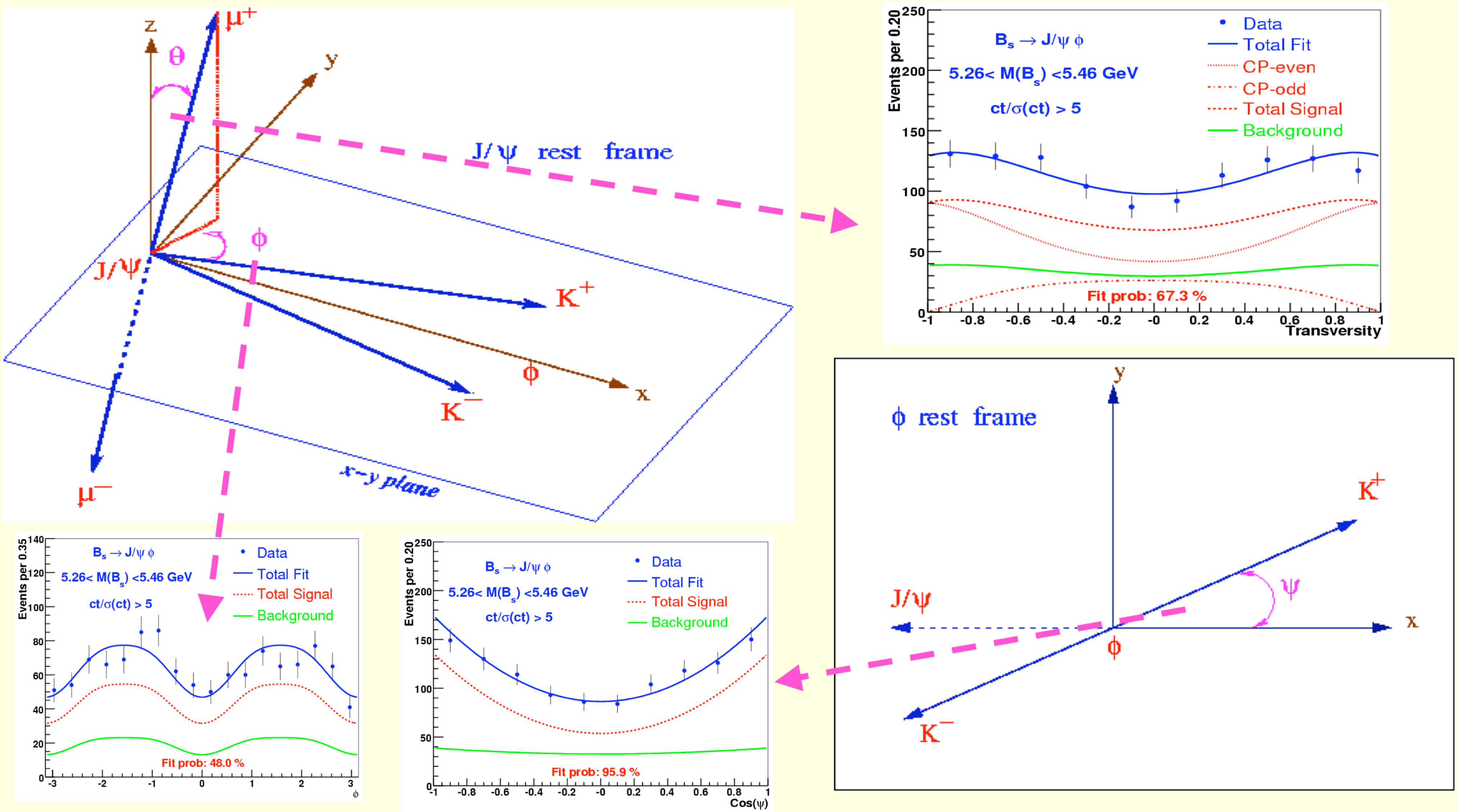
Pre-Selection

- Cut on Mass region of di-muon sample $4.5 < m_{\mu\mu} < 7$ GeV/c2
- Two medium muons with a net charge of zero and a p_T greater than 2.5 GeV
- The triggered muons have reconstructed tracks in the tracker with
  - at least 3 hits in the Silicon tracker
  - at least 4 hits in the Fiber tracker
- Good reconstructed vertex (χ^2 cut)
- Cut on the uncertainty of the transverse decay length $\sigma(Lxy) < 150\ \mu m$
- A minimum pT of the Bs candidate of 5 GeV is required

Systematic Uncertainties

Source	Relative Uncertainty [%]	
	RunIIa	RunIIb
$\epsilon^{B^\pm}_{\mu\mu K}/\epsilon^{B^0_s}_{\mu\mu}$	6.7	9.0
# of $B^\pm \to J/\psi K^\pm$	3.2	5.7
$\mathcal{B}(B^\pm \to J/\psi K^\pm)$	4.0	4.0
$\mathcal{B}(J/\psi \to \mu\mu)$	1.7	1.7
$f_{b\to B^0_s}/f_{b\to B^\pm}$	12.7	12.7
background uncertainty	25	33

$B_s \rightarrow J/\psi\ \phi$ angles



Flavor Specific B_s Lifetime

Flavor specific decays carry equal amounts of B_H and B_L

$$|B_s \rightarrow D_s \mu \nu\rangle = \frac{1}{\sqrt{2}}\left(|B_H\rangle + |B_L\rangle\right)$$

$$e^{-t/\tau_{FS}} \equiv \frac{1}{2}\left(e^{-t/\tau_H} + e^{-t/\tau_L}\right)$$

Get the flavor specific lifetime when you fit FS data with single exponential

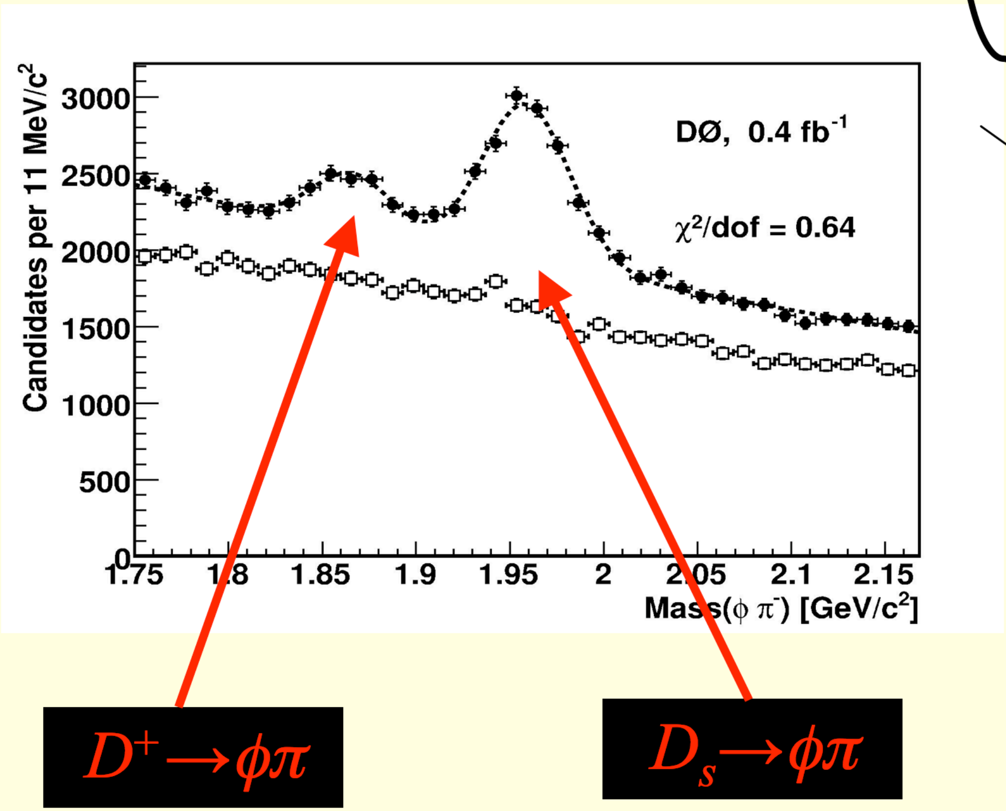
$$\tau_{FS} = \frac{1}{\overline{\Gamma}_s}\left(\frac{1+y^2}{1-y^2}\right)$$

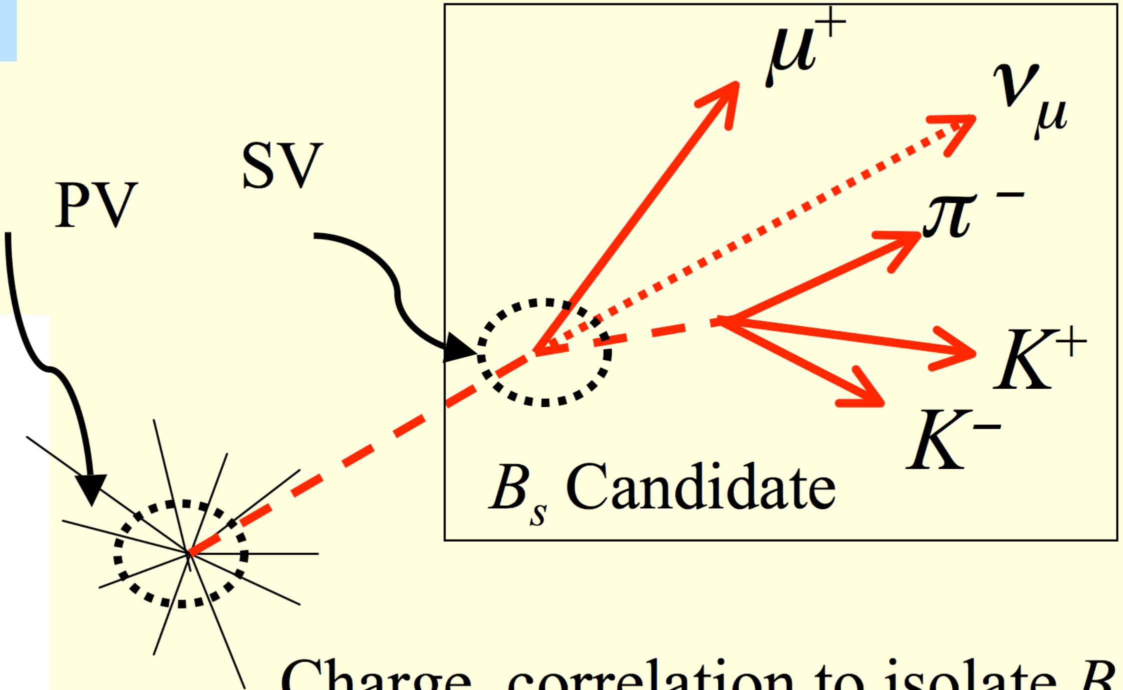
$$y = \frac{\Delta\Gamma}{2\Gamma}$$

Maps out a 2-D constraint on the average width and the width difference

hep-ph/0201071

B_s Semileptonic Sample





Charge correlation to isolate B_s sample

Transverse decay length determined in lab frame

Boost back using MC to estimate neutrino momentum

$B_s \rightarrow J/\psi\ \phi$: $P \rightarrow VV$

Even and odd paths distinguishable with angular analysis of final state particles

$A_0\ A_{||}$

Even waves

$A_\perp$

Odd waves

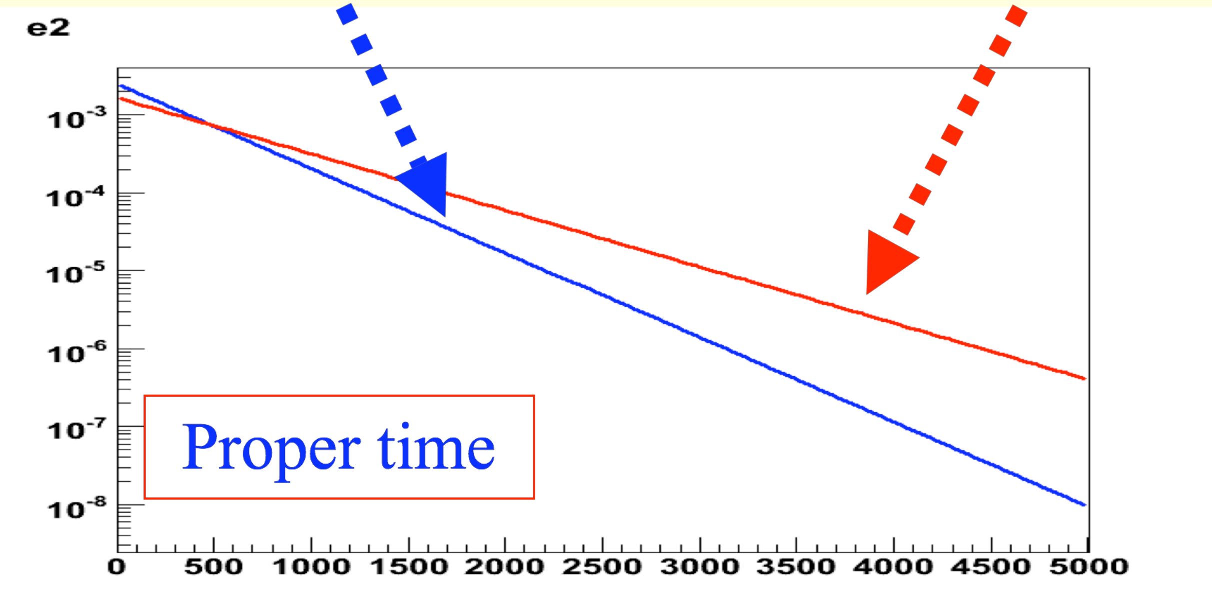
Proper time

$B_s \rightarrow J/\psi\ \phi$: $P \rightarrow VV$

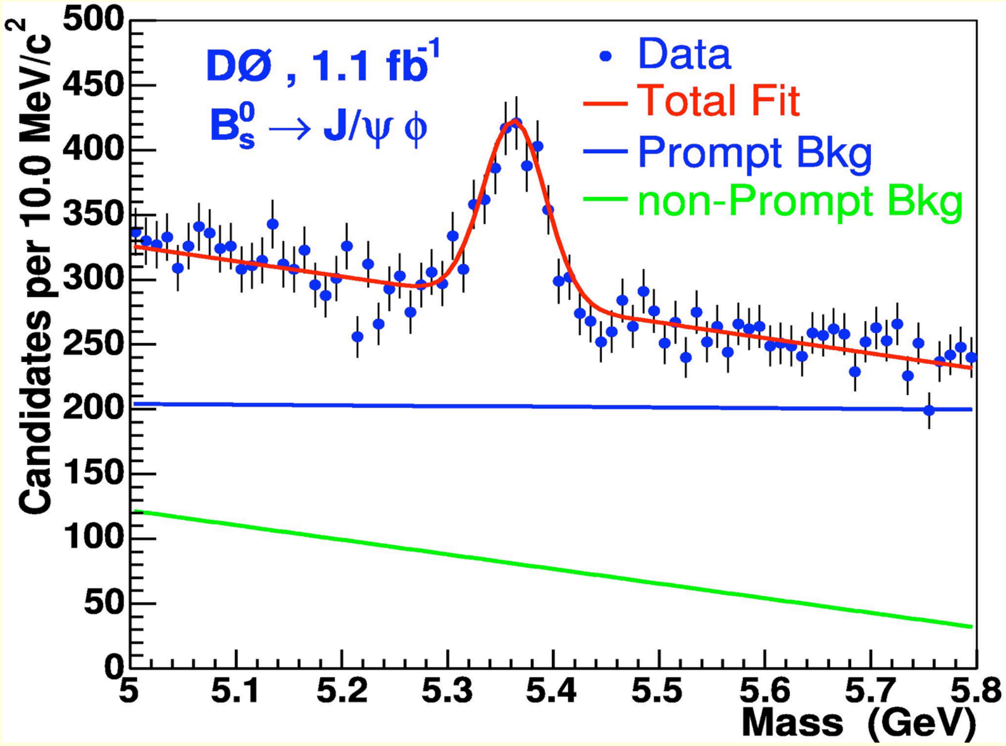
Even and odd paths distinguishable with angular analysis of final state particles

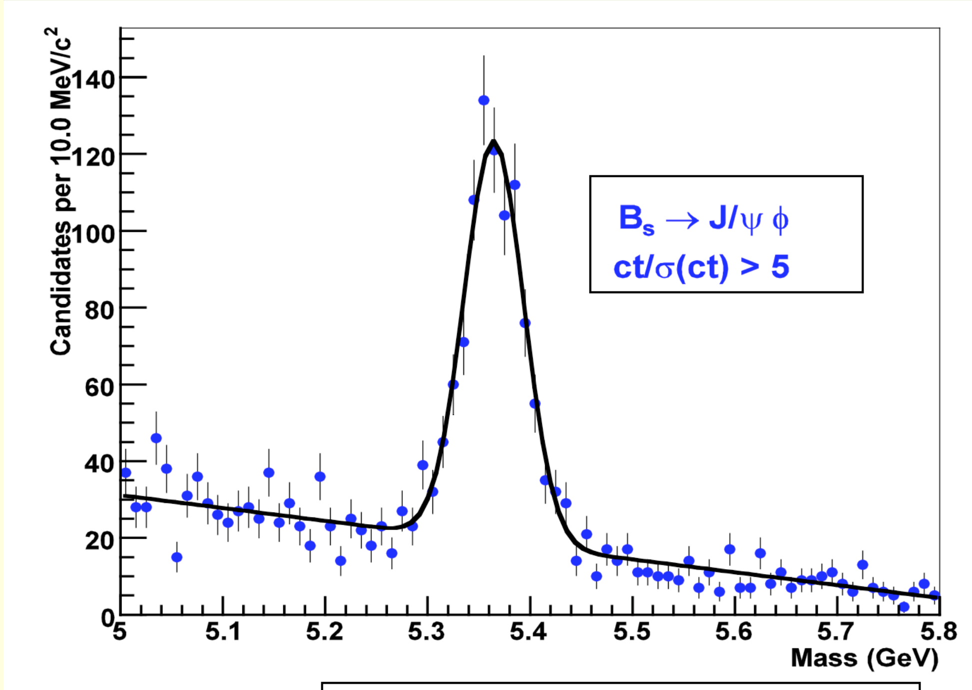
A_0 $A_{||}$ — Even waves

$A_{\perp}$ — Odd waves



$B_s \rightarrow J/\psi\ \phi$





Flight length significance > 5

1039±45 B_s Candidates