B Hadron Lifetimes at DØ

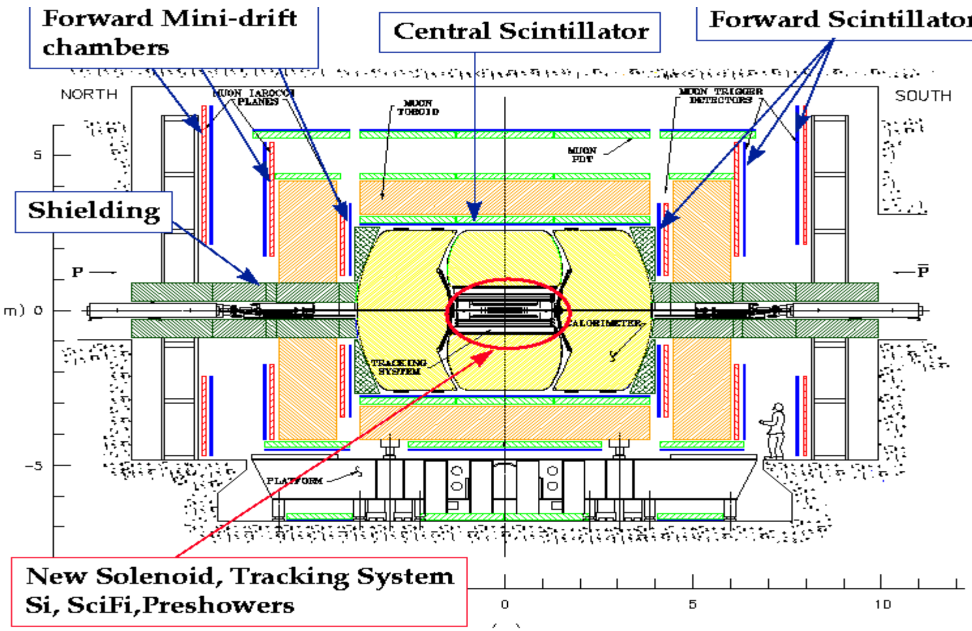
Claus Peter Buszello
for the DØ Collaboration

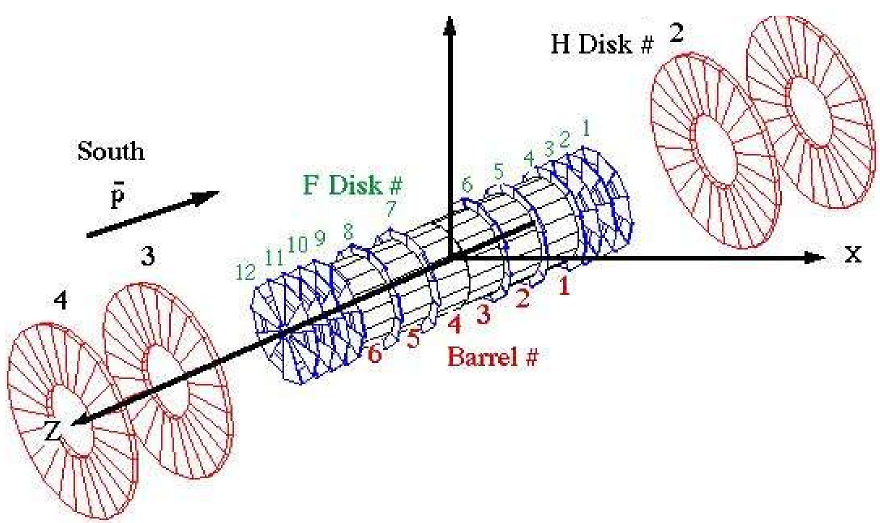
The DØ Detector

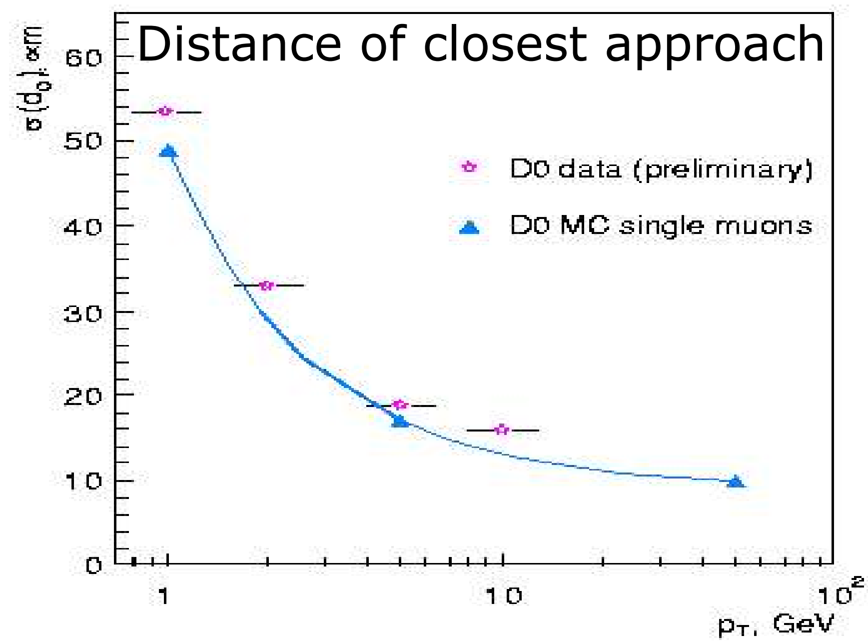
Clean muon ID at $|\eta|<2$

Compact tracker:
- Central fibre tracker (CFT)
- Silicon microstrip tracker (SMT)

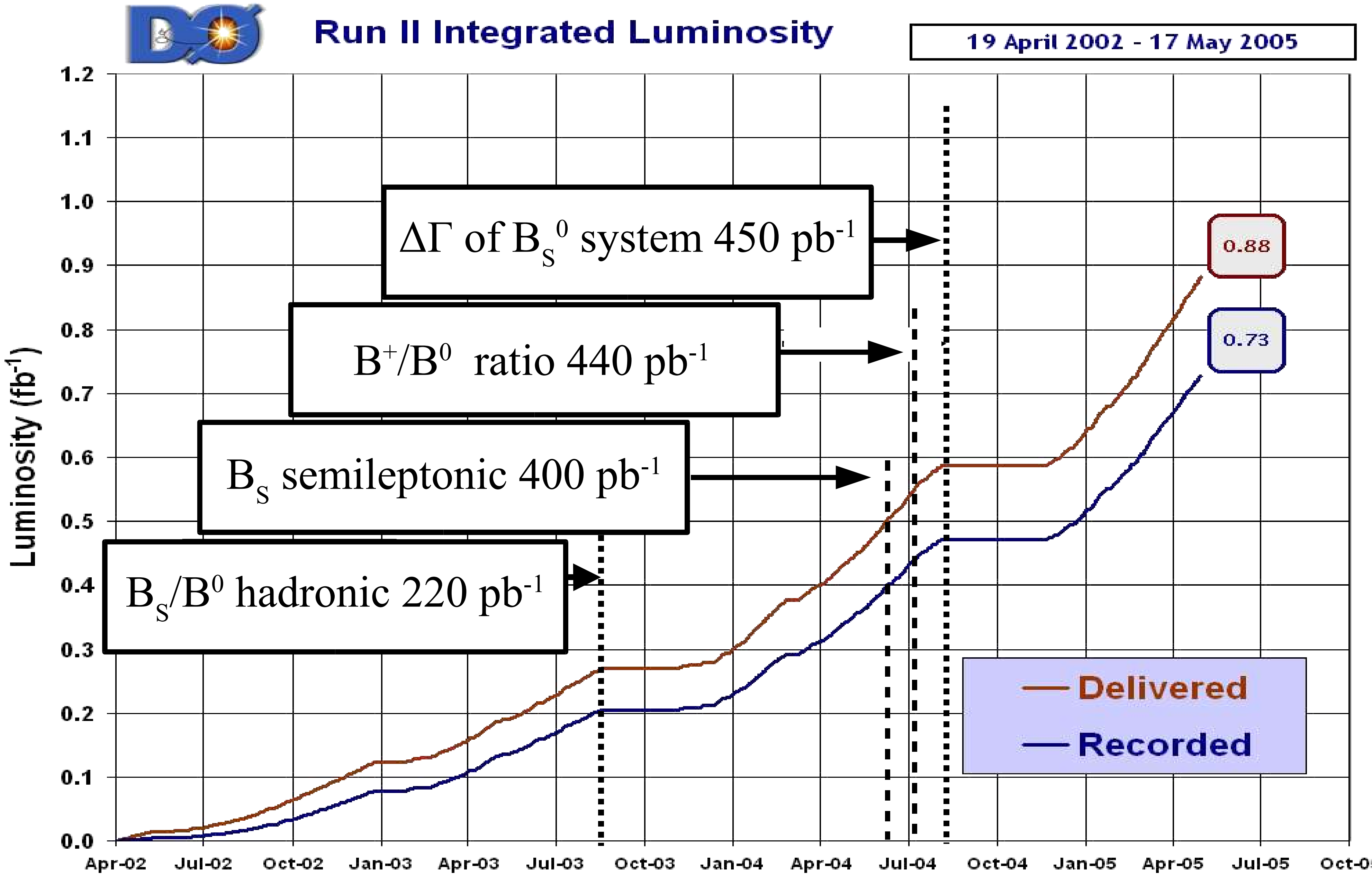
Trigger system:
- Level 1 – Hardware -> 1.5 kHz
- Level 2 – Hardware -> 800 Hz
- Level 3 – Software -> 50 Hz







Data Collected



General Remarks

Transverse decay length
Far better resolution in XY only:

$$L = c\tau\beta\gamma = c\tau \frac{p}{m} \quad => L_{XY} = c\tau \frac{p_T}{m}$$

Lifetime fits
Simultaneous unbinned likelihood fit to mass and lifetime distributions:

$$L = \prod_i^N [f_{sig} F_{sig}^i + (1 - f_{sig}) F_{bg}^i]$$

Visible proper decay length (VPDL)
If neutrinos present in decay use P_T of visible decay products

K-factors
Use MC to find correction factor for VPDL

$$K = \frac{P_T(D_S\,\mu)}{P_T(B_S)}$$

Triggers
B-physics events triggered by well understood muon triggers

Typical crosschecks
Divide data into different kinematic regions; MC ensemble tests;
Bias tests by varying measured value in MC input

Outline

1. **B^+/B^0 lifetime ratio**
2. **Exclusive hadronic decay modes**
   - $B_s \rightarrow J/\psi\ \varphi$ lifetime
   - $B^0 \rightarrow J/\psi\ K^{*0}$ lifetime
   - B_s/B^0 lifetime ratio
   - $\Lambda_B \rightarrow J/\psi\ \Lambda^0$ lifetime and ratio
3. **B_s semileptonic decay**
   - $B_s \rightarrow D^-_s \mu^+ \nu X$ lifetime
4. **B_s lifetime difference**
   - $\Delta\Gamma/\Gamma$

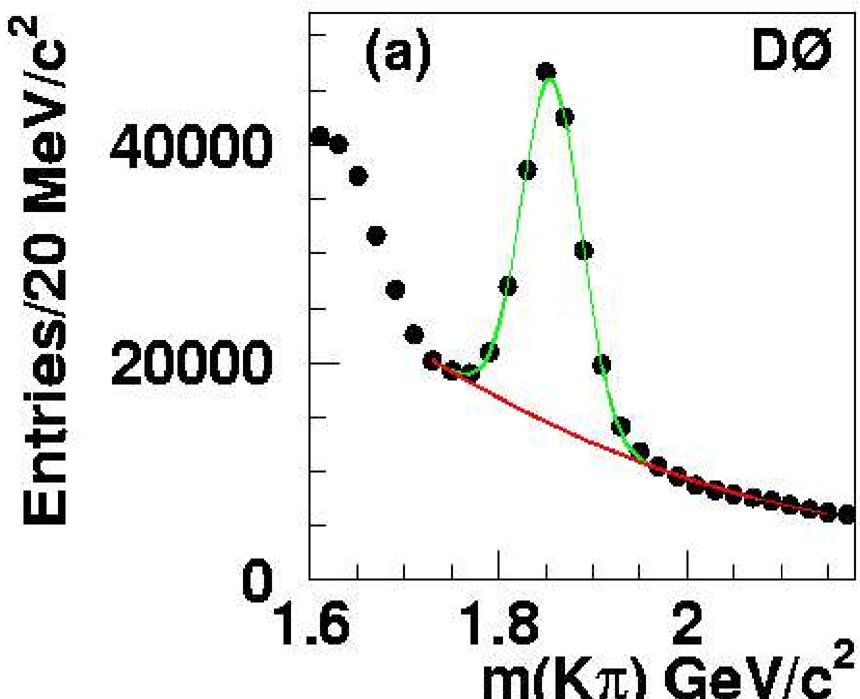
B^+/B^0 Lifetime Ratio

- Ratio is a good precision variable:

- Precise theoretical prediction from HQE : $\tau(B^+)/\tau(B^0) = 1.06 \pm 0.02$
- Systematics cancel if channels chosen well.

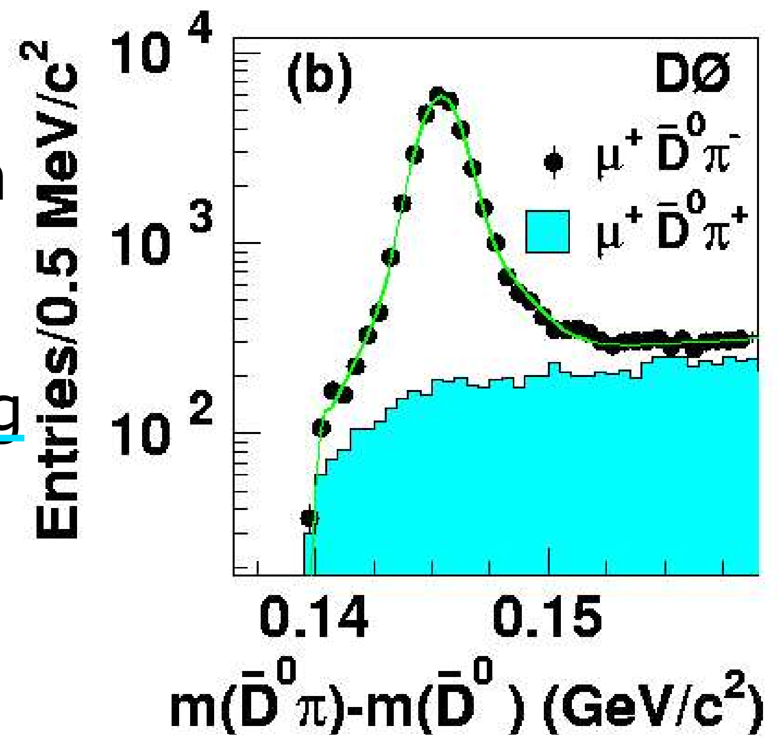
$B^+ \rightarrow \mu^+ \nu\, \mathbf{D^0}\, X \quad (\mathbf{D^0} \rightarrow K\pi)$

$B^0 \rightarrow \mu^+ \nu\, D^{*-}\, X \rightarrow \mu^+ \nu\, \mathbf{D^0} \pi^-\, X$



find slow pion

classify into right or wrong signed

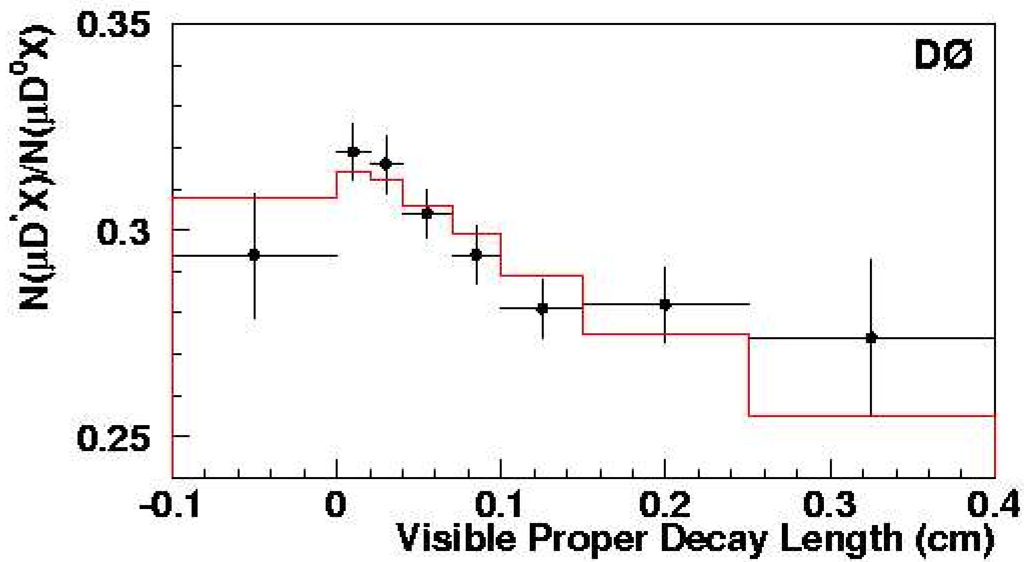


B^+/B^0 Ratio Results

Unusal approach:

if lifetimes are *equal,* ratio of B^+ and B^0 events *constant* in VPDL
=> Fit ratio of number of events:

$$\min \chi^2(\varepsilon,k) = \sum_i \frac{(r_i - r_i^e(\varepsilon,k))^2}{\sigma^2(r_i)}$$



Free parameters:

$k := \tau^+/\tau^0 - 1$

ε : reconstruction efficiency of pion

r_i ratio from data

r_i^e expected ratio (from MC and data)

$\tau^+/\tau^0 = 1.080 \pm 0.016(\text{stat}) \pm 0.014(\text{syst})$

WA: 1.086 ± 0.017

Some main systematics:	
Branching ratio	0.0059
Resolution difference	0.0053
Fitting procedure	0.0086

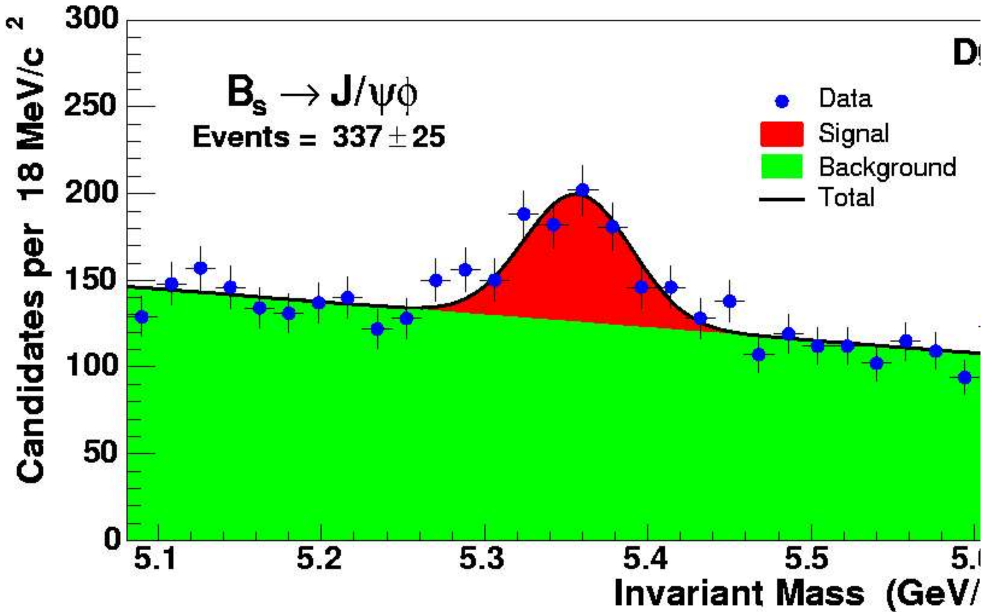
$B_s \to J/\psi\ \varphi$ Signal

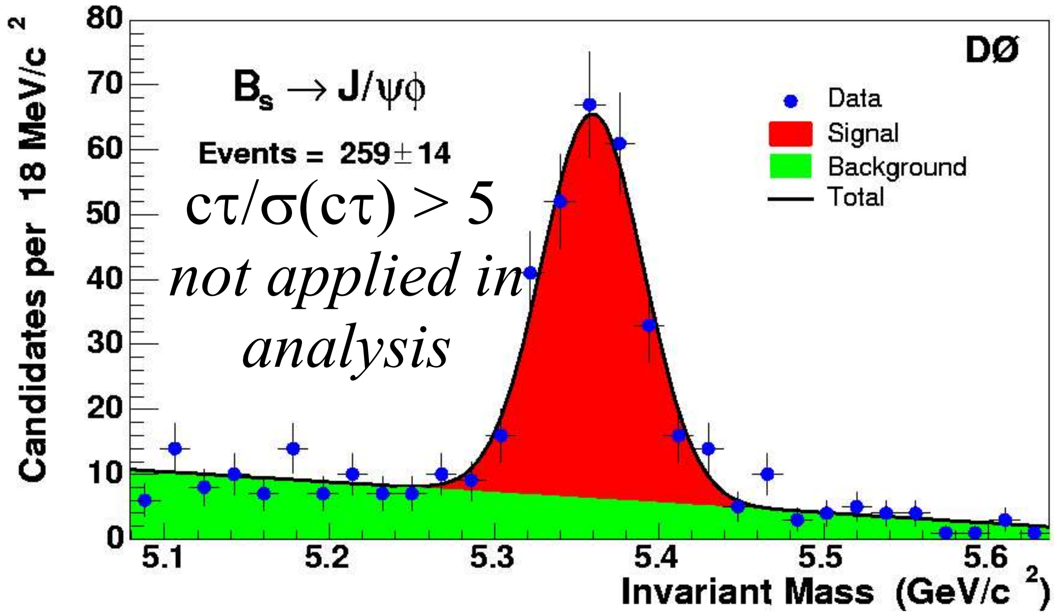
- Ratio of B_s/B^0 predicted to be smaller than B^+/B^0: $\approx 1\%$
- $B_s \to J/\psi\ \varphi$ CP even dominated (see $\Delta\Gamma$) and not flavour specific

Use $B_s \to J/\psi\ \varphi\ (J/\psi \to \mu\mu, \varphi \to KK)$ with 220 pb^{-1} of data

Besides kinematic cuts...

- Find J/ψ (to two muons)
- Two opposite signed tracks with inv. mass nearest to φ -mass
- Fit 4 track secondary vertex constrained by J/ψ mass
- *No* lifetime cut





$B_s \to J/\psi\ \varphi$ Fitting Procedure

Imperial College London

Unbinned maximum likelihood fit to mass and lifetime distribution

Signal:

Lifetime distribution

exponential-decay convoluted with gaussian

width = σ(PDL) (per Event)

global scale factor for σ(PDL)

Mass distribution

gaussian

Background:

Lifetime distributions

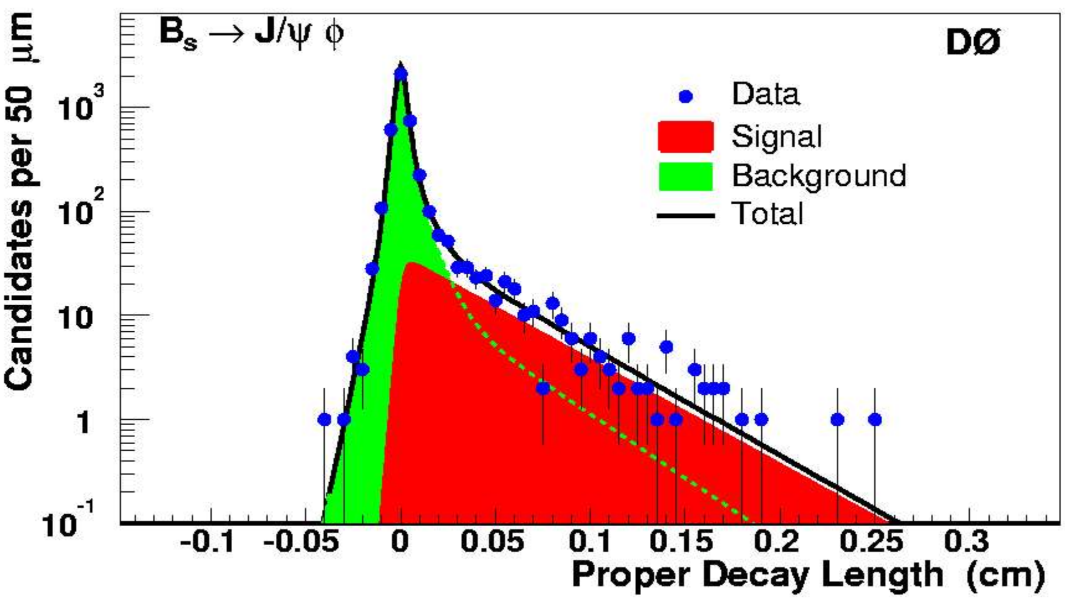
1 gaussian for prompt decay

3 exponential decays

2 short-, 1 longlived

Mass distribution

first order polynomial



$$\tau(B_s) = 1.444^{+0.098}_{-0.071} \pm 0.020 \text{ ps}$$

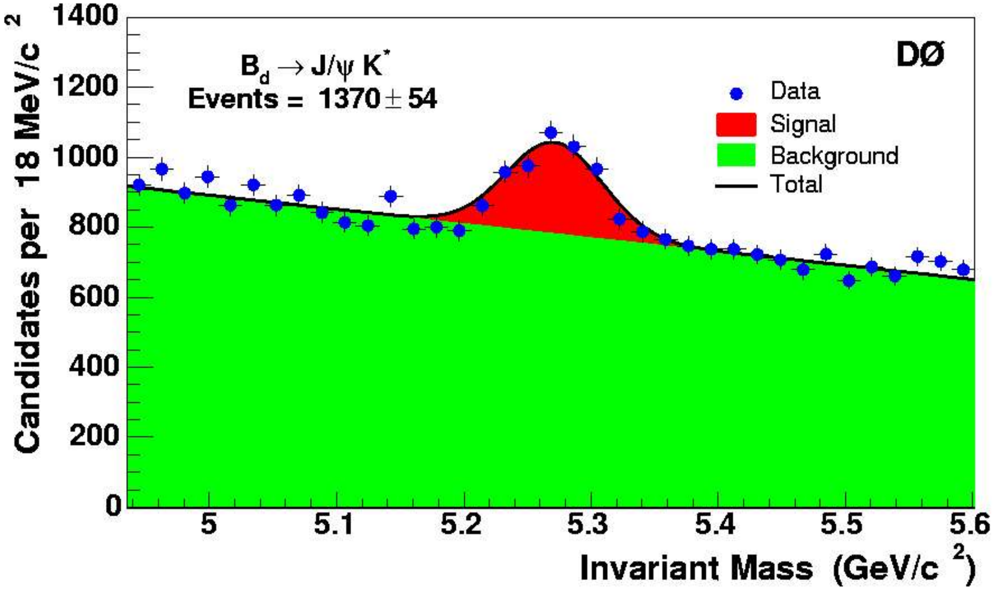
$B^0 \to J/\psi\ K^{*0}$ Signal

Similar topology:

$B^0 \to J/\psi\ K^{*0}$ $(J/\psi \to \mu\mu, K^{*0} \to \pi K)$

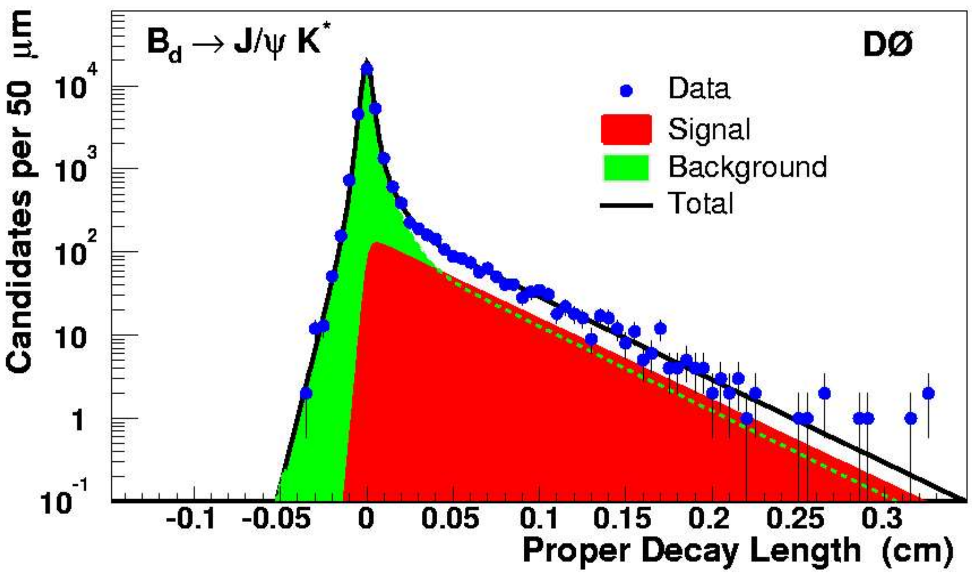
→ similar systematics

→ Use identical fitting procedure



Differences:

- lower P_T cut for pion 0.8 → 0.5 GeV
- assume pion and K mass for tracks
- invariant mass closest to $K^{*0}(892)$



$\tau(B^0) = 1.473^{+0.052}_{-0.050} \pm 0.023$ ps

B^0/B_s Systematics and Ratio

Imperial College London

Source	$c\tau(B_s)$ (μm)	$c\tau(B^0)$ (μm)	$\tau(B_s)/\tau(B^0)$
Alignment	2	2	0.000
J/ψ Vertex	3	4	0.002
Resolution Model	3	3	0.000
Background	4	5	0.002

$\tau(B_s) = 1.444^{+0.098}_{-0.071} \pm 0.020$ ps

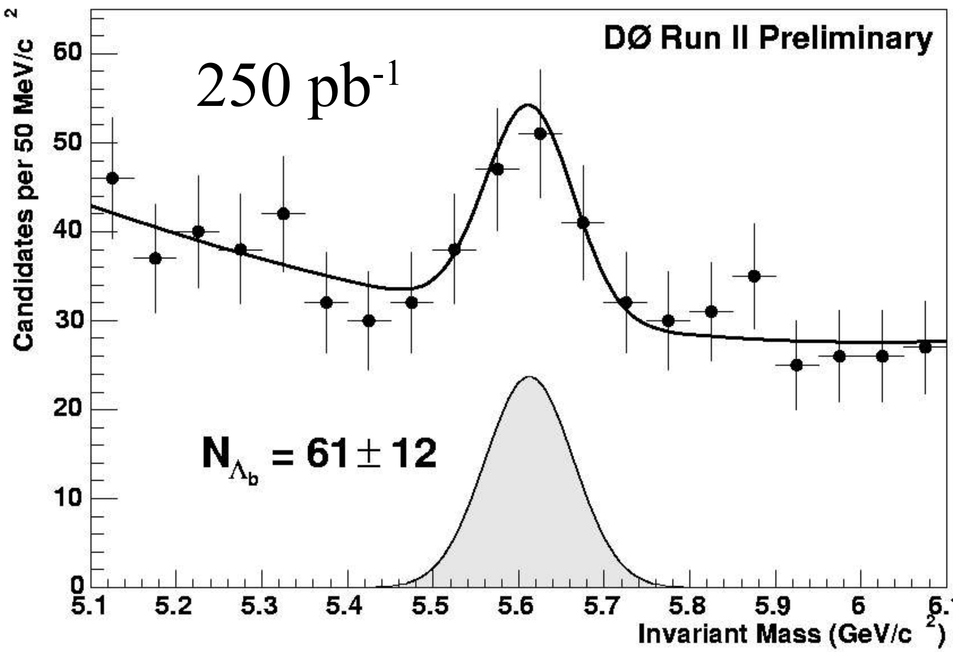
$\tau(B^0) = 1.473^{+0.052}_{-0.050} \pm 0.023$ ps

$\tau(B_s)/\tau(B^0) = 0.980^{+0.076}_{-0.071} \pm 0.003$

$\Lambda_B \to J/\psi\ \Lambda^0$ Lifetime

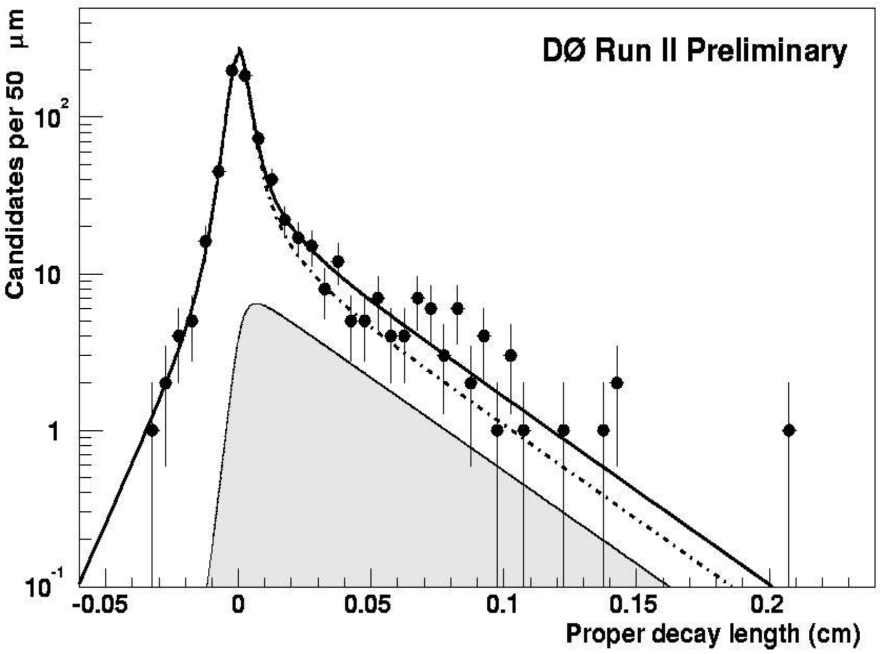
Again similar topology:

$\Lambda_B \to J/\psi\ \Lambda^0\ (J/\psi \to \mu\mu, \Lambda^0 \to \pi p)$



$\tau(\Lambda_B) = 1.22^{+0.22}_{-0.18} \pm 0.04$ ps

$\tau(\Lambda_B)/\tau(B^0) = 0.87^{+0.17}_{-0.10} \pm 0.03$



Source	$c\tau(\Lambda_B)/\mu m$	ratio
Alignment	5.4	0.002
Resolution model	6.7	0.010
Background model	2.7	0.005
Signal Mass model	0.2	0.000
Background mass	2.5	0.007
Long lived comp.	1.5	0.003
Contamination	8.8	0.023

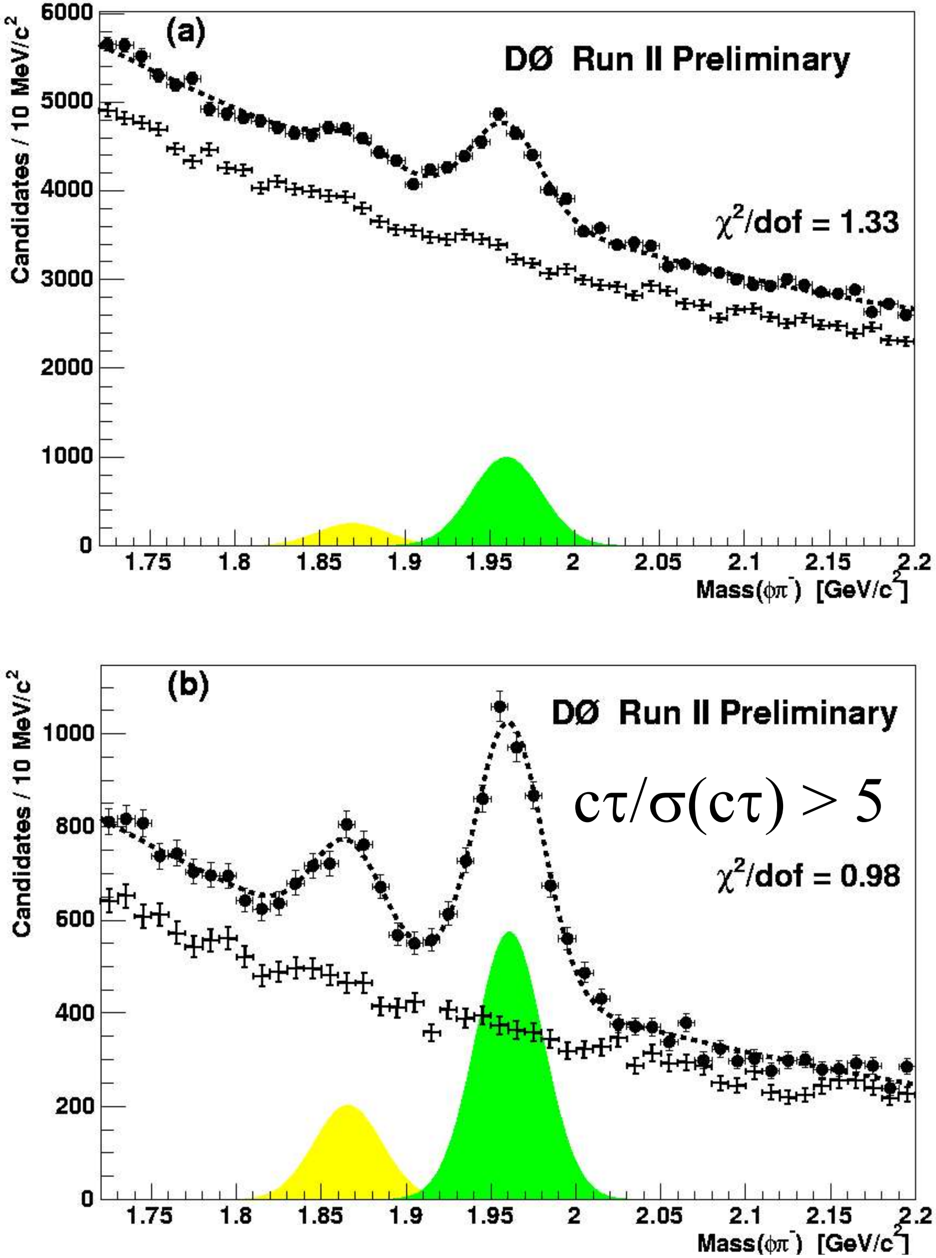
$B_s \rightarrow D^-_s \mu^+ \nu X$ Signal

- Best single measurement from DØ
- Independent input to $\Delta\Gamma/\Gamma$
- Helps understand decay for Δm_s

$B_s \rightarrow D^-_s \mu^+ \nu X$

$D^-_s \rightarrow \varphi \pi^-$ $\varphi \rightarrow K^+ K^-$

- Reconstructed D^- must have *positive* displacement...
- ...but *no* lifetime cut
- Use correlation in φ decay: Transversity angle Φ between K^- and D^- in φ restframe, $\cos(\Phi) < 0.4$



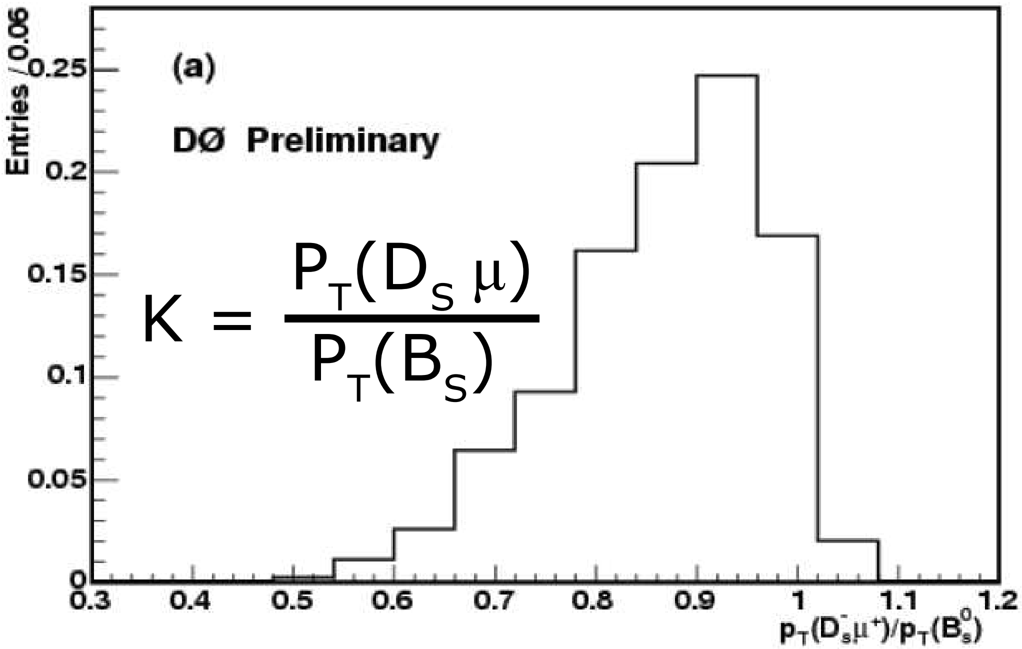
B contamination of background

Decay mode	rel. eff.
$B \rightarrow D_s^{(*)-} D^{(*)+} X'$	5.3%
$B \rightarrow D_s^{(*)-} D^{(*)0} X'$	5.3%
$B \rightarrow D_s^{(*)+} D_s^{(*)-} X'$	4.4%

$B_s \to D_s^- \mu^+ \nu X$ MC Input

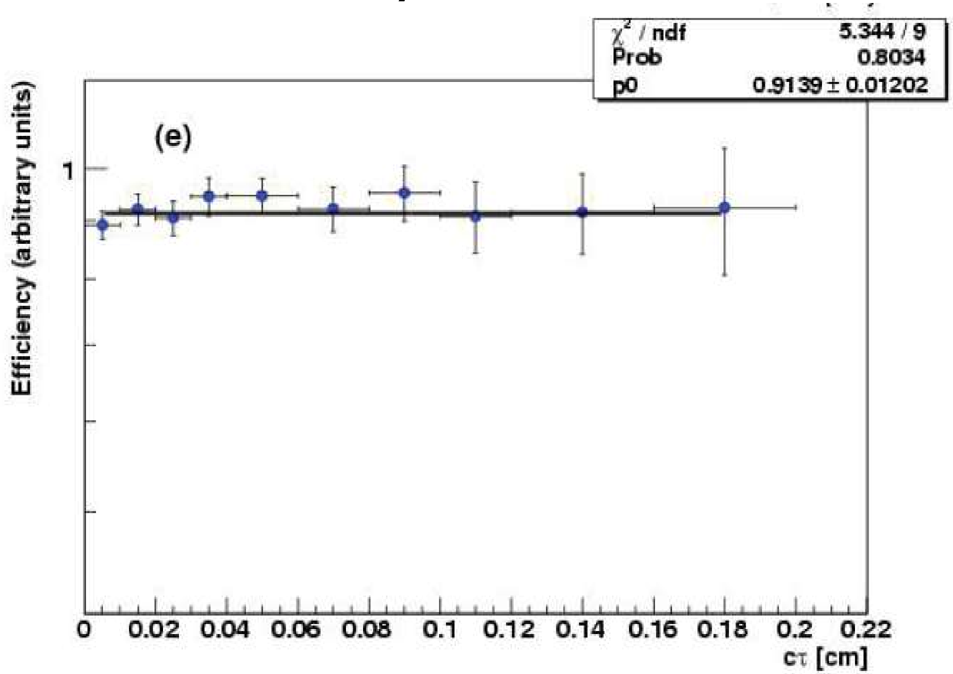
Imperial College London

Combined K-factor



$$K = \frac{P_T(D_S\,\mu)}{P_T(B_S)}$$

Efficiency vs $c\tau$



<K-factor> for diff. signal ch.

$B_s^0 \to D_s^- \mu^+ \nu X$		0.8848±0.0024
$B_s^0 \to D_s^{*-} \mu^+ \nu X$		0.8608±0.0014
$B_s^0 \to D_{s0}^{*-} \mu^+ \nu X$		0.8471±0.0081
$B_s^0 \to D_{s1}^{'-} \mu^+ \nu X$		0.8166±0.0055

$B_s \to D_s^- \mu^+ \nu X$ Fitting Procedure

Imperial College London

Simultaneous fit to signal and background (i.e. D^- sidebands) lifetime distributions

$$L = \prod_i^{N_s} [f_{sig} F_{sig}^i + (1 - f_{sig}) F_{bg}^i] \prod_j^{N_B} F_{bg}^j$$

$$F_{sig}^i = \int dK H(K) [\frac{K}{c\tau} e^{-K\lambda_j / c\tau} \otimes G]$$

$$F_{bg}^j = (1 - f_+ - f_{++} - f_-) G$$

$$+ f_+ \frac{e^{-\lambda_j / \lambda^+}}{\lambda^+} \quad (\lambda_j \geq 0)$$

$$+ f_{++} \frac{e^{-\lambda_j / \lambda^{++}}}{\lambda^{++}} \quad (\lambda_j \geq 0)$$

$$+ f_- \frac{e^{-\lambda_j / \lambda^-}}{\lambda^-} \quad (\lambda_j < 0)$$

Signal parameters
- 1 lifetime
- 1 signal fraction

Background parameters
- 3 background fractions
- 3 lifetimes
- 1 width for prompt decay

General parameters
- 1 $c\tau$ resolution scale factor

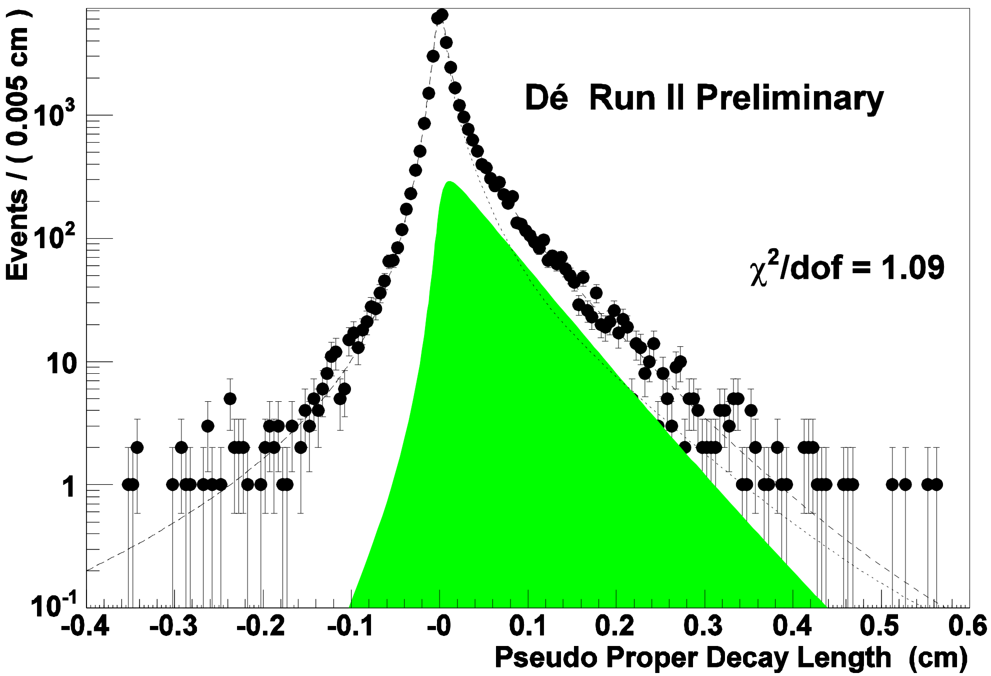
Total 10 parameters

$B_s \to D^-_s \mu^+ \nu X$ Systematics

Imperial College London

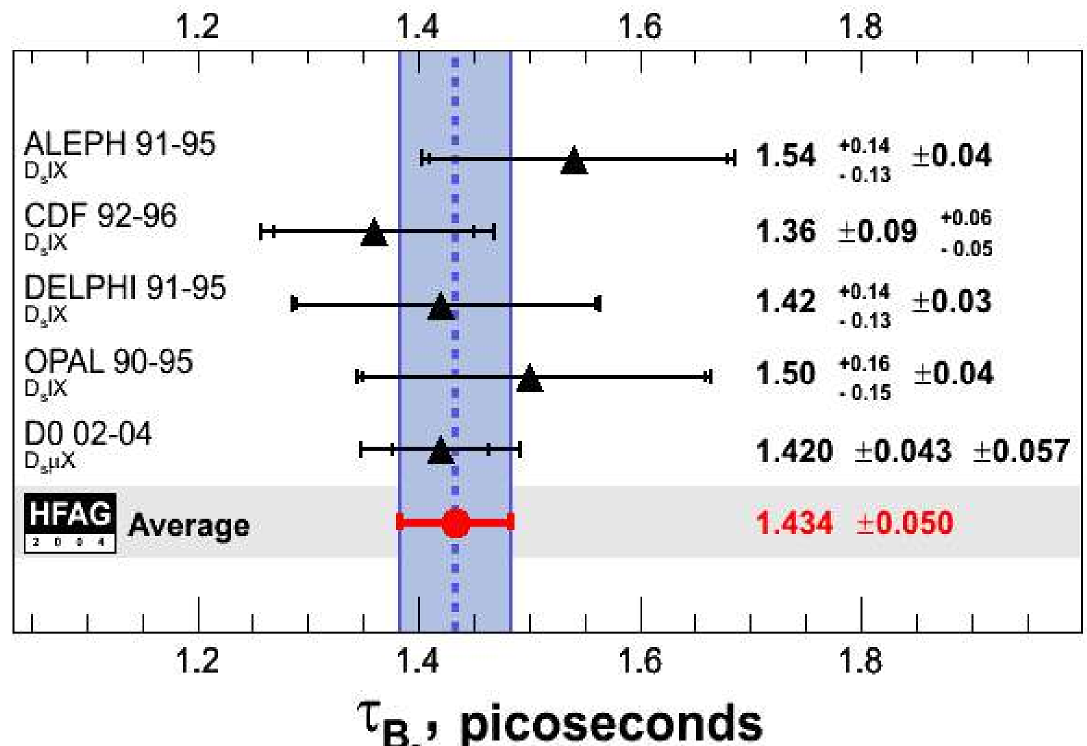
Non B_s^0 backgrounds	-4.4/+3.6 μm
K factor determination	± 3.5 μm
Decay length resolution	± 1.6 μm
Detector alignment	± 5.0 μm
Cut selection bias	+ 3.6 μm
K factor convolution	- 2.2 μm
Background evaluation from left and right sideband longlived contributions	± 15.0 μm **Work in Progress**
Total (added in quadrature)	**± 17.0 μm**

$B_s \to D^-_s \mu^+ \nu X$ Results



τ=1.420±0.043(stat)±0.057(syst)ps

Preliminary



Previous World Average:
1.461 ± 0.057 ps
New:
1.434 ± 0.050 ps

$\Delta\Gamma/\Gamma$: Introduction

CP eigenstates:

$$|B_s^{even}\rangle = 1/\sqrt{2}(|B_S^0\rangle - |\bar{B}_S^0\rangle)$$

$$|B_s^{odd}\rangle = 1/\sqrt{2}(|B_S^0\rangle + |\bar{B}_S^0\rangle)$$

Mass eigenstates:

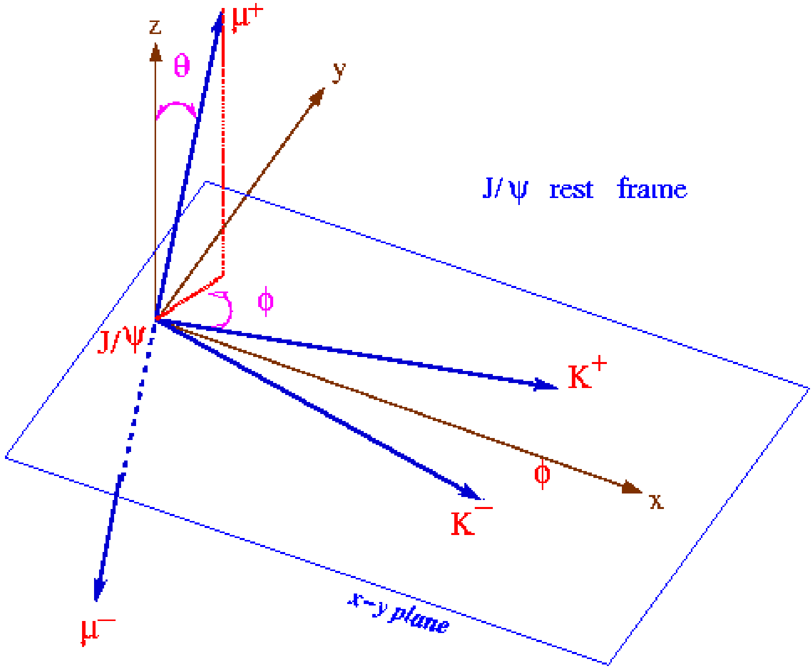
$$|B_L\rangle = (p|B_S^0\rangle + q|\bar{B}_S^0\rangle)$$

$$|B_H\rangle = (p|B_S^0\rangle - q|\bar{B}_S^0\rangle)$$

- $B_S \rightarrow J/\psi\ \varphi$ not flavour specific
  final state for both CP eigenstates
  with different lifetimes $=> \Delta\Gamma$
- Semileptonic decays are flavour specific ($|\bar{B}_S^0\rangle$ *or* $|B_S^0\rangle$)
- Negligible CP violation in SM
  => CP states = Mass states

$\Delta\Gamma/\Gamma$: Transversality

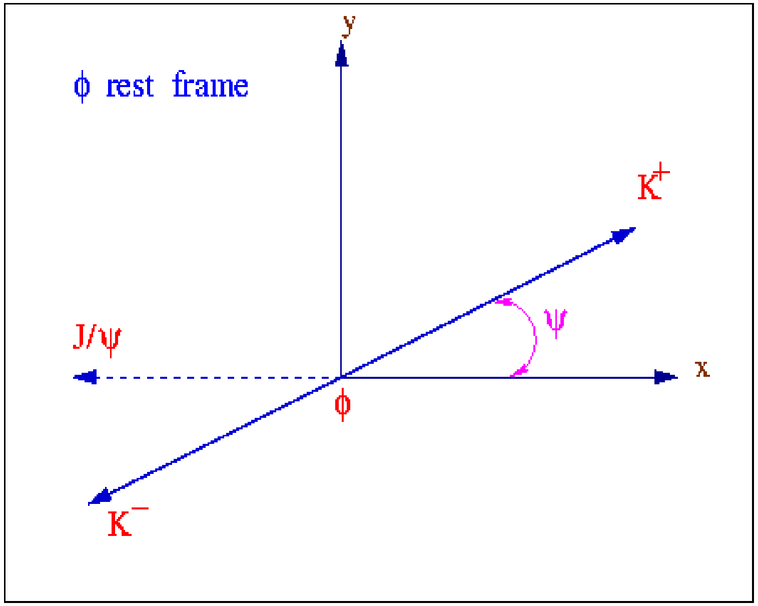
$B_s \rightarrow J/\psi\ \phi$,
Pseudoscalar → Vector Vector decay



Both CP-even and CP-odd present,
but well separated in transversity

Transversity angle: $\cos(\theta)$

- Measure two distinct lifetimes ($equivalently$: $\Delta\Gamma/\Gamma$ and τ) by fitting time evolution and transversity distr. In untagged $B_s \rightarrow J/\psi\ \phi$ decays.
- If CP is conserved, they can be interpreted as the lifetimes of the two B_s mass eigenstates.



$\Delta\Gamma/\Gamma$: Parameterisation

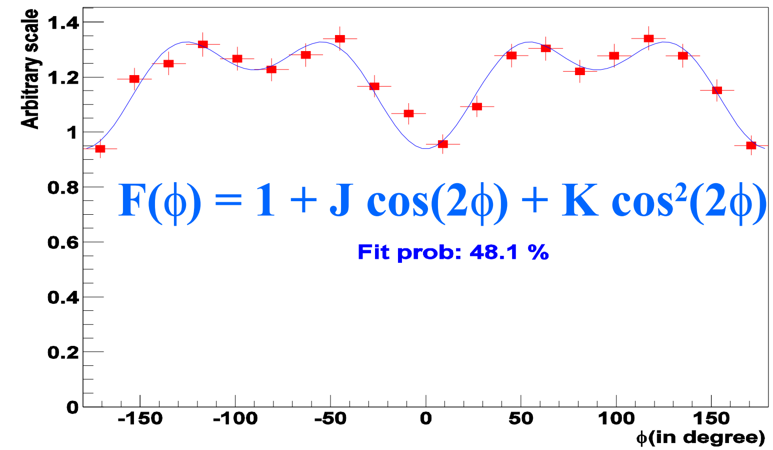
Imperial College London

Three amplitudes: A_0, $A_{||}$, $A_\perp$

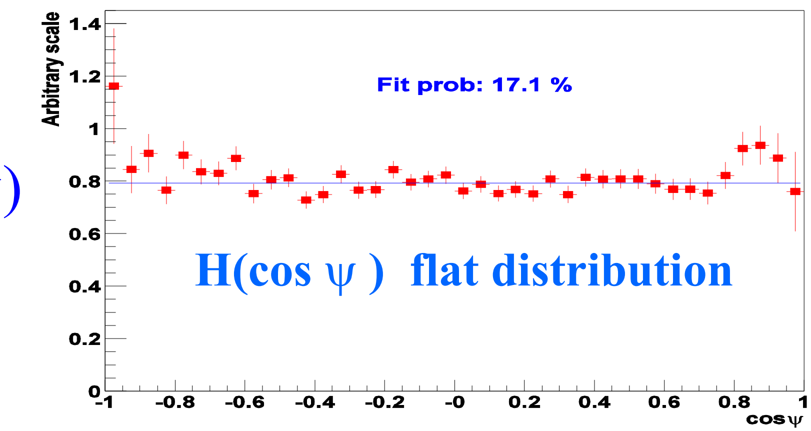
CP even: linear combination of A_0, $A_{||}$

CP odd: $A_\perp$

Define: $R_\perp := |A_\perp(0)|^2$



$$\frac{d^4\Gamma \rightarrow J/\psi(l^+l^-)\phi(K^+K^-)}{d\cos\theta\, d\phi\, d\psi\, dt} = L(\cos\theta, \phi, \psi, t, A_0, A_{||}, A_\perp)\cdot F(\phi)\cdot G(\cos\theta)\cdot H(\cos\psi)$$



Insert F(), H() and integrate over ψ and φ

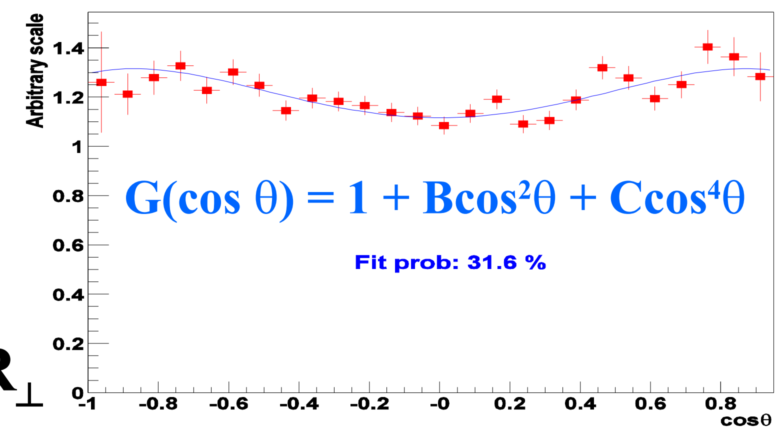
=>

$$\frac{d^2\Gamma \rightarrow J/\psi(l^+l^-)\phi(K^+K^-)}{d\cos\theta\, dt} = L(\cos\theta, t, |A_\perp|^2, |A_{||}|^2-|A_0|^2, |A_{||}|^2+|A_0|^2)\cdot G(\cos\theta)$$

$R_\perp$

0.355 ± 0.066 (from CDF)

$= 1-|A_\perp(0)|^2 = 1-R_\perp$



$\Delta\Gamma/\Gamma$: Likelihood Fit

Imperial College London

Simultaneous fit to mass, proper decay length and transversity

Signal Parameters

1	f_{sig}	signal fraction
2	m_S,σ	signal mass, width
1	$R_\perp$	CP-odd fraction at t=0
1	$c\tau = c/\bar{\Gamma}$,	$\bar{\Gamma} = (\Gamma_L + \Gamma_H)/2$
1	$\Delta\Gamma/\bar{\Gamma}$	

Background Parameters

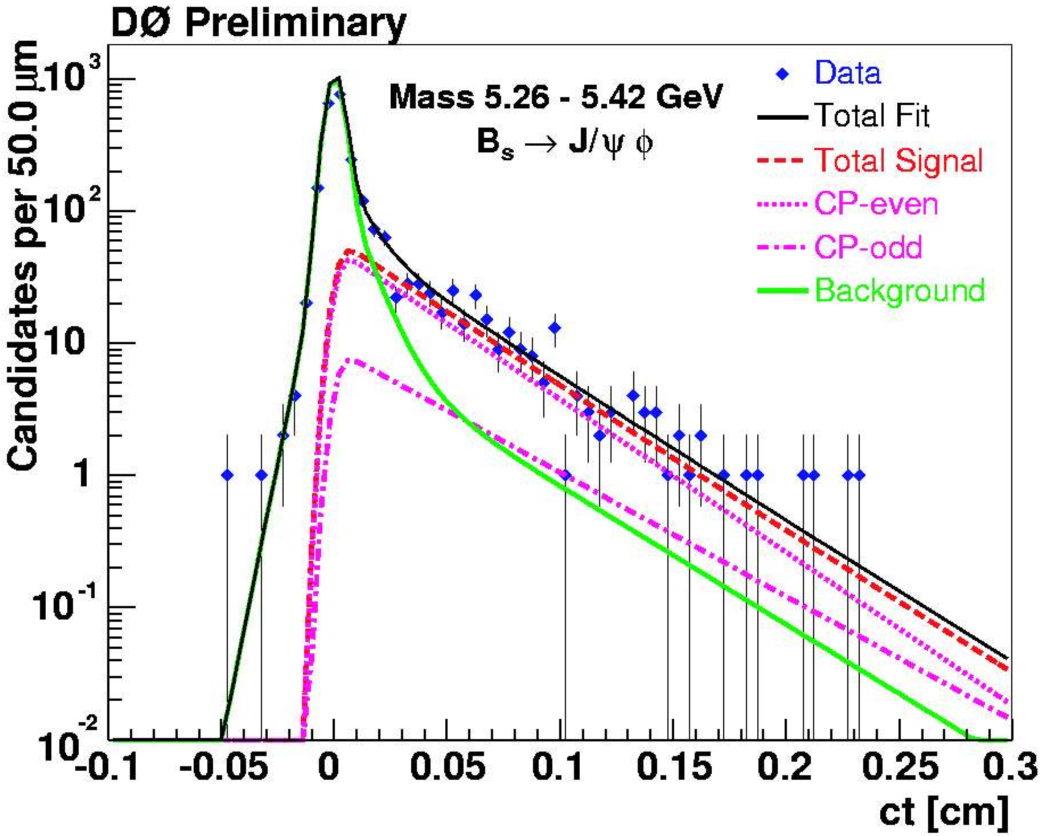
2	slope in mass (1 prompt, 1 long-lived)
6	ct shape
4	transversity (2 prompt +2 long-lived)

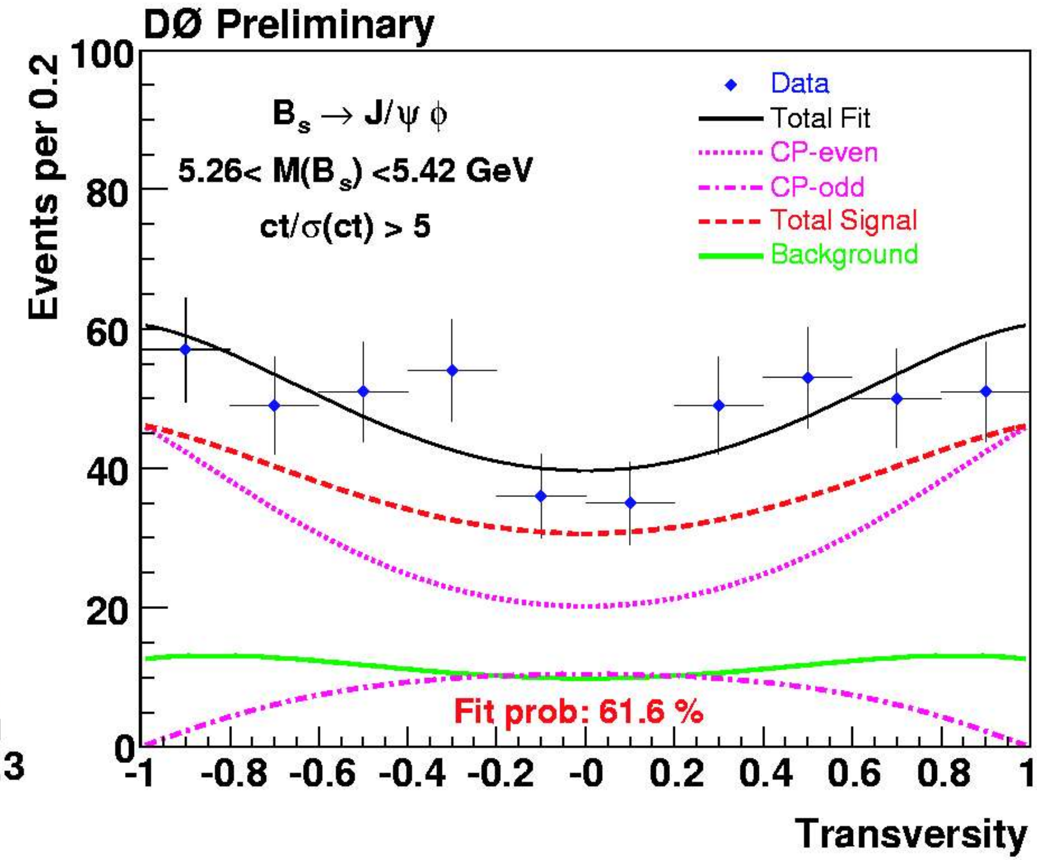
General Parameter

1	σ(ct) scale

Total: **19 parameters**

ΔΓ/Γ: Results





$$\bar{\tau}(B_s^0) = 1.39^{+0.13}_{-0.14} \pm 0.08\, ps$$

$$\frac{\Delta\Gamma}{\bar{\Gamma}} = 0.21^{+0.27}_{-0.40} \pm 0.20$$

$$R_\perp = 0.17 \pm 0.10 \pm 0.02$$

$\Delta\Gamma/\Gamma$: Systematics

Source	$c\tau$ (in μm)	$R_\perp$	$\Delta\Gamma / \bar{\Gamma}$	
Signal ε vs $\cos\theta$	**±0.6**	**±0.005**	**±0.001**	**MC**
Signal ε vs ϕ, ψ angles including: $(\|A_0\|^2 - \|A_\|\|^2)$	**±0.2**	**±0.02**	**±0.001**	**MC + CDF**
Signal mass model	**±0.4**	**±0.006**	**±0.016**	**data**
Procedure bias	**±2**	**±0.01**	**±0.025**	**MC**
Detector alignment	**±2**	**--**	**--**	**data**
Bkg lifetime model	**0.5**	**0.005**	**0.016**	**data**

ΔΓ/Γ: Comparisons

- Consistent with ΔΓ/Γ CDF result

- Agrees well with theoretical prediction 0.12 ± 0.05

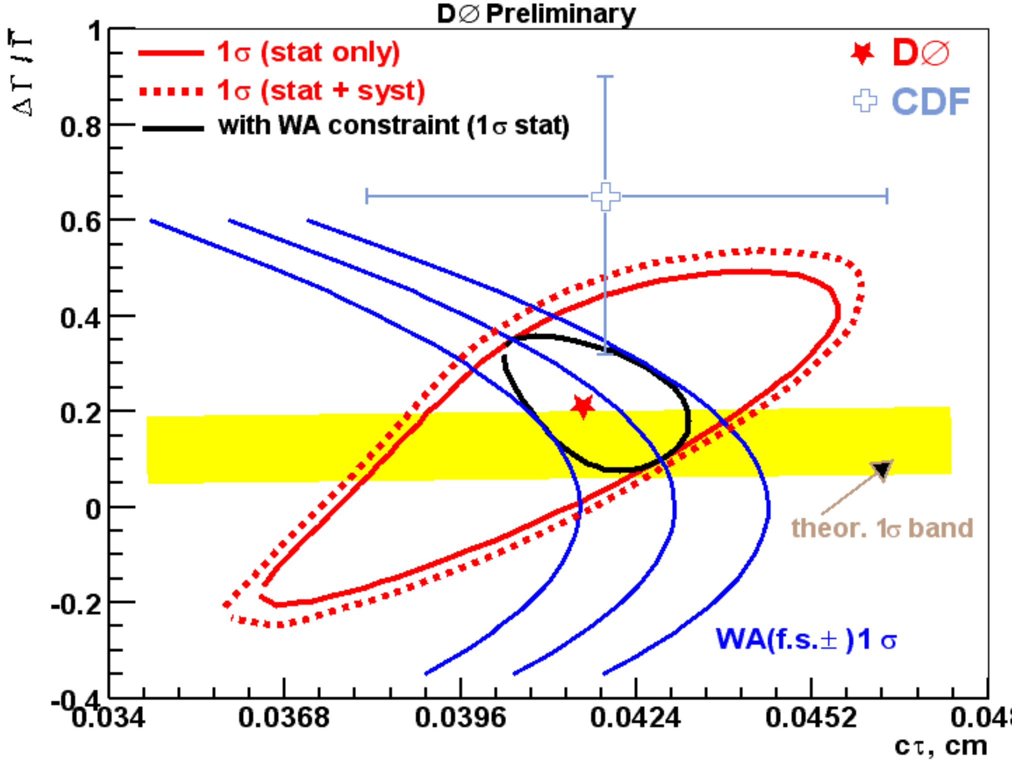
- The WA flavor specific lifetime provides independent relation of ΔΓ and Γ

$$\Gamma_{fs} = \bar{\Gamma}\left(\frac{1-\left(\Delta\Gamma/2\bar{\Gamma}\right)^2}{1+\left(\Delta\Gamma/2\bar{\Gamma}\right)^2}\right)$$

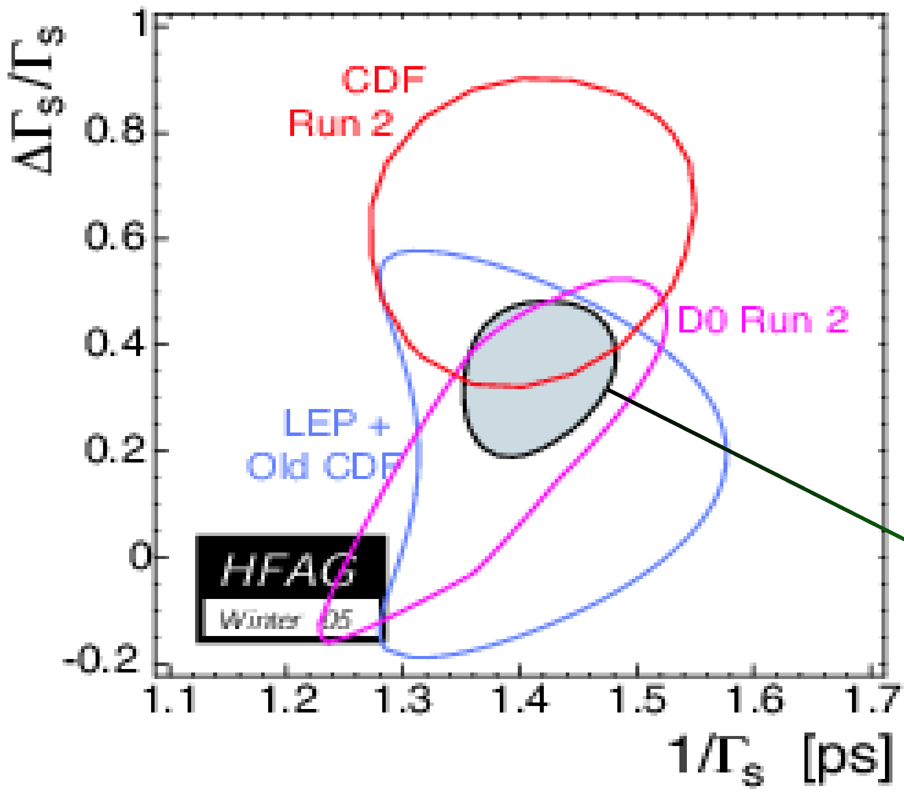
$$\overline{\tau_{fs}} = 1.43 \pm 0.05\,ps$$

$$\Rightarrow \frac{\Delta\Gamma}{\Gamma} = 0.23^{+0.16}_{-0.17}$$

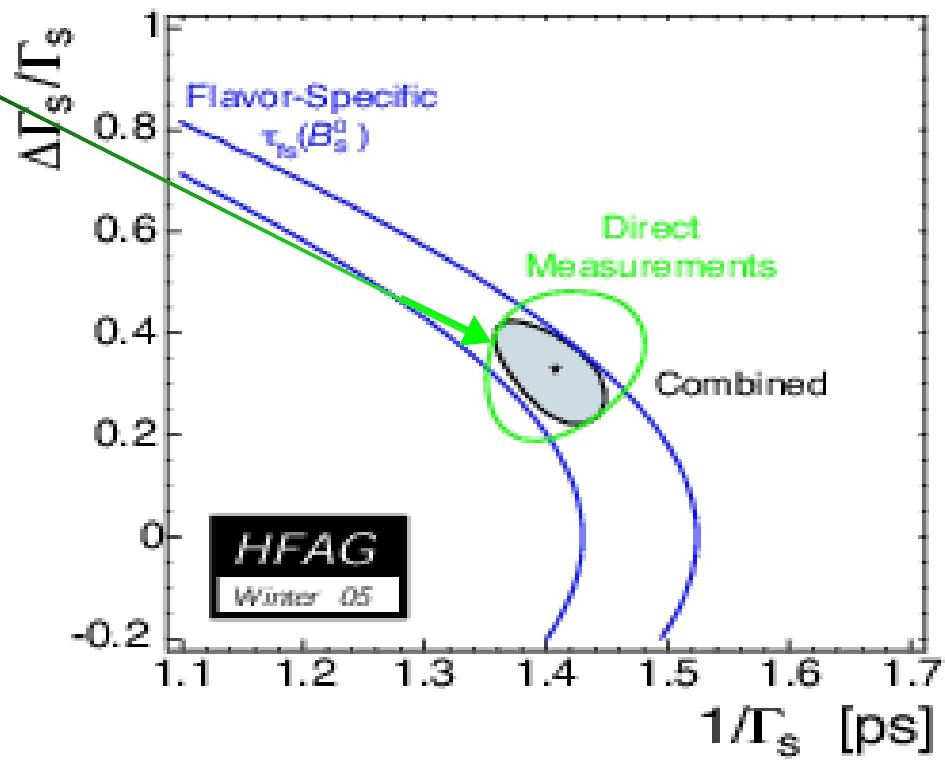
=>significant improvement to ΔΓ



$\Delta\Gamma/\Gamma$: Averages



Averages of b-hadron Properties as of Winter 2005
Heavy Flavor Averaging Group (HFAG)
hep-ex/0505100

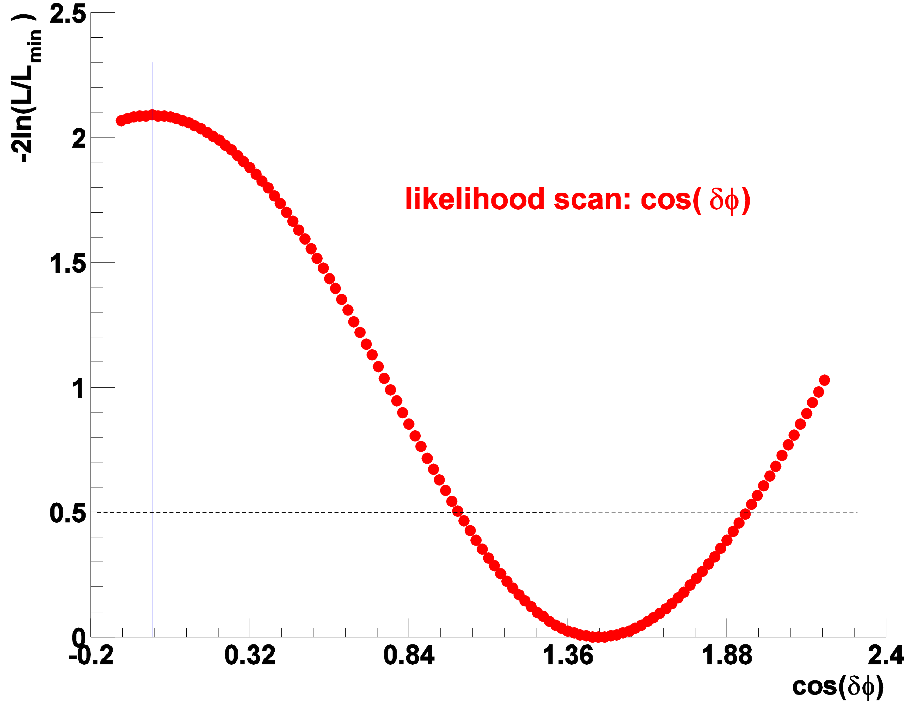


$\Delta\phi$: Probe for New Physics

Imperial College London

- Intruducing CP violating phase as free parameter
- Interpret measured $\Delta\Gamma/\Gamma$ as $(\Delta\Gamma/\Gamma)_{SM} \cos^2(\delta\phi)$ (I. Dunietz, R. Fleischer, U.Nierste hep-ph/0012219)

1. we measured $\Delta\Gamma/\Gamma = (\Delta\Gamma/\Gamma)_{SM} \cos^2(\delta\phi)$ and τ
2. flavour specific lifetime constrains $\Delta\Gamma/\Gamma$ further.
3. SM predicts (A. Lenz,hep-ph/0412007) $(\Delta\Gamma/\Gamma)_{SM} = 0.12 \pm 0.05$



$$|\cos(\delta\phi)| = 1.46^{+0.73}_{-0.69}$$

Summary

D0 produces a wealth of B physics results!
All results are competitive and test theory in a meaningful way

	measured	predicted	publ./prel.
B^+/B^0 ratio	$1.080 \pm 0.016 \pm 0.014$	1.06 ± 0.02	published
Λ_B lifetime	$1.22^{+0.22}_{-0.18} \pm 0.04$ps		published
Λ_B/B^0 ratio	$0.87^{+0.17}_{-0.10} \pm 0.03$	0.9-1.0	published
B_S/B^0 ratio	$0.980^{+0.076}_{-0.071} \pm 0.003$	≈1%	published
$B_S \rightarrow D^-_s \mu^+ \nu X$	$1.420 \pm 0.043 \pm 0.057$ps		preliminary
$\Delta\Gamma/\Gamma$	$0.21^{+0.24}_{-0.40} \pm 0.20$	0.12 ± 0.05	preliminary