B hadron Lifetimes at D∅

Marcus Lewin
Lancaster University, UK
on Behalf of the D∅ Collaboration

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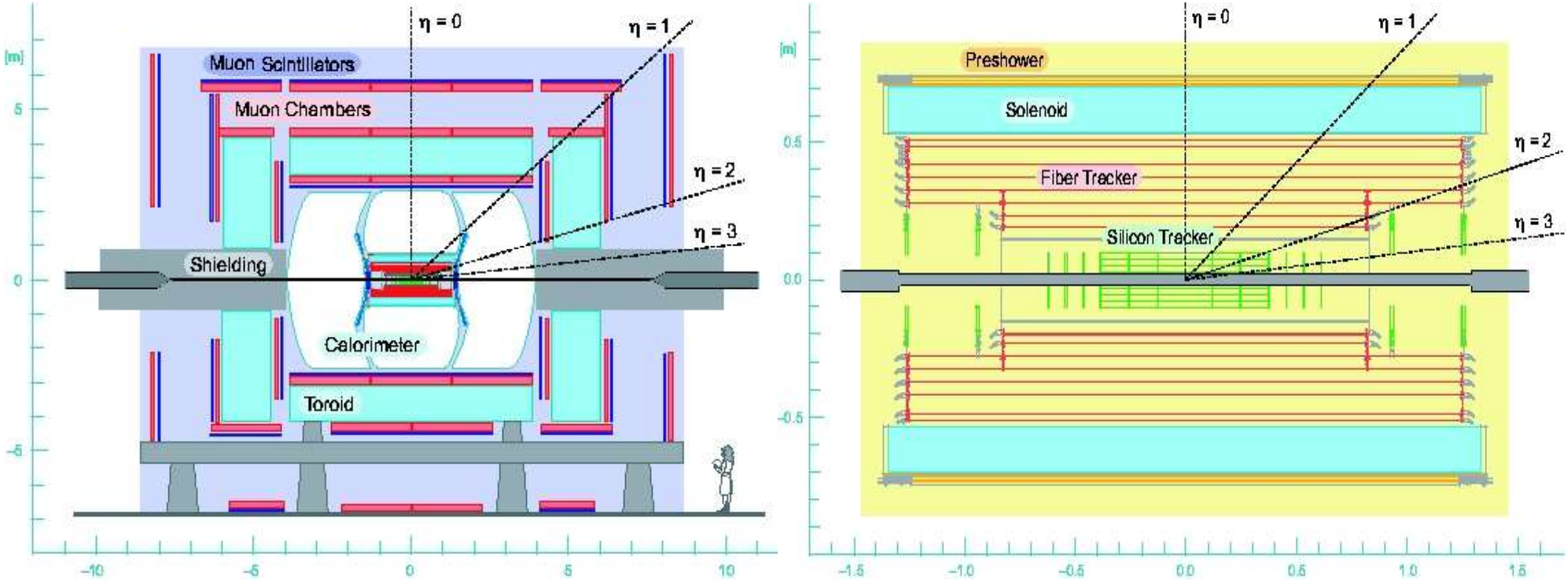
Introduction

- All B hadrons, including, B^+, B_d, B_s and Λ_b produced at the Tevatron – $\sqrt{s}$ =1.96TeV gives large boost which is good for lifetime studies
- HQE theory predicts hierarchy of B hadron lifetimes due to spectator effects on decay of b quark
- Possible to measure absolute lifetimes or measure ratios directly
- Ratios are more interesting for theory and many sources of systematic errors cancel
- Exclusive channel analyses – B_s/B_d and Λ_b/B_d
- Semileptonic analyses – B^+/B^0 ratio and B_s lifetime

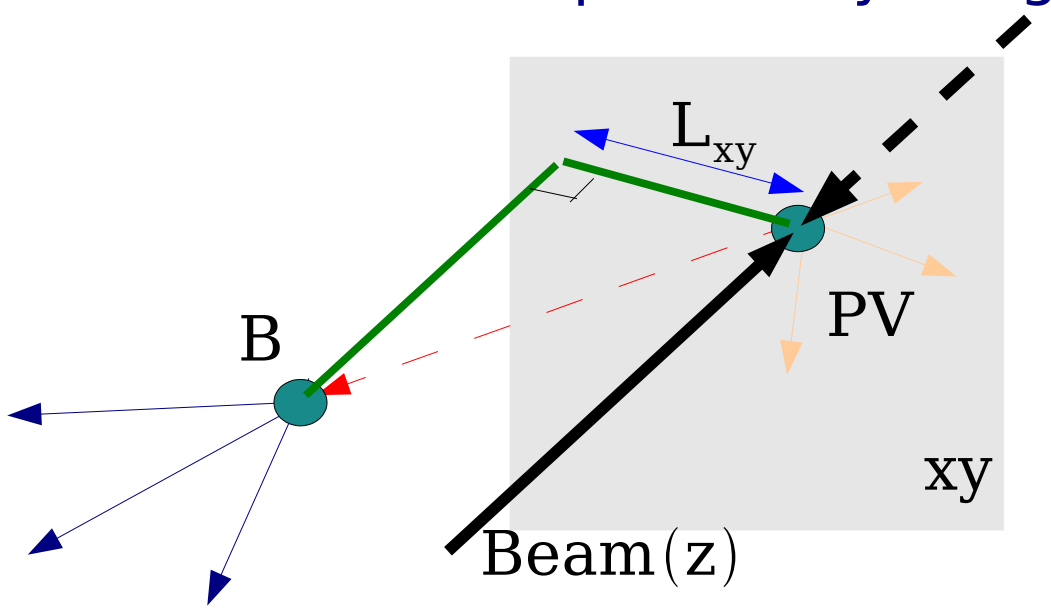
DØ Detector



- Tracking – Silicon microstrips and scintillating fibers in 2T magnetic field
- Muon system – drift tubes and scintillation trigger counters, good coverage out to η=2

Measuring Lifetimes

- Reconstruct the primary vertex and decay vertex of a B hadron candidate
- Calculate the Proper Decay Length in transverse plane



$$\lambda = L_{xy}\frac{M_B}{p_T(B)} = \frac{L_{xy}}{(\beta\gamma)_T}$$

- For semileptonic decays use measured visible proper decay length and a K factor distribution to correct momentum

Max Likelihood Fits

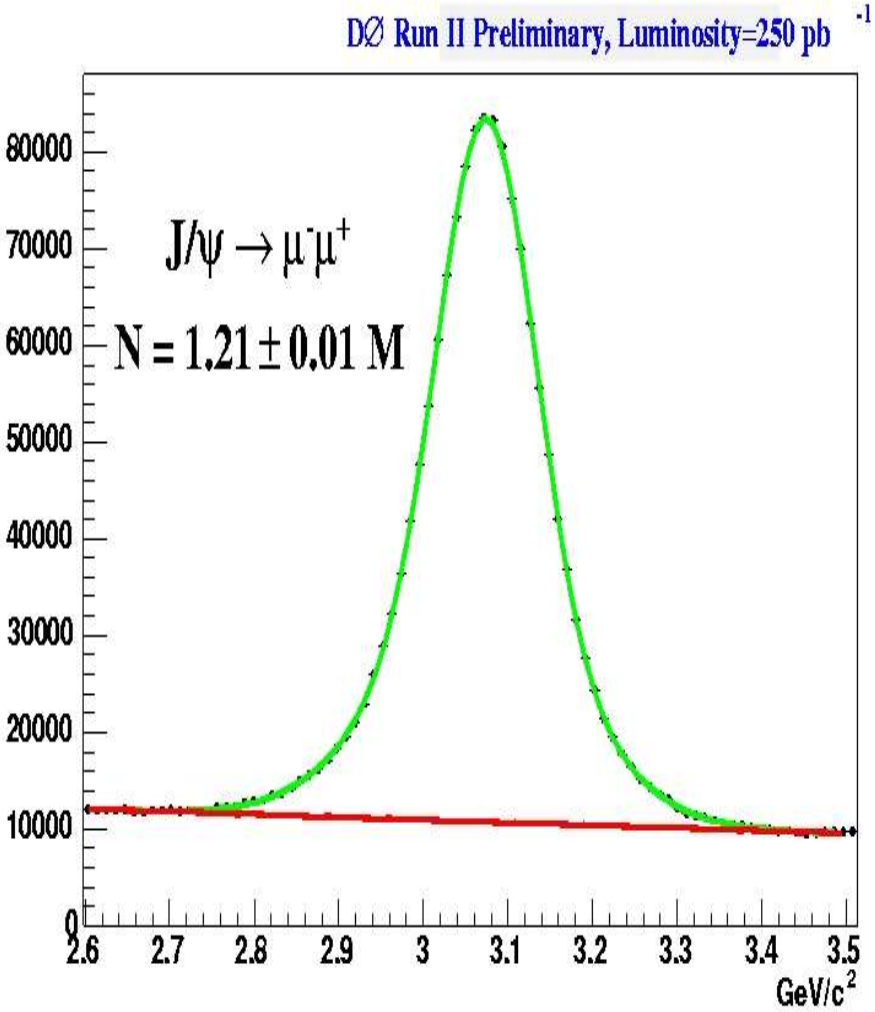
- Fit proper decay length (and mass for fully reconstructed B) using unbinned maximum likelihood fit,

$$L=\Pi_{j=1}^{N}\left[f_s S_M(M_j) S_L(\lambda_j,\sigma_j)+(1-f_s) B_M(M_j) B_L(\lambda_j,\sigma_j)\right]$$

- Signal lifetime PDF, S_L:
  - Exponential decay
  - Gaussian resolution
- Background lifetime PDF, B_L:
  - +ve and -ve exponentials for combinatoric background
  - Exponential for long lived heavy flavor
  - Gaussian resolution

Hadronic Modes

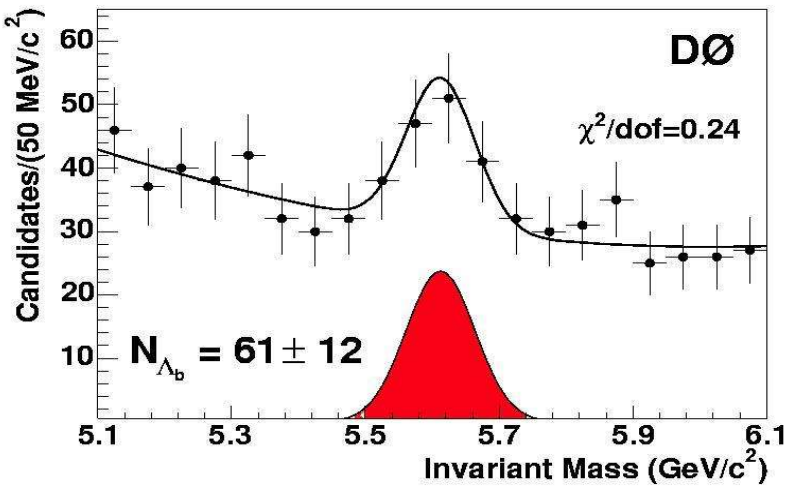
- Use dimuon events – **J**/ψ
- Match a neutral decaying to 2 charged tracks:
  - $\Lambda_b^0 \rightarrow \mathbf{J}/\psi(\mu^+\mu^-)\ \Lambda^0(\mathbf{p}\ \pi^-)$
  - $B_d^0 \rightarrow \mathbf{J}/\psi(\mu^+\mu^-)\ \mathbf{K_s}^0(\pi^+\pi^-)$
- Match another 2 tracks:
  - $B_s^0 \rightarrow \mathbf{J}/\psi(\mu^+\mu^-)\ \phi(\mathbf{K}^+\mathbf{K}^-)$
  - $B_d^0 \rightarrow \mathbf{J}/\psi(\mu^+\mu^-)\ \mathbf{K}^{*0}(\mathbf{K}^+\pi^-)$
- Search for similar topologies together – measure ratios

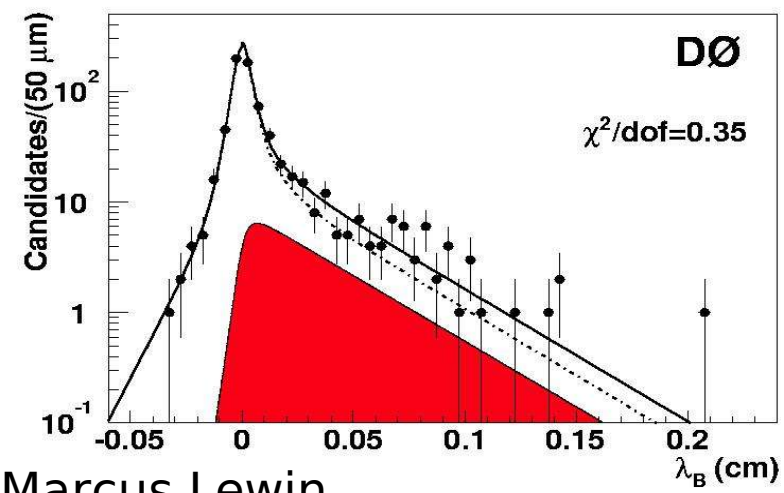


Λ_b and B_d Lifetimes

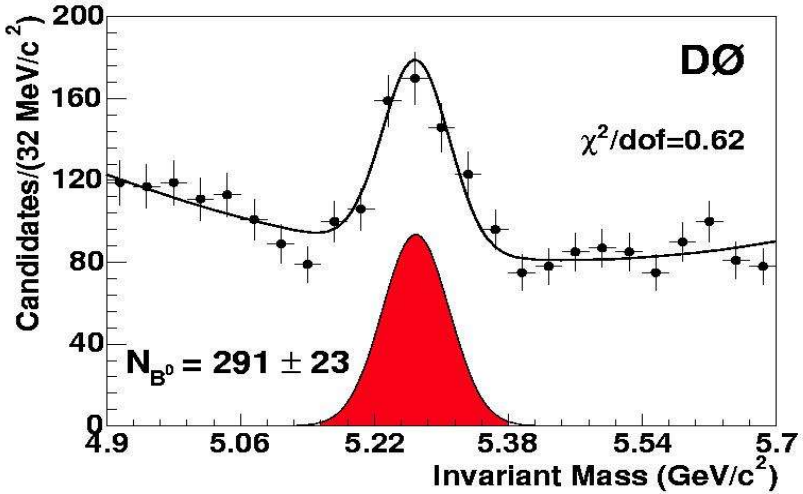
250 pb^{-1}

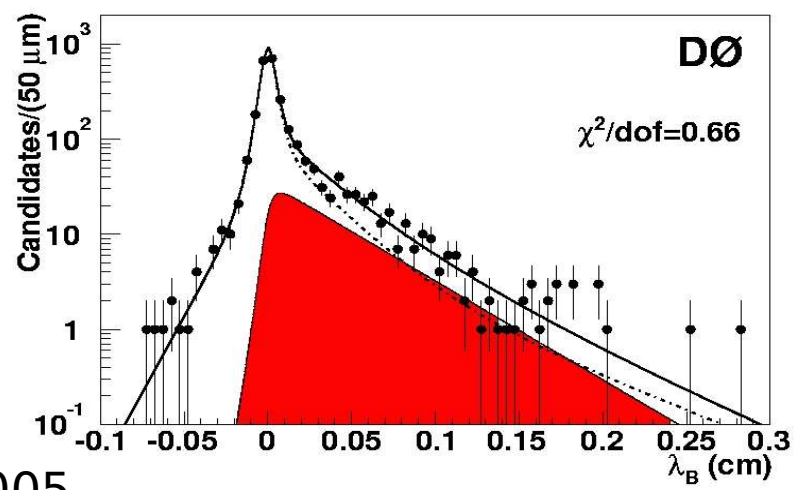
$\Lambda_b^0 \rightarrow J/\psi\ \Lambda^0$





$B_d^0 \rightarrow J/\psi\ K_s^0$





Λ_b and B_d Results

$$\tau(\Lambda_b) = 1.22^{+0.22}_{-0.18}(\text{stat}) \pm 0.04(\text{syst})\,\text{ps}$$

$$\tau(B_d) = 1.40^{+0.11}_{-0.10}(\text{stat}) \pm 0.03(\text{syst})\,\text{ps}$$

$$\frac{\tau(\Lambda_b)}{\tau(B_d)} = 0.87^{+0.17}_{-0.14}(\text{stat}) \pm 0.03(\text{syst})$$

- Ratio consistent with theory 0.9 – 1.0 and measurement average of 0.797± 0.052

Contamination	$c\tau(\Lambda_b)(\mu m)$	$c\tau(B_d)(\mu m)$	Ratio
Alignment	5.4	5.4	0.002
Model for λ Resolution	6.7	2.7	0.010
Model for λ background	2.7	3.1	0.005
Model for signal mass	0.2	0.0	0.000
Model for background mass	2.5	6.2	0.007
Long lived components	1.5	0.1	0.003
Contamination	8.8	0.8	0.023
Total	12.9	9.2	0.028

Systematic Errors

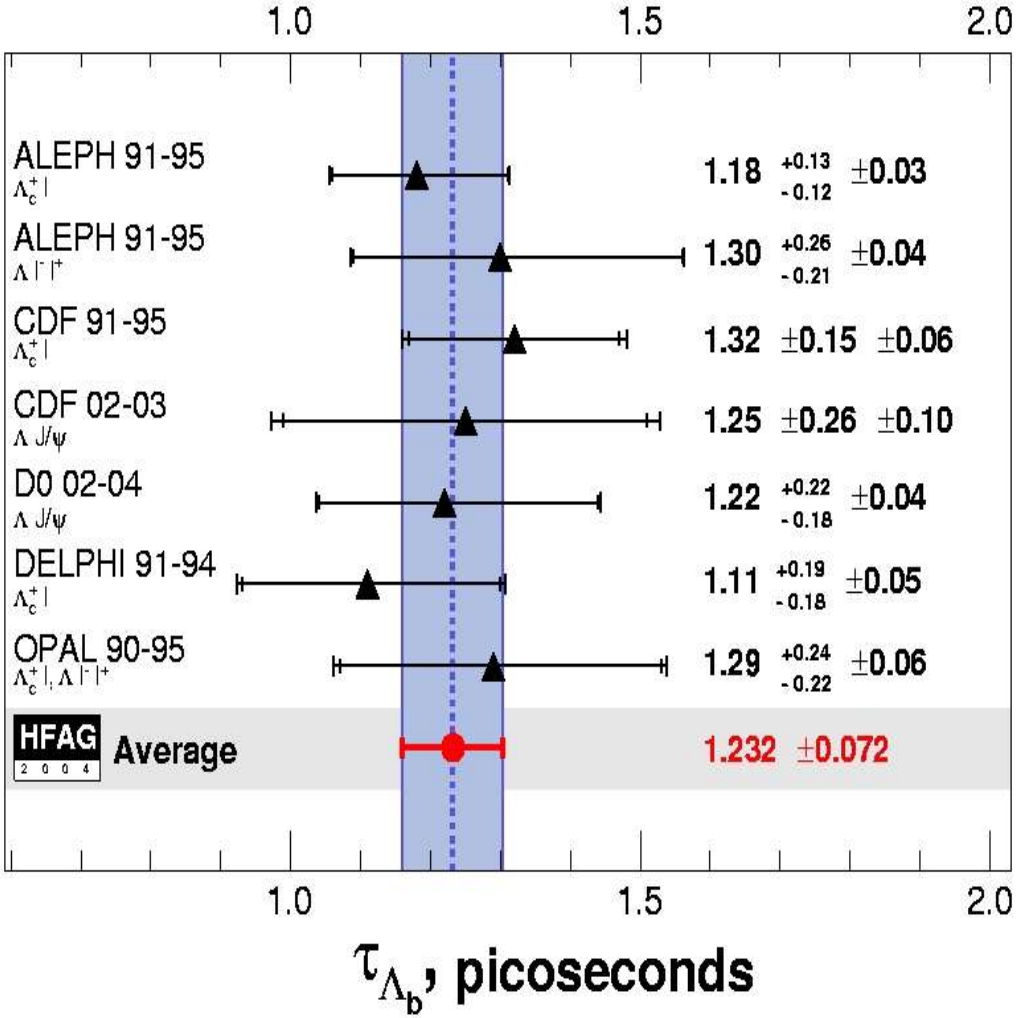
- Contamination:
  - From MC – 19 ± 2 B_d events
  - Fit their mass and decay length from MC and add to fit as fixed parameters and refit
- Alignment:
  - Move silicon sensors out by alignment error, refit
- Long lived background:
  - Lifetime varies with mass
  - Fit sidebands – do fit using linear combination
- Models for lifetime and mass:
  - 2 Gaussians, vary parametrizations for background

Consistency Checks

- The analyses use similar checks for consistency:
  - Fit similar statistics in reconstructed MC to check for biases in fitting procedure
  - Vary the mass windows used in selection
  - Use the reconstructed B hadron mass instead of the PDG value
  - Split the sample into different detector or kinematic regions
  - Use the **J**/ψ vertex instead of the B hadron vertex
  - Model background using only sidebands

Λ_b Results

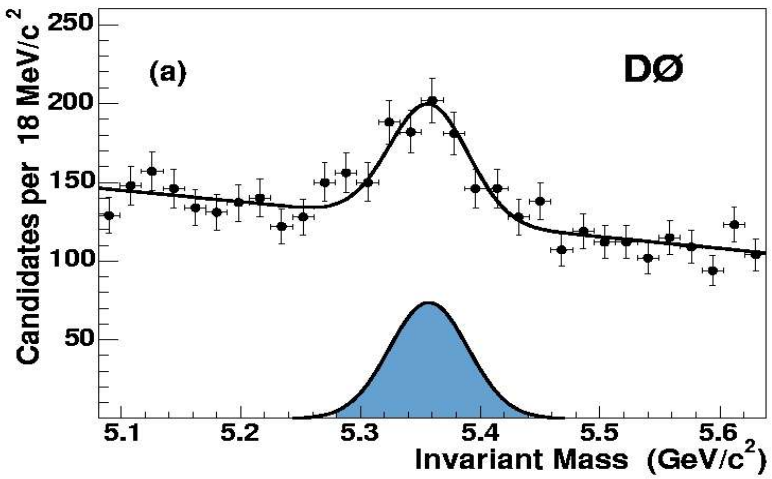
- Best measurement in a fully reconstructed channel
- Consistent with previous world average of 1.229 ± 0.080 ps
- B_d measurement is consistent with world average 1.536 ± 0.014 ps

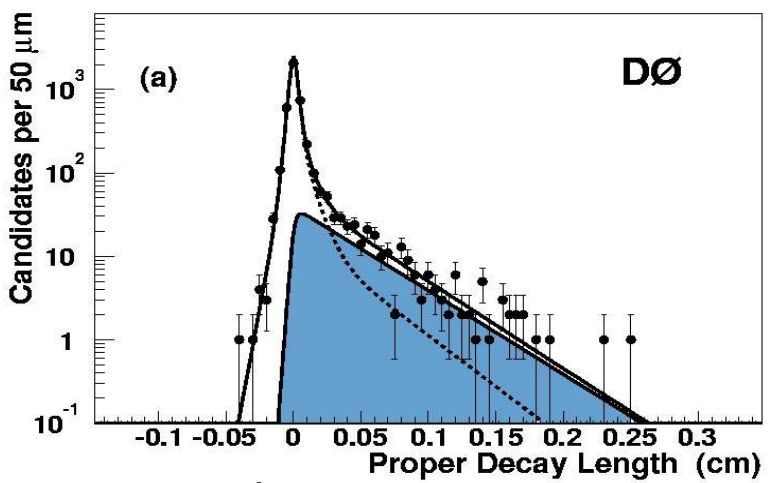


B_s and B_d Lifetimes

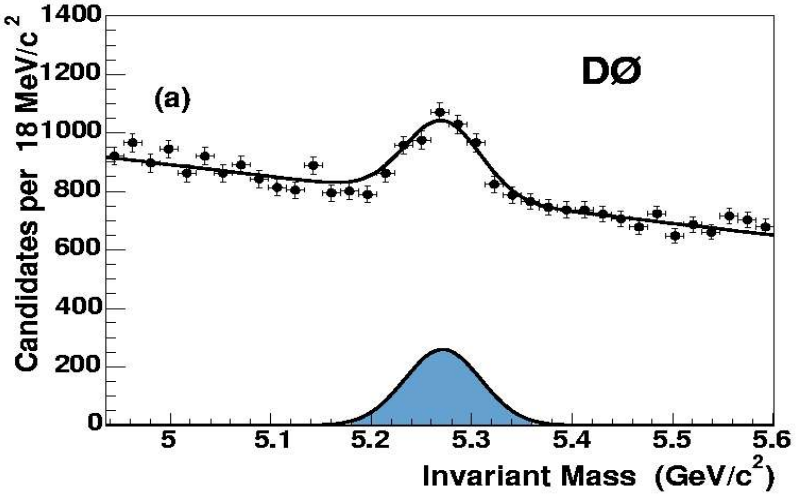
220 pb-1

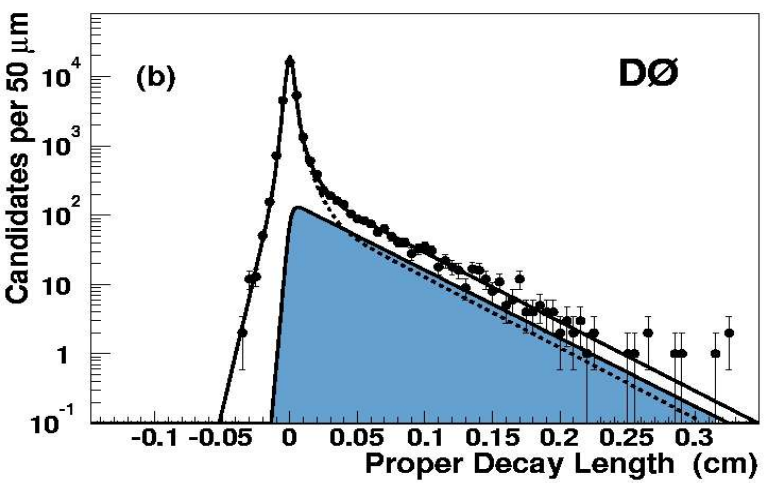
$B_s^0 \rightarrow J/\psi\ \phi$





$B_d^0 \rightarrow J/\psi\ K^{*0}$





B_s and B_d Results

$$\tau(B_s)=1.444^{+0.098}_{-0.090}(\text{stat})\pm0.020(\text{syst})\,\text{ps}$$

$$\tau(B_d)=1.473^{+0.052}_{-0.050}(\text{stat})\pm0.023(\text{syst})\,\text{ps}$$

$$\frac{\tau(B_s)}{\tau(B_d)}=0.980^{+0.076}_{-0.071}(\text{stat})\pm0.003(\text{syst})$$

- Ratio consistent with theory which predicts ~1% difference

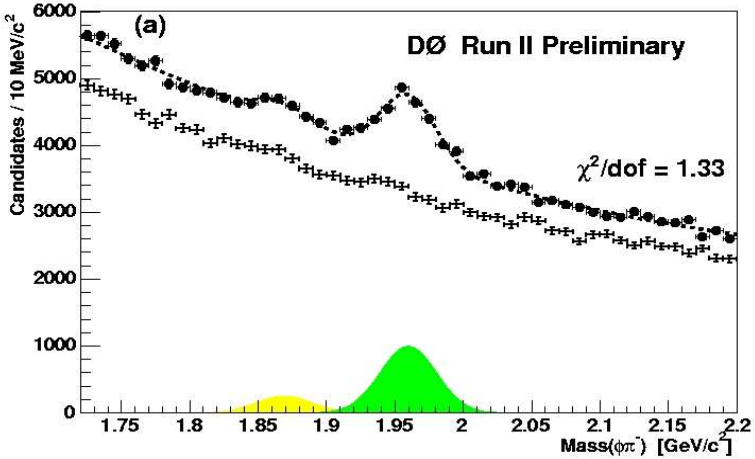
- Both consistent with previous world averages – later
- Systematic error on secondary vertex – observe a shift when **J**/ψ tracks only are used

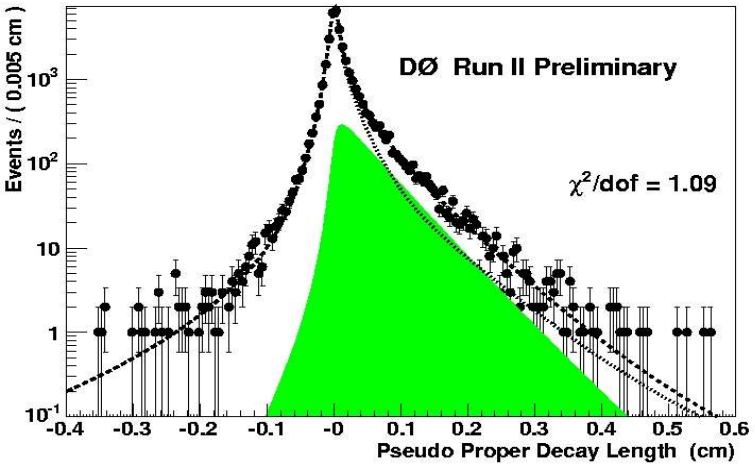
Source	$c\tau(B_s)(\mu m)$	$c\tau(B_d)(\mu m)$	Ratio
Alignment	2	2	0.000
J/Psi vertex	3	4	0.002
Model for Resolution	3	3	0.000
Background	4	5	0.002
Total	6	7	0.003

Semileptonic Modes

- Most events satisfy single muon triggers
- $\mathbf{B_s^0 \rightarrow D_s^- \mu^+ \upsilon X}$ where $\mathbf{D_s^- \rightarrow \phi\,(K^+K^-)\,\pi^-}$ used for measurement of B_s lifetime
  - Signal proper decay length PDF is smeared with K factor determined using Monte Carlo
- $\mathbf{B \rightarrow \mu^+ \upsilon\, D^{*-}(\bar{D}^0 \pi^-)\, X}$ and $\mathbf{B \rightarrow \mu^+ \upsilon\, \bar{D}^0(K^+\pi^-) X}$ used for direct measurement of lifetime ratio of B^+ and B^0.

B_s Lifetime





- 450 pb^{-1}
- Signal of 5153 events
- Excess at lower mass due to Cabibbo suppressed decay $\mathbf{D^- \rightarrow \phi\, \pi^-}$
- Approx 10% contamination of signal by non combinatorial background
  - Estimated using MC
  - $B \rightarrow \mathbf{D^*\, D^*}$

B_s Result

$$\tau(B_s)=1.420\pm0.043(\mathrm{stat})\pm0.057(\mathrm{syst})\,\mathrm{ps}$$

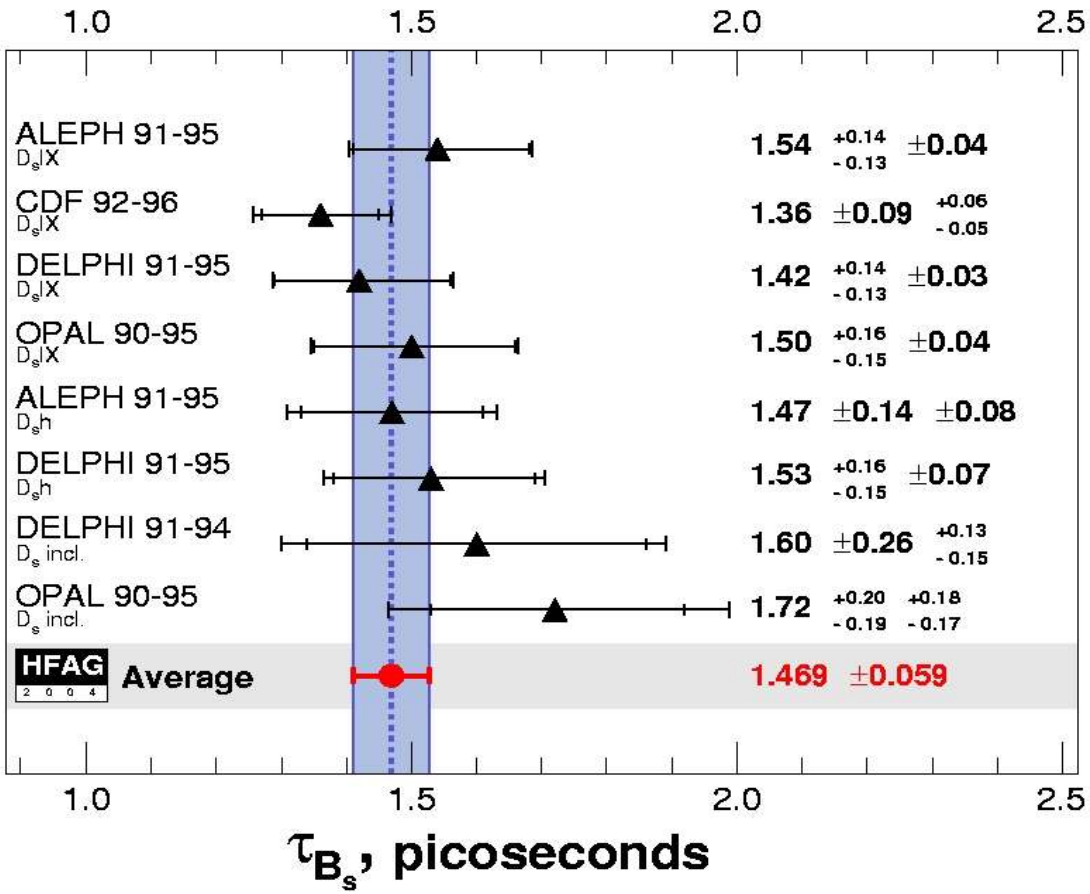
- Systematic errors:
  - Largest is on background estimate, significant shift when left sideband is used

Source	$c\tau(B_s)(\mu m)$
Alignment	5.0
Background estimate	15.0
Selection criteria	3.6
Decay length resolution	1.6
K-factor determination	+3.5 -4.1
Non-combinatorial background	+3.6 -4.4
Total	17.0

B_s Summary

$\tau(B_s) = 1.444^{+0.098}_{-0.090}(\text{stat}) \pm 0.020(\text{syst})\,\text{ps}$ Hadronic

$\tau(B_s) = 1.420 \pm 0.043(\text{stat}) \pm 0.057(\text{syst})\,\text{ps}$ Semileptonic

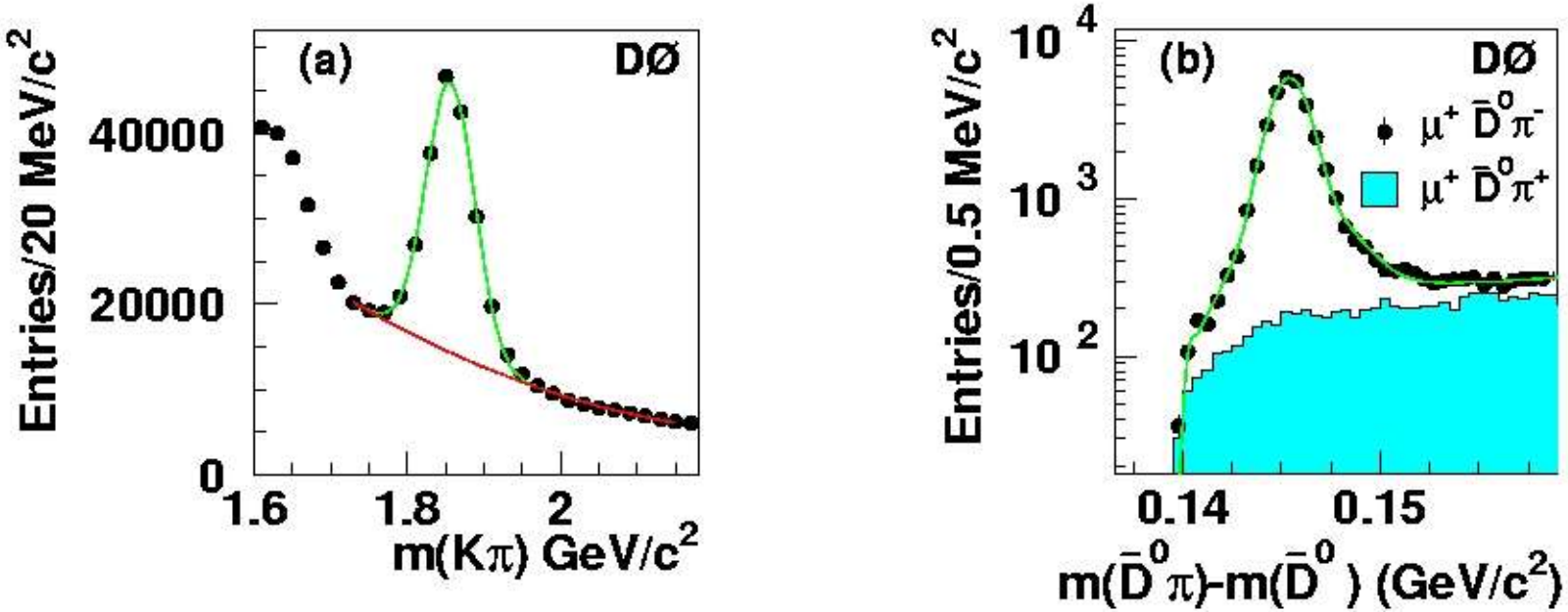


- Both measurements consistent with previous world average
- Our semileptonic measurement is currently the most precise: 1.420 ± 0.071 ps

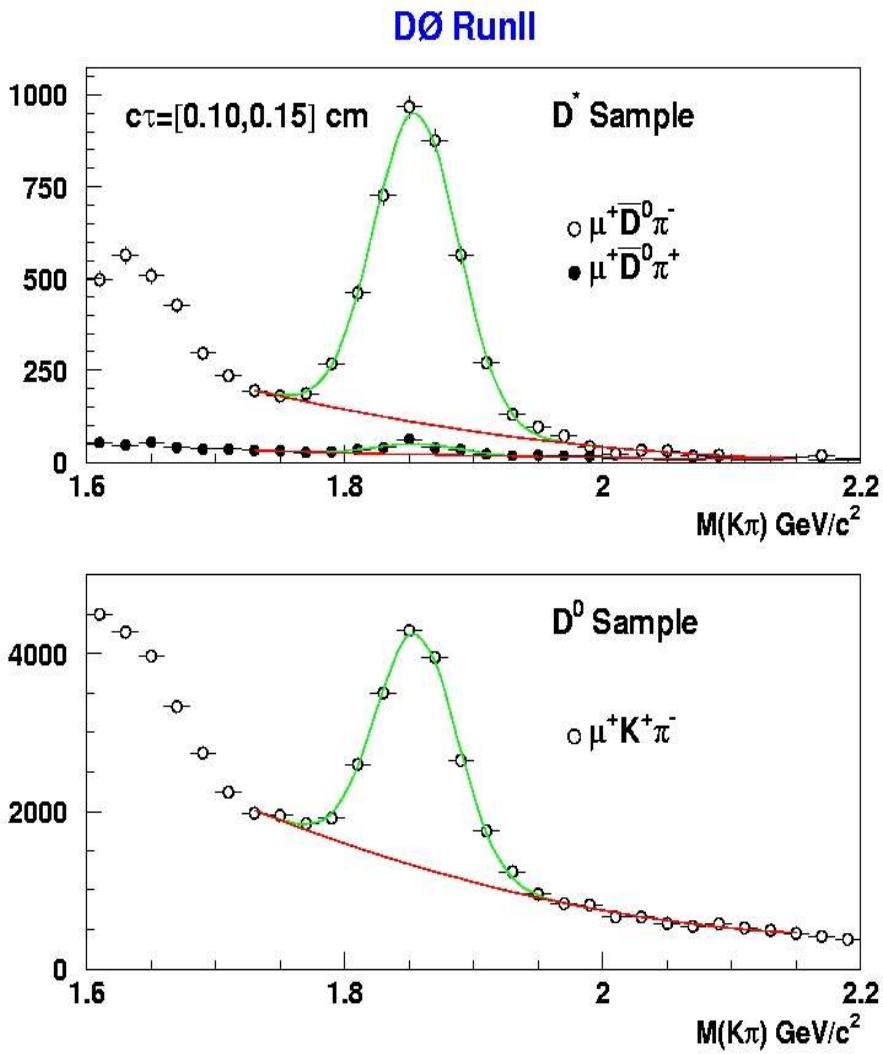
B^+/B^0 Lifetime Ratio

- $\mathbf{B} \rightarrow \mu^+ \upsilon\, \mathbf{D}^{*-}\, \mathbf{X}$ dominated by B^0 decays ~86%
- $\mathbf{B} \rightarrow \mu^+ \upsilon\, \bar{\mathbf{D}}^0\, \mathbf{X}$ dominated by B^+ decays ~82%
- Look for the extra pion from $\mathbf{D}^{*-} \rightarrow \bar{\mathbf{D}}^0 \pi^-$

440 pb^{-1}



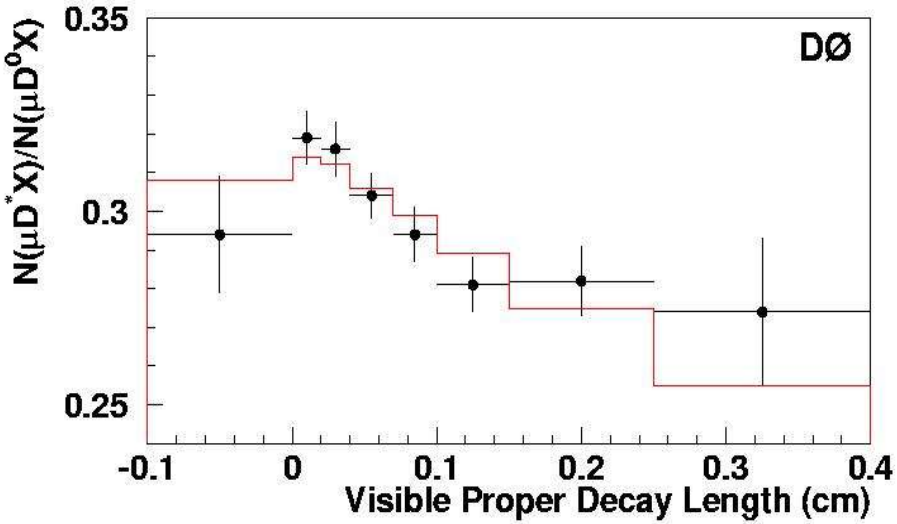
B^+/B^0 Lifetime Ratio



- Split each sample into bins of visible proper decay length
- Fit the number of events in each.

B^+/B^0 Fitting

- χ^2 fit of the bins using the observed ratio of events and an expected ratio which has the lifetime difference as a free parameter
- Expected ratio uses K factor distributions, detector resolution and reconstruction efficiencies from MC, and existing measurements of branching fractions



B^+/B^0 Result

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

- Theory predicts 1.06 ±0.02

- Main systematics:
  - Fitting procedure is the largest, different signal and background parametrizations used ~0.0086
  - Branching fractions, each varied by 1σ
  - efficiency dependence on decay length – use decay length independent efficiencies
- Consistency check with different bins is performed
- Most precise measurement of this ratio
- Agrees well with world average 1.086 ± 0.017

Summary

- DØ is very active in the area of B hadron lifetimes
- All our results are very competitive:
  - Semileptonic B_s lifetime measurement is the best
  - B^+/B^0 lifetime ratio is the best measurement
  - Hadronic lifetime measurement of Λ_b lifetime is the best in a fully reconstructed channel
- Significant contribution to world averages
- All our results are consistent with theory and world averages
- More on the way!!