B Lifetime Results from CDF and D0

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(D0 Collaboration)

Beauty 2003

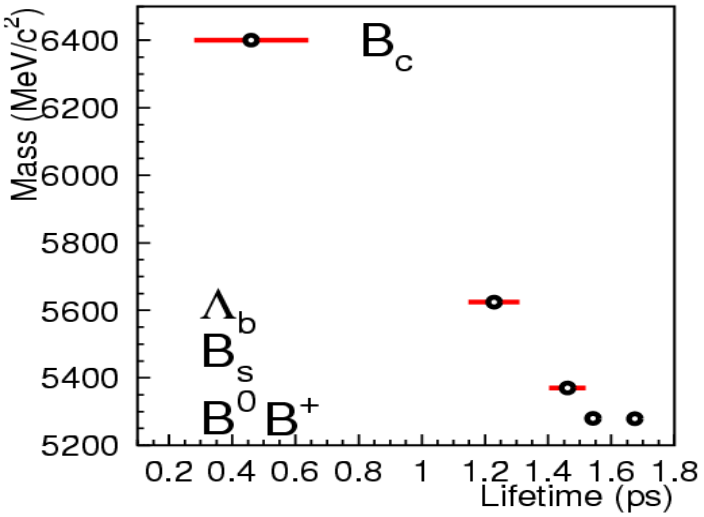
See also recent CDF talks: Sinead Farrington, EPS, July 03

: Kevin Pitts, LP03, August 03

Outline

- **Introduction – expectations**
- **Tevatron Run II – B triggers and data**
- **Inclusive B → J/ψ + X**
- **Exclusive B → J/ψ + X channels**
  - **$B^+ \rightarrow J/\psi + K^+$**
  - **$B^0_d \rightarrow J/\psi + K^*$**
  - **$B^0_s \rightarrow J/\psi + \varphi$**
  - **$\Lambda_b \rightarrow J/\psi + \Lambda$**
- **Semileptonic B Decays**

B Hadron Lifetimes:
Expectations and Existing Data

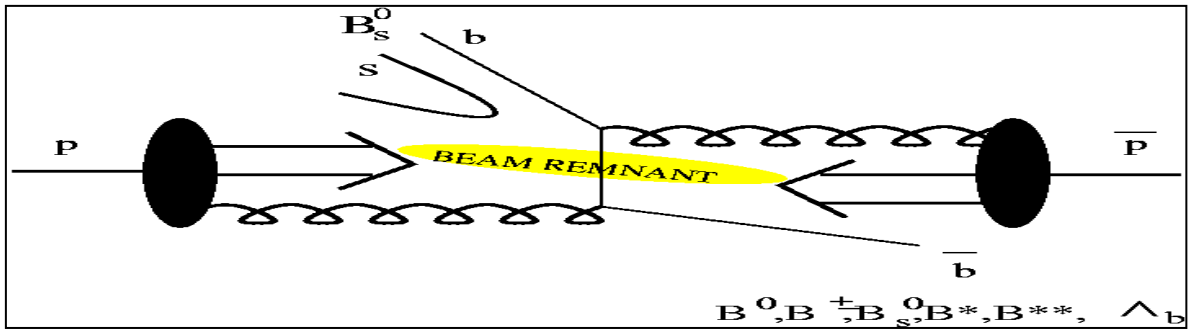


- **In the naive quark spectator model, the decay is a 1 → 3 process common to all *b* hadrons.**
- **(NLO) QCD predicted deviations in ≈ agreement with data**

	Heavy Quark Expansion	Experiment
• $\tau(B^+)/\tau(B_d)$	= 1.06± 0.02	1.074± 0.014
• $\tau(B_s)/\tau(B_d)$	= 1.00± 0.01	0.948 ± 0.038
• $\Delta\Gamma_s / \Gamma_s$	≈ 0.1	<0.54 (CL=95%)
• $\tau(\Lambda_b)/\tau(B_d)$	= 0.90 ± 0.05	0.796 ± 0.052

The main goal is to measure the ratios accurately.

B Physics at the Tevatron



Pros

- Large BB cross section:
  - ~ 100 μbarn total
  - ~ 3-5 μbarn "reconstructible"
- At $4 \times 10^{31} cm^{-2} s^{-1}$ → ~150 Hz of "reconstructible" B's
- All B species produced

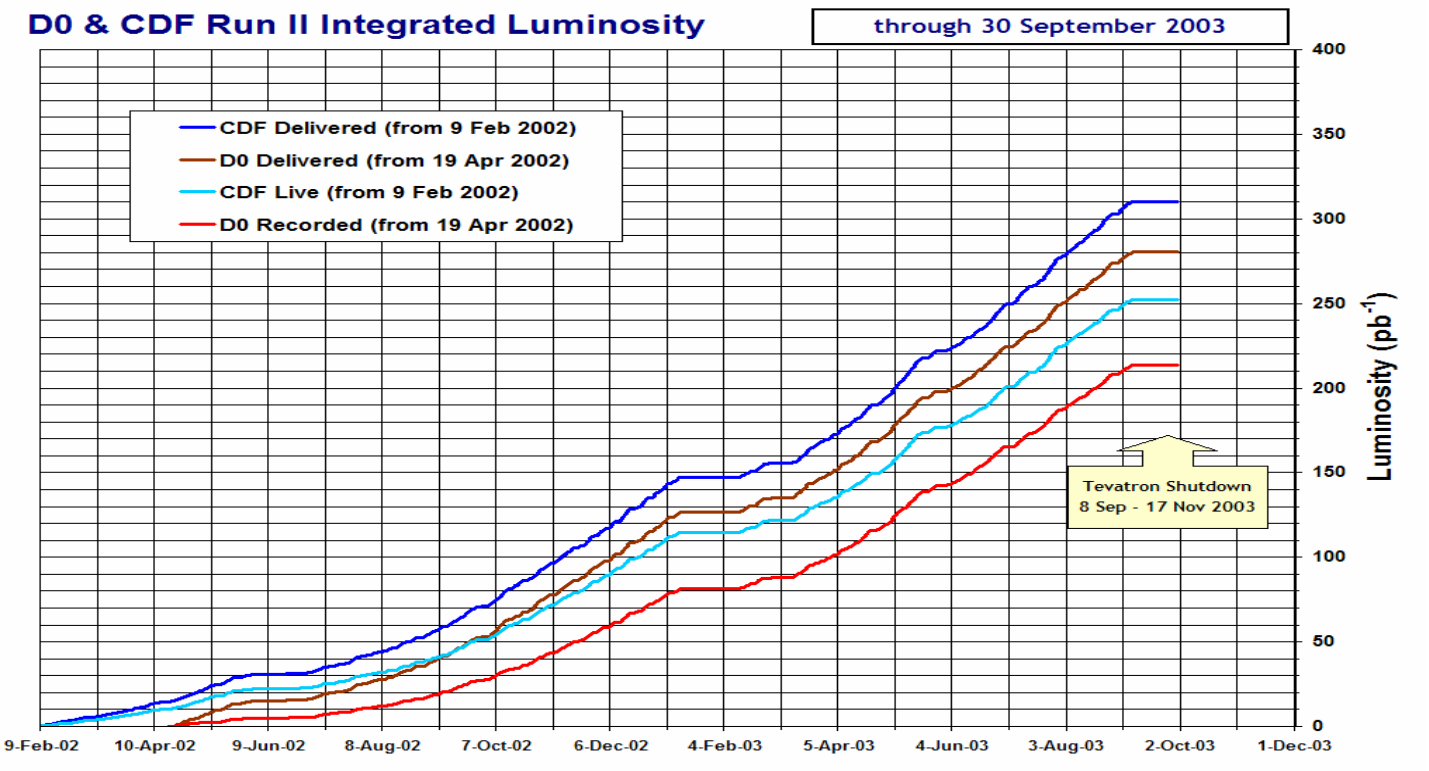
  Tevatron – world best source of B_s and Λ_b
- Production is incoherent
  - reconstruction of both Bs not needed

Cons

- Large background
  - B cross section ~10^{-3} total inelastic
  - special triggers (leptons, displaced tracks)
  - combinatorics in reconstruction
- Typical kinematic cuts:
  - $p_T(\mu) > 1.5$ GeV/c for μ's from J/ψ
  - $p_T(B) > 5$ (6) GeV/c

Run II at the Tevatron

data available by September shutdown



- **Analyses presented here based on:**
  - **CDF 138 pb $^{-1}$ (di-μ trig.);**
  - **D0 114 pb $^{-1}$ (di-μ trig.); 12 pb $^{-1}$ (single-μ trig.);**

Triggers for B Lifetime Studies

- **CDF**

Di-muon (J/ψ) $p_T(\mu) > 1.5$ GeV/c , $|\eta(\mu)| < 0.7$

l + displaced track $p_T(e/\mu) > 4$ GeV/c
$p_T(trk) > 2$ GeV/c , $120\ \mu m < d_0(trk) < 1$ mm

Two displaced tracks $p_T(trk) > 2$ GeV/c , $120\ \mu m < d_0(trk) < 1$ mm

- **D0**

Di-muon, $p_T(\mu) > 3$ GeV/c, $|\eta(\mu)| < 2.2$ (unprescaled)
$p_T(\mu) > 1.5$ GeV/c, $|\eta(\mu)| < 2.2$ (Lum. dependent prescale)

Single μ, $p_T(\mu) >$ 3-5 GeV/c, $|\eta(\mu)| < 2.2$ (Lum. dependent prescale)

Displaced tracks – after shutdown

List of Analysis Techniques

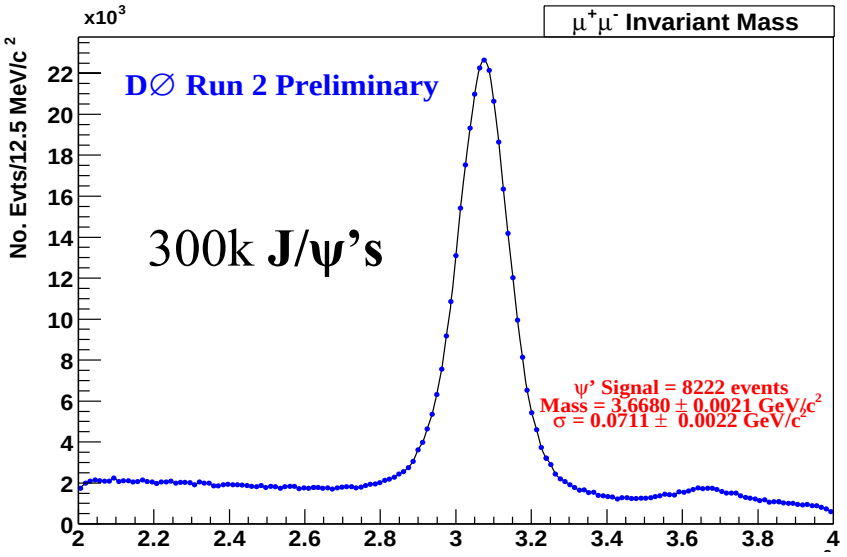
- **1D:** **bkg template from sideband**

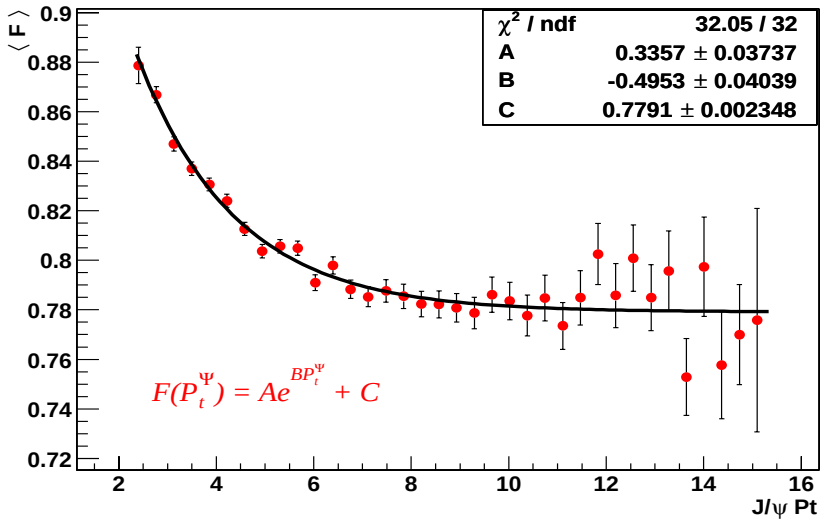
  (variations: allow LSB ≠ RSB)

- **2D:** **simultaneous fit to (mass, cτ), free bkg parameters**

Channel	1D	2D
Inclusive B → J/ψ X	CDF, D0	
B^+ → J/ψ K^+	D0	CDF
B^0_d → J/ψ K*		CDF, D0
B_s → J/ψ φ		CDF, D0
Λ_b → J/ψ Λ	CDF	
Semileptonic	D0	

Inclusive B → J/ψ + X Lifetime (D0)





- **Measure:** $\lambda_\psi = L_{xy}\ M_\psi / p^\psi{}_T$
- **Need:** $\lambda_B = L_{xy}\ M_B / p^B{}_T$

Correction factor:

$F = \lambda_\psi / \lambda_B = M_\psi\ p^B{}_T / M_B\ p^\psi{}_T$

MC provides mean $F(p^\psi{}_T)$ in slices of $p^\psi{}_T$

← D0 parametrization of $F(p^\psi{}_T)$

Inclusive B → J/ψ + X Lifetime (D0)

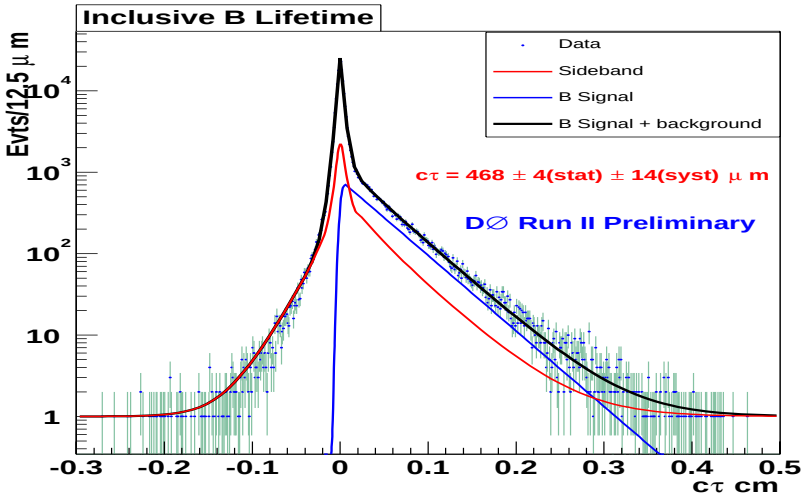
Fitting technique

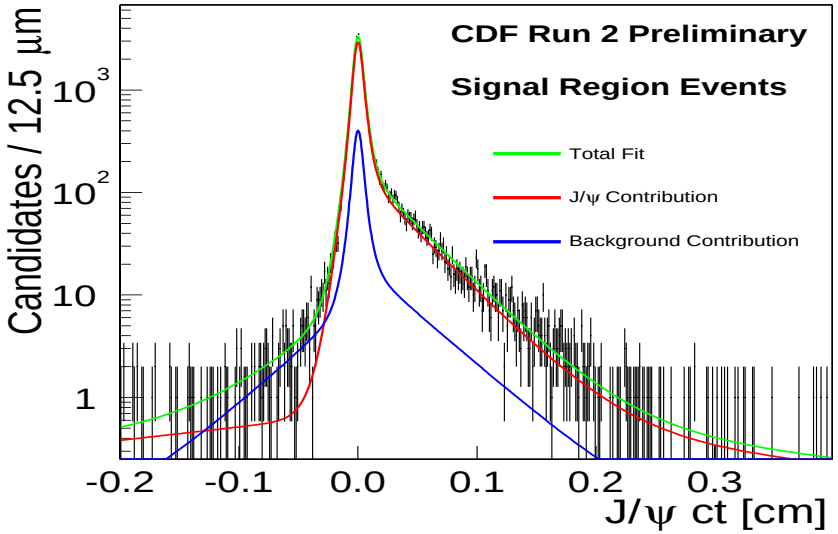
Two steps:

- **fit λ distribution of the sidebands to get the shape of the background. The bkg parametrization $g_{bkg}(\lambda)$:**
  - **Prompt ← taken from MC (Gaussian plus exponential tails)**
  - **(λ>0) and (λ<0) exponentials**
- **fit λ distribution in the signal region allowing for:**
  - **bkg distribution $g_{bkg}(\lambda)$**
  - **Prompt J/ψ (similar to prompt bkg)**
  - **Exponential decay convoluted with Gaussian (b→J/ψ +X)**

Inclusive B → J/ψ + X Lifetime

D0 and CDF results





- **D0 (114 pb $^{-1}$)**

  τ = 1.562±0.013(*stat*)±0.045(*syst*) ps

  main *syst* uncertainties:

  correction factor: 1.6 %

  MC bias: 1.9 %

  → 82% J/ψ's prompt

- **CDF (18 pb $^{-1}$, 2002)**

  τ = 1.526±0.034(*stat*)±0.035(*syst*) ps

  main *syst* uncertainties:

  correction factor: 1.1 %

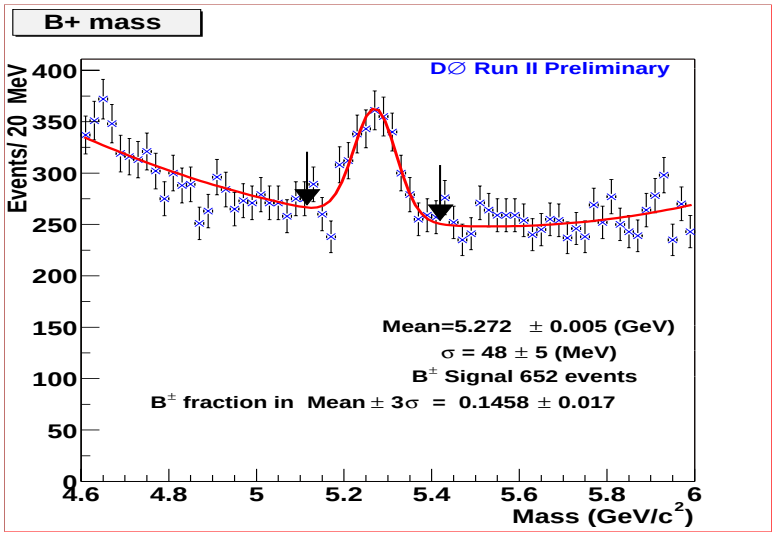
  resolution function: 1.5 %

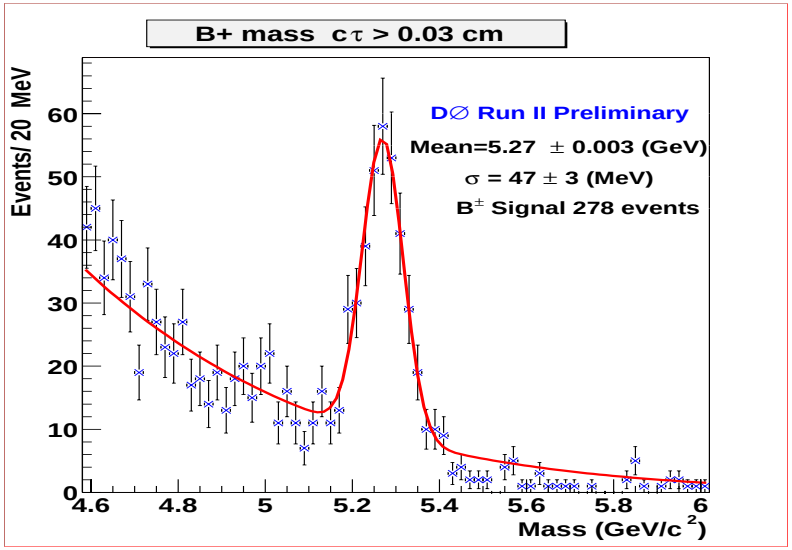
  bkg parametrization: 1.1 %

  → 83% J/ψ's prompt

$B^+ \rightarrow J/\psi + K^+$ Lifetime (D0)

Data and Fitting technique





1D fit → steps:

- **Fit λ distribution of the right sideband**
  - **Prompt & (λ>0) and (λ<0) exponentials**

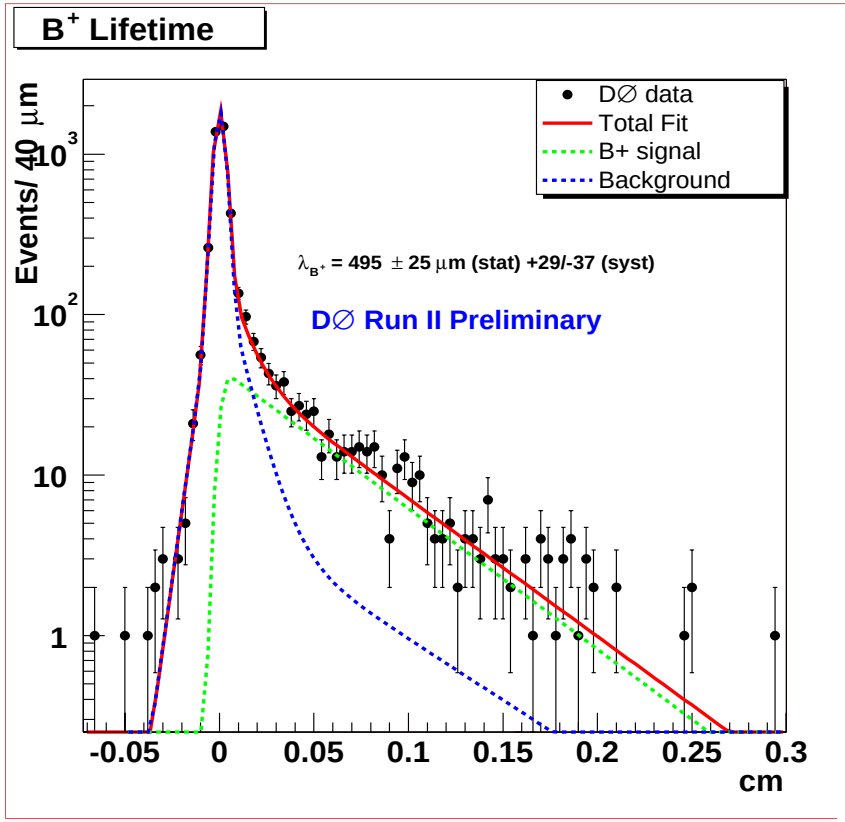
- **Fit λ distribution in the left sideband with an extra term for feeddown from multibody B decay channels**

- **Fit the signal region**

Norm. of feeddown = 0.12 ± 0.01 (MC)

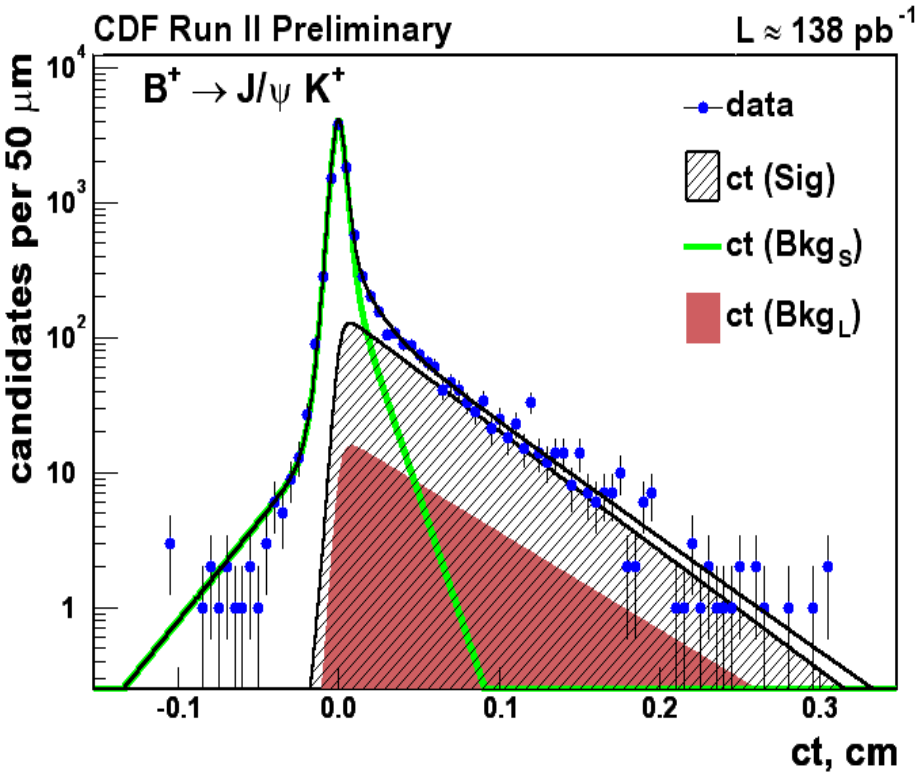
$B^+ \rightarrow J/\psi\ K^+$; Results

D0



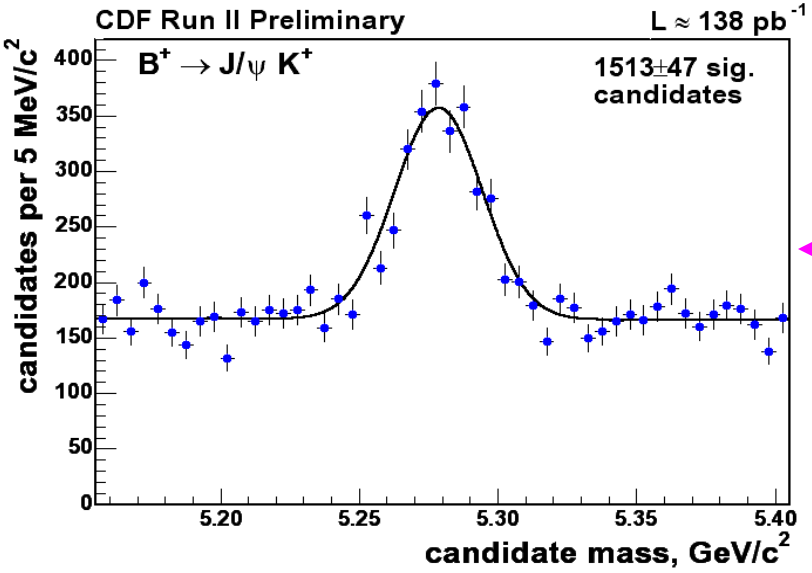
τ =1.65 ±0.08(*stat*) +0.09-0.12(*syst*) ps

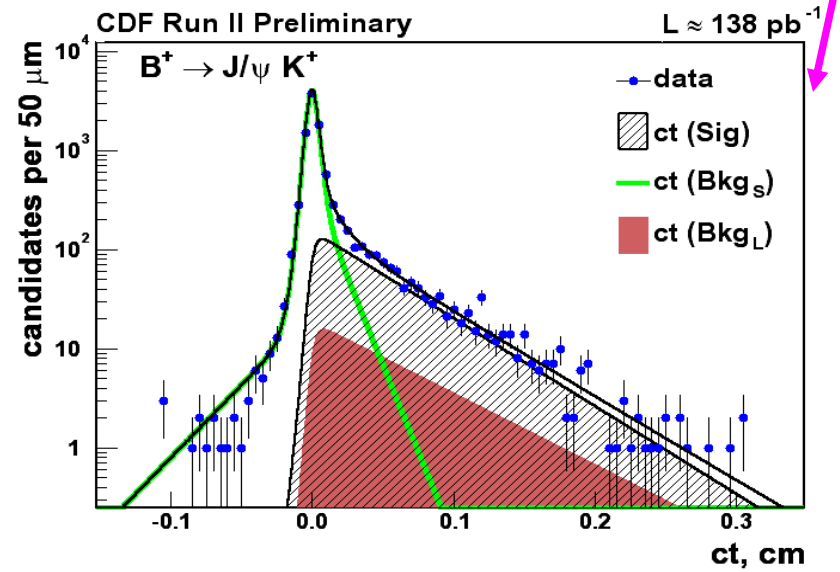
CDF



τ =1.63±0.05(*stat*) ±0.04(*syst*) ps

Exclusive B→J/ψX Lifetimes; X= K$^+$, K*, φ (CDF)





Fit Method:
Simultaneous fit of
M(B) → signal fraction, define sidebands
cτ(B) → lifetime

Signal Contribution:

$$F_{sig} = \frac{1}{c\tau}\exp\left(\frac{-t}{c\tau}\right) \otimes G(t, s\sigma_i)$$

Background Parameterisation:

$$F_{bkg} = \left(\begin{array}{l} (1 - f_- - f_+ - f_{++})\delta(t) \\ + \frac{f_-}{c\tau_-}\exp\left(\frac{t}{c\tau_-}\right) + f_+ \frac{f_+}{c\tau_+}\exp\left(\frac{-t}{c\tau_+}\right) \\ + \frac{f_{++}}{c\tau_{++}}\exp\left(\frac{-t}{c\tau_{++}}\right) \end{array} \right) \otimes G(t, s\sigma_i)$$

$B_s \rightarrow J/\psi\ \varphi$

with $B_d \rightarrow J/\psi\ K^*$ as a control channel

CDF

138 pb^{-1} of data

2D fit (Mass, $c\tau$)

Signal events: 120 ± 13

- $p_T(B) > 6$ .5 GeV/c
- $p_T(\varphi) > 2$ GeV/c

- run averaged beam spot: 33μm
  track impact parameter resol: 35μm

D0

114 pb^{-1} of data

2D fit (Mass, $c\tau$)

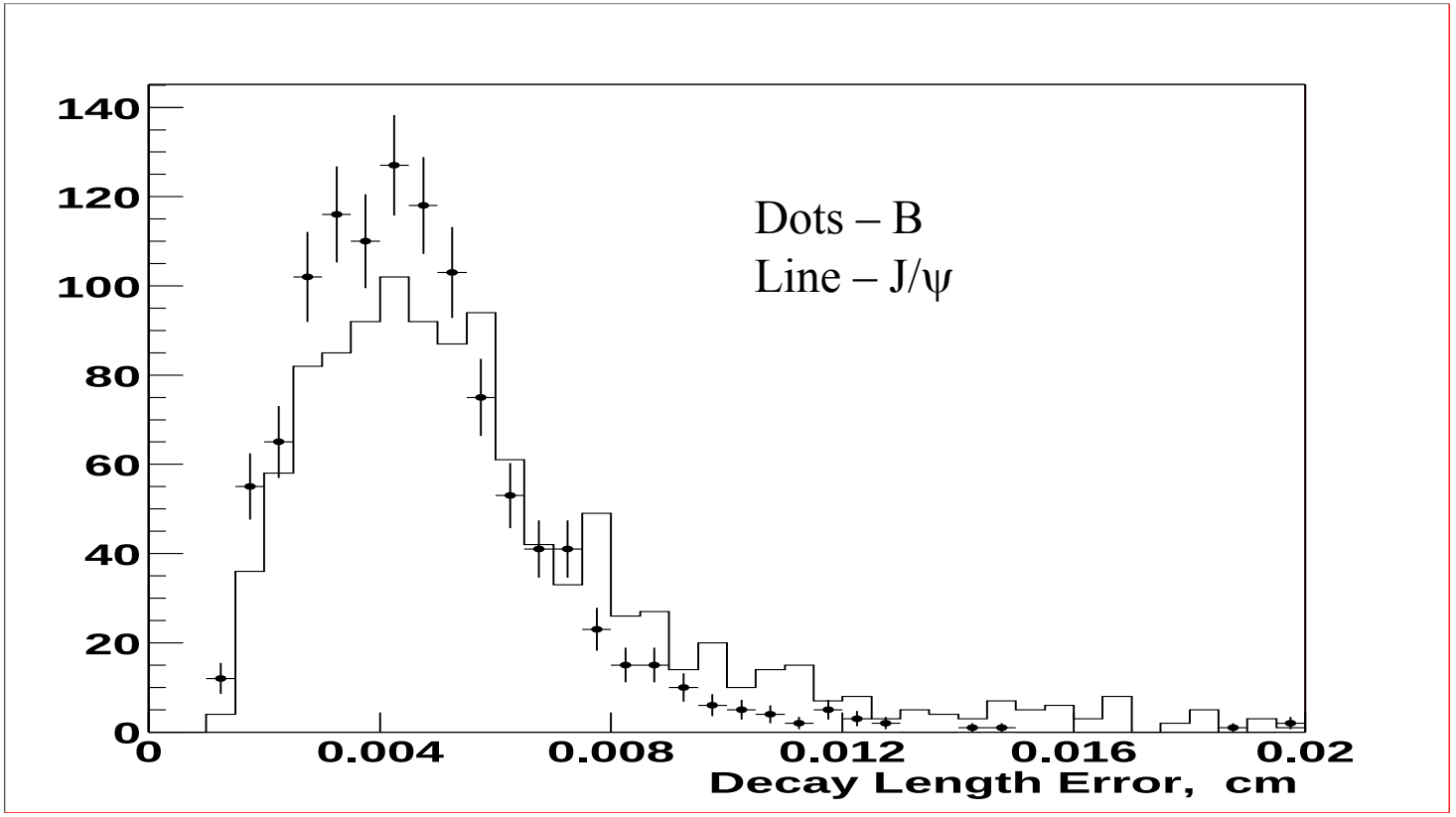
Signal events: 69 ± 14

- $p_T(B) > 6$ GeV/c
- $p_T(\varphi) > 2$ GeV/c
- $p_T(K) > 1$ GeV/c

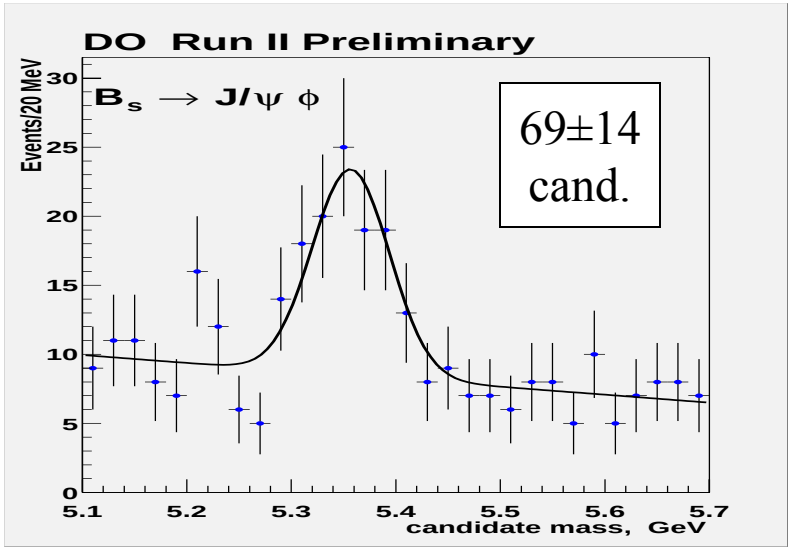
- event by event PV
- L_{xy} resolution ≈ 40 μm

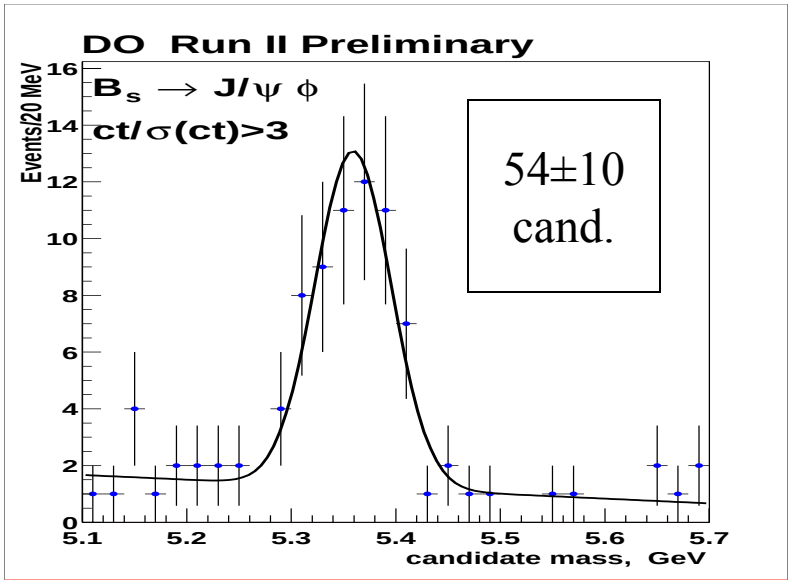
$B^0_s \rightarrow J/\psi + \varphi$; Data (D0)

Decay Length resolution

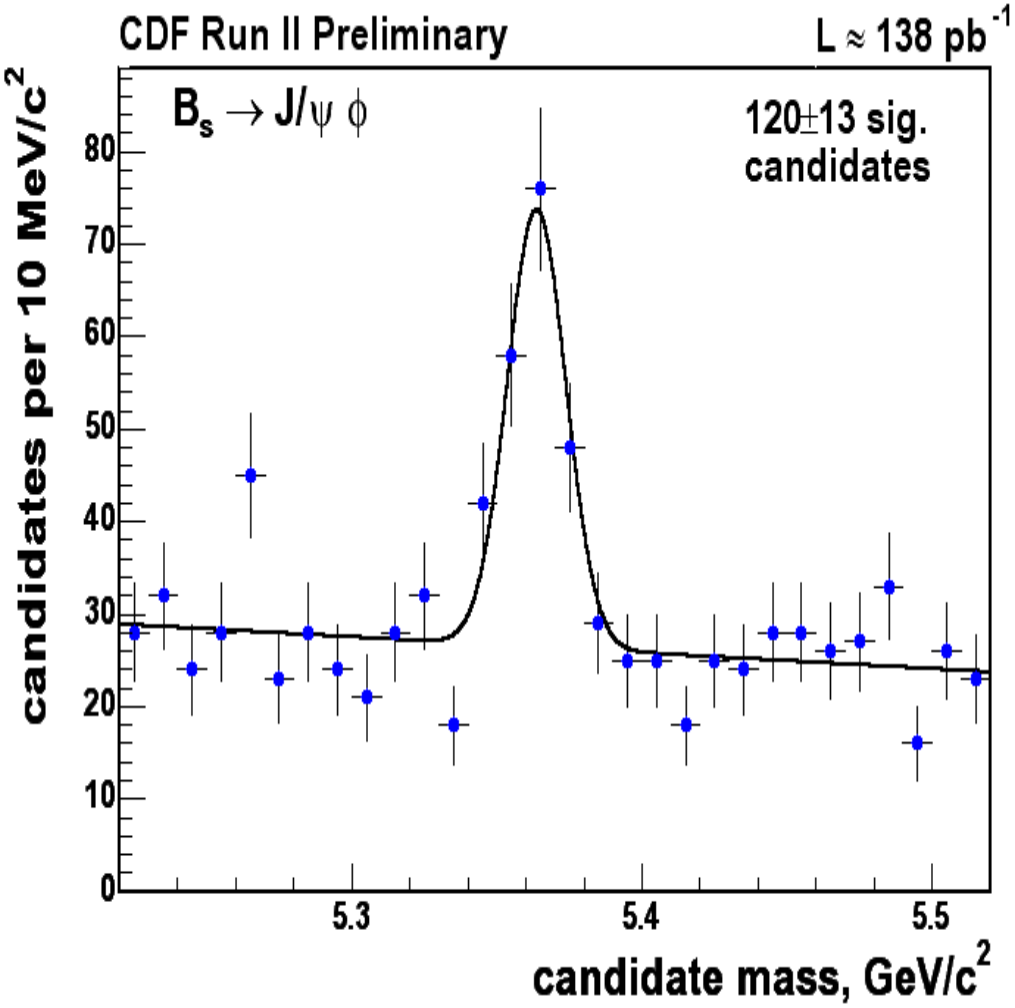


$B^0_s \rightarrow J/\psi + \varphi$; Data



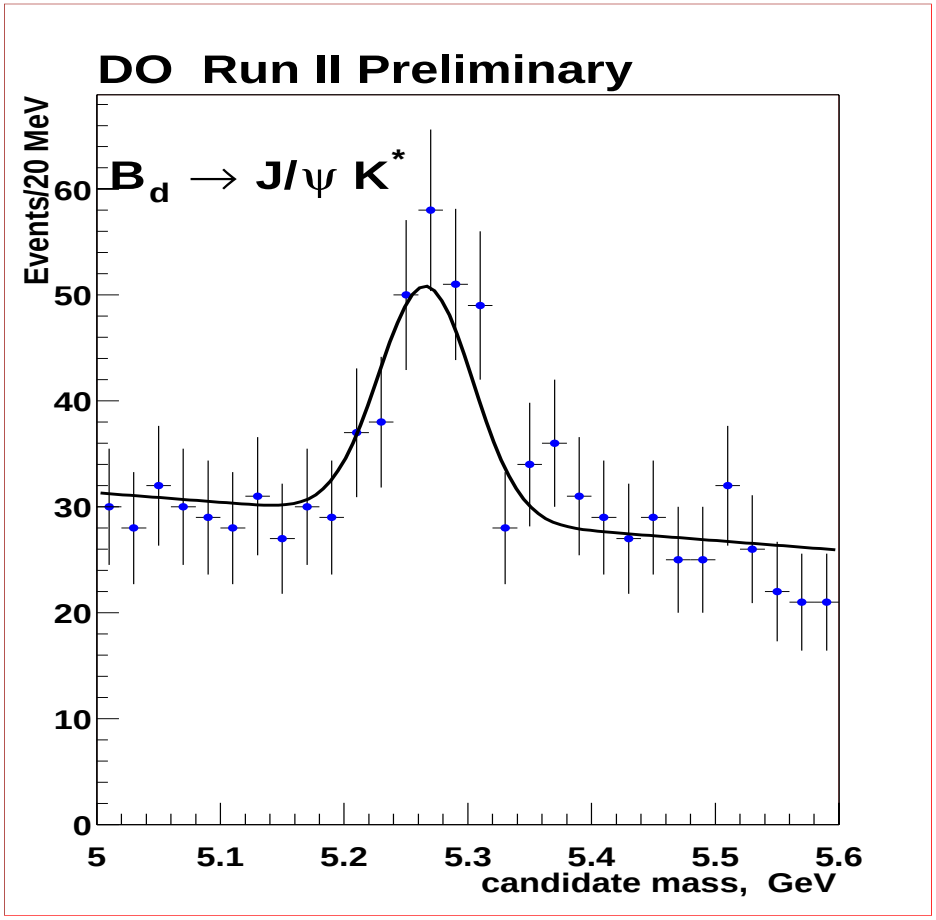


CDF

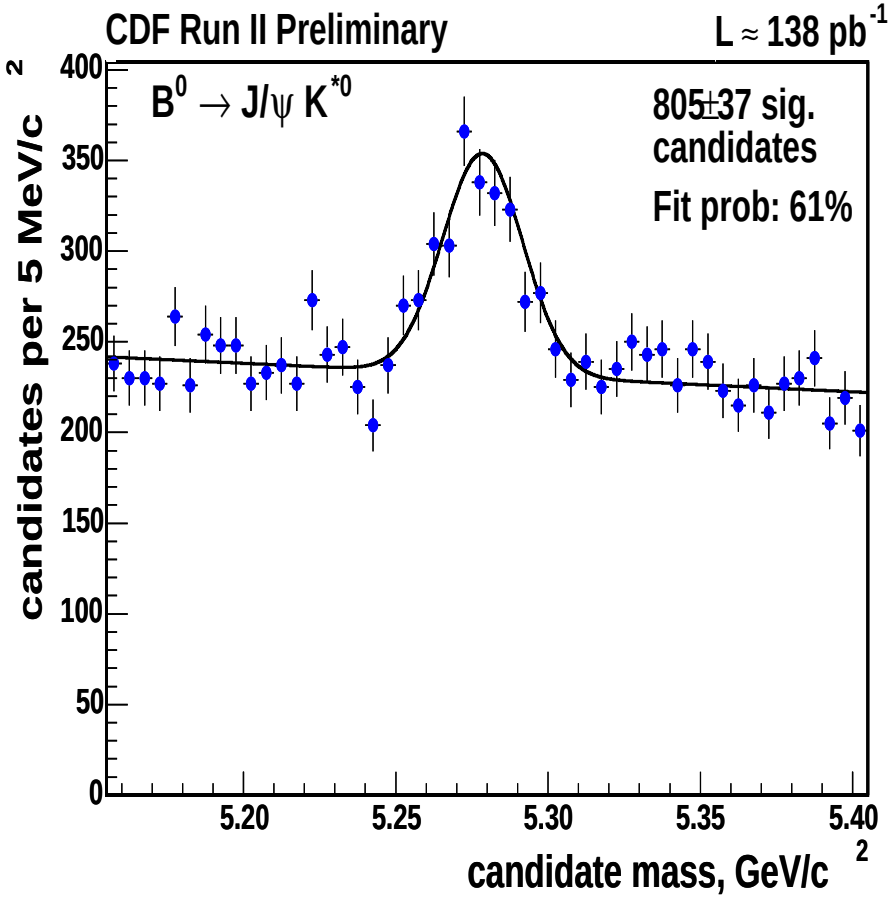


$B^0_d \rightarrow J/\psi + K^*$; Data

D0

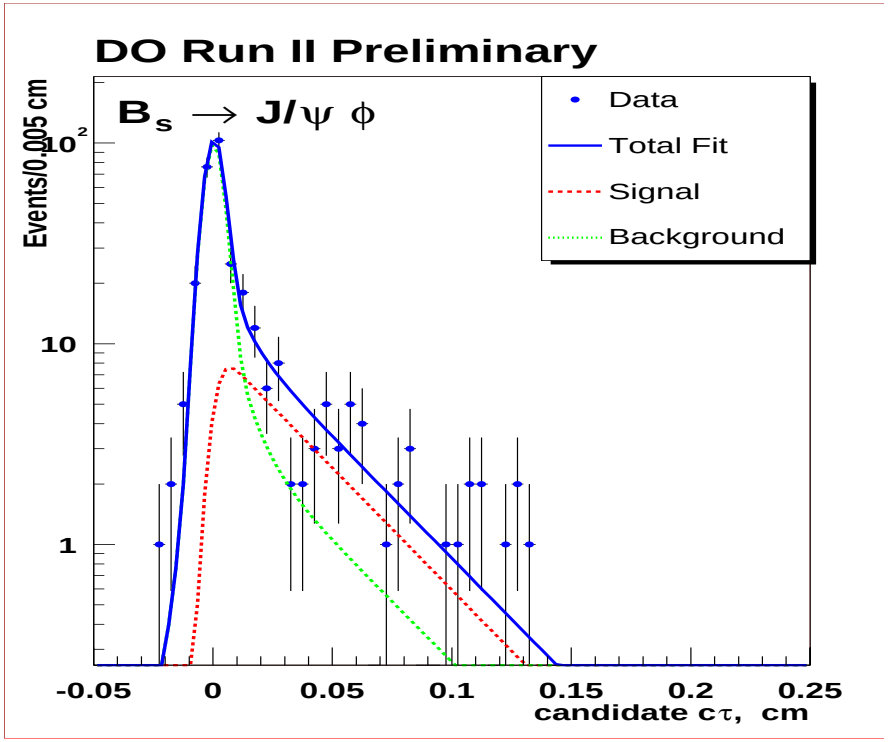


CDF



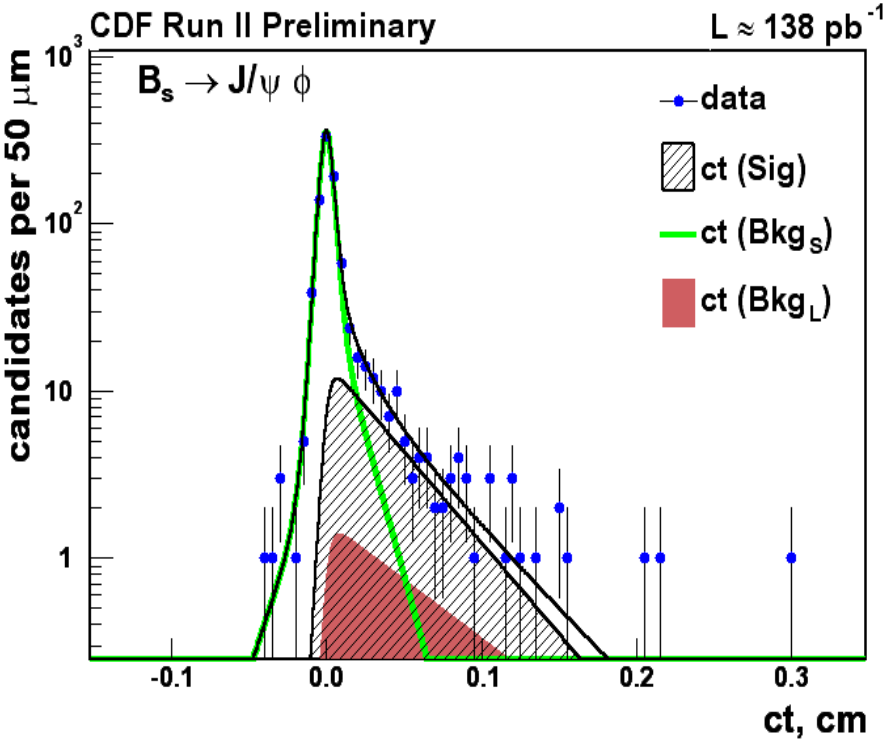
$B^0_s \rightarrow J/\psi + \varphi$; Fit results

D0



τ =1.19 ±0.18(*stat*) ±0.14(*syst*) ps

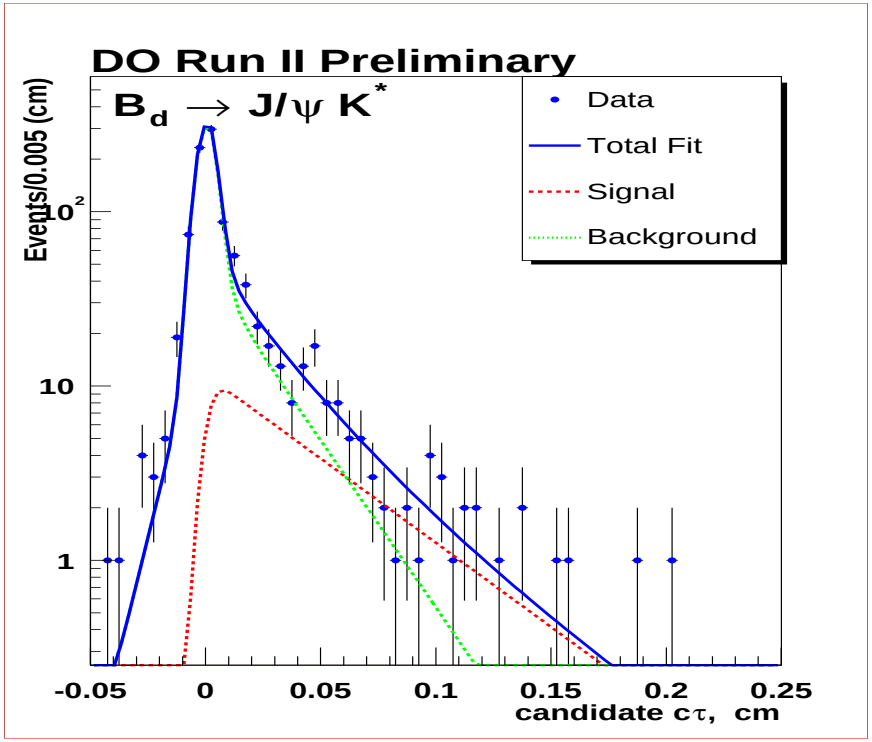
CDF



τ =1.33 ±0.14(*stat*) ±0.02(*syst*) ps

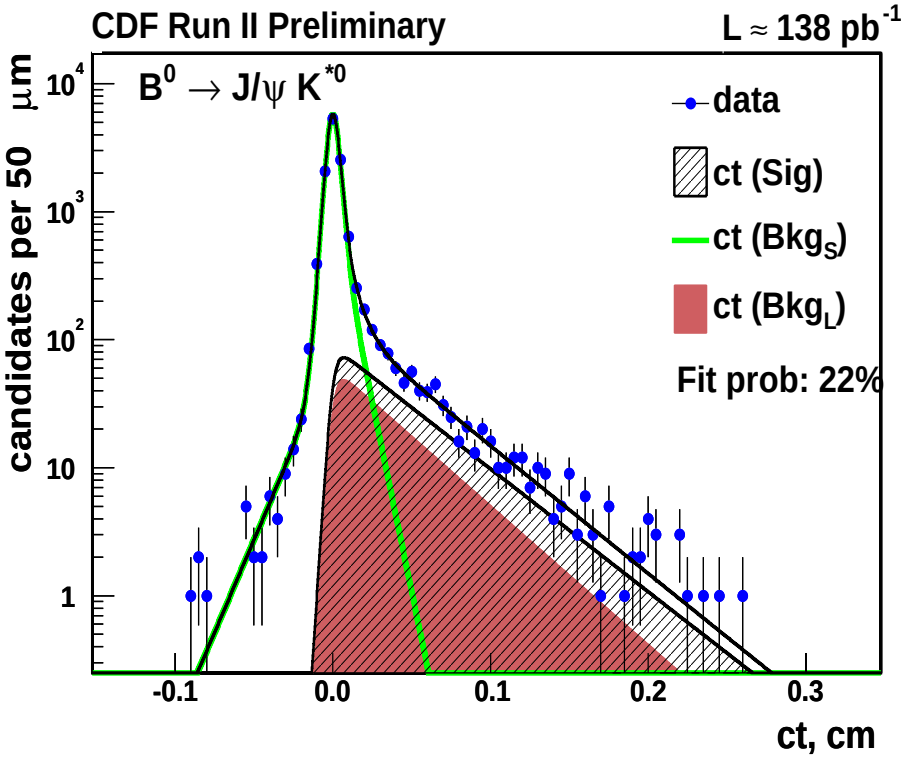
$B^0_d \rightarrow J/\psi + K^*$; Fit results

D0



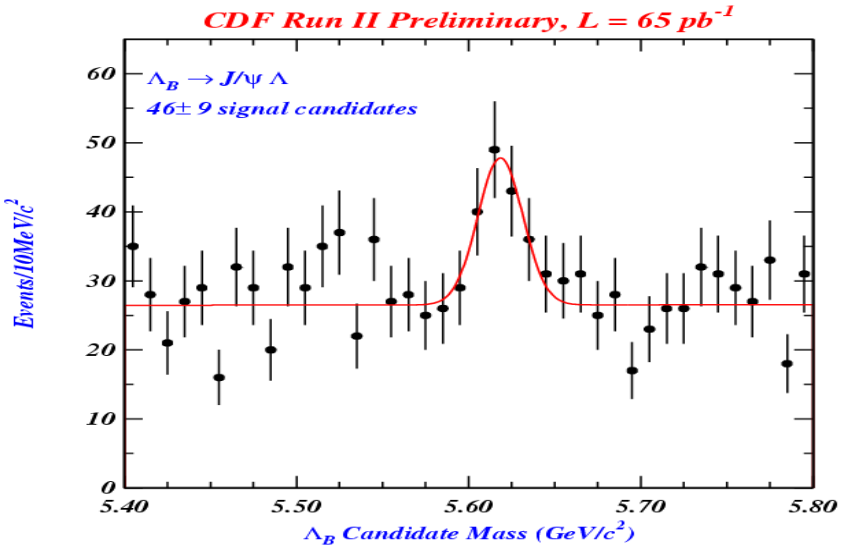
τ =1.51 ±0.18(*stat*) ±0.20(*syst*) ps

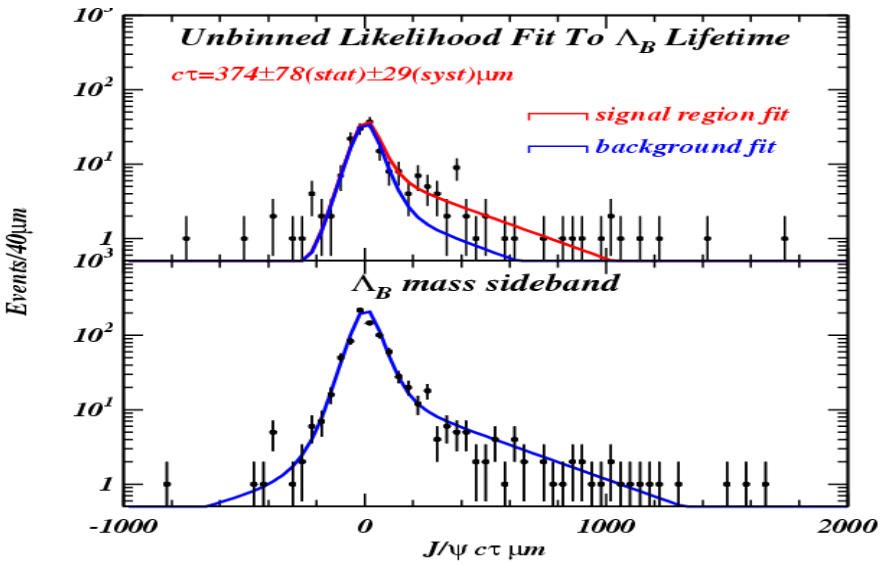
CDF

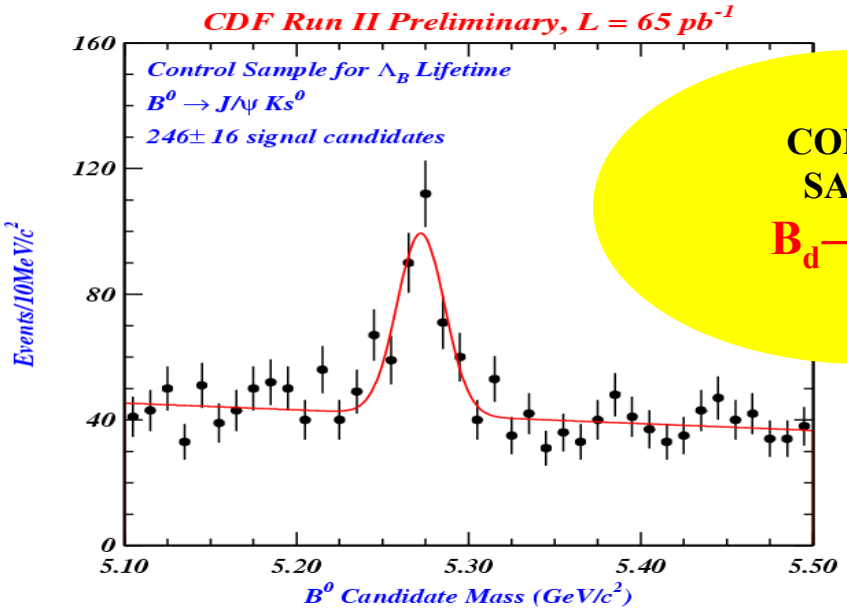


τ =1.51 ±0.06(*stat*) ±0.02(*syst*) ps

$\Lambda_b \rightarrow J/\psi\ \Lambda$ Lifetime and Crosscheck (CDF)

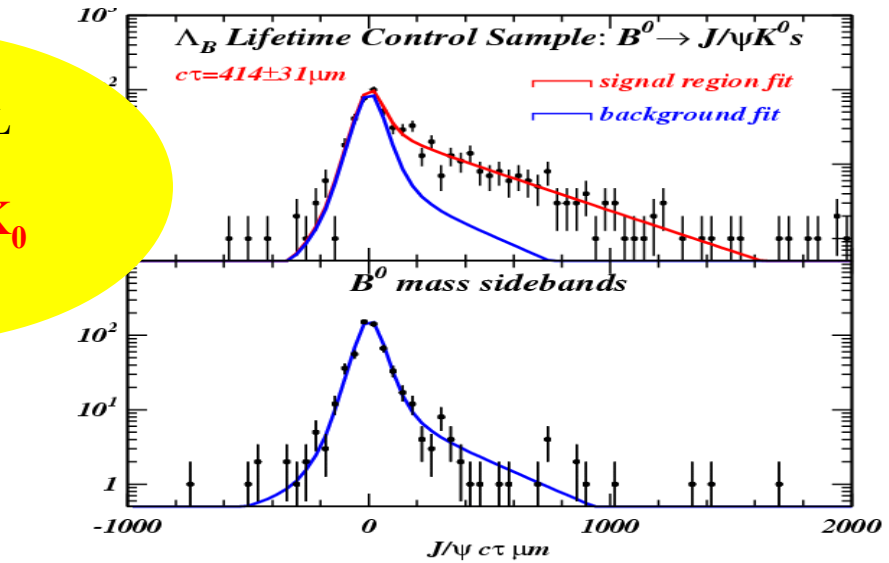




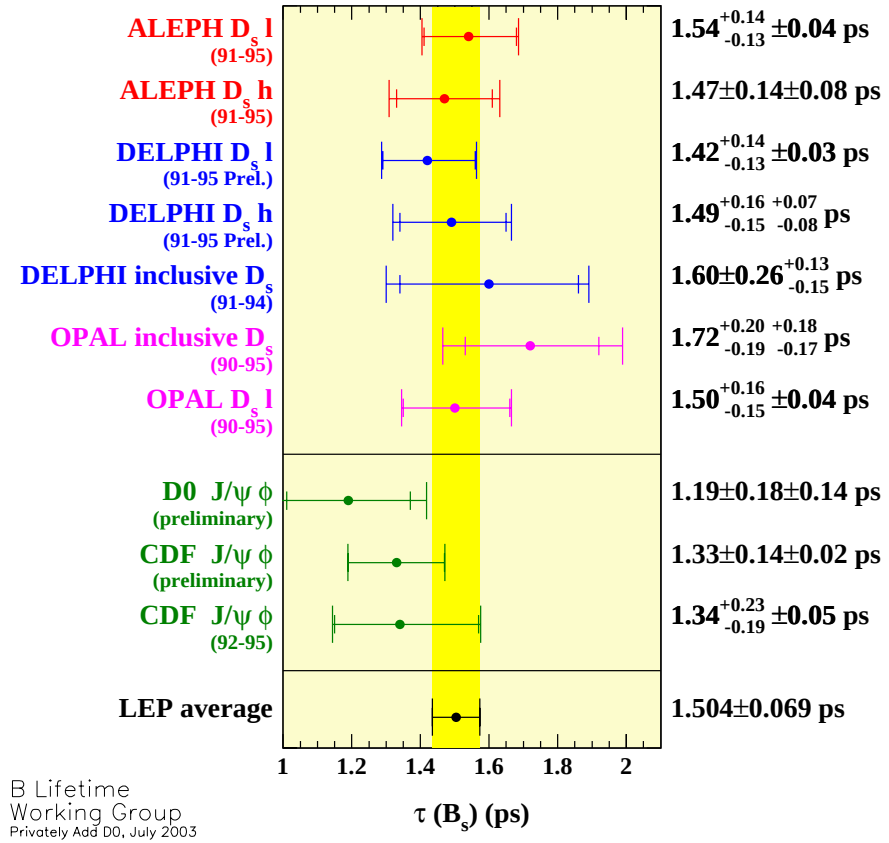


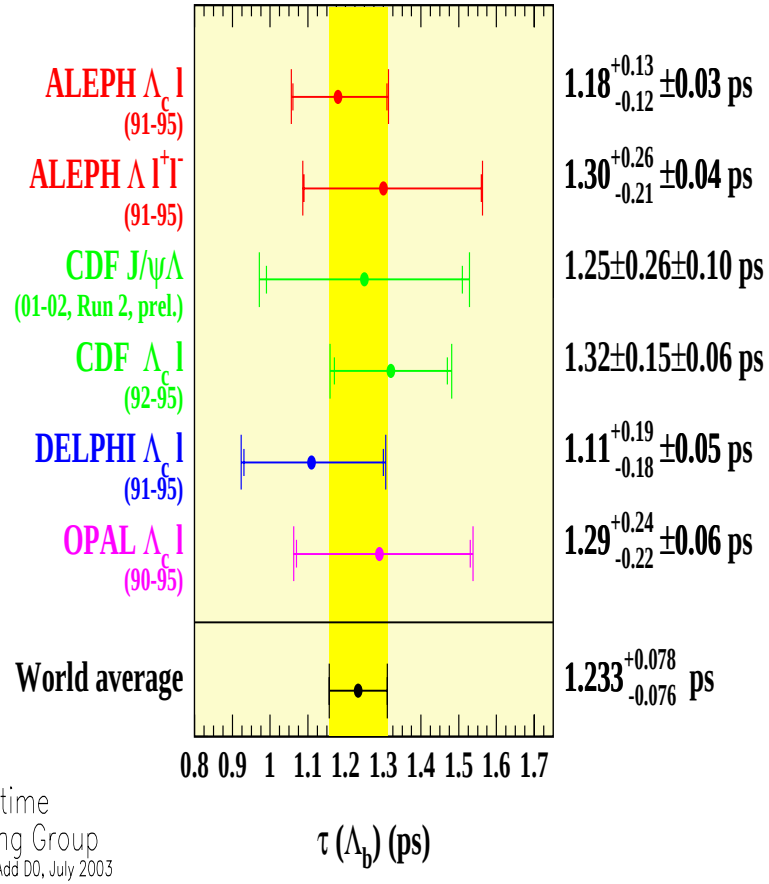
CONTROL SAMPLE

$B_d \rightarrow J/\psi K_0$



B_s and Λ_b Lifetimes - Summary





B_s CP =+1 & CP = -1 Lifetimes

- **$B^0_s \rightarrow J/\psi\ \varphi$ unknown mixture of CP =+1 & CP = -1 states**

Standard Model predicts $\Delta\Gamma_s/\Gamma_s \sim 0.1$

$\Gamma_s = (\Gamma_{Light} + \Gamma_{Heavy})/2$; $\Delta\Gamma_s = \Gamma_{Light} - \Gamma_{Heavy}$

CP=+1 CP=-1

In the case of untagged decay, the CP – specific terms evolve like:

CP - even: $(|A_0(0)|^2 + |A_{||}(0)|^2)\exp(-\Gamma_{Light}t)$

CP - odd: $|A_\perp(0)|^2 \exp(-\Gamma_{Heavy}t)$

- **Flavor specific final states (e.g. $B^0_s \rightarrow l\nu D_s$) provide:**

$$\Gamma_{fs} = \Gamma_s - (\Delta\Gamma_s)^2 / 2\Gamma_s + \text{Ό}((\Delta\Gamma_s)^3 / \Gamma_s^{\,2})$$

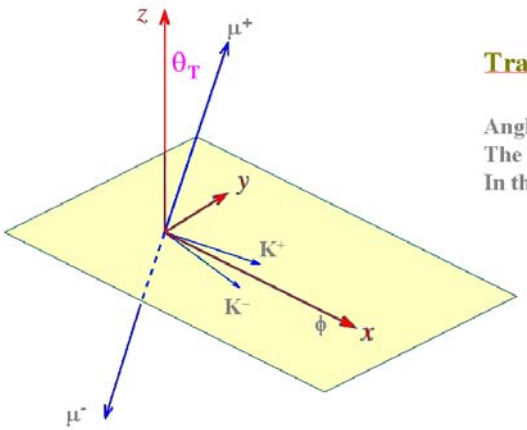
B_s Lifetimes, *transversity* variable θ_T

The CP-even and CP-odd components have distinctly different decay distributions.

The distribution in *transversity* variable θ_T and its time evolution is:

$$d\Gamma(t)/d\cos\theta_T \propto (|A_0(t)|^2 + |A_{||}(t)|^2)(1+\cos^2\theta_T) + |A_\perp(t)|^2\, 2\sin^2\theta_T$$

3 linear polarization states: **J/ψ and φ polarization vectors:**
longitudinal (0) to the **B** direction of motion;
transverse and parallel (||) and ($\perp$) to each other

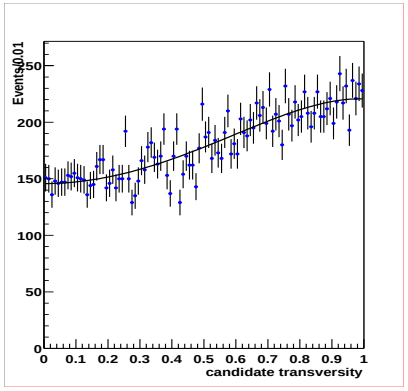


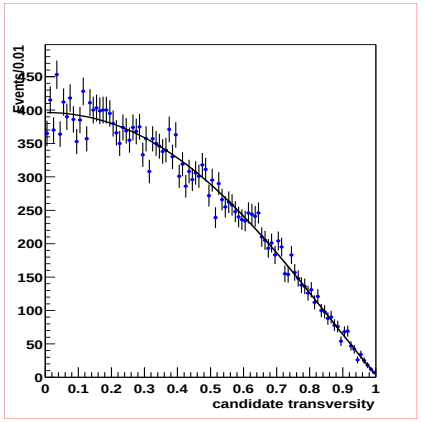
Transversity Angle θ_T:

Angle between μ^+ and
The normal to the K+K- plane
In the J/ψ rest frame.

$B_s \to J/\psi\ \phi$
$\phi \to K^+K^-$
$J/\psi \to l^+l^-$

- **MC distributions for CP = +1 & CP= -1 for accepted events (D0)**

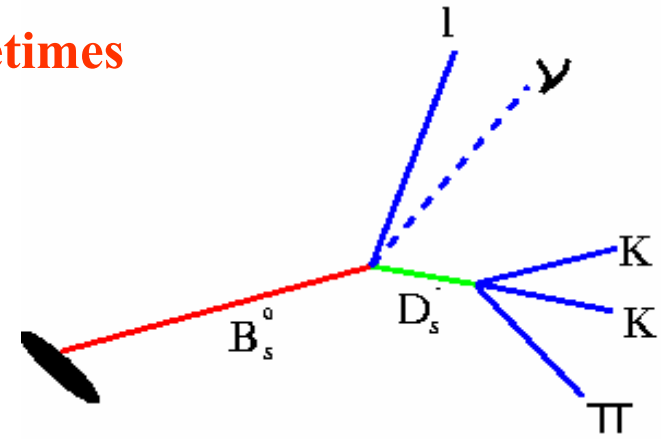




→ Fit extension from 2-D to 3-D in progress

Semileptonic Lifetimes

- **The goal is to extract the B_s and Λ_b lifetimes using lepton + D^0 as a control channel**



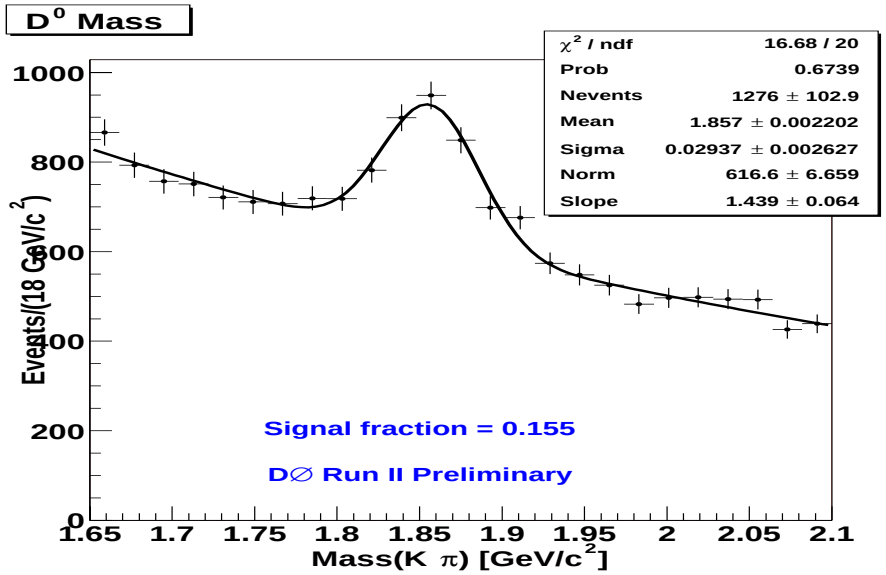
- **reconstruct the D decay near lepton**
- **B decay not fully reconstructed**
  → extract the boost factor from MC:
- **extract lifetime from decay length**

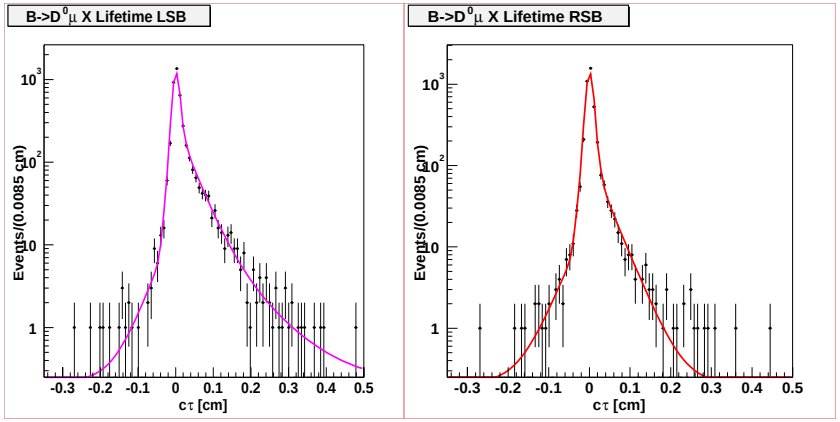
CDF: **lepton + displaced track trigger**
small statistical uncertainty

D0: **single muon trigger (prescaled at high luminosity)**

Semileptonic Lifetimes (D0)

B → D^0 μ X benchmark analysis





1D Analysis

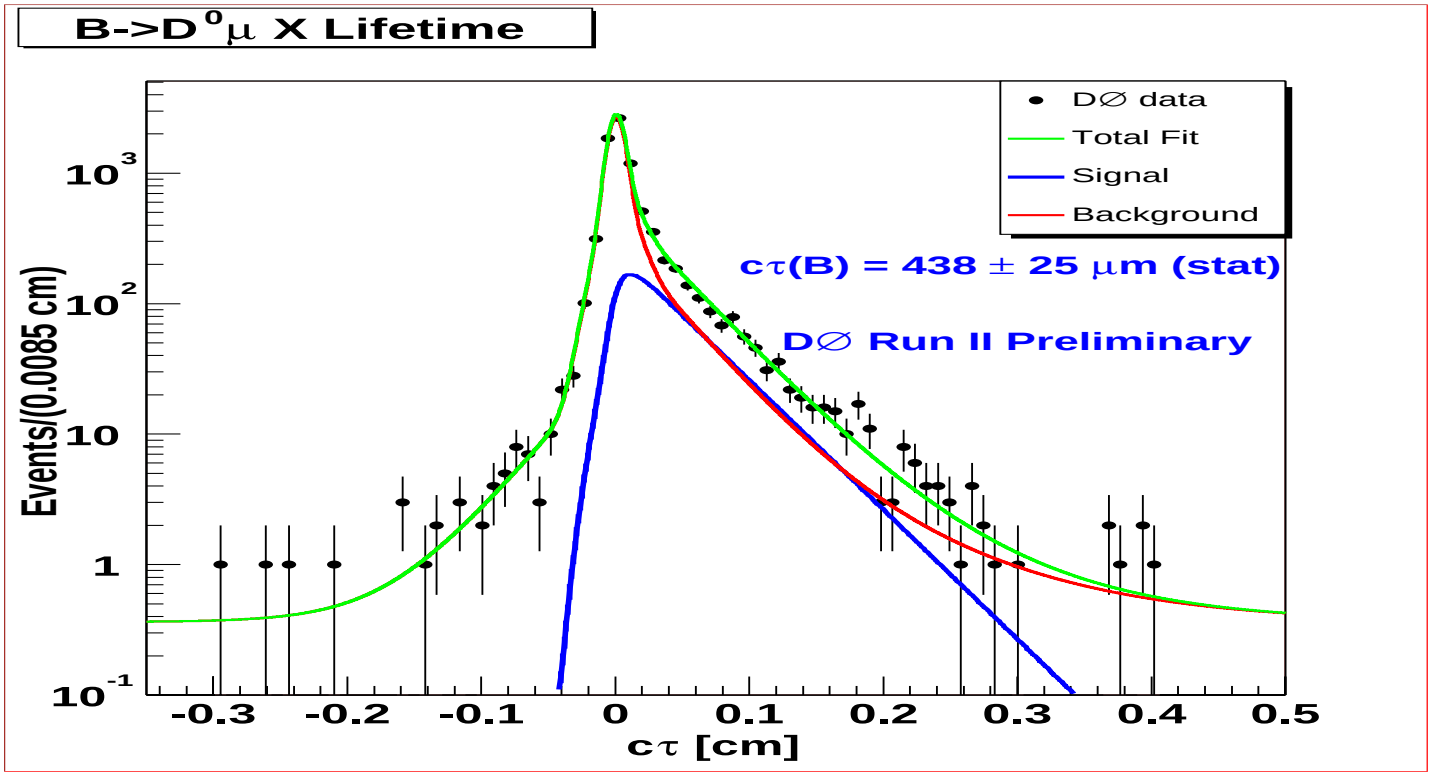
- **Factor $K = p_T(D^0+\mu)/p_T(B)$**

  from MC (generator level, confirmed with reco'ed tracks)

- **Bkg model:**
  - Prompt &
  - +ve exp,-ve exp &
  - additional +ve (left side)
- **Resolution: double Gaussian**
- **Results → see next page**

Semileptonic Lifetimes

D0 results for the B → D^0 μ X benchmark analysis



τ =1.46 ± 0.083(*stat*) ps - to be compared with

τ =1.60 ± 0.02 ps ← WA for this channel

Summary

- **Lifetime measurements for inclusive B $\rightarrow$J/ψ X decays and for exclusive B $\rightarrow$J/ψ X channels by both CDF and D0:**

	CDF	D0	World average
B^+	1.63 ± 0.05 ± 0.04 ps	1.65 ± 0.08 ± 0.12 ps	1.671 ± 0.018 ps
B^0_d	1.51 ± 0.06 ± 0.02 ps	1.51 ± 0.18 ± 0.20 ps	1.542 ± 0.016 ps
B^0_s	1.33 ± 0.14± 0.02 ps	1.19 ± 0.18 ± 0.14 ps	1.461 ± 0.057 ps
Λ_b	1.25 ± 0.26 ± 0.10 ps	→ In progress	1.233 ± 0.077 ps

- **Measurements of polarization states in B^0_s decay and of $\Delta\Gamma_s/\Gamma_s$ → in progress**
- **Lepton + displaced vertex trigger has been implemented at CDF for the first time**
  - **expects high statistical accuracy for B^0_s and Λ_b lifetime**
- **Benchmark measurement of B → D^0 μ X (D0)**

Backup slides

B_s Lifetime
Summary of existing measurements

Flavor-specific final states:

$$\Gamma_{fs} = \Gamma_s - (\Delta\Gamma_s)^2 / 2\Gamma_s + Ó((\Delta\Gamma_s)^3 / \Gamma_s^2)$$

$$\Gamma_{fs} \approx \Gamma_s = (\Gamma_{Light} + \Gamma_{Heavy})/2$$

CP=+1 CP=-1

$$\Delta\Gamma_s = \Gamma_{Light} - \Gamma_{Heavy}$$

Unknown mixture of Γ_{Light}, Γ_{Heavy}

(predominantly CP = +1)

Value(10^{-12}s)	Experiment (channel)
1.42±0.14±0.03	DLPH (l^+)
1.53±0.16±0.07	DLPH (D_s)
1.36±0.09±0.06	CDF (D_s l^+)
1.72±0.20±0.18	OPAL (D_s)
1.50±0.16±0.04	OPAL (D_s l^+)
1.47±0.14±0.08	ALEPH (D_s)
1.60±0.26±0.14	DLPH (D_s)
1.54±0.14±0.04	ALEPH (D_s l^+)

1.34±0.21±0.05	CDF – (J/ψ φ)
1.33±0.14±0.02	CDF (J/ψ φ) - prelim
1.19±0.18±0.14	D0 (J/ψ φ) - prelim

Systematic uncertainties (CDF)

Systematic effect	Uncertainty on $c\tau$ (B^+), μm	Uncertainty on $c\tau$ (B^0_d), μm	Uncertainty on $c\tau$ (B_s), μm
Alignment	± 5	← same	← same
Resolution function	± 3	← same	← same
Fit Model	negligible	← same	← same
Event Selection	negligible	← same	← same
Fitter Bias	negligible	← same	← same
B^+ Pathology	± 9	n/a	n/a
Handling (Kπ) swap	n/a	negligible	n/a
Total	± 11	± 6	± 6

Systematic uncertainties (D0)

Systematic effect	Uncertainty on $c\tau$ (B^0_d), μm	Uncertainty on $c\tau$ (B_s), μm	Method
Alignment	± 5	← same	data
Resolution function	negligible	← same	data
Fit Model (bkg)	± 6	← same	data
Fit Model (signal)	± 5	± 3	data
Event Selection (V mass)	± 7	← same	data
Event Selection (p_T)	± 20	← same	MC
Fitter & Reco Bias	± 56	± 35	MC
Total	± 60	± 42	