B Lifetimes at CDF Run II

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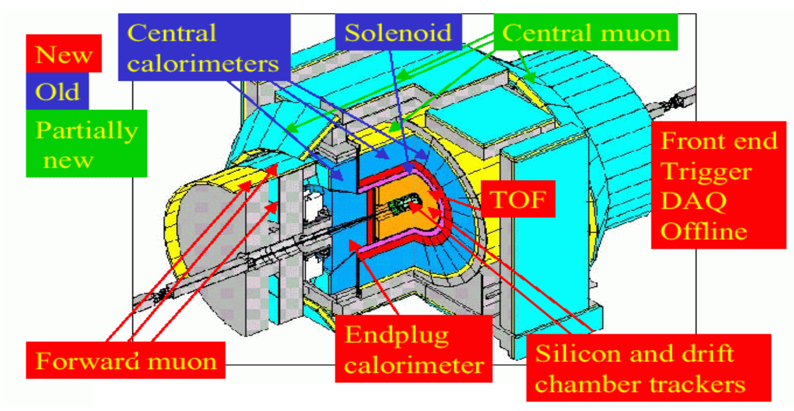
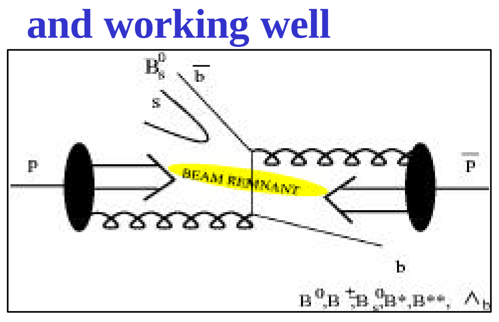
The CDF Run II Detector:



The detector is fully commissioned and working well



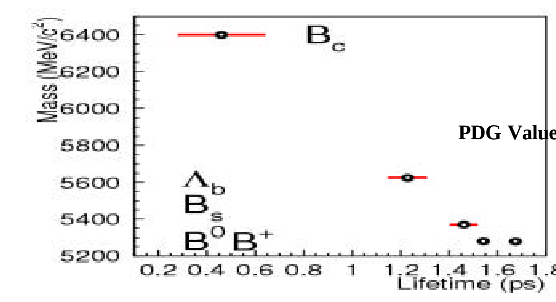
$p\bar{p}$ collisions produce a wide spectrum of B hadrons in a challenging environment

$\sigma(b\bar{b}) \ll \sigma(p\bar{p}) \Rightarrow$ B events are selected with specialised triggers:

Di-Muon (J/ψ) (conventional)	$p_T(\mu)$>1.5 GeV/c	J/ψ modes at low $p_T(J/\psi) \geq 0$ GeV/c Measure x-section J/ψ Yield=2x Run I
l+displaced track (NEW!)	$p_T(e/\mu)$>4 GeV/c $p_T(trk)$>2 GeV/c 120 μm<$d_0(trk)$<1mm	Semileptonic modes Lifetimes, flavour tagging B Yields 3x Run I
Two displaced tracks	$p_T(trk)$>2 GeV/c 120 μm<$d_0(trk)$<1mm	Hadronic modes Charm Physics, B^0_s mixing

Indivdual data samples of about 140pb^{-1} accumulated

According to the spectator model all B mesons would have the same lifetime… *but that is not the whole story!*



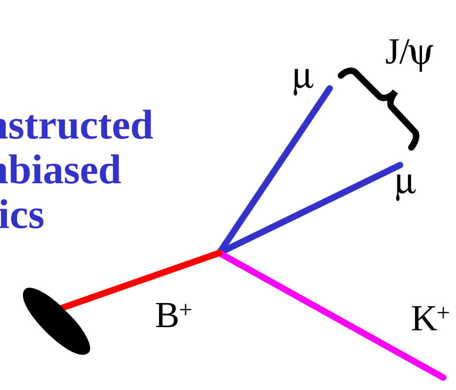
The HQE predicts by how much the lifetimes differ.
Aim 1: Measure lifetimes accurately to inform theories
Aim 2: Prove the detector and triggers are working
Aim 3: Measure $\Delta\Gamma_s/\Gamma_s$
$B^0_s \rightarrow J/\psi\phi$ is an admixture of CP even and CP odd states

$$\frac{1}{2}e^{-\Gamma t}\left[\left(1+\left|\frac{p}{q}\right|^2\right)\cosh\left(\frac{\Delta\Gamma}{2}t\right)+\left(1-\left|\frac{p}{q}\right|^2\right)\cos(\Delta m t)\right]\approx\frac{1}{2}e^{-\Gamma t}$$

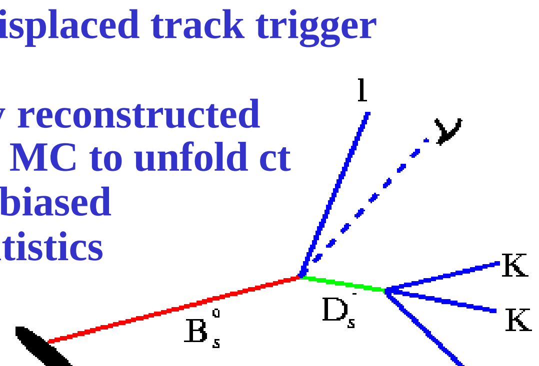
Pair it with fully CP even or CP odd state (or use polarisation analysis) and measure $\Delta\Gamma_s/\Gamma_s$

Lifetime Measurements:

Exclusive:
J/ψ trigger
- clean
- fully reconstructed
- lifetime unbiased
- low statistics



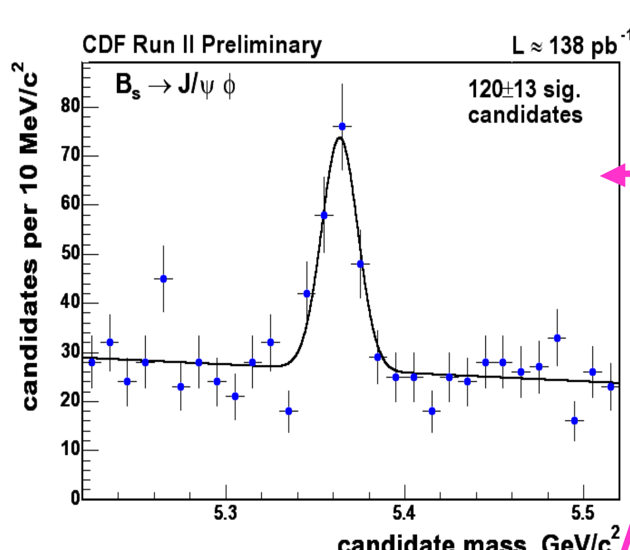
Semileptonic:
lepton+displaced track trigger
- clean
- partially reconstructed
  - need MC to unfold ct
- lifetime biased
- good statistics

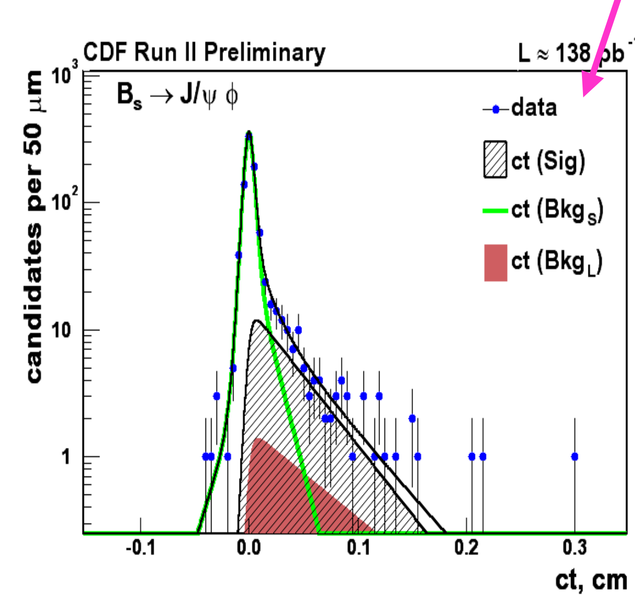


- Reconstruct decay length by vertexing
- Measure p_T of decay products

$$ct = \frac{L_{xy}m(B)}{p_T(B)}$$

Exclusive Lifetime Measurements





Fit Methodology:
Simultaneous fit of
$M(B) \rightarrow$ signal fraction, define sidebands
$ct(B) \rightarrow$ lifetime

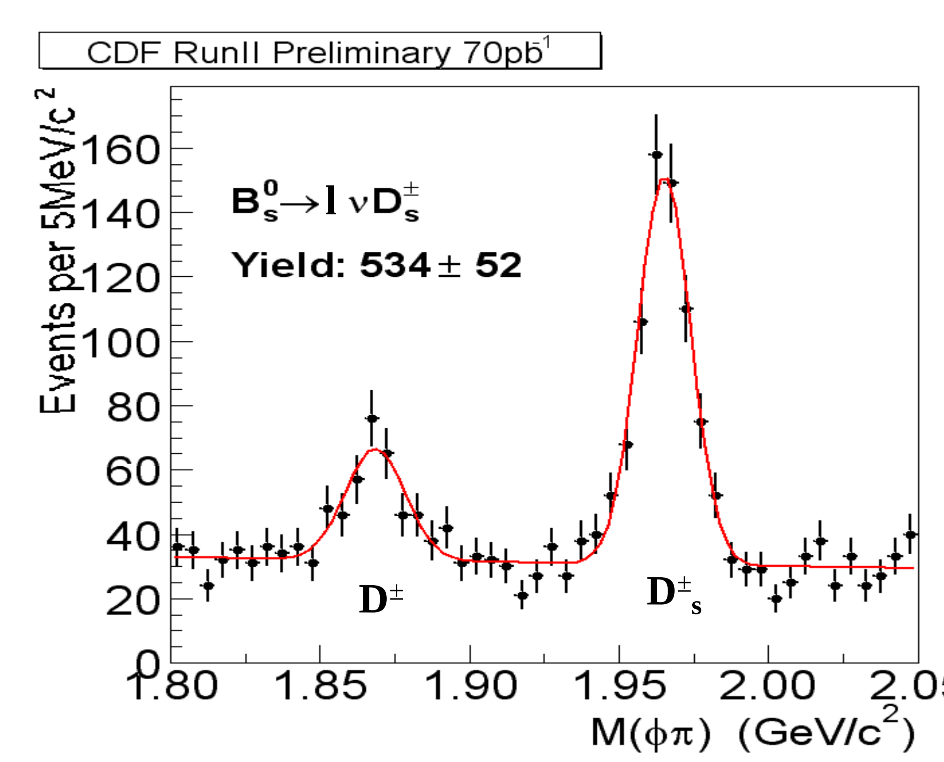
Reconstructed channels:
$B^0 \rightarrow J/\psi\, K^{0*}$
$B^+ \rightarrow J/\psi\, K^+$
$\Lambda_b \rightarrow J/\psi\, \Lambda$
$B^0_s \rightarrow J/\psi\, \phi$

CDF Run II Preliminary	
B^+	1.63±0.05±0.04 ps
B^0_d	1.51±0.06±0.02 ps
B^0_s	1.33±0.14±0.02 ps
Λ_b	1.25±0.26±0.10 ps

Semileptonic Lifetime Measurements

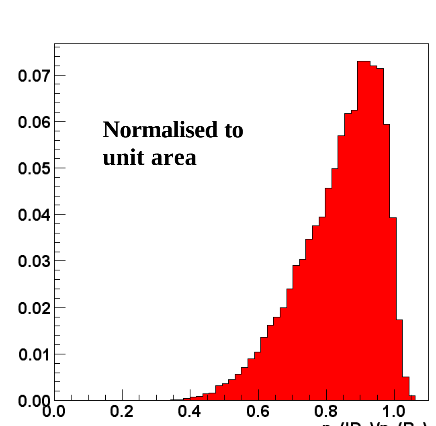
Lepton+ displaced track trigger implemented successfully for the first time!
$\rightarrow$ samples rich in B hadron semileptonic decays

Follow the standard methodology:
- reconstruct the D decay near to lepton



- B decay not fully reconstructed

$\rightarrow$ extract the bg factor from Monte Carlo:



- extract lifetime from decay length:

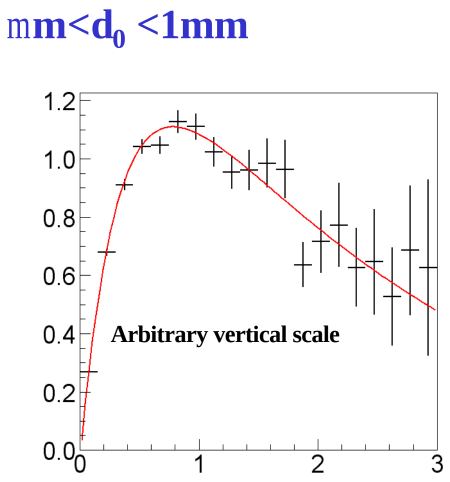
$$ct = \frac{L_{xy}m(B^0_s)}{p_t(B^0_s)} = \frac{L_{xy}m(B^0_s)}{p_t(lD^\pm_s)}K; K = \frac{p_t(lD^\pm_s)}{p_t(B^0_s)}$$

- but:

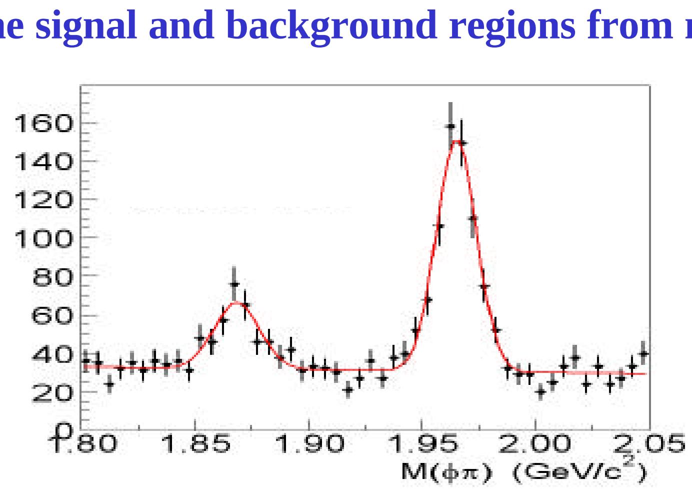
lifetime bias from the displaced vertex trigger:

2 GeV track with 120 μm<d_0 <1mm

→Emulate trigger with Monte Carlo and model the lifetime bias which is factored into the fit function.



Unbinned maximum likelihood fit to $ct(B)$
Define signal and background regions from mass peak:



– Background is parameterised by delta function and positive exp both convoluted with Gaussian resolution:

$$F_{bkg} = \left[(1-f_+)\delta(t-\Delta_D) + \frac{f_+}{t_+}\exp\left(\frac{\Delta_E - t}{t_+}\right)\right]\otimes G(t,s_G)$$

Free parameters: Δ_D Δ_E t_+ f_+ s_G

– Signal: exp convoluted with Gaussian resolution, K factor distribution, P(K), and bias function, e

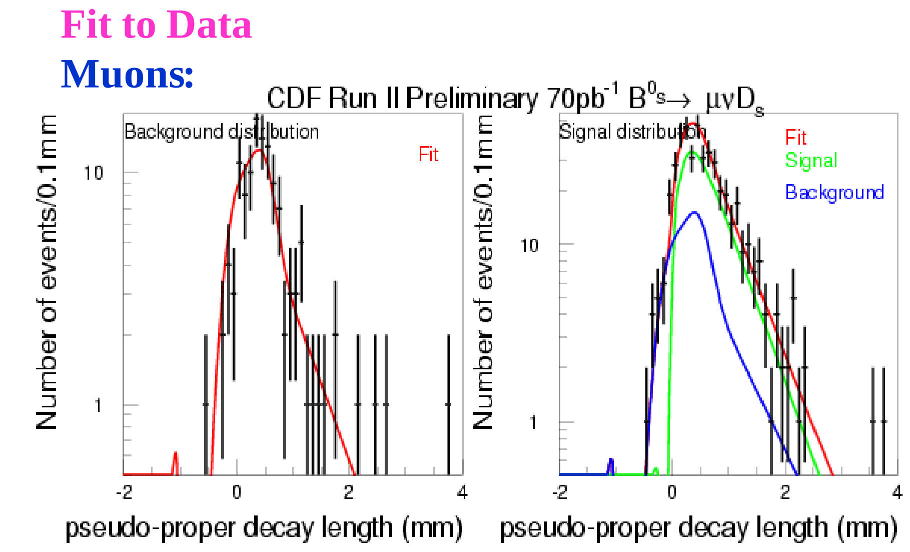
$$F_{sig} = N\frac{K}{ct}\exp\left(\frac{-Kt}{t}\right)e(Kt)\otimes G(t,ss_i)\otimes P(K)$$

– Maximum likelihood function:

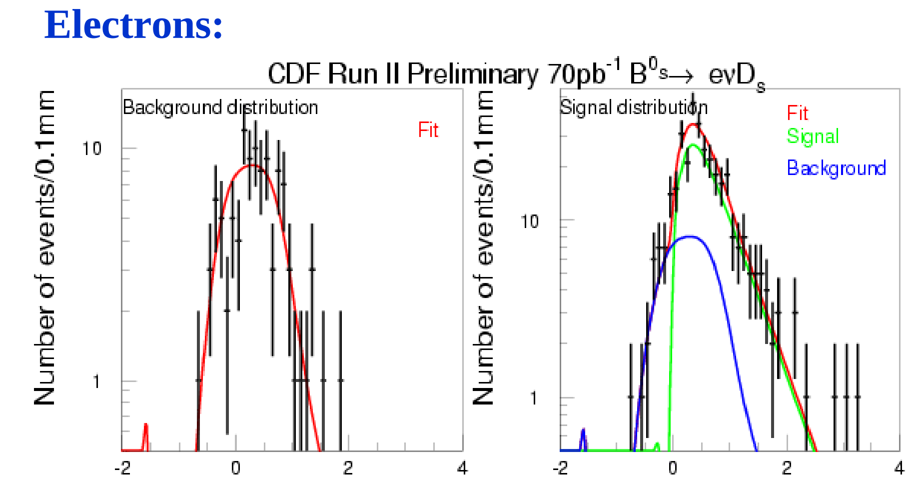
$$L = \prod_i^{N_{sig}}\left[(1-f_{bkg})F^i_{sig} + f_{bkg}F^i_{bkg}\right]\cdot\prod_j^{N_{bkg}}F^j_{bkg}$$

Fit to Data

Muons:



Electrons:



Lifetime statistical error projections	
B^+	± 0.04 ps
B^0_d	± 0.06 ps
B^0_s	± 0.07 ps
Λ_b	± 0.09 ps