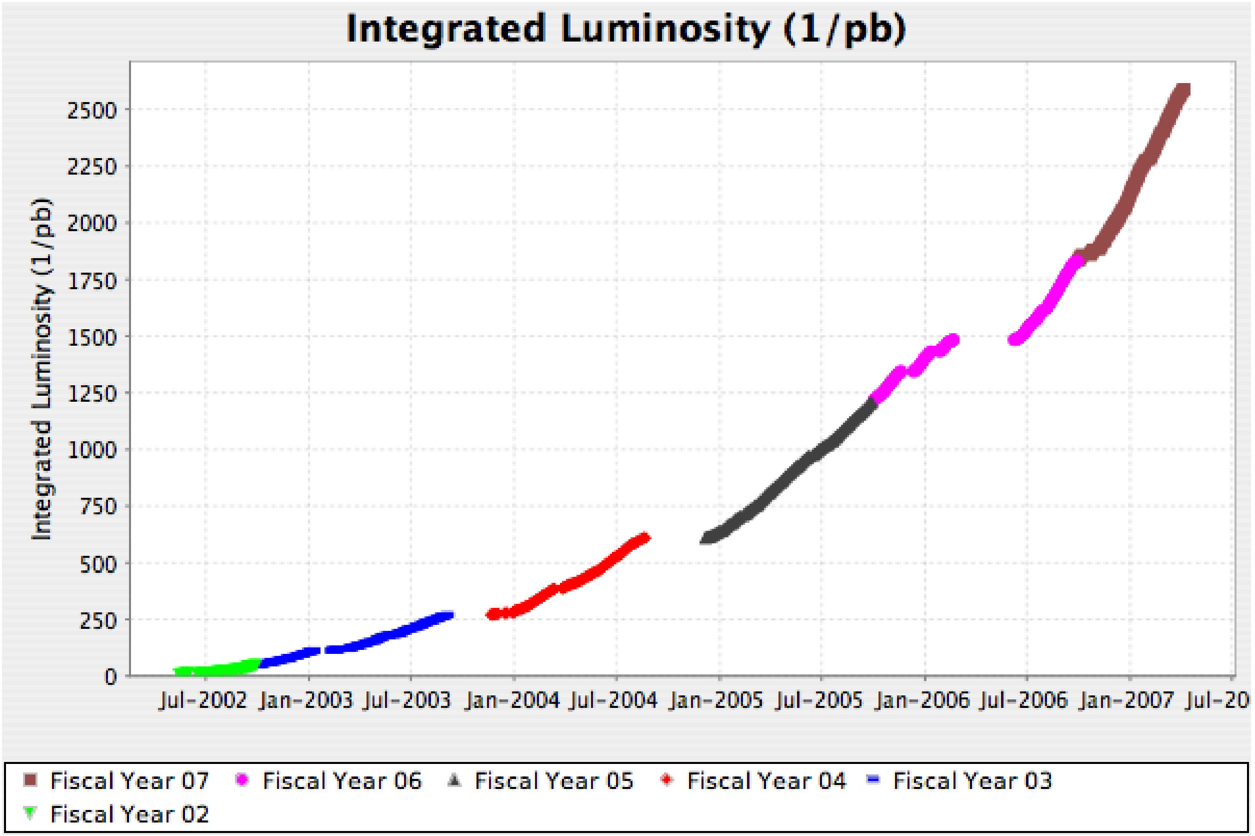
B hadron rare decays and lifetimes

$B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$
B meson and Λ_b lifetimes

Marj Corcoran for the CDF and D0 collaborations

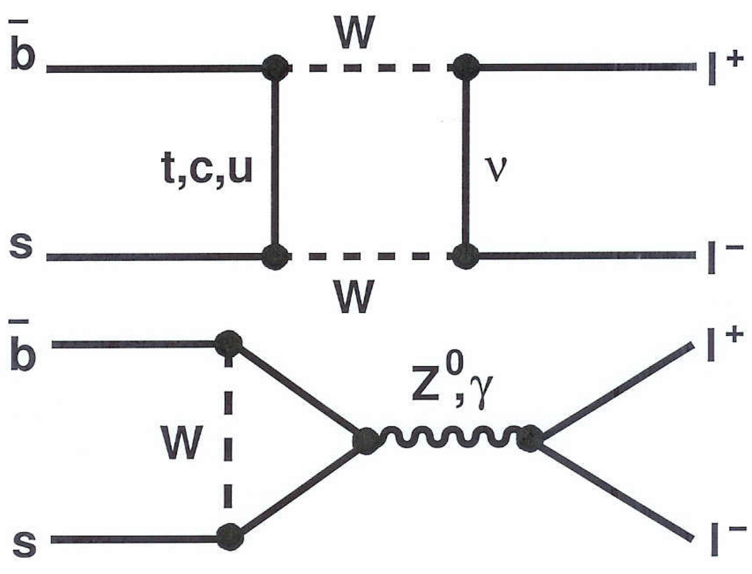
The TeVatron is working well!



Many measurements are now within reach for the first time!

$B_s \to \mu\mu$ and $B_d \to \mu\mu$

$B_s \to \mu\mu$ and $B_d \to \mu\mu$ are FCNC in the Standard Model and are therefore highly suppressed. $B_d \to \mu\mu$ is suppressed even further by V_{td}/V_{ts}.



Standard Model expectations :

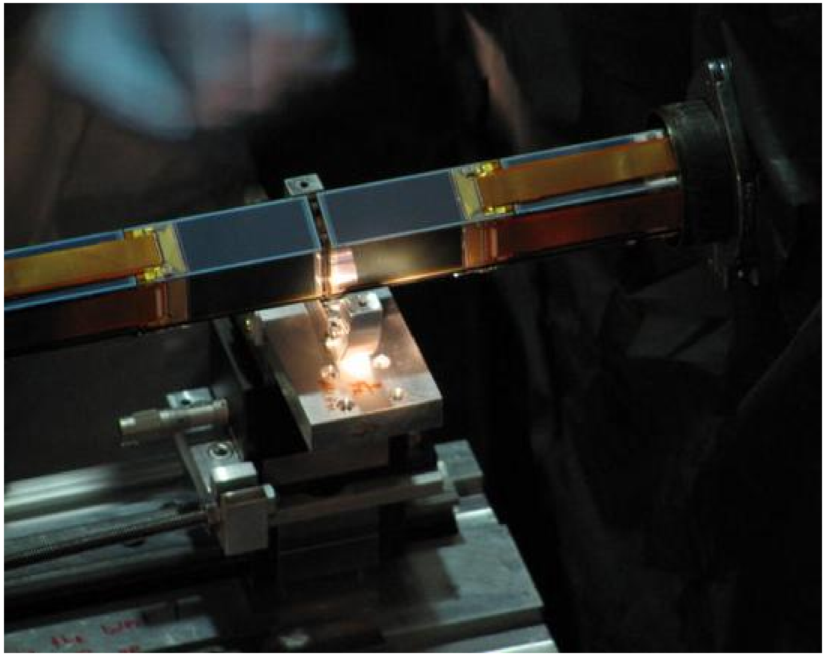
$BR(B_s \to \mu\mu)=(3.42 \pm 0.54) \times 10^{-9}$

$BR(B_d \to \mu\mu)=(1.0 \pm 0.14) \times 10^{-10}$

Many models beyond the SM enhance these BRs by orders of magnitude.

And different models can effect B_d and B_s differently.

$B_s \to \mu\mu$ at D0 –first result using L0!



L0 goes into the heart of D0 in the summer of 2006 with less than 1mm clearance!

RunIIa= pre-upgrade and RunIIb=post-upgrade.

$B_s \rightarrow \mu\mu$ using 2 fb^{-1}

Data selection:

Two muons with p_t>2.5 GeV and $|\eta|$< 2 which form a good vertex

Dimuon mass between 4.5 and 7 GeV

Dimuon p_t > 5 GeV.

For RunIIa, there are 163K candidates

For RunIIb, there are 36K candidates

Early RunIIb data had several problems (firmware, timing).

Some are recoverable, some not, all problems are now fixed.

Many analyses at the TeVatron use likelihood ratios. One selects variables that distinguish between signal and background. For each event calculate

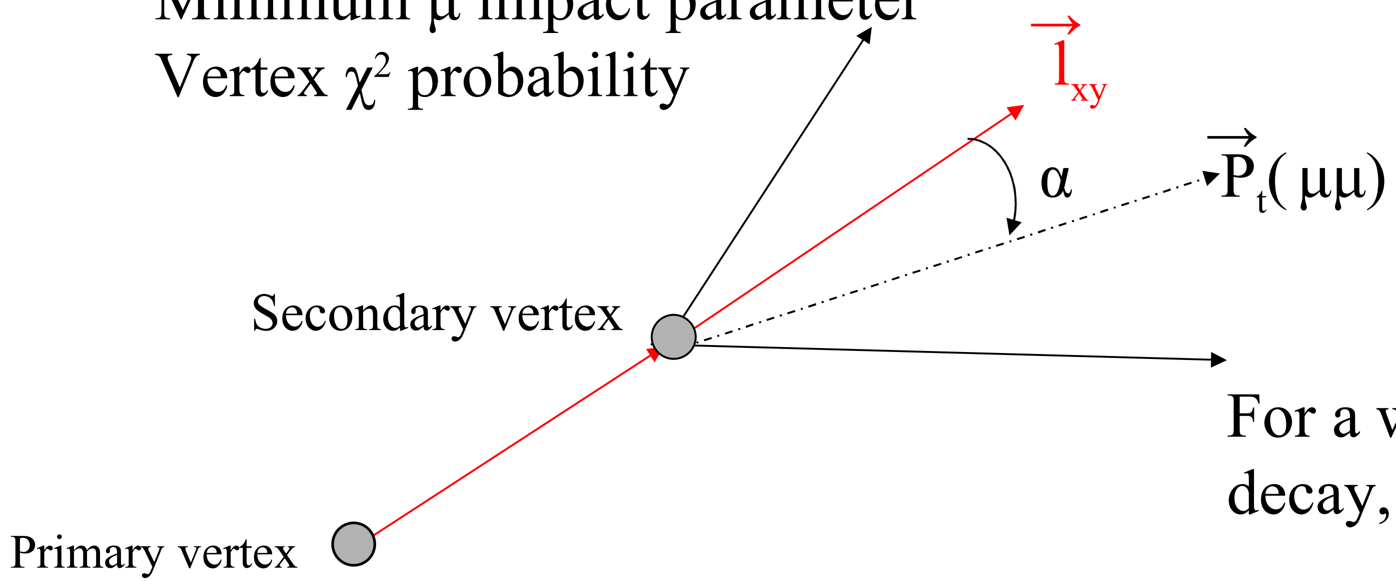
$$LHR = \Pi S_i / (\Pi S_i + \Pi B_i)$$

where S_i and B_i are the probability density functions for signal and background for each variable. LHR should be close to 1 for signal events and close to 0 for background.

$B_s \rightarrow \mu\mu$ using 2 fb^{-1}

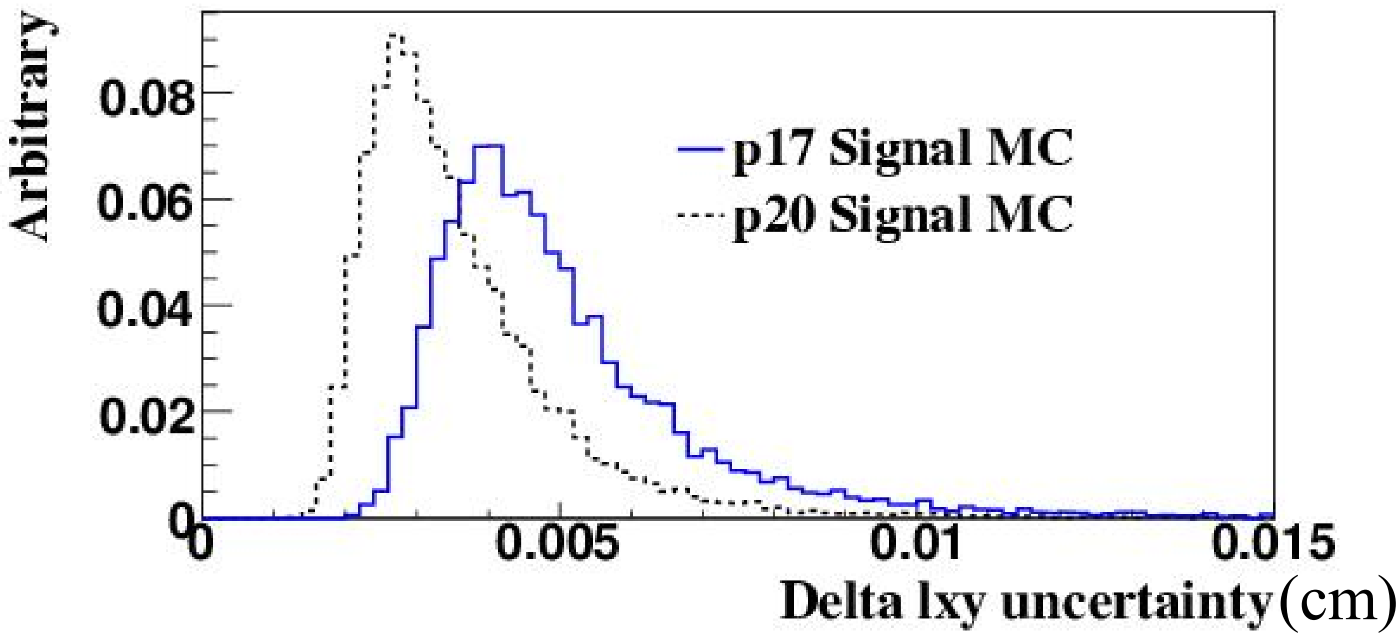
Form a likelihood ratio based on six variables:

- Muon pair isolation ($\Delta R=1$)
- Transverse decay length significance $(l_{xy} \cdot \vec{P}_t)/(|\vec{P}_t|\ \delta_{xy})$
- Pointing angle α (see below)
- B impact parameter
- Minimum μ impact parameter
- Vertex χ^2 probability



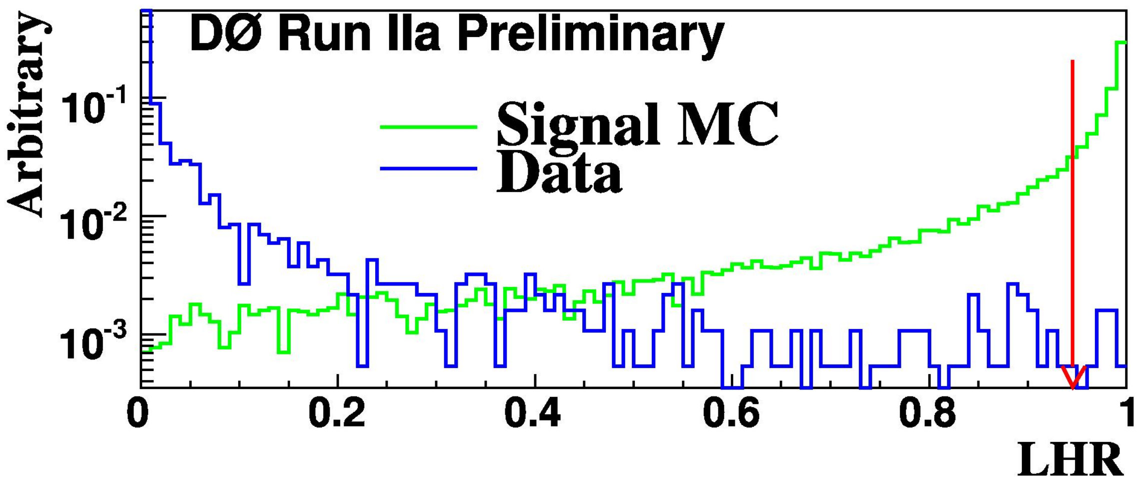
For a well-reconstructed decay, α should be small.

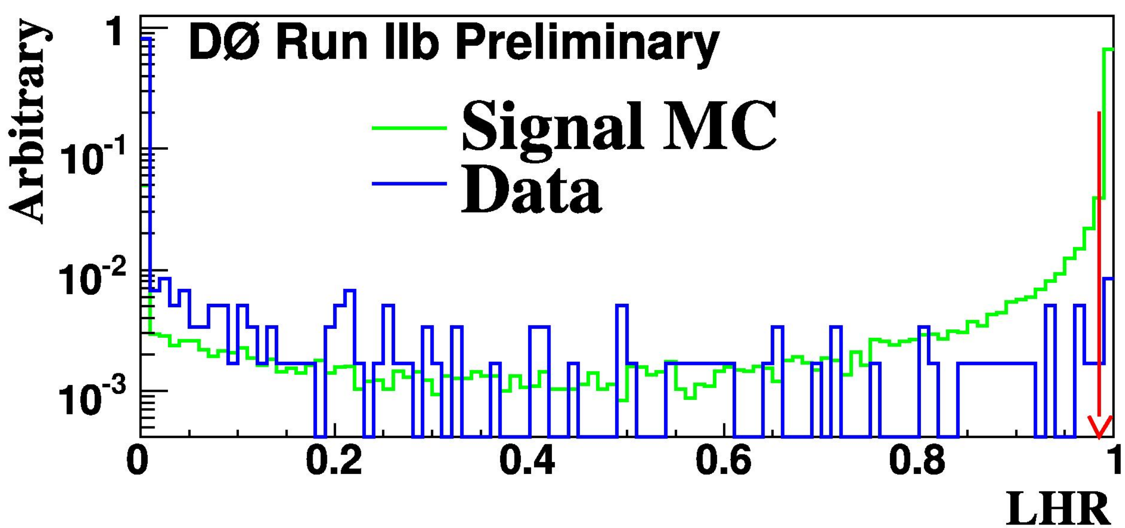
$B_s \rightarrow \mu\mu$ using 2 fb^{-1}



The effects of L0 are apparent in the improved uncertainty in the transverse decay length. "p17" is the pre-L0 data; "p20" is the post-L0 data.

$B_s \rightarrow \mu\mu$





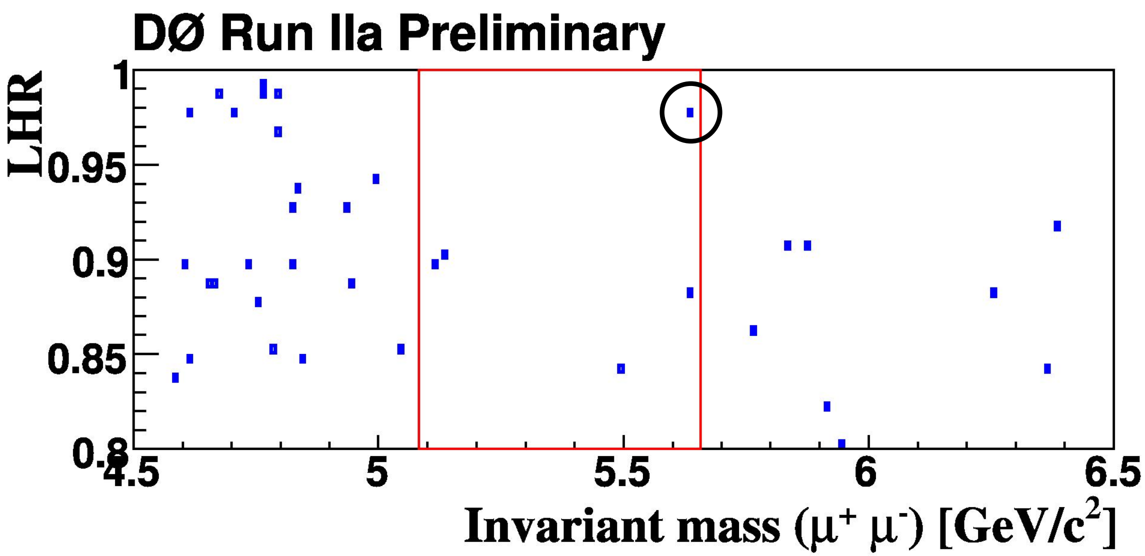
MC distributions are used for the signal; $M_{\mu\mu}$ sidebands are used for the background distributions. The red arrows shows the optimized cut location.

LHR>0.946 for IIa

LHR>0.982 for IIb

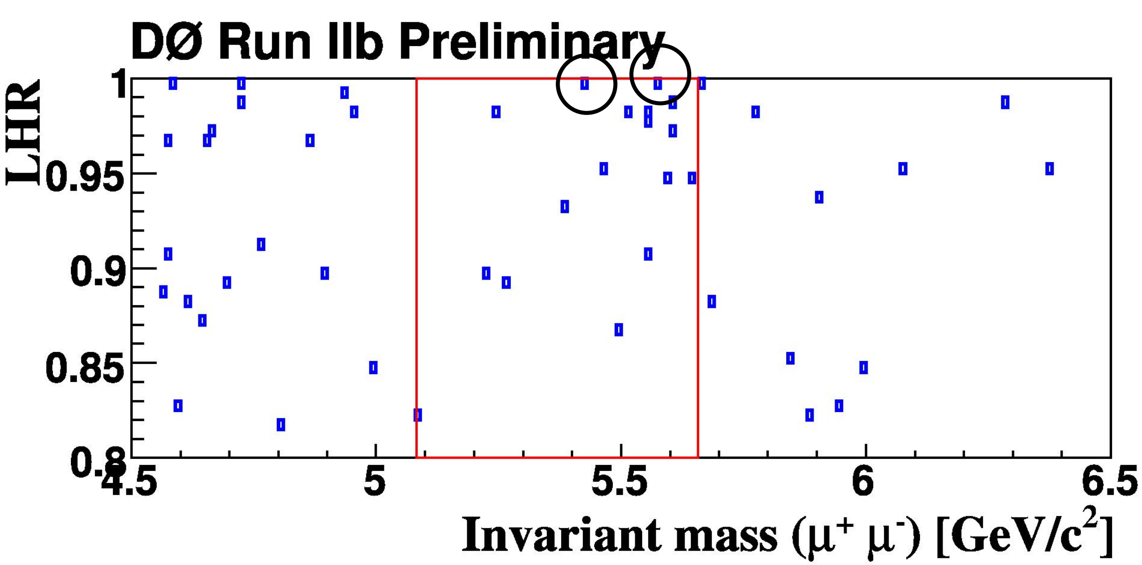
Optimization was done before the signal box was opened!

$B_s \to \mu\mu$ at D0



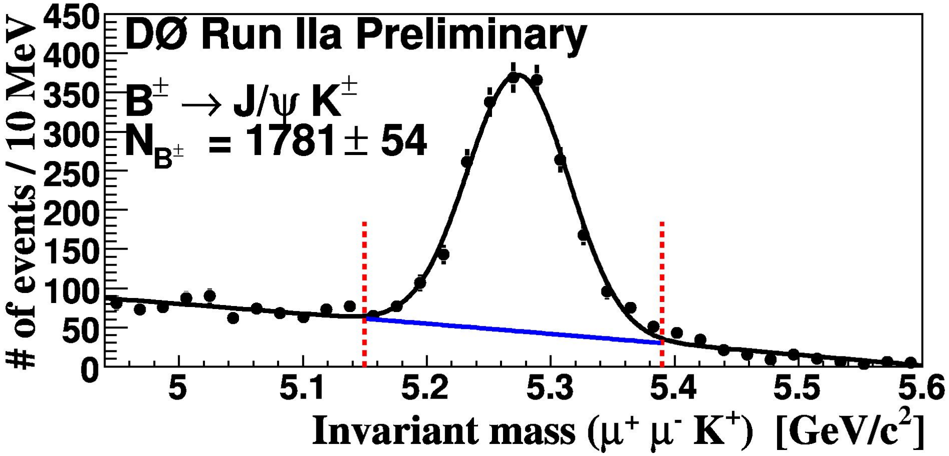
Mass window 5.05-5.62 GeV/c^2

For the pre-upgrade data, there is one event in the signal region in mass and likelihood ratio. Expected background is 0.8 ± 0.2 events.



For the post-upgrade data, there are two events in the signal region, with an expected background of 1.5 ± 0.3 events

$B_s \rightarrow \mu\mu$



Normalization mode is
$B^+ \rightarrow J/\psi\ K^+$ with $J/\psi \rightarrow \mu\mu$

Relative efficiencies of signal and normalization determined from MC.

Preliminary results:

From RunIIa: $BR(B_s \rightarrow \mu\mu) < 9.5 \times 10^{-8}$ at 95% CL

From RunIIb: $BR(B_s \rightarrow \mu\mu) < 4.0 \times 10^{-7}$ at 95% CL

Combined 95% CL limit is 9.3×10^{-8}

Recall that the SM expectation is 3.42×10^{-9}

This limit/SM expectation=27

$B_s \to \mu\mu$ and $B_d \to \mu\mu$ at CDF

CDF's results are based on 780 pb^{-1} of data. They have limits for both B_s and B_d.

Data selection:

The data are divided into two subsets-- one subset with both muons in the central muon system (CMU-CMU), and the second subset with one muon in the central muon extension (CMU-CMX).

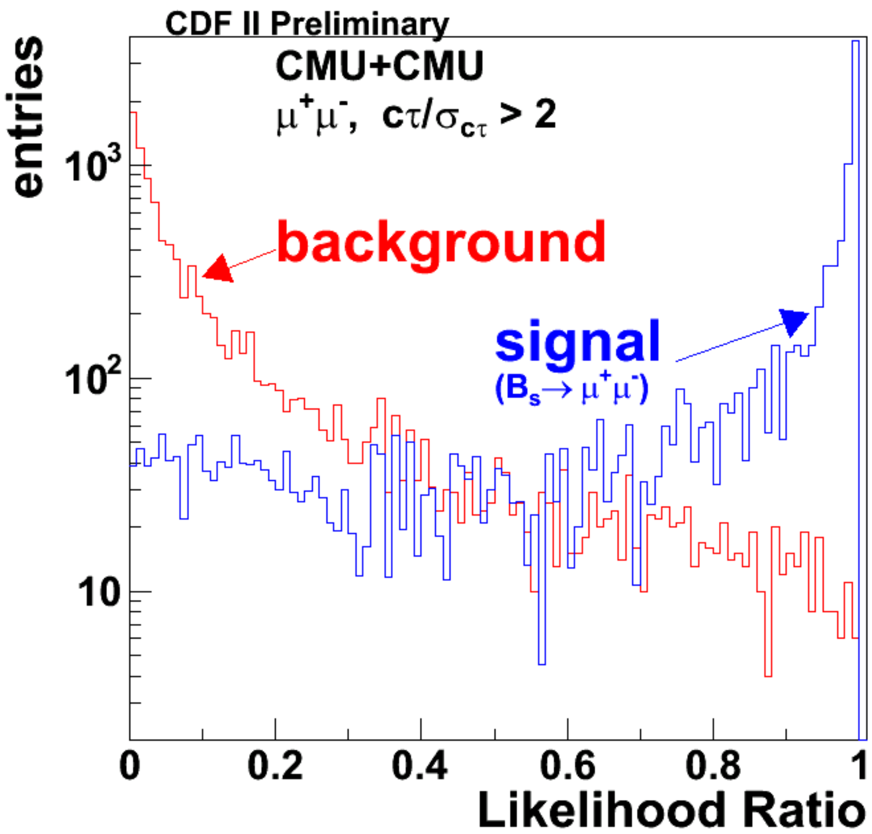
Muon $p_t > 2$ GeV and $|\eta| < 0.6$ in CMU

Muon $p_t > 2.2$ GeV and $0.6 < |\eta| < 1.0$ in CMX

P_t of muon pair > 4 GeV

Muon pair form a good vertex

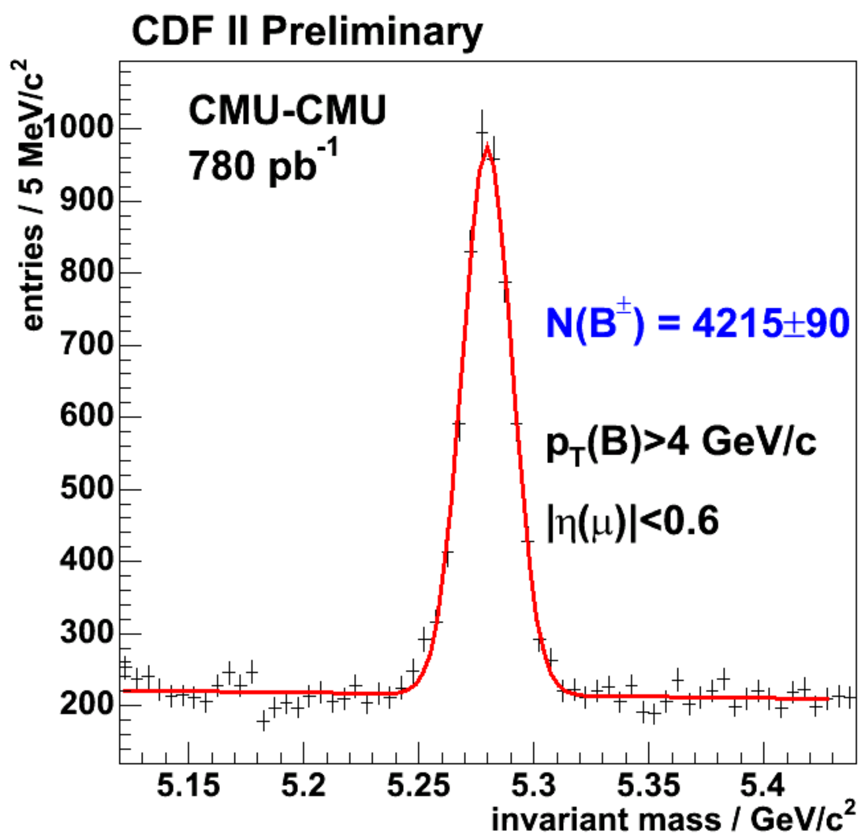
$B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$ at CDF



A likelihood ratio is formed based on three variables: Isolation of the B candidate, 3D pointing angle, and $P(\lambda)=\exp(-\lambda/c\tau_A)$ where $\lambda=c\tau$ for a given event and τ_A is the world average B lifetime.

Background distributions are taken from sidebands in $M_{\mu\mu}$. Signal distributions are from Monte Carlo.

$B_s \to \mu\mu$ and $B_d \to \mu\mu$ at CDF

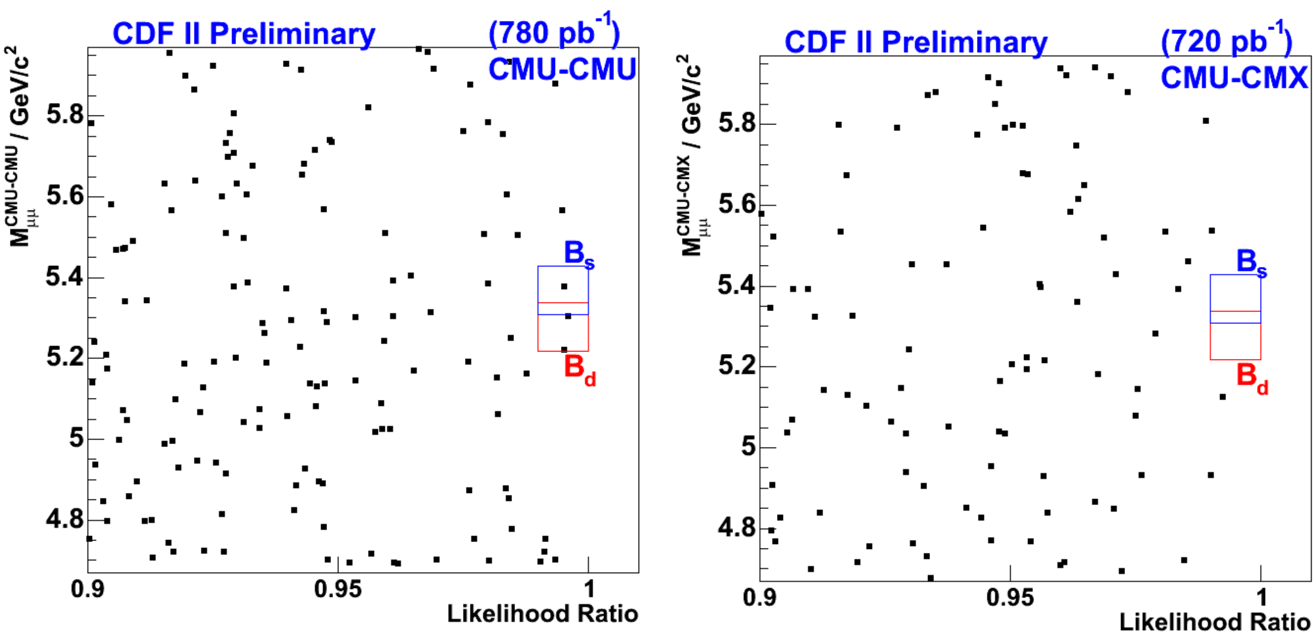


Normalization mode is

$B^+ \to J/\psi K$ with $J/\psi \to \mu\mu$

with relative efficiencies determined by MC.

$B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$ at CDF



Signal region:
LR>0.99
±60 MeV in mass
around known mass
(2.5 σ)

Likelihood ratio vs $M_{\mu\mu}$. One event is observed for $B_s \rightarrow \mu\mu$ and two events are observed for $B_d \rightarrow \mu\mu$. Expected backgrounds are 1.27 ±0.37 for B_s and 2.45 ± 0.40 for B_d.

$B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$ at CDF

Preliminary CDF result for these decays:

$BR(B_s \rightarrow \mu\mu) < 1.0 \times 10^{-7}$ at 95% CL

$BR(B_d \rightarrow \mu\mu) < 2.3 \times 10^{-8}$ at 95% CL.

Recall the SM expectation

$BR(B_s \rightarrow \mu\mu) = 3.42 \times 10^{-9}$ (Limit/SM=29)

$BR(B_d \rightarrow \mu\mu) = 1.0 \times 10^{-10}$ (Limit/SM=230)

B hadron lifetime measurements

B hadron lifetimes can be calculated in Heavy Quark Expansion models. To lowest order all b hadron lifetimes would be the same. To second and third order splittings occur but are expected to be small.

Expect $\tau(B^+) > \tau(B^0) \sim \tau(B_s) > \tau(\Lambda_b)$.

D0 has recent measurements:

- $\Lambda_b \rightarrow J/\psi\Lambda$ with $J/\psi \rightarrow \mu\mu$
- $\Lambda_b \rightarrow \Lambda_c \mu \upsilon X$ (semileptonic)

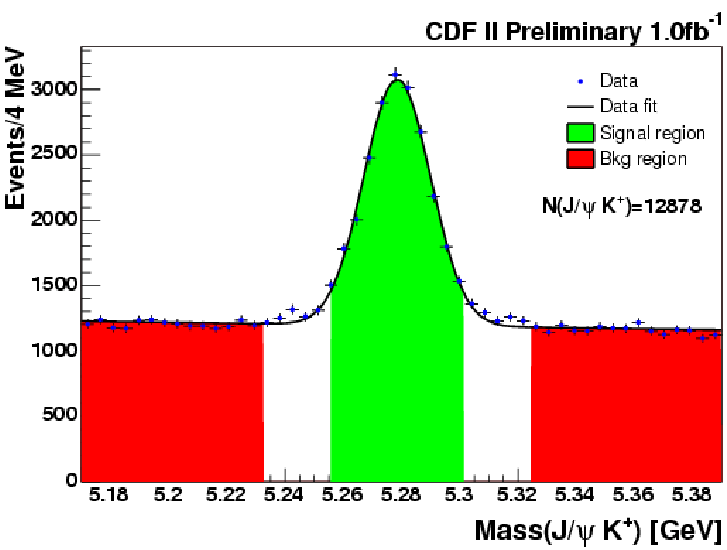
CDF has recent measurements:

- $\Lambda_b \rightarrow J/\psi\Lambda$ with $J/\psi \rightarrow \mu\mu$
- Precision lifetime measurements of B^+, B^0, and B_s.

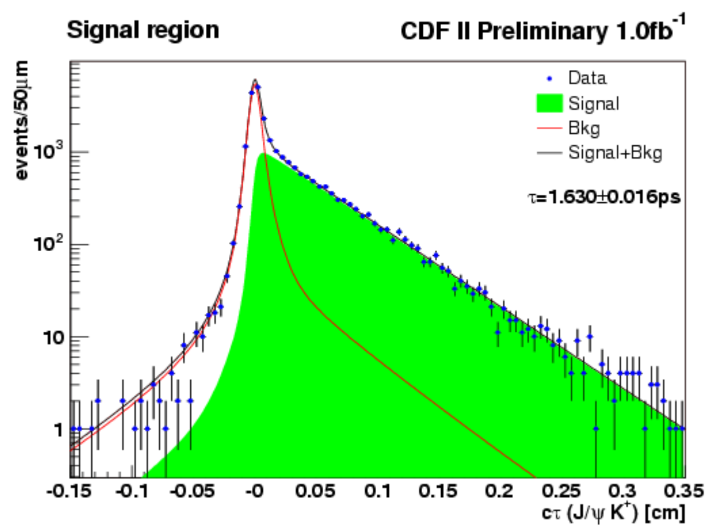
B meson lifetime measurements from CDF

Care in understanding resolution functions and backgrounds yield precision measurements of the B meson lifetimes in these channels, based on 1fb^{-1} of data.

$B^+ \rightarrow J/\psi K^+$ $B^0 \rightarrow J/\psi K^*$ and $J/\psi K_s$ $B_s \rightarrow J/\psi \Phi$



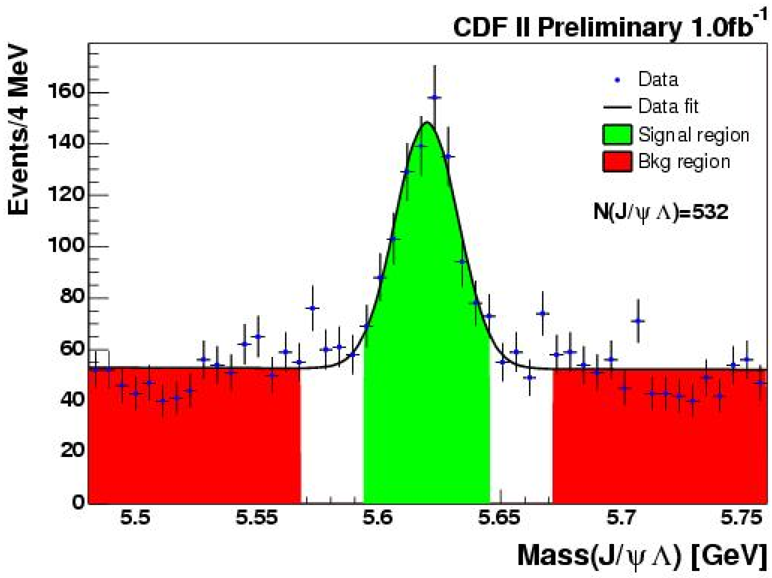
B$^+$ mass showing the sidebands used to estimate the background.



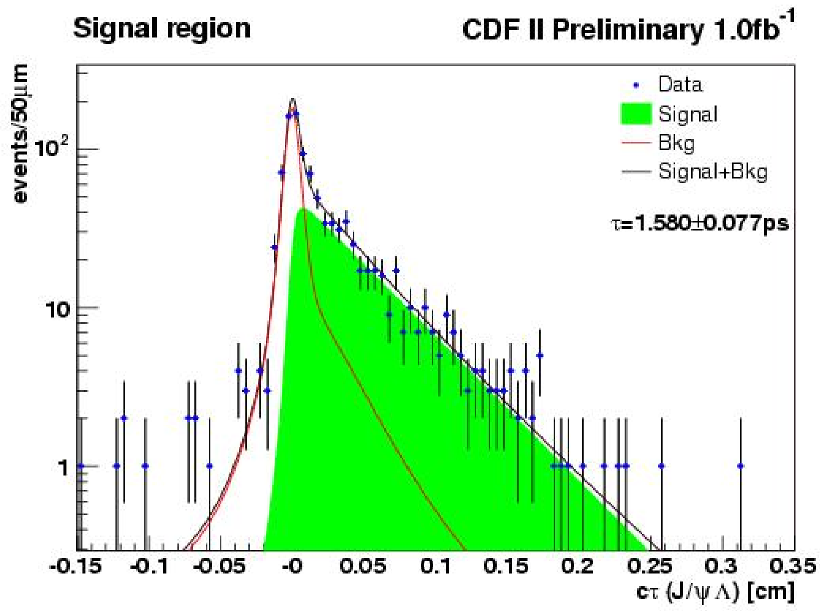
A maximum likelihood fit on three variables (mass, cτ, and error on cτ) yields the lifetime

Λ_b lifetime measurement from CDF

Using the same method as in the high-statistics modes, CDF has measured the Λ_b lifetime in the channel $\Lambda_b \to J/\psi \Lambda$ with $J/\psi \to \mu\mu$ and $\Lambda \to p\pi$, based on $1 fb^{-1}$ of data.



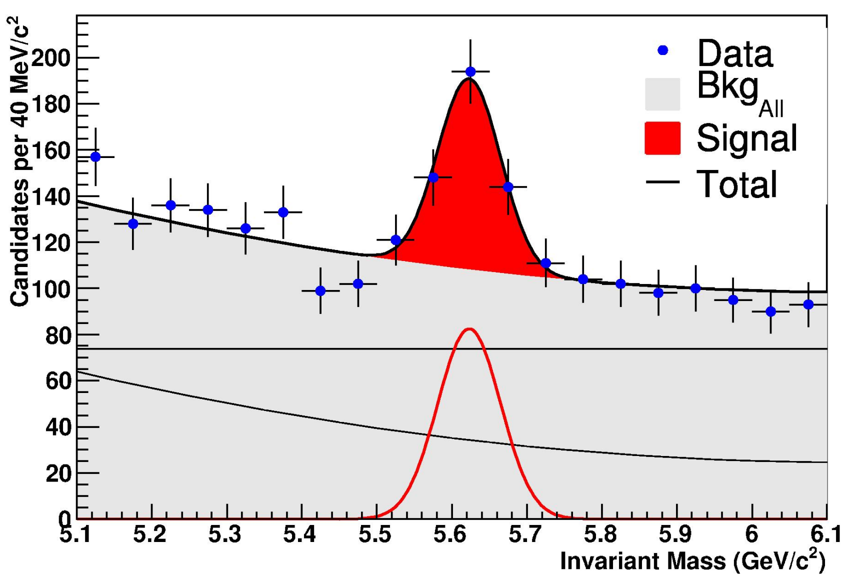
Reconstructed Λ_b mass



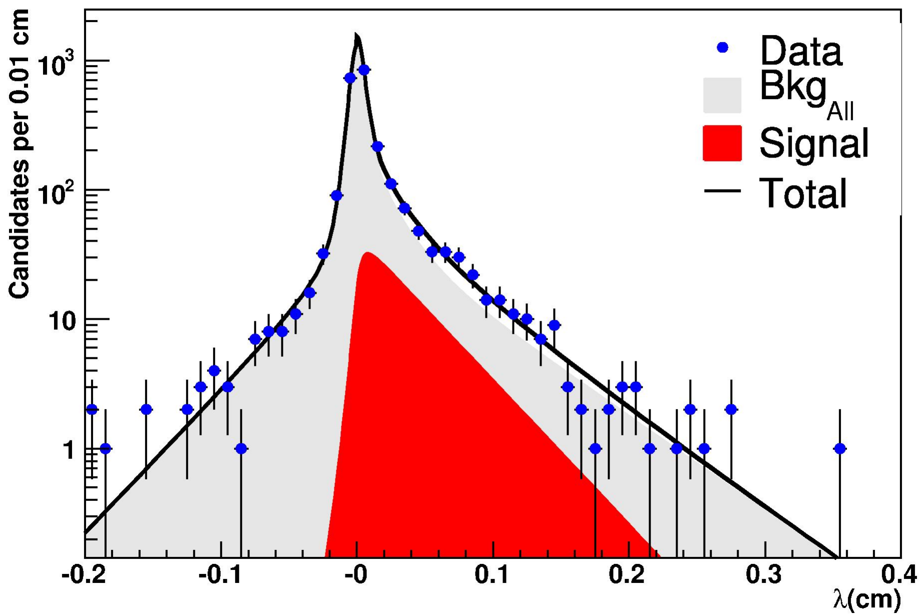
A maximum likelihood fit on three variables (mass, $c\tau$, and error on $c\tau$) yields the lifetime.

Λ_b lifetime measurements from D0

Based on 1fb^{-1}, the Λ_b is observed in the decay $\Lambda_b \rightarrow J/\psi\Lambda$ with $J/\psi \rightarrow \mu\mu$ and $\Lambda \rightarrow p\pi$. A B^0 lifetime measurement is also made with this dataset.



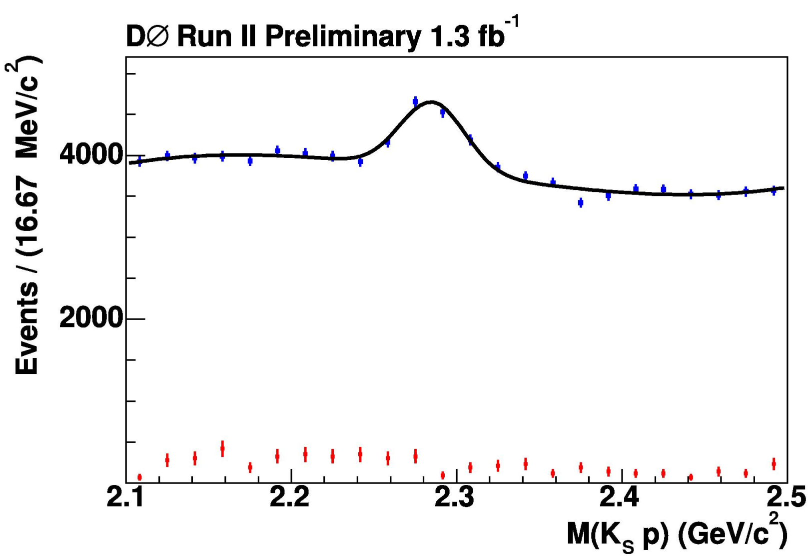
Λ_b mass, 174 ± 21 events



Maximum likelihood fit using the proper decay length and mass yields the lifetime.

Λ_b lifetime measurement in the semileptonic channel

D0 has also made a measurement of the Λ_b lifetime in the semileptonic channel $\Lambda_b \rightarrow \Lambda_c^+ \mu^- \bar{\upsilon} X$ with $\Lambda_c^+ \rightarrow pK_s$

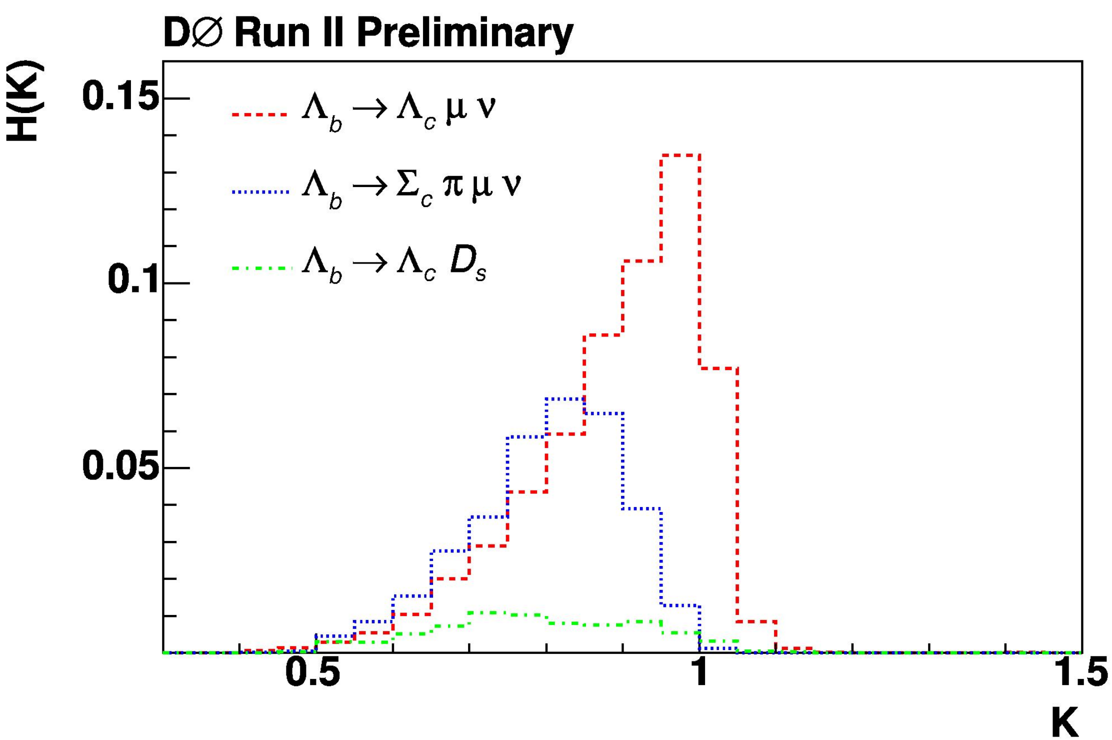


Example Λ_c mass plot for one bin of visible decay length.

Backgrounds are reduced by requiring a minimum distance between the Λ_b and Λ_c vertices, and also by using a likelihood ratio with five variables (isolation of the Λ_b; P_t of the K_s, p, and Λ_c; and $M(\Lambda_c\mu)$)

χ^2 fits to the lifetime are done in bins of visible proper decay length.

Λ_b lifetime measurement in the semileptonic channel



K factor contributions for each subprocess.

The visible proper decay length must be corrected for the p_t carried by the unobserved neutrino. The K factor is

$K = p_t(\Lambda_c \mu)/p_t(\Lambda_b)$

and is determined from MC.

The final fit yielded 4437 ±329 Λb events.

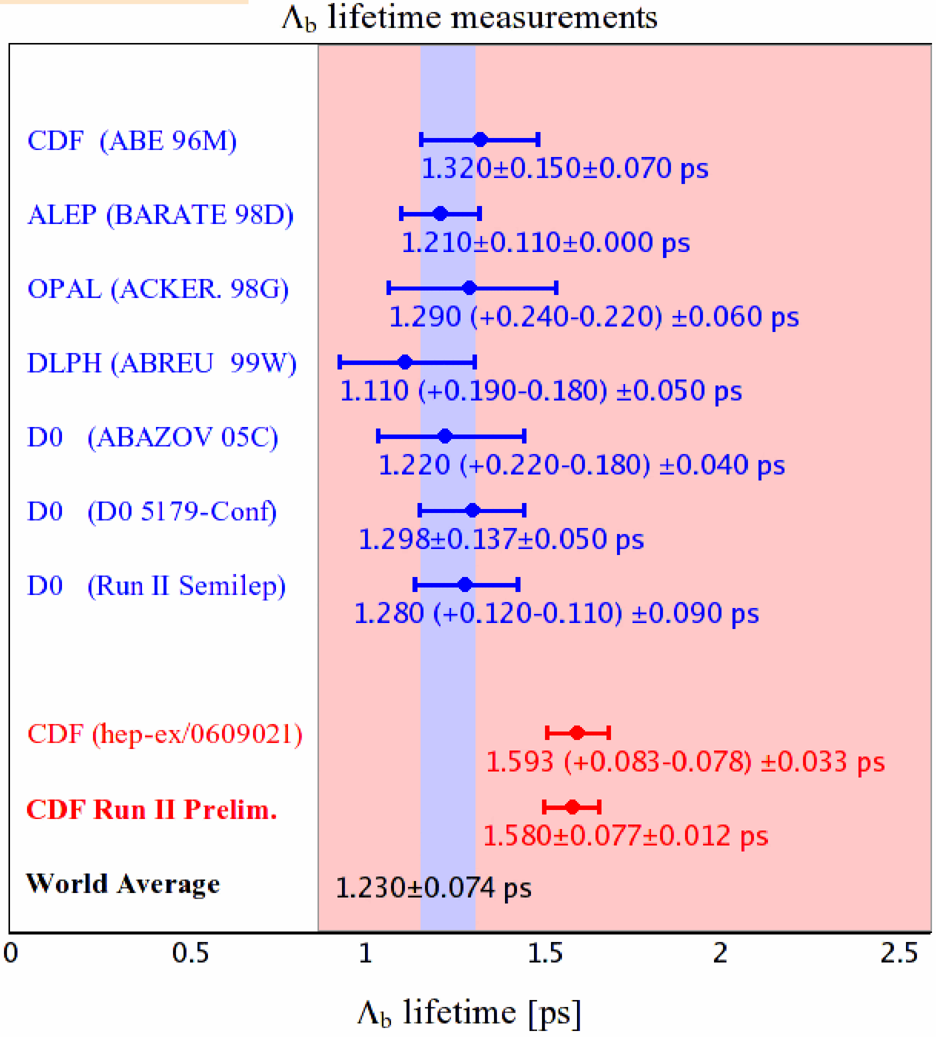
CDF is expected to have a high-statistics Λ_b lifetime measurement in the semileptonic mode soon.

Λ_b lifetime summary

Recent D0 and CDF measurements are **preliminary**.

The world average does not include the most recent measurements.

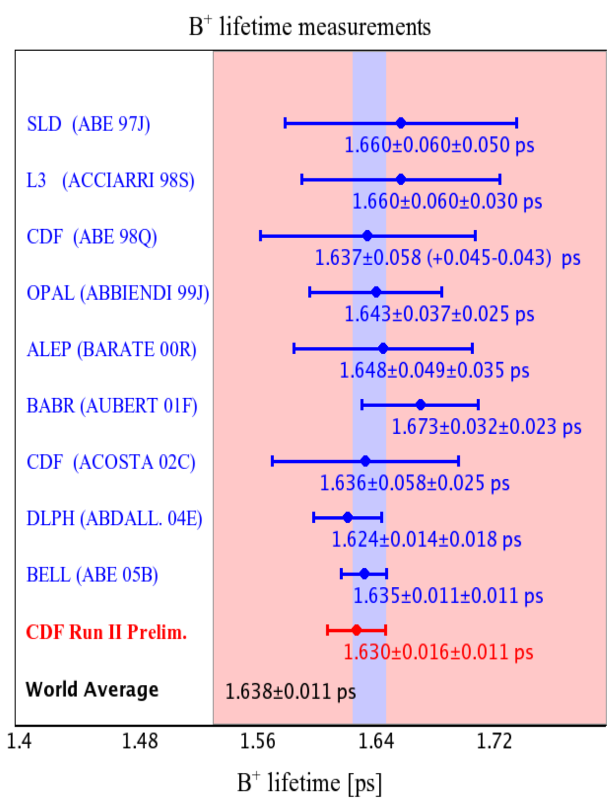
There appears to be a discrepancy of about 3.2 sigma in Λ_b lifetime measurements from the world average and the most recent CDF measurements.

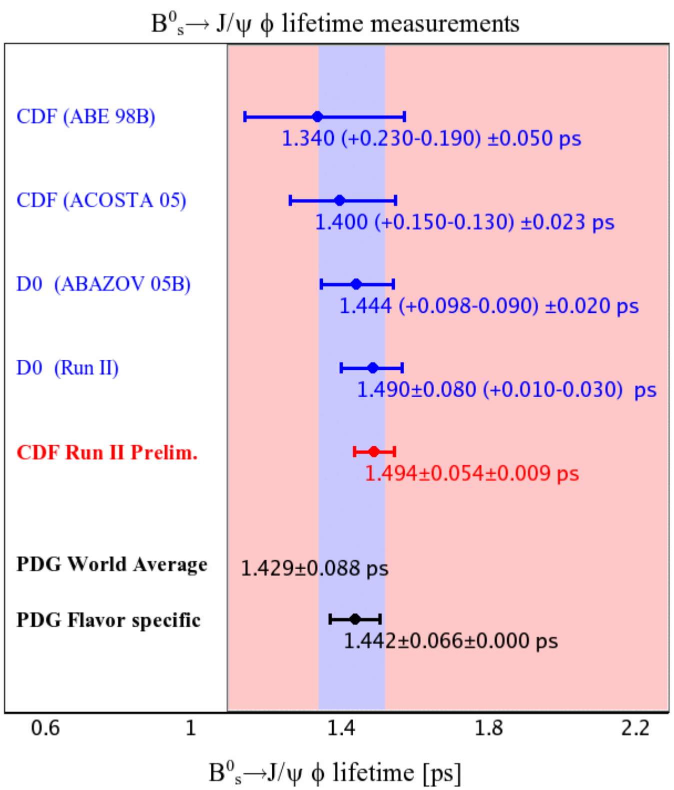


The expected ratio of $\tau(\Lambda_b)/\tau(B^0)$ from HQE is 0.86-0.95.

The PDG value of $\tau(B^0)=1.53\pm0.009$.

B hadron lifetime measurements





Other measurements are in good agreement.

More on B_s lifetimes

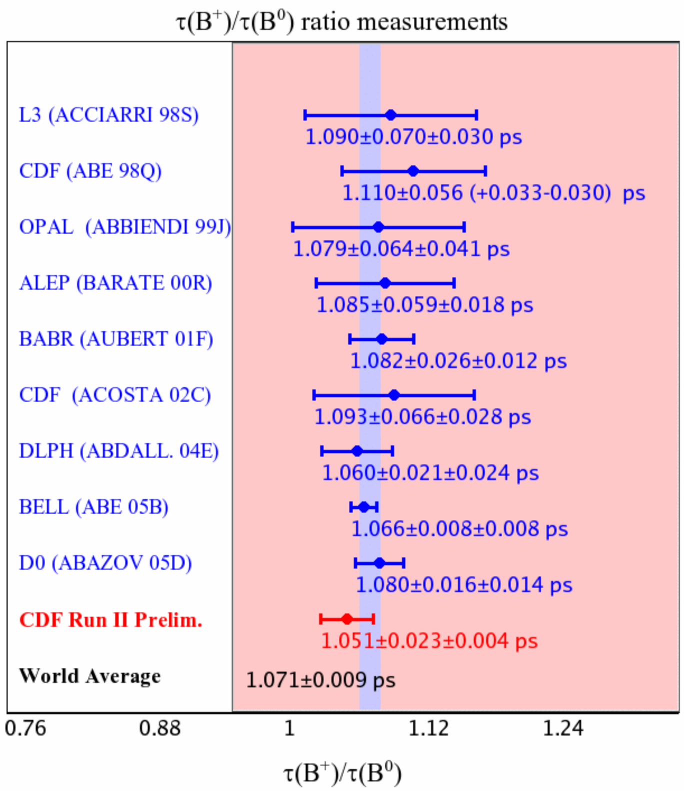
Lifetime measurements have reached the level of precision that we have to be aware of the lifetime difference between the two mass eigenstates, B_{sH} (heavy), and B_{sL} (light).

Semileptonic decays are an equal mixture and would therefore measure the average. Specific final states, such as $J/\psi\Phi$ also measure a mixture but a different mixture.

See Bob Kehoe's talk from Tuesday:

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

B hadron lifetime measurements



The most sensitive comparison to calculations is the ratio, which is in good agreement for B^+ and B^0 mesons.

Expectation from heavy quark expansion for $\tau(B^+)/\tau(B^0)=1.04-1.08$, in good agreement with observation.

Conclusions

Spectacular B physics is being done at CDF and D0!

No new physics yet! (Drat!)

Limits on $B_s \rightarrow \mu\mu$ and $B_d \rightarrow \mu\mu$ are still well above the SM expectation, but they are starting to push on expectations from physics beyond the SM.

Preliminary results, at 95% CL:

$BR(B_s \rightarrow \mu\mu) < 1.0 \times 10^{-7}$ (CDF)

$BR(B_d \rightarrow \mu\mu) < 2.3 \times 10^{-8}$ (CDF)

$BR(B_s \rightarrow \mu\mu) < 9.3 \times 10^{-8}$ (D0)

Unofficial combined limit: $BR(B_s \rightarrow \mu\mu) < 5.8 \times 10^{-8}$

Limit/SM=17

Conclusions 2

Precision lifetime measurements are being made of B mesons and hadrons. These is perhaps a 3 σ disagreement in Λ_b lifetime, otherwise all measurements are consistent.

There are many results I could not show due to time constraints.

In particular CDF has reported the first observation of these charmless rare B decays:

$B_s \rightarrow K\pi$ $\Lambda_b \rightarrow p\pi$ $\Lambda_b \rightarrow pK$

$BR(B_s \rightarrow K\pi) = (5.0 \pm 0.75\ (stat) \pm 1.0(sys))\ x\ 10^{-6}$

Prospects

These results are based on at most 2fb^{-1} of data; many on 1fb^{-1} or less. Both experiments now have more than 2fb^{-1} recorded, and the data continues to come in at an impressive rate.

Visit the CDF and D0 web sites!
www-cdf.fnal.gov/physics/new/bottom/bottom.html
www-d0.fnal.gov/Run2Physics/WWW/results/b.htm

Thanks to CDF B group for their help!
Thanks to my D0 colleagues who did the work.