New measurement of b-Hadron Lifetimes at CDF

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for the CDF Collaboration

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Why study b-Hadrons ?

- b-hadrons probe a unique region of parameter space (i.e., mass, energy, momentum, velocity) that can be studied using a wide range of tools (potential models, HQET, lattice gauge calculations)

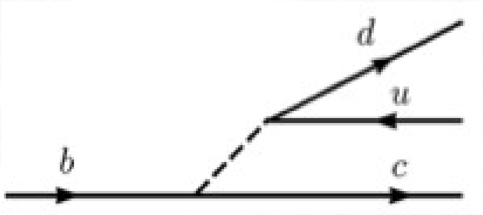
Why b-Hadron Lifetimes ?

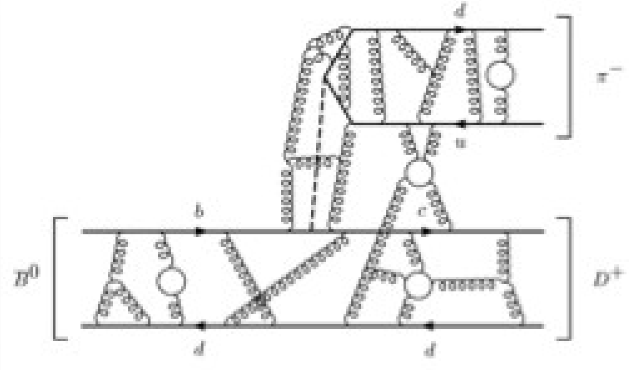
- The measurement of lifetimes (and ratios) can be used to evaluate deviations from the naive spectator quark model : b quark decays like free "particle" => all B hadron lifetimes are equal

b-hadron lifetimes

b-hadrons Lifetime largely determined by charged weak decay of b quark

Interactions of quarks inside hadrons change these lifetimes by up to about 10%





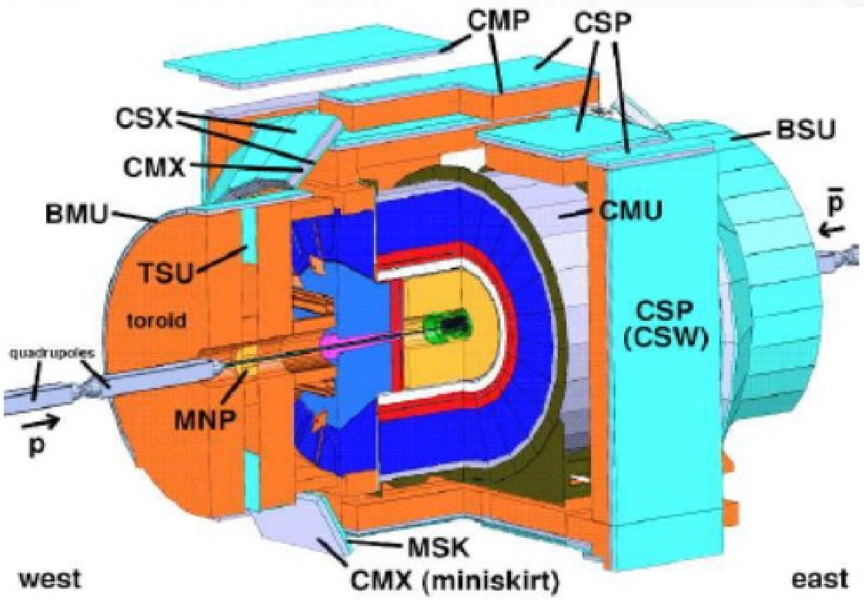
HQE predicts $\tau(B_u) > \tau(B_d) \sim \tau(B_s) > \tau(\Lambda_b) >> \tau(B_c) \rightarrow$ can be proved experimentally

HQE is used to calculate Γ_{12} and semileptonic asymmetry

=> Lifetime measurements allow a test of theory predictions

Introduction to the Tevatron and CDF

- ppbar collisions at 1.96 TeV
- Excellent performance of Tevatron accelerator
- CDF has already>7 **fb^{-1}** on tape (50pb^{-1}/week)
- Expect ~10 fb^{-1} on tape by end 2011
- High cross section σ (**p$\bar{\text{p}}$** $\rightarrow$ **b$\bar{\text{b}}$**) ~ 40 μb at $\sqrt{s}$ = 2 TeV (vs 1 nb at the Υ(4s) resonance)
- Huge bkg to the process σ (**p$\bar{\text{p}}$**$\rightarrow$**b$\bar{\text{b}}$**) in Tevatron:O(0.05 b)
- To overcome the QCD background B hadrons filtered online using selective triggers based on clear signatures, e.g.:
  - events selected by a $J/\psi \rightarrow \mu\mu$ oriented dimuon trigger



CDF detector

- Drift chamber (COT)

$\Rightarrow$ Good tracking resolution

$\Rightarrow$ Important for triggering

- Silicon vertex detector

$\Rightarrow$ Good vertex resolution

- Muon System up to $|\eta| < 1.5$

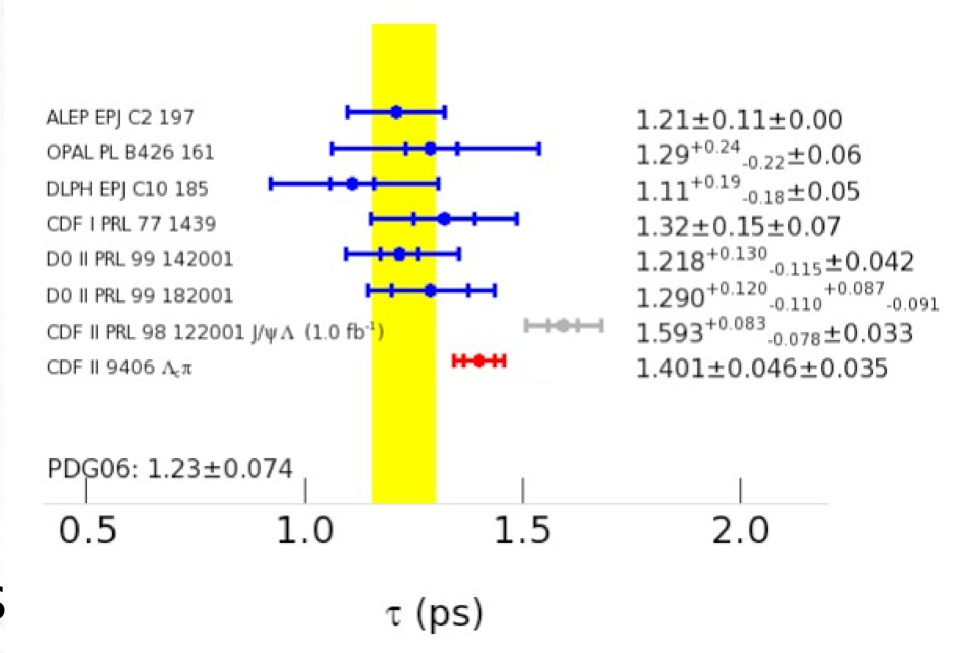
$\Rightarrow$ Important for triggering

Lifetimes in decays with J/Ψ

4 Channels : $B^+ \rightarrow J/\Psi\ K^+$ (4-track 2^{ary} vertex[vtx])
$B^0 \rightarrow J/\Psi\ K^*$ (3-track vtx)
$B^0 \rightarrow J/\Psi\ K_s$ (2-track vtx +displaced vtx)
$\Lambda_b \rightarrow J/\Psi\ \Lambda$ (2-track vtx +displaced vtx)

Uses 4.3fb^{-1} of data
Aims to solve the Λ_b 'puzzle'

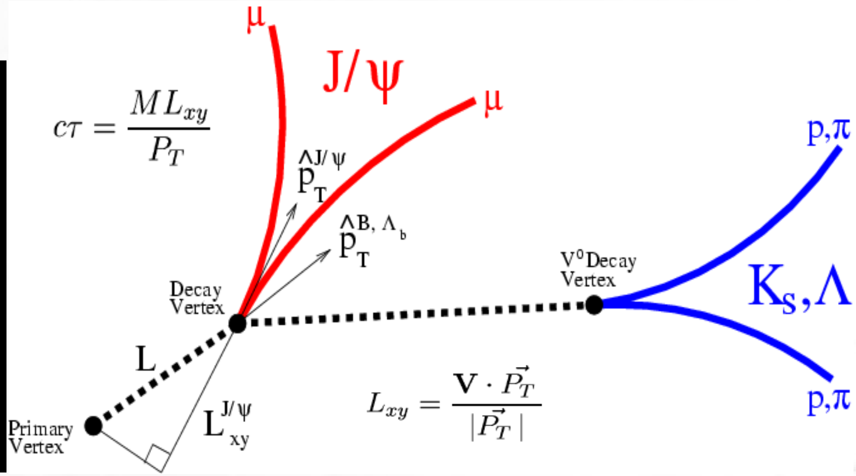
Besides, yield in the control modes gives opportunity for the most precise B^+ and B^0 lifetimes



Analysis strategy

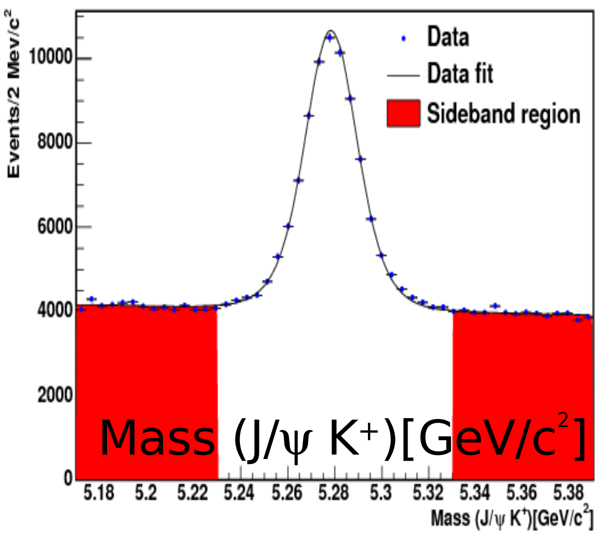
J/ψ→μμ decays used to find large samples of fully reconstructed B decays

$B^+ \to J/\psi K^+$	45000 ± 230
$B^0 \to J/\psi K^*$	16860 ± 140
$B^0 \to J/\psi K_s$	12070 ± 120
$\Lambda_b \to J/\psi \Lambda$	1710+50



Use J/ψ vertex to get the Decay Vertex (L_{xy}) ⇒ similar detector resolution for all channels

Careful and extensively-tested fitting model developed on the decay modes with higher statistics then applied to Λ_b



How do we model this data?

Lifetime extracted from an un-binned likelihood fit, simultaneously in three variables. The likelihood function is a sum of two terms: one for signal and one for the background.

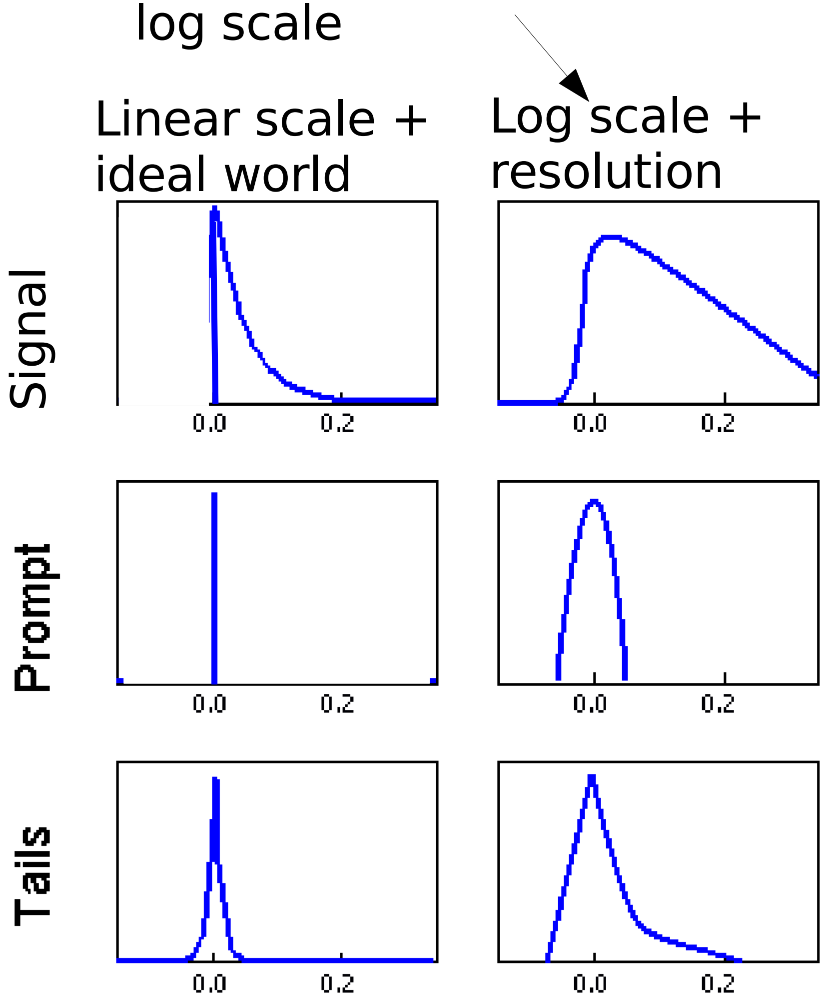
$$\mathcal{L} = \prod [f_s \cdot P_m^s(m \,|\sigma^m) \cdot T_t^s(ct \,|\sigma^{ct}) \cdot S_{\sigma^{ct}}^s(\sigma^{ct})$$
$$+ \; (1 - f_s) \cdot P_m^b(m \,) \cdot T_t^b(ct \,|\sigma^{ct}) \cdot S_{\sigma^{ct}}^b(\sigma^{ct})],$$

The mass (*P*(m)) and the reconstructed proper decay time (*T*(ct)) distributions are described as follows ...

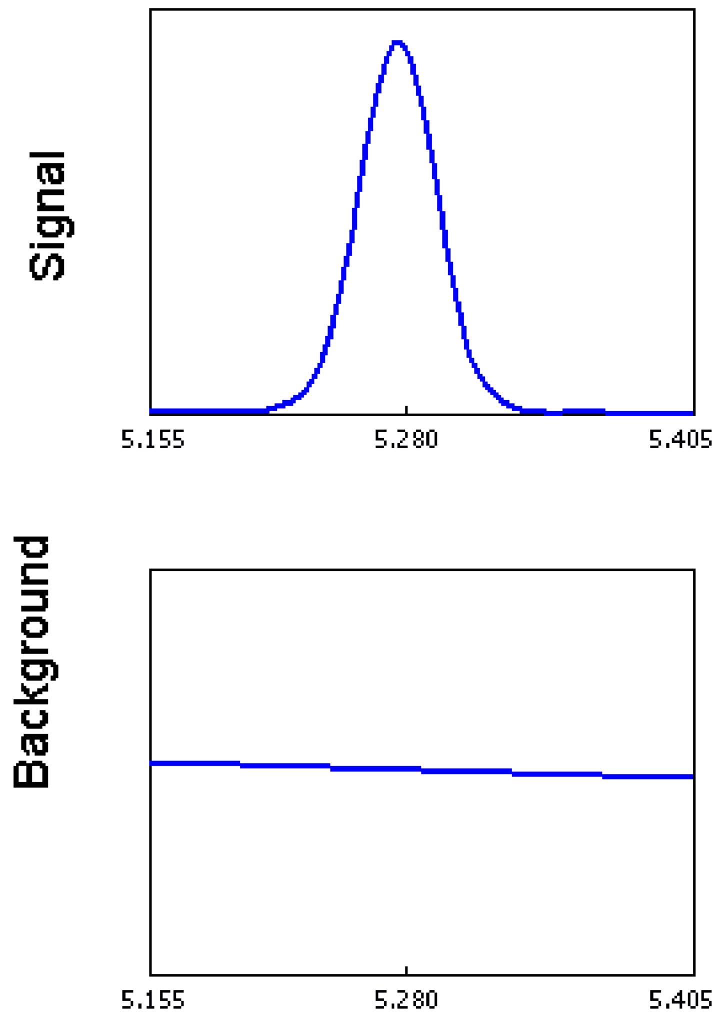
Fitting Model

$c\tau$

Typically show reconstructed proper decay time in log scale

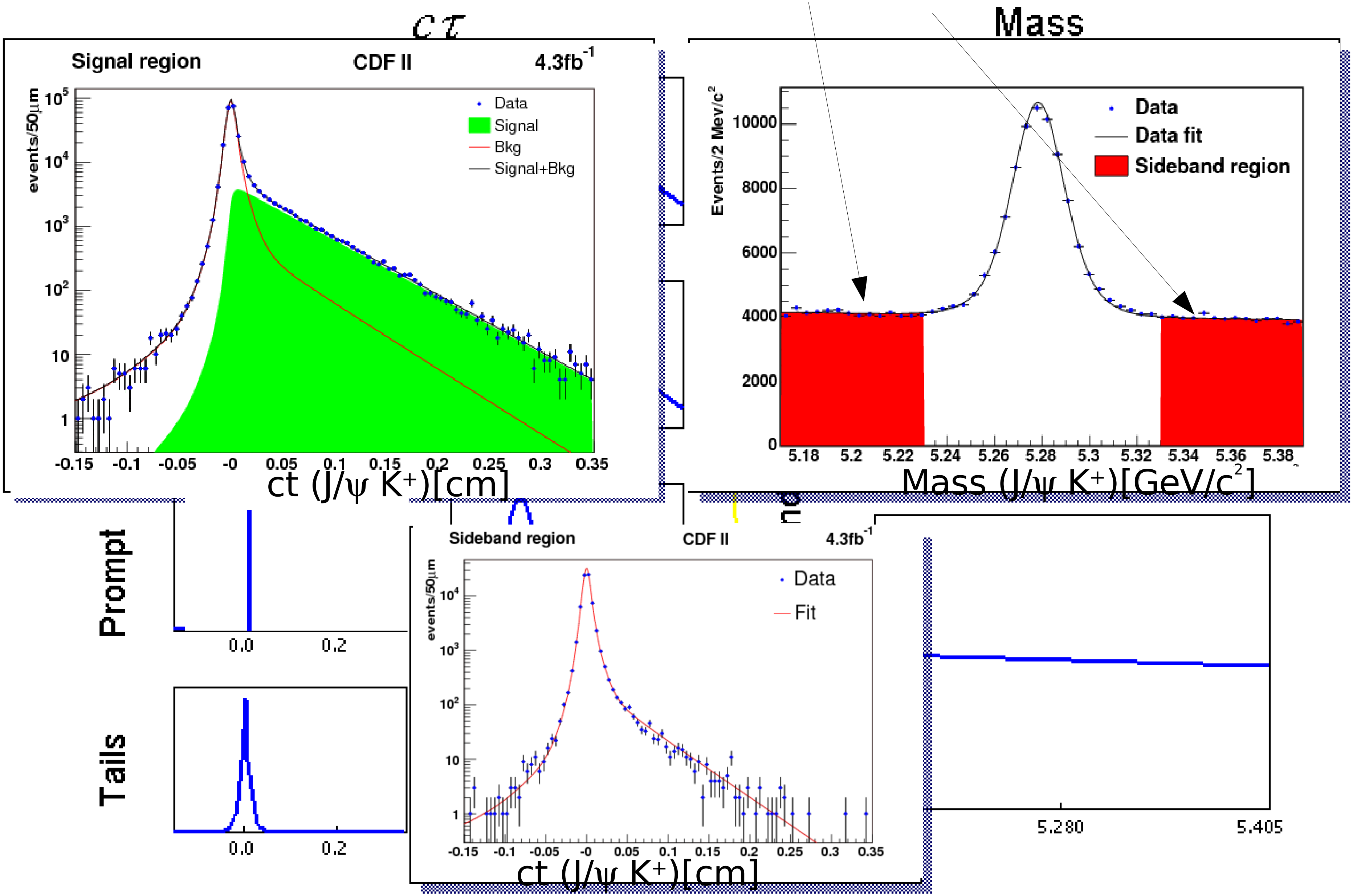


Mass



Fitting Model

We get the resolution model from sideband events.



Controlling systematic uncertainties

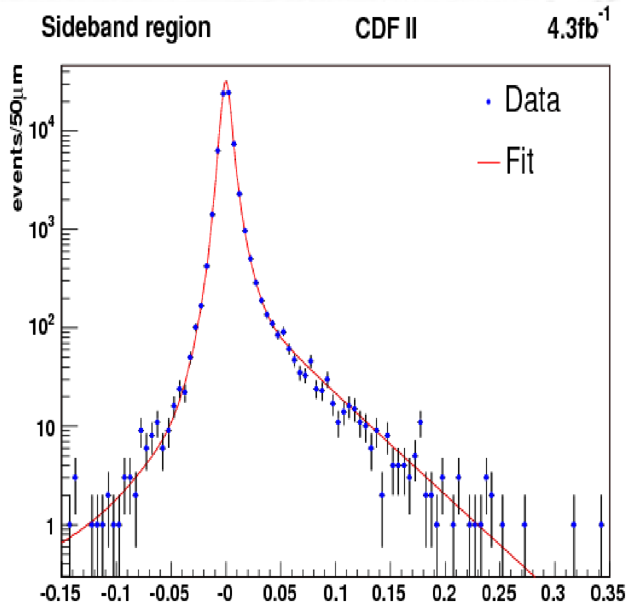
Large yields in B^+ & B^0 $\rightarrow$ Systematically limited using simple modeling of detector resolution. Background is mainly prompt.

Carefully model the mass sideband data $\rightarrow$ extract the scale factors that determine the detector resolution.

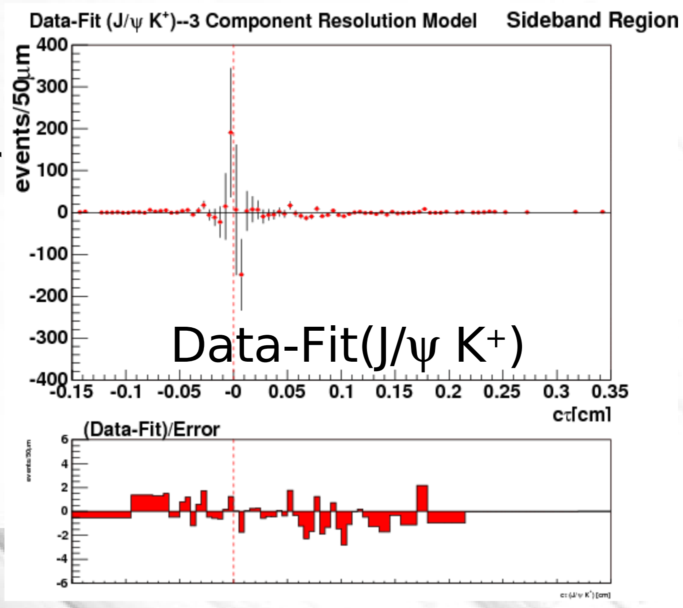
Overall systematic reduction for analysis 0.016 ps $\rightarrow$ 0.008 ps (B^0)

Systematic error now limited by detector alignment (that cancel in ratios)

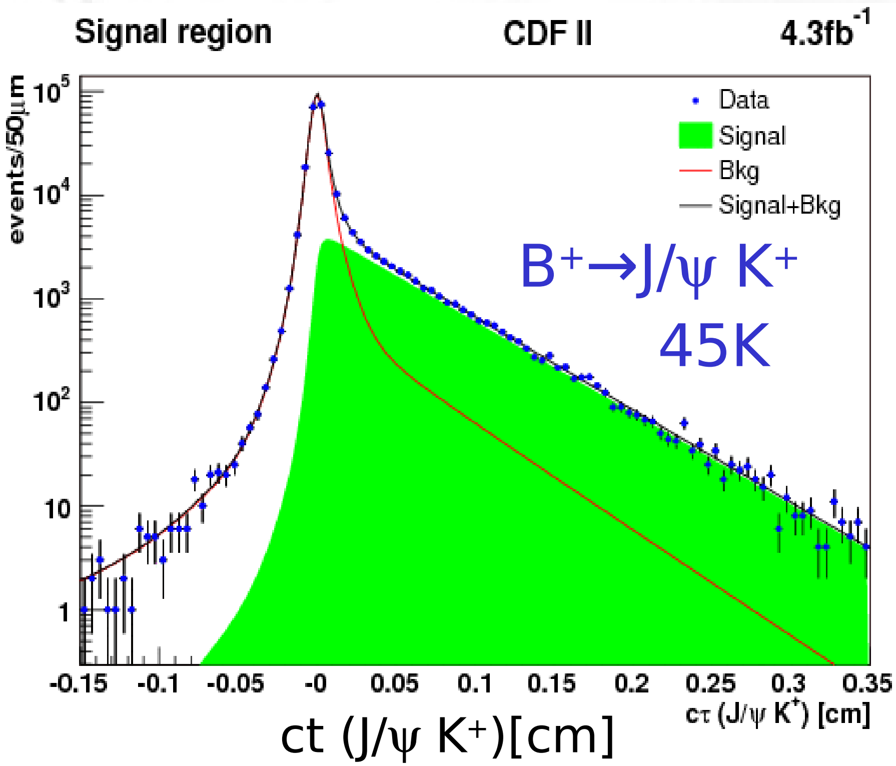
The alignment was determined in MC retracking with different alignment constants ; took largest shift (2 μm)

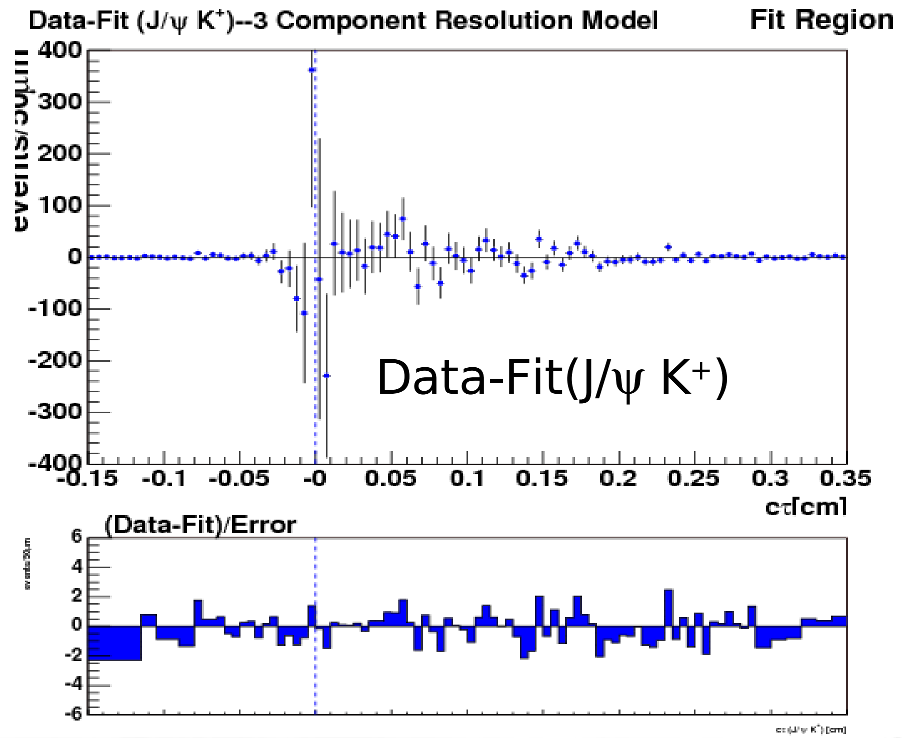


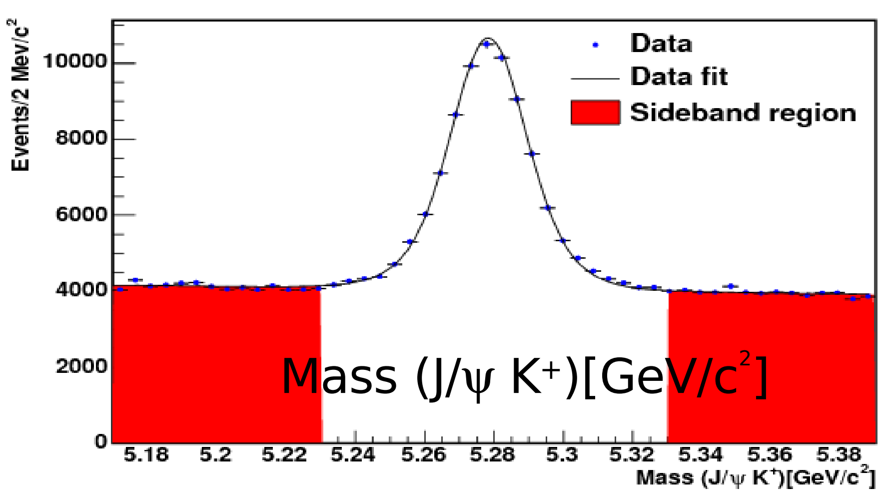
ct (J/ψ K+)[cm]

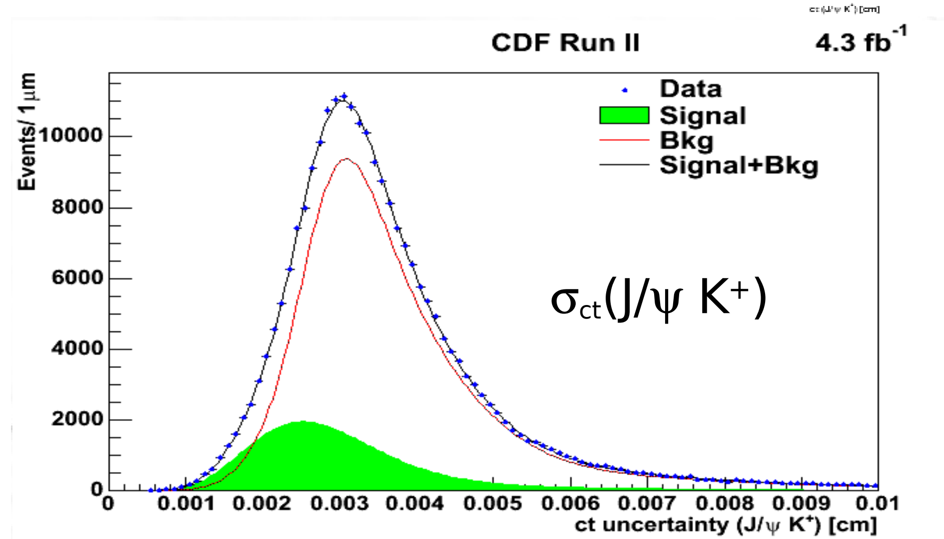


B$^+$ (data and fit projections)

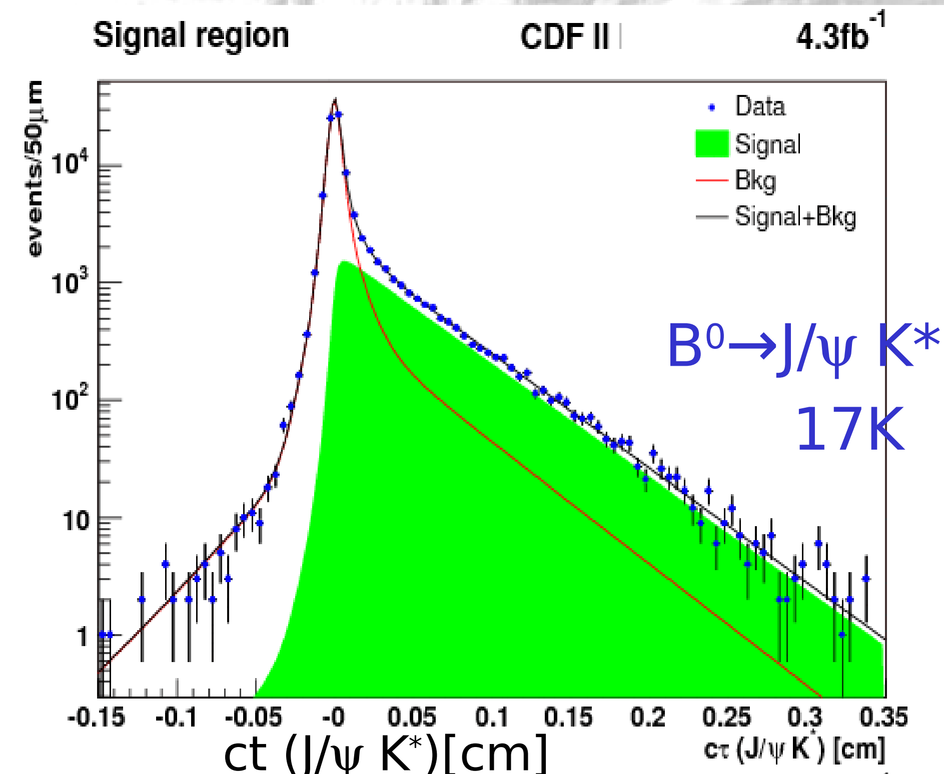


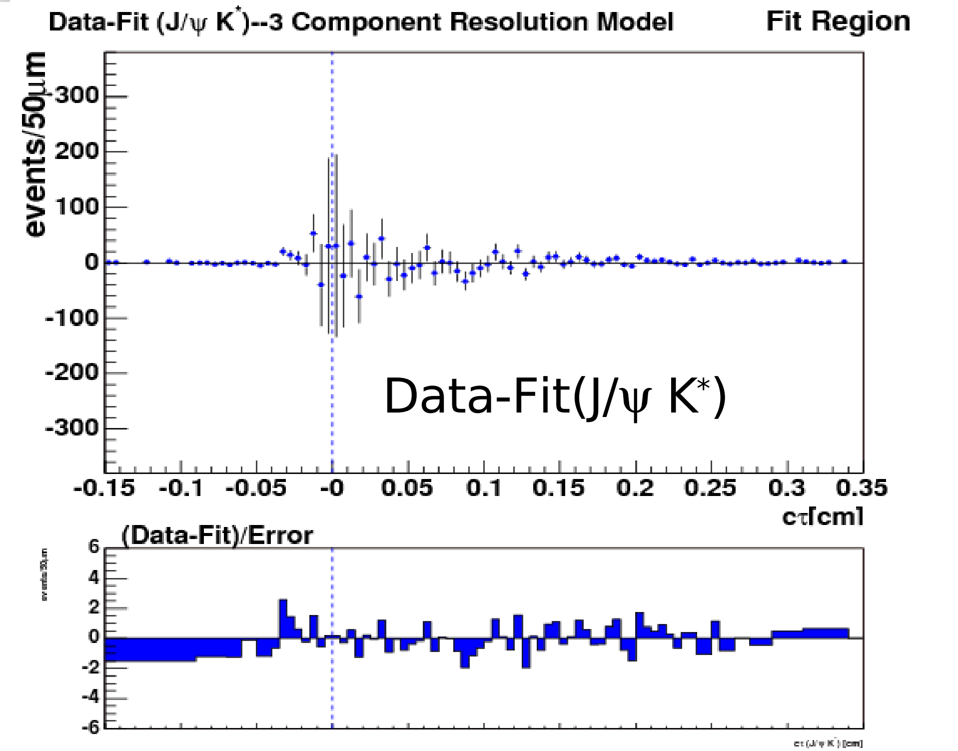


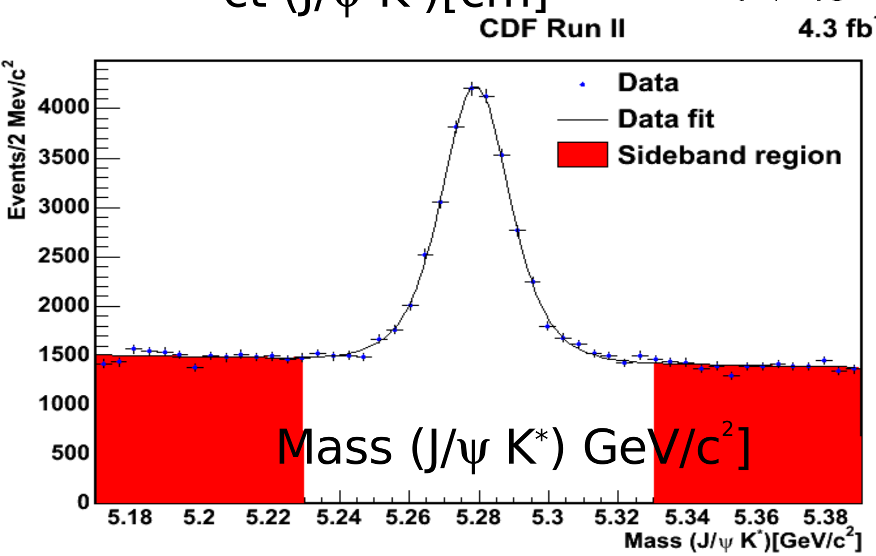


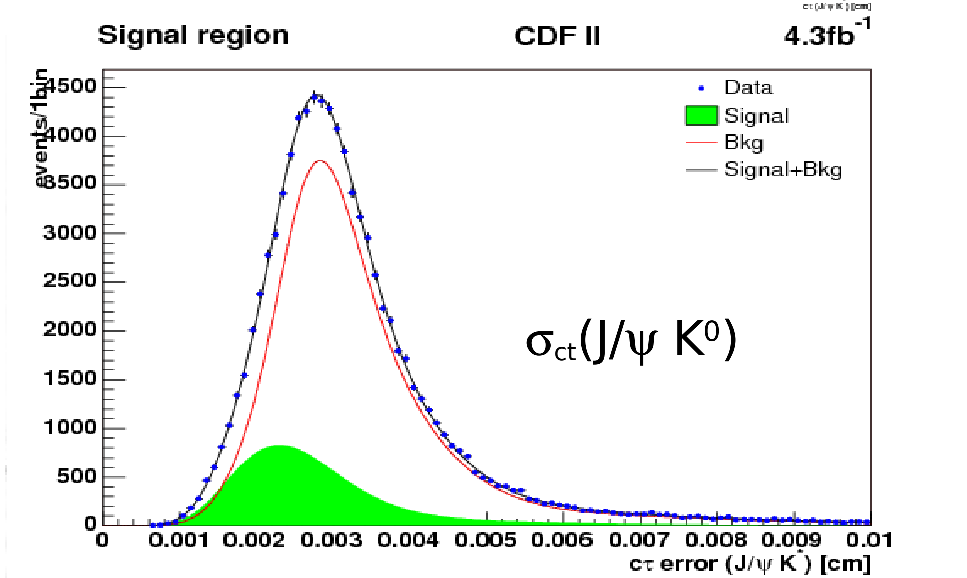


B^0 (data and fit projections)

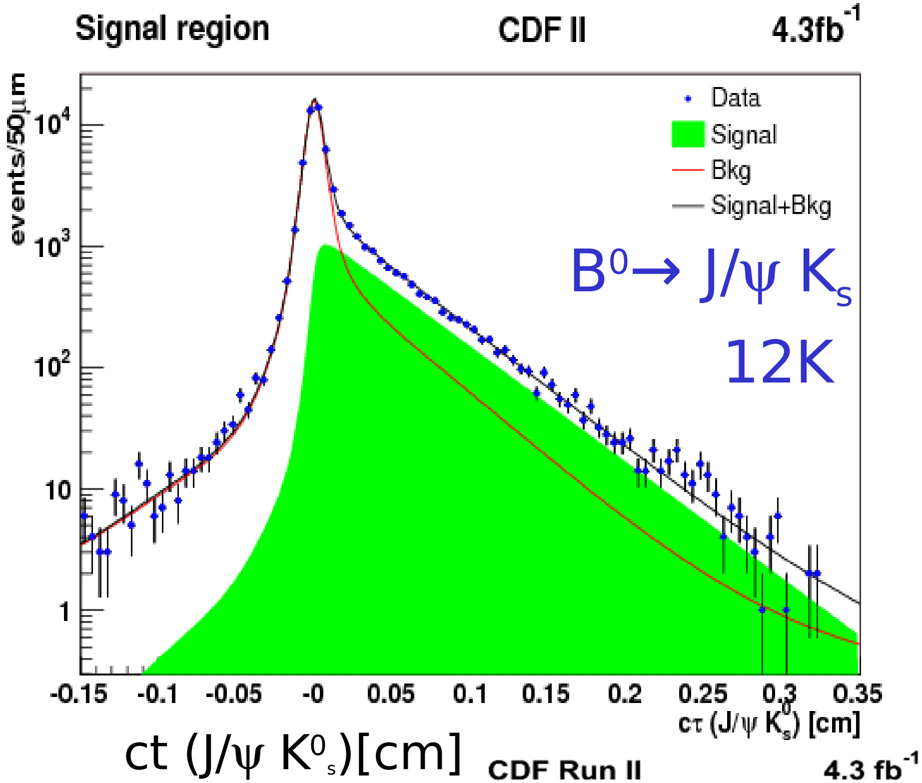


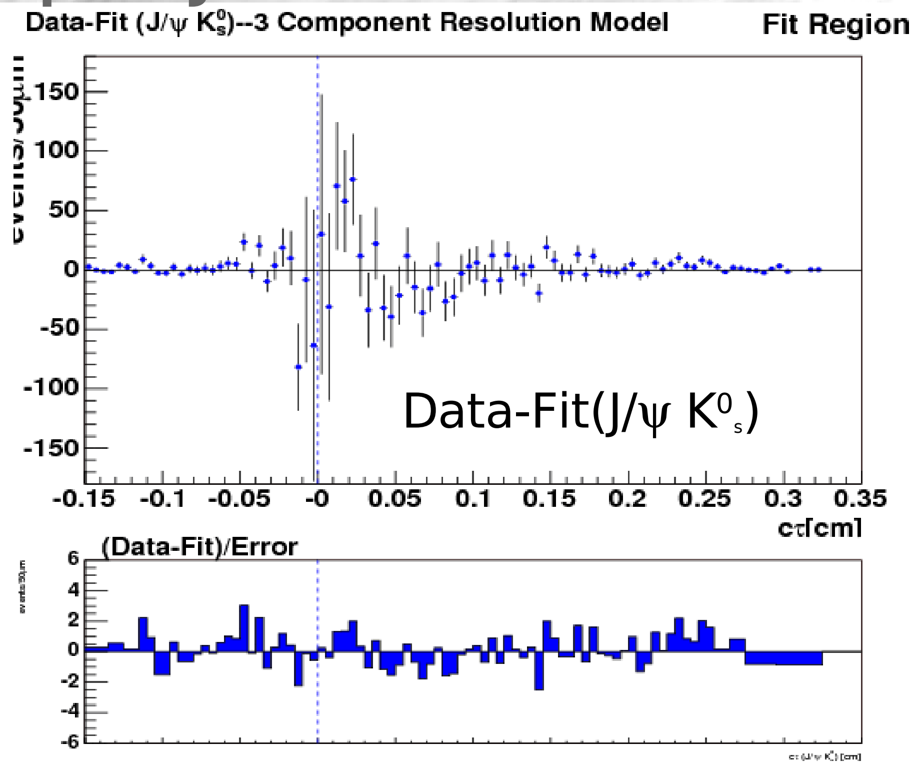


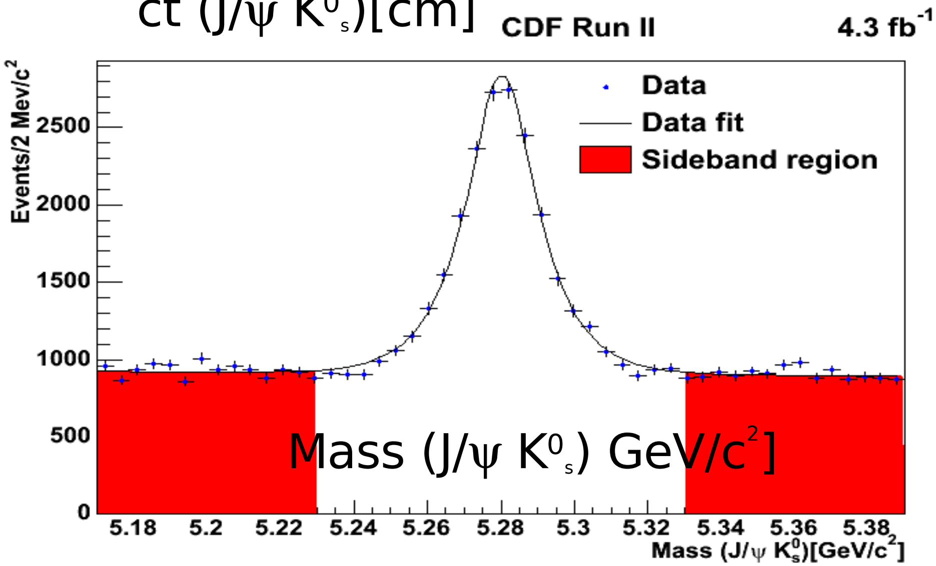


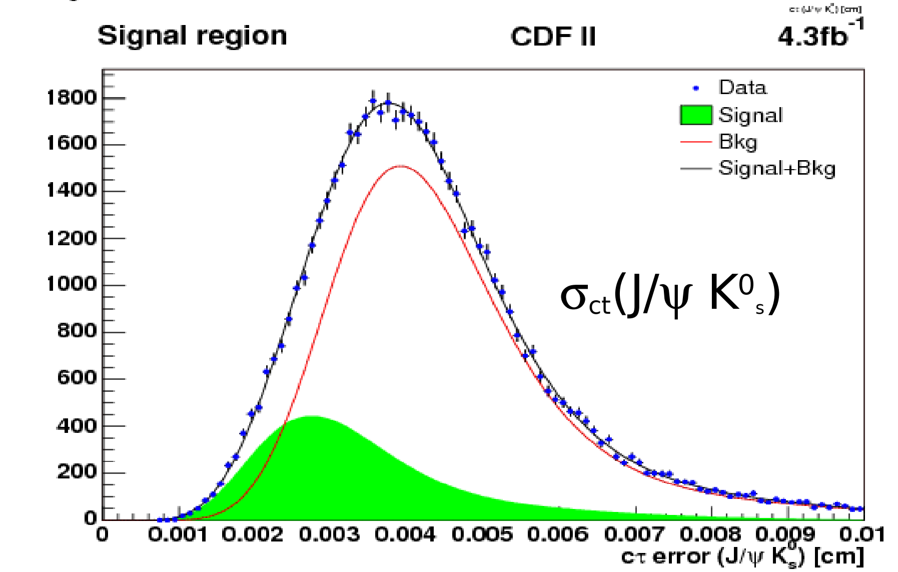


B^0 (data and fit projections)





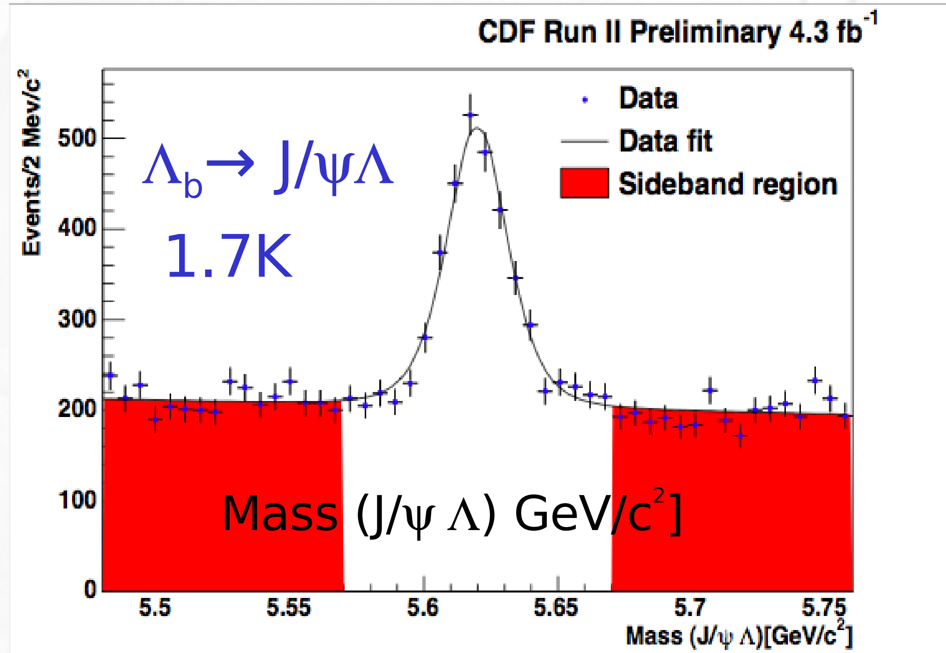


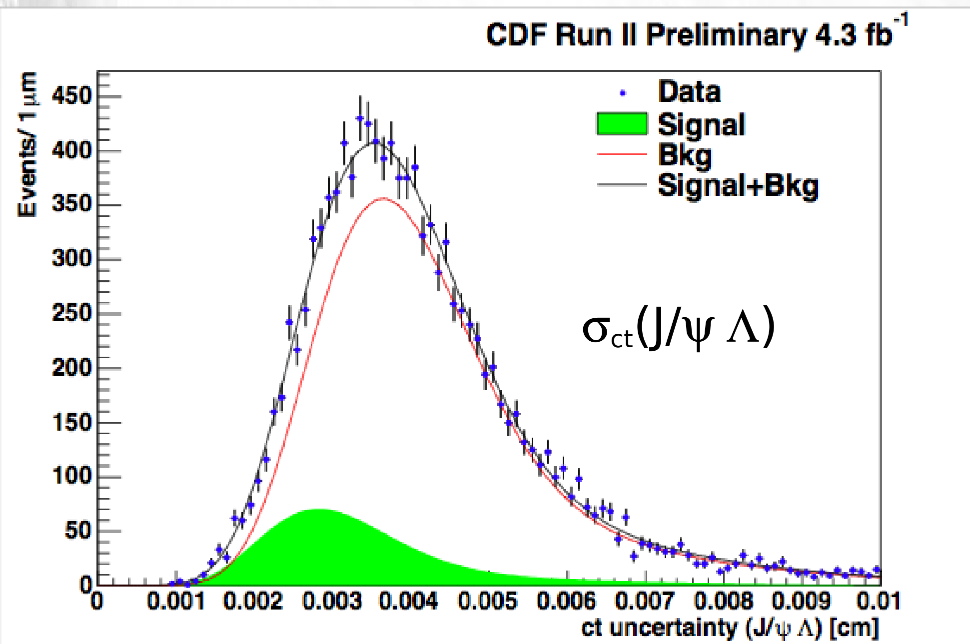


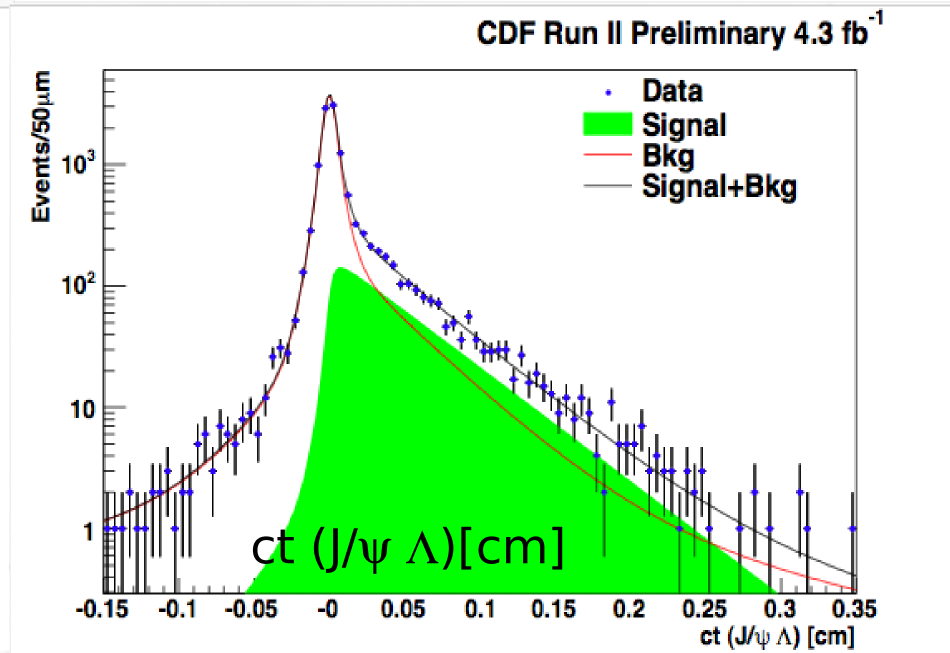
Λ_b (data and fit projections)

$\tau(\Lambda^0_b)$ =
1.537±0.045±0.014 ps

This is the world's best measurement of the Λ_b lifetime







B hadron lifetime: All results

With 4.3 fb^{-1} the Λ^0_b lifetime remains higher than previous measurements. $\tau(\Lambda^0_b) = 1.537 \pm 0.045 \pm 0.014$ ps

Ratio : $\tau(\Lambda^0_b)/\tau(B^0) = 1.020 \pm 0.030(stat) \pm 0.008(syst)$

Theory: $\tau(\Lambda^0_b)/\tau(B^0) = 0.88 \pm 0.05$ (A.Lenz, arXiv:0802.0977)

Some theories favour higher ratio 0.9-1.0 (I.I Bigi,hep-ph/0001003)
[predictions for Λ^0_b less accurate than mesons due to lack of NLO corrections]

World's most precise measurement of $\tau(B^+)$, $\tau(B^0)$ & $\tau(B^+)/\tau(B^0)$

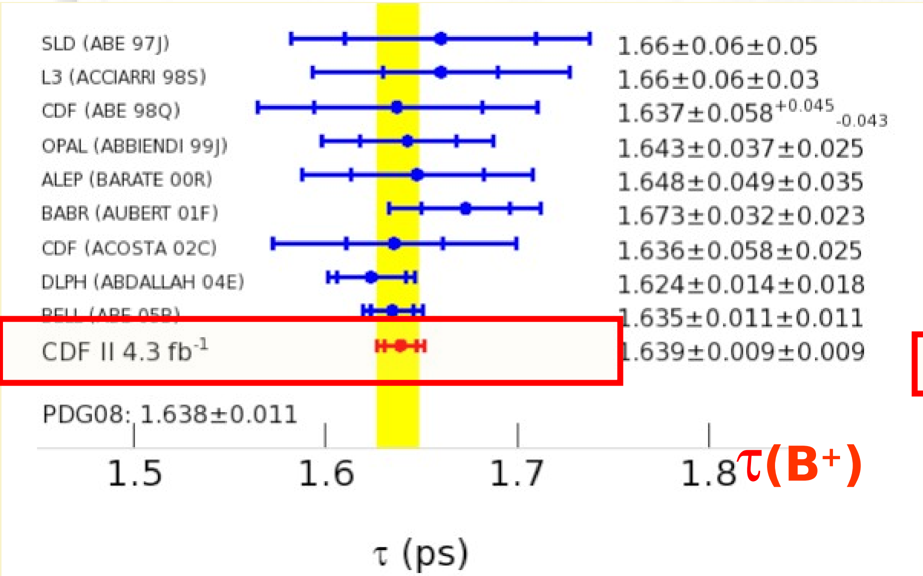
$\tau(B^+) = 1.639 \pm 0.009(stat) \pm 0.009$ (syst) ps
$\tau(B^0) = 1.507 \pm 0.010(stat) \pm 0.008$ (syst) ps
$\tau(B^+)/\tau(B^0) = 1.088 \pm 0.009(stat) \pm 0.004$ (syst)

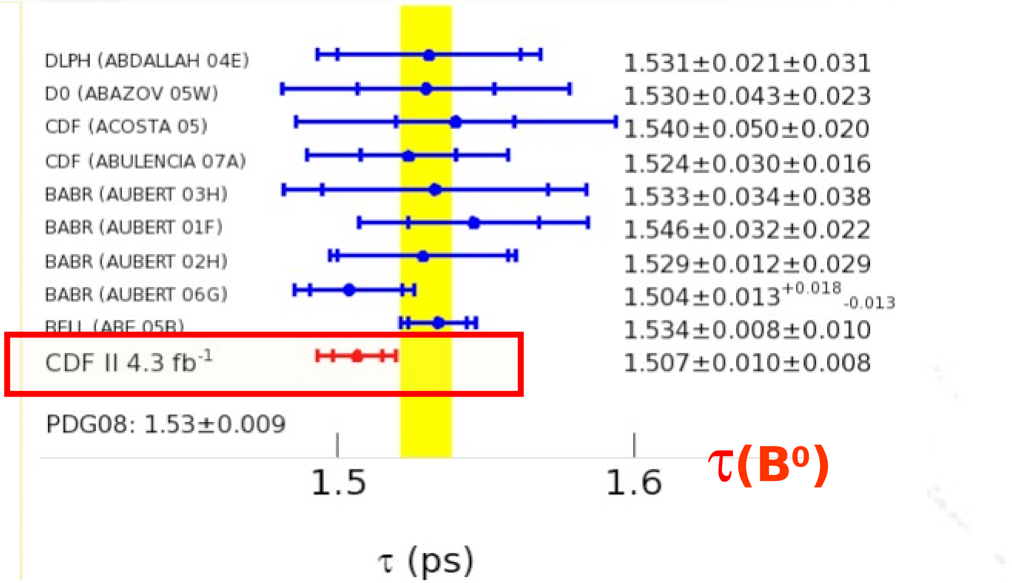
In agreement with theoretical prediction:

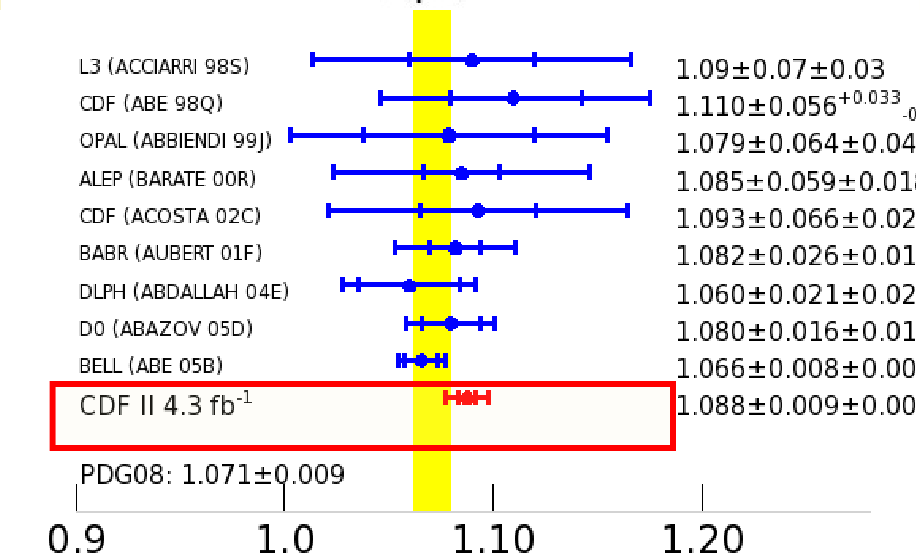
$\tau(B^+)/\tau(B^0) = 1.063 \pm 0.027$ [PLB667(20068),hep-ph/0310241(2004)]

http://www-cdf.fnal.gov/physics/new/bottom/091217.blessed-JpsiX4.3/jpsix.html
To be submitted to PRL soon

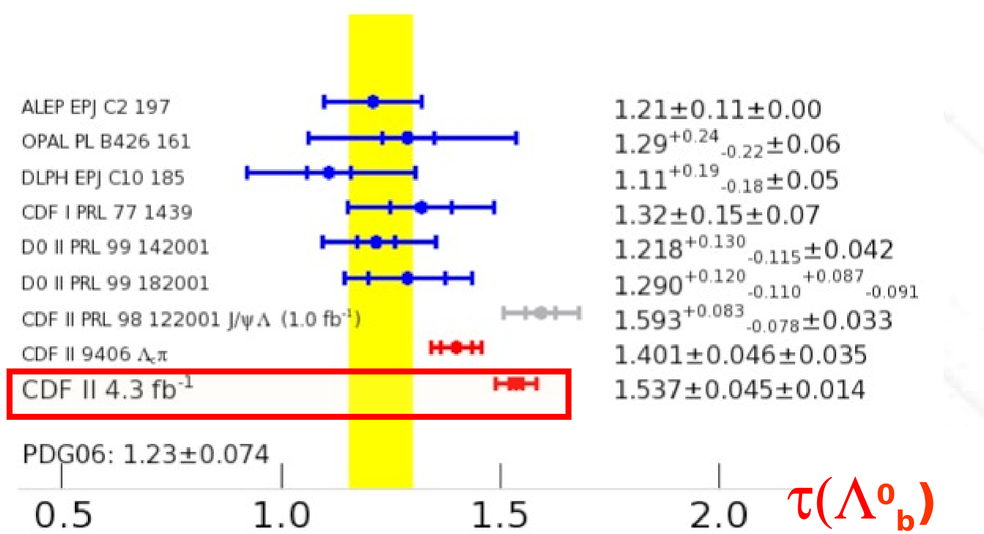
B hadron lifetime: summary







τ(B+)/τ(B0)

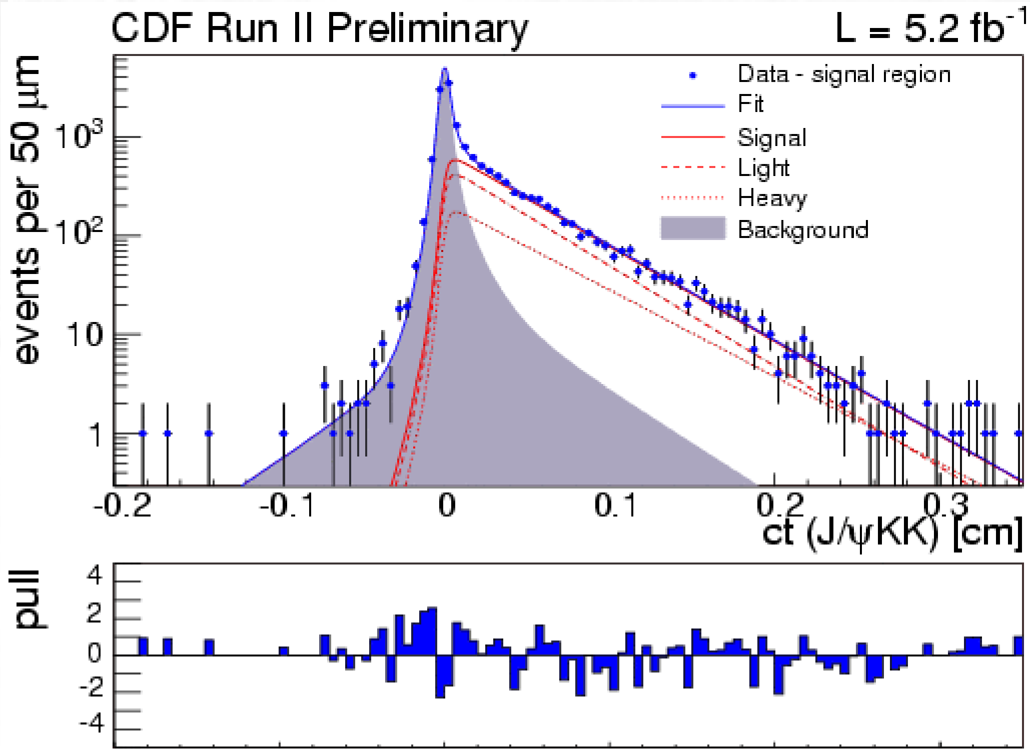


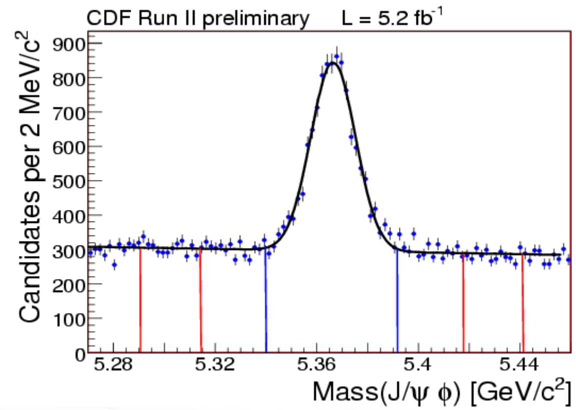
Λ^0_b measurement still dominated by statistical uncertainty; we have a significant margin of improvement for next iteration.

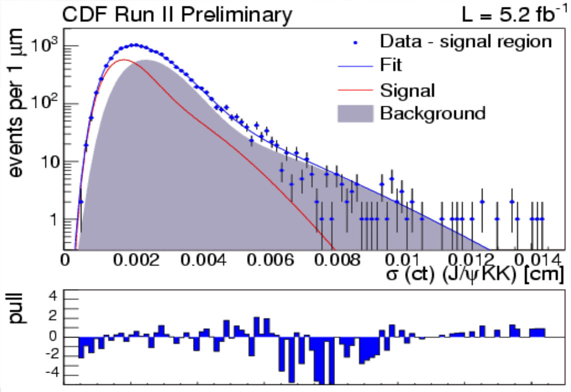
Lifetime measurement of $B^0_s \to J/\psi\,\phi$

$\tau(B^0_s)$= 458.7 ± 7.5(stat)± 3.6 (syst) microns

Results obtained in the context of CP Violating Phase $\beta_s^{J/\psi\phi}$ measurement (see G.Giurgiu's talk [Track06 ;Sat 24/7 14:30, 242A])







http://www-cdf.fnal.gov/physics/new/bottom/100513.blessed-BsJpsiPhi_5.2fb

Conclusions

Large, well understood data sample & fantastic Tevatron performance $\Rightarrow$ most precise lifetime and lifetime ratio measurements with fully reconstructed decays.

$\tau(B^+)/\tau(B^0)$ in agreement with theory/other experiments

$\tau(B^0_s)/\tau(B^0) \sim 1$ (see G.Giurgiu's talk [CP violation measurement])

$\tau(\Lambda^0_b)/\tau(B^0) \sim 4\sigma$ from PDG-2006

Our next and last iteration, with the full sample of ~10/fb, will provide measurements that will all be limited by systematics.

Tevatron will continue to set tough standards to beat. A few exciting years of competition with LHC ahead!

Back up

How we model this data:

* The likelihood function is a sum of two terms: one for signal and one for the background.
* Each piece is probability density function (PDF) in three variables:
reconstructed mass (m)
reconstructed proper decay time (ct)
reconstructed proper decay time error (σ_{ct})
* The mass is described as:
A sum of two Gaussians, widths governed by event-per-event mass errors and collective scale factors, for the signal.
A linear background shape.
* The reconstructed proper decay time error distribution is modeled in an ad-hoc way using Gamma Distributions.

The biggest challenge is modeling the data in the very highest statistics channel.
* The reconstructed proper decay time distribution is described as:
For the signal: an exponential convolved with a model of the resolution.
For the background:
Two smeared positive exponentials models long-lived backgrounds.
One smeared negative exponential models background from “other” B
A delta function convolved with the resolution-model models a background of prompt J/ψ events

We get the resolution model from sideband events.

How do we model this data?

$S(\sigma_{ct})$ modeled in an ad-hoc way using Gamma Distributions : $S(\sigma_{ct}) = A \cdot \sigma_{ct}^{\alpha} e^{-\sigma_{ct}/\beta}$ [A a normalization constant ;$A = 1/(\Gamma(\alpha+1)\, \beta^{\alpha+1})$]