B lifetimes, X,Y,Z states at the Tevatron

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06/04/2011

for the CDF Collaboration

Beauty 2011 – Amsterdam

Why study b-Hadrons ?

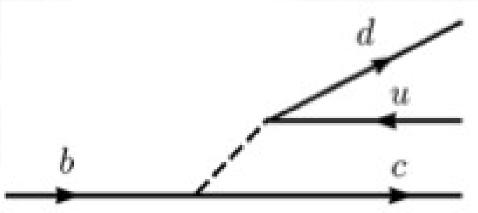
- b-hadrons probe a unique region of parameter space (i.e., mass, energy, momentum, velocity) that can be studied using a wide range of tools (potential models, HQET, lattice gauge calculations)

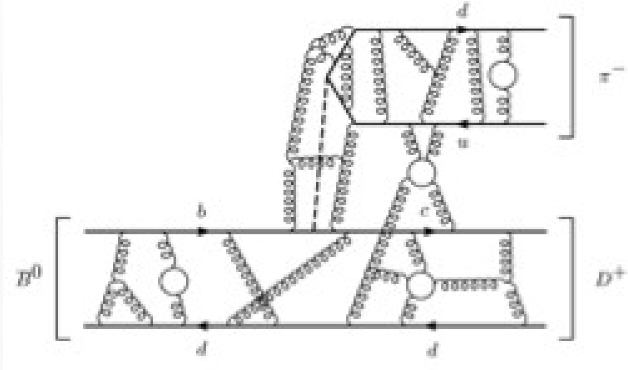
Why b-Hadron Lifetimes ?

- 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

- In reality QCD: interactions of quarks inside hadrons change these lifetimes by up to about 10% => lifetimes of B hadrons study the interplay between strong and weak interaction



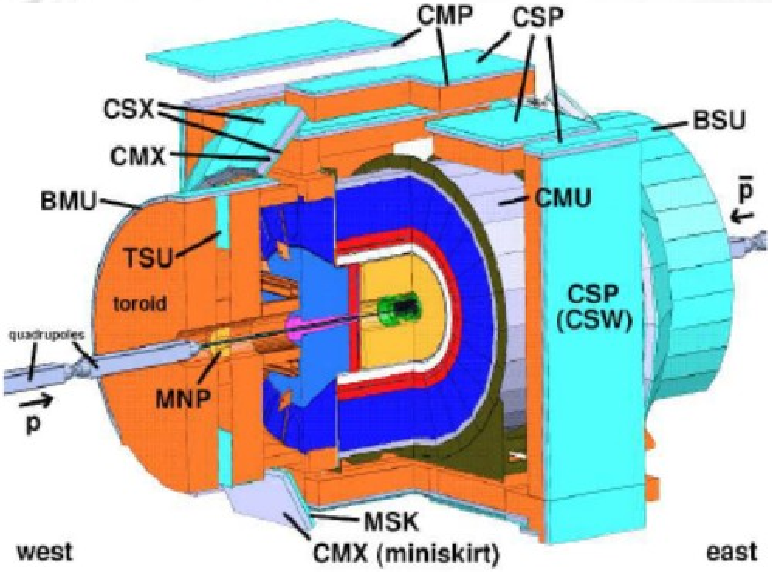


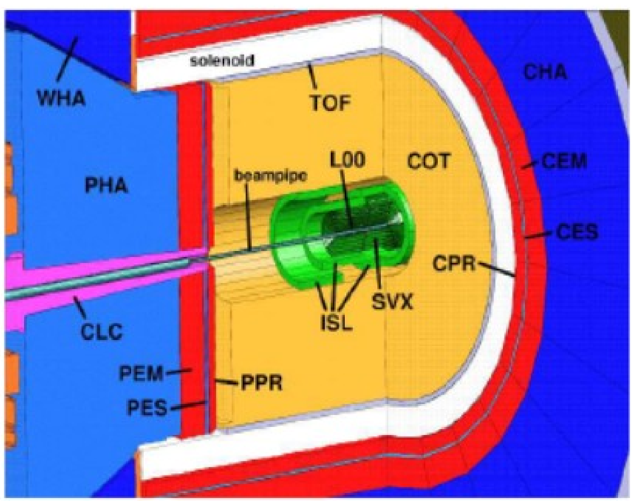
HQE predicts $\tau(B_u) > \tau(B_d) \sim \tau(B_s) > \tau(\Lambda_b) >> \tau(B_c) \rightarrow$ can be proved experimentally

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

=> Lifetime measurements allow a test of theory predictions

CDF detector





- Drift chamber (COT)

⇒ Good tracking resolution

$\sigma(p_T)/p_T \sim 0.07\%\ p_T\ \mathrm{GeV}^{-1}$

(for COT + silicon)

⇒ Important for triggering

- Silicon vertex detector

⇒ Good vertex resolution

(~30 μm in rϕ ; ~70 μm in z)

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

⇒ Important for triggering

- TOF and dE/dx from COT

⇒ Good particle identification

Lifetimes in decays with J/Ψ

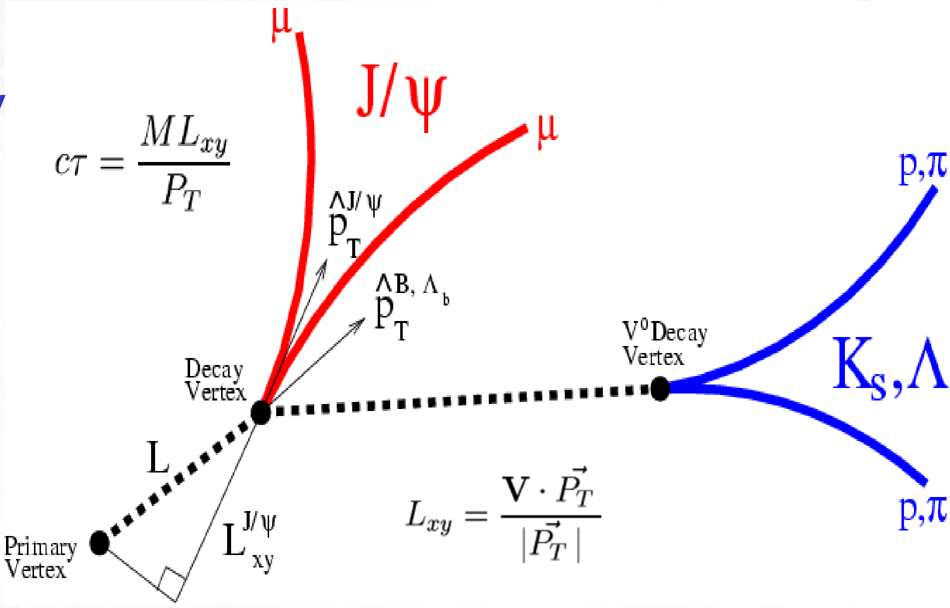
J/ψ→μμ triggered to find large samples of fully reconstructed B's

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

Analysis strategy

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

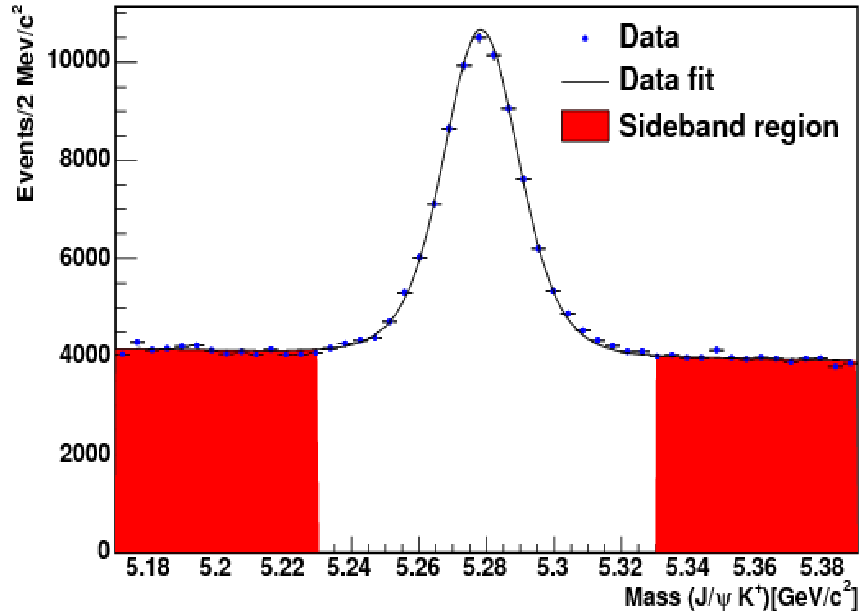
Careful and extensively-tested fitting model developed on the decay modes with higher statistics then applied to Λ_b



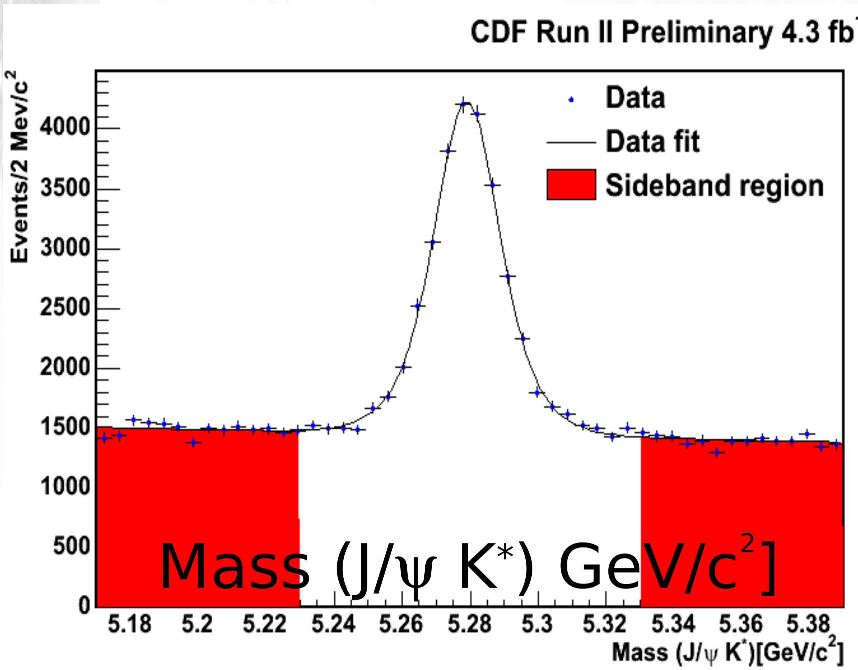
Yields

Selection based on rectangular cuts only

Uses 4.3fb^{-1} of data



Mass (J/ψ K^+)[GeV/c^2]

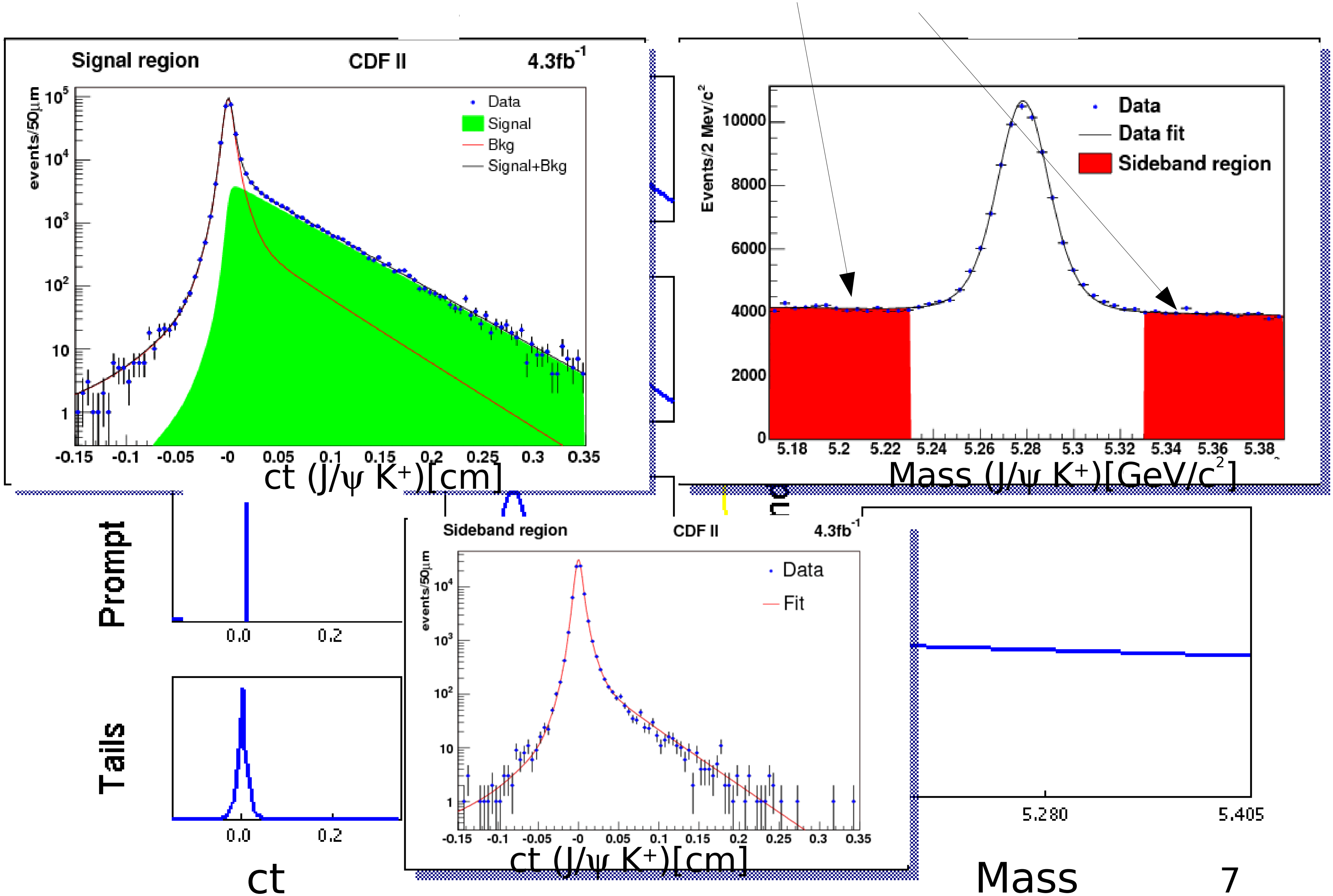


Mass (J/ψ K^*) GeV/c^2]

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

Fitting Model

We get the resolution model from sideband events.



Controlling systematic uncertainties

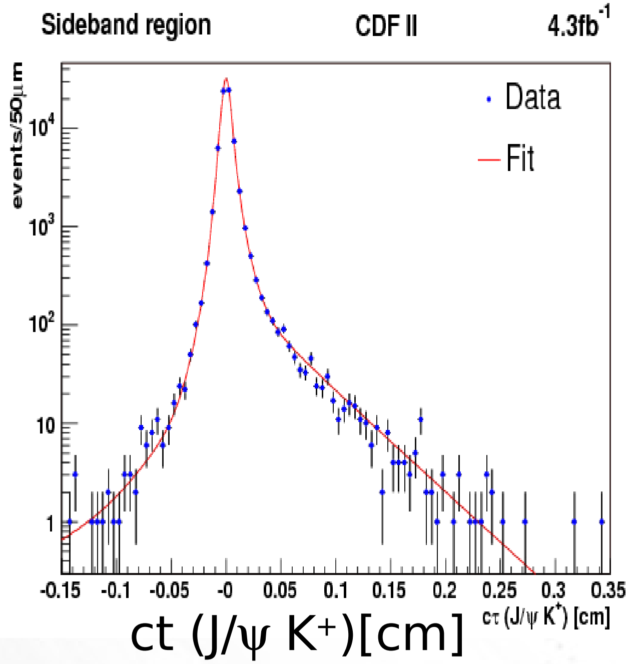
Large yields in B^+ & B^0 $\rightarrow$ Systematically limited using simple modeling of detector resolution. Background is mainly prompt.

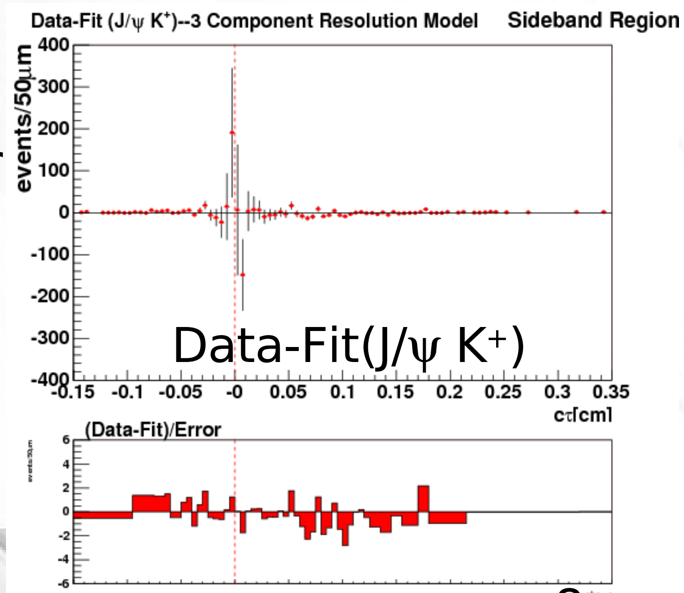
Carefully model the mass sideband data $\rightarrow$ extract the scale factors that determine the detector resolution.

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

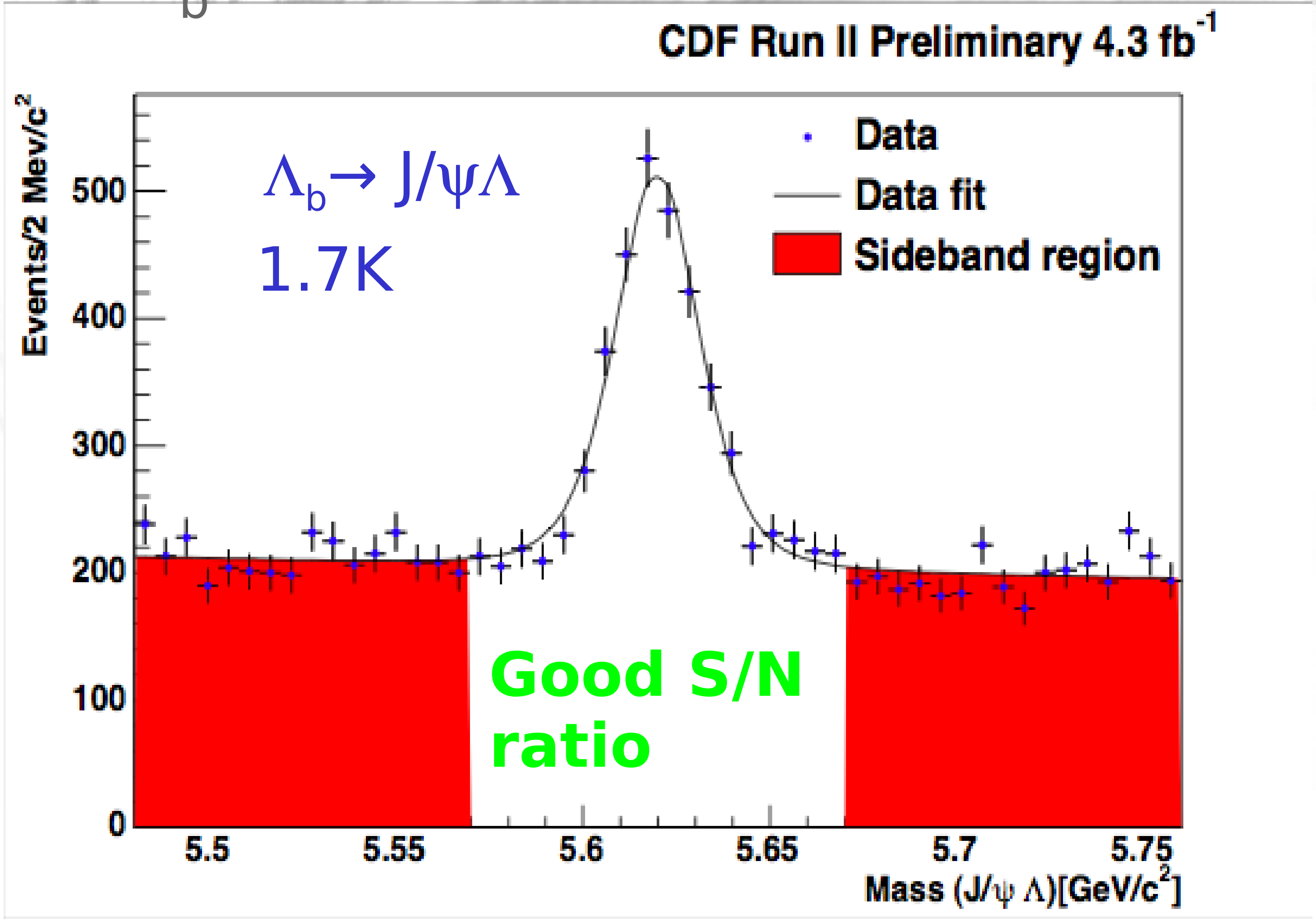
Systematic error now limited by detector alignment (that cancel in ratios)

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



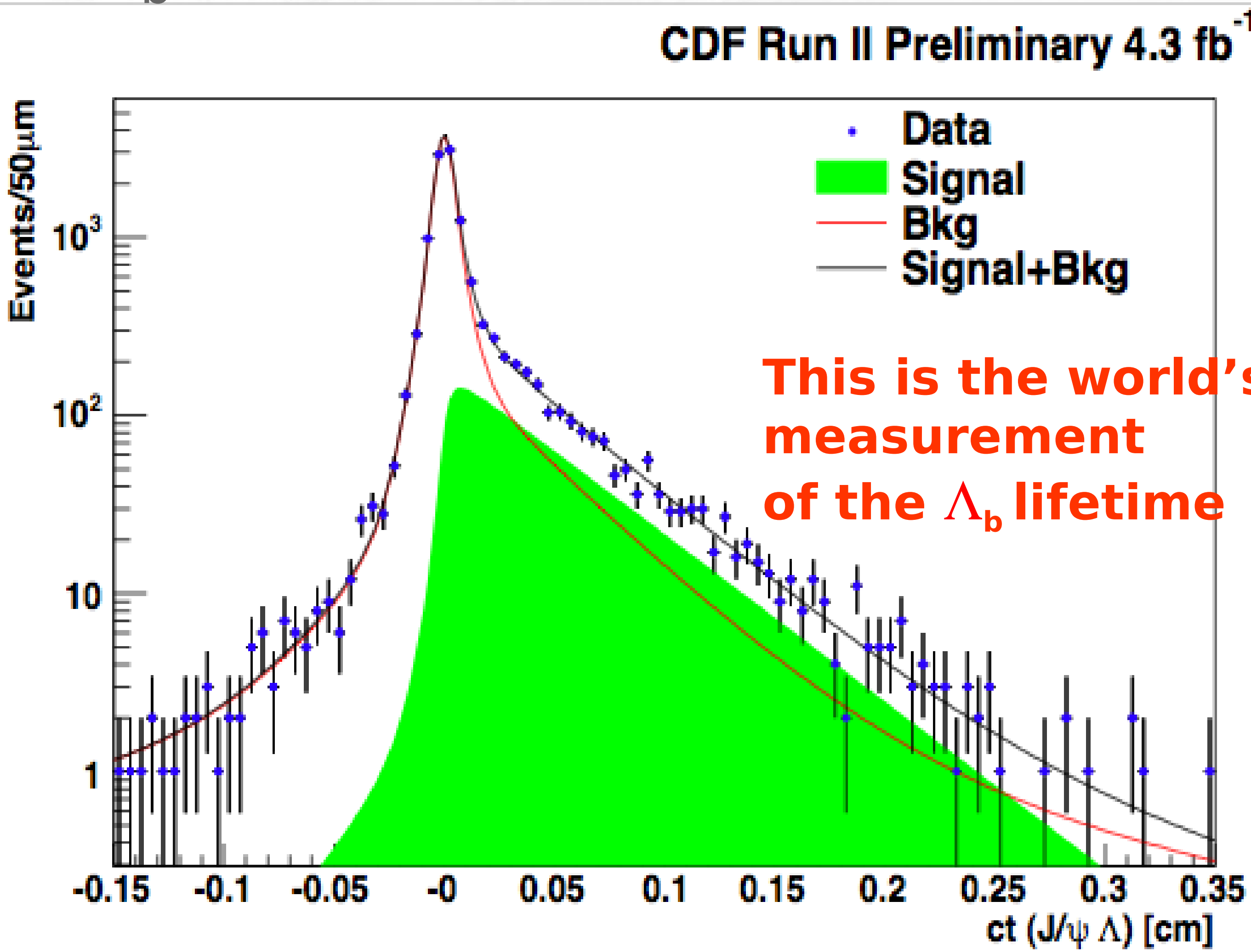


Λ_b (data and fit projections)



Mass (J/ψ Λ) GeV/c^2]

Λ_b (data and fit projections)



ct (J/ψ Λ)[cm]

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

B hadron lifetime: results

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

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

Theory: $\tau(\Lambda^0_b)/\tau(B^0)$ =0.88± 0.05 (C.Tarantino, Eur.Phys.J. C 33, S895 (2003))

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

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

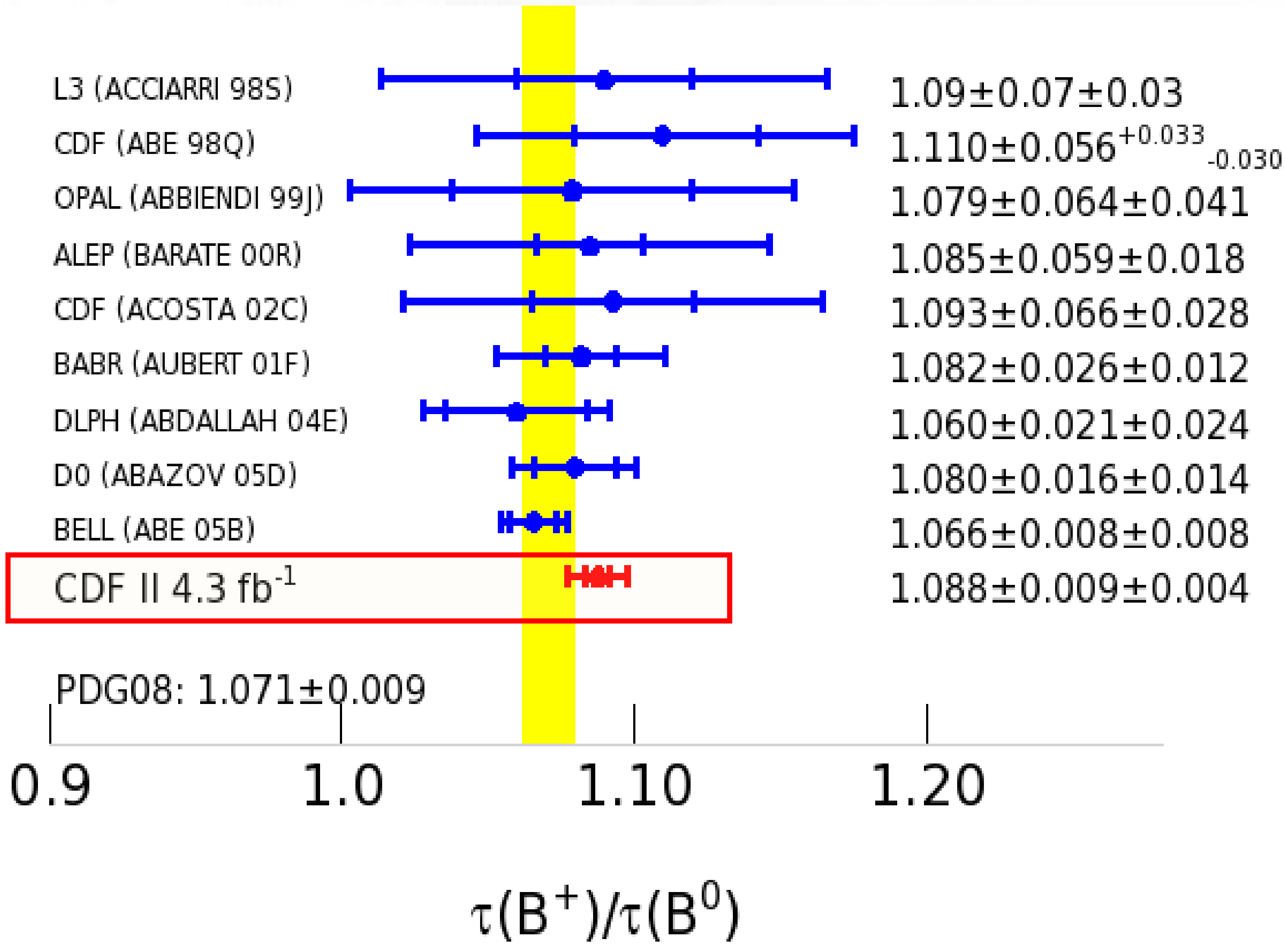
$\tau(B^+)$= 1.639 ± 0.009(stat)± 0.009 (syst) ps
$\tau(B^0)$= 1.507 ± 0.010(stat)± 0.008 (syst) ps
$\tau(B^+)/\tau(B^0)$= 1.088 ± 0.009(stat)± 0.004 (syst)

In agreement with theoretical prediction:

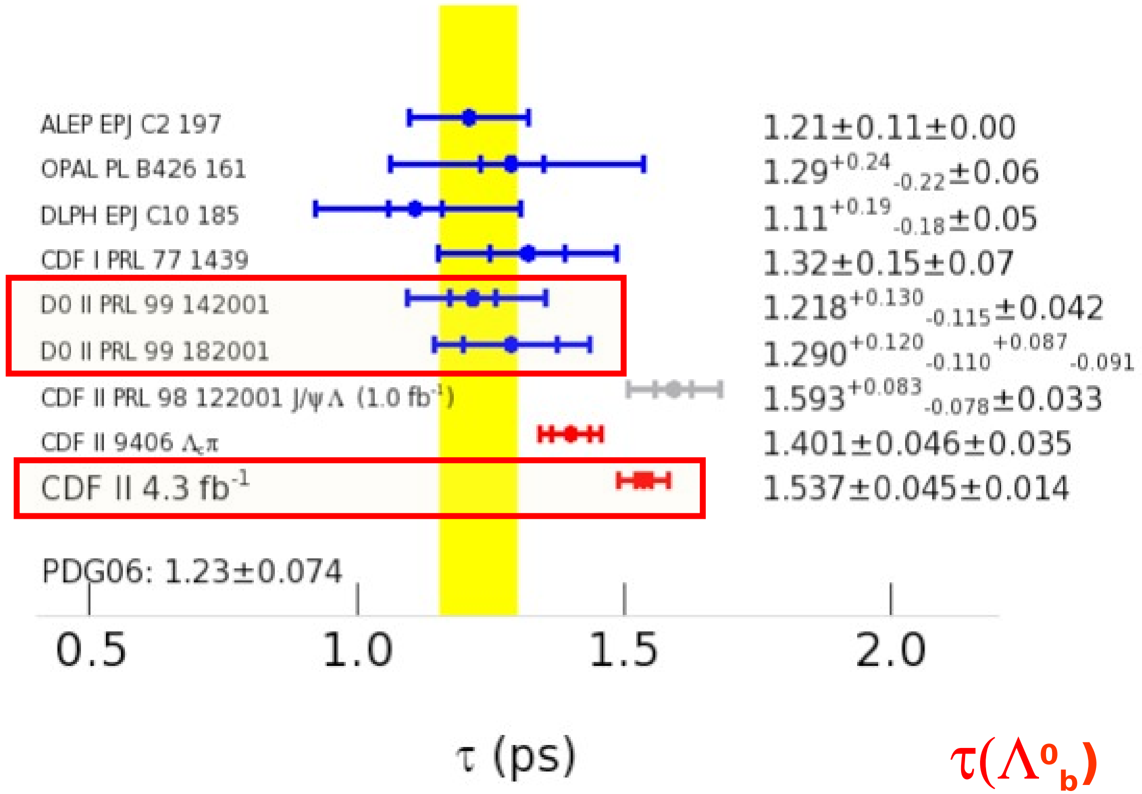
$\tau(B^+)/\tau(B^0)$ =1.063± 0.027 [A.Lenz, AIP Conf. Proc. 1026, 36 (2008)]

Phys. Rev. Lett. 106, 121804

B hadron lifetime: summary



B hadron lifetime: summary



$\tau(\Lambda^0_b)$

Λ^0_b measurement still dominated by statistical uncertainty. Expect ~0.030 ps error with full statistics

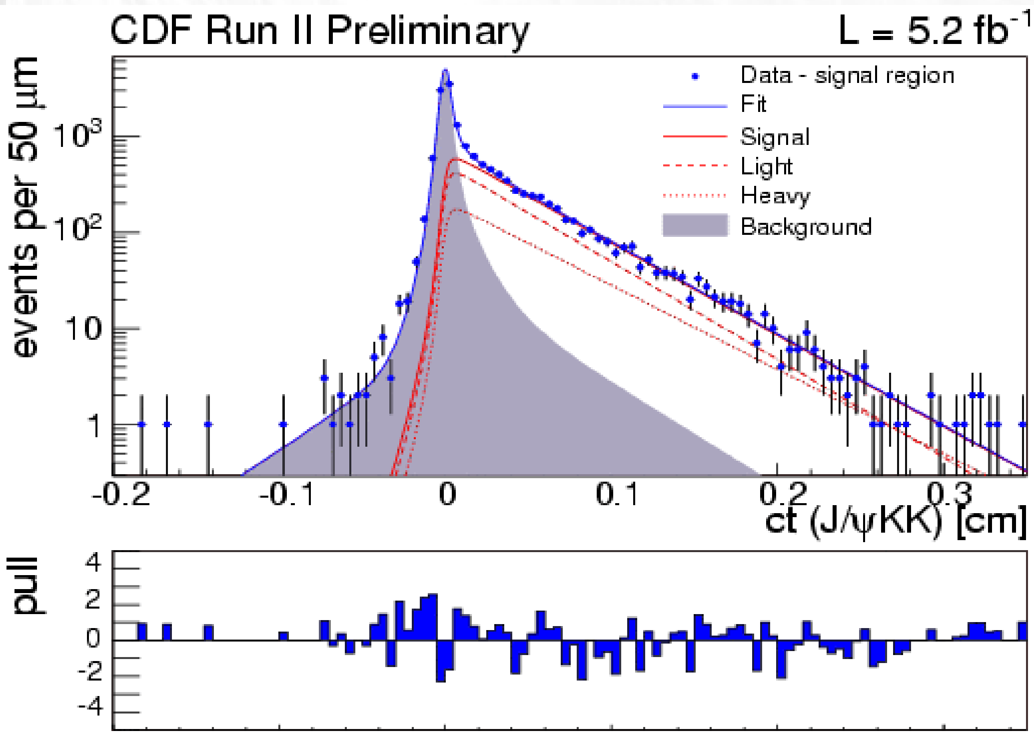
Lifetime measurement of $B^0_s \to J/\psi\, \phi$

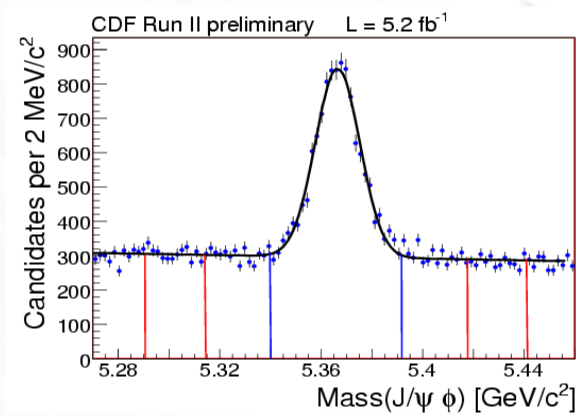
$\tau(B^0_s) = 1.530 \pm 0.025(\text{stat}) \pm 0.012\ (\text{syst})$ ps

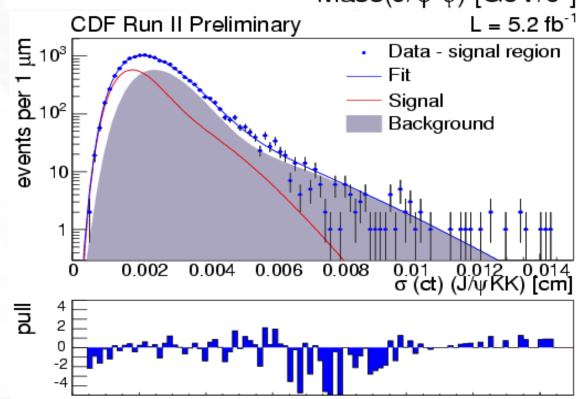
Results obtained in the context of CP Violating Phase $\beta_s^{J/\psi\phi}$ measurement

$\Delta\Gamma_s = 0.075 \pm 0.035\ (\text{stat}) \pm 0.01(\text{syst})\ \text{ps}^{-1}$

World's most precise single measurement of the B^0_s lifetime and decay width difference







We find the S-wave contamination of the signal φ meson to be < 6.7% at the 95% CL

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

XYZ states : Introduction

Significant role in the study of exotic XYZ states

- 1st confirmation of X(3872) PRL 93,072001 (2004)

- measurements of its quantum numbers PRL 96, 102002 (2006) and PRL 98,132002 (2007)

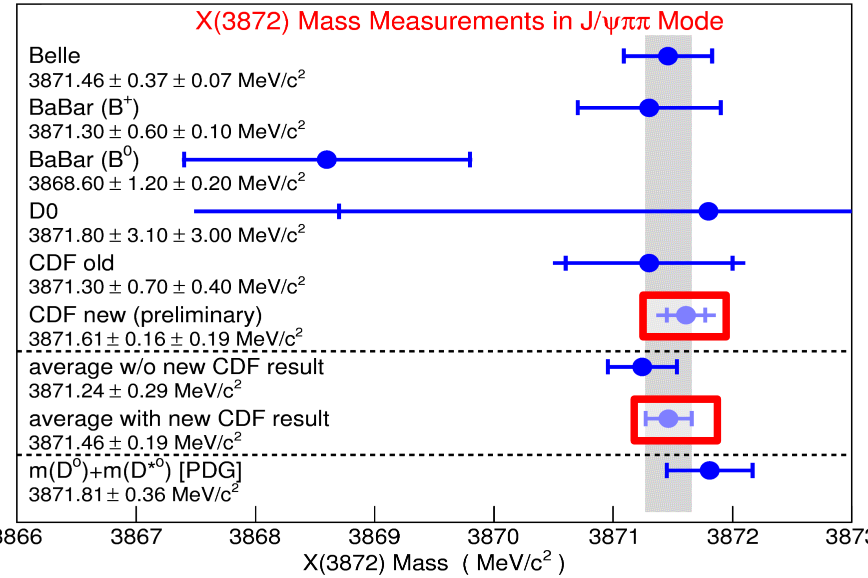
  Quantum numbers $J^{PC} = 1^{++}$ and 2^{-+} preferred

- precision mass PRL 103, 152001 (2009)

  The largest sample to date

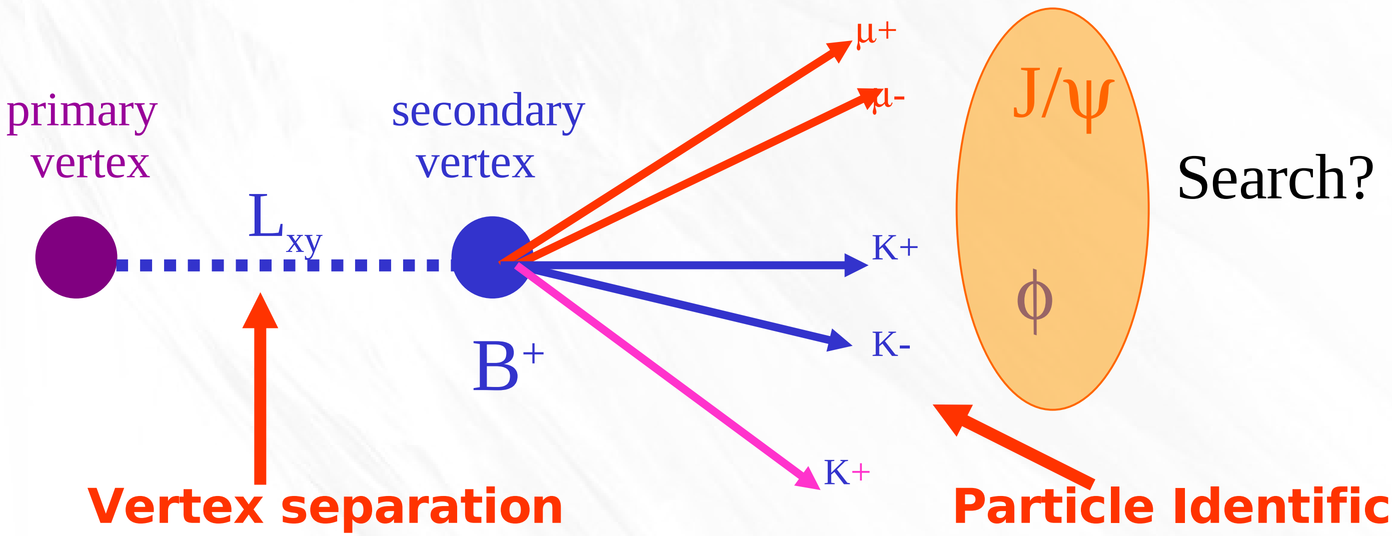
  m(X(3872)) = 3871.61± 0.16(stat)±0.19 (syst) MeV

- Y(4140) evidence PRL 102, 242002 (2009)



Y(4140): Near-Threshold Structure in the *J/ψ φ* from *B+* → *J/ψ φ K+* Decay

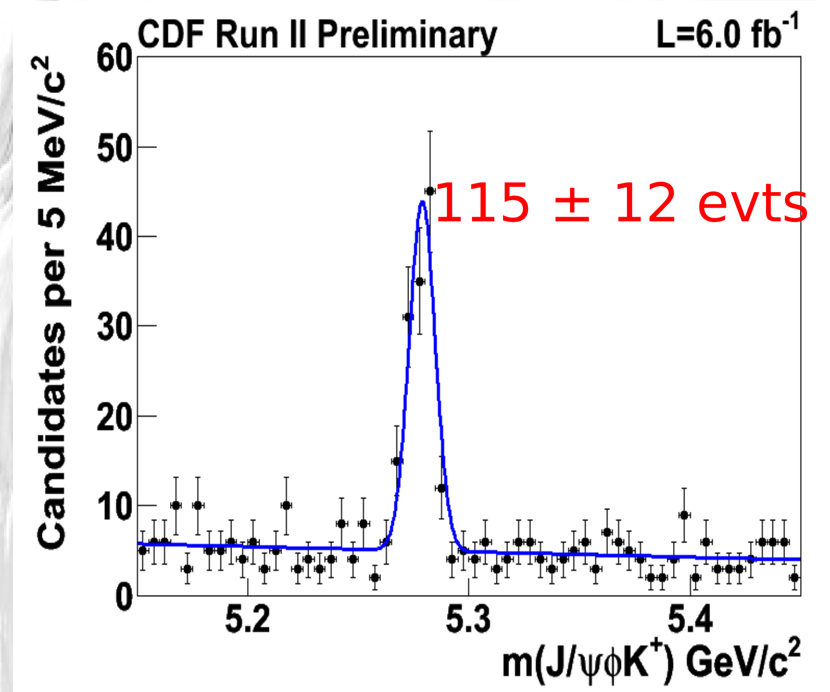
- Reconstruct B^+ as: $B^+ \rightarrow J/\psi\ \varphi\ K+$, $J/\psi \rightarrow \mu+\mu-$; $\varphi \rightarrow K+ K-$
- Search for structure in $J/\psi\ \varphi$ mass spectrum inside B^+ mass window

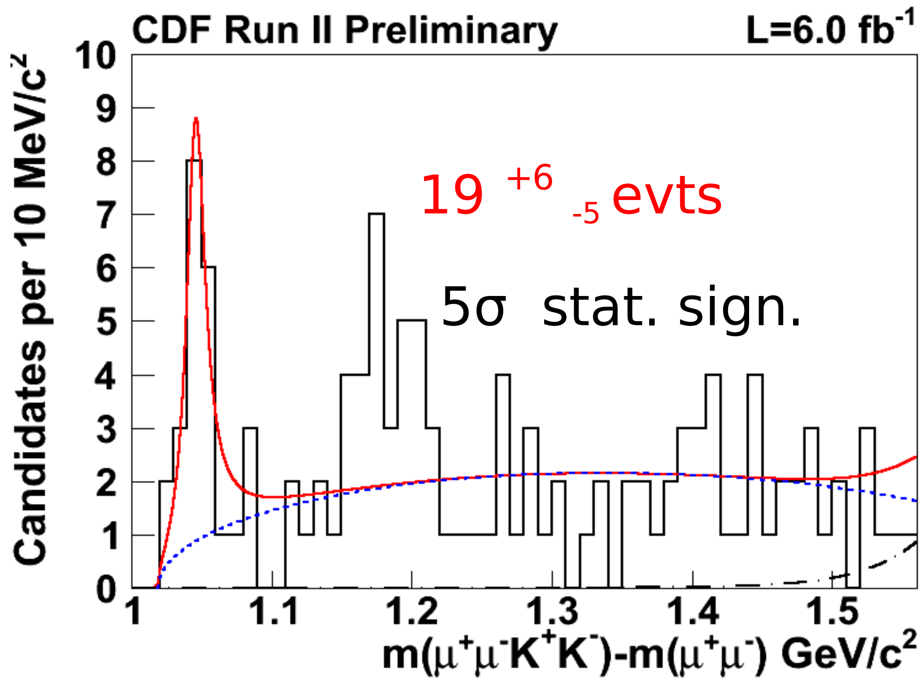


- Mayor points : use L_{xy} to separate B vertex from P.V.
- Use kaon particle identification to reduce comb. bg.

$B^+ \to Y(4140)K^+$: 6 fb^{-1} analysis

Selection freezed to one used in PRL 102, 242002 (2009)



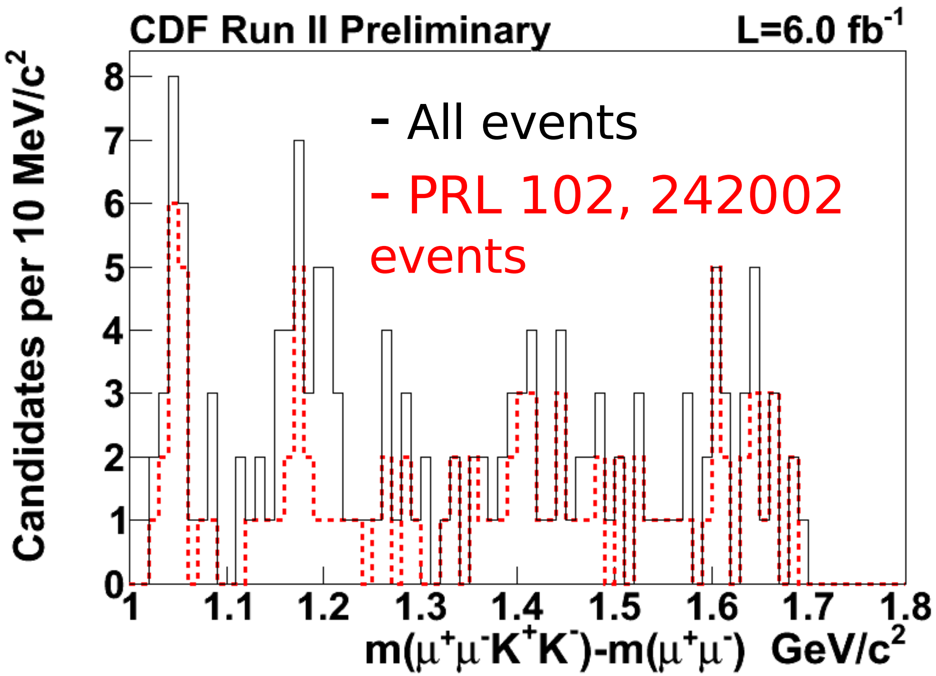


- Signal modelled with S-wave relativistic BW ⊗ resolution (1.7MeV)
- Background : three-body decay phase space
- The statistical significance of the signal is over 5.0 σ

Mayor changes w.r.t PRL 102, 242002 (2009):

• Added ~2 fb^{-1} and another trigger. This adds some 50% of B^+ events

• ΔM spectrum blinded. Decision of looking at it once toy-MC tests indicated >75% chance of having 5σ

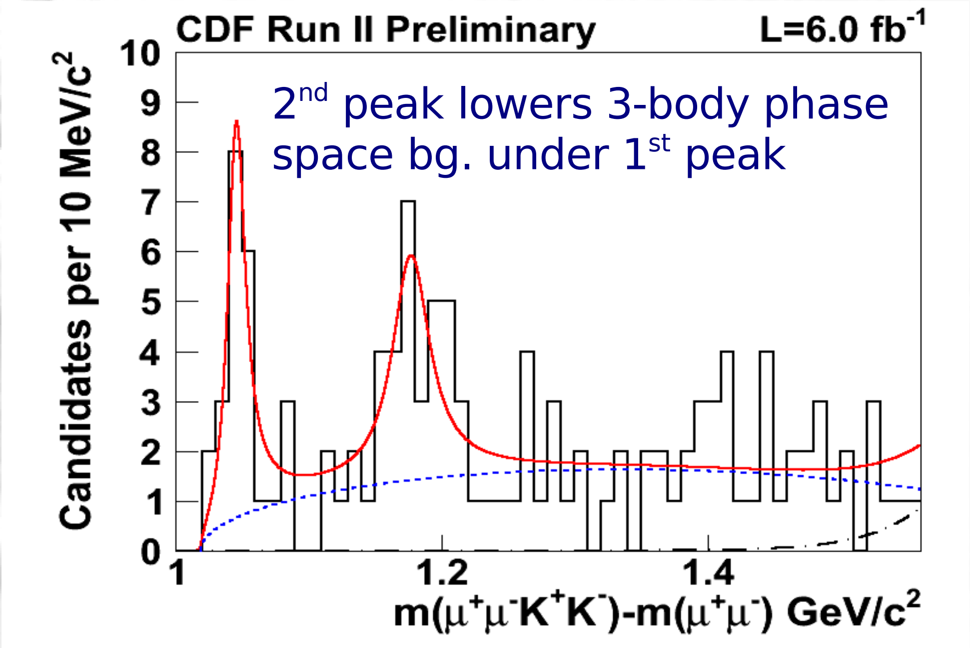


• Previous (2009) analysis, background model had two components: 3-body phase space + flat component (combinatorial events under the B^+ peak)

• Extensive tests at higher statistics showed that 3-body phase space is a good background model - no evidence for deviations from this

Y(4140) – 6 fb^{-1} analysis (cont'd)

Prominent cluster of events at 4275 MeV



- S-wave BW ⊗ 3.0 MeV resolution

$M = 4274.4\ ^{+8.4}_{-6.7} \pm 1.9$ MeV
$\Gamma = 32.3\ ^{+21.9}_{-15.3} \pm 7.6$ MeV

- 3σ significance

$M[Y(4140)] = 4143.4\ ^{+2.9}_{-3.0} \pm 0.6$ MeV (above open charm)
$\Gamma[Y(4140)] = 15.3\ ^{+10.4}_{-6.1} \pm 2.5$ MeV (probably a strong decay)
Rate relative to $B^+ \rightarrow J/\psi \phi K^+$ is (15 ± 5)%

What is it : does not fit into charmonium ; molecular? Many exotic interpretations proposed

http://arxiv.org/pdf/1101.6058v1

Conclusions

Large, well understood data sample & fantastic Tevatron performance $\Rightarrow$ Y(4140) observation, most precise lifetime and lifetime ratio measurements

CDF

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

$\tau(B^0_s)/\tau(B^0) \sim 1$

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

D0

$\tau(\Lambda^0_b)/\tau(B^0)$ and $\tau(\Lambda^0_b)$ semil. in agreement with PDG-2006

With ~8 fb^{-1} accumulated data per experiment and more to come, heavy flavor physics at Tevatron is at its peak precision.

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

Back up

Introduction to the Tevatron and detectors

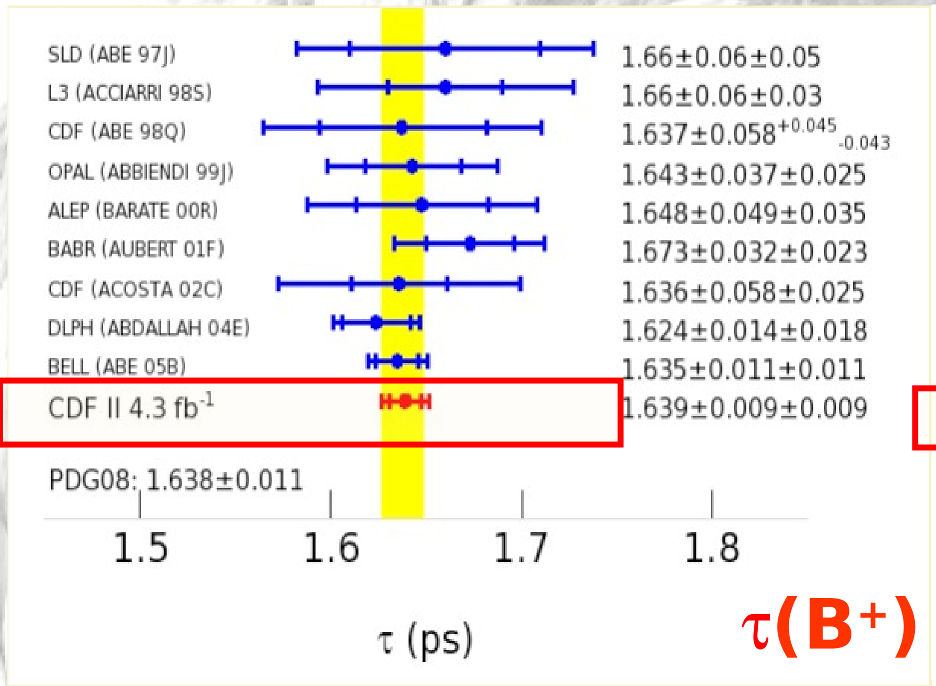
- ppbar collisions at 1.96 TeV
- Excellent performance of Tevatron accelerator
- CDF has already>8 **fb^{-1}** on tape ($50pb^{-1}$/week)
- Expect ~10 fb^{-1} on tape by end 2011

CDF detector

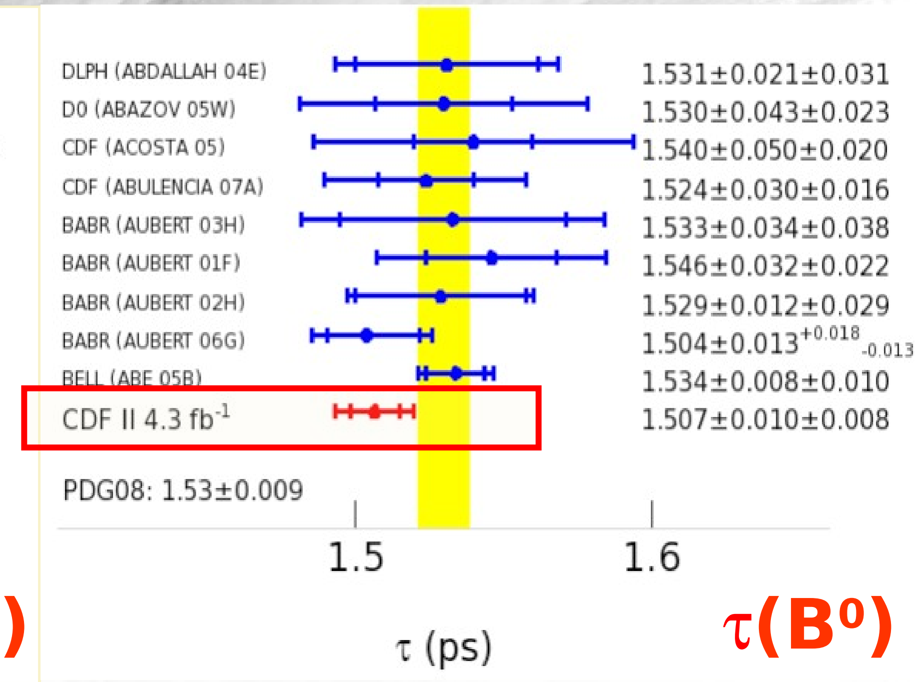
- silicon microvertex detectors
- axial solenoid
- central tracking
- high rate trigger/DAQ system
- calorimeter & muon systems

- Silicon vertex trigger
- Particle ID (TOF and dE/dx)
- Excellent mass resolution

- High cross section σ ($\mathbf{p\bar{p}} \to \mathbf{b\bar{b}}$) ~ 40 μb at $\sqrt{s}$ = 2 TeV (vs 1 nb at the Υ(4s) resonance)
- Huge bkg to the process σ ($\mathbf{p\bar{p}} \to \mathbf{b\bar{b}}$) 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 $J/\psi \to \mu\mu$ oriented dimuon trigger



SLD (ABE 97J)
1.66±0.06±0.05
L3 (ACCIARRI 98S)
1.66±0.06±0.03
CDF (ABE 98Q)
1.637±0.058+0.045 -0.043
OPAL (ABBIENDI 99J)
1.643±0.037±0.025
ALEP (BARATE 00R)
1.648±0.049±0.035
BABR (AUBERT 01F)
1.673±0.032±0.023
CDF (ACOSTA 02C)
1.636±0.058±0.025
DLPH (ABDALLAH 04E)
1.624±0.014±0.018
BELL (ABE 05B)
1.635±0.011±0.011
CDF II 4.3 fb-1
1.639±0.009±0.009
PDG08: 1.638±0.011
1.5
1.6
1.7
1.8
τ (ps)
τ(B+)



DLPH (ABDALLAH 04E)
1.531±0.021±0.031
D0 (ABAZOV 05W)
1.530±0.043±0.023
CDF (ACOSTA 05)
1.540±0.050±0.020
CDF (ABULENCIA 07A)
1.524±0.030±0.016
BABR (AUBERT 03H)
1.533±0.034±0.038
BABR (AUBERT 01F)
1.546±0.032±0.022
BABR (AUBERT 02H)
1.529±0.012±0.029
BABR (AUBERT 06G)
1.504±0.013+0.018 -0.013
BELL (ABE 05B)
1.534±0.008±0.010
CDF II 4.3 fb-1
1.507±0.010±0.008
PDG08: 1.53±0.009
1.5
1.6
τ (ps)
τ(B0)

How do we model this data?

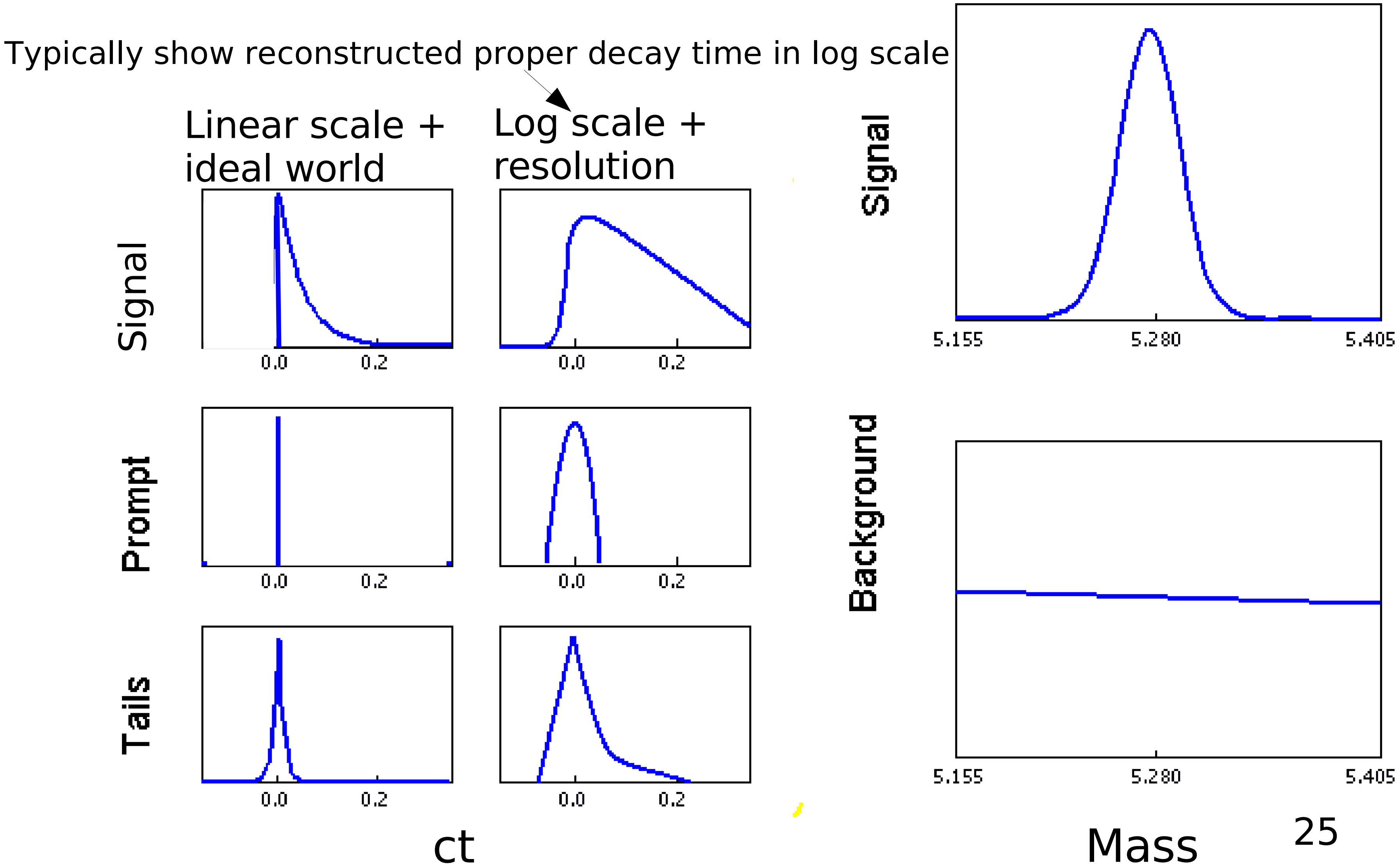
Lifetime extracted from an un-binned likelihood fit, simultaneously in three variables. The likelihood function is a sum of two terms: one for signal and one for the background.

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

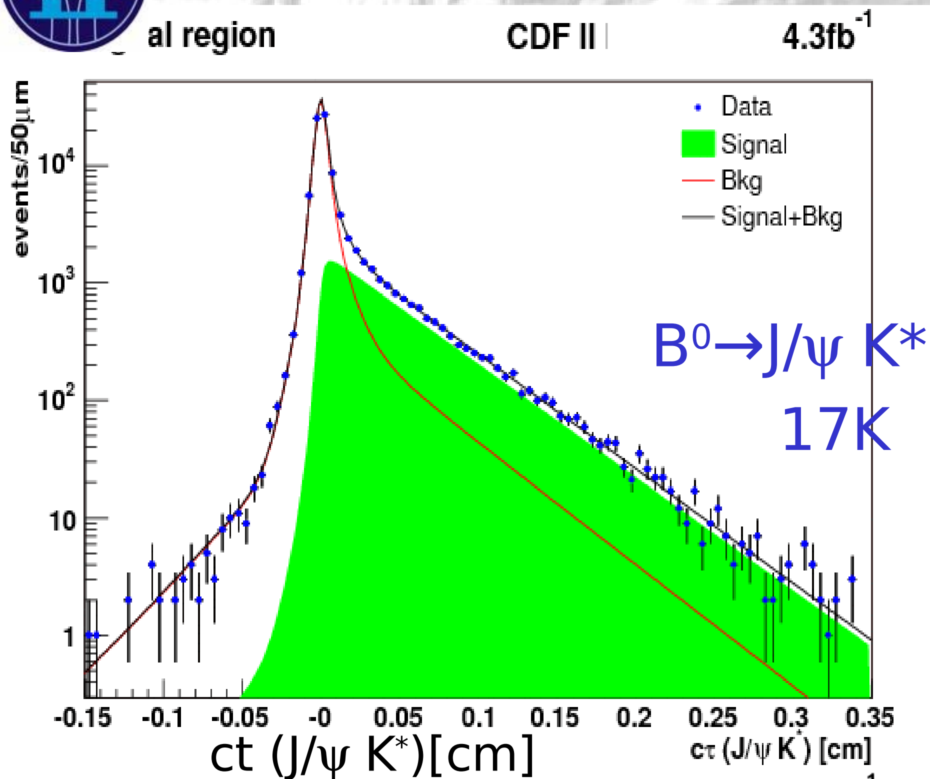
The mass (*P*(m)) and the reconstructed proper decay time (*T*(ct)) distributions are described as follows ...

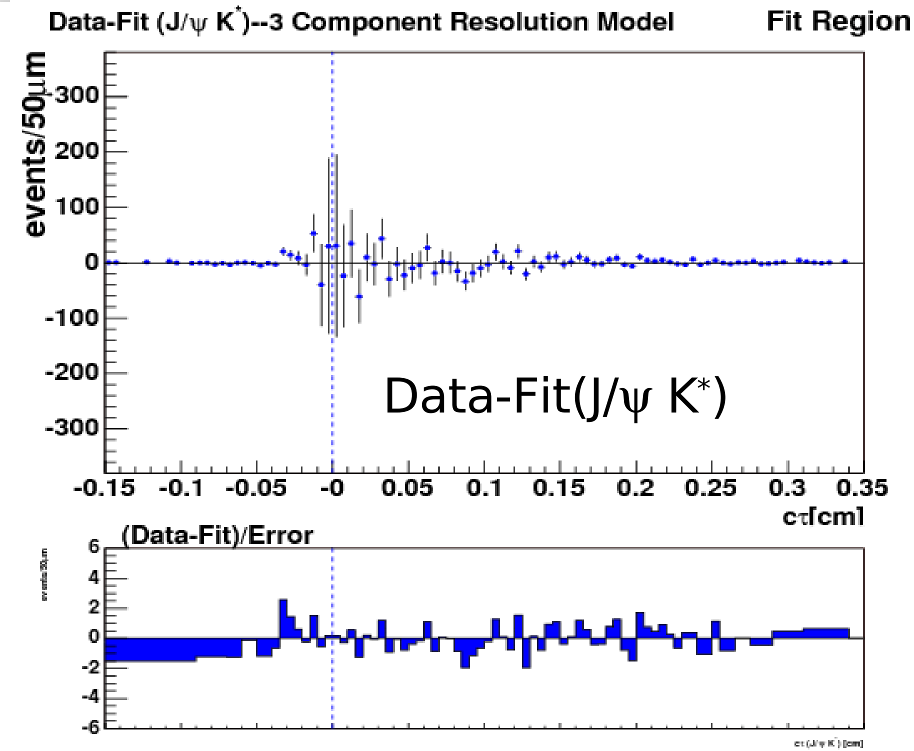
How do we model this data ?

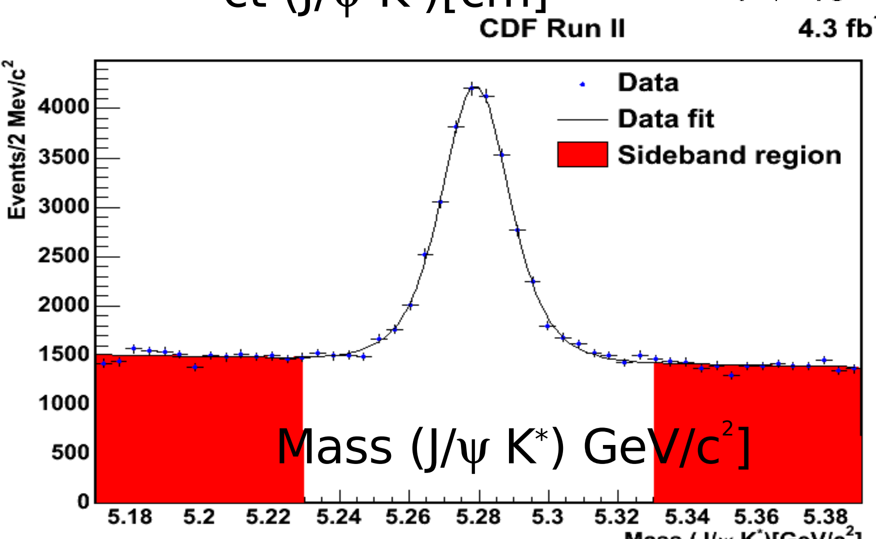
Lifetime extracted from an un-binned likelihood fit, simultaneously in three variables (m, ct, σ(ct)). The mass and the reconstructed proper decay time distributions are described as follows ...

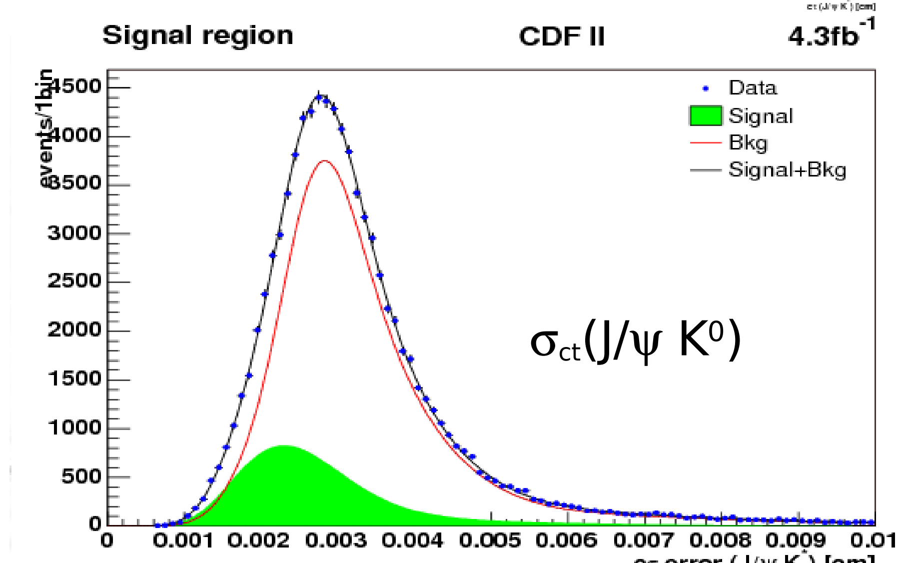


B^0 (data and fit projections)

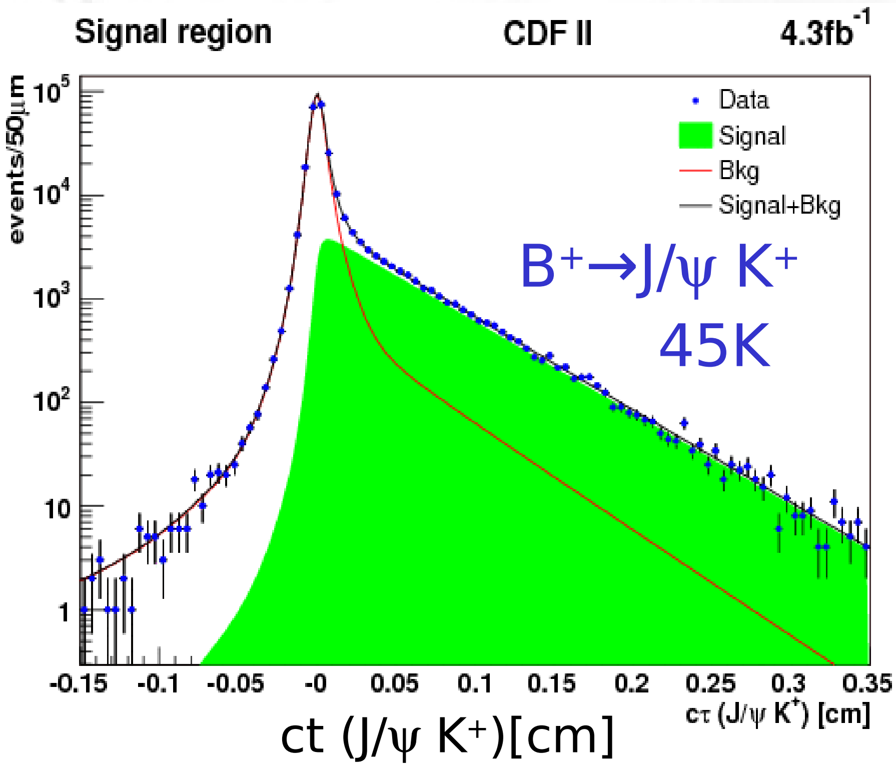


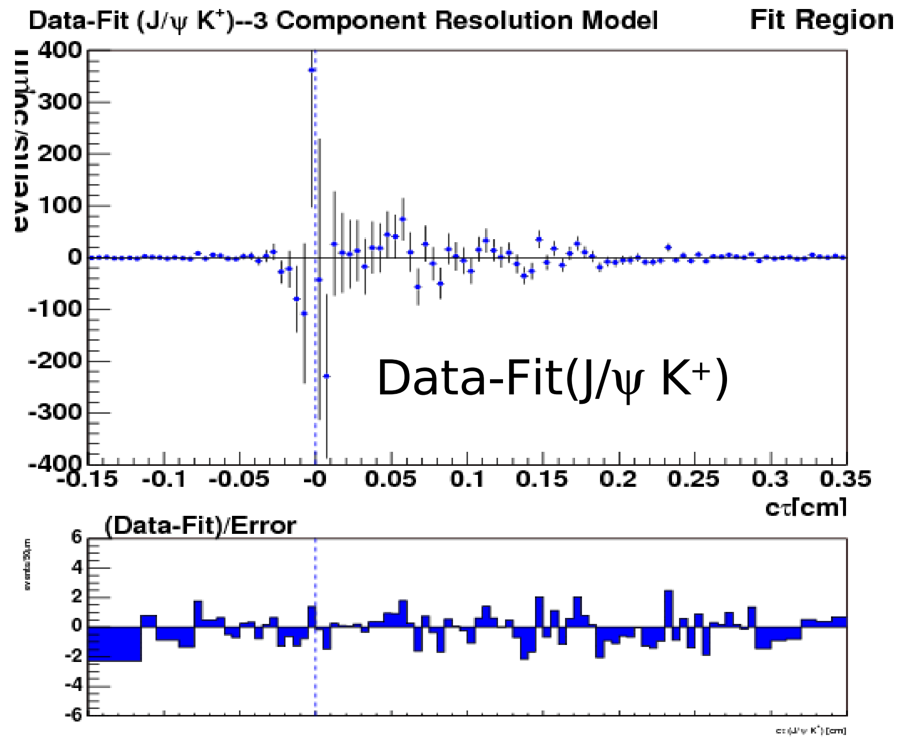


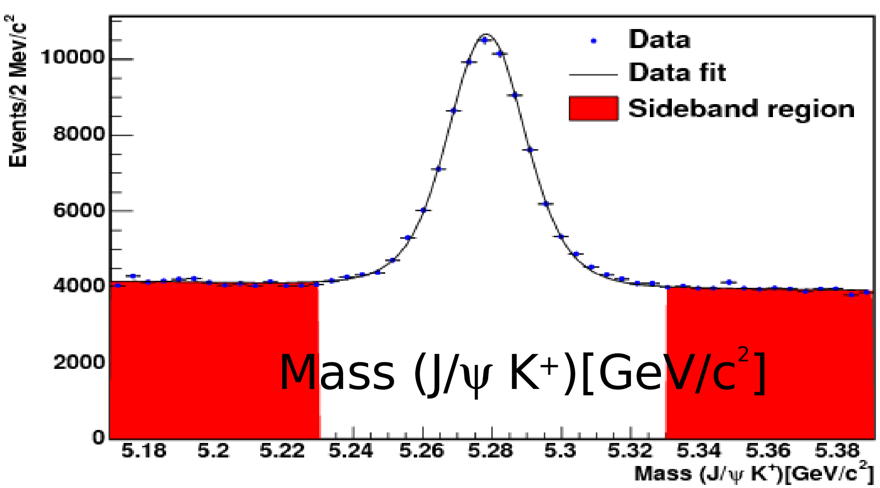


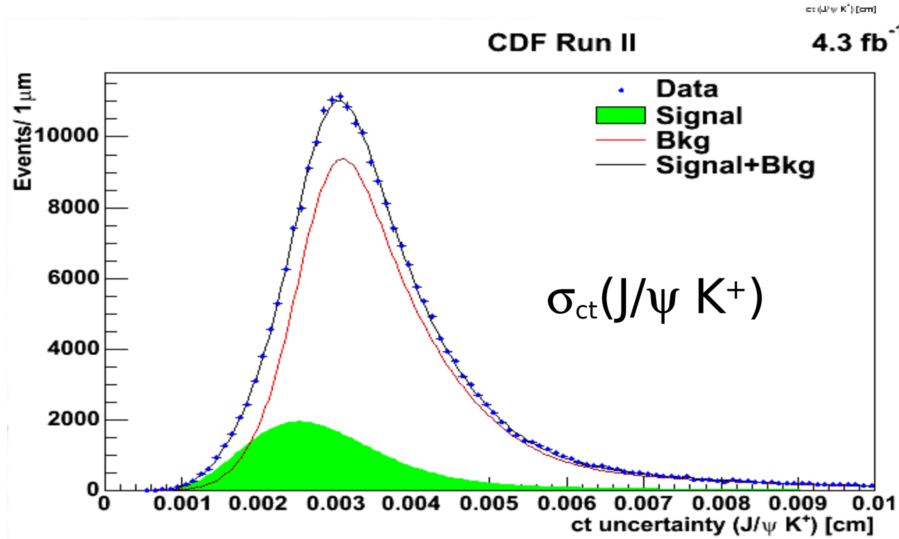


B^+ (data and fit projections)

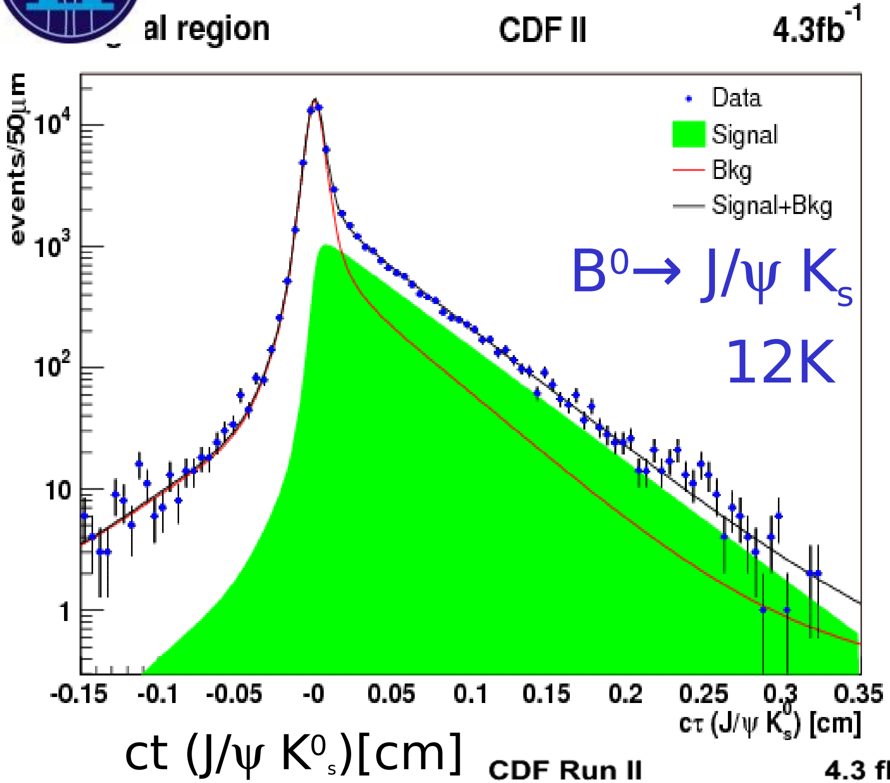


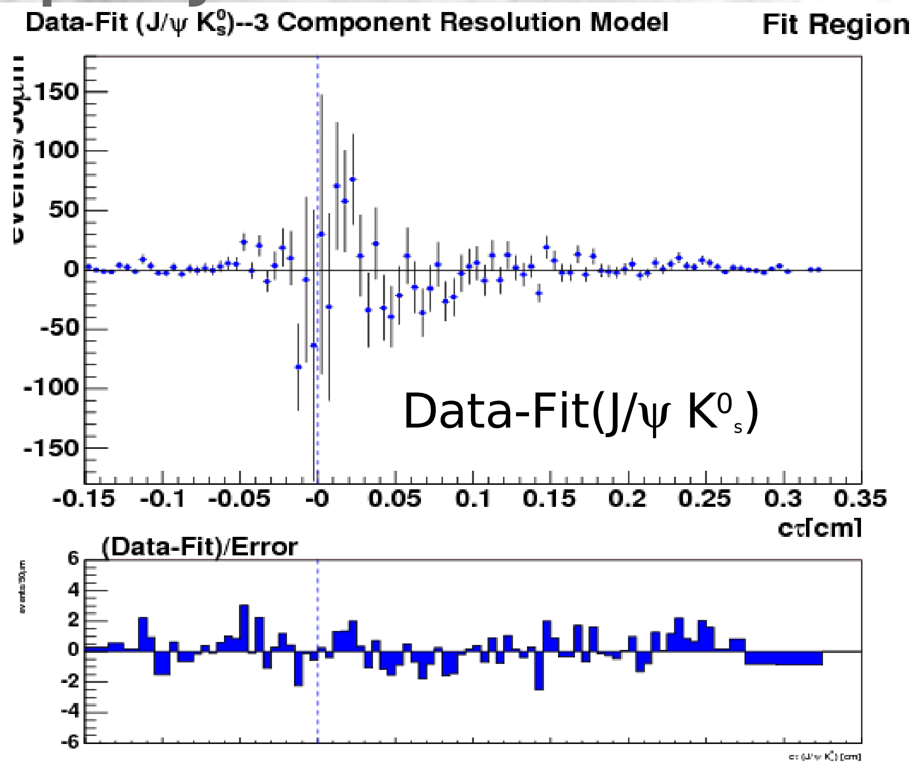


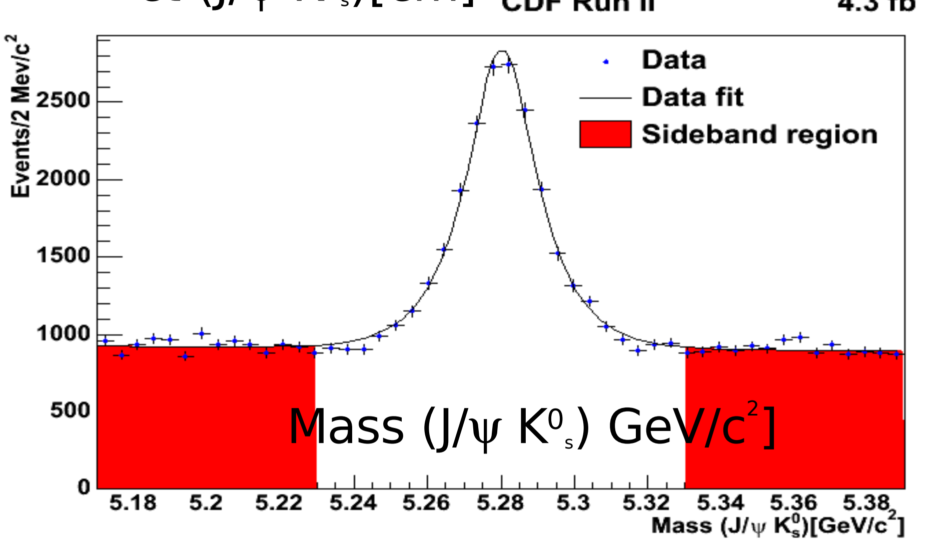


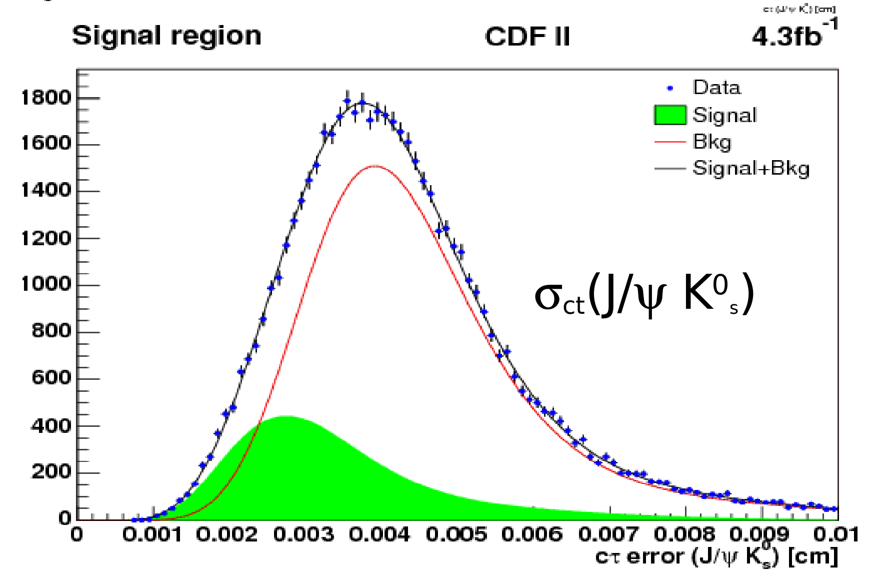


B^0 (data and fit projections)



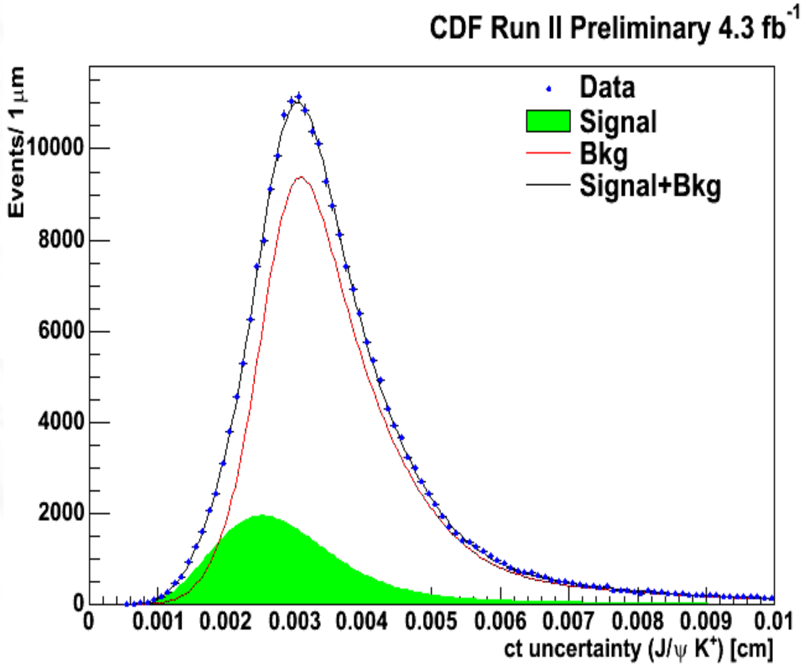






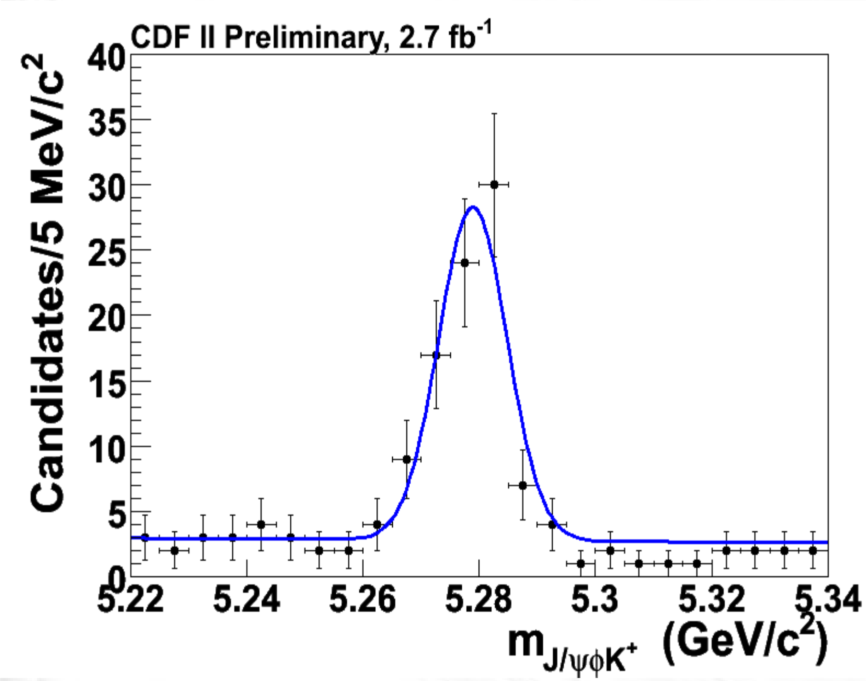
How do we model this data?

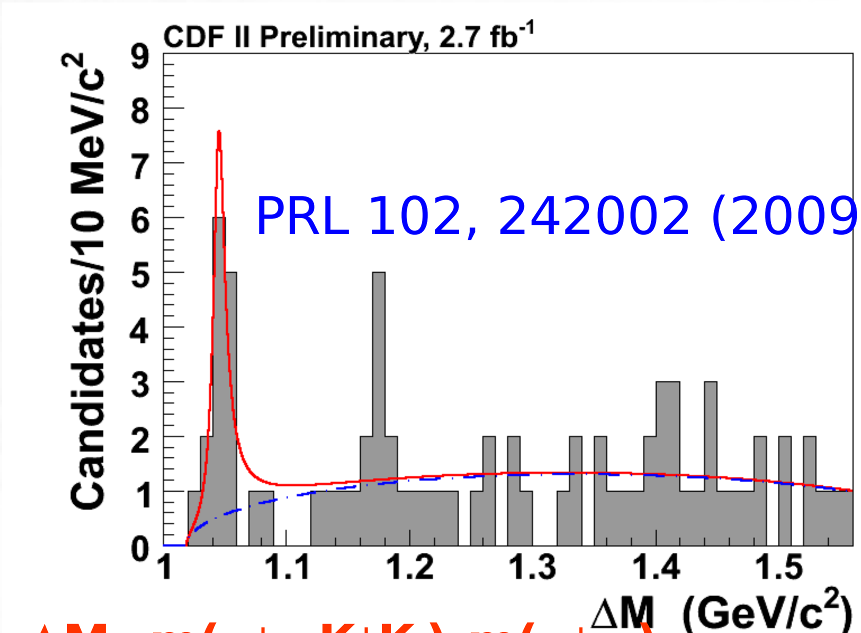
$S(\sigma_{ct})$ modeled in an ad-hoc way using Gamma Distributions : $S(\sigma_{ct}) = A \cdot \sigma_{ct}^{\alpha} e^{-\sigma_{ct}/\beta}$ [A a normalization constant ; $A = 1/(\Gamma(\alpha+1)\, \beta^{\alpha+1})$]



$B^+ \to Y(4140)K^+$:recap

2009: Evidence of $J/\psi\ \varphi$ structure at 4140 MeV in $B^+ \to J/\psi\ \varphi\ K+$



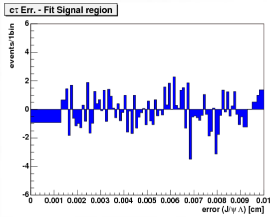


$\Delta M = m(\mu^+\mu^- K^+ K^-) - m(\mu^+\mu^-)$

M = 4143 ± 2.9 ± 1.2 MeV (above open charm)
$\Gamma = 11.7\ ^{+8.3}_{-5.0} \pm 3.7$ MeV (probably a strong decay)
Many exotic interpretations proposed. No signal seen by Belle which sets a limit on Br < 6 x 10^{-6} at 90%CL

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.