Suppressed Decays of B_s Mesons

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On behalf of the CDF collaboration

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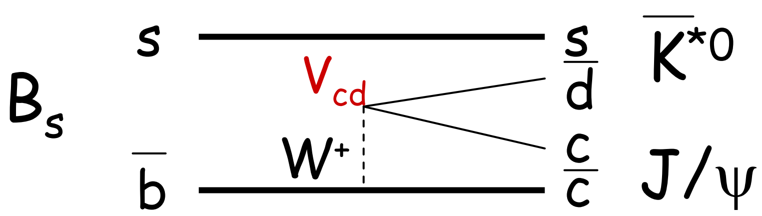
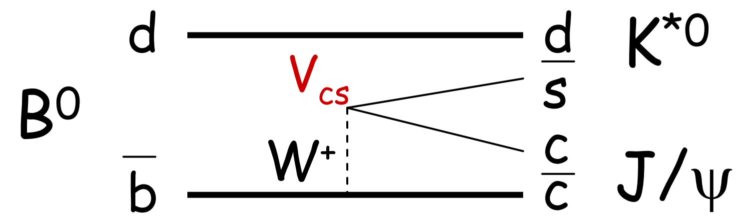
Motivation

o Most of the B_s suppressed decays have not been observed yet

$\Rightarrow B_s \to J/\psi K^*(892)$, $B_s \to J/\psi K_S$, $B_s \to J/\psi f^0$, …





Only difference is the V_{cd} contribution vs the V_{cs}

o All of these modes have the possibility of providing further information on lifetime difference and CP asymmetries in B_s decays.

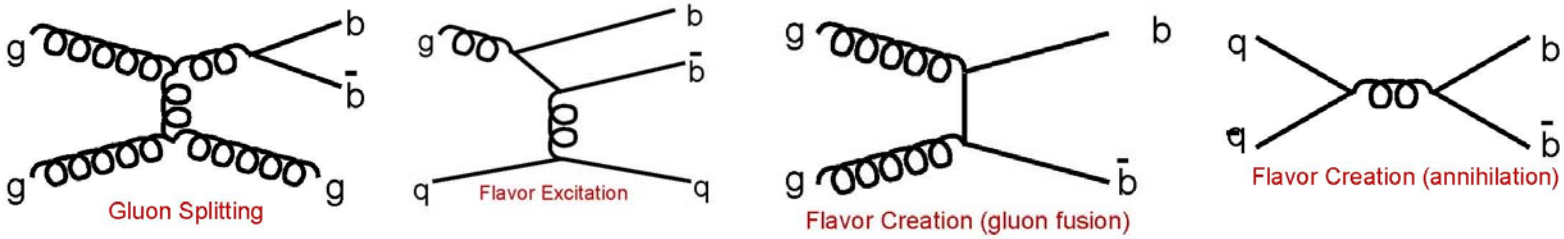
$\Rightarrow B_s \to J/\psi\ K_S$ is a CP eigenstate, measurement of the lifetime in this mode is a direct measurement of $\tau_{Bs\ (Heavy)}$

$\Rightarrow B_s \to J/\psi\ K_S$ can be used to extract the angle γ of unitary triangle (R. Fleischer, Eur.Phys. J.C10:299-306,1999)

$\Rightarrow B_s \to J/\psi\ K^*$ contains an admixture of CP final states, an angular analysis can be done to extract $\sin(2\beta_s)$ (complementary to $B_s \to J/\psi\phi$)

B production at Tevatron

- Tevatron is a source of all B-hadron species: B_d, B_u, B_c, B_s and Λ_b
  - $\Rightarrow$ At CDF the $\sigma_b = 29.4 \pm 0.6 \pm 6.2$ μb ($|\eta| < 1$)



- Some of them are not produced at the B-factories
  - $\Rightarrow$ B_s, B_c, B^{**}, B_s^{**}, Λ_b, Σ_b, Ξ_b,..
- More decays are accessible thanks to the amount of luminosity collected
  - $\Rightarrow$ CDF has more than 7.5 fb^{-1} on tape
- CDF has excellent mass resolution, vertex resolution and trigger system for flavor physics

Measurements

- Branching ratio measurement

$$\frac{Br(B_s \to J/\psi\ h)}{Br(B^0 \to J/\psi\ h)} = \frac{N(B_s \to J/\psi\ h)}{N(B^0 \to J/\psi\ h)} * \frac{f_d}{f_s} * A_{rel}$$

where $h = K_S$ or K^*

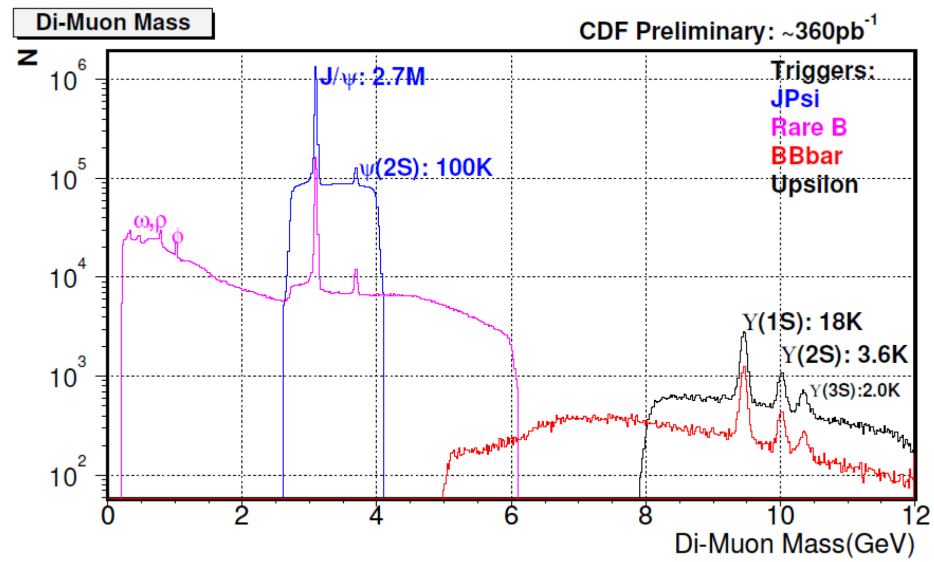
- Branching ratio of B_s relative to B^0
- Yield of B_s and B^0 events (from data)
- Fragmentation fractions (from CDF result)
- Relative Acceptance (from MC)

- *Analysis strategy*
  - ⇒ Reconstruct $B \to J/\psi\ K^*$ and $B \to J/\psi\ K_S$ from a large sample of di-muon ($J/\psi \to \mu^+ \mu^-$ decays)
  - ⇒ Apply specific optimization cuts to remove backgrounds
  - ⇒ Likelihood fit to the invariant mass distribution to get the ratio of yields

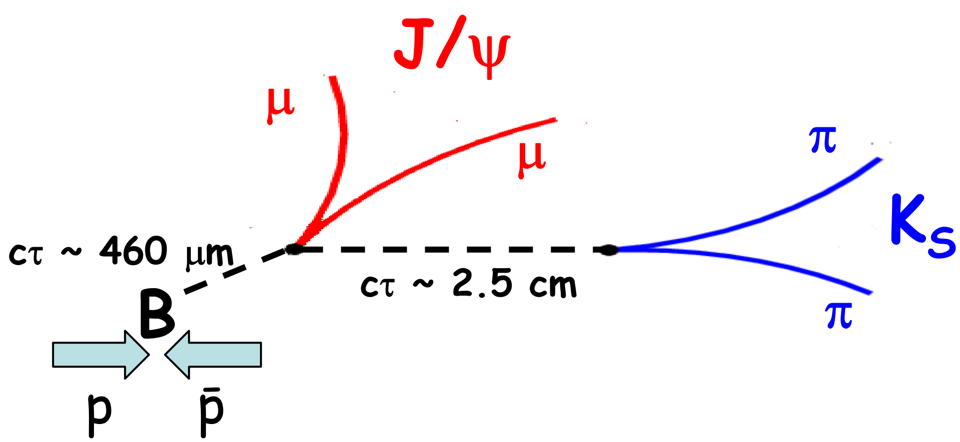
Reconstruction

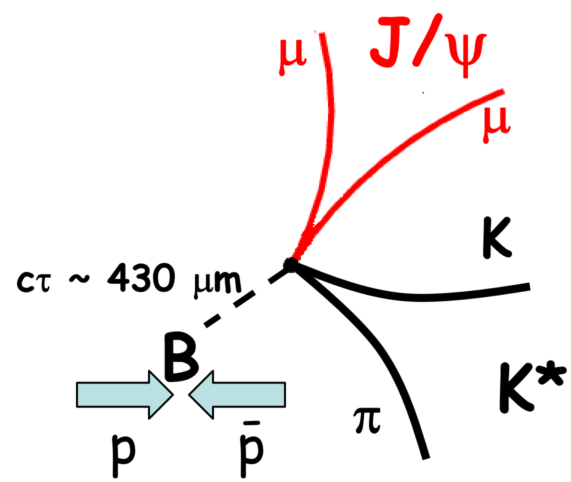
- Data from di-muon triggers

  ⇒ J/ψ triggers, mainly looking for:
  - two low p_T muons : p_T>1.5 GeV/c^2
  - two muons have opposite charge
  - $\Delta\phi$ (between 2 muons) <120 degrees



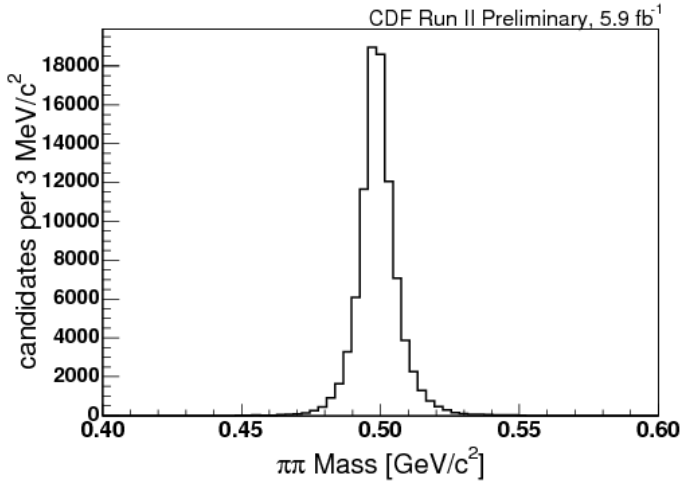
- Reconstruction





$B \rightarrow J/\psi\ K_S$ Analysis

- Advantage: K_S has a long life ($c\tau$~ 2.5 cm) and is a narrow resonance
  $\Rightarrow$ easy to get a pure K_S sample
- Disadvantage: expecting small B_s signal
  $\Rightarrow$ important to suppress combinatorial background contribution

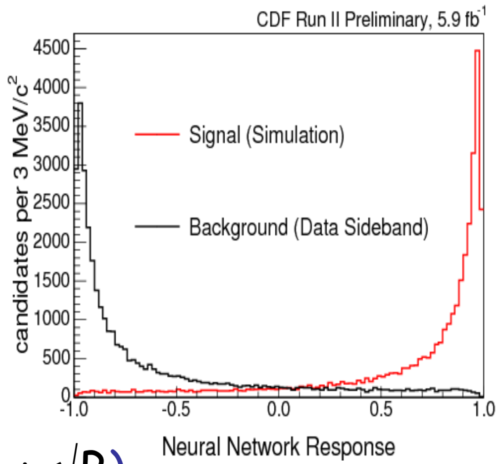


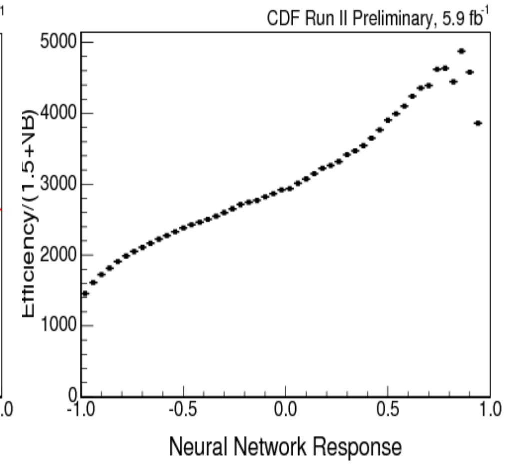
- A Neural Network is used to discriminate between signal and combinatorial background

$\Rightarrow$ 22 different kinematic variables
p_T, d0, $c\tau$, helicity angles, mass,..

$\Rightarrow$ Trained using B_s MC for Signal and data sideband for BKG

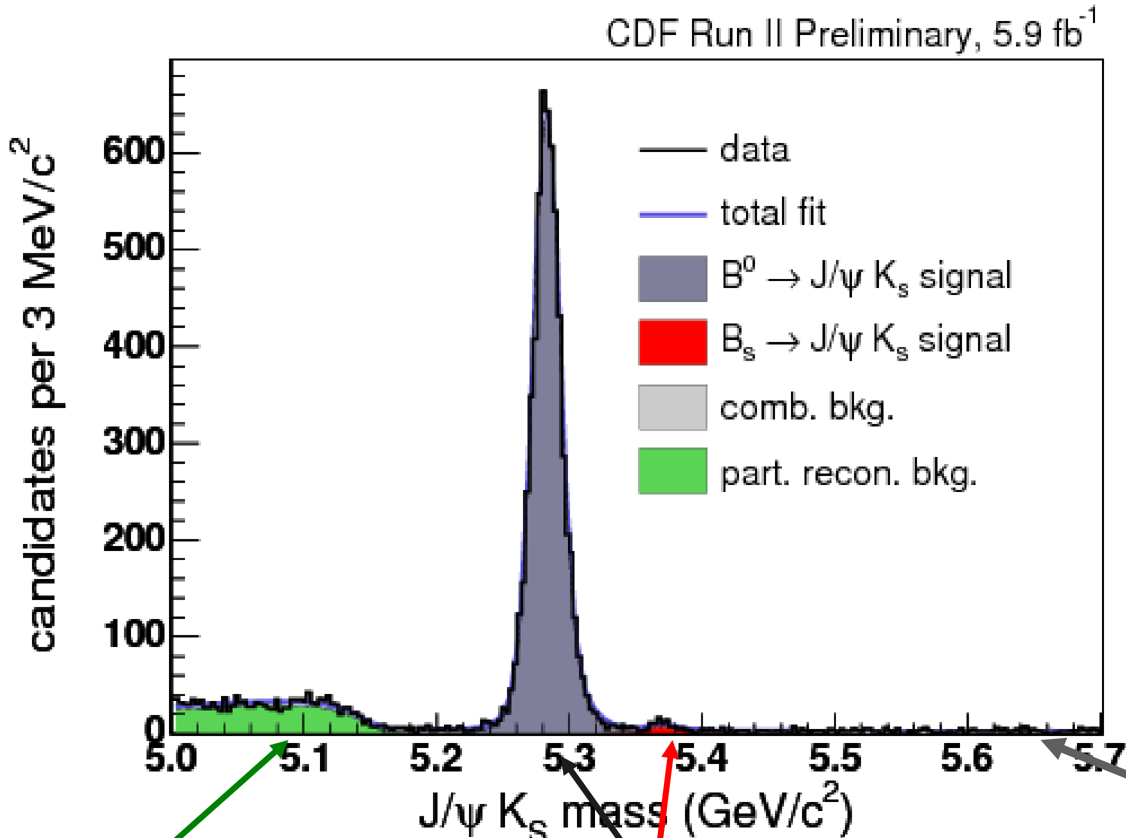
$\Rightarrow$ Optimization procedure geared towards maximizing efficiency/(1.5 + $\sqrt{B}$)





Fit contributions for $B \to J/\psi\ K_S$

- The invariant mass distribution is fitted with binned Likelihood



Signal

B^0 and B_s decays

Background

- Partial reconstruction multibody decays where π, K or γ missing
- Combinatorial background
- $\Lambda_b \to J/\psi\Lambda$ contribution

Negligible after specific cut

Argus function convoluted with a Gaussian

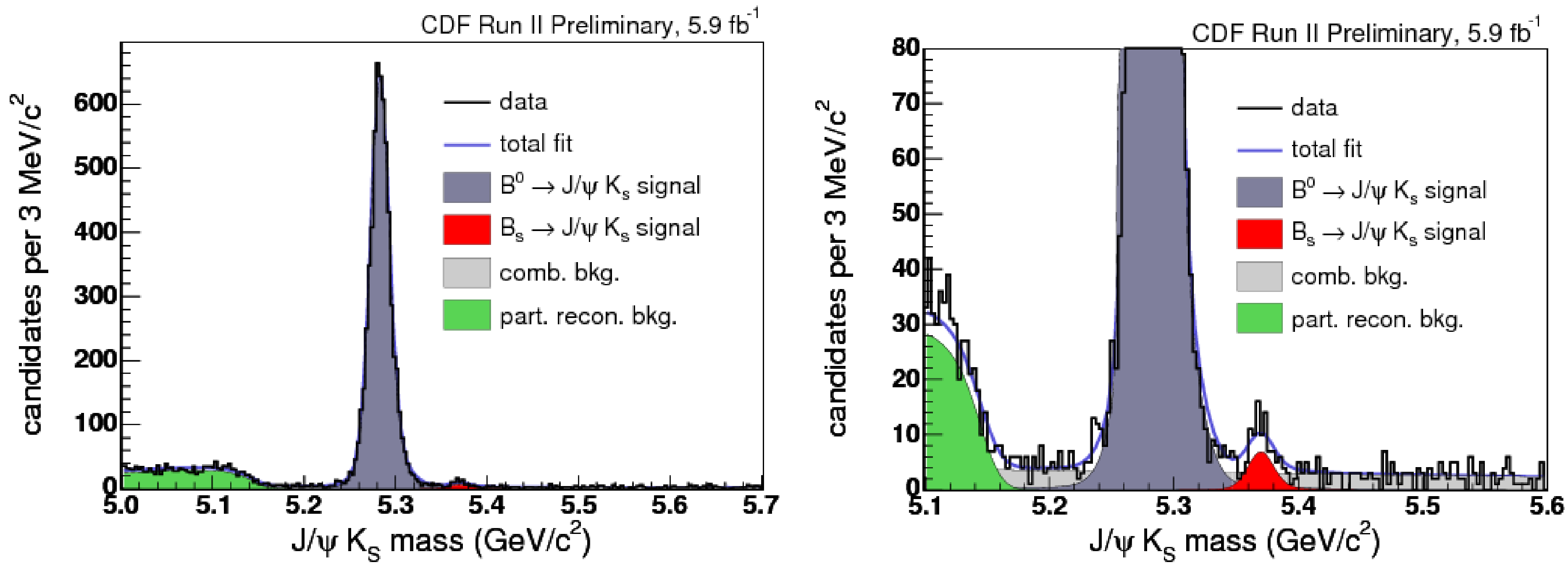
3 Gaussian template extracted from B^0 simulation

Use $m(B_s)$-$m(B^0)$ for extrapolation

Exponential function

First observation of $B_s \to J/\psi\ K_S$!!!

$$\frac{Br(B_s \to J/\psi\ K_S)}{Br(B^0 \to J/\psi\ K_S)} = \frac{N(B_s \to J/\psi\ K_S)}{N(B^0 \to J/\psi\ K_S)} * \frac{f_d}{f_s} * A_{rel}$$



$N(B^0) = 5954 \pm 79$; $N(B_s) = 64 \pm 14$; $N(B_s)/N(B^0) = 0.0108 \pm 0.0019$

- The p- value for B_s signal compared to the background hypothesis

p-value = $3.85\ 10^{-13}$ or 7.2σ

B→J/ψ K* Analysis

o Disadvantage: K* is not a long-lived particle and is a wider resonance

⇒ more background contributions to deal with

o Advantage: expecting bigger B_s signal

⇒ not necessary sophisticated tools to remove combinatorial background

o Rectangular cuts optimization to maximize efficiency/(1.5 + $\sqrt{B}$)

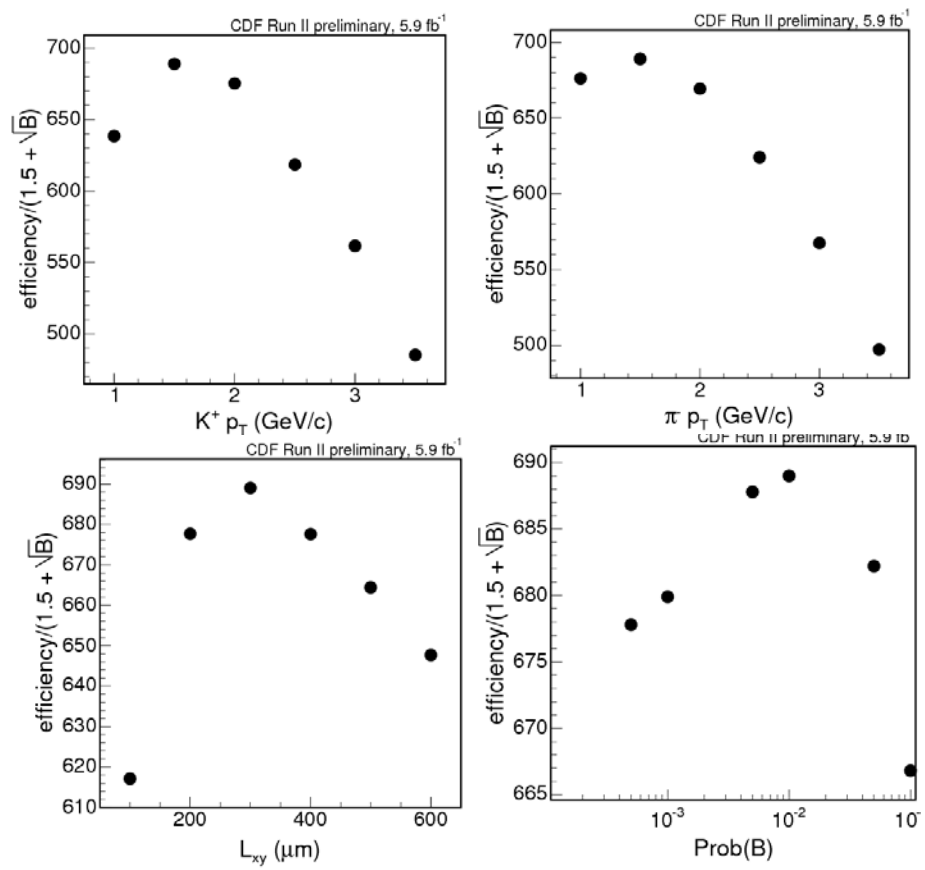
p_T (B) >6 GeV/c

Flight distance L_{xy} (B) >300 μm

Impact parameter d_{xy} (B) < 50 μm

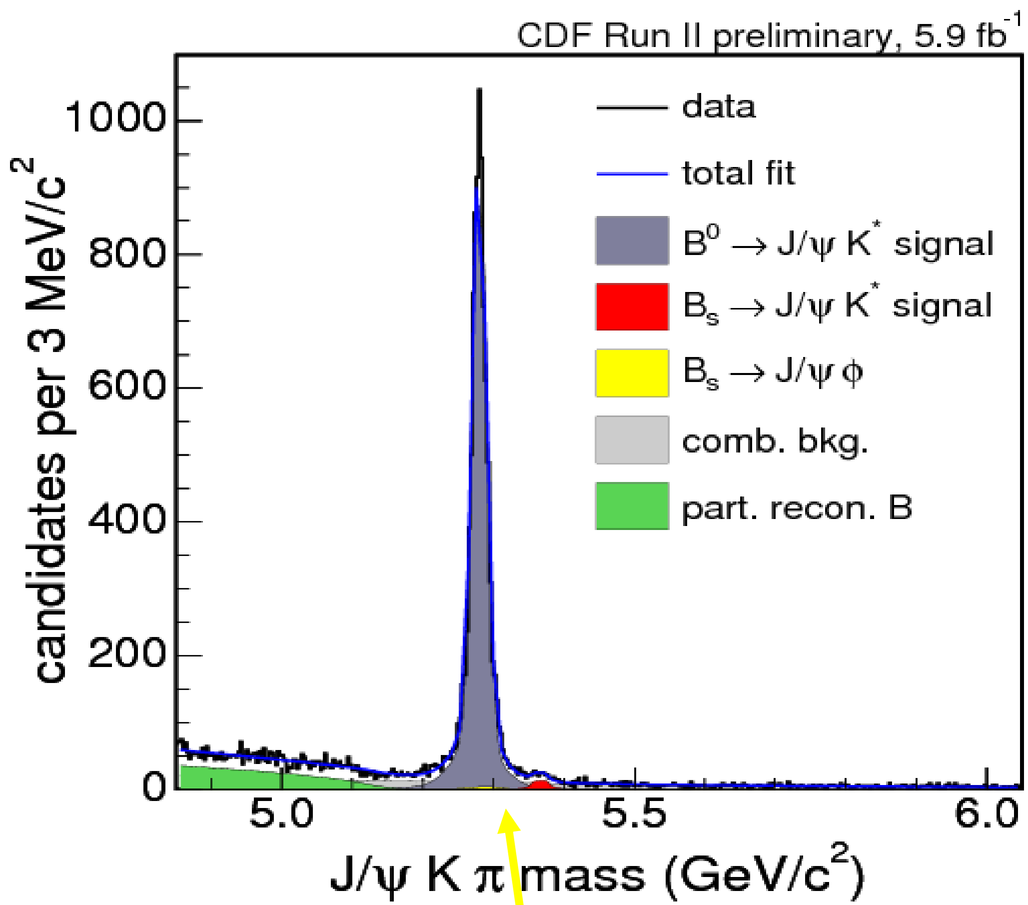
Fit vertex Probability (B) >0.01

p_T (K^+, π^-) >1.5 GeV/c



Fit contributions for $B \to J/\psi\ K^*$

o Same contributions than in the $B \to J/\psi\ K_S$ analysis plus additional backgrounds



Signal

B^0 and B_s decays

Background

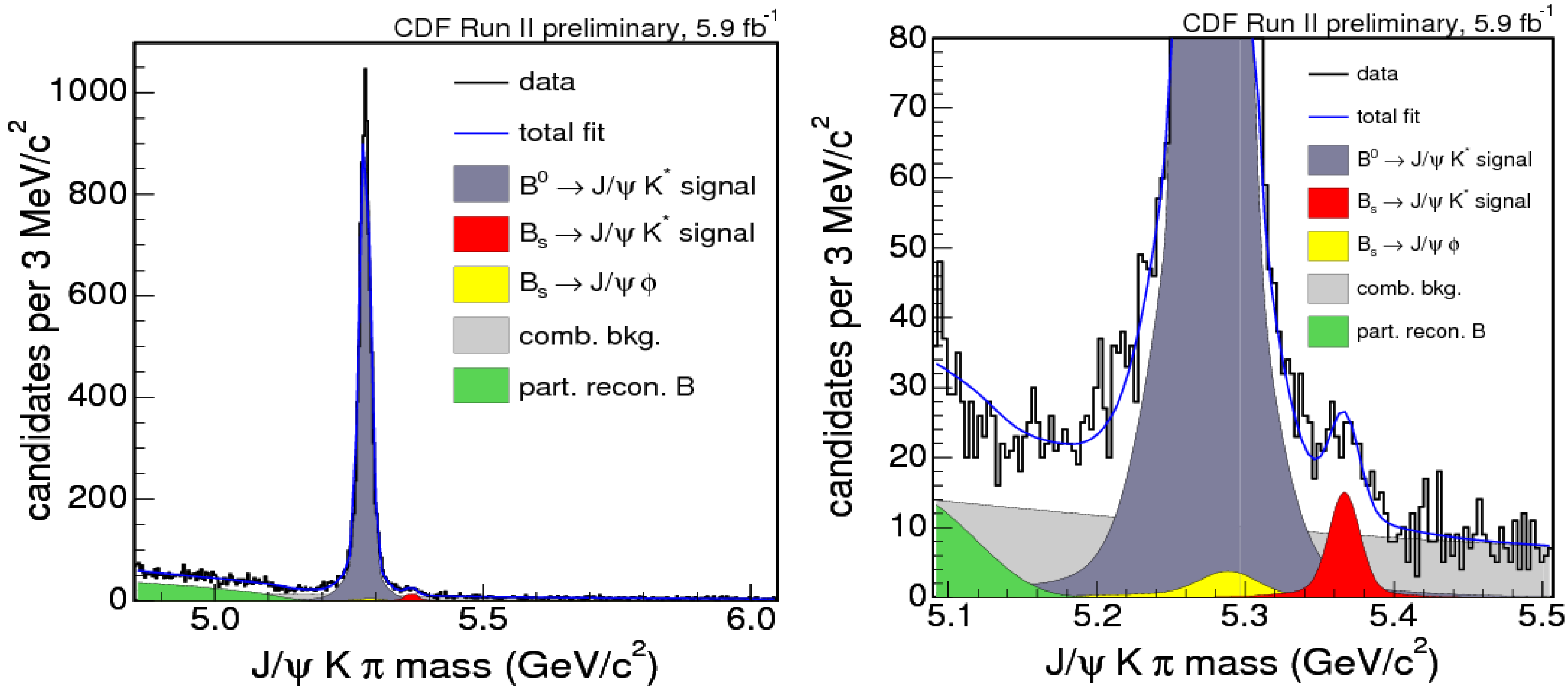
- Partial reconstruction
- Combinatorial background
- $B_s \to J/\psi\phi$ contribution
- $B_s \to J/\psi f^0$ contribution

last one is negligible

$B_s \to J/\psi\ \phi$ modeled by 2 Gaussians template

Extracted from simulation but contribution constrained using data

First observation of $B_s \rightarrow J/\psi\ K^*$!!!



N (B^0) = 9530 ± 110 ; N (B_s) = 151 ± 25 ; N(B_s)/N(B^0) = 0.0159 ± 0.0022

- The p- value for B_s signal compared to the background hypothesis

p-value = 8.9 10^{-16} or 8σ

Systematic uncertainties

Difference sources of systematic uncertainties have been considered

Sources	$B \to J/\psi\ K^*$	$B \to J/\psi\ K_S$
Signal modeling	4.4 %	4.6%
Mass difference (B_s-B^0)	~0.1%	~0.1%
Combinatorial background (different modeling)	1.25%	5.6%
Combinatorial background (fixing the contribution)	31%	5.6%
$B_s \to J/\psi\phi$	1.25%	-

$B \to J/\psi K^*$	$N(B_s)/N(B^0) = 0.0159 \pm 0.0022$ (stat.) ± 0.0050 (sys.)
$B \to J/\psi K_S$	$N(B_s)/N(B^0) = 0.0108 \pm 0.0019$ (stat.) ± 0.0010 (sys.)

Relative Acceptance Calculation

$$\frac{Br(B_s \to J/\psi\ h)}{Br(B^0 \to J/\psi\ h)} = \frac{N(B_s \to J/\psi\ h)}{N(B^0 \to J/\psi\ h)} * \frac{f_d}{f_s} * \boxed{A_{rel}}$$

- Relative Acceptance evaluation using simulation

$$A_{rel} = \frac{N(B^0 \to J/\psi K_s\ passed)/N(B^0 \to J/\psi K_s\ generated)}{N(B_s \to J/\psi K_s\ passed)/N(B_s \to J/\psi K_s\ generated)}$$

$B \to J/\psi K^*$	$A_{rel} = 1.057 \pm 0.010\ (stat) \pm 0.263 (sys.)$
$B \to J/\psi K_S$	$A_{rel} = 1.012 \pm 0.010\ (stat) \pm 0.042\ (sys.)$

- Systematic uncertainties

Source	$B \to J/\psi\ K^*$	$B \to J/\psi\ K_S$
$c\tau$ in B^0 and B_s MC	0.9%	2.8%
p_T spectrum	2.7%	3%
polarization	24.6%	-

Recap of all numbers

$$\frac{Br(B_s \to J/\psi\ h)}{Br(B^0 \to J/\psi\ h)} = \frac{N(B_s \to J/\psi\ h)}{N(B^0 \to J/\psi\ h)} * \frac{f_d}{f_s} * A_{rel}$$ where $h = K_S$ or K^*

$\Rightarrow N(B_s \to J/\psi\ h)/N(B^0 \to J/\psi\ h)$:

$B \to J/\psi K^*$	0.0159 ± 0.0022 (stat.) ± 0.0050 (sys.)
$B \to J/\psi K_S$	0.0108 ± 0.0019 (stat.) ± 0.0010 (sys.)

$\Rightarrow f_s/f_d$ from CDF(Phys.Rev. D77, 072003 (2008)) combined with new PDG value for $Br(D_s \to \phi\pi)$

0.269 ± 0.033

$\Rightarrow A_{rel}$:

1.057 ± 0.010 (stat) ± 0.263 (sys)

1.012 ± 0.010 (stat) ± 0.042 (sys)

Branching Ratios Measurement

$$\frac{Br(B_s \to J/\psi\ K^*)}{Br(B^0 \to J/\psi\ K^*)} = 0.062 \pm 0.009\ (stat.) \pm 0.025\ (sys.) \pm 0.008\ (frag.)$$

$$\frac{Br(B_s \to J/\psi\ K_S)}{Br(B^0 \to J/\psi\ K_S)} = 0.041 \pm 0.007\ (stat.) \pm 0.004\ (sys.) \pm 0.005\ (frag.)$$

⇒ Using PDG values: $Br(B^0 \to J/\psi\ K^*) = (1.33 \pm 0.06) * 10^{-3}$

$Br(B^0 \to J/\psi\ K^0) = (8.71 \pm 0.32) * 10^{-4}$

$Br(B_s \to J/\psi\ K^*) = (8.3 \pm 1.2\ (stat.) \pm 3.3\ (sys.) \pm 1.0\ (frag.) \pm 0.4\ (PDG)) * 10^{-5}$

$Br(B_s \to J/\psi\ K^0) = (3.5 \pm 0.6\ (stat.) \pm 0.4\ (sys.) \pm 0.4\ (frag.) \pm 0.1\ (PDG)) * 10^{-5}$

Summary

o Two new Cabibbo and color suppressed decays of B_s mesons have been observed by CDF : $B_s \rightarrow J/\psi K^*$ and $B_s \rightarrow J/\psi K_S$

$\Rightarrow$ significance greater than 7σ

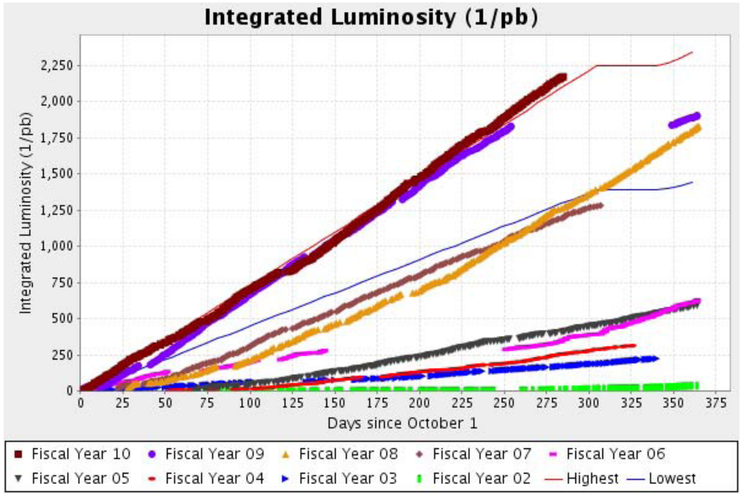
o A preliminary measurement of their Branching Ratios relative to the B^0 decays have been done

$\Rightarrow$ For K^* : 0.062 ± 0.009 (stat.) ± 0.025 (sys.) ± 0.008 (frag.)

$\Rightarrow$ For K_S : 0.041 ± 0.007 (stat.) ± 0.004 (sys.) ± 0.005 (frag.)

o These modes are going to provide further information on lifetime difference and CP asymmetries in B_s decays

o CDF is collecting a lot of more events every hour…so stay tuned because more decays are coming soon



Back up

Signals and Background Contributions

Both analysis have some common Background contributions and signals

- Signals (B^0 and Bs) templates are obtained from simulation (B^0 MC)

$$f_{B^0} = N_{B^0} \cdot \left(\frac{f_1}{\sigma_1\sqrt{2\pi}} e^{-(x-\mu_1)^2/2\sigma_1^2} + \frac{f_2}{\sigma_2\sqrt{2\pi}} e^{-(x-\mu_2)^2/2\sigma_2^2} + \frac{f_3}{\sigma_3\sqrt{2\pi}} e^{-(x-\mu_3)^2/2\sigma_3^2}\right)$$

The same template for B^0 and Bs taking into account Δm=86.8 MeV/c^2

- Combinatorial background

$$f_{comb}(x) = N_0 \cdot e^{C_0 x}$$

Exponential function

(Float in the final fit)

- Partial reconstruction contribution for 5 bodies B^0 decays

$$f_{ARGUS}(x) = N_1 \cdot \sqrt{1 - \frac{x^2}{m_0^2}} \cdot e^{-C_1 \frac{x^2}{m_0^2}}$$

Argus function

m_0 cut off ~5.14

mass (B^0)-mass (π^0)

More Backgrounds

$B \to J/\psi\ K^*$ analysis has more backgrounds that need to be modeled

- $Bs \to J/\psi\ \phi$
  - ⇒Templates are obtained from simulation: 2 Gaussians (Fixed in the final fit)
  - ⇒ Contribution constrained using $Bs \to J/\psi\ \phi$ data sample

- Partial reconstruction contribution for 5 bodies Bs decays
  - ⇒ modeled with another ARGUS function
    - m_0 cut off at 5.22 GeV/c2 : mass (Bs)-mass(π^0)
  - ⇒ exponential constant constrained to be identical to the previous one

Background studied but considered negligible contributions

- In $B \to J/\psi\ K^*$ analysis: $B \to J/\psi\ f_0$
- In $B \to J/\psi\ Ks$ analysis: $\Lambda_b \to J/\psi \Lambda$