CDF public note 8448

Search for η_b at CDF

The CDF Collaboration*
URL http://www-cdf.fnal.gov

(Dated: August 18, 2006)

We report on a search for the spin-zero $b\bar{b}$ bound state, η_b, through the exclusive η_b decay into $J/\psi J/\psi$, where both J/ψ's decay into a dimuon pair at CDF. Using the 1.1 fb^{-1} of data, we observed 3 candidates while expecting 3.6 background events in the search window from 9.0 to 9.5 GeV. The η_b production cross section, relative to the cross section of the b-Hadron decay to $J/\psi X$, is measured in this analysis. The upper limit of the η_b production cross section times decay branching fraction is found to be

$$\frac{\sigma(p\bar{p} \to \eta_b X; |y(\eta_b)| < 0.6, p_T(\eta_b) > 3.0\text{GeV})) \cdot Br(\eta_b \to J/\psi J/\psi)}{\sigma(p\bar{p} \to H_b \to J/\psi X); |y(J/\psi)| < 0.6, p_T(J/\psi) > 3.0\text{GeV})} < 5.0 \times 10^{-3}$$

I. INTRODUCTION

In the bottomonium ($b\bar{b}$) system, many bottomonia particles have been observed and matched well with the NRQCD predictions [1]. But the $b\bar{b}$ spin singlet pseudo-scalar meson, η_b, has not been observed yet. The η_b production cross section, predicted by NRQCD, is on the order of a few mircobarns [1] at the Tevatron energy scale. This large cross section suggests η_b should be observable during the Tevatron Run II program. The observation of this η_b could be a good test of NRQCD.

Various potential models predict the mass splitting between the η_b and the $\Upsilon(1S)$ to be 30 to 160 MeV [2–13]. The η_b width is predicted to be narrower than the spin-zero $c\bar{c}$ bound state, η_c, width of (25.5±3.4) MeV [15].

A possible search at the CDF experiment is to look for the exclusive η_b decay into two J/ψ's. This search channel takes advantage of the dedicated J/ψ-dimuon trigger. But the leading order contribution in NRQCD shows the branching ratio of $\eta_b \to J/\psi J/\psi$ to be exactly zero. The same should be true for the $\eta_c \to \phi\phi$. However measurements of the $\eta_c \to \phi\phi$ branching ratio show it to be about 1% [14]. This indicates some next-leading-order contribution or other (non-perturbative) mechanism allows the quarkonia meson to decay into two vector meson states. By scaling the $\eta_c \to \phi\phi$ by $(m_c/m_b)^4$, to account for the c and b quark mass difference, the estimated $\eta_b \to J/\psi J/\psi$ branching fraction is 7 $\times 10^{-5}$ to 7 $\times 10^{-3}$. The branching fraction of the $J/\psi + J/\psi \to \mu^+\mu^- + \mu^+\mu^-$ is $(5.88 \pm 0.10)\%$ [15]. This gives the total branching fraction of $\eta_b \to J/\psi + J/\psi \to \mu^+\mu^- + \mu^+\mu^-$ to be 2.5 $\times 10^{-6\pm1}$.

From the NRQCD matrix elements, the calculated differential cross section after multiplying the decay branching fraction gives $(Br \cdot d\sigma/dy) \sim 0.3 \times 10^{\pm1}$ pb [1]. This yields a rough estimate of 0.2 to 20 signal events with 1.1 fb^{-1} of data, in a rapidity interval of ±0.6 and an assumed 10% acceptance for each $J/\psi \to \mu^+\mu^-$. In a previous search using CDF Run I data, 7 events with 1.2 expected background contribution were seen with ~100 pb^{-1} [16]. This corresponds to a 2.2σ statistical significance. An upper limit of 18 pb was set on the η_b production cross section times branching fraction.

In this note, we report on a search for η_b decaying into two J/ψ's at CDF using 1.1 fb^{-1} of data. The CDF detector is described in detail elsewhere [17]. We explicitly require one of the J/ψ (leading) has to come from a pair of muons which are charged particles reconstructed in the CDF drift chamber (COT) with a track segment in the muon detectors. The central muon detector (CMU) detect muons with $p_T > 1.4$ GeV in the range of $|\eta| < 0.6$, where $\eta = -\ln(\tan(\theta/2))$ and θ is the angle of the track with respect to the beamline. The central muon extension (CMX)

*Electronic address: `rslu@fnal.gov`

convers $0.6 < |\eta| < 1.0$ for muon candidates with $p_T > 2.0$ GeV. The other J/ψ (non-leading) is a combination of a muon and a charged particle. The charged particles or muons used in the reconstruction are required to pass the standard track quality cuts.

The dimuon invariant mass spectrum is shown in Fig. 1 for 1.1 fb^{-1} of data. There are about 8 million J/ψ and 260 thousand $\psi(2S)$ signal candidates in the mass spectrum. A narrow resonance close to 9.4 GeV in the $J/\psi J/\psi$ invariant mass spectrum will be evidence of the η_b meson. If there is no significant evidence of the existence of η_b, an η_b production upper limit relative to the J/ψ production from the b-Hadron decay will be quoted. This is defined as:

$$\frac{\sigma(p\bar{p} \to \eta_b X) \cdot Br(\eta_b \to J/\psi J/\psi)}{\sigma(p\bar{p} \to H_b \to J/\psi X)}$$

II. J/ψ PRODUCTION

The $p\bar{p} \to b \to J/\psi X$ process is used as the reference channel for the η_b production measurement. This relative production has the advantage of canceling the uncertainty from luminosity measurement and reconstruction efficiency of the leading J/ψ. The inclusive J/ψ and $p\bar{p} \to b \to J/\psi X$ production cross sections were published using earlier CDF Run II data [18]. The results can be used to extract the absolute η_b production.

The J/ψ's are reconstructed with CMU muon pairs which are required to pass the trigger requirements. The muons are further required to satisfy the track and muon quality selections and have p_T greater than 2.0 GeV. A J/ψ is formed from the muon pair if:

- the muon pair has an invariant mass within 2.95 to 3.25 GeV
- the muon pair has a p_T greater than 3.0 GeV
- the rapidity is within -0.6 to 0.6
- the opening angle of the dimuon is smaller than 130 degrees.

The yields of the J/ψ signal are based on a fit to the invariant mass spectrum. The J/ψ signal component is modeled by the empirical Crystalball-line (CBline) function together with a Gaussian function. The CBline function is parametrized to model the radiative tail of a particle decay. It is written as :

$$\text{CBline} = \begin{cases} A \cdot e^{\frac{(Et-Em)^2}{2\sigma^2}} & \text{for } Em > Et - \alpha * \sigma \\ A \cdot (\frac{n}{\alpha})^n \frac{e^{\frac{\alpha^2}{2}}}{(\frac{(Et-Em)}{\sigma} + \frac{n}{\alpha} - \alpha)^n} & \text{for } Em < Et - \alpha * \sigma, \end{cases}$$

where the Em is the measured value, Et is the true value, A is the area, σ is the width, and α and n are the empirical parameters. A first-order polynomial models the background.

The J/ψ from prompt production and B decays are measured by fitting the proper decay length ($c\tau$) distribution. Since the J/ψ doesn't have a measurable lifetime, the "long-lived" J/ψ's are mostly from B decays which have displaced vertices. The J/ψ candidates are required to have three or more hits in the CDF silicon detectors (SVXII) for better vertex resolution. The vertex fit of the J/ψ candidates are required to have a fit probability greater than 0.1%. An unbinned-maximum-likelihood fit is used to perform a mass and proper decay length simultaneous fit and obtain the prompt and long-lived J/ψ fraction from the inclusive J/ψ production. The probability density functions (PDFs) used in the likelihood fit are :

- The J/ψ signal mass distribution is modeled by the combination of the Crystalball-line function and a Gaussian.
- The background distribution of the mass spectrum is modeled by a first-order polynomial.
- The proper decay length of the J/ψ signal is modeled by two Gaussian functions for the prompt component and an exponential function convoluted by a Gaussian for the long-lived J/ψ component. The exponential-convoluted-by-Gaussian function can be written as :

  $$Exp \otimes G = \frac{1}{c\tau_B} exp\left[\frac{\sigma^2}{2c\tau_B^2} - \frac{x}{c\tau_B}\right] - \left[1 - Freq(\frac{\sigma}{c\tau_B} - \frac{x}{\sigma})\right] \quad ,$$

  where the $c\tau_B$ is the mean of proper decay length, σ is the error of proper decay length measurement, x is the measured proper length distribution.

- The background contribution in the $c\tau$ spectrum is modeled by prompt (double-Gaussian), symmetric-long-lived (exponential-convoluted-by-Gaussian) and asymmetric-long-lived (exponential-convoluted-by-Gaussian) components.

The likelihood is defined as

$$\begin{aligned} L \;=\; & f_s \cdot P_s^{mass}\left(f_p P_p^{c\tau} + (1-f_p)P_{E\otimes G}^{c\tau}\right) + \\ & (1-f_s)\cdot P_{bg}^{mass}\left(f_{sym}P_{sym}^{c\tau} + f_{a+}P_{a+}^{c\tau} + f_{a-}P_{a-}^{c\tau} + (1-f_{sym}-f_{a+}-f_{a-})P_{prompt}^{c\tau} \right) \;, \end{aligned}$$

where the

- f_s is the J/ψ signal fraction from the total number of candidates in the fit;
- f_p is the fraction of the prompt J/ψ yield;
- f_{sym} is the fraction of the symmetric-long-lived background component;
- f_{a+} is the fraction of the positive-asymmetric-long-lived background component;
- f_{a-} is the fraction of the negative-asymmetric-long-lived background component;
- P is the corresponding PDF function.

There are a total of 20 variables in the fit. The projected distributions of mass and proper decay length with the fit results are shown in Fig. 2 for J/ψ candidates in the p_T range of 3.0 to 3.25 GeV. The J/ψ signal and long-lived components are also shown in the $c\tau$ distribution. The J/ψ signal yield and prompt fraction in different p_T ranges for 1.1 fb^{-1} of data are summarized in Table I.

The acceptance of inclusive J/ψ production is estimated from a sample of Monte-Carlo (MC) J/ψ events. The p_T spectrum used in the MC is obtained from a previous CDF measurement [18]. The J/ψ events are also generated with flat distributions in ϕ and rapidity. The acceptance is computed by dividing the number of J/ψ reconstructed by the number of J/ψ generated in each p_T range.

The acceptance of J/ψ from B decays is estimated by generating $b \to J/\psi X$ events. The MC samples contain B^0, B^+, B_s and Λ_b in the ratio of (0.389 : 0.389 : 0.106 : 0.116). The decays of b's are tuned to have their J/ψ p_T spectrum consistent with the measurement of ($p\bar{p} \to b \to J/\psi X$) cross section [18], as shown in Fig. 3. Also the J/ψ decays are tuned to have their decay angular distribution consistent with $\alpha_{eff} = -0.13$, which is obtained by propagating BaBar's J/ψ polarization measurement [19] to the CDF environment. The $\cos\theta$ distribution of the μ^+ and J/ψ in the J/ψ rest frame at generator level with α_{eff} is shown in Fig. 3. The acceptance in bins of p_T is summarized in Table I.

III. η_b PRODUCTION

The measurement of η_b production times branching fraction relative to the ($p\bar{p} \to b \to J/\psi X$) production can be written as

$$\frac{\sigma(p\bar{p}\to \eta_b X)\cdot BR(\eta_b \to J/\psi J/\psi)}{\sigma(p\bar{p}\to b \to J/\psi X)} = \frac{\alpha(J/\psi)}{\alpha(\eta_b)}\cdot\frac{\epsilon(J/\psi)}{\epsilon(\eta_b)}\frac{1}{BR(J/\psi\to\mu\mu)}\frac{N(\eta_b)}{N(J/\psi)},$$

where α is the acceptance obtained from MC, ϵ is the reconstruction efficiency and the N is the number of observed candidates.

Since we are extracting the relative production rate, most of the efficiencies on the leading J/ψ will be canceled, with exception of the trigger efficiency. The correction factor of trigger efficiency between η_b and J/ψ data sample is estimated to be 1.01 ± 0.02. The efficiencies on offline muon reconstruction, quality cuts and the SVX cuts efficiency are summarized in Table II.

The offline reconstruction efficiency for the additional two particles from the second J/ψ is calculated. They are a combination of a CMU or CMX muon with a charge particle. The offline efficiency for CMU (CMX) muon and a charged particle pair is 0.79 ± 0.03 (0.74 ± 0.11). The η_b MC data sample shows 94% of the candidate events are CMU muon and charge particle pairs. The combined efficiency is 0.79 ± 0.05. The uncertainty, 6.4%, is assigned to the leading J/ψ for the offline reconstruction systematic error. The systematic uncertainties are:

- J/ψ acceptance of 1.0%.

TABLE I: The J/ψ yields, MC acceptance for prompt J/ψ, prompt J/ψ fraction, J/ψ yield from B decays and MC acceptance for long-lived J/ψ in different p_T ranges for 1.1 fb^{-1} of data.

p_T range (GeV)	J/ψ Yield	MC acceptance prompt J/ψ	prompt fraction	J/ψ from B	MC acceptance J/ψ from B
3.0 - 3.25	108131.7 ± 711.5	0.0120 ± 0.0005	0.887 ± 0.002	12218.9 ± 85.0	0.0122 ± 0.0005
3.25 - 3.5	155312.6 ± 927.1	0.0193 ± 0.0007	0.884 ± 0.001	18016.3 ± 109.5	0.0199 ± 0.0007
3.5 - 3.75	181646.9 ± 1042.4	0.0267 ± 0.0009	0.878 ± 0.001	22160.9 ± 129.7	0.0284 ± 0.0009
3.75 - 4.0	191102.8 ± 1084.7	0.0342 ± 0.0012	0.872 ± 0.001	24461.2 ± 141.6	0.0353 ± 0.0011
4.0 - 4.25	200645.0 ± 1157.8	0.0422 ± 0.0014	0.868 ± 0.001	26485.1 ± 155.8	0.0452 ± 0.0013
4.25 - 4.5	207545.1 ± 1262.5	0.0500 ± 0.0017	0.865 ± 0.001	28018.6 ± 173.5	0.0523 ± 0.0015
4.5 - 4.75	205229.3 ± 1355.2	0.0578 ± 0.0019	0.857 ± 0.001	29347.8 ± 196.8	0.0648 ± 0.0018
4.75 - 5.0	196905.6 ± 1351.4	0.0694 ± 0.0023	0.852 ± 0.001	29142.0 ± 202.9	0.0749 ± 0.0021
5.0 - 5.5	361731.1 ± 1964.1	0.0811 ± 0.0020	0.842 ± 0.001	57153.5 ± 317.7	0.0836 ± 0.0017
5.5 - 6.0	312883.8 ± 1941.3	0.0976 ± 0.0026	0.829 ± 0.001	53503.1 ± 338.2	0.1046 ± 0.0022
6.0 - 6.5	259556.5 ± 1888.5	0.1142 ± 0.0034	0.823 ± 0.001	45941.5 ± 338.9	0.1204 ± 0.0027
6.5 - 7.0	213324.9 ± 1866.9	0.1334 ± 0.0043	0.802 ± 0.001	42238.3 ± 373.4	0.1351 ± 0.0032
7.0 - 8.0	315216.0 ± 2463.4	0.1565 ± 0.0042	0.784 ± 0.001	68086.7 ± 539.1	0.1589 ± 0.0030
8.0 - 9.0	194979.1 ± 1964.5	0.1870 ± 0.0062	0.759 ± 0.001	46990.0 ± 477.5	0.1892 ± 0.0041
9.0 - 10.0	121419.6 ± 1400.7	0.2019 ± 0.0087	0.730 ± 0.002	32783.3 ± 388.7	0.2069 ± 0.0053
10.0 - 12.0	125642.5 ± 1591.3	0.2331 ± 0.0097	0.694 ± 0.002	38446.6 ± 499.4	0.2275 ± 0.0053
12.0 - 14.0	55321.3 ± 875.9	0.2589 ± 0.0168	0.648 ± 0.003	19473.1 ± 321.2	0.2598 ± 0.0081
14.0 - 17.0	34817.5 ± 633.2	0.2981 ± 0.0246	0.589 ± 0.004	14310.0 ± 277.8	0.2891 ± 0.0103
17.0 - 20.0	13080.6 ± 386.2	0.2933 ± 0.0439	0.541 ± 0.007	6004.0 ± 193.5	0.3253 ± 0.0174
3.0 - 20.0	3454492 ± 6375.2	0.0466 ± 0.0002		614780.8 ± 1340.5	0.0755 ± 0.0005

TABLE II: Summary of trigger and offline reconstruction efficiencies.

Selection or cut	Efficiency
L1/L2/L3	$(\epsilon(\eta_b)/\epsilon(J/\psi) = (1.01 \pm 0.02)$
COT offline	$\epsilon(p_T > 1.5\text{GeV}) = (99.61 \pm 0.02 \pm 0.91)\%$
Muon(CMU) offline	$\epsilon(p_T > 2.0\text{GeV}) = (96.6 \pm 1.4)\%$
Muon(CMX) offline	$\epsilon(p_T > 3.5\text{GeV}) = (91.3 \pm 7.1)\%$
SVX offline	$(95.3 \pm 1.0)\%$
$Z_0(\mu) < 60$cm	$(95.6 \pm 0.3)\%$
$\Delta Z(\mu\mu) < 5$cm	$(99.9 \pm 0.2)\%$
$\chi^2_\mu < 9.0$	$(99.6 \pm 1.5)\%$
offline cuts	MC acceptance

- η_b acceptance of 2.2(stat.) $\pm$ 3.3(syst. from p_T) $\pm$ 3.5 (syst. from cuts)%. This is described in section IV.
- Leading J/ψ trigger and offline efficiency of 6.7%.
- 2nd J/ψ offline efficiency of 6.4%.
- Branching fraction of $(J/\psi \to \mu\mu)$ of 1.7% (from PDG).
- Number of J/ψ yield from B of 0.2%.

The total uncertainty is estimated to be 10.8%.

IV. η_b ANALYSIS FOR SEARCH AND PRODUCTION

The η_b signal decay is generated with a mass of 9.4 GeV and width of 20 MeV. The η_b width is predicted to be narrower than the η_c width of (25.5 ± 3.4) MeV; so a smaller value was chosen. The p_T distribution of the signal MC, shown in Fig. 4, is obtained using the $\Upsilon(1S)$ measurement from CDF Run I data [20]. One assumes both particles have the same p_T distribution during their production. The uncertainty of the $\Upsilon(1S)$ p_T distribution contributes 3.3% to the systematic error of the η_b acceptance.

For the search of the η_b, the candidate muons and track are required to pass a series of cuts. The initial 4 final state particles must pass the basic track and muon quality cuts. In addition, the candidates must be prompt. This is defined by having a transverse vertex displacement and impact parameter to be within 3 sigma of the collision spot resolution.

The candidate particles are then formed into J/ψ candidates. The leading J/ψ must have an invariant mass within ± 60 MeV of the PDG value and ± 30 MeV for the non-leading J/ψ.

Four additional variables are examined to purify the sample: χ^2 of η_b vertex fit, p_T of non-leading J/ψ, p_T of the charged particle and the dE/dx residual of the charged particle. The cuts for these parameters are optimized by an N-1 iteration. The optimal cut values maximizes the significance which is defined as $S/(1.5+\sqrt{B})$. S is the number of signal MC events which passed the cuts and B is the number of predicted background events. The background is estimated by the projection of a polynomial fit to the sideband of the mass window. The optimized cut values are: χ^2 of η_b less than 21.0; p_T of non-leading J/ψ greater than 3.0 GeV; p_T of the charged particle greather than 0.6 GeV; dE/dx residual of the charged particle less than 3.7. The mass spectrum for the events which passed the final selection cuts is shown in Fig. 5. The MC acceptance based on the cuts is estimated to be 1.59%.

An unbinned maximum likelihood fit is used to search for the narrow η_b resonance. A mass window from 8.5 to 10 GeV was scanned in steps of 20 MeV and the significance of an excess was measured for each step. The likelihood function is defined as:

$$\mathcal{L} = \prod_{\mathrm{N}}^{\mathrm{event}} (a \cdot G(x,\sigma) + (1-a)P(x,s)) \ ,$$

where G is a Gaussian, P is the first-order polynomial, a is the signal fraction, x is the candidate mass and σ is the Gaussian width which is fixed from the Monte Carlo result. The signal significance is defined as $\sqrt{-2\ log(L_{max}/L_0)}$, where L_{max} is the maximum likelihood and L_0 is the likelihood with zero signal yield.

The significance scan of the experimental data shows the highest point is located at 9.17 GeV with a 1.3 σ significance (see Fig. 5). A repeated fit with a floated Gaussian mean gives a fit result of 6.0 ± 5.2 signal yield at 9.171 GeV with a local statistical significance value of 1.3σ.

For the η_b production cross section measurement, the p_T requirement on the tracks is increased and the fiducial region is restricted to a narrower rapidity range to avoid regions where the efficiencies are not well understood or changing rapidly. The changes are :

- The leading J/ψ has to be a CMU-CMU muon pair with $|y(J/\psi)| < 0.6$ and $p_T(J/\psi) > 3.0$ GeV. Both μ's are required to have $p_T > 2.0$ GeV.
- The μ's from the second J/ψ should have $p_T > 2$ GeV if it is a CMU muon; $p_T > 3.5$ GeV for CMX muons.
- The charged track of the second J/ψ should have $p_T > 1.5$ GeV.
- The η_b candidates have a rapidity within ± 0.6 and $p_T > 3.0$ GeV.

The other selection cuts are the $\chi^2 < 18.5$ and p_T(2nd J/ψ) > 3.0 GeV. The acceptance of the η_b after the selection cuts is estimated to be 0.38%.

After applying all the selection cuts, 8 η_b candidates remained in the mass window of 8.5 to 10.0 GeV. This mass spectrum is shown in Fig. 6. A group of 3 events yields a local significant bump. Using the same unbinned-Maximum-Likelihood package mentioned earlier, it yields 2.6 ± 1.4 events at 9.319 GeV with a 2.5σ local significance.

The Bayesian method is used to calculate the upper limit for the yield at 95% C.L [21]. The background template is made from the first-order polynomial function with the slope and function area obtained by a fit on the sideband of the mass spectrum. The slope obtained is -0.03 with 10.94 expected background contribution between 8.5 to 10 GeV. The fluctuation of background contribution, 19.2%, is obtained from the statistical uncertainty of 27 events which are used to determine the background template. The signal template is based on the distribution obtained from signal MC. The distribution is then assigned to the different mass points that we are interested in for the upper limit calculation. The area of the signal template is set to 1.0 for the single event excess. The 10.8% uncertainty of the signal area is obtained by the total systematic error from the acceptance, efficiency and the number of J/ψ from the fit. The Bayesian 95% upper limits at corresponding η_b mass values are also shown in Fig. 6. The highest UL [22] point is at 9.32 GeV with $N_{UL}(\eta_b)$ equal to 7.18 events.

The formula of the relative production can then be written down as

$$\frac{\sigma(p\bar{p} \to \eta_b X) \cdot BR(\eta_b \to J/\psi J/\psi)}{\sigma(p\bar{p} \to b \to J/\psi X)} = \frac{\alpha(J/\psi)}{\alpha(\eta_b)} \cdot \frac{\epsilon(J/\psi)}{\epsilon(J/\psi_{leading};\eta_b)} \cdot \frac{1}{\epsilon(J/\psi_{2nd};\eta_b)} \cdot \frac{1}{BR(J/\psi \to \mu\mu)} \cdot \frac{N(\eta_b)}{N(J/\psi)}$$
$$< 6.93 \times 10^{-4} \cdot N_{UL}(\eta_b)$$
$$< 5.0 \times 10^{-3}$$

V. SUMMARY

We have searched for the exclusive η_b decay to $J/\psi J/\psi$ where both J/ψ's decay to dimuons in CDF. The experimental data used in the search corresponds to 1.1 fb^{-1}. Three out of the four muons in the final states are required to be CDF CMU or CMX muons while the last one is a charged track. The selection cuts are optimized for the search. No significant narrow resonance signal is observed.

A η_b production times decay branching fraction relative to the J/ψ production from a B hadron is reported. The inclusive J/ψ signal yields together with the J/ψ yield from the B decays are measured. The selection cuts for η_b candidates are tightened to avoid regions where the efficiencies are not well understood or changing rapidly. There are in total 3 candidates remaining in the search window of 9.0 GeV to 9.5 GeV with 3.6 expected background contribution. The Bayesian method is used to calculate the η_b yield upper limit at 95% C.L.. The highest limit is found at an invariant mass of 9.32 GeV with a yield of less than 7.18 events. This yield limit corresponds to a production limit of

$$\frac{\sigma(p\bar{p} \to \eta_b X; |y(\eta_b)| < 0.6, p_T(\eta_b) > 3.0\text{GeV}) \cdot Br(\eta_b \to J/\psi J/\psi)}{\sigma(p\bar{p} \to H_b \to J/\psi X); |y(J/\psi)| < 0.6, p_T(J/\psi) > 3.0\text{GeV})} < 5.0 \times 10^{-3}.$$

Using the CDF Run II measurement of $\sigma(p\bar{p} \to b \to J/\psi X, |y(J/\psi)| < 0.6, p_T(J/\psi) > 3GeV) = (0.152 \pm 0.005 \pm 0.015)\mu$b [18], the result of η_b production limit corresponds to

$$\sigma(p\bar{p} \to \eta_b X, |y(\eta_b)| < 0.6, p_T(\eta_b) > 3\text{GeV}) \cdot Br(\eta_b \to J/\psi J/\psi) \cdot [Br(J/\psi \to \mu\mu)]^2 < 2.6 \text{ pb [23]}.$$

[1] E. Braaten *et al.*, Phys. Rev. D **63**, 094006 (2001).
[2] C. Itoh *et al.*, Prog.Theor.Phys.**114**:359 368 (2005). and 2005partial update for edition 2006.
[3] E. J. Eichten and C. Quiggs, Phys. Rev. D **49**, 5845 (1994).
[4] E. Eichten and F. Feinberg, Phys. Rev. D **23**, 2724 (1981).
[5] S. N. Gupta *et al.*, Phys. Rev. D **34**, 201 (1986).
[6] M. Baldicchi and G. M. Prosperi, Phys. Rev. D **62**, 114024 (2000).
[7] B. A. Kniehl *et al.*, Phys. Rev. Lett. B **92**, 114024 (2004).
[8] Y. -Q. Chen and Y. -P. Kuang, Phys. Rev. D **46**, 1165 (1992).
[9] G. S. Bali, K. Schilling and A. Wachter, Phys. Rev. D **66**, 2566 (1997).
[10] S. N. Gupta *et al.*, Phys. Rev. D **39**, 974 (1989).
[11] D. Ebert *et al.*, Mod. Phys. Lett. A **18**, 1597 (2003).
[12] S. Godfrey and N. ISgur, Phys. Rev. D **32**, 189 (1985).
[13] L.Motyka and K. Zalewski, Eur. Phys. J. C **4**, 1079 (1998).
[14] F. Maltoni and A. D. Polosa, Phys. Rev. D **70** 054014 (2004).
[15] S. Eidelman *et al.*, (Particle Data Group),Phys. Lett. B **592**, 1 (2004)
[16] CDF Collaboration, J. Tseng, in *Proceedings of the 5th International Conference on Quark Confinement and the Hadron Spectrum* V, edited by N. Brambilla and G. M. Prosperi (World Scientific, Singapore, 2003).
[17] D. Acosta *et al.*, CDF Collaboration, Phys. Rev. D **71**, 032001 (2005).
[18] D. Acosta *et al.*, Phys. Rev. D 71, 032001 (2005); M. Bishai *et al.*, CDF note 6285 (2004); T. Yamashida *et al.*, CDF note 6288 (2004).
[19] B. Aubert *et al.*, Phys. Rev. D **67**, 032002 (2003).
[20] D. Acosta *et al.*, Phys. Rev. Lett. **88**, 161802 (2002).
[21] C.L: Confidence Limit
[22] UL: Upper Limit
[23] The previous CDF Run I limit was 18 pb. This result over the equivalent physics range of of $|y(\eta_b)| < 0.4$ and $p_T(\eta_b) > 0$ GeV improves the limit to 2.5 pb.

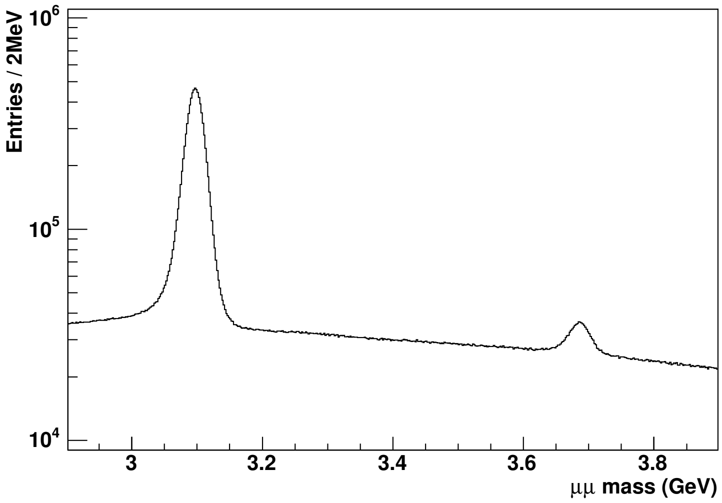

FIG. 1: The dimuon invariant mass spectrum.

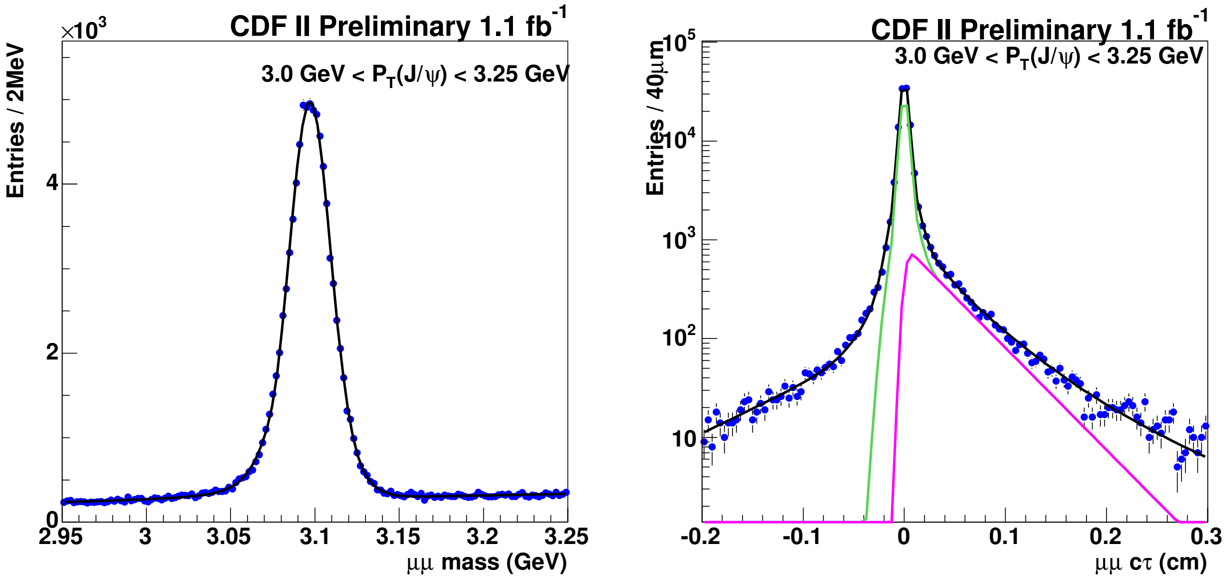

FIG. 2: The projection distributions of mass and proper decay length with the unbinned maximum likelihood fit result for J/ψ candidates with p_T range from 3.0 to 3.25 GeV. The solid-black curves show the total fit results. The green (magenta) curve in the proper decay length projection shows the J/ψ signal (long-live) component.

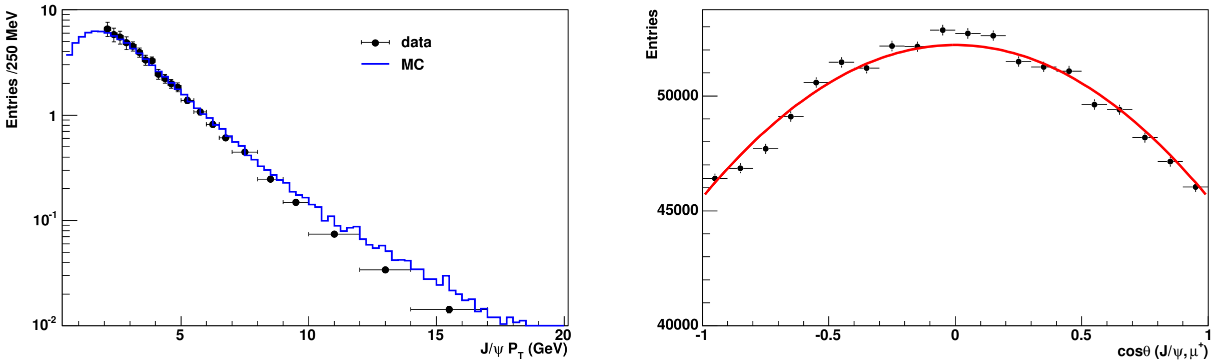

FIG. 3: Left : The generated J/ψ Pt spectrum and the measured cross section of J/ψ from b. Right : The $\cos\theta$ distribution between μ^+ and J/ψ in the J/ψ rest frame at the generator level. The red curve shows the polarization distribution for $\alpha = -0.13$.

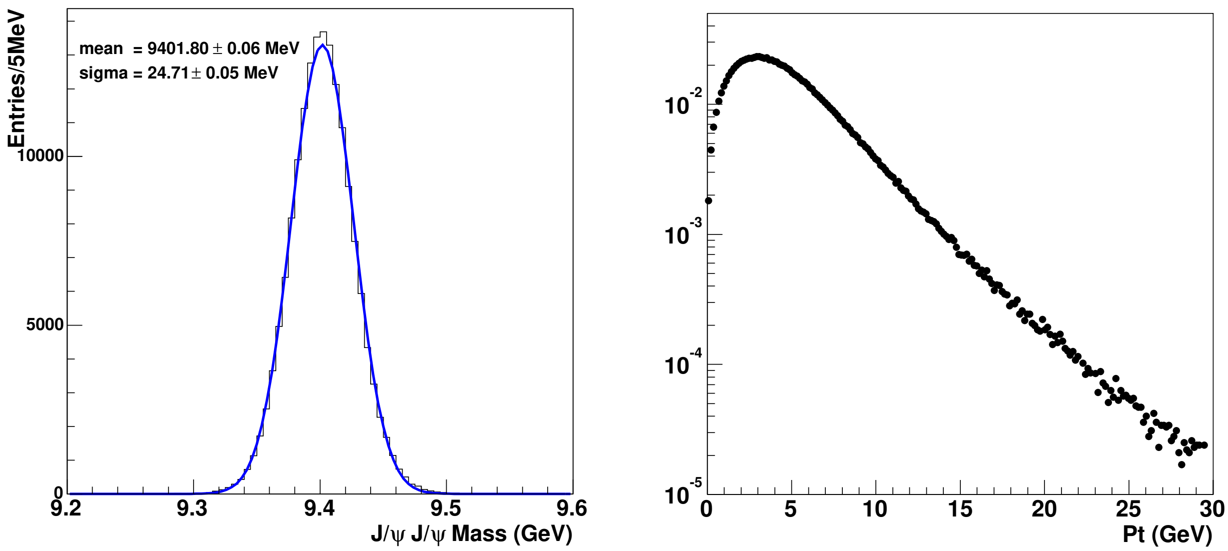

FIG. 4: Left : The mass spectrum of η_b signal Monte Carlo. Right : The p_T distribution of η_b candidates at the generator level.

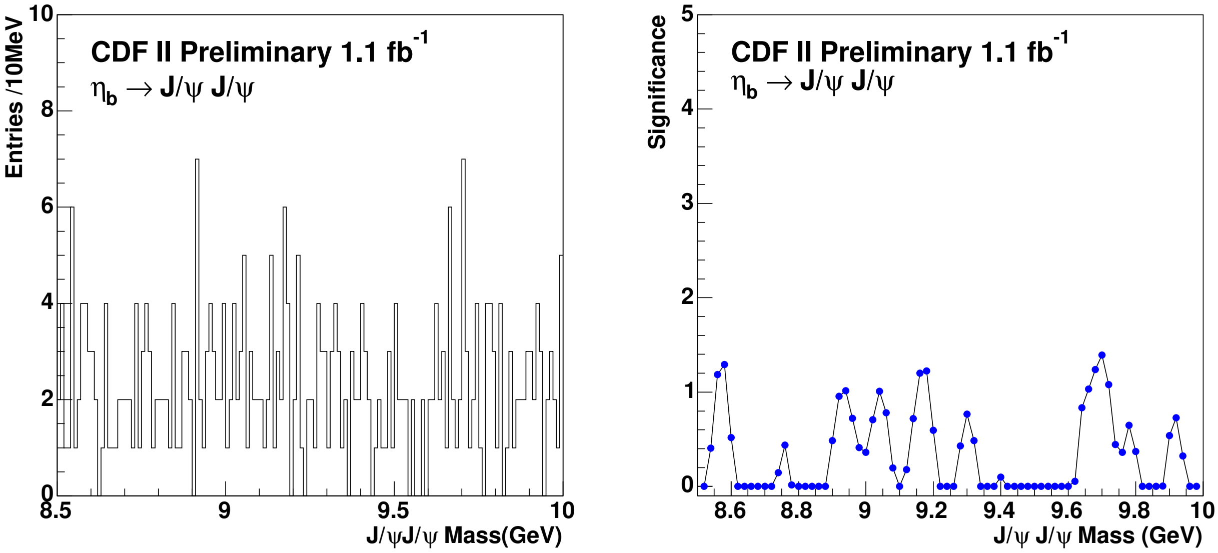

FIG. 5: Left : The mass spectrum for $\eta_b \rightarrow J/\psi J/\psi$ search. Right : The signal significance values at corresponding mass points evaluated by the unbinned maximum likelihood fit.

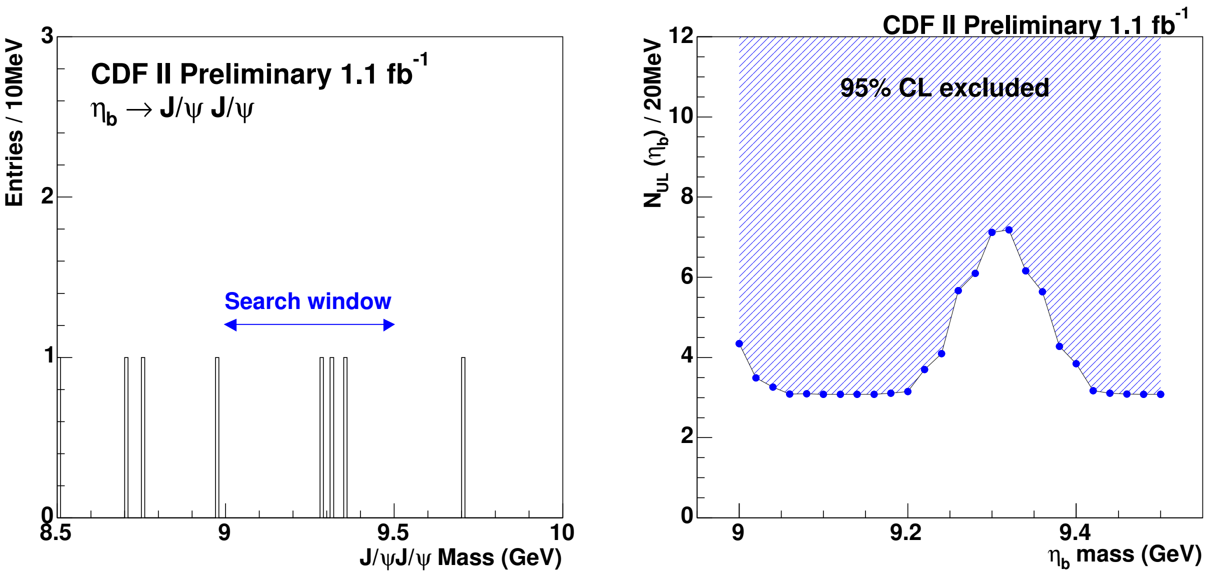

FIG. 6: Left : The mass spectrum of $J/\psi J/\psi$ after applying cuts for the production upper limit. Right : The yield upper limit for η_b production at corresponding mass values.