Measurement of B Meson Masses in the Exclusive J/ψ Channels

Text for the blessed web page – CDF 6963

The CDF Collaboration

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Abstract

We measure the mass of b-hadrons in exclusive J/ψ -decay modes. The correct momentum scale is established by the following steps: validate and quantify distortions or systematic effects in the Central Outer Tracker and Silicon Vertex Detector, apply and fine tune the energy loss corrections per track, and finally tune the magnetic field scale. With the momentum scale established, we find:

$$\begin{aligned} m(B^+) &= 5279.10 \pm 0.41_{(stat)} \ \pm 0.36_{(sys)}, \\ m(B^0) &= 5279.63 \pm 0.53_{(stat)} \ \pm 0.33_{(sys)}, \\ m(B_s^0) &= 5366.01 \pm 0.73_{(stat)} \ \pm 0.33_{(sys)}, \\ m(\Lambda_b) &= 5619.7 \pm 1.2_{(stat)} \ \pm 1.2_{(sys)} \ \mathrm{MeV/c^2}. \end{aligned}$$

The measurements of the Λ_b and B_s masses are the current world best. The value of the Λ_b mass is consistent with the CDF run I measurement resolving a discrepancy in the PDG average.

1 Description

This analysis relies on the calibrated momentum scale to measure the B hadron masses. The updated calibration procedure is documented in CDF note 6963.

The analysis relies on data from the J/psi trigger. The signals are reconstructed in $B^{\pm} \rightarrow J/\psi K^{\pm}$, $B^0 \rightarrow J/\psi K^{*0}$, $B_s^0 \rightarrow J/\psi\phi$ and $\Lambda_b \rightarrow J/\psi\Lambda$. As a control samples $\psi(2s) \rightarrow J/\psi\pi\pi$ and $B^0 \rightarrow J/\psi K_s^0$ are reconstructed. The result are the world best measurements of the B_s^0 meson and Λ_b baryon mass and very competative $B^{\pm}$ and B^0 mass determinations.

Our largest systematic error comes from tracking misalignments, and is comparable in size to the statistical uncertainty of the measurement.

2 Blessed Numbers

This section summarizes the numbers which have been blessed for this analysis.

2.1 Fit results

2.2 Systematic errors

2.3 Final result

$$m(B^+) = 5279.10 \pm 0.41_{(stat)} \ \pm 0.36_{(sys)} \ \mathrm{MeV}/c^2$$

For comparison, the 2002 Particle Data Group fit result is:

$$m(B^+) = 5279.0 \pm 0.5\mathrm{MeV}$$

$$m(B^0) \ = 5279.63 \pm 0.53_{(stat)} \ \pm 0.33_{(sys)} \ \mathrm{MeV}/c^2$$

Table 1: An overview of the likelihood functions used for each mode. The functions are described in detail in CDF note 6963.

decay mode	likelihood function
$B_s^0 \rightarrow \mathrm{J}/\psi\phi$	$(1 - f_{bg}) \cdot G(m, \sigma, m_{\mathrm{fit}}) + f_{bg} \cdot L(m, a_{\mathrm{bg1}})$
$B^0 \rightarrow \mathrm{J}/\psi\mathrm{K_s^0}$	$(1 - f_{bg}) \cdot G(m, \sigma, m_{\mathrm{fit}}) + f_{bg} \cdot L(m, a_{\mathrm{bg1}})$
$\Lambda_B \rightarrow \mathrm{J}/\psi\Lambda$	$(1 - f_{bg}) \cdot G(m, \sigma, m_{\mathrm{fit}}) + f_{bg} \cdot L(m, a_{\mathrm{bg1}})$
$\psi(2s) \rightarrow \mathrm{J}/\psi\pi\pi$	$(1 - f_{bg}) \cdot G(m, \sigma, m_{\mathrm{fit}}) + f_{bg} \cdot P2(b_{\mathrm{bg}}, a_{\mathrm{bg2}}, m)$
$B^{\pm} \rightarrow \mathrm{J}/\psi\mathrm{K}^{\pm}$	$(1 - f_{bg}) \cdot ((1 - f_{g2}) \cdot G(m, \sigma, m_{\mathrm{fit}}) + f_{g2} \cdot G(m, \sigma_2, m_{\mathrm{fit}})) +$
	$f_{bg} \cdot (f_T \cdot T(m, \mu_T, \sigma_T) + f_\pi \cdot B_\pi(m, \mu_\pi, \lambda_\pi) + (1.0 - f_T - f_\pi) \cdot L(m, a_{\mathrm{bg1}}))$
$B^0 \rightarrow \mathrm{J}/\psi\mathrm{K}^{*0}$	$(1 - f_{bg}) \cdot (0.81 \cdot G(m, \sigma, m_{\mathrm{fit}}) + 0.19 \cdot (0.78 \cdot G(m, \sigma_1, m_{\mathrm{fit}} + \mathrm{shift}_1) +$
	$0.22 \cdot G(m, \sigma_2, m_{\mathrm{fit}} + \mathrm{shift}_2))) + f_{bg} \cdot L(m, a_{\mathrm{bg1}})$

Table 2: The results of the unbinned likelihood fit of the $\psi' \to J/\psi\pi\pi$ sample.

Parameter	Fit Output
Gaussian Mean $m_{\rm fit}$	3685.66 ± 0.08 MeV/c^2
Gaussian Sigma σ	3.45 ± 0.07 MeV/c^2
Background Fraction $f_{\rm b}$	0.8680 ± 0.0026
Background Slope $a_{\rm bg2}$	2284.5 ± 26.0 (GeV/c^2)$^{-2}$
Quadratic Background $b_{\rm bg}$	-304.5 ± 3.5 (GeV/c^2)$^{-3}$
Fit Probability	30.9%

Table 3: The results of the unbinned likelihood fit of the B^+ sample.

Parameter	Fit Output
Gaussian Mean $m_{\rm fit}$	5279.10 ± 0.41 MeV/c^2
Gaussian Sigma σ	11.76 ± 0.99 MeV/c^2
Background Fraction $f_{\rm b}$	0.6727 ± 0.0076
Background Slope $a_{\rm bg1}$	-1.82 ± 0.37 (GeV/c^2)$^{-2}$
Second Gaussian Fraction $f_g 2$	0.452 ± 0.099
Turn-on Fraction f_T	0.114 ± 0.020
$J/\psi\pi$ Background f_π	0.0250 ± 0.0071
Fit Probability	52.0%

Table 4: The results of the unbinned likelihood fit of the B^0 sample.

Parameter	Fit Output
Gaussian Mean $m_{\rm fit}$	5279.63 ± 0.53 MeV/c^2
Gaussian Sigma σ	12.33 ± 0.54 MeV/c^2
Background Fraction $f_{\rm b}$	0.7562 ± 0.0080
Background Slope $a_{\rm bg1}$	-2.33 ± 0.22 (GeV/c^2)$^{-2}$
Fit Probability	14.0%

Table 5: The results of the unbinned likelihood fit of the B_s^0 sample.

Parameter	Fit Output
Gaussian Mean $m_{\rm fit}$	5366.02 ± 0.73 MeV/c^2
Gaussian Sigma σ	8.35 ± 0.63 MeV/c^2
Background Fraction $f_{\rm b}$	0.645 ± 0.024
Background Slope $a_{\rm bg1}$	-2.90 ± 0.73 (GeV/c^2)$^{-2}$
Fit Probability	75.0%

For comparison, the 2002 Particle Data Group fit result is:

$$m(B^0) \; = 5279.4 \pm 0.5\text{MeV}$$

$$m(B_s^0) \; = 5366.01 \pm 0.73_{\,(stat)} \; \pm 0.33_{\,(sys)} \; \text{MeV}/c^2$$

For comparison, the 2002 Particle Data Group fit result is:

$$m(B_s^0) \; = 5369.6 \pm 2.4\text{MeV}$$

$$m(\Lambda_b) \; = 5619.7 \pm 1.2_{\,(stat)} \; \pm 1.2_{\,(sys)} \; \text{MeV/c}^2$$

For comparison, the 2002 Particle Data Group fit result is:

$$m(\Lambda_b) \; = 5624 \pm 9 \; \text{MeV/c}^2$$

The combined PDG average uses 3 measurements and includes a 1.8 error scale factor. The scale factor is introduced, because the DELPHI measurement shows a deviation from the CDF and ALEPH results that lies outside the quoted uncertainty. Our current estimate agrees well with the best previous measurement from CDF RUN I

$$m(\Lambda_b) \; = 5621 \pm 4_{\,(stat)} \; \pm 3_{\,(sys)} \; \text{MeV/c}^2$$

This mass determination will help to resolve the issue with the PDG average.

Table 6: The results of the unbinned likelihood fit of the $B^0 \to J/\psi K^0_s$ sample.

Parameter	Fit Output
Gaussian Mean $m_{\rm fit}$	5280.46 ± 0.63 MeV/c^2
Gaussian Sigma σ	10.58 ± 0.54 MeV/c^2
Background Fraction $f_{\rm b}$	0.307 ± 0.024
Background Slope $a_{\rm bg1}$	-2.5 ± 2.5 (GeV/c^2)$^{-2}$
Fit Probability	11.4%

Table 7: The results of the unbinned likelihood fit of the Λ_b sample.

Parameter	Fit Output
Gaussian Mean $m_{\rm fit}$	5619.7 ± 1.2 MeV/c^2
Gaussian Sigma σ	8.5 ± 1.0 MeV/c^2
Background Fraction $f_{\rm b}$	0.818 ± 0.021
Background Slope $a_{\rm bg1}$	-0.73 ± 0.50 (GeV/c^2)$^{-2}$
Fit Probability	23.3%

Table 8: Compilation of systematic uncertainty for the B mass measurements. All values are in MeV/c^2. The unbiased high statistics B^0 values have been used for the final $B^\pm$ and B_s systematics.

Source	$B^0 \to J/\psi K^{*0}$	$B^\pm \to J/\psi K^\pm$	$B^0_s \to J/\psi \phi$
Tracking & Corrections			
momentum scale	0.20	0.22	0.20
Tracking	0.18	from B^0	from B^0
False Curvature	0.02	from $B^\pm$	from $B^\pm$
Fitting	0.10	from B^0	from B^0
Resolution bias	0.13	0.13	0.13
Fit Systematics			
K^{*0}'s with K-π Swapped	0.06	—	—
$J/\psi\pi$ contamination	—	0.13	—
Total Systematic Uncertainty	0.33	0.36	0.33

Table 9: Compilation of systematic uncertainty for the Λ_b mass measurement. All values are in MeV/c^2. The high statistics B^0 values have been used for the final Λ_b systematics.

Source	$B^0 \to J/\psi K^0_s$	$\Lambda_b \to J/\psi\Lambda$
Tracking & Corrections		
momentum scale	0.2	0.2
Tracking	1.0	from $B^0 \to J/\psi K^0_s$
Fitting	0.7	from $B^0 \to J/\psi K^0_s$
Total Systematic Uncertainty	1.2	1.2

3 Blessed Figures

The following figures have been blessed for the mass measurement. More text can be found in CDF 6963.

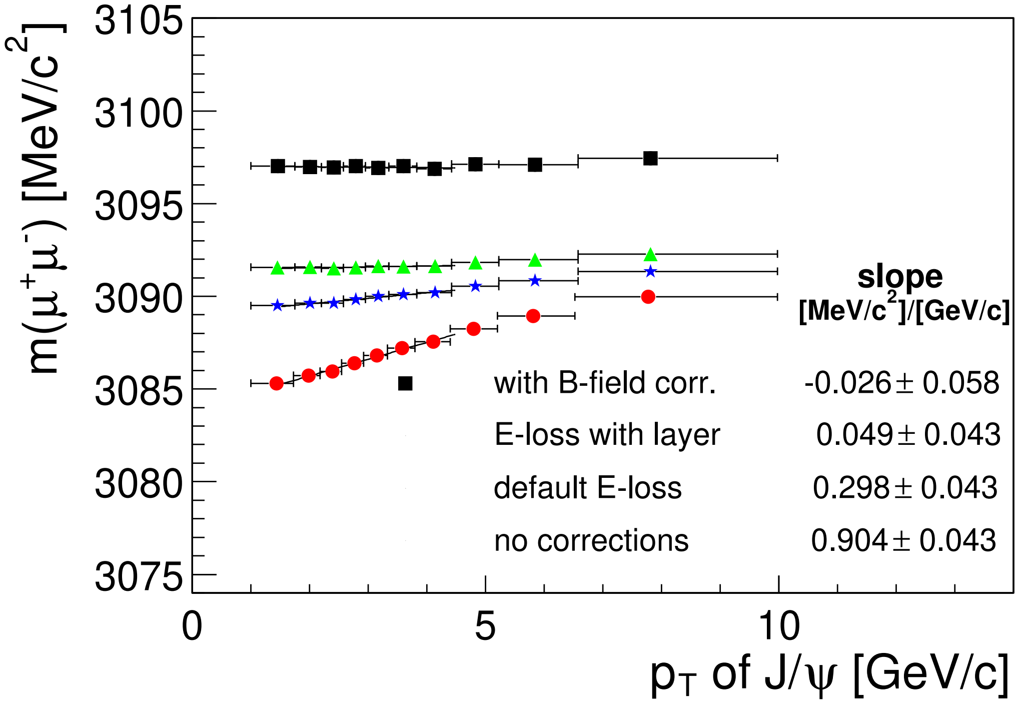

Figure 1: Illustration of the momentum scale calibration using the J/ψ sample .

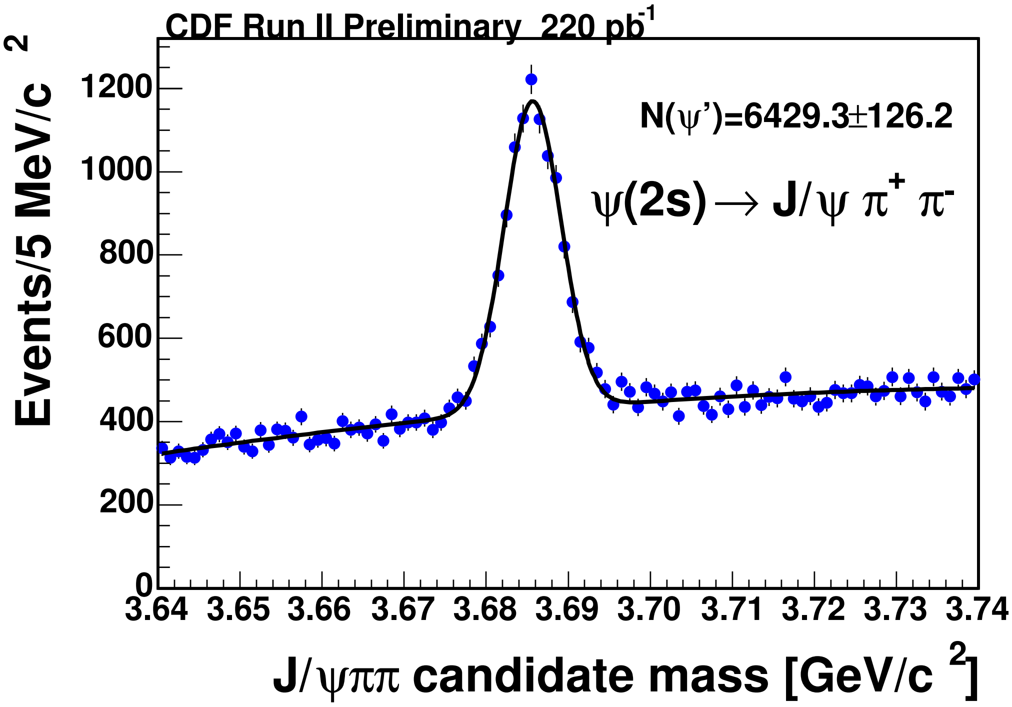

Figure 2: The mass distribution for the $\psi' \to J/\psi\pi^+\pi^-$ sample . The result of the log likelyhood fit is superimposed.

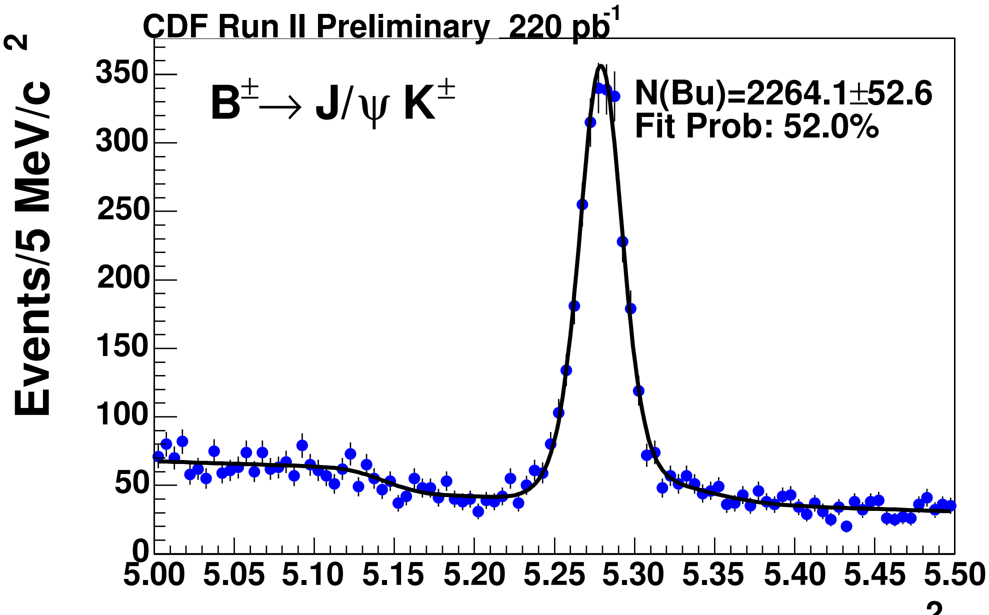

Figure 3: The B^+ mass distribution. The result of the log likelyhood fit is superimposed.

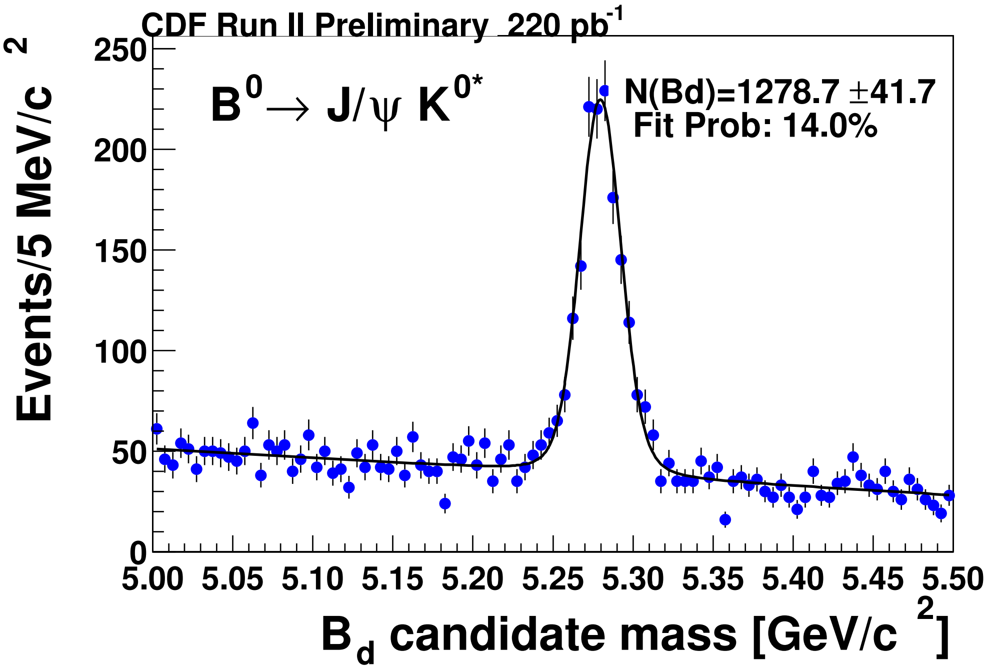

Figure 4: A plot of the B^0 sample. The result of the log likelyhood fit is superimposed.

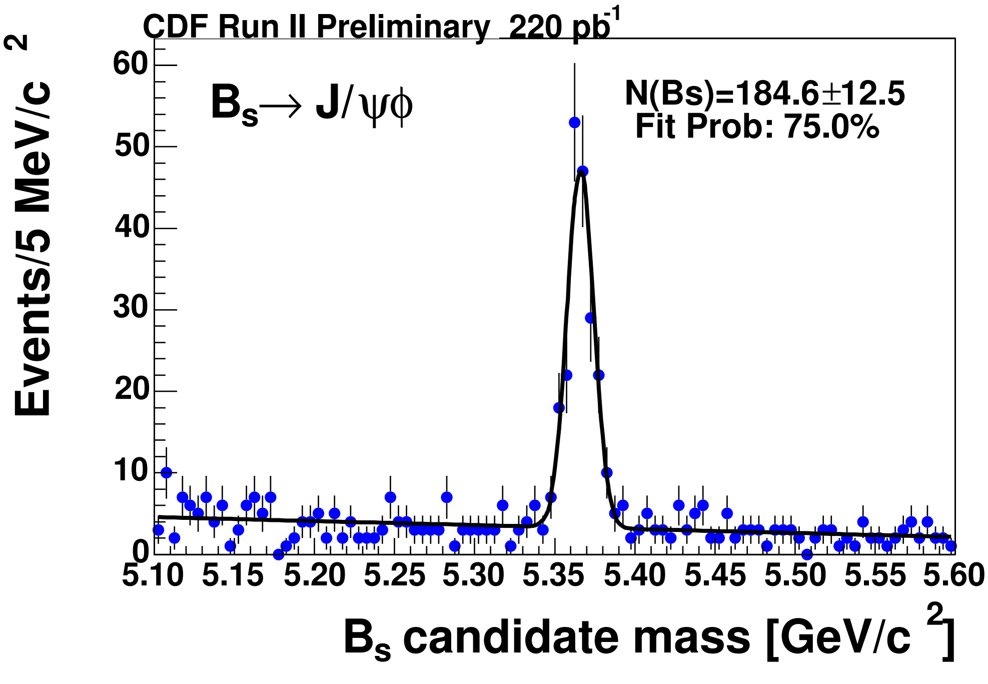

Figure 5: The mass distribution for B_s^0 candidates. The result of the log likelyhood fit is superimposed.

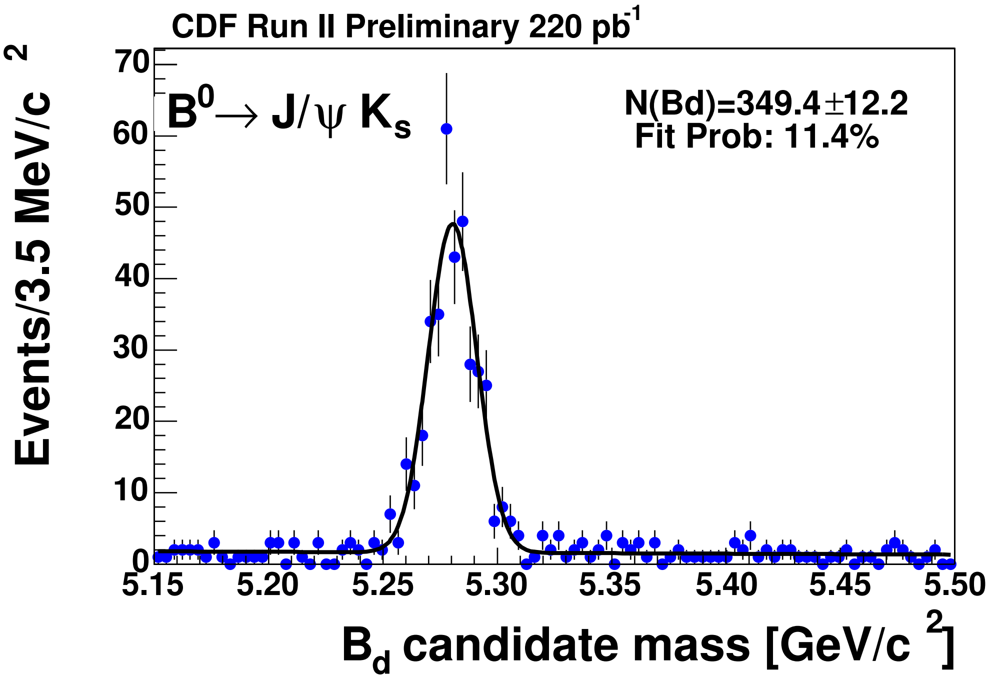

Figure 6: A plot of the $B^0 \to \mathrm{J}/\psi \mathrm{K}^0_\mathrm{s}$ sample. The result of the log likelyhood fit is superimposed.

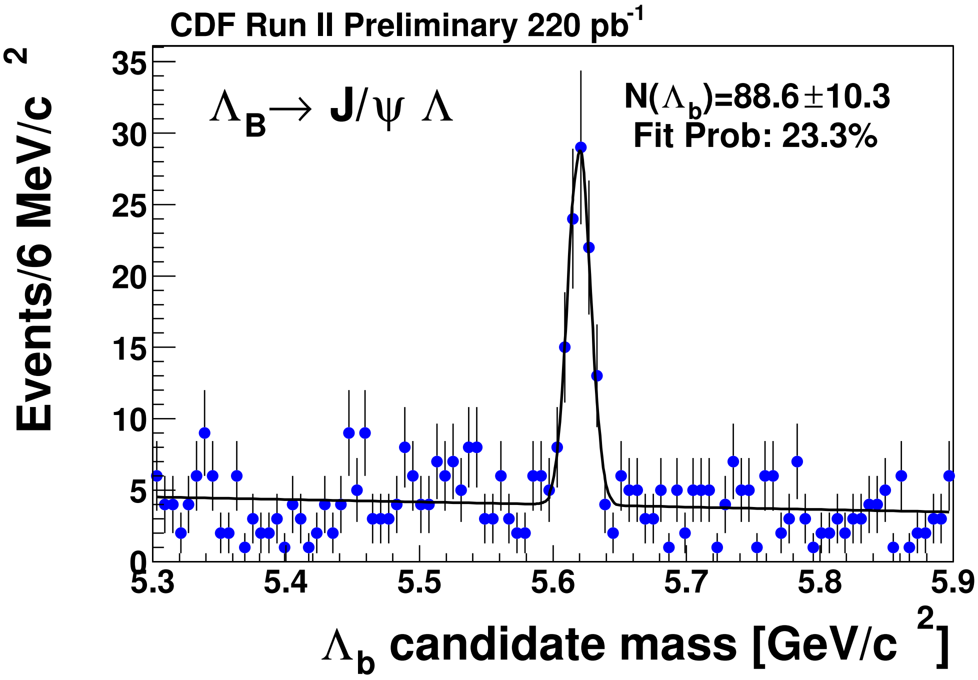

Figure 7: The mass distribution for Λ_b candidates. The result of the log likelyhood fit is superimposed.

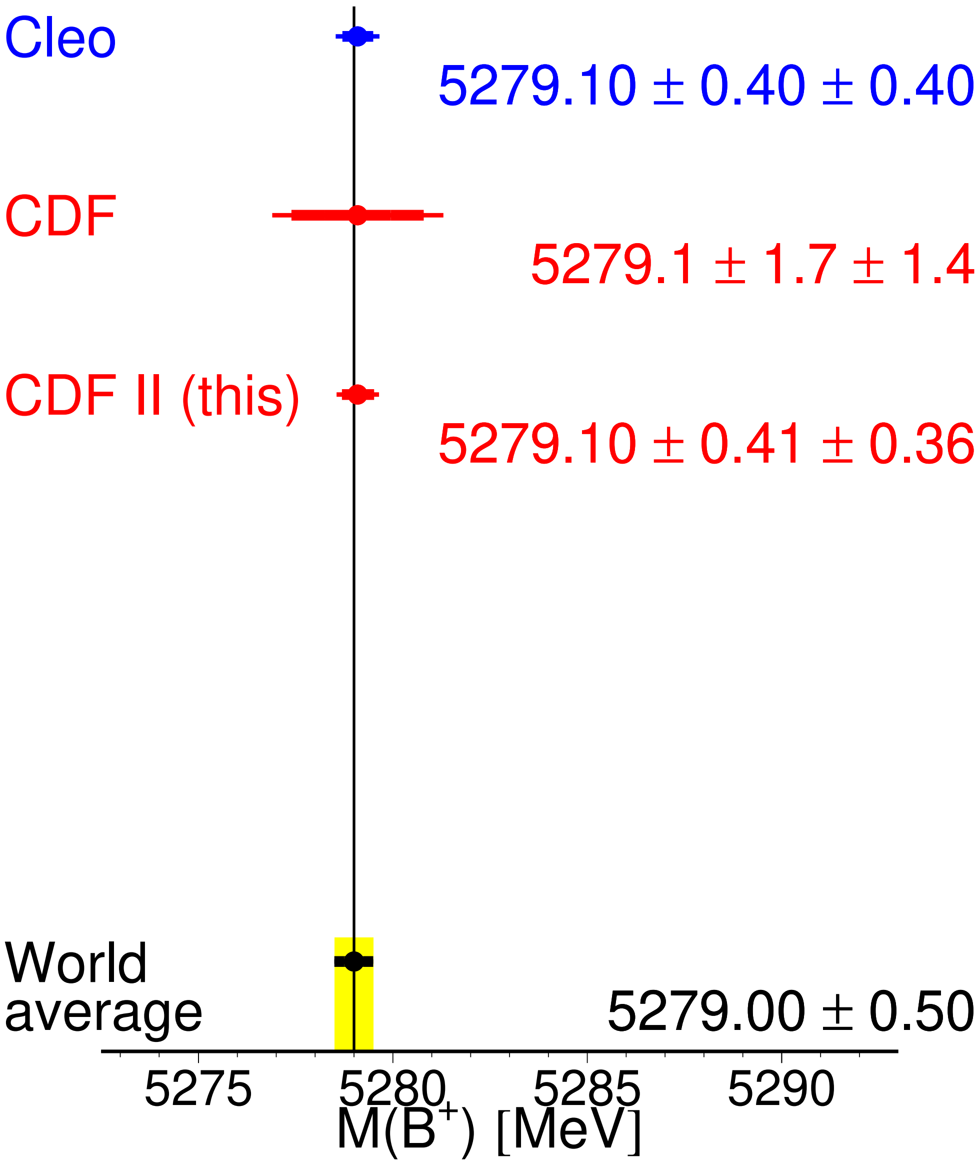

Figure 8: Comparison of $B^{\pm}$ mass measurements.

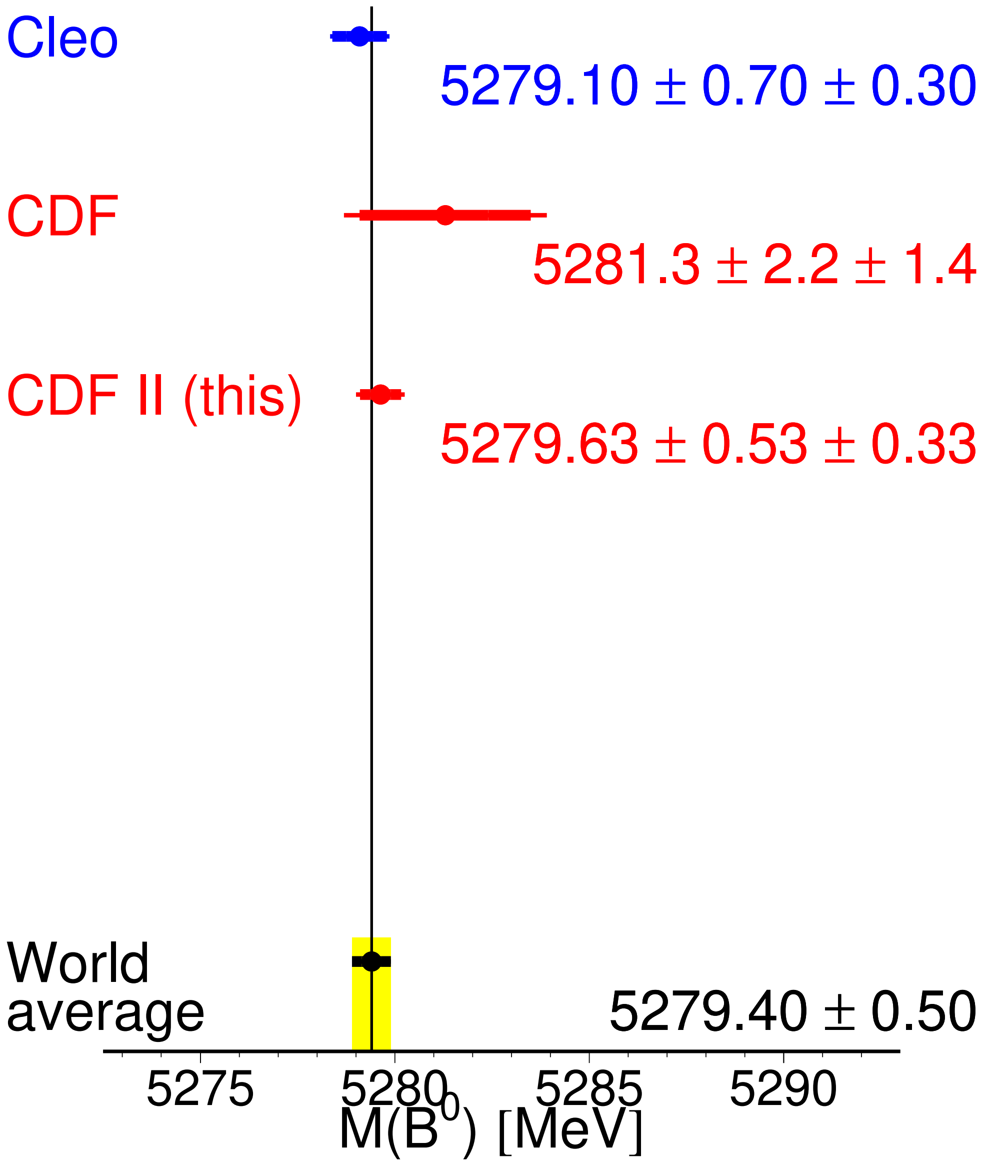

Figure 9: Comparison of B^0 mass measurements.

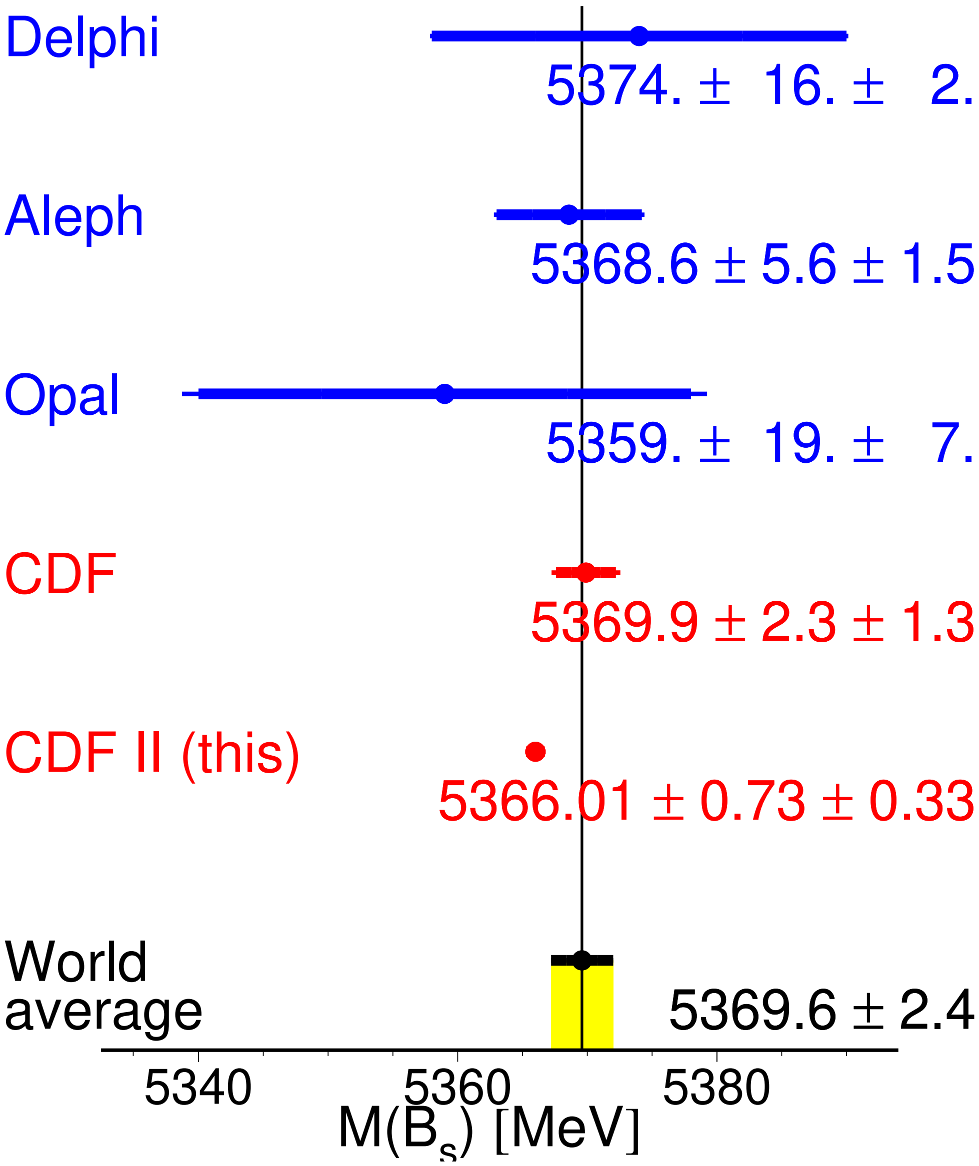

Figure 10: Comparison of B_s^0 mass measurements.

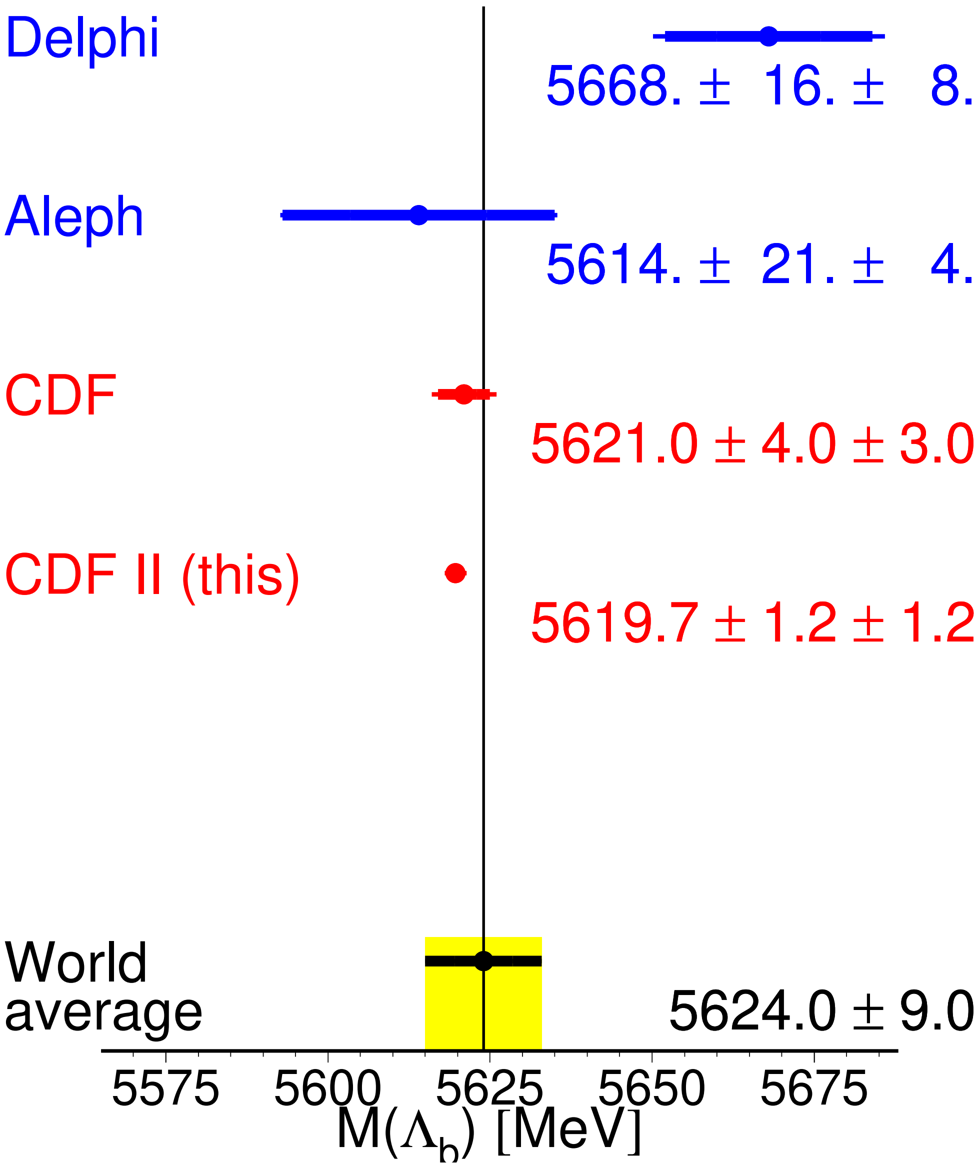

Figure 11: Comparison of Λ_B mass measurements.