Measurements of *b*-hadron properties at CDF

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For the CDF collaboration

Contents

Measurement of masses

Measurement of lifetimes

Case of B_s: separate CP-even and CP-odd components: measurement of $\Delta\Gamma_s$

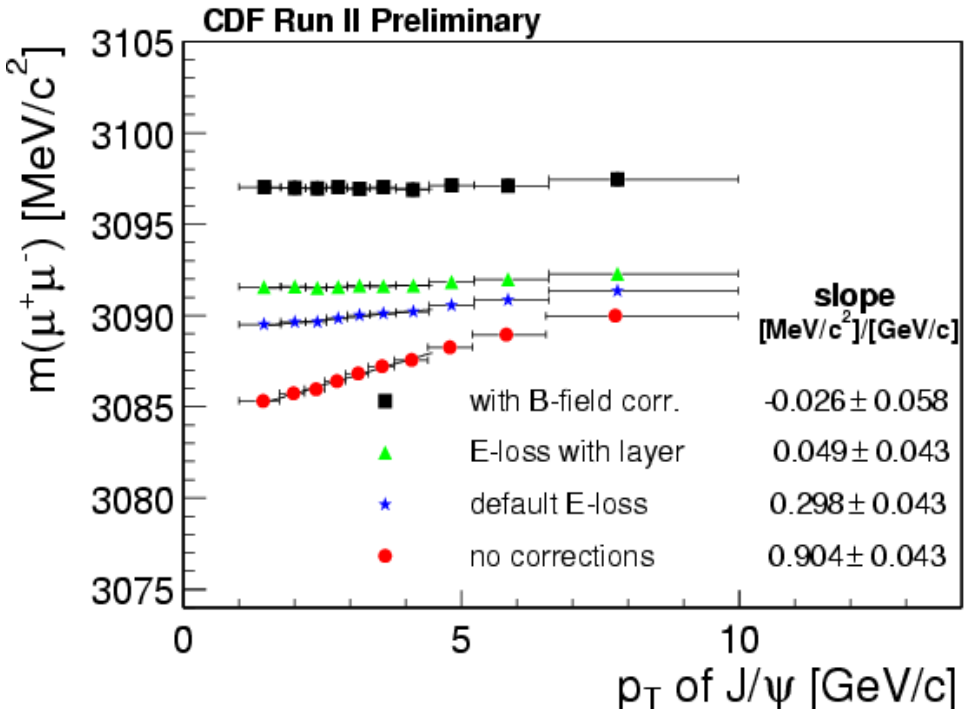
- B-Physics at CDF is based on 3 trigger types:
- **di-lepton trigger (J/ψ): 2 opposite charge μ, p_t > 1.5 GeV/c**
- **two tracks with d_0 > 120 μm (aka *2-Track Trigger* or *hadronic b trigger*)**
- Lepton + track with impact parameter > 120μm (*lepton+SVT*)

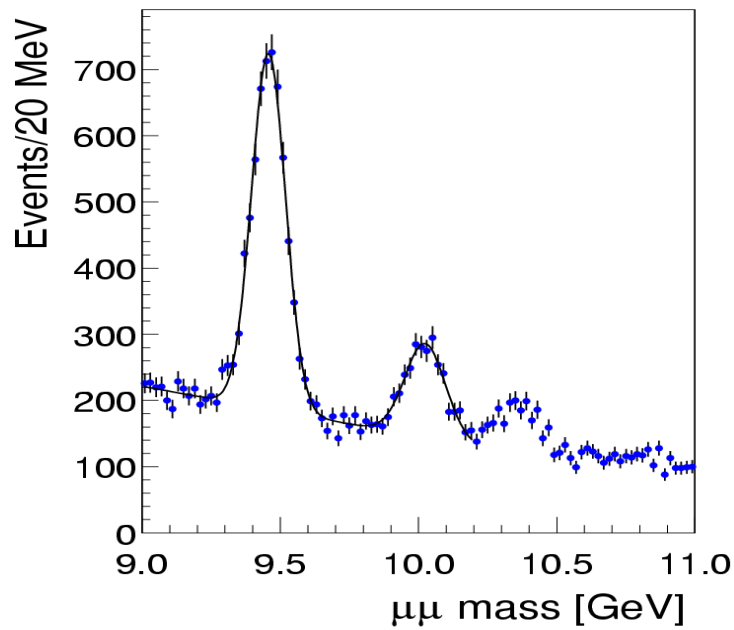
All results presented in this talk come from the di-lepton trigger:

- clean signal,
- high statistics,
- No lifetime bias.

The hadronic trigger is becoming competitive in terms of yield,
will be used in future also for mass determination and lifetime measurements.
In the semileptonic stream we are assessing the systematic error
due to trigger bias and to the background composition.

The di-lepton trigger has a large statistics of fully reconstructed B decays
Mass scale calibrated on J/ψ ($2\ 10^6$), check performed on ψ(2S) and ϒ(1S)





dE/dx: use GEANT description
Material adjustment
Magnetic field: +0.165%

	CDF mass	PDG mass
Ψ(2S)	3685.80 ± 0.12	3685.96 ± 0.09
ϒ(1S)	9462.2 ± 1.0	9460.30 ± 0.26

All B to 2-body decays, similar but slightly different topology

Common Analysis cuts:

$P_t(\mu^\pm)$: > 1.5 GeV/c

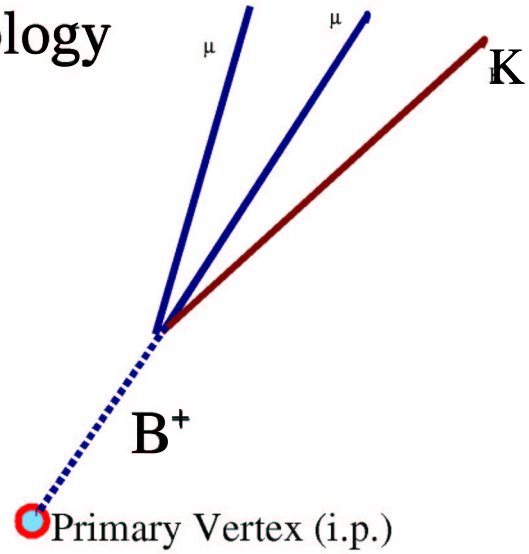
J/Ψ mass window: ±80 MeV/c^2

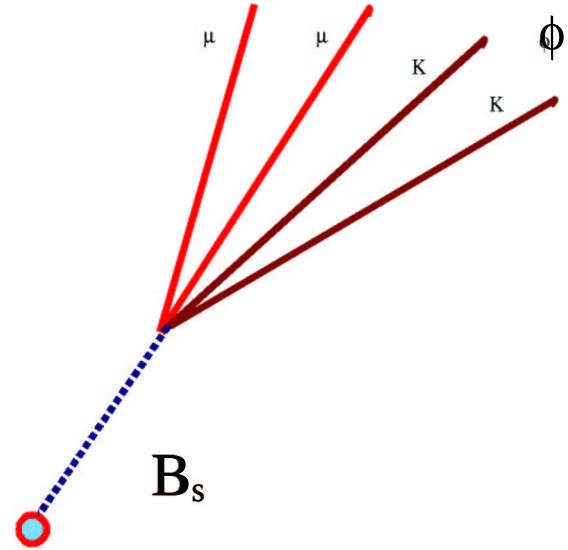
P_t(2nd particle) : > 2 GeV/c

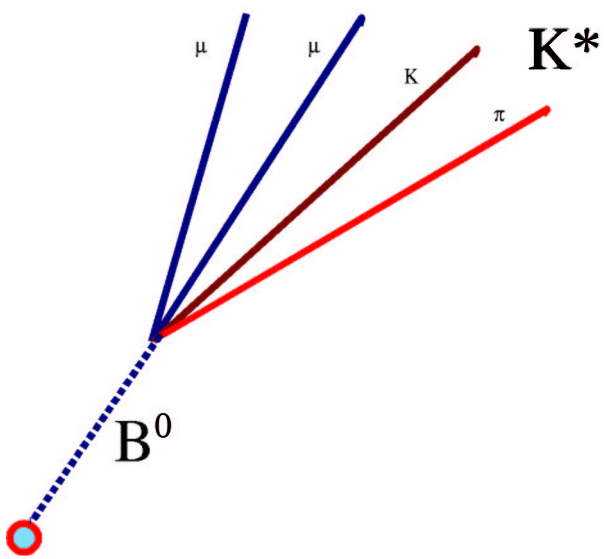
Decay length (B): >100 μm

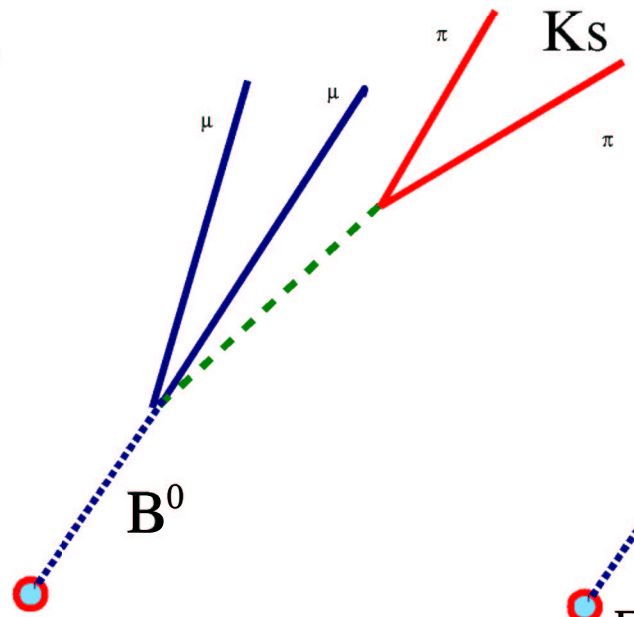
Pt (B) > 6.5 GeV/c

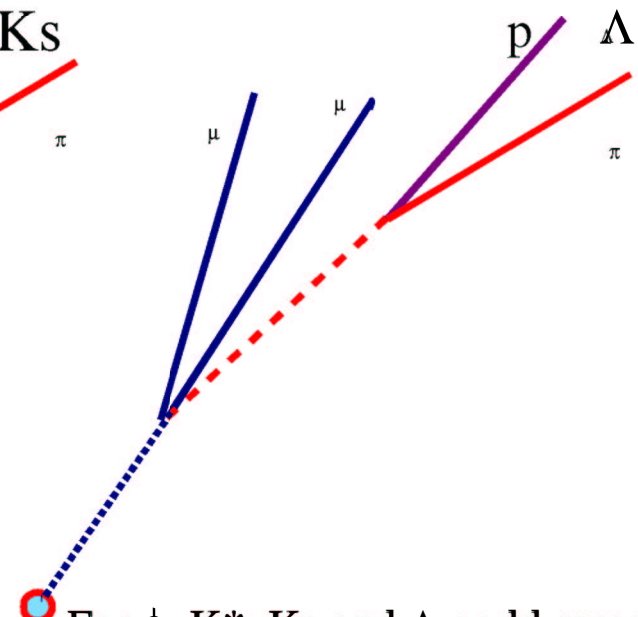
Fit probability : > 0.1%











For ϕ, K*, Ks and Λ_b: add mass cut

For Ks and Λ_b: add pointing

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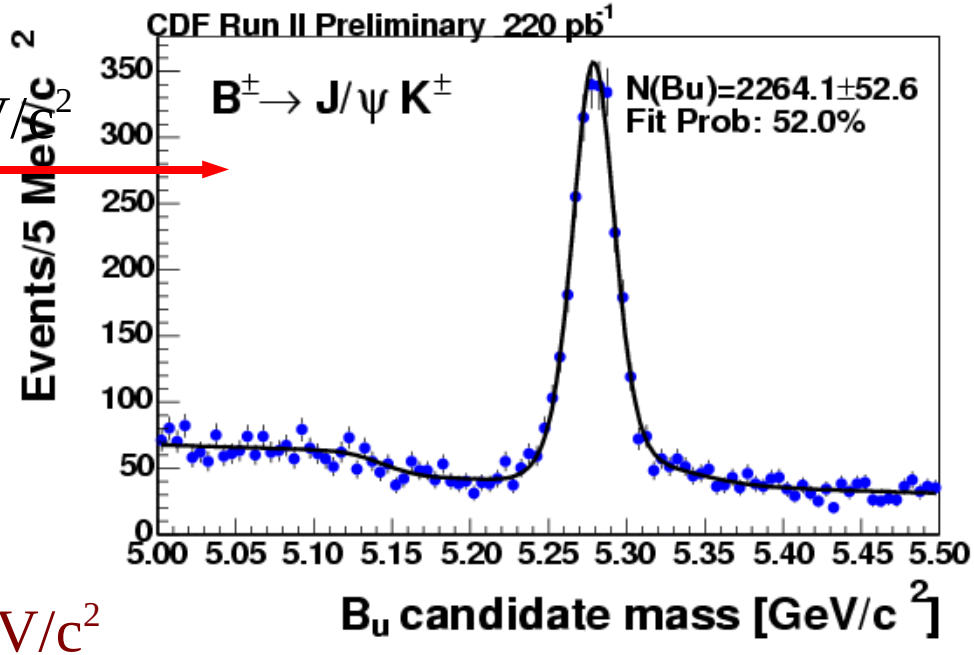
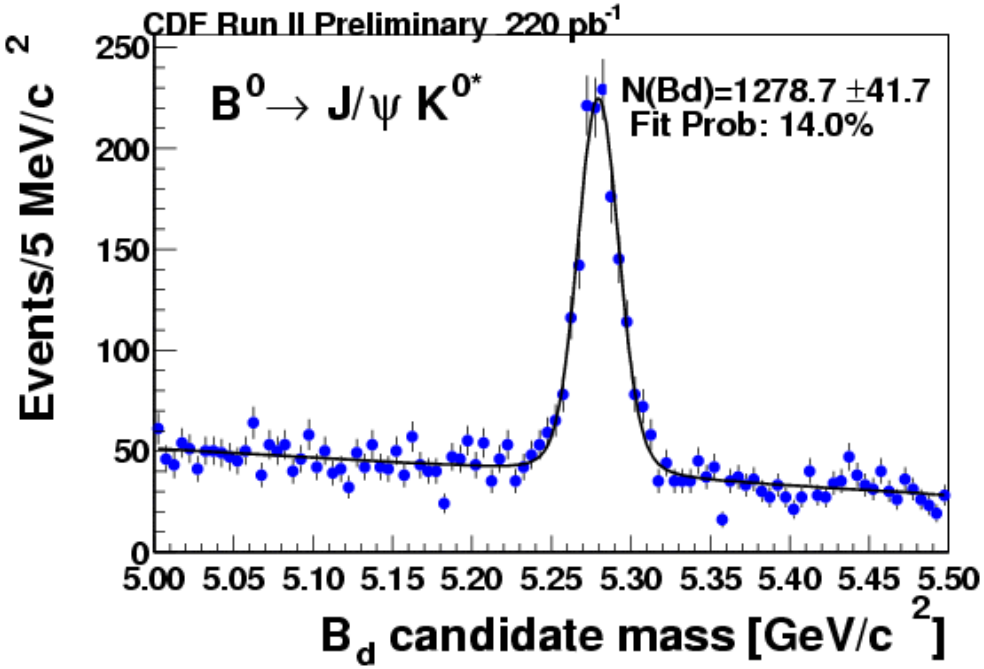
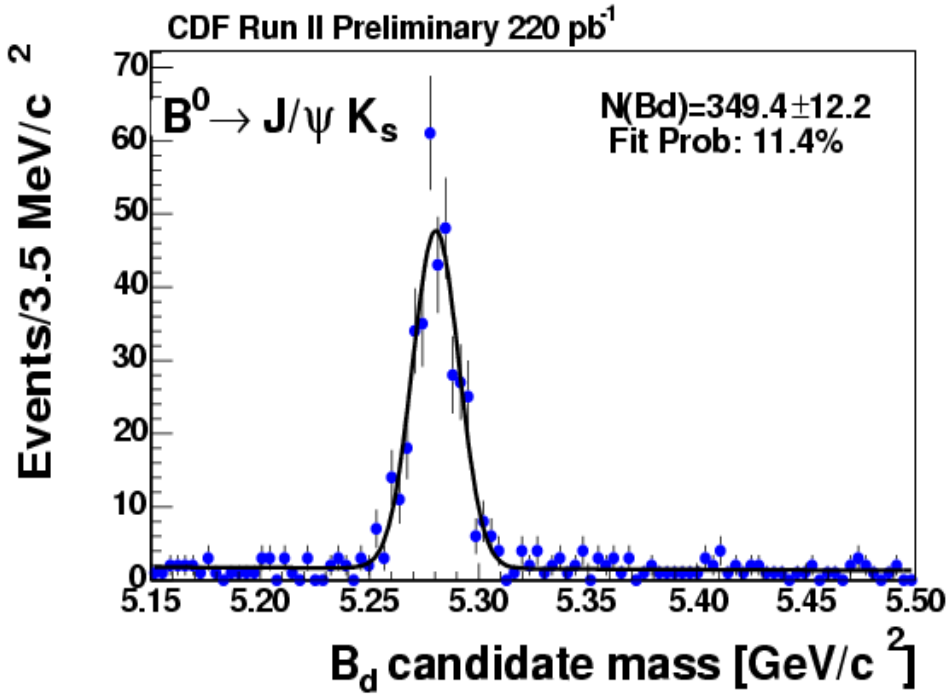
Masses: results

$M_{B+} = (5279.10 \pm 0.41 \pm 0.36)\ MeV/c^2$

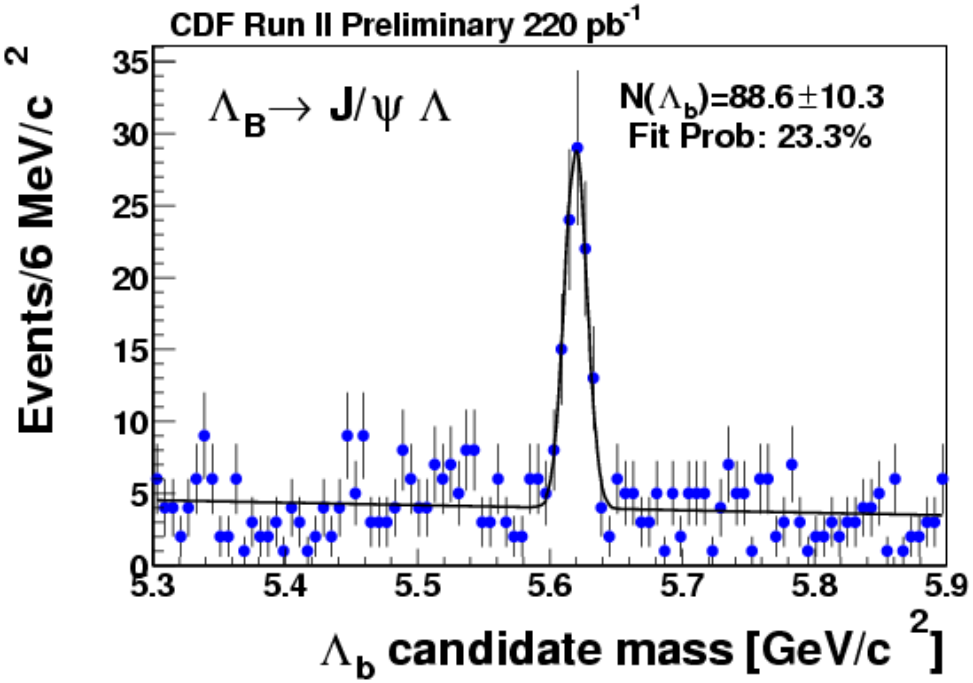


$M_{B0} = (5279.63 \pm 0.53 \pm 0.33)\ MeV/c^2$

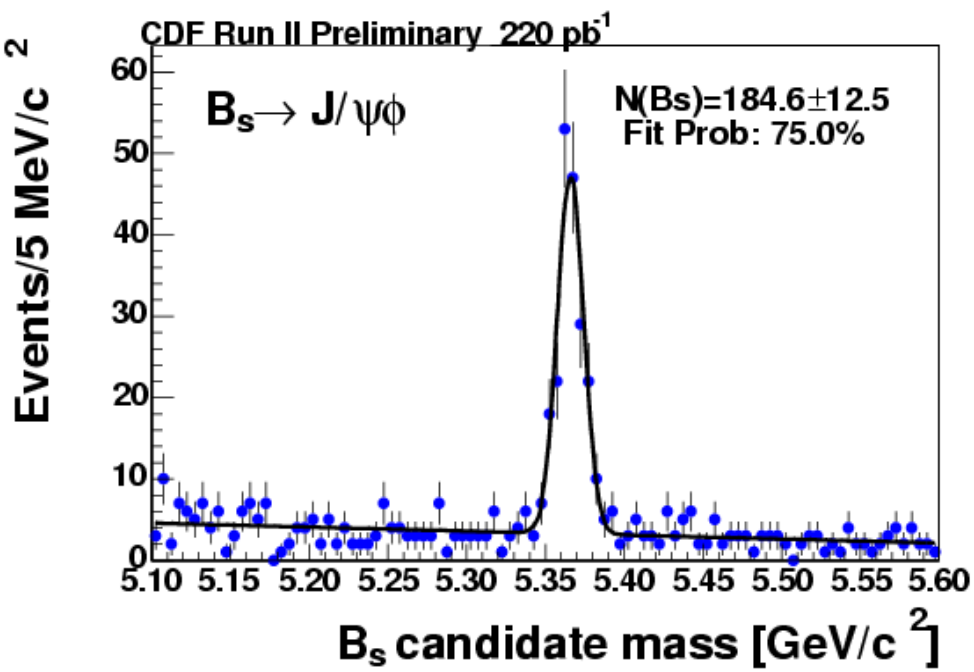




Masses: results

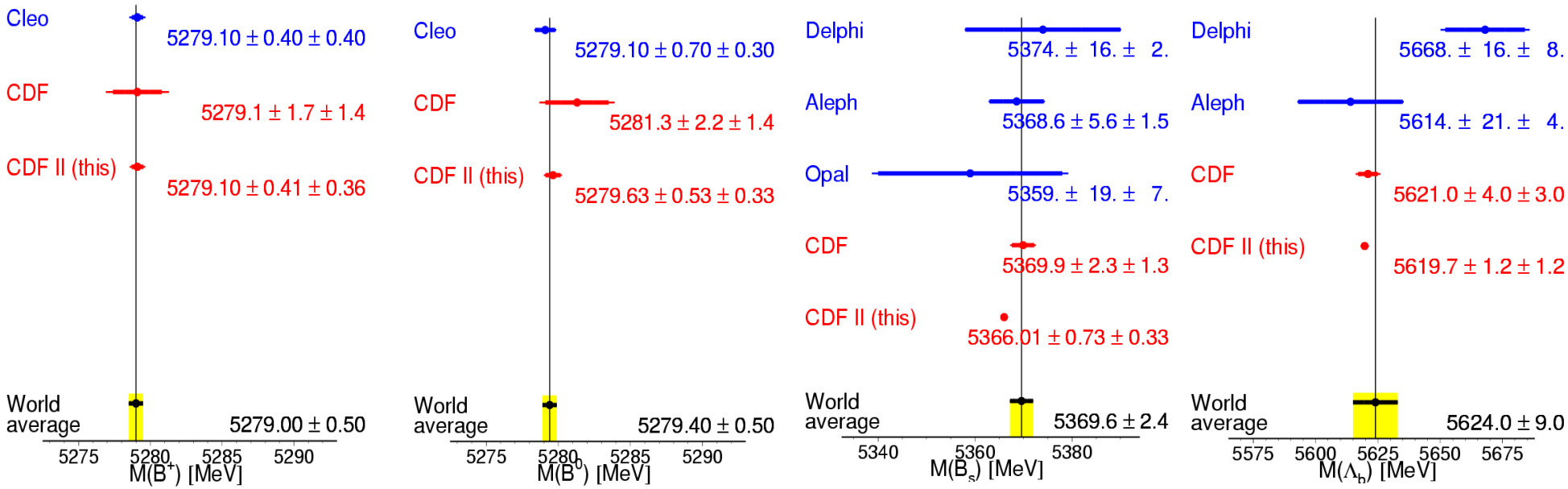


$M_{\Lambda b} = (5619.7 \pm 1.2 \pm 1.2)\ \mathrm{MeV}/c^2$



$M_{Bs} = (5366.01 \pm 0.73 \pm 0.33)\ \mathrm{MeV}/c^2$

Masses: Summary

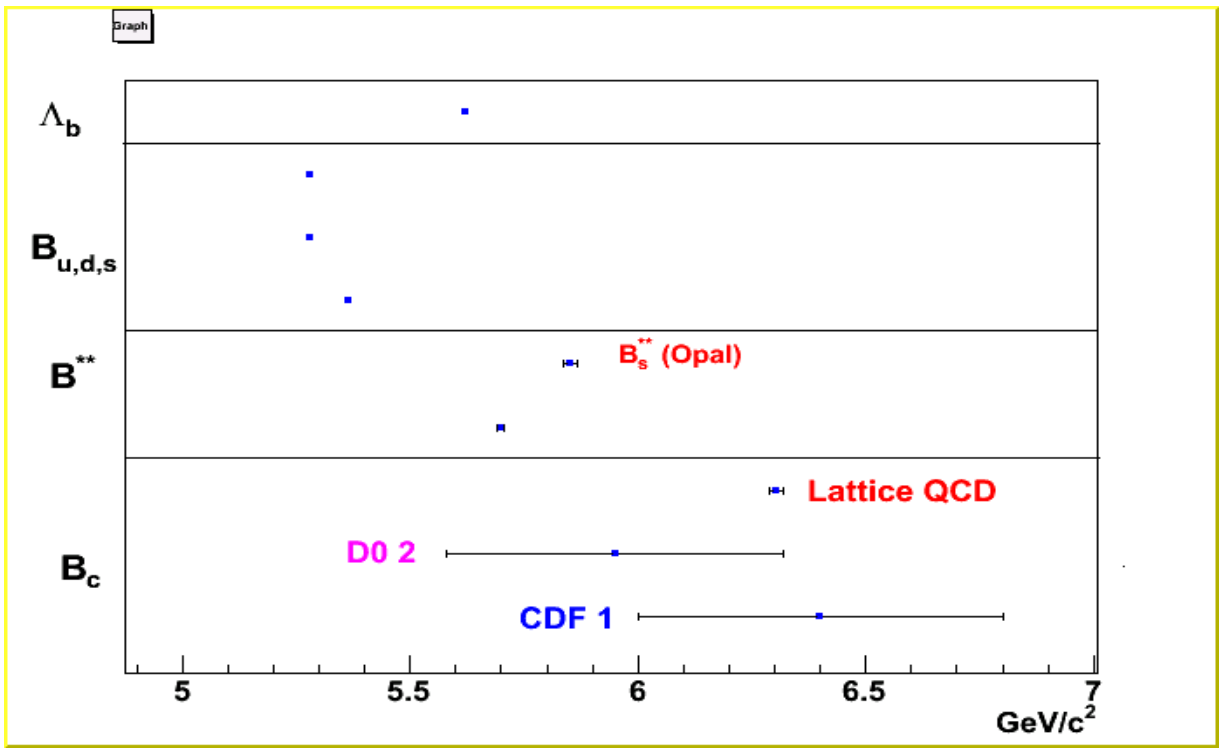


	Mass (MeV/c)	Best single meas. PDG	PDG fit
B+	5279.10 ± 0.41 ± 0.36	5279.1 ± 0.4 ± 0.4	5279.0 ± 0.5
B0	5279.63 ± 0.53 ± 0.33	5279.1 ± 0.7 ± 0.3	5279.4 ± 0.5
B_s	**5366.01 ± 0.73 ± 0.33**	5369.9 ± 2.3 ± 1.3	5369.6 ± 2.4
Λ_b	**5619.7 ± 1.2 ± 1.2**	5621± 4 ± 3	5624 ± 9

Main sources of systematic uncertainty:

Fit	0.13
B-field corrections	0.02
dE/dx corrections	0.2
Alignment/tracking	0.18

- Present limit is statistics: statistical errors scale with integrated Luminosity
- Systematic errors have been reduced by 3x in 1 year with an impressive work
- Correct for smaller and smaller effects whith larger statistics.
- Mass of other Meson, Baryons will be measured.... soon:



B_c only observed in semileptonic decay. Searches in $J/\psi\ \pi$ and $a_1\ \pi$ are on-going

B_c test bench for lattice QCD real prediction

Other states missing: η_b Ξ_b...

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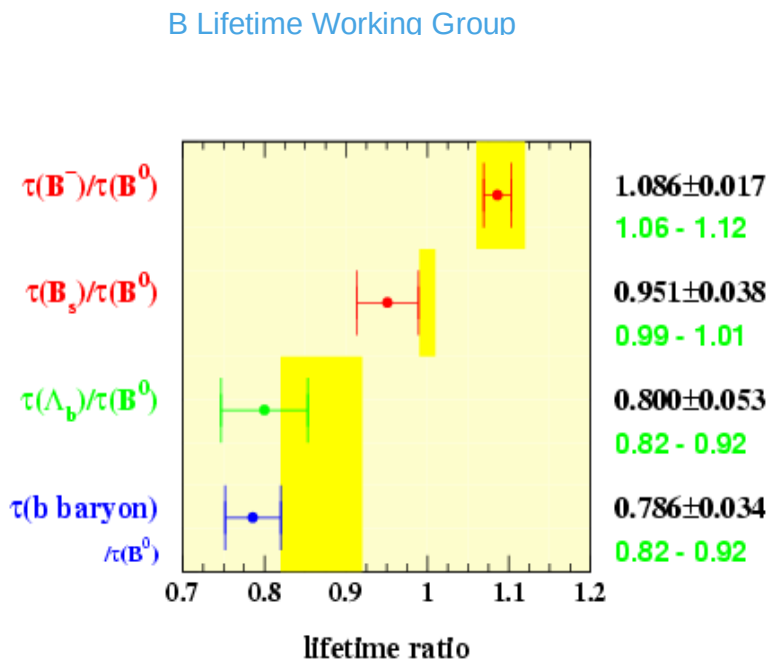
Lifetime measurements

Precision lifetimes for:

- Test of Heavy Quark Expansion theory
- Time-dependant measurements:
  - Oscillations
  - $\Delta\Gamma$



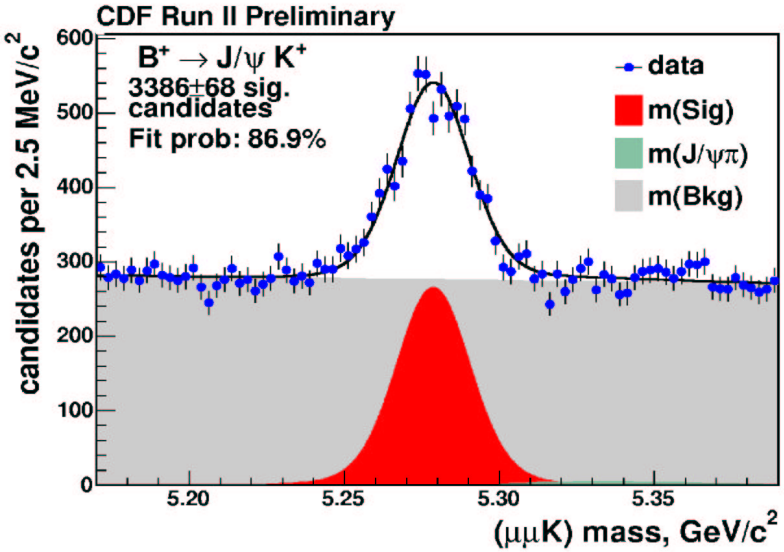
Method: use loose selection cuts and fit at the same time mass and lifetime.
Sample composition studed to minimize the systematic effects.
Unbinned likelihood, 12 parameters:

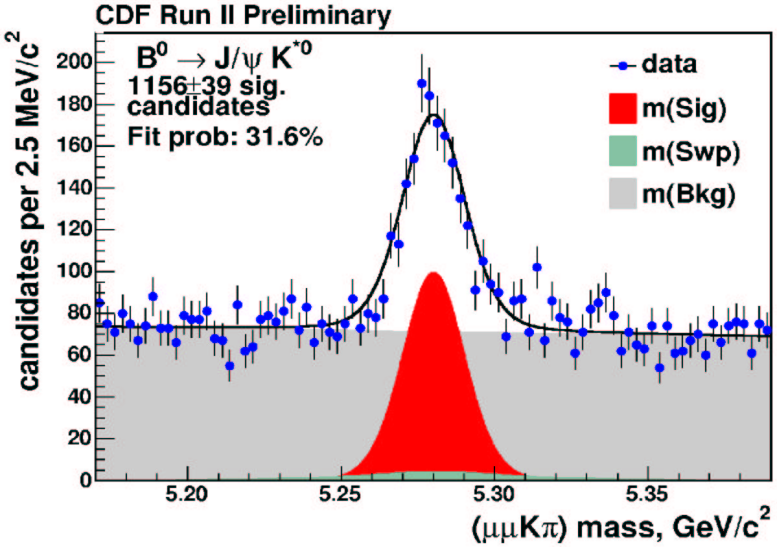
Global parameter: number of signal events
Mass dimension: gaussian + linear background (3 parameters)
Proper time dimension: resolution gaussian convoluted on each event with:

- Signal exponential +
- Negative exponential +
- sum of 2 positive exponentials

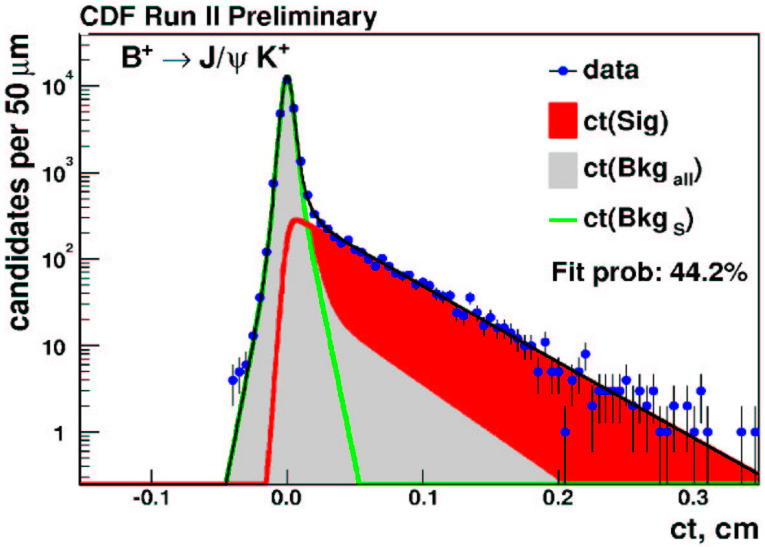
$$\mathcal{L} = -2\,log \prod_i f(m_i, \sigma_{m_i}, ct_i, \sigma_{ct_i} | \overrightarrow{\text{parameters}})$$

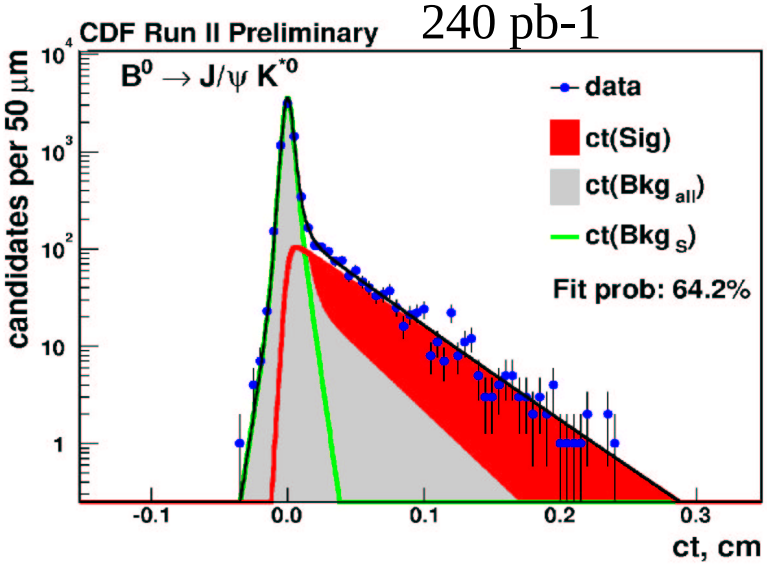
Lifetime results: B^+ B^0 :





240 pb-1

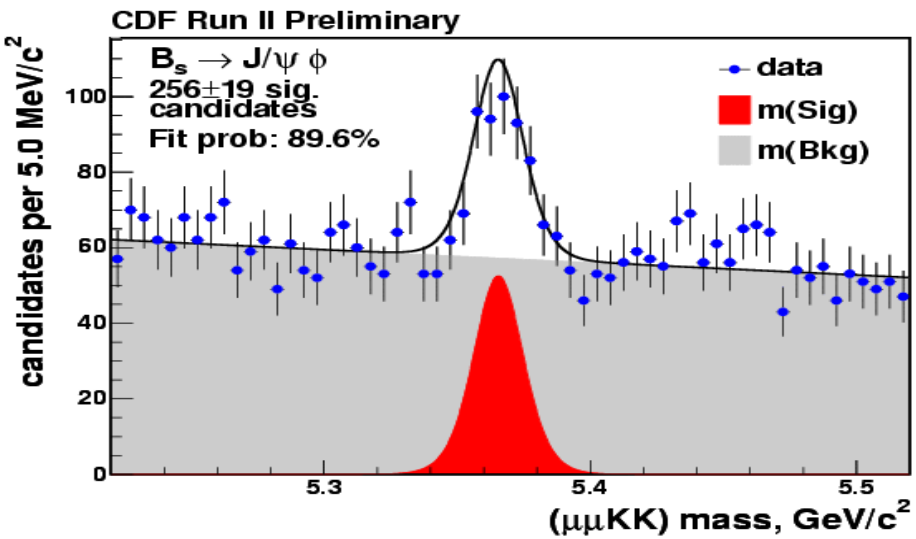


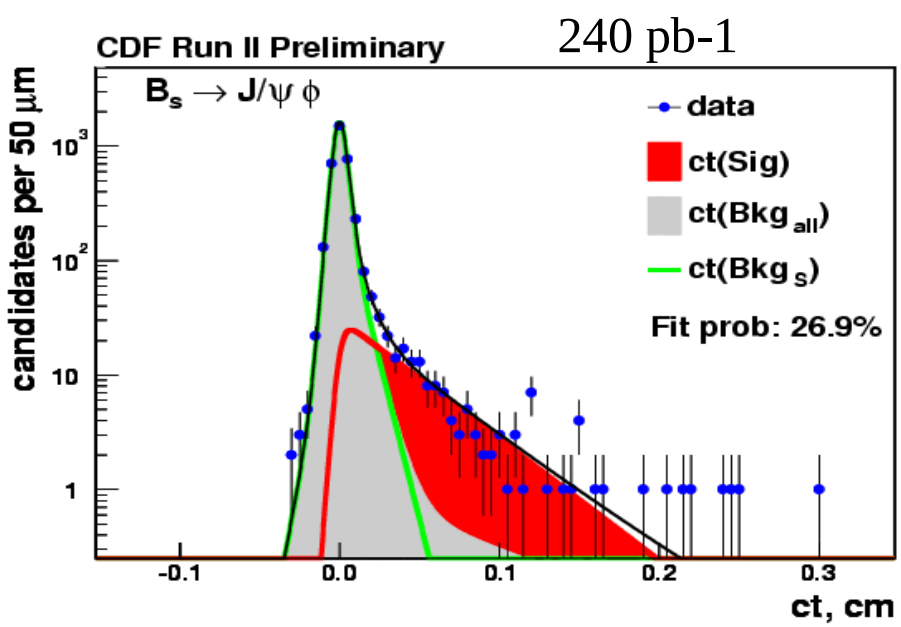


$\tau = (1.662 \pm 0.033 \pm 0.008)\ ps$

$\tau = (1.539 \pm 0.051 \pm 0.008)\ ps$

Lifetime results: B_s





$\tau = (1.369 \pm 0.100 \pm 0.008)$ ps

However.....

B_s mixing may imply sizeable $\Delta\Gamma_s$

Expect $\Delta\Gamma_s / \Gamma_s = 12\%$

$$|B_s^H> = p\,|B_s> + q\,|\overline{B}_s> = 1/\sqrt{2}\,(|B_s> + |\overline{B}_s>)$$ CP-Odd

$$|B_s^L> = p\,|B_s> - q\,|\overline{B}_s> = 1/\sqrt{2}\,(|B_s> - |\overline{B}_s>)$$ CP-Even

In our cases: psudoscalar decays to 2 vectors: $(0^-) \rightarrow (1^{--})\,(1^{--})$
Decay allows orbital angular momentum L = 0, 1, 2;
L = 0, 2 have Even parity → CP even
L = 1 has odd parity → CP odd
different relative contributions to the decay amplitude.
Disentangling P-wave isolate the two $B_s^{(H,L)}$ states.

Perform lifetime fit at the same time as orbital angular momentum fit.
Obtain:

- Polarization amplitudes and
- separate lifetime for CP-even and CP-odd.

- Test on B^0
- Apply to the B_s

No flavour tagging at production required

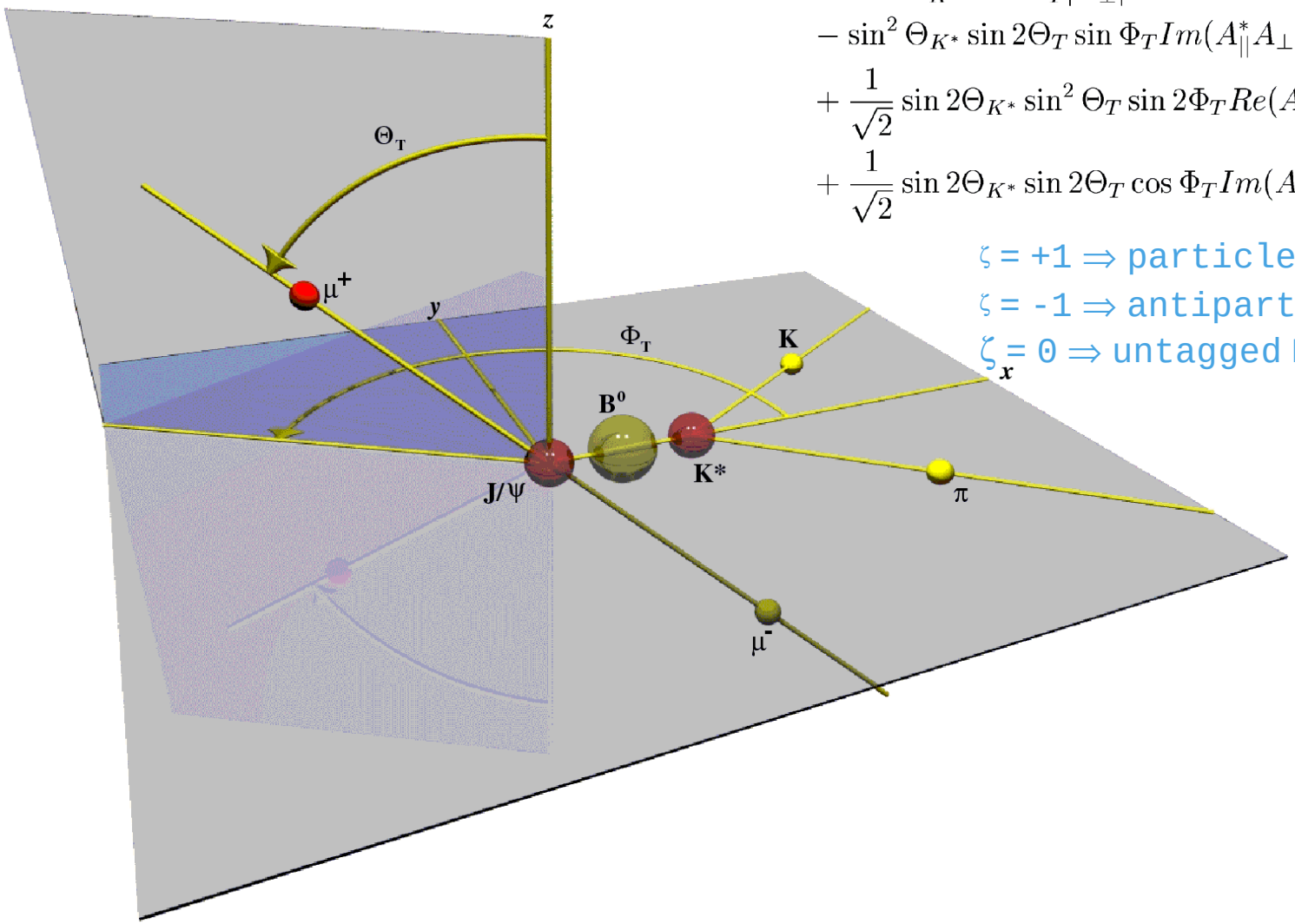
In the J/ψ rest frame

$$\mathcal{G} = \frac{9}{32\pi}\Big\{ 2\cos^2\Theta_{K^*}(1-\sin^2\Theta_T\cos^2\Phi_T)|A_0|^2 + \sin^2\Theta_{K^*}(1-\sin^2\Theta_T\sin^2\Phi_T)|A_{||}|^2 + \sin^2\Theta_{K^*}\sin^2\Theta_T|A_\perp|^2 - \sin^2\Theta_{K^*}\sin 2\Theta_T\sin\Phi_T Im(A_{||}^*A_\perp)\zeta + \frac{1}{\sqrt{2}}\sin 2\Theta_{K^*}\sin^2\Theta_T\sin 2\Phi_T Re(A_0^*A_{||}) + \frac{1}{\sqrt{2}}\sin 2\Theta_{K^*}\sin 2\Theta_T\cos\Phi_T Im(A_0^*A_\perp)\zeta \Big\}$$

$\zeta = +1 \Rightarrow$ particle

$\zeta = -1 \Rightarrow$ antiparticle

$\zeta = 0 \Rightarrow$ untagged B_s



Fit parameters:

Signal:

Mass, signal fraction, lifetime H, lifetime L, A_0, $A_{//}$, $A_\perp$,
mass covariance scale, lifetime covariance scale

Background:

Slope in mass, non prompt negative tail, positive exponential,
long-lived positive exponential, B_0, $B_{//}$, $B_\perp$

Fit functions: B_s

$$\frac{d^4\mathcal{P}}{d\vec{\rho}\,dt} \propto |A_0|^2 \cdot e^{-\Gamma_L t} \cdot f_1(\vec{\rho}) + |A_{\|}|^2 \cdot e^{-\Gamma_L t} \cdot f_2(\vec{\rho}) + |A_\perp|^2 \cdot e^{-\Gamma_H t} \cdot f_3(\vec{\rho}) + Re(A_0^* A_{\|}) \cdot e^{-\Gamma_L t} \cdot f_5(\vec{\rho})$$

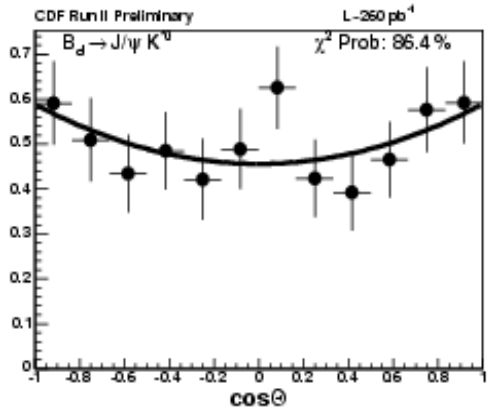
$\vec{\rho} = (\cos\theta\,,\ \phi,\ \cos\psi)$

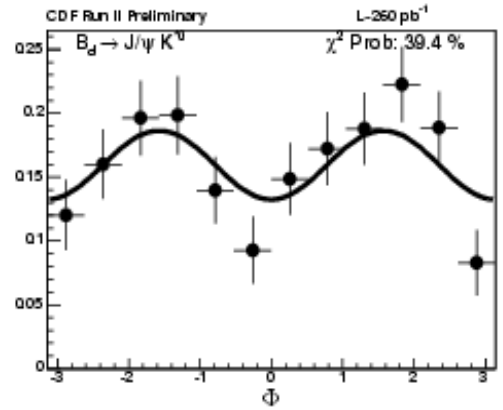
B^0

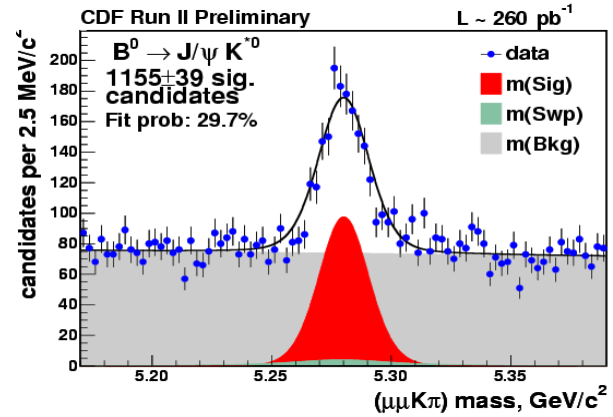
$$\frac{d^4\mathcal{P}}{d\vec{\rho}\,dt} \propto \Big\{ |A_0|^2 \cdot f_1(\vec{\rho}) + |A_{\|}|^2 \cdot f_2(\vec{\rho}) + |A_\perp|^2 \cdot f_3(\vec{\rho}) \pm Im(A_{\|}^* A_\perp) \cdot f_4(\vec{\rho}) + Re(A_0^* A_{\|}) \cdot f_5(\vec{\rho}) \pm Im(A_0^* A_\perp) \cdot f_6(\vec{\rho}) \Big\} \cdot e^{-\Gamma_d t}$$

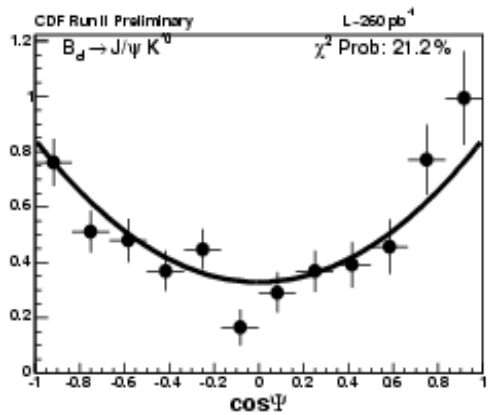
Angular projections: B^0 case

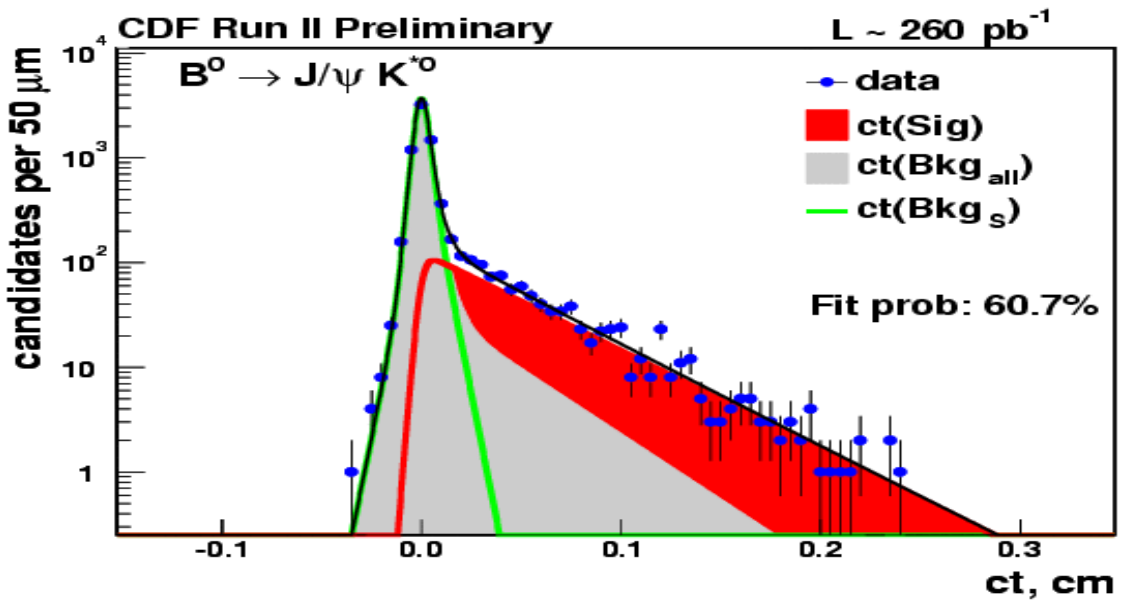
Sideband subtracted,
acceptance corrected.
Projections from full likelihood fit











Fit to one lifetime:

$\Delta\Gamma_d / \Gamma_d < 1\%$ (SM)

$$C\tau = (462 \pm 15 \pm 4)\ \mu m$$

$$\tau = (1.54 \pm 0.05 \pm 0.02)\ ps$$

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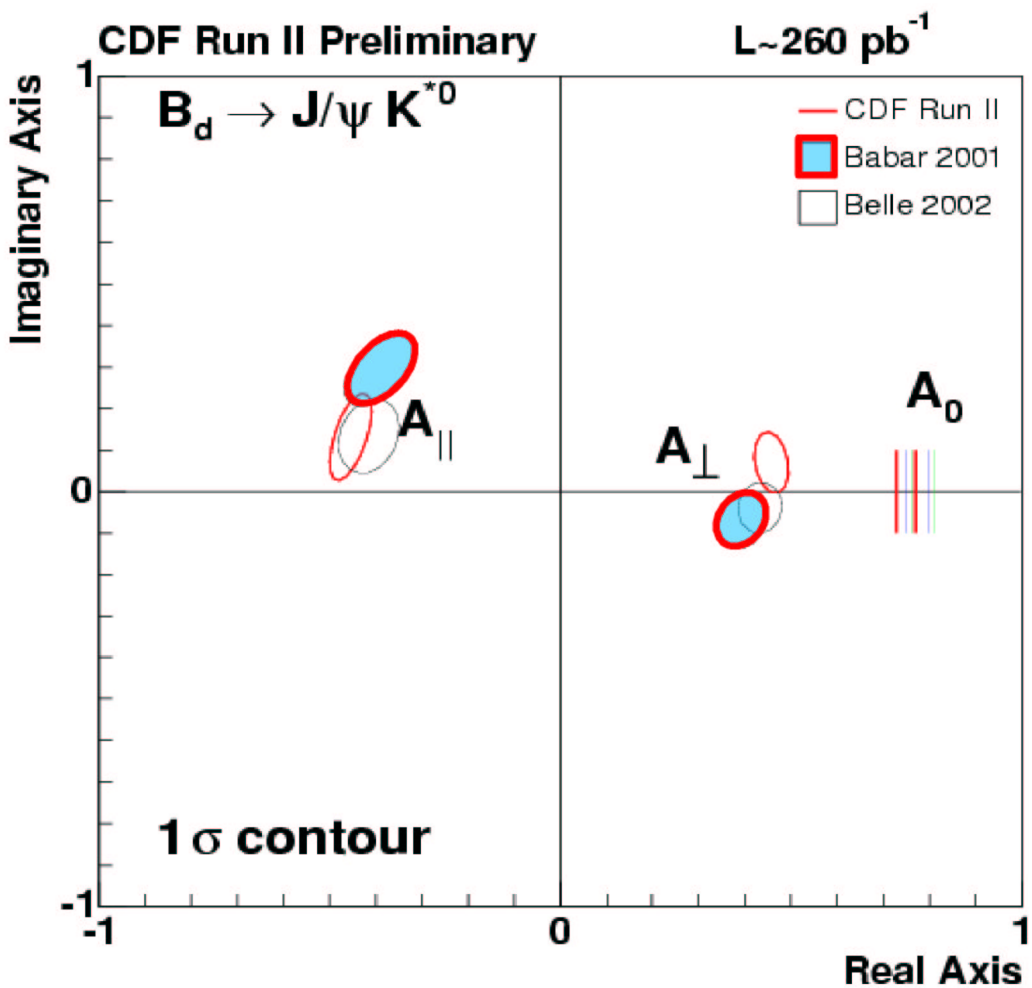
$B^0 \rightarrow J/\psi\, K^{*0}$

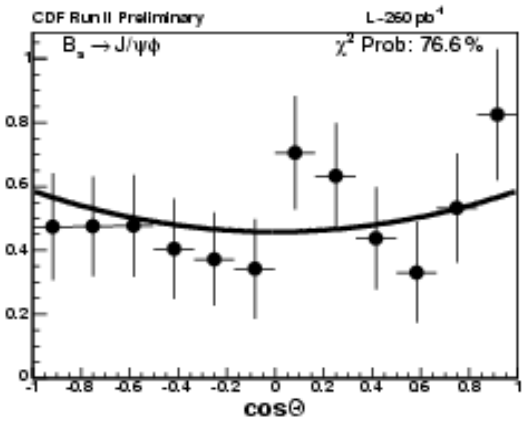


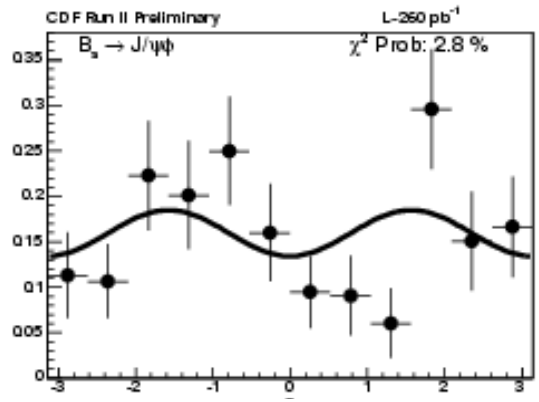
$A_0 = 0.750 \pm 0.017 \pm 0.012$

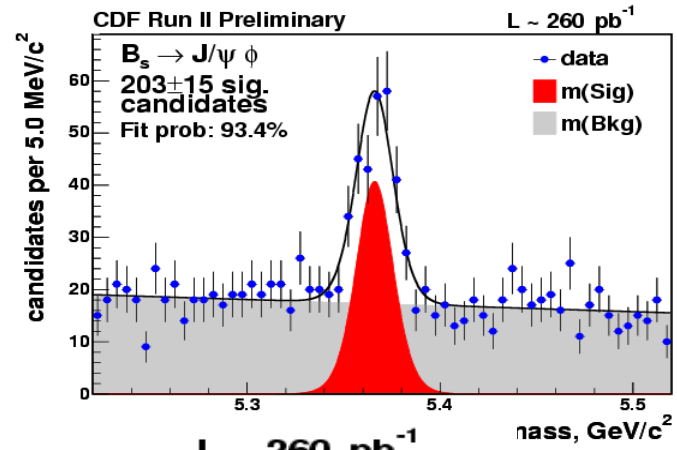
$A_{\parallel} = (0.473 \pm 0.034 \pm 0.006)\, e^{(2.86 \pm 0.22 \pm 0.07)\, i}$

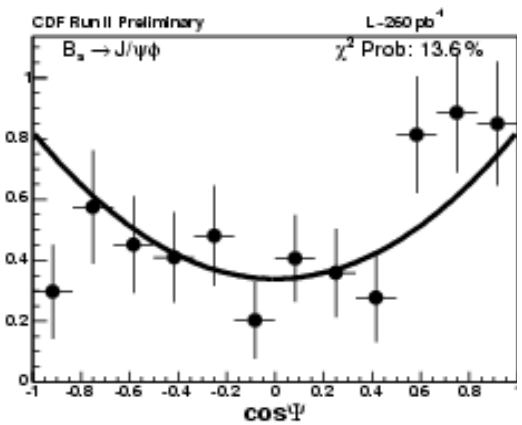
$A_{\perp} = (0.464 \pm 0.035 \pm 0.007)\, e^{(0.15 \pm 0.15 \pm 0.04)\, i}$

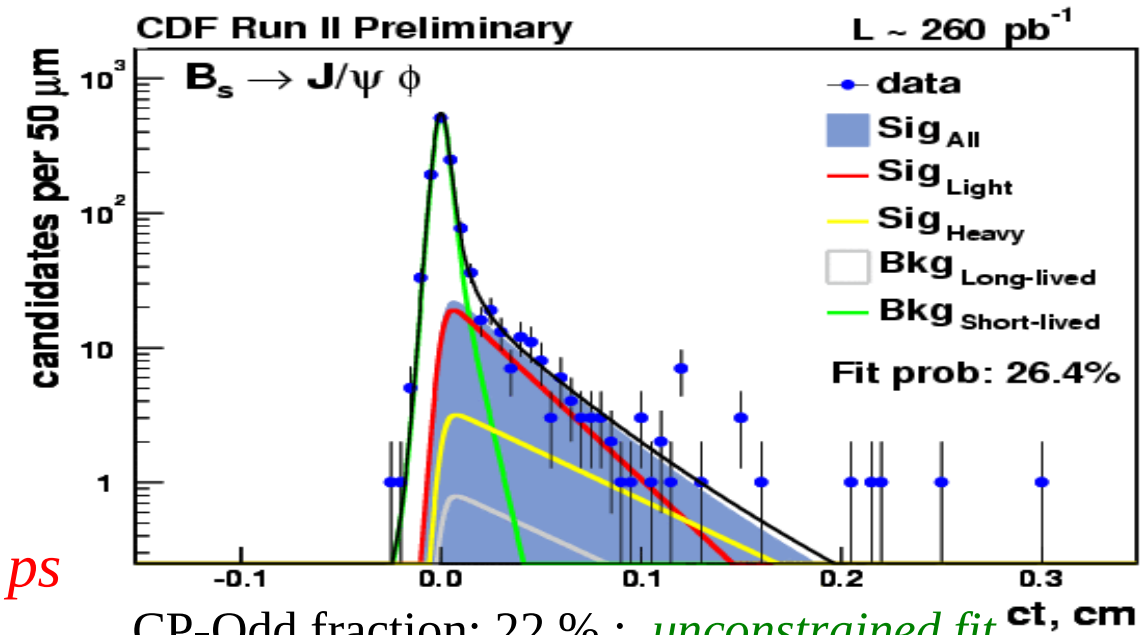
$B^0 \rightarrow J/\psi\ \phi$











$\tau_L = (1.05\ ^{+0.16}_{-0.13} \pm 0.02)\ ps$

$\tau_H = (2.07\ ^{+0.58}_{-0.46} \pm 0.03)\ ps$

CP-Odd fraction: 22 % ; *unconstrained fit.*

$$\Delta\Gamma_s = (0.47\ ^{+0.19}_{-0.24} \pm 0.01\ )\ ps^{-1}$$

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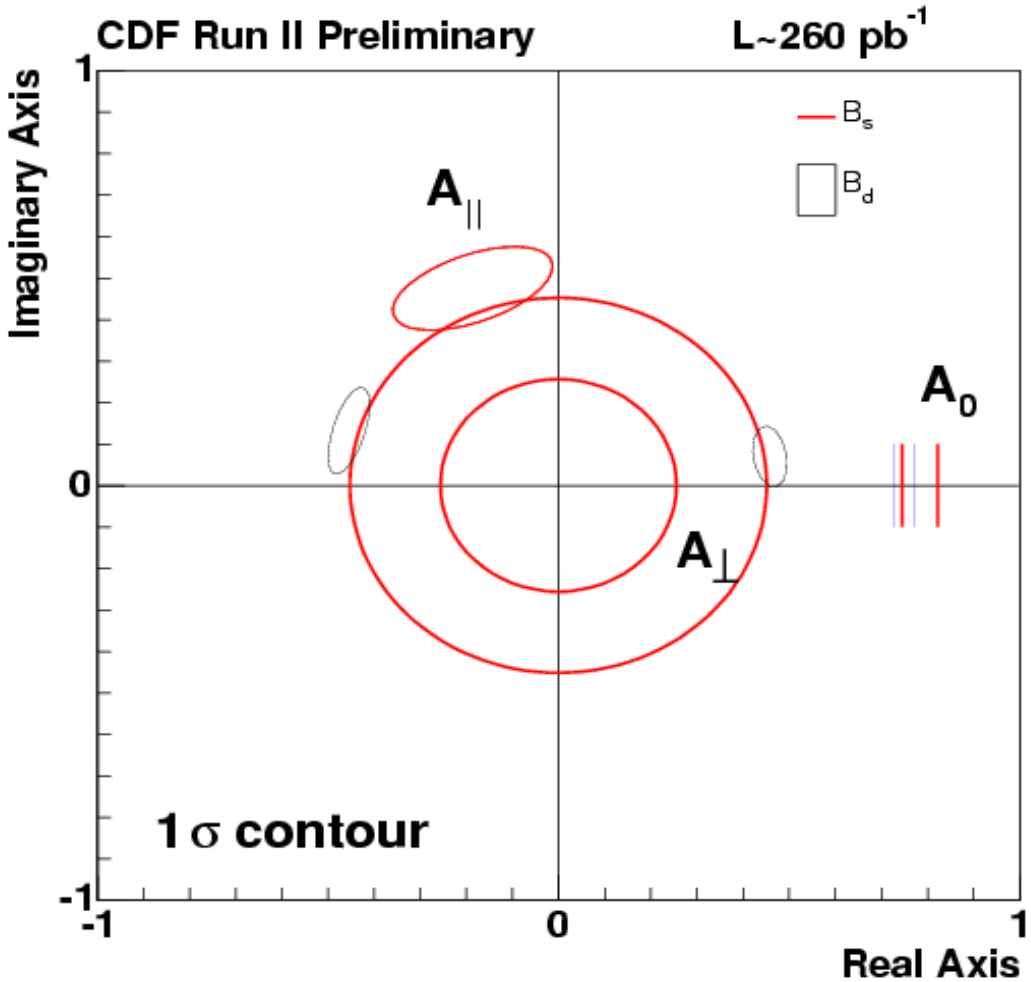


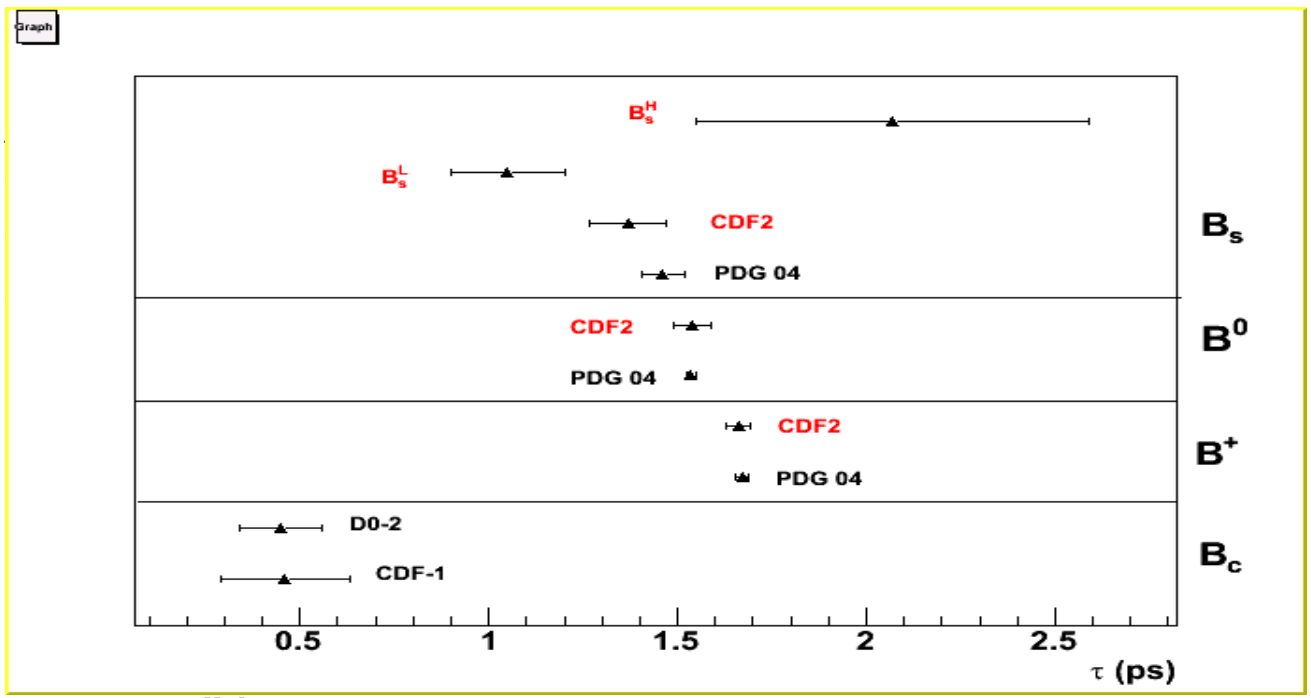
$A_0 = 0.784 \pm 0.039 \pm 0.007$

$A_{||} = (0.510 \pm 0.082 \pm 0.013)\ \exp\ (1.94 \pm 0.36 \pm 0.03)\ i$

$|A_\perp| = 0.354 \pm 0.098 \pm 0.003$

	This work	PDG '04 (eval)	Best single
B^+	$1.662 \pm 0.033 \pm 0.008$	1.671 ± 0.018	$1.695 \pm 0.026 \pm 0.015$
B^0	$1.539 \pm 0.051 \pm 0.008$	1.536 ± 0.014	$1.523 \pm 0.024 \pm 0.022$
B_s	$1.369 \pm 0.100\ ^{+0.008}_{-0.010}$	1.461 ± 0.057	$1.36 \pm 0.09 \pm 0.06$
B_s^L	$1.05 \pm ^{+0.16}_{-0.13} \pm 0.02$		
B_s^H	$2.07 \pm ^{+0.58}_{-0.46} \pm 0.03$		

$$c\tau_{B^+} = 498.1 \pm 9.9\,(stat.) \pm 2.4(syst.)\ \mu\mathrm{m}$$
$$c\tau_{B^0} = 461.3 \pm 15.4\,(stat.) \pm 2.4(syst.)\ \mu\mathrm{m}$$
$$c\tau_{B_s} = 410.4 \pm 30.0\,(stat.)^{+2.4}_{-2.9}(syst.)\ \mu\mathrm{m}$$



Conclusions

Hadron Collider experiments can make precision measurements in the sector of *b* Physics.

CDF measurements of *b* hadron masses are more precise or at the very same level as e^+e^- experiments, thanks to the great performances of our tracking chamber.

New measurements of masses are coming soon (B_c, ...)

Lifetimes can also be measured very precisely thanks to a good event selection and good space resolution (Silicon Vertex).

Angular analysis have allowed us to measure for the first time the lifetime difference of the two components of the B_s.

$$\boxed{\Delta\Gamma_s = (0.47\ ^{+0.19}_{-0.24} \pm 0.01)\ ps^{-1}}$$

Backup slides

Comparisons

Exp	Sample	Result	$\Delta\Gamma_s/\Gamma_s$
DELPHI	$D_s^- l^+ \nu_l X$	$\tau_{SL} = (1.42 \pm 0.14)\,\text{ps}$	< 0.46
OTHERS	$D_s^- l^+ \nu_l X$	$\tau_{SL} = (1.46 \pm 0.07)\,\text{ps}$	< 0.30
L3	incl. b		< 0.67
DELPHI	D_s^-hadron	$\tau_{B_s^{D_s-had}} = (1.46 \pm 0.07)\,\text{ps}$	< 0.69
ALEPH	$\varphi\varphi X$	$\text{BR}(B_s^{\text{short}} \to D_s^{(*)+} D_s^{(*)-}) = 23^{+21}_{-13}\%$	$0.26^{+0.30}_{-0.15}$
ALEPH	$\varphi\varphi X$	$\tau_{short} = (1.27 \pm 0.34)\,\text{ps}$	$0.45^{+0.80}_{-0.49}$
CDF I	$J/\psi\varphi$	$\tau_{B_s^{\psi\varphi}} = (1.34 \pm 0.23)\,\text{ps}$	$0.33^{+0.45}_{-0.42}$
CDF II	$J/\psi\varphi$	$\tau_L = (1.13^{+0.13}_{-0.09} \pm 0.02)\,\text{ps}$ $\tau_H = (2.38^{+0.56}_{-0.43} \pm 0.03)\,\text{ps}$	$0.71^{+0.24}_{-0.28}$

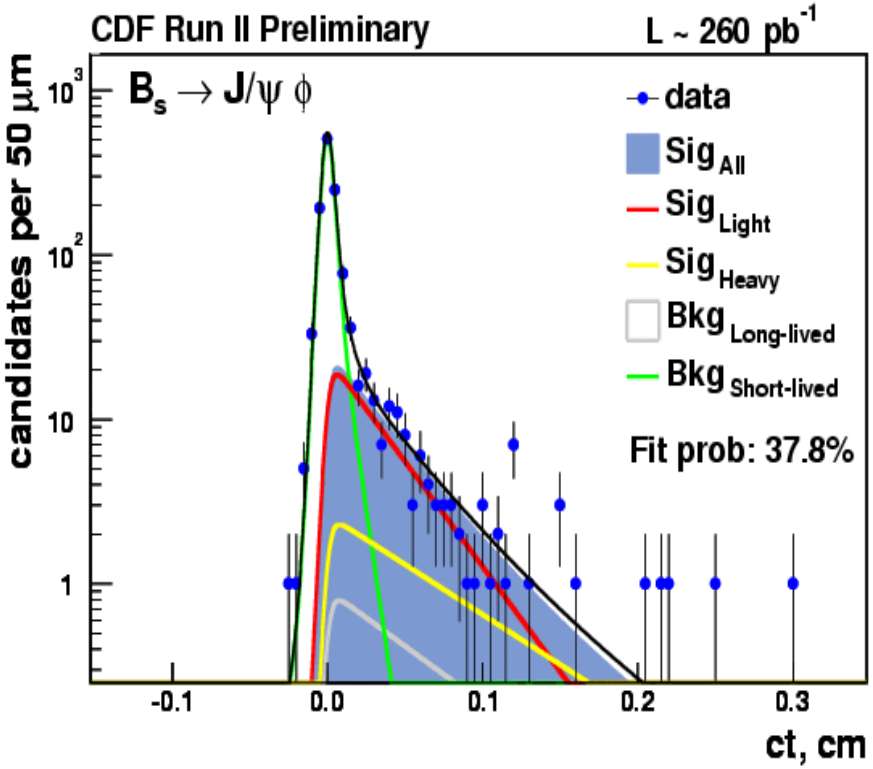
Constrained fit

From C. Gay, CDF-Yale

Constrained fit:

Invoke SM constraint $\Gamma_s = ½ (\Gamma_H + \Gamma_L) = \Gamma_d$ Expected correct to 1%

Set $\tau_s = (1.54 \pm 0.021)$ ps



$$\tau_L = 1.13^{+0.13}_{-0.09} \pm 0.02\,\text{ps}$$
$$\tau_H = 2.38^{+0.56}_{-0.43} \pm 0.03\,\text{ps}$$

$$\Delta\Gamma_s = 0.46 \pm 0.18 \pm .01\ \text{ps}^{-1}$$
$$\frac{\Delta\Gamma_s}{\Gamma_s} = 0.71^{+0.24}_{-0.28} \pm 0.01$$