Recent B Physics Results at the Tevatron

Gavril Giurgiu, Johns Hopkins University
on behalf of CDF and DØ collaborations

Aspen 2008 Winter Conference
January 14, 2008

Outline

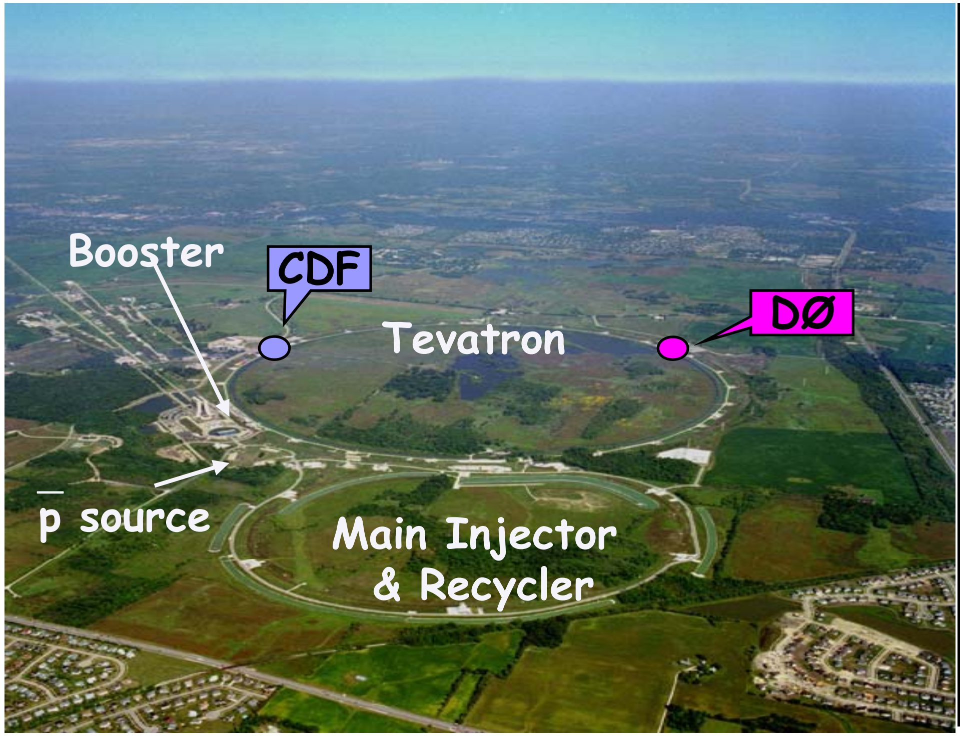
- Introduction
  - Tevatron, CDF and DØ detectors
  - B Physics at the Tevatron
- Recent results
  - lifetime, lifetime difference and CP violation in neutral B_s system
  - charge asymmetry in semileptonic B_s decays
  - CP asymmetry in $B^+ \rightarrow J/\Psi K^+$ and $\Lambda_b \rightarrow p\,\pi(K)$ decays
  - Ξ_b baryons
  - B_c mass and lifetime
  - Rare decays
  - D^0 mixing
- Topics not covered
- Conclusions

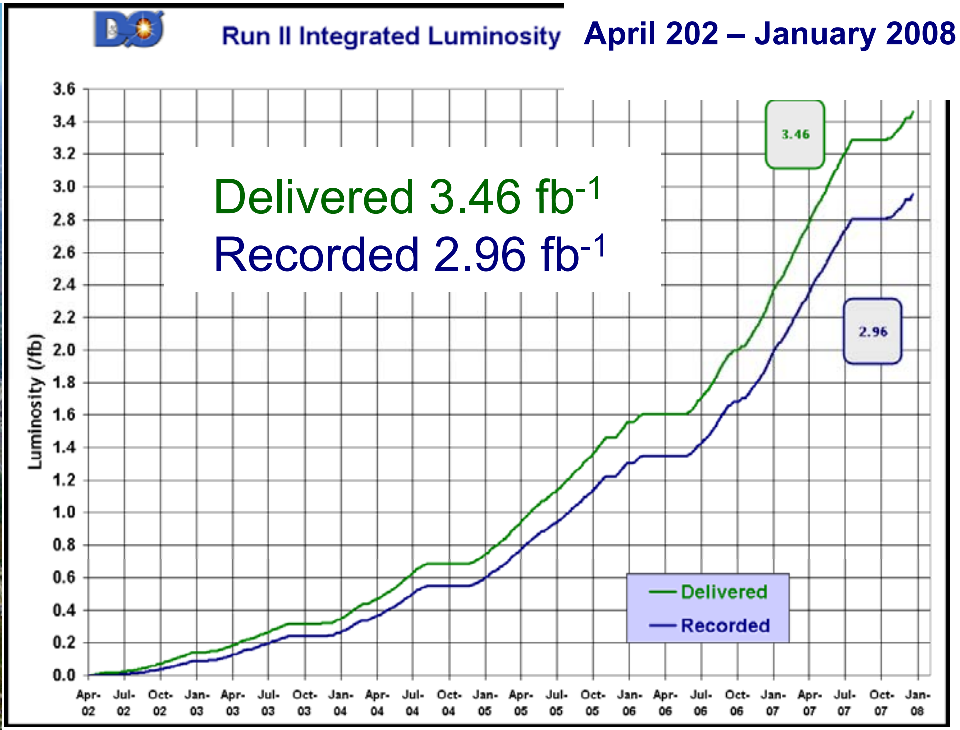
Tevatron

- $p\bar{p}$ collisions at 1.96 TeV

close to 3 fb^{-1} data on tape
Initial instantaneous luminosity $3 \times 10^{32} cm^{-2} s^{-1}$

- Buffalos are doing well, they don't know about the Fermilab budget cuts…





CDF II Detector

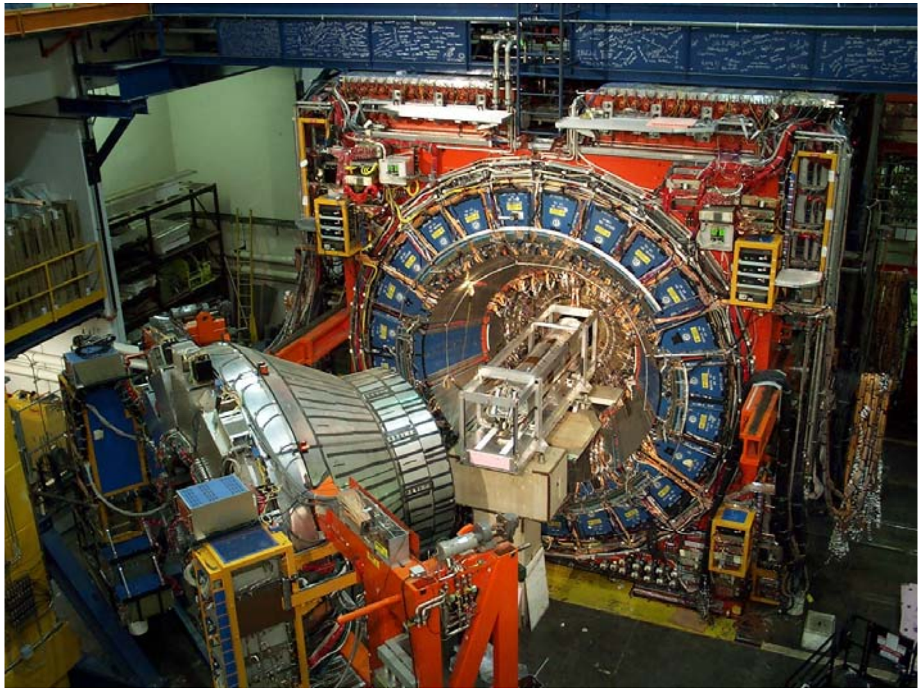
- Central tracking: - silicon vertex detector
  - drift chamber

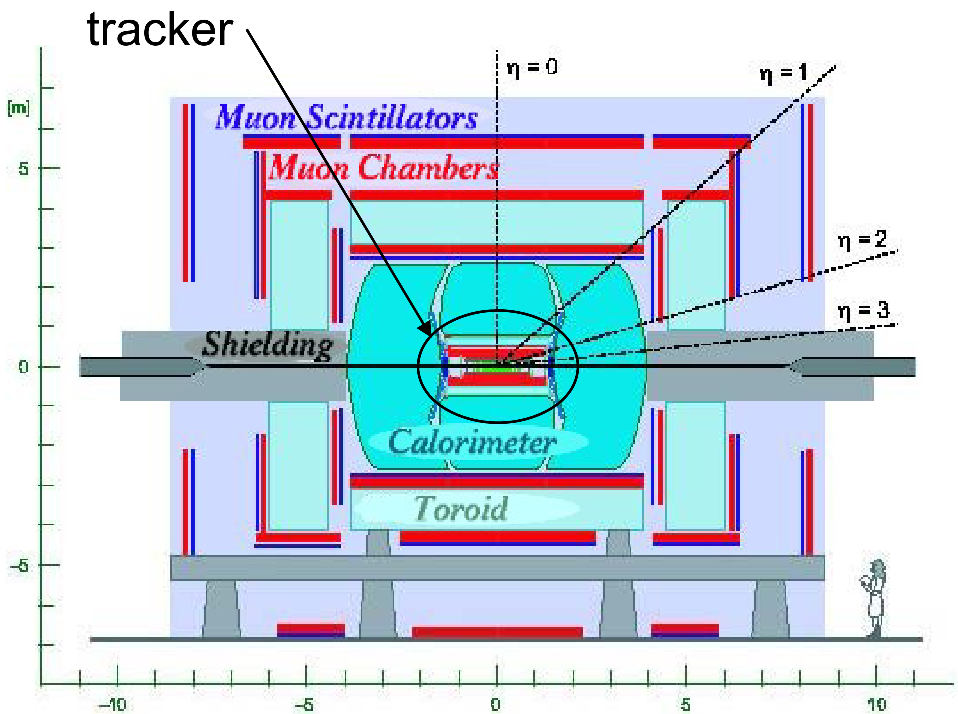
  $\delta p_T / p_T = 0.0015\ p_T$

  → excellent mass resolution
- Particle identification: dE/dX and TOF
- Good electron and muon ID by calorimeters and muon chambers

DØ Detector

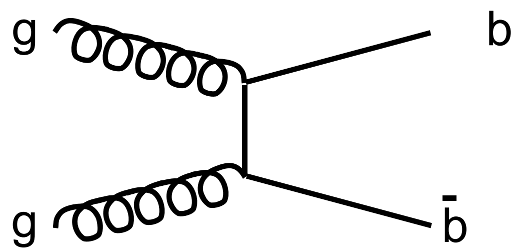
- Excellent tracking and muon coverage
- Excellent calorimetry and electron ID
- 2 Tesla solenoid, polarity reversed weekly
  → good control of charge asymmetry systematic effects
- Silicon layer 0 installed in 2006 improves track parameter resolution





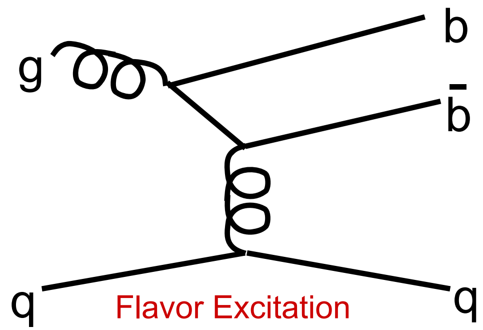
B Physics at the Tevatron

- Mechanisms for b production in $p\bar{p}$ collisions at 1.96 TeV

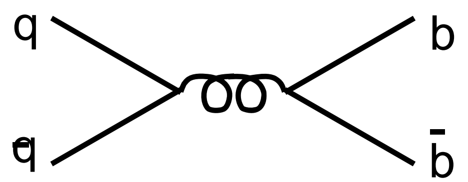


Flavor Creation (gluon fusion)

Gluon Splitting



Flavor Excitation



Flavor Creation (annihilation)

- At Tevatron, b production cross section is much larger compared to B-factories
  → Tevatron experiments CDF and DØ enjoy rich B Physics program

- Plethora of states accessible only at Tevatron: B_s, B_c, Λ_b, Ξ_b, Σ_b…
  → complement the B factories physics program

- Total inelastic cross section at Tevatron is ~1000 larger than b cross section
  → large backgrounds suppressed by triggers that target specific decays

CP Violation in B_s System

- Standard Model CP violation occurs through complex phases in the unitary CKM quark mixing matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Expanded in $\lambda = \sin(\theta_{Cabibbo}) \approx 0.23$:

Large CP violation ~ λ^3

Highly suppressed CP violation ~ λ^5

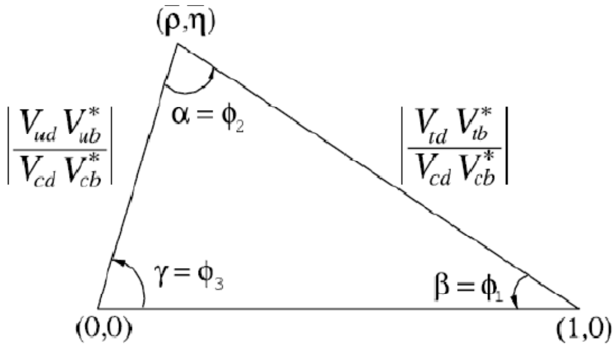
$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & -A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

Large CP violation ~ λ^3 | Suppressed CP violation ~ λ^4

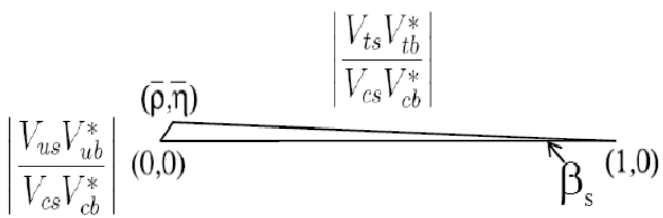
- Unitarity relations: $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$ | $V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$

- Unitarity triangles

B_d unitarity triangle



B_s unitarity triangle



Neutral B_s System

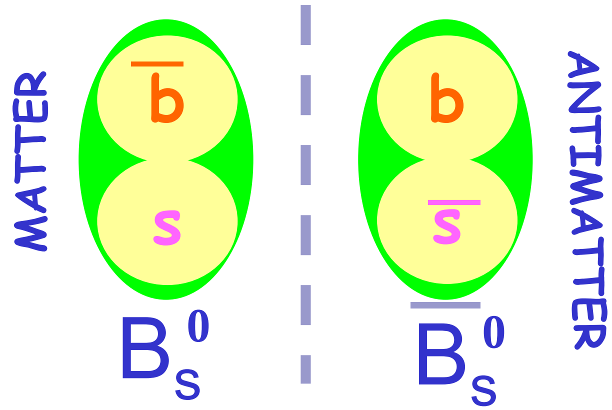
- Time evolution of B_s flavor eigenstates described by Schrodinger equation:

$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(\mathbf{M} - \frac{i}{2}\mathbf{\Gamma}\right)\begin{pmatrix}|B_s^0(t)\rangle \\ |\bar{B}_s^0(t)\rangle\end{pmatrix}$$

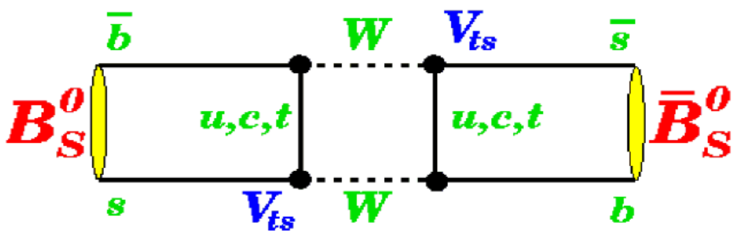
- Diagonalize mass (M) and decay (Γ) matrices
  → mass eigenstates

$$|B_s^H\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle \qquad |B_s^L\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle$$

where $q/p = \frac{V_{tb}V_{ts}^*}{V_{tb}^*V_{ts}}$



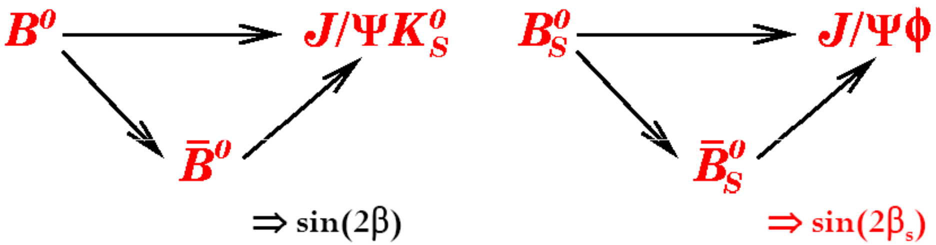
- Flavor eigenstates differ from mass eigenstates and mass eigenvalues are different ($\Delta m_s = m_H - m_L \approx 2|M_{12}|$)
  → B_s oscillates with frequency Δm_s
  precisely measured by
  CDF Δm_s = 17.77 +/- 0.12 ps^{-1}
  DØ Δm_s = 18.56 +/- 0.87 ps^{-1}

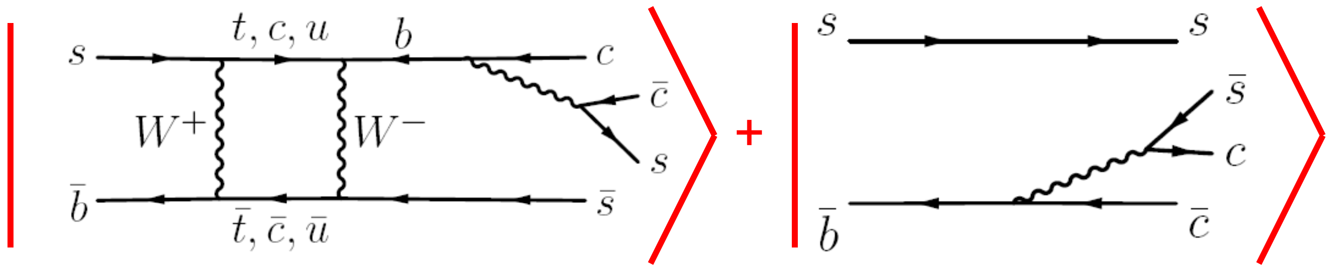


- Mass eigenstates have different decay widths
  $\Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}| \cos(\Phi_s)$ where $\phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4 \times 10^{-3}$

CP Violation in $B_s \to J/\Psi\Phi$ Decays

- Analogously to the neutral B^0 system, CP violation in B_s system occurs through interference of decay with and without mixing:





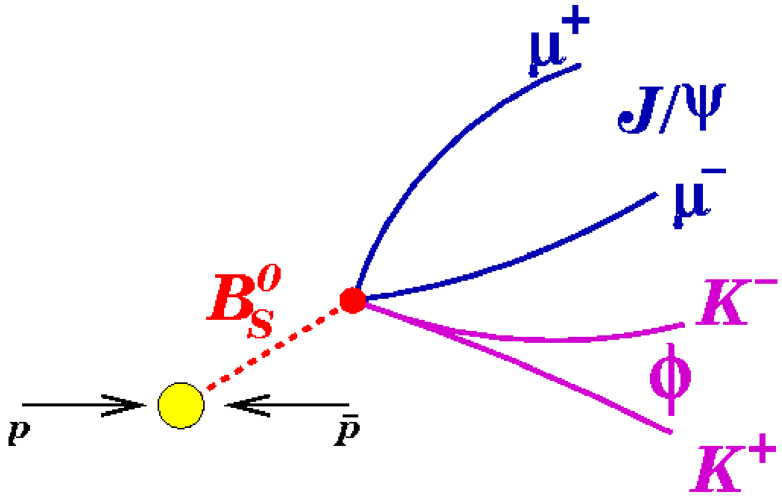
- CP violation phase β_s in SM is predicted to be very small:

$$\beta_s^{\rm SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$$

- New Physics affects the CP violation phase as: $2\beta_s = 2\beta_s^{\rm SM} - \phi_s^{\rm NP}$

- If NP phase $\phi_s^{\rm NP}$ dominates $\to$ $2\beta_s = -\phi_s^{\rm NP}$

$B_s \to J/\Psi\Phi$ Phenomenology



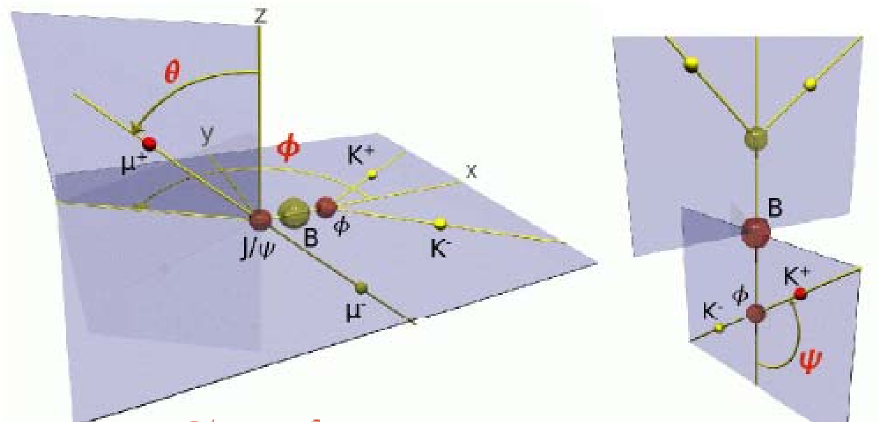
- Extremely physics rich decay mode

- Can measure lifetime, decay width, and, using known Δm_s, CP violating phase β_s

- The decay of B_s (spin 0) to J/Ψ(spin 1) Φ(spin 1) leads to three different angular momentum final states:

L = 0 (s-wave), 2 (d-wave) → CP even $\overset{\Phi_s \approx 0}{\approx} |B_s^L\rangle$

L = 1 (p-wave) → CP odd $\overset{\Phi_s \approx 0}{\approx} |B_s^H\rangle$



J/ψ rest frame

φ rest frame

- three decay angles $\vec{\rho} = (\theta,\phi,\psi)$ describe directions of final decay products

$B_s \rightarrow J/\Psi\Phi$ Phenomenology (2)

- Three angular momentum states form a basis for the final $J/\Psi\Phi$ state

- Use alternative "transversity basis" in which the vector meson polarizations w.r.t. direction of motion are either:

  - longitudinal (0) → CP even
  - transverse (∥ parallel to each other) → CP even

  - transverse (⊥ perpendicular to each other) → CP odd

- Corresponding decay amplitudes: A_0, $A_\parallel$, $A_\perp$

- At good approximation ($\Phi_s \approx 0$), mass eigenstates $|B_s^L\rangle$ and $|B_s^H\rangle$ are CP eigenstates
  → use angular information to separate heavy and light states
  → determine decay width difference
  $$\Delta\Gamma = \Gamma_L - \Gamma_H$$
  → some sensitivity to CP violation phase β_s

- Determine B_s flavor at production (flavor tagging)
  → improve sensitivity to CP violation phase β_s

$B_s \to J/\Psi\Phi$ Phenomenology (3)

- $B_s \to J/\Psi\Phi$ decay rate as function of time, decay angles and initial B_s flavor:

$$\frac{d^4P(t,\vec{\rho})}{dtd\vec{\rho}} \propto |A_0|^2\mathcal{T}_+ f_1(\vec{\rho}) + |A_\parallel|^2\mathcal{T}_+ f_2(\vec{\rho}) + |A_\perp|^2\mathcal{T}_- f_3(\vec{\rho}) + |A_\parallel||A_\perp|\mathcal{U}_+ f_4(\vec{\rho}) + |A_0||A_\parallel|\cos(\delta_\parallel)\mathcal{T}_+ f_5(\vec{\rho}) + |A_0||A_\perp|\mathcal{V}_+ f_6(\vec{\rho}),$$

time dependence terms

angular dependence terms

terms with β_s dependence

$$\mathcal{T}_\pm = e^{-\Gamma t} \times [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2) \mp \eta\sin(2\beta_s)\sin(\Delta m_s t)],$$

terms with Δm_s dependence due to initial state flavor tagging

$$\mathcal{U}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t) - \cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

$$\mathcal{V}_\pm = \pm e^{-\Gamma t} \times [\sin(\delta_\perp)\cos(\Delta m_s t) - \cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t) \pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)].$$

'strong' phases:

$$\delta_\parallel \equiv \arg(A_\parallel^* A_0)$$

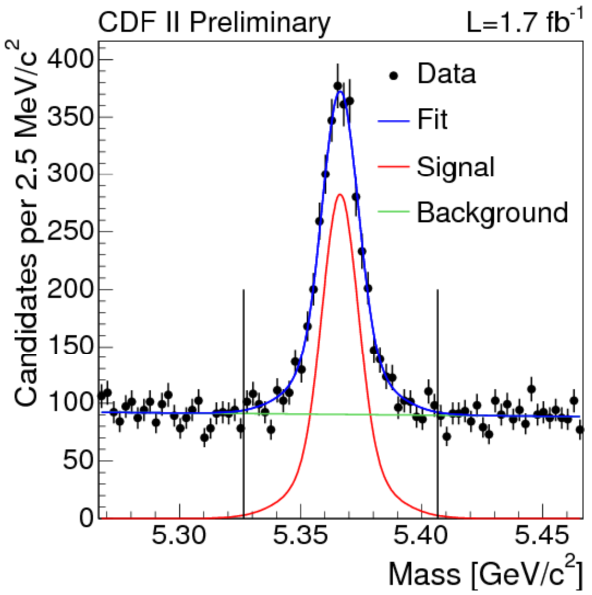
$$\delta_\perp \equiv \arg(A_\perp^* A_0)$$

- Tagging → better sensitivity to β_s

B_s Lifetime in $B_s \rightarrow J/\Psi\Phi$ Decays

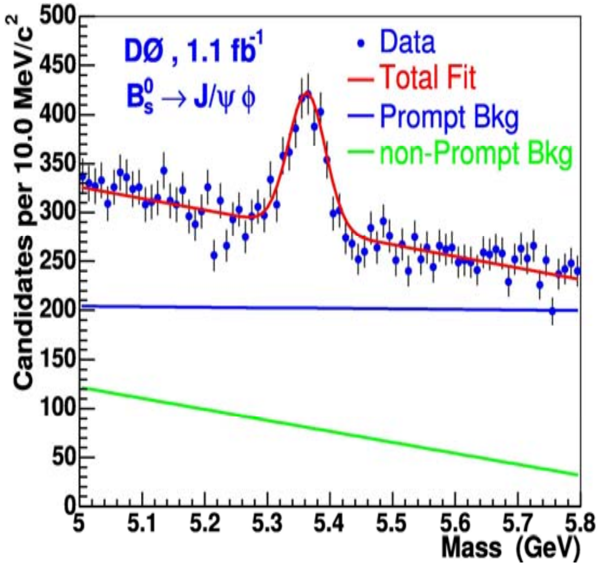
- Most precise B_s lifetime measurements from $B_s \rightarrow J/\Psi\Phi$ decays:
(assuming no CP violation, $\beta_s = 0$)

CDF
~2500 signal events in ~1.7 fb^{-1}



τ_s = 1.52 +/- 0.04 (stat) +/- 0.02 (syst) ps
best measurement

DØ
~1040 signal events in ~1.1 fb^{-1}



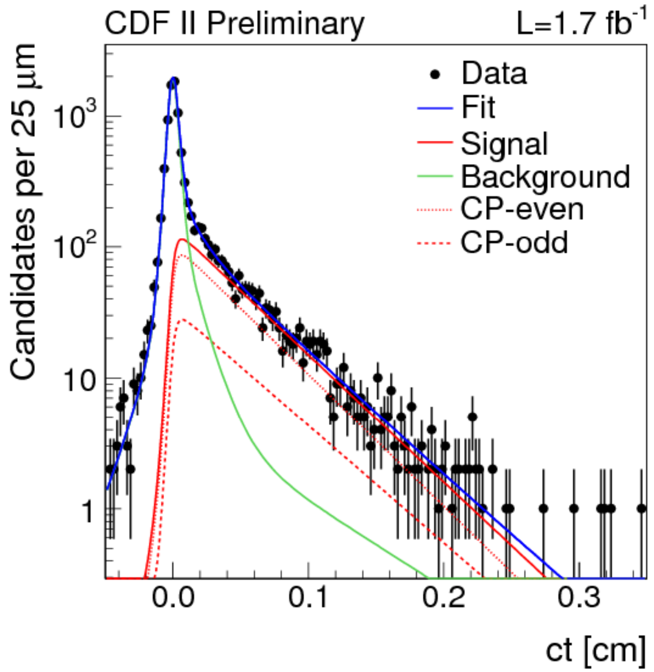
1.52 +/- 0.08(stat) $^{+0.01}_{-0.03}$(syst) ps

arXiv:0712.2348

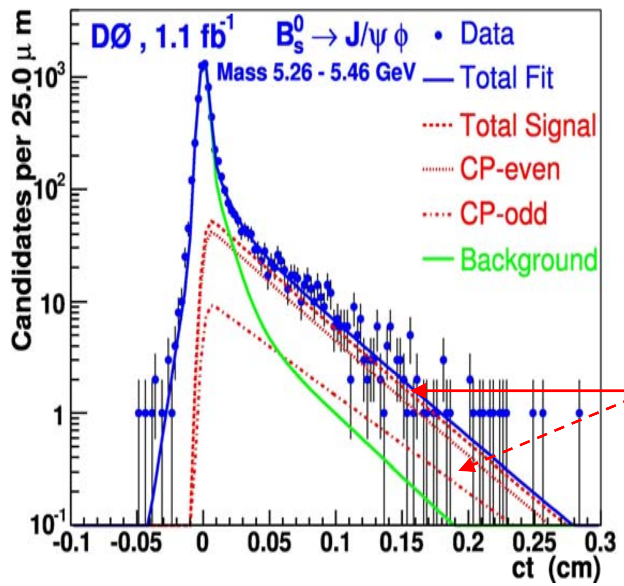
PRL 98, 121801 (2007)

B_s Decay Width

CDF



DØ



CP-even ($\approx B_s^{light}$) and CP-odd ($\approx B_s^{heavy}$) components have different lifetimes $\rightarrow \Delta\Gamma \neq 0$

$\Delta\Gamma$ = 0.08 +/- 0.06 (stat) +/- 0.01 (syst) ps^{-1} $\quad$ 0.12 $^{+0.08}_{-0.10}$ (stat) +/- 0.02 (syst) ps

best measurement

- Cross check: CDF measures decay amplitudes and strong phases in high statistics $B^0 \rightarrow J/\Psi\, K^{*0}$ sample $\rightarrow$ agreement and competitive with B factories

arXiv:0712.2348
http://www-cdf.fnal.gov/physics/new/bottom/070809.blessed-DG-BsPsiPhi/public_note_BsBd.pdf

PRL 98, 121801 (2007)

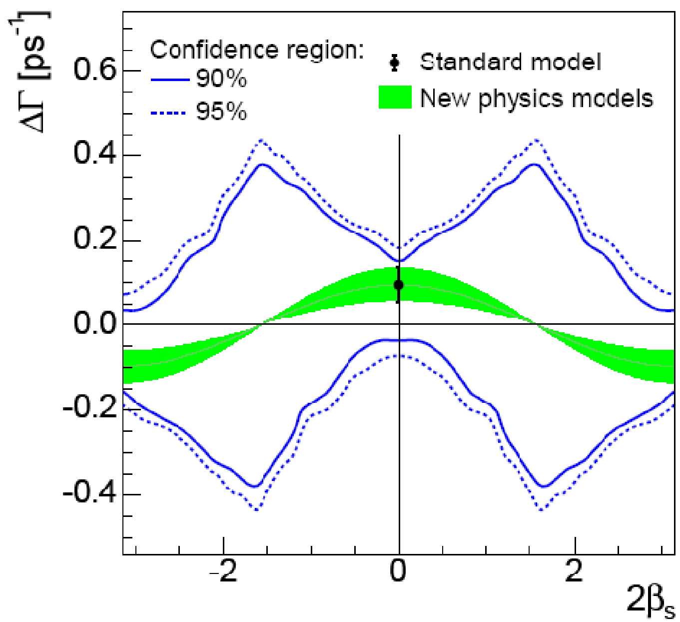
CP Violation Phase β_s in Un-tagged $B_s \rightarrow J/\Psi\Phi$ Decays

- Without identification of the initial B_s flavor still have sensitivity to β_s

- Due to irregular likelihood and biases in fit, CDF only quotes Feldman-Cousins confidence regions (Standard Model probability 22%)
- DØ quotes point estimate: $\Phi_s = -0.79 \pm 0.56\ (\text{stat})\ ^{+0.14}_{-0.01}\ (\text{syst})$

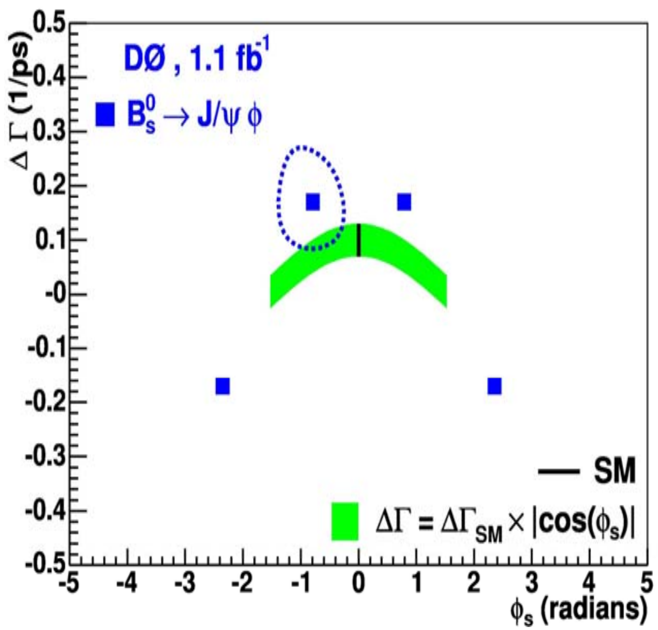
- Symmetries in the likelihood → 4 solutions are possible in $2\beta_s$-$\Delta\Gamma$ plane

CDF: 90%, 95% C.L



arXiv:0712.2348

DØ: 39% C.L.



PRL 98, 121801 (2007)

CP Violation Phase β_s in Tagged $B_s \rightarrow J/\Psi\Phi$ Decays

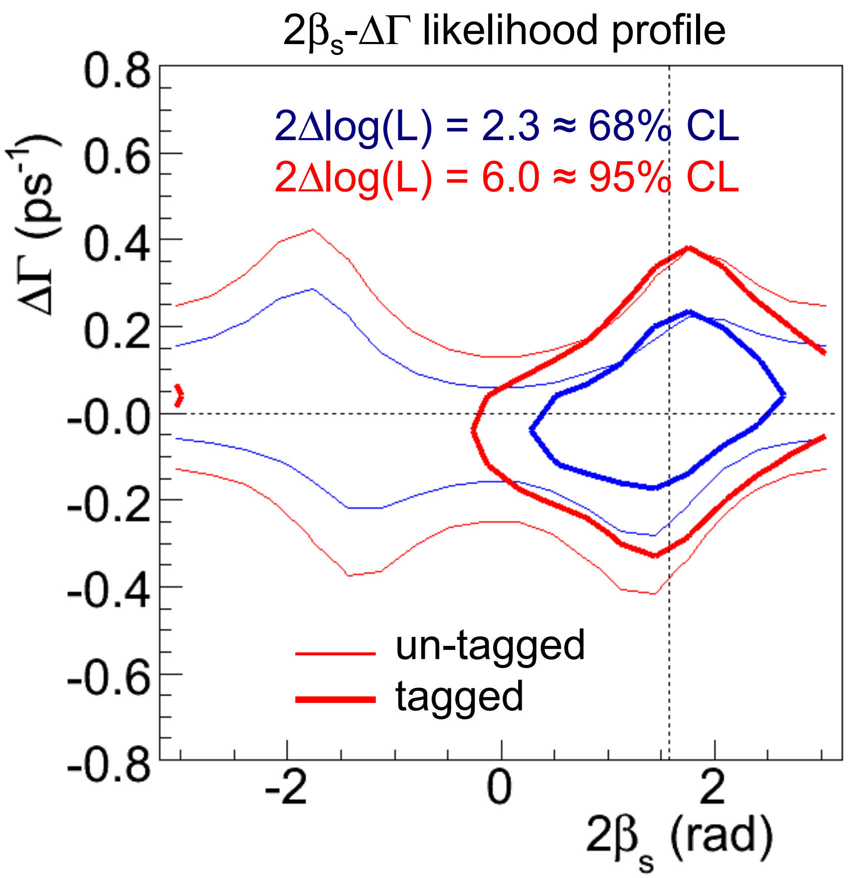
- Likelihood expression predicts better sensitivity to β_s but still double minima due to symmetry:

$$2\beta_s \rightarrow \pi - 2\beta_s$$
$$\Delta\Gamma \rightarrow -\Delta\Gamma$$
$$\delta_{\parallel} \rightarrow 2\pi - \delta_{\parallel}$$
$$\delta_{\perp} \rightarrow \pi - \delta_{\perp}$$

- Study expected effect of tagging using pseudo-experiments

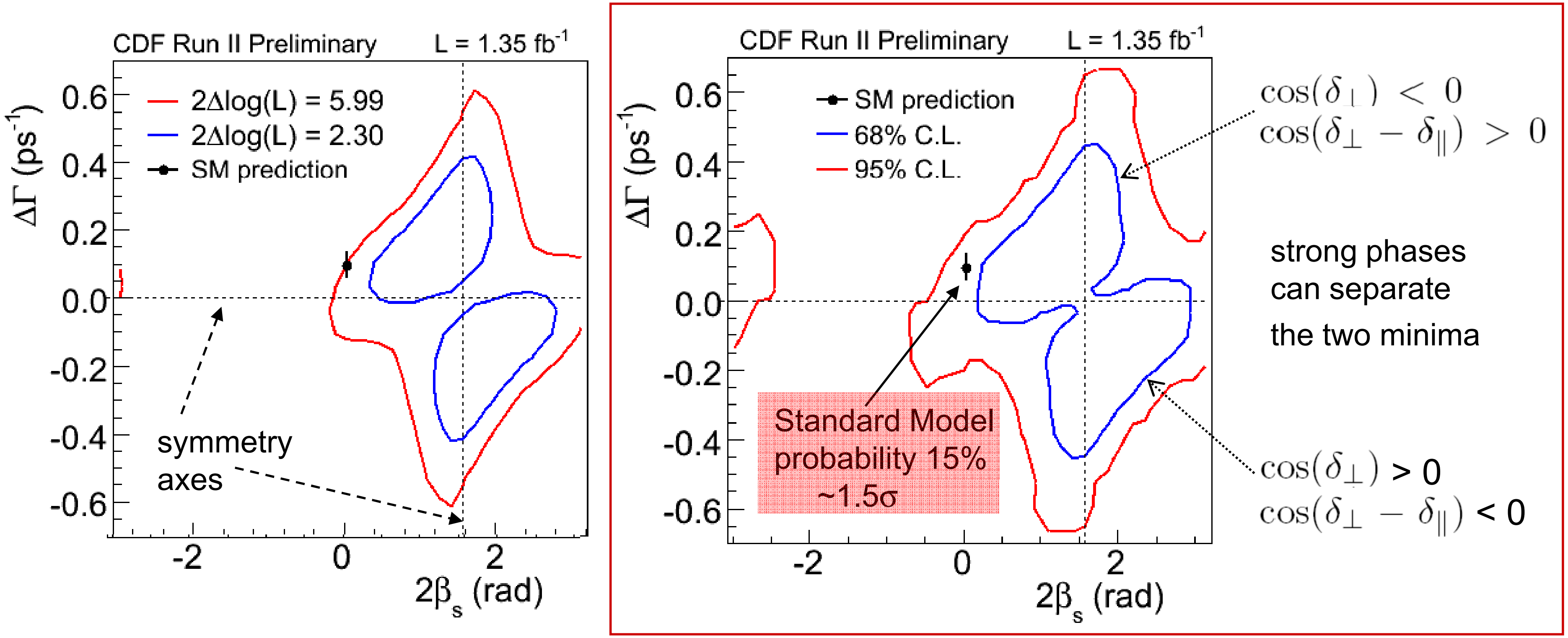
- Improvement of parameter resolution is small due to limited tagging power ($\varepsilon D^2 \sim 4.5\%$ compared to B factories ~30%)

- However, $\beta_s \rightarrow -\beta_s$ no longer a symmetry
  → 4-fold ambiguity reduced to 2-fold ambiguity
  → allowed region for β_s is reduced to half



CP Violation Phase β_s in Tagged $B_s \rightarrow J/\Psi\Phi$ Decays (CDF, 1.4 fb-1)

- First tagged analysis of $B_s \rightarrow J/\Psi\Phi$ (1.4 fb^{-1}) **arXiv:0712.2397**
- Signal B_s yield ~2000 events with S/B ~ 1
- As in un-tagged analysis, irregular likelihood does not allow quoting point estimate
- Quote Feldman-Cousins confidence regions

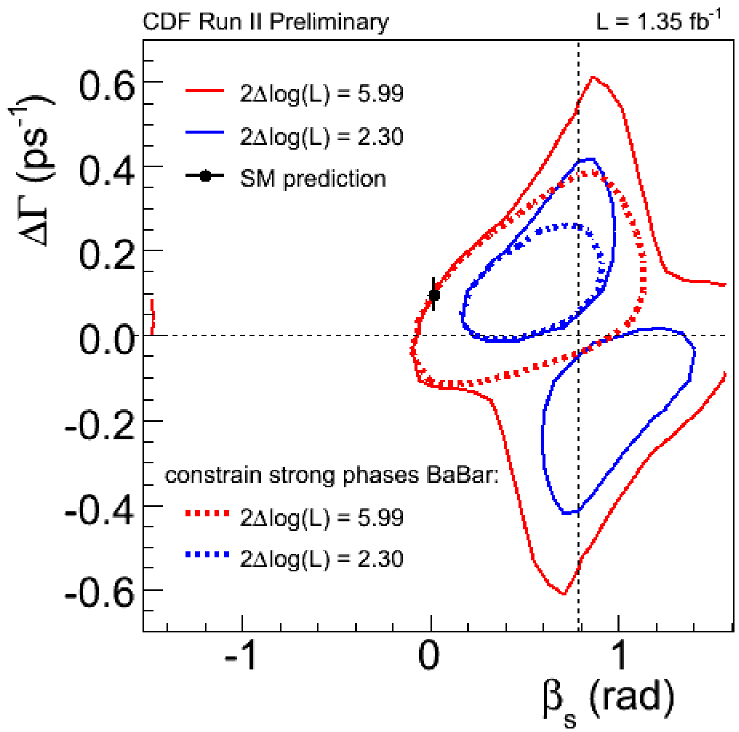


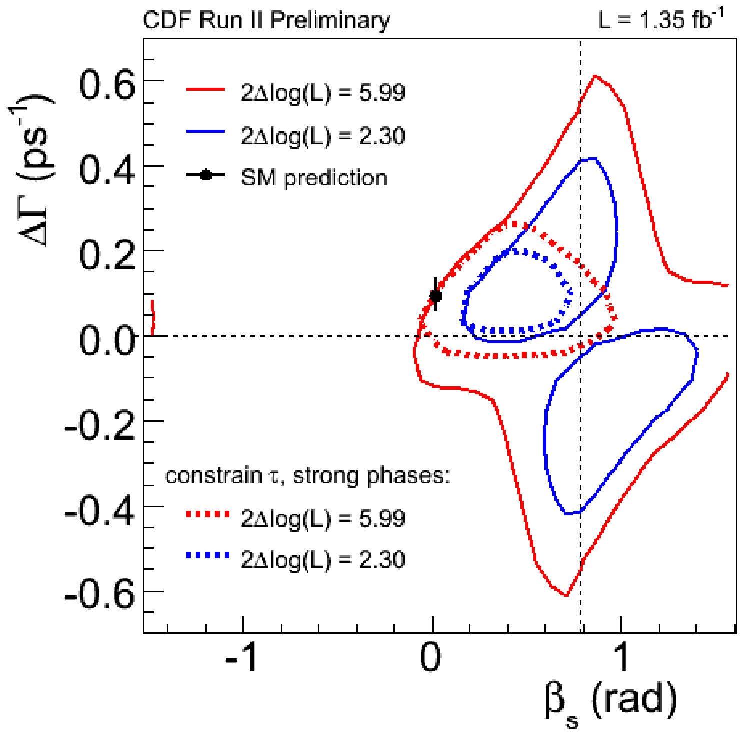
- Confidence regions are underestimated when using 2ΔlogL = 2.3 (6.0) to approximate 68% (95%) C.L. regions

β_s in Tagged $B_s \rightarrow J/\Psi\Phi$ Decays with External Constraints (CDF)

- Spectator model of B mesons suggests that B_s and B^0 have similar lifetimes and strong phases
- Likelihood profiles with external constraints from B factories:

constrain strong phases: constrain lifetime and strong phases:

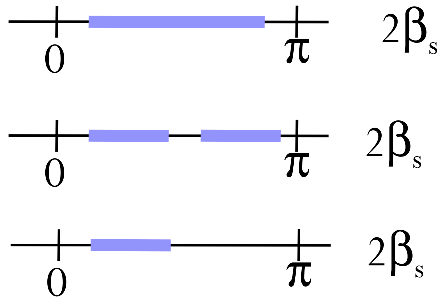




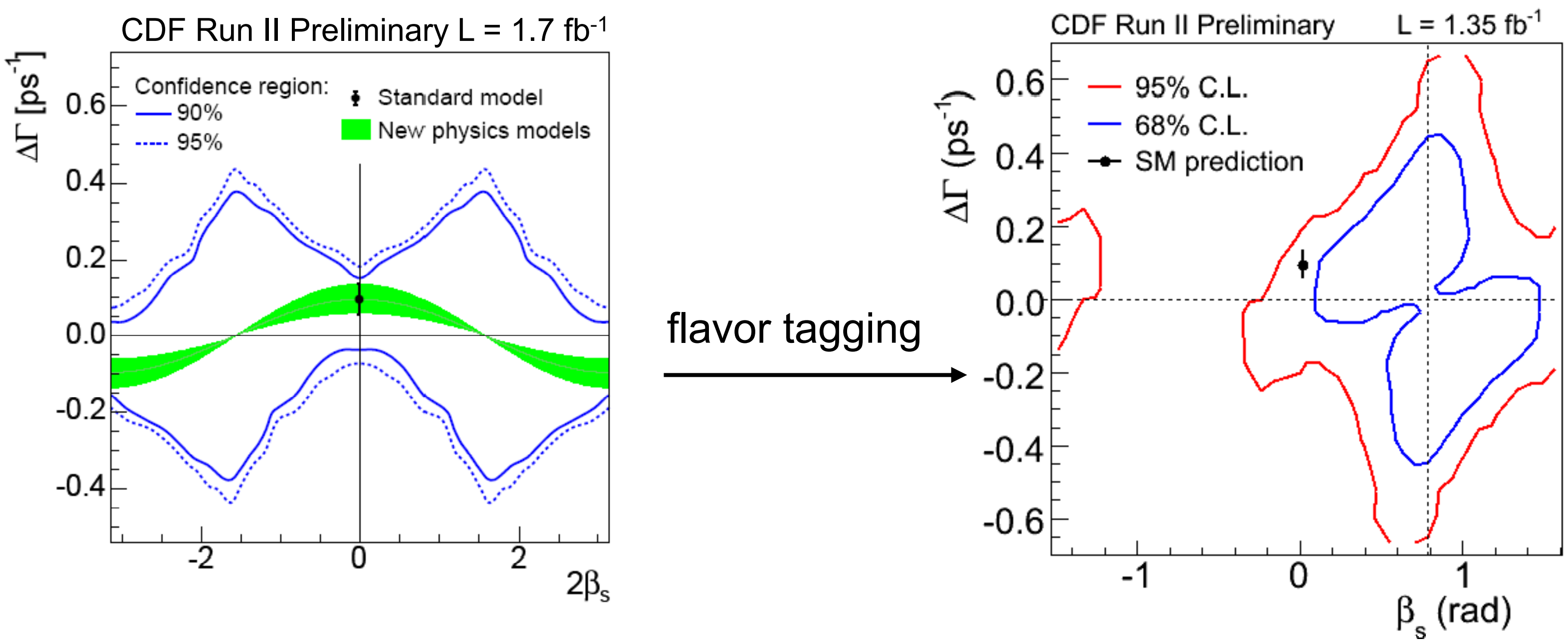
- External constraints on strong phases remove residual 2-fold ambiguity

β_s in Tagged $B_s \rightarrow J/\Psi\Phi$ Decays Final Results (CDF)

- 1D Feldman-Cousins procedure without external constraints:
  $2\beta_s$ in [0.32, 2.82] at the 68% C.L.
- with theoretical input $\Delta\Gamma$ = 0.096+/- 0.039
  $2\beta_s$ in [0.24, 1.36] U [1.78, 2.90] at 68% C.L.
- with external constraints on strong phases, lifetime and $\Delta\Gamma$
  $2\beta_s$ in [0.40, 1.20] at 68% C.L.



- β_s parameter space is greatly reduced when using flavor tagging:



arXiv:0712.2348

arXiv:0712.2397

- DØ results on β_s using flavor tagging expected soon

Charge Asymmetry in Semileptonic $B_s \to \mu D_s X$ Decays (DØ, 1.3 fb-1)

- Study $B_s^0 \to \mu^+ D_s^- \nu X$ with $D_s^- \to \phi\pi^-$ $\phi \to K^+K^-$ RL 98, 151801 (2007)
- L = 1.3 fb^{-1} with total signal yield ~27K events
- Compare decay rates of B_s and $\overline{B}_s$:

$$A_{SL}^{s,unt} = \frac{N(\mu^+ D_s^-) - N(\mu^- D_s^+)}{N(\mu^+ D_s^-) + N(\mu^- D_s^+)} = [1.23 \pm 0.97\,(\mathrm{stat}) \pm 0.17\,(\mathrm{syst})] \times 10^{-2}$$

- Suppressed systematic uncertainties due to regular change of magnet polarity at DØ
- Semileptonic charge asymmetry is related to $\phi_s^{\mathrm{SM}} = \arg(-M_{12}/\Gamma_{12})$

$$A_{SL}^{s,unt} = \frac{1}{2}\frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s$$

- In SM Φ_s is predicted to be very small (≈ $4\mathrm{x}10^{-3}$)
- NP can significantly modify SM prediction $\phi_s = \phi_s^{\mathrm{SM}} + \phi_s^{\mathrm{NP}}$

- If ϕ_s^{NP} dominates $2\beta_s = -\phi_s^{\mathrm{NP}} = -\phi_s$

- Can combine this result with β_s measurement in $B_s \to J/\Psi\Phi$ to constrain NP

Charge Asymmetry in Inclusive B_s Decays (DØ, CDF)

- Measure same sign muon charge asymmetry at DØ with 1 fb-1:

$$A = \frac{N^{++} - N^{--}}{N^{++} + N^{--}} = \frac{1}{4f}\left[A_{B^0} + \frac{f_s \chi_{s0}}{f_d \chi_{d0}} A_{B_s^0}\right]$$

$$f \cdot A \; = \; -0.0023 \pm 0.0011 \text{ (stat)} \pm 0.0008 \text{ (syst)}$$

- With knowledge of fragmentation fractions f_s and f_d, the integrated oscillation probabilities χ_d and χ_s and known B^0 semileptonic asymmetry from B factories:

A_s = -0.0064 +/- 0.0101 (stat+syst) **PRD 74, 092001 (2006)**

- Similar measurement at CDF with 1.6 fb-1:

A_s = 0.020 ± 0.021 (stat) ± 0.016 (syst) ± 0.009 (inputs)

http://www-cdf.fnal.gov/physics/new/bottom/070816.blessed-acp-bsemil/

- These measurements can be combined with asymmetries in $B_s \to \mu D_s X$ to further constrain CP violation phase

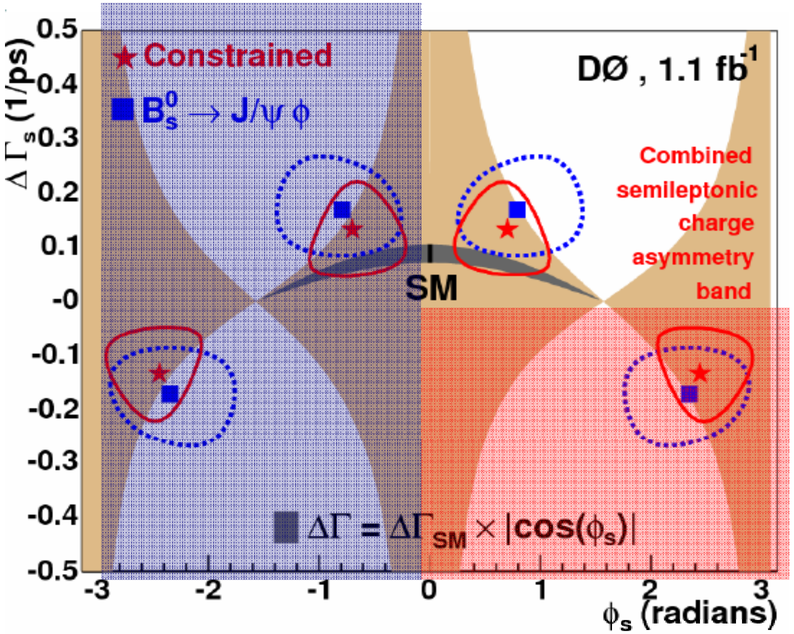
Combined DØ Constraints on $\Delta\Gamma$ and Φ_s

Phys. Rev. D 76 , 057101 (2007)

- Combine width difference and CP violation phase from time dependent angular analysis $B_s \to J/\Psi\Phi$ with measurements from charge asymmetry in semileptonic decays
- Contours indicate 39% C.L. regions:

- Final combined DØ results with ~1 fb^{-1} :

$$\Delta\Gamma_s = 0.13 \pm 0.09 \text{ ps}^{-1}$$
$$\phi_s = -0.70^{+0.47}_{-0.39}.$$



- From tagged $B_s \to J/\Psi\Phi$ analysis, CDF excludes ~half available space in Φ_s-$\Delta\Gamma$ plane (two LHS solutions)

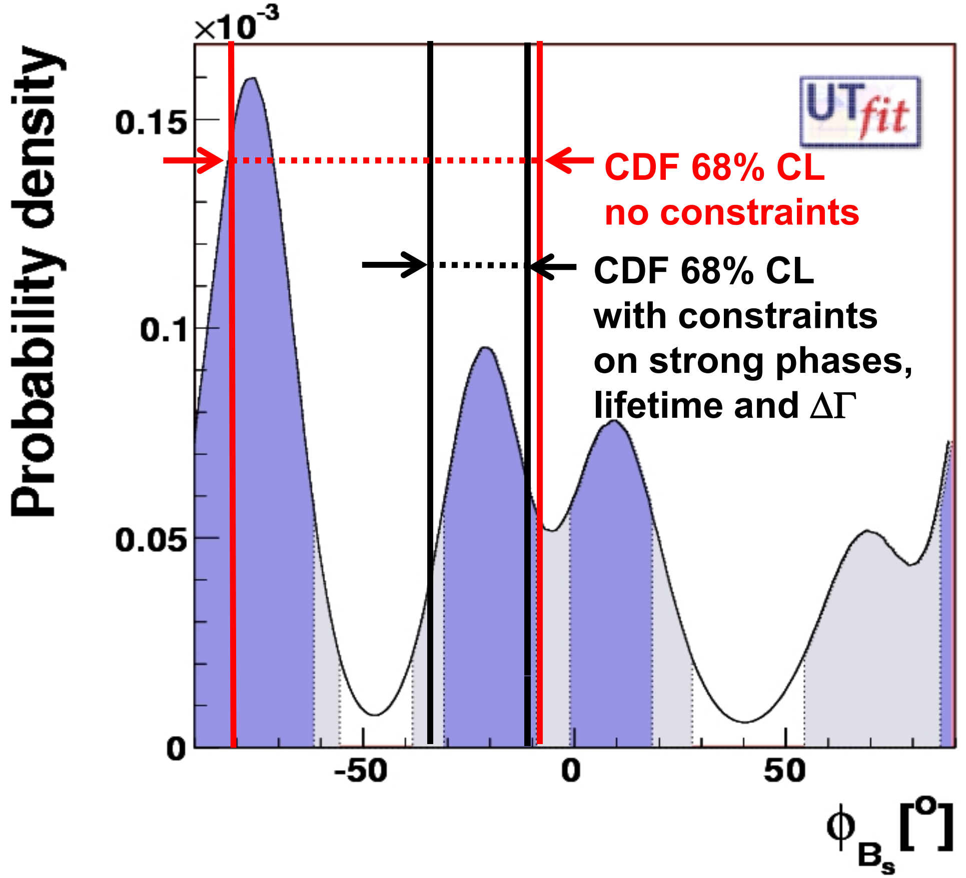
- Assuming same lifetime and strong phases for B^0 and B_s, CDF constrains strong phases to B factories measurements → bottom – right solution is suppressed as well

- Expect tagged $B_s \to J/\Psi\Phi$ analysis from DØ soon
- Expect updated analyses with 2x data from both experiments soon

CDF Impact on Φ_s World Average

- Overlay CDF result on UT world average which includes DØ combined result

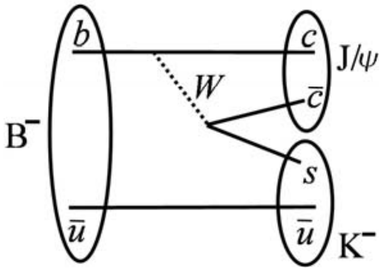
http://www.utfit.org/

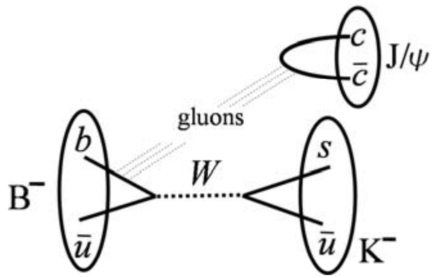


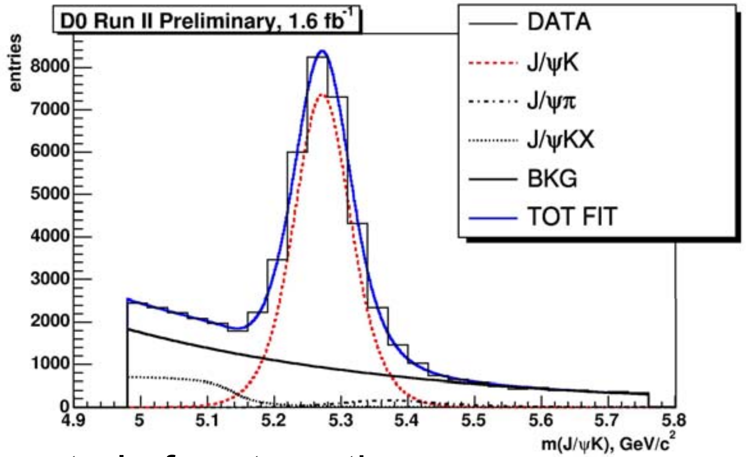
- CDF measurement suppresses large fraction of CP violation parameter space !

Direct CP Violation in $B^+ \rightarrow J/\Psi K^+$ Decays (DØ, 1.6 fb^{-1})

- SM predicts small (~1%) direct CP violation in $B^+ \rightarrow J/\Psi K^+$
- Due to interference between direct and annihilation amplitudes







- Signal yield ~28K $B^+ \rightarrow J/\Psi K^+$ decays
- DØ reverses magnet polarities frequently → good control of systematic uncertainties in charge asymmetry measurements
- Correct for K^+/K^- asymmetry

$$A = \frac{N(B^- \to J/\psi K^-) - N(B^+ \to J/\psi K^+)}{N(B^- \to J/\psi K^-) + N(B^+ \to J/\psi K^+)} = +0.0067 \pm 0.0074(stat) \pm 0.0026(syst)$$

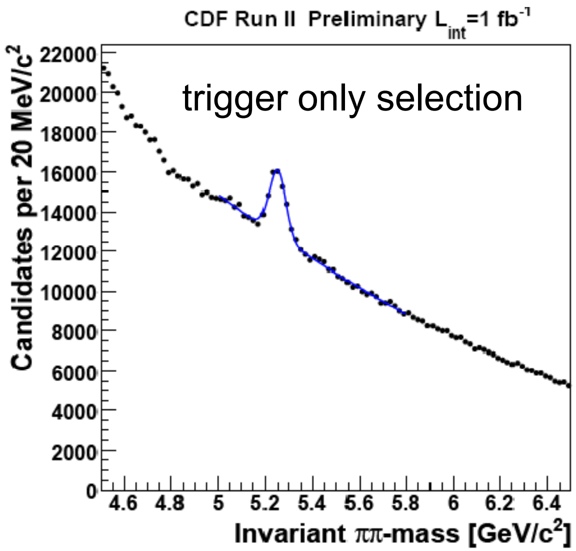
- Consistent with world average: $A_{CP}(B^+ \to J/\psi K^+) = +0.015 \pm 0.017$

but factor of two better precision → best measurement

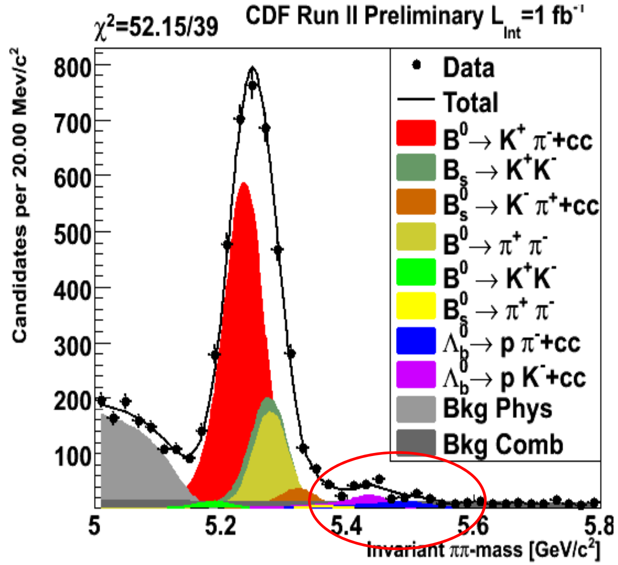
http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B49/B49.pdf

Branching Fractions and CP Asymmetry in $\Lambda_b \rightarrow p\,\pi(K)$ (CDF, 1 fb^{-1})

- First study of CP asymmetry in b baryon decays (SM prediction ~10%)
- Use large sample collected by two displaced track trigger



offline selection →



- Different states that contribute to $\pi^+\pi^-$ invariant mass are not separated in mass
- Use additional kinematic and dE/dx information to achieve better statistical separation

http://www-cdf.fnal.gov/physics/new/bottom/071018.blessed-ACP_Lambdab_ph/

Branching Fractions and CP Asymmetry in $\Lambda_b \to p\,\pi(K)$ (CDF, 1 fb^{-1})

-Results:

$$A_{CP}(\Lambda_b^0 \to p\pi^-) = \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}\pi^+)}{\mathcal{B}(\Lambda_b^0 \to p\pi^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}\pi^+)} = 0.03 \pm 0.17\ (stat.) \pm 0.05\ (syst.)$$

$$A_{CP}(\Lambda_b^0 \to pK^-) = \frac{\mathcal{B}(\Lambda_b^0 \to pK^-) - \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}K^+)}{\mathcal{B}(\Lambda_b^0 \to pK^-) + \mathcal{B}(\overline{\Lambda}_b^0 \to \bar{p}K^+)} = 0.37 \pm 0.17\ (stat.) \pm 0.03\ (syst.)$$

- First CP asymmetry measurement in b baryon decays

- Additionally, first measurement of branching fraction relative to $B^0 \to K\pi$ decays:

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV}/c)}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV}/c)} \frac{\mathcal{B}(\Lambda_b^0 \to p\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0415 \pm 0.0074\ (stat.) \pm 0.0058\ (syst.)$$

$$\frac{\sigma(p\bar{p} \to \Lambda_b^0 X, p_T > 6\ \mathrm{GeV}/c)}{\sigma(p\bar{p} \to B^0 X, p_T > 6\ \mathrm{GeV}/c)} \frac{\mathcal{B}(\Lambda_b^0 \to pK^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.0663 \pm 0.0089\ (stat.) \pm 0.0084\ (syst.)$$

http://www-cdf.fnal.gov/physics/new/bottom/071018.blessed-ACP_Lambdab_ph/

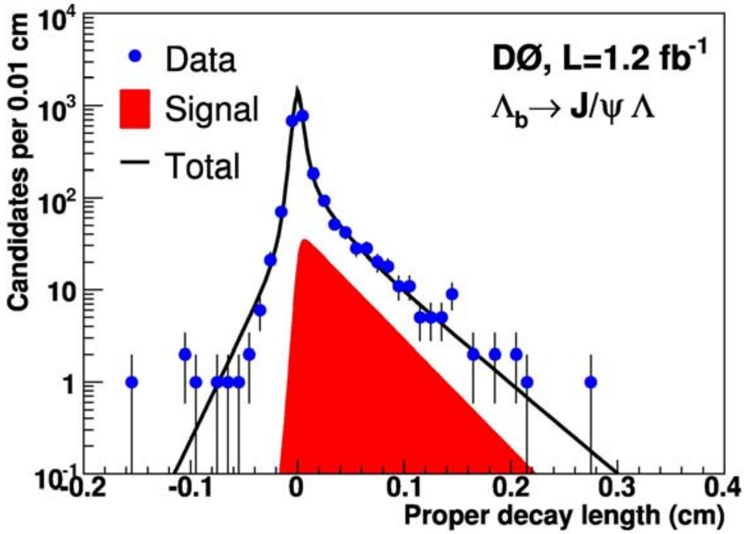
Λ_b Lifetime (DØ, 1.3 fb^{-1})

PRL 99, 142001 (2007), PRL 99, 182001 (2007)

- Important test of models that describe interactions between heavy and light quarks within bound states
- HQET + Lattice QCD predicts: $\tau(\Lambda_b)/\tau(B^0) = 0.88 \pm 0.05$ Tarantino, Eur.Phys.J. C33(2004)
- DØ measures Λ_b lifetime in two decay modes:

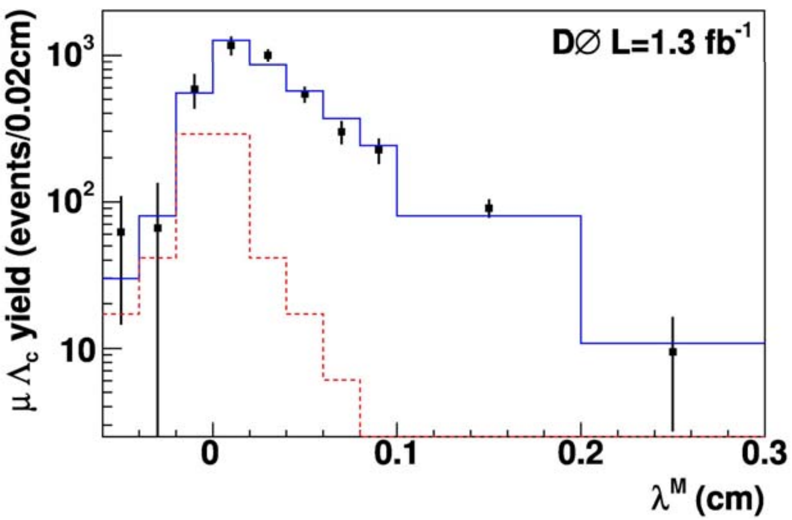
$\Lambda_b \to J/\psi\ \Lambda$

1.2 fb^{-1}, ~170 signal events



$\Lambda_b^0 \to \mu\bar{\nu}\Lambda_c^+ X$

1.3 fb^{-1}, ~4400 signal events



$$\tau(\Lambda_b) = 1.218^{+0.130}_{-0.115}(\text{stat}) \pm 0.042(\text{syst})\ \text{ps} \qquad \tau(\Lambda_b^0) = 1.290\ ^{+0.119}_{-0.110}\ (\text{stat})\ ^{+0.087}_{-0.091}\ (\text{syst})$$

$$\frac{\tau(\Lambda_b)}{\tau(B^0)} = 0.811^{+0.096}_{-0.087}\ (\text{stat}) \pm 0.034\ (\text{syst})$$

Λ_b Lifetime Current Status

- DØ measurements are in agreement with the theoretical predictions and with the world average $\tau(\Lambda_b^0) = 1.230 \pm 0.074$ ps.

- CDF measurement in $\Lambda_b \to J/\psi\ \Lambda$ is ~3σ high w.r.t world average

  arXiv:hep-ex/0609021v1

- Expect CDF measurement in hadronic mode soon

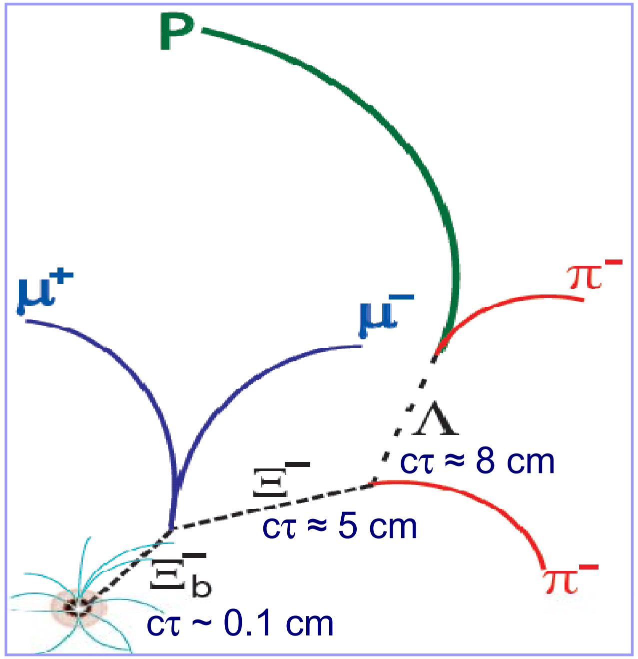
decay mode	CDF lifetime (ps), 1 fb-1	DØ lifetime (ps), 1.3 fb-1
$\Lambda_b \to J/\psi\ \Lambda$	$1.593\ ^{+0.083}_{-0.078}$ (stat.) $\pm\ 0.033$ (syst.)	$1.218^{+0.130}_{-0.115}$(stat) $\pm\ 0.042$(syst) ps
$\Lambda_b^0 \to \mu\bar{\nu}\Lambda_c^+ X$	x	$1.290\ ^{+0.119}_{-0.110}$ (stat) $^{+0.087}_{-0.091}$ (syst)
$\Lambda_b^0 \to \Lambda_c^+\pi^-$	expected soon	x

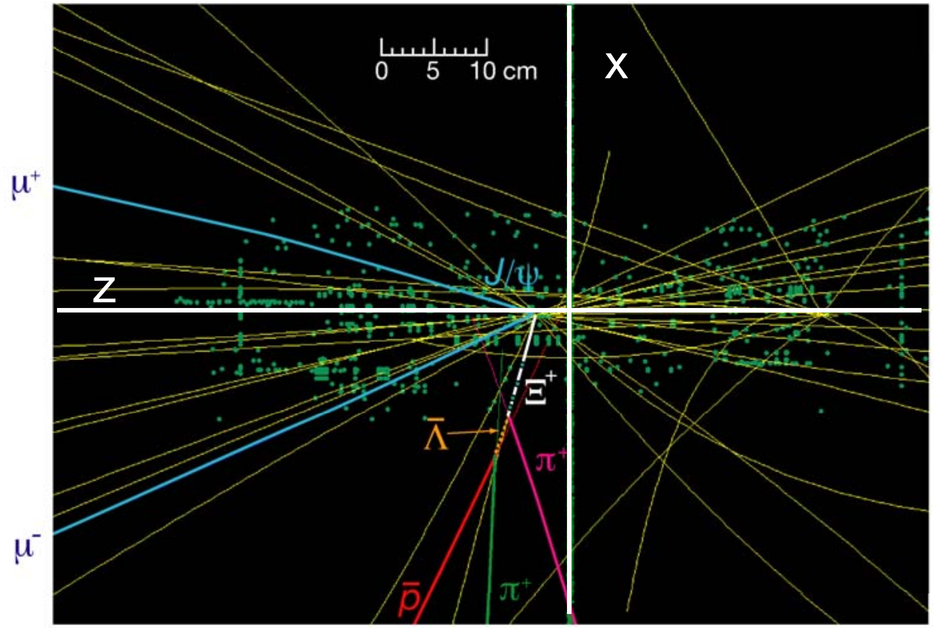
Ξ_b Baryons (DØ, 1.3 fb^{-1})

Phys. Rev. Lett. 99 , 1052001 (2007)

- Ξ_b (quark content: *bds*) → third observed b baryon after Λ_b and CDF's recent discovery of Σ_b
- Study b baryons → great way to test QCD which predicts $M(\Lambda_b) < M(\Xi_b) < M(\Sigma_b)$
- Predicted mass: 5805.7 ± 8.1 MeV
- Discovery decay mode at DØ:

$$\Xi_b^- \to J/\psi\,\Xi^-, \text{ with } J/\psi \to \mu^+\mu^-, \text{ and } \Xi^- \to \Lambda\pi^- \to p\pi^-\pi^-$$





Run 179200, Event 55278820, $M(\Xi_b)$ = 5.788 GeV

Ξ_b Mass Measurement (DØ, 1.3 fb^{-1})

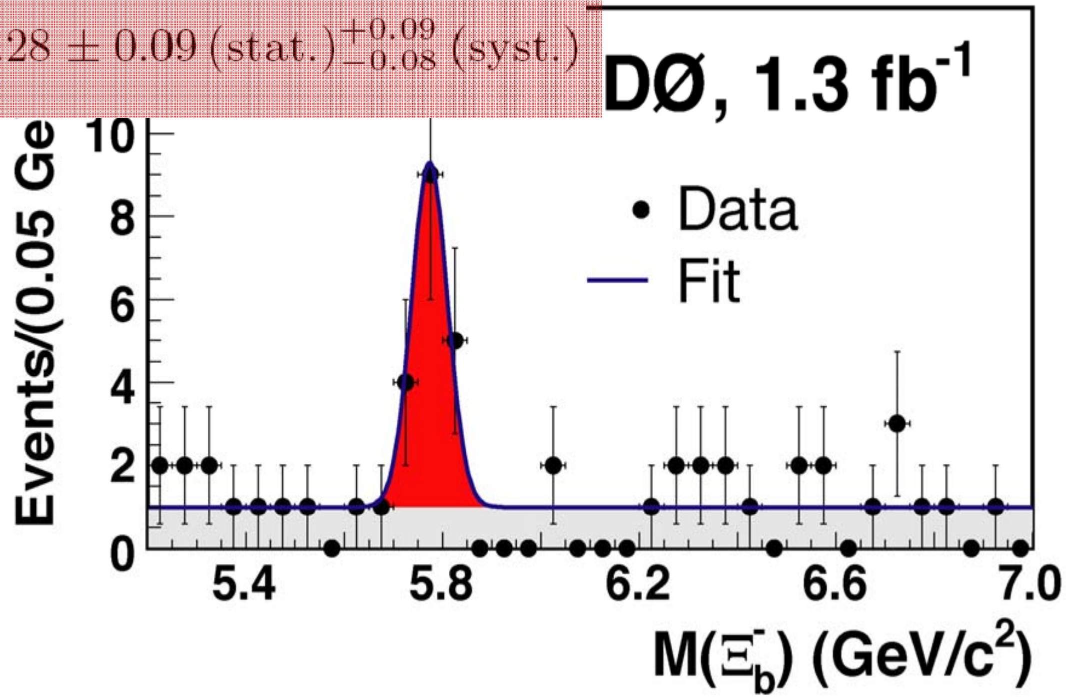
- Clear excess in Ξ_b invariant mass distribution
- Significance ~5.5σ

Number of signal events: 15.2 ± 4.4(stat) $^{+1.9}_{-0.4}$ (syst)
Mass: 5.774 ± 0.011(stat) ± 0.015(syst) GeV (prediction 5805.7 ± 8.1 MeV)

- Width: 0.037 ± 0.008 GeV in good agreement with MC expectation 0.035 GeV
- Production relative to $\Lambda_b \rightarrow J/\Psi\ \Lambda$

$$\frac{f(b \to \Xi_b^-) \cdot Br(\Xi_b^- \to J/\psi\, \Xi^-)}{f(b \to \Lambda_b) \cdot Br(\Lambda_b \to J/\psi\, \Lambda)} = 0.28 \pm 0.09\,(\text{stat.})^{+0.09}_{-0.08}\,(\text{syst.})$$

where f(b→X) : fraction of times b quark hadronizes to X

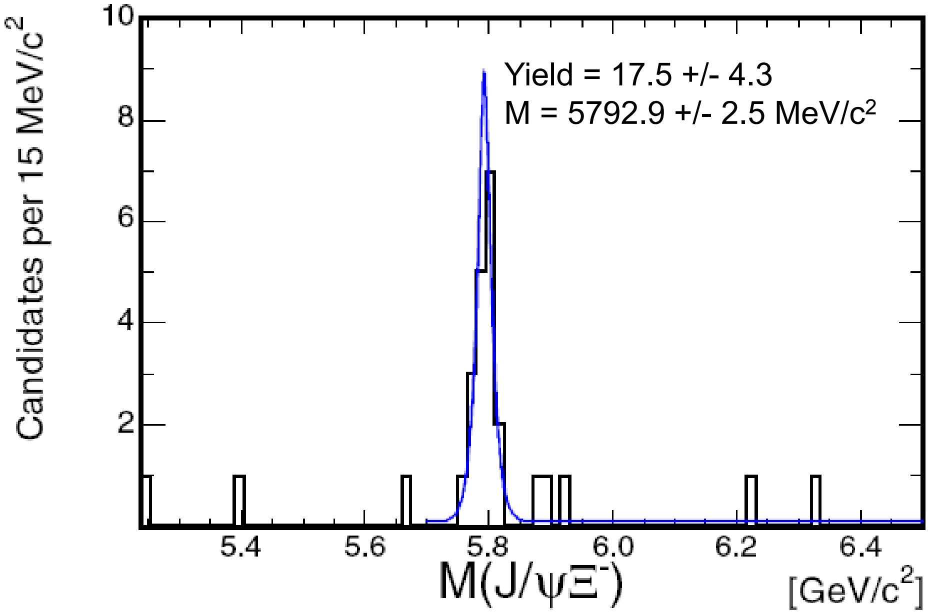


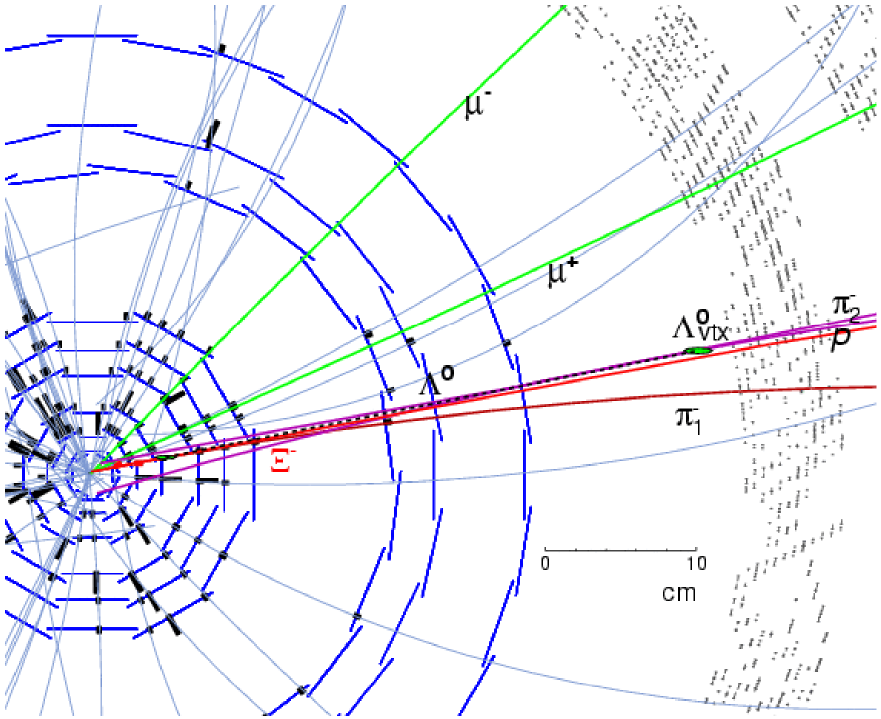
Phys. Rev. Lett. 99 , 1052001 (2007)

Ξ_b Mass Measurement (CDF, 1.9 fb^{-1})

Phys. Rev. Lett. 99, 052002 (2007)

- Ξ tracked in silicon vertex detector for the first time at hadron collider
  - → reduce background
  - → improve secondary vertex precision



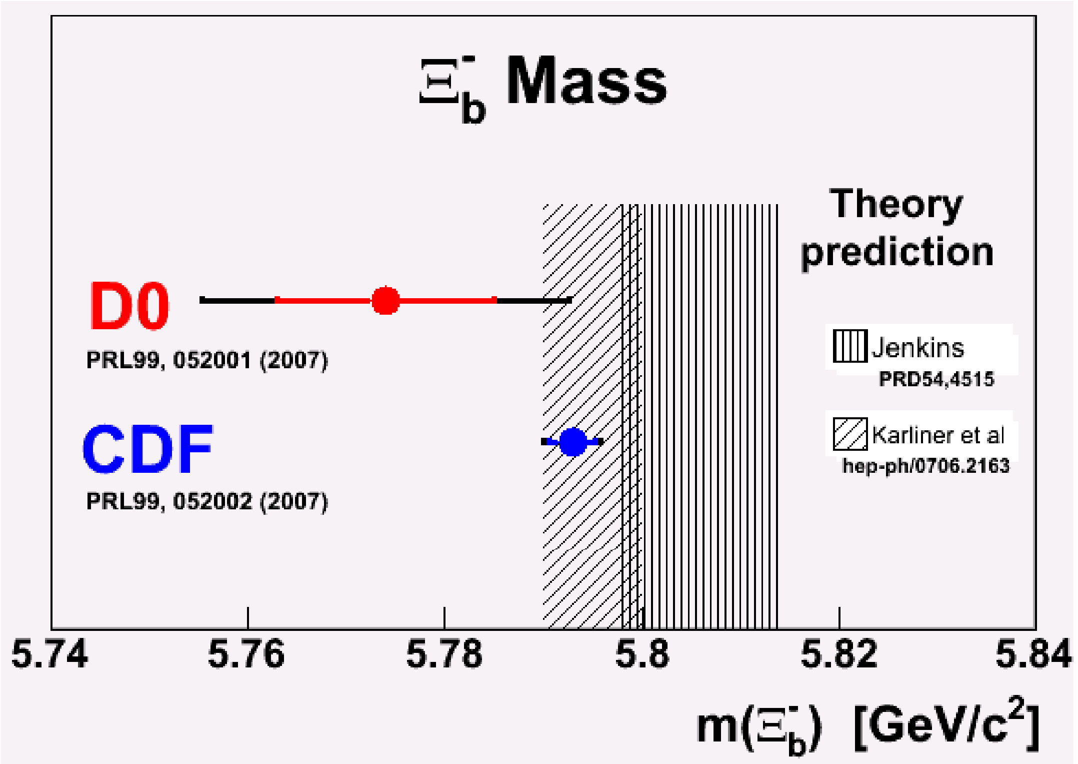


$$M(\Xi_b^-) = (5,792.9 \pm 2.4(stat.) \pm 1.7(syst.))\ \mathrm{MeV}/c^2$$

most precise measurement at 7.8σ significance

Ξ_b Current Status

Phys. Rev. Lett. 99 , 1052001 (2007), Phys. Rev. Lett. 99, 052002 (2007)



- Ξ_b can be measured in hadronic decays at CDF
- With more data will study other properties of Ξ_b

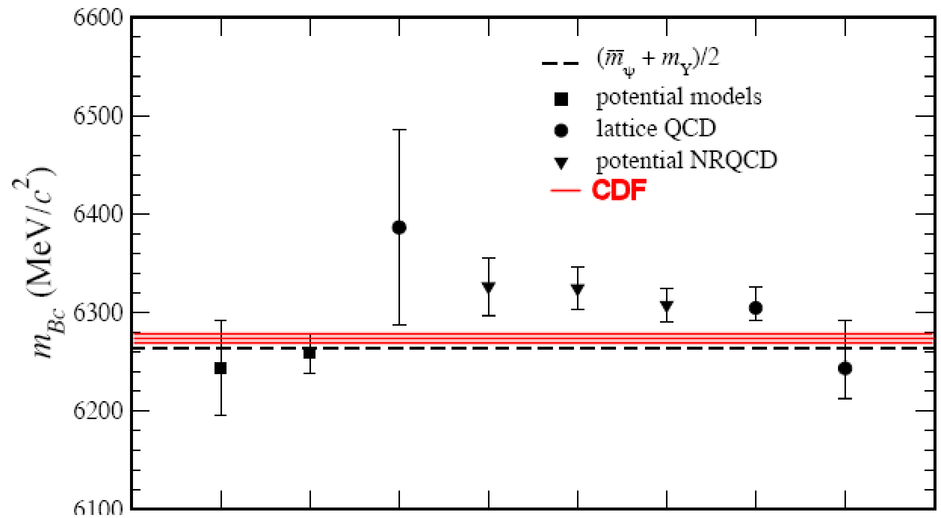
B_c Mass in $B_c \to J/\Psi\pi$ (CDF, 2.4 fb^{-1})

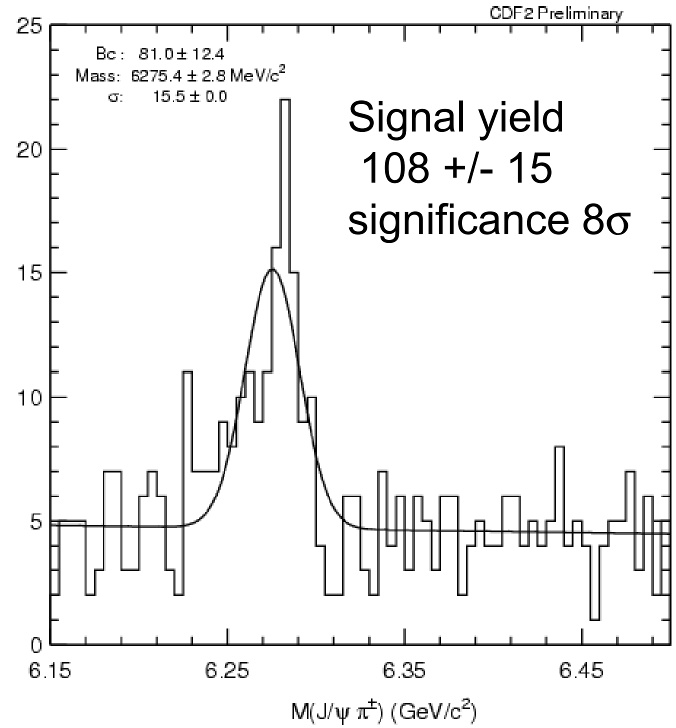
arXiv:0712.1506

- B_c contains both heavy quarks b, c → each quark can decay
- Mass predictions:
  - NR potential models 6247 - 6286 MeV
  - lattice QCD 6304 +/- 12 $^{+18}_{-0}$ MeV
- Three decay possibilities:
  - c quark decays: $B_c^+ \to B_s^0\pi^+$, and $B_c^+ \to B_s^0\ell^+\nu$
  - b quark decays: $B_c^+ \to J/\psi\pi^+$; $B_c^+ \to J/\psi D_s^+$; $B_c^+ \to J/\psi\ell^+\nu$
  - annihilation: $B_c^+ \to \ell^+\nu$.

- Best mass measurement:

$$6275.6 \pm 2.9\,(\text{stat.}) \pm 2.5\,(\text{syst.})\ \text{MeV}/c^2$$





B_c Lifetime in $B_c \to J/\Psi\mu X$ (DØ, 1.4 fb^{-1})

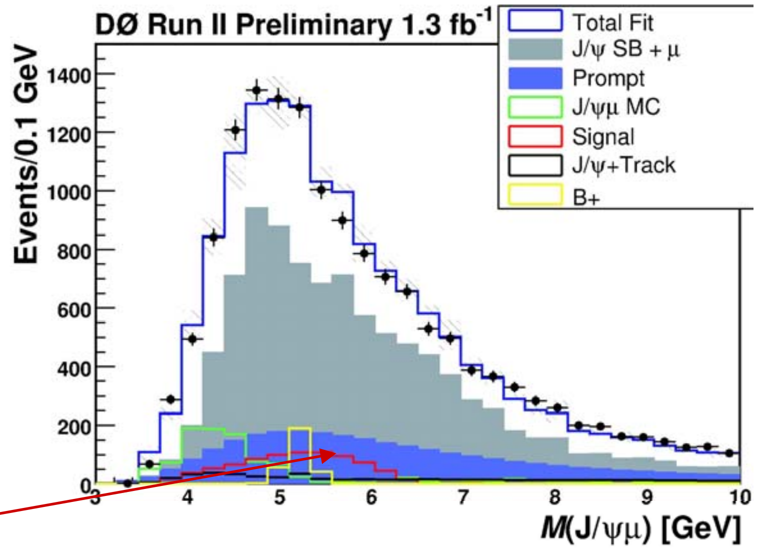
- Lifetime expected ~1/3 of other B mesons
- Main challenge in partially reconstructed mode $B_c^+ \to J/\psi \ell^+ \nu$ is understanding multiple backgrounds:
  - real J/Ψ + fake muon
  - fake J/Ψ + real muon
  - real J/Ψ + real muon → from bb events
  - $B^+ \to J/\psi K^+$ where K → μνν
  - prompt J/Ψ + μ

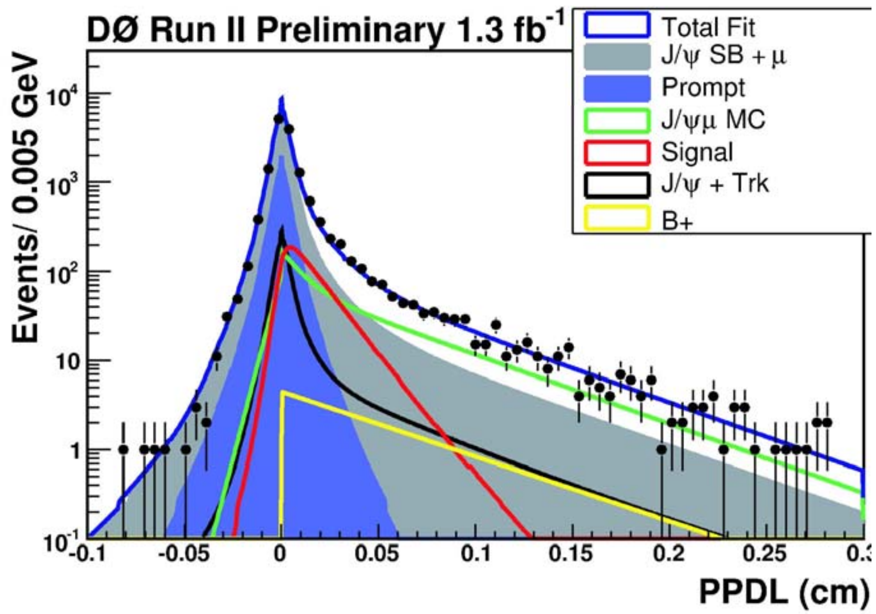
- Mass – lifetime simultaneous fit used to disentangle small signal fraction among large fraction of backgrounds

- Most precise B_c lifetime measurement:

$$\tau(B_c^{\pm}) = 0.444^{+0.039}_{-0.036}\,(\mathrm{stat})^{-0.039}_{-0.034}\,(\mathrm{sys})\,\mathrm{ps}.$$

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B52/



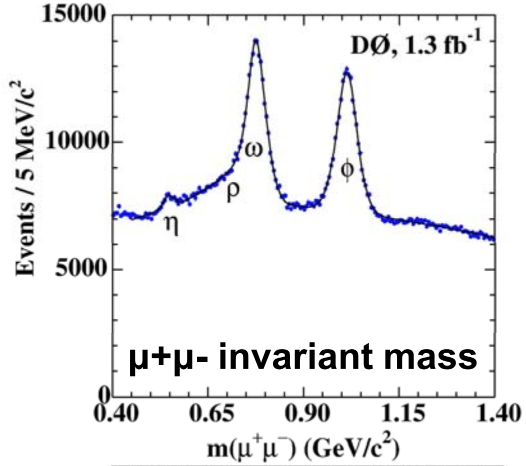


Rare Decays (DØ)

- In SM FCNC processes are forbidden at tree level → only occur at higher order
- In many new physics models, decay rates of FCNC decays of b- or c-mesons are enhanced w.r.t. SM expectations
- $B_s \to \mu^+\mu^-$ theoretical SM prediction $\mathcal{B}(B_s \to \mu^+\mu^-) = (3.42 \pm 0.54) \cdot 10^{-9}$
- DØ limit with 2.0 fb^{-1}:

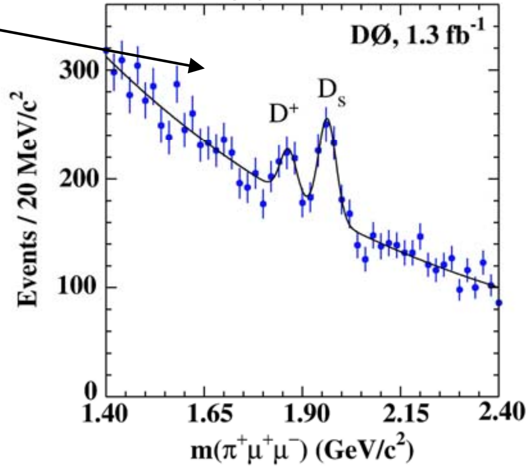
$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 7.5\,(9.3) \times 10^{-8}$ at 95(90)%CL

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B48/



- In case of c-mesons branching fraction SM expectations are ~10^{-9}
- Reconstruct $D^+ \to \pi^+\mu^+\mu^-$ where muons come from Φ

- First observation of $D_s^+ \to \phi\pi^+ \to \mu^+\mu^-\pi^+$
- First evidence for $D^+ \to \phi\pi^+ \to \mu^+\mu^-\pi^+$



- Search for FCNC $D^+ \to \pi^+\mu^+\mu^-$ outside Φ → μμ mass window
- No signal seen → set most stringent upper limit:

1.3 fb^{-1}

$\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-) < 3.9 \times 10^{-6}$ at 90% CL

hep-ex/0708.2094

Rare Decays (CDF)

- With 2.0 fb^{-1}, best limit in:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 5.8 \times 10^{-8}\ (4.7 \times 10^{-8}) \text{ at 95(90)\%CL}$$
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.8 \times 10^{-8}\ (1.5 \times 10^{-8}) \text{ at 95(90)\%CL}$$

arXiv:0712.1708

- 0.9 fb-1

$B(B^+ \to \mu^+\mu^- K^+) = (0.60 \pm 0.15 \pm 0.04)\times 10^{-6}$,
$B(B^0 \to \mu^+\mu^- K^{*0}) = (0.82 \pm 0.31 \pm 0.10)\times 10^{-6}$
} consistent with world average and competitive with best measurements

$B(B_s \to \mu^+\mu^-\varphi)/ B(B_s \to J/\psi\varphi) < 2.61(2.30)\times 10^{-3}$ at 95(90)%CL best limit

http://www-cdf.fnal.gov/physics/new/bottom/061130.blessed_bmumuh/

- First observation of $\overline{B}_s^0 \to D_s^{\pm} K^{\mp}$ in 1.2 fb^{-1}

109 +/- 9 signal events with ~8 sigma significance
Measure branching fraction relative to Cabibbo allowed mode:

$$\mathcal{B}(\overline{B}_s^0 \to D_s^{\pm} K^{\mp})/\mathcal{B}(\overline{B}_s^0 \to D_s^{+}\pi^{-}) = 0.107 \pm 0.019(\text{stat}) \pm 0.008(\text{sys})$$

http://www-cdf.fnal.gov/physics/new/bottom/070524.blessed-Bs-DsK/

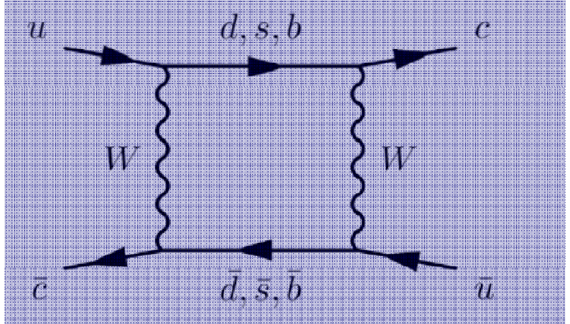
D^0 Mixing

arXiv:0712.1567

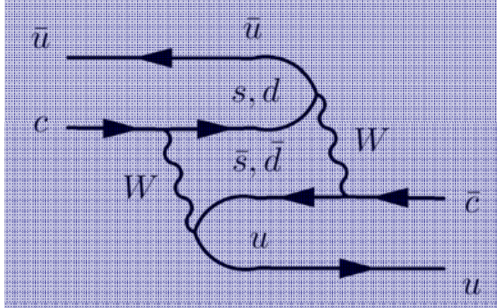
- After recent observation of fastest neutral meson oscillations in B_s system by CDF and DØ $\rightarrow$ time to look at the slowest oscillation of D^0 mesons ☺

- D^0 mixing in SM occurs through either:

'short range' processes
(negligible in SM)



'long range' processes



	$\Delta M/\Gamma$	$\Delta\Gamma/\Gamma$
K^0	0.474	0.997
B^0	0.77	<0.01
B_s	27	0.15
D^0	< few%	< few%

- Recent D^0 mixing evidence $\leftarrow$ different D^0 decay time distributions in

Belle
$D^0 \rightarrow \pi\pi$, KK (CP eigenstates)
compared to $D^0 \rightarrow K\pi$

BaBar
doubly Cabibbo suppressed (DCS) $D^0 \rightarrow K^+\pi^-$
compared to Cabibbo favored (CF) $D^0 \rightarrow K^-\pi^+$
(*Belle* does not see evidence in this mode)

Evidence for D^0 Mixing at CDF (1.5 fb-1)

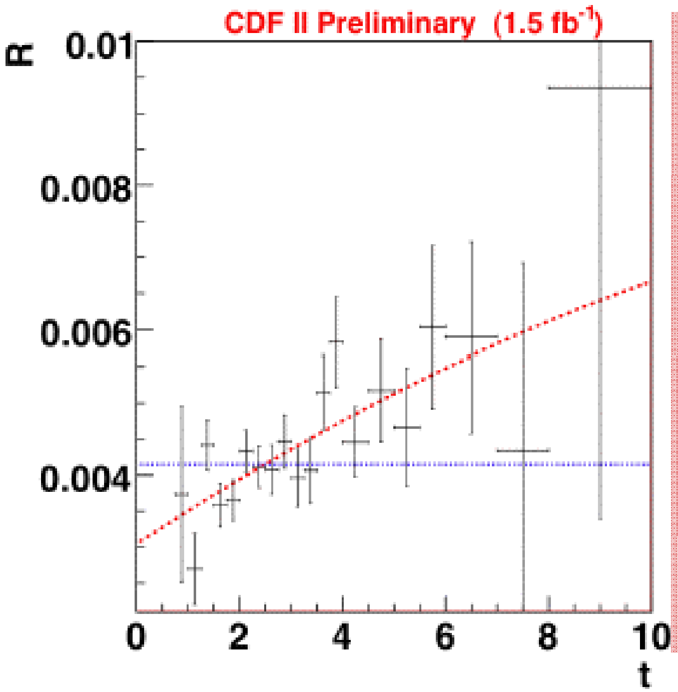
- CDF sees evidence for D^0 mixing at 3.8σ significance by comparing DCS $D^0 \to K^+\pi^-$ decay time distribution to CF $D^0 \to K^-\pi^+$ (confirms *BaBar*)
- Ratio of decay time distributions:

$$R(t/\tau) = R_D + \sqrt{R_D} y' (t/\tau) + \frac{x'^2 + y'^2}{4} (t/\tau)^2$$

where $x' = x \cos\delta + y \sin\delta$ and $y' = -x \sin\delta + y \cos\delta$

δ is strong phase between DCS and CF amplitudes

mixing parameters $x = \Delta M/\Gamma \quad y = \Delta\Gamma/2\Gamma$ are 0 in absence of mixing



Fit type	$R_D (10^{-3})$	$y' (10^{-3})$	$x'^2 (10^{-3})$	χ^2 / d.o.f.
Unconstrained	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	19.2 / 17
Physically allowed	3.22 ± 0.23	6.0 ± 1.4	0	19.3 / 18
No mixing	4.15 ± 0.10	0	0	36.8 / 19

Experiment	$R_D (10^{-3})$	$y' (10^{-3})$	$x'^2 (10^{-3})$	Mixing Signif.
CDF	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	3.8
BABAR	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37	3.9
Belle	3.64 ± 0.17	$0.6^{+4.0}_{-3.9}$	$0.18^{+0.21}_{-0.23}$	2.0

Topics Not Covered

- Many other recent results not covered in this talk:

  - B_s oscillations
  - $B_s \to D_s^{(*)} D_s^{(*)}$
  - $\Psi(2S)$ production,
  - Y(1S), Y(2S) polarization
  - $B^0 \to J/\psi\ K^{*0}$ angular analysis
  - orbitally excited B mesons
  - b-$\bar{b}$ correlations
  - CP asymmetry in $B^+ \to D^0 K^+$

Conclusions

- Very rich B physics program at the Tevatron

- Complementary and competitive with *Belle* and *BaBar*

- Great Tevatron performance

  → accumulate data fast

  → expect ~6 fb^{-1} by the end of the run

- Expect updates of many analyses

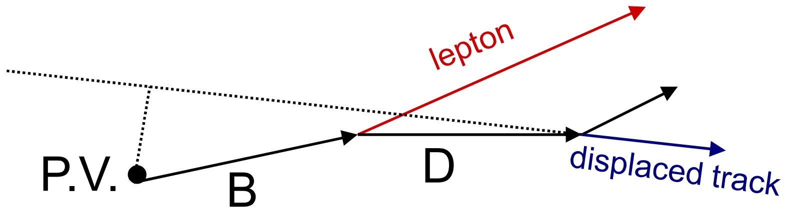
- Exciting time to study CP violation and search for new phenomena in B physics at Tevatron !

Backup Slides

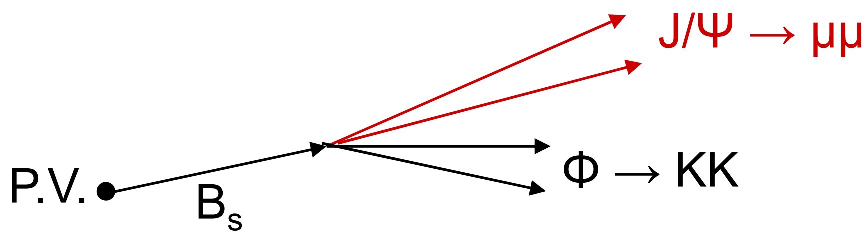
Triggers

- Triggers designed to select events with topologies consistent with B decays:

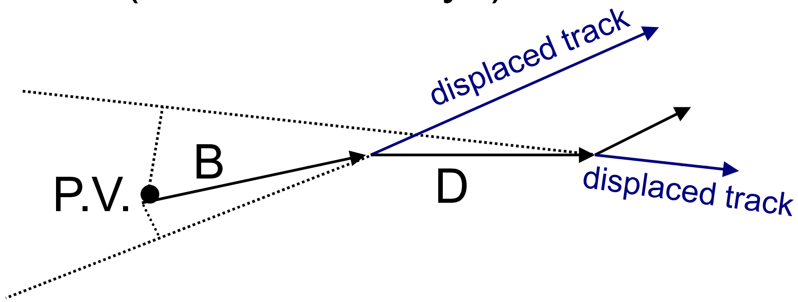
  - single lepton (+ displaced track) (semileptonic decays) ← DØ (CDF)



  - di-lepton (B → J/Ψ, B → μμ, B →μμ + hadrom) ← both CDF and DØ

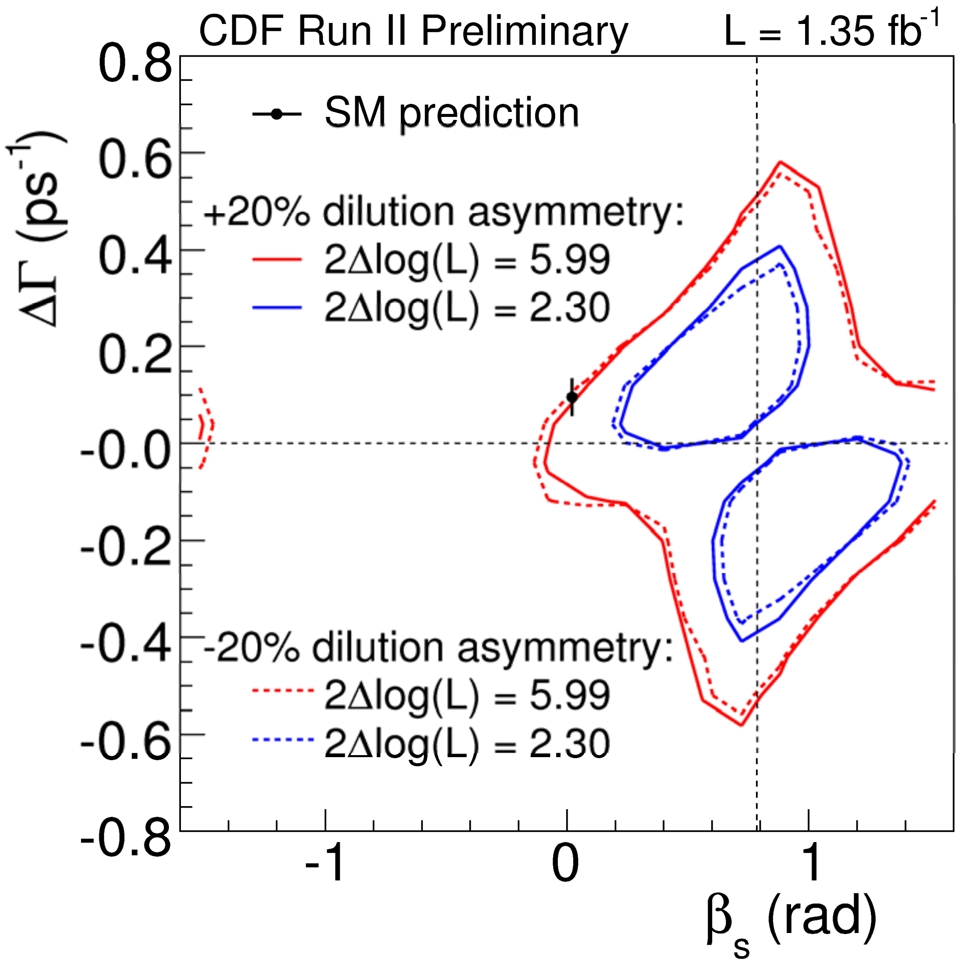


  - displaced tracks (hadronic decays) ← CDF



Effect of Dilution Asymmetry on β_s

- Effect of 20% b-bbar dilution asymmetry is very small



Branching Fractions and CP Asymmetry in $B^+ \to D^0 K^+$ (CDF, 1 fb^{-1})

- Measures quantities relevant for determination of the CKM angle

$$\gamma = arg(-V_{ud}V^*_{ub}/V_{cd}V^*_{cb})$$

$$A_{CP+} = \frac{BR(B^- \to D^0_{CP+}K^-) - BR(B^+ \to D^0_{CP+}K^+)}{BR(B^- \to D^0_{CP+}K^-) + BR(B^+ \to D^0_{CP+}K^+)}$$

$$R_{CP+} = \frac{R_+}{R}$$ where:

$$R = \frac{BR(B^- \to D^0 K^-) + BR(B^+ \to \overline{D}^0 K^+)}{BR(B^- \to D^0\pi^-) + BR(B^+ \to \overline{D}^0 \pi^+)}$$

$$R_+ = \frac{BR(B^- \to D^0_{CP+}K^-) + BR(B^+ \to D^0_{CP+}K^+)}{BR(B^- \to D^0_{CP+}\pi^-) + BR(B^+ \to D^0_{CP+}\pi^+)}$$

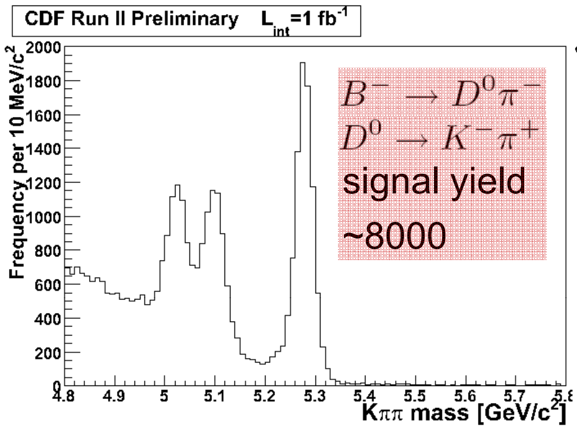
CP even eigenstate:

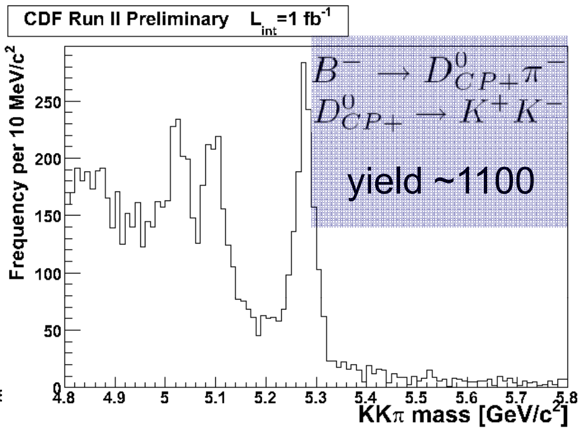
$D^0_{CP+} \to K^+K^-$

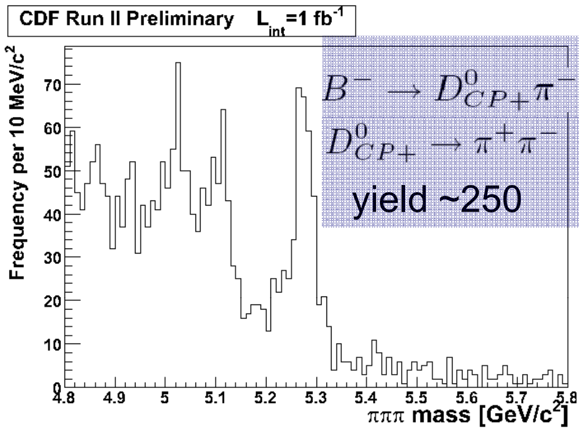
$D^0_{CP+} \to \pi^+\pi^-$

Flavor eigenstate:

$D^0 \to K^-\pi^+$

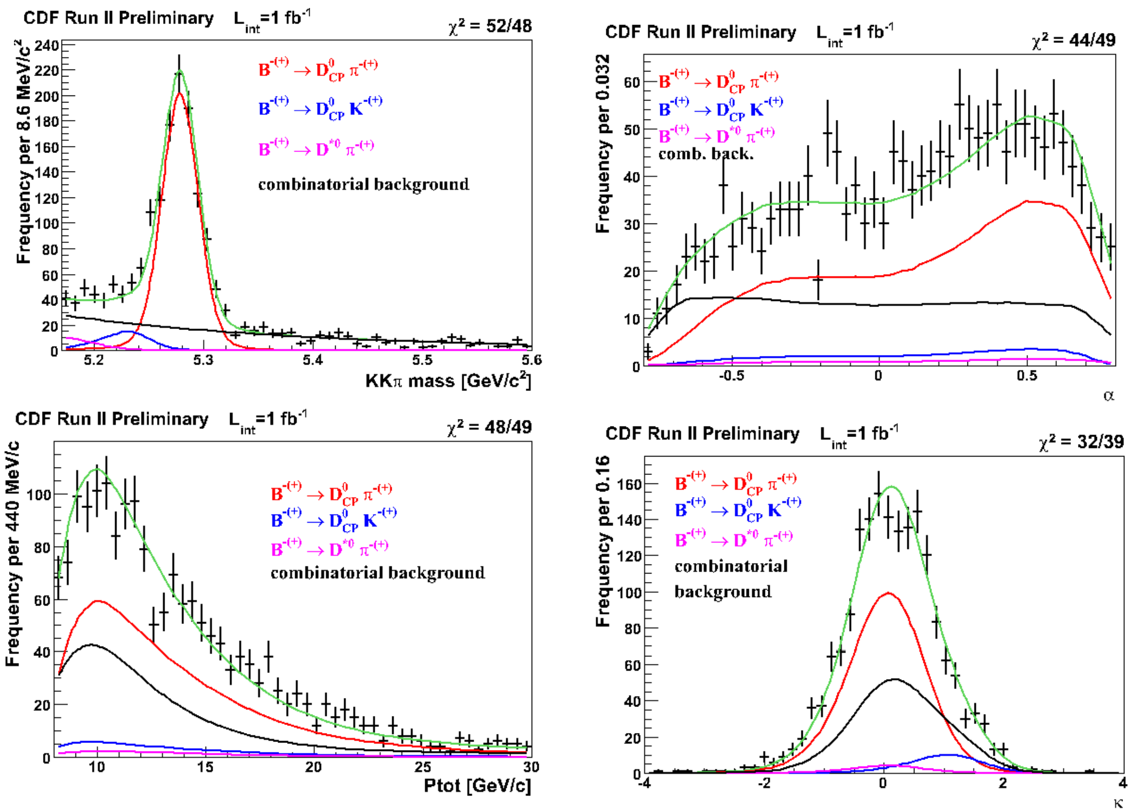


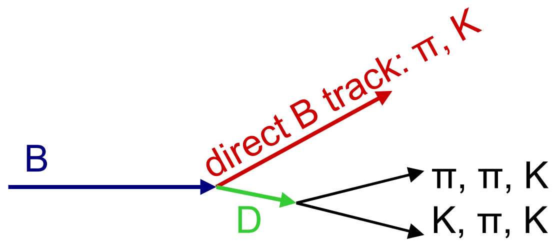




Branching Fractions and CP Asymmetry in $B^+ \to D^0 K^+$ (CDF, 1 fb^{-1})

- Discriminating variables used to disentangle decay modes:
  - (D^0,track) invariant mass
  - momentum imbalance: $p_{tr} < p_{D^0}$ $\alpha = 1 - p_{tr}/p_{D^0} > 0$
  - total momentum $p_{tr} \geq p_{D^0}$ $\alpha = -(1 - p_{D^0}/p_{tr}) \leq 0.$
  - 'kaonness' contains dE/dx information of direct B track $p_{tot} = p_t + p_{D^0}$





Branching Fractions and CP Asymmetry in $B^+ \rightarrow D^0 K^+$ (CDF, 1 fb^{-1})

http://www-cdf.fnal.gov/physics/new/bottom/071018.blessed-BDK/

- Results:
  - ratio of branching fractions:

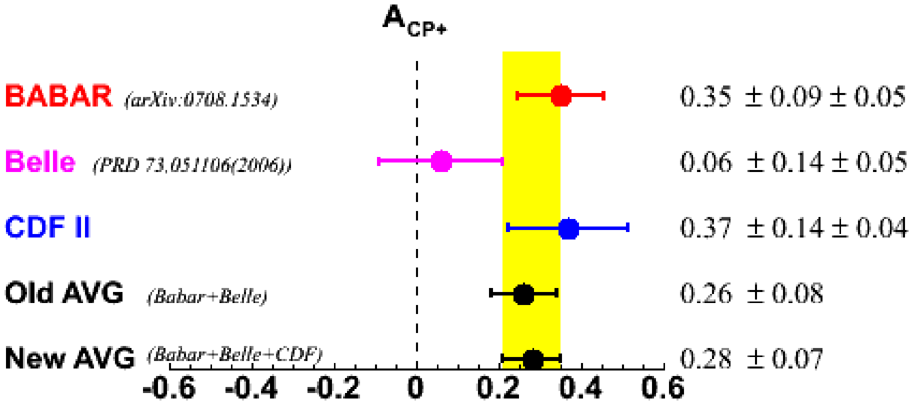
$$R = \frac{BR(B^- \to D^0 K^-) + BR(B^+ \to \overline{D}^0 K^+)}{BR(B^- \to D^0 \pi^-) + BR(B^+ \to \overline{D}^0 \pi^+)} = 0.0745 \pm 0.0043(stat.) \pm 0.0045(syst.)$$

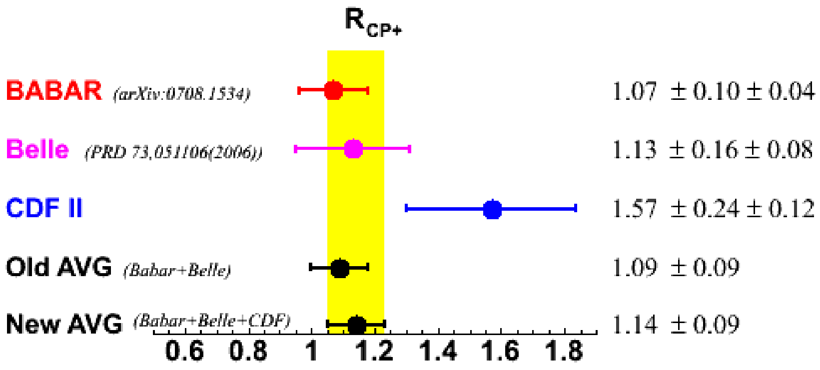
$$R_{CP+} = \frac{BR(B^- \to D^0_{CP+} K^-) + BR(B^+ \to D^0_{CP+} K^+)}{[BR(B^- \to D^0 K^-) + BR(B^+ \to \overline{D}^0 K^+)]/2} = 1.57 \pm 0.24(stat.) \pm 0.12(syst.)$$

  - direct CP asymmetry:

$$A_{CP+} = \frac{BR(B^- \to D^0_{CP+} K^-) - BR(B^+ \to D^0_{CP+} K^+)}{BR(B^- \to D^0_{CP+} K^-) + BR(B^+ \to D^0_{CP+} K^+)} = 0.37 \pm 0.14(stat.) \pm 0.04(syst.).$$

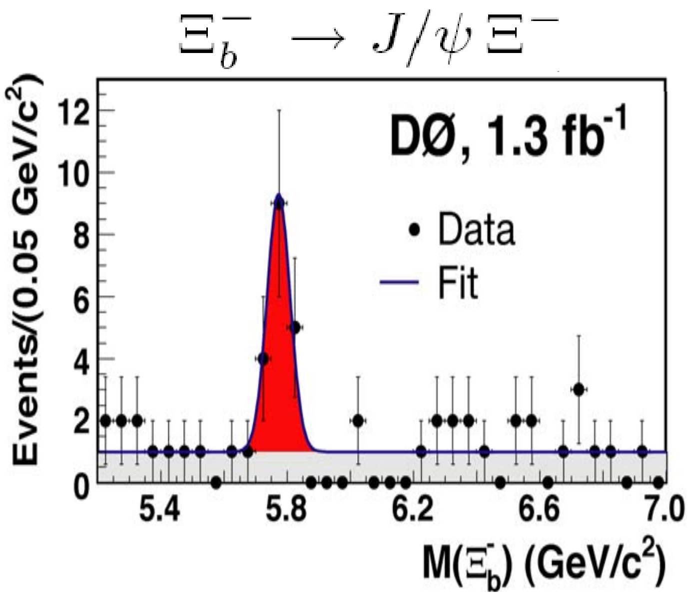
- Quantities measured for the first time at hadron colliders
- Results in agreement and competitive with B factories

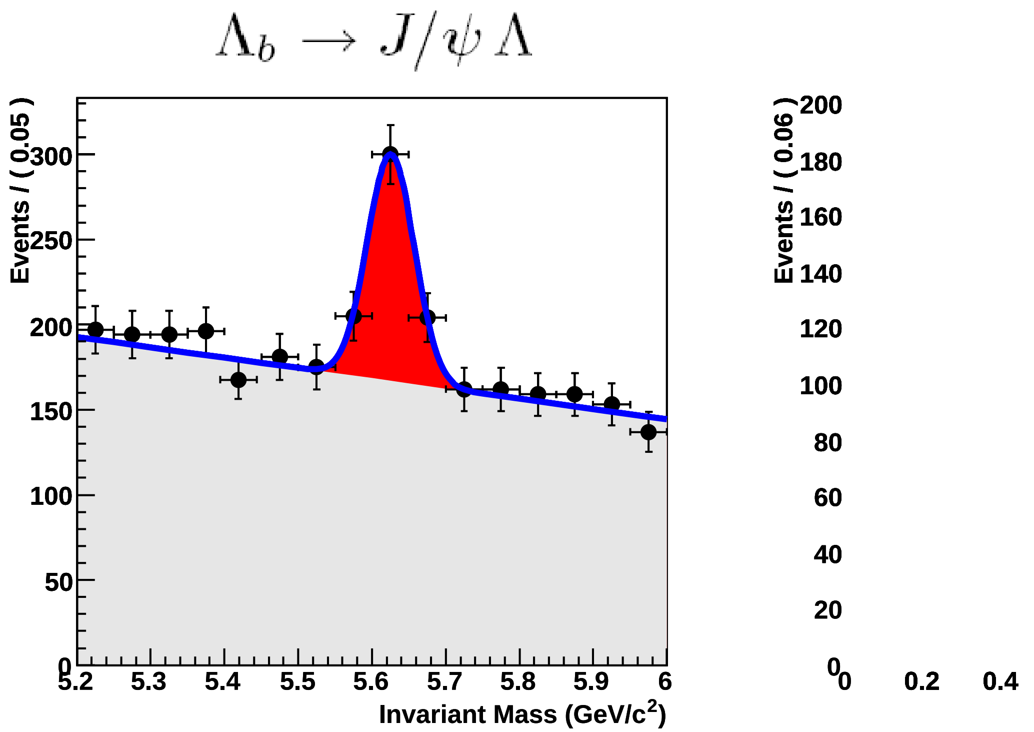




Ξ_b Production (DØ, 1.3 fb^{-1})

- Normalize Ξb production to Λb production
- Normalization mode Λb →J/Ψ Λ





$$\frac{f(b \to \Xi_b^-)\cdot Br(\Xi_b^- \to J/\psi\,\Xi^-)}{f(b \to \Lambda_b)\cdot Br(\Lambda_b \to J/\psi\,\Lambda)} = 0.28 \pm 0.09\,(\text{stat.})^{+0.09}_{-0.08}\,(\text{syst.})$$

where f(b→X) : fraction of times b quark hadronizes to X