Heavy Flavor Physics at CDF

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on behalf of CDF collaboration

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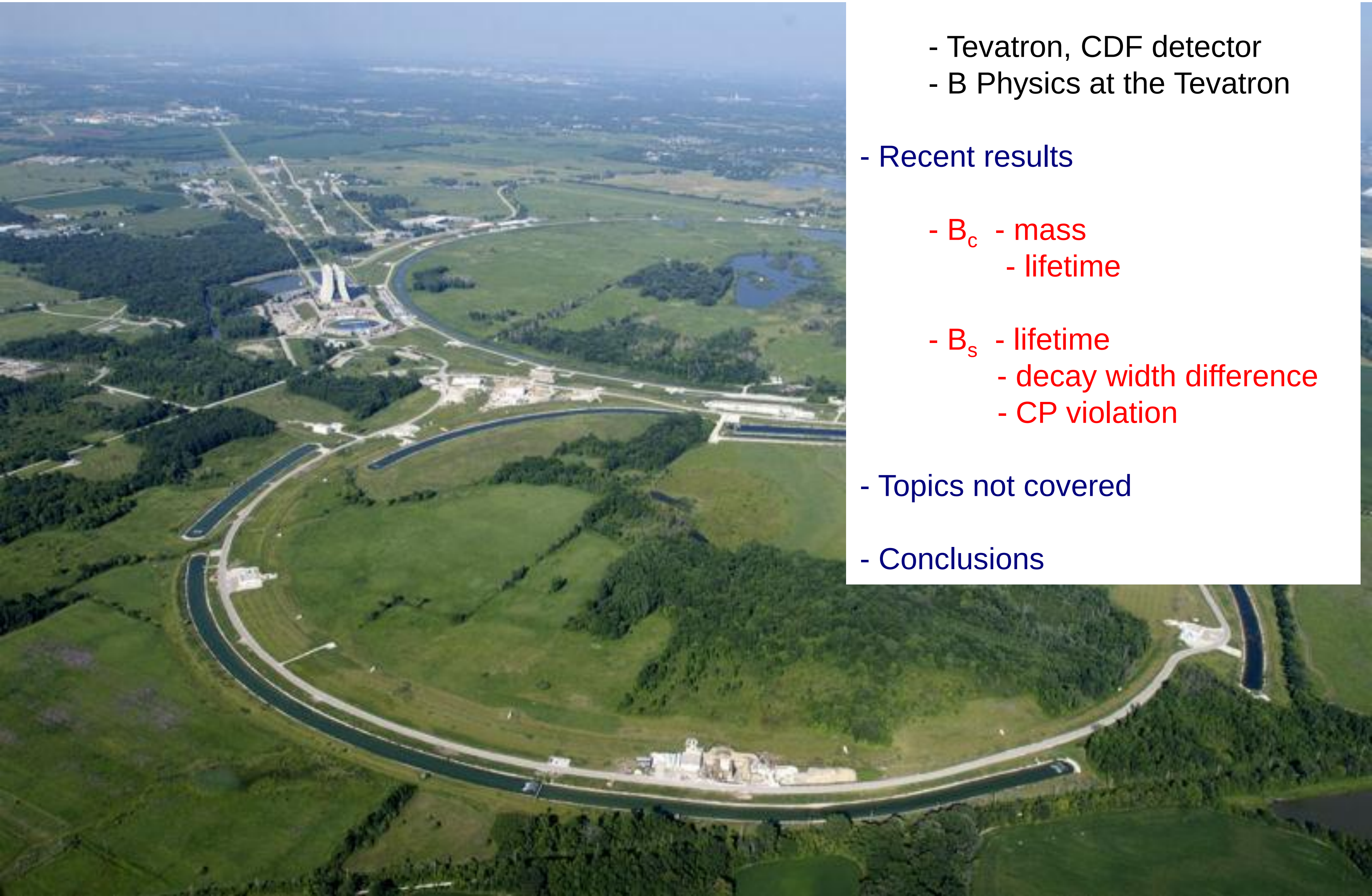
Outline

- Introduction
  - Tevatron, CDF detector
  - B Physics at the Tevatron
- Recent results
  - B_c - mass
    - lifetime
  - B_s - lifetime
    - decay width difference
    - CP violation
- Topics not covered
- Conclusions

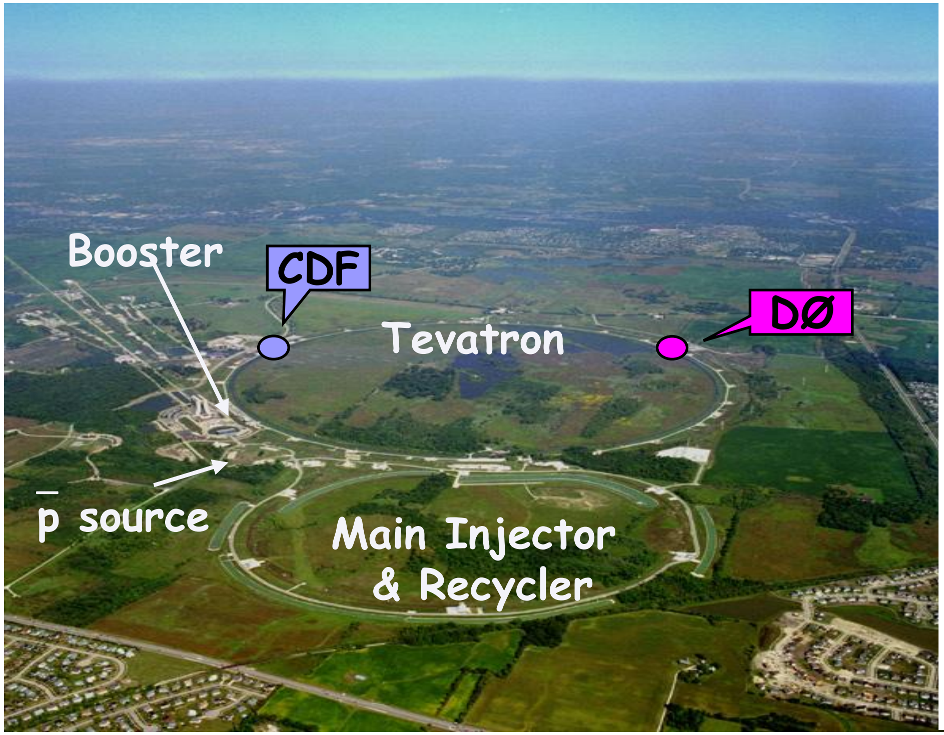


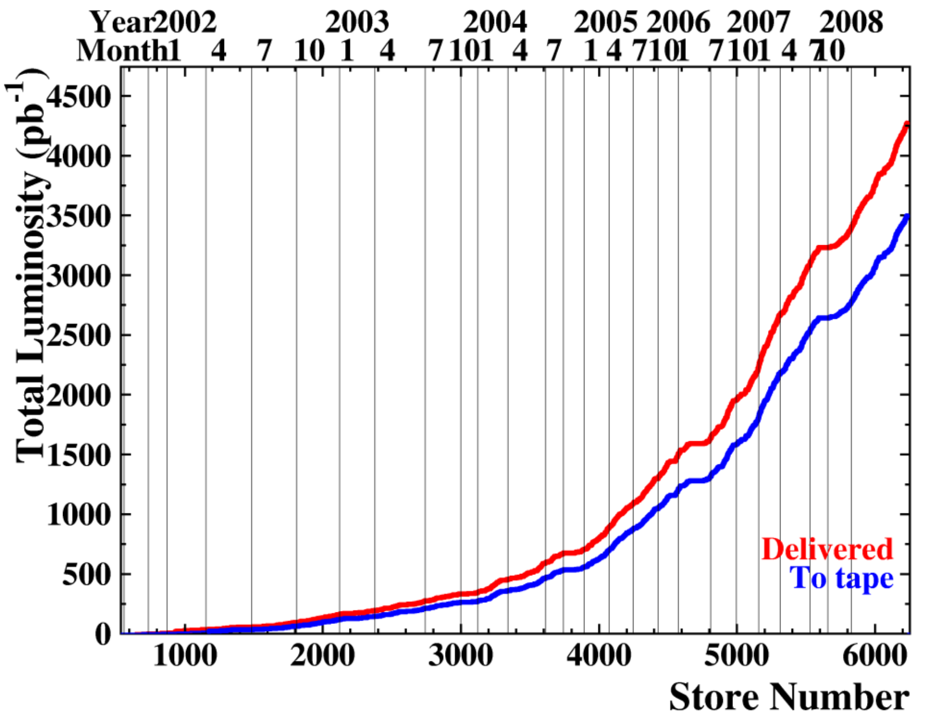
Tevatron

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

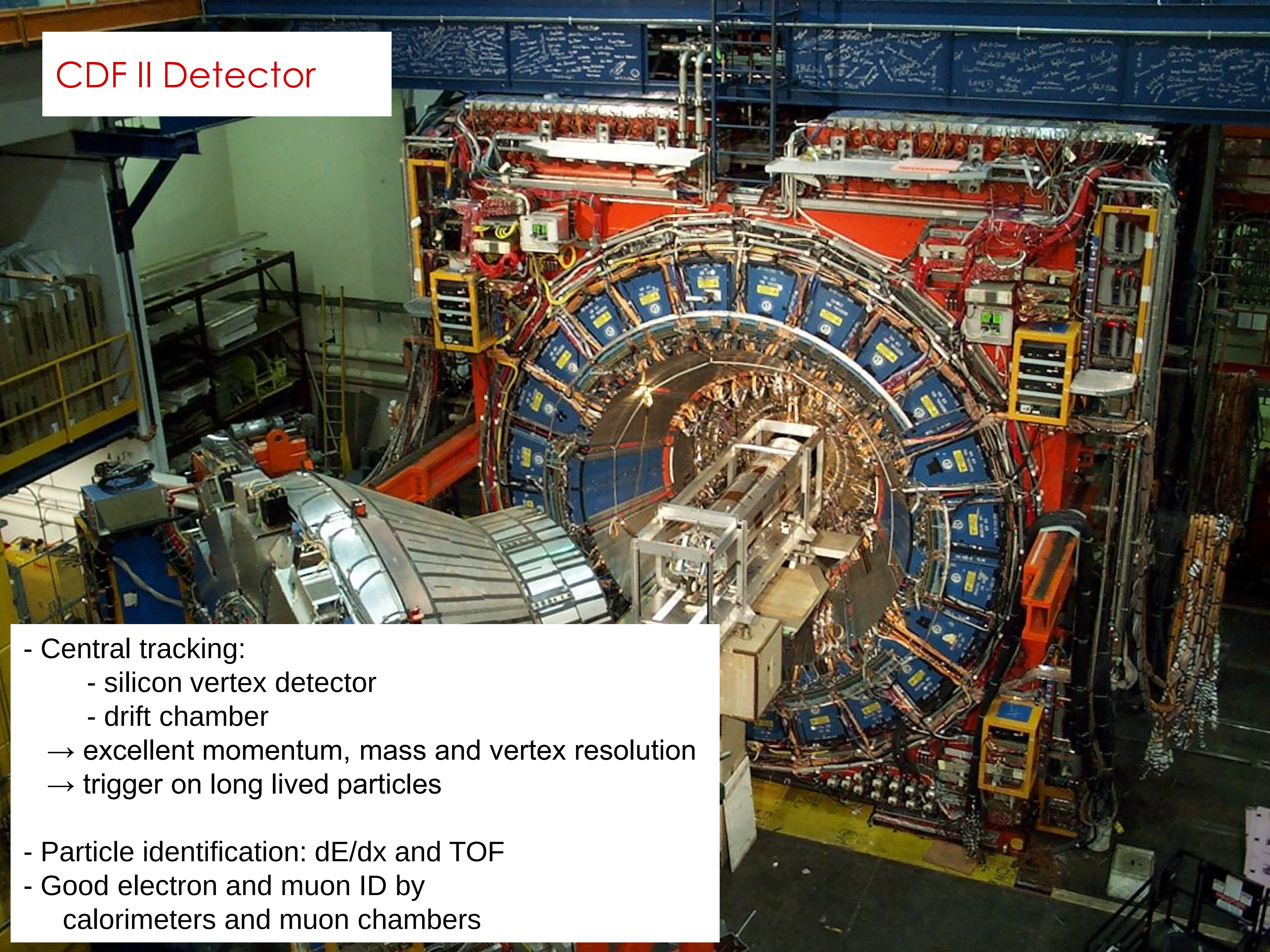
~3.5 fb^{-1} data on tape

- Initial instantaneous luminosity $3x10^{32}cm^{-2}s^{-1}$





CDF II Detector



- Central tracking:
    - silicon vertex detector
    - drift chamber

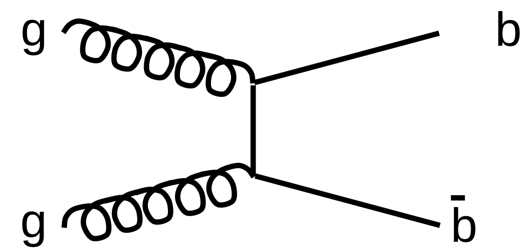
  → excellent momentum, mass and vertex resolution

  → trigger on long lived particles

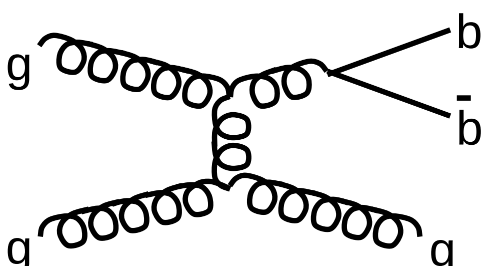
- Particle identification: dE/dx and TOF
- Good electron and muon ID by calorimeters and muon chambers

B Physics at the Tevatron

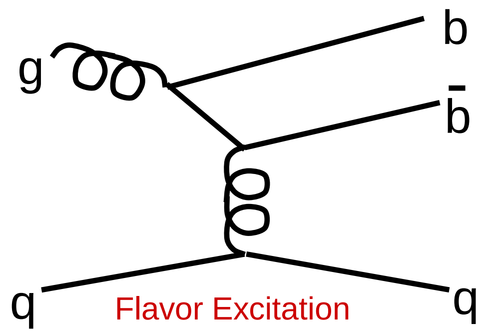
- Mechanisms for b production in $p\bar{p}$ collisions at 1.96 TeV



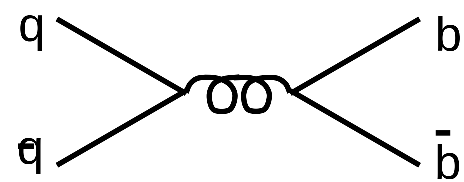
Flavor Creation (gluon fusion)



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

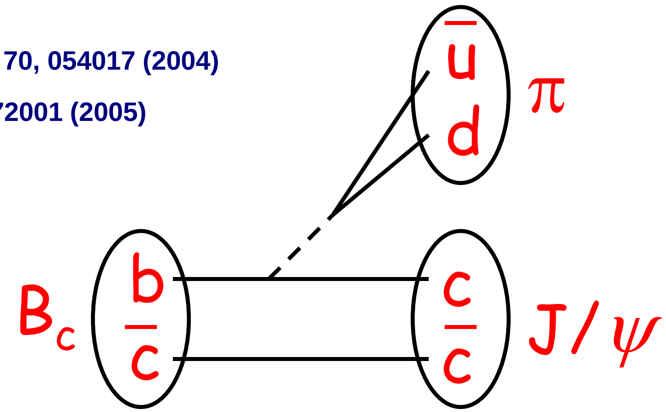
- Plethora of states accessible only at Tevatron: B_s, B_c, Λ_b, Ξ_b, Σ_b…
  → complement the B factories physics program

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

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

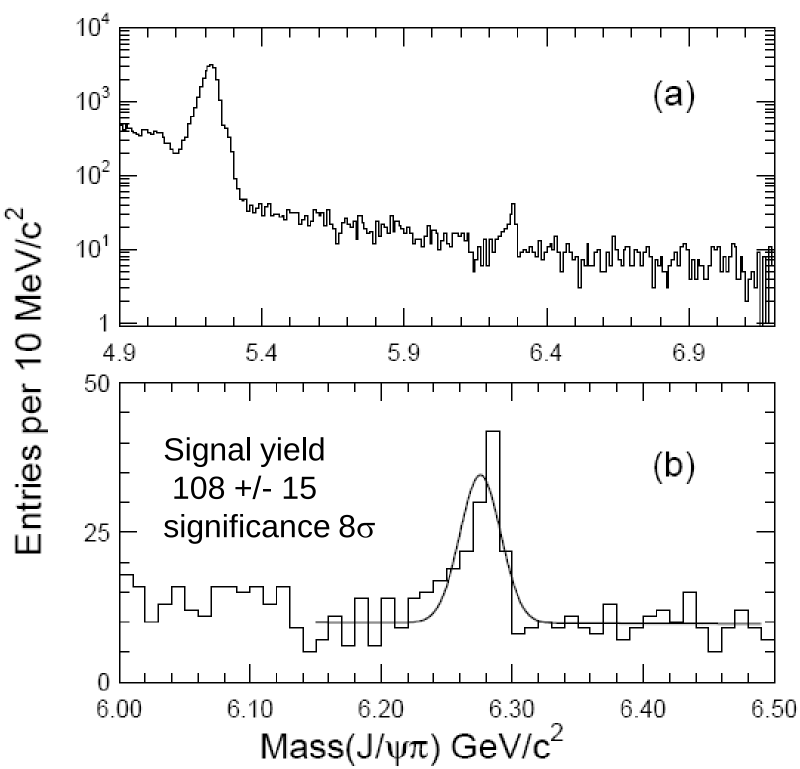
Phys.Rev.Lett.100:182002,2008

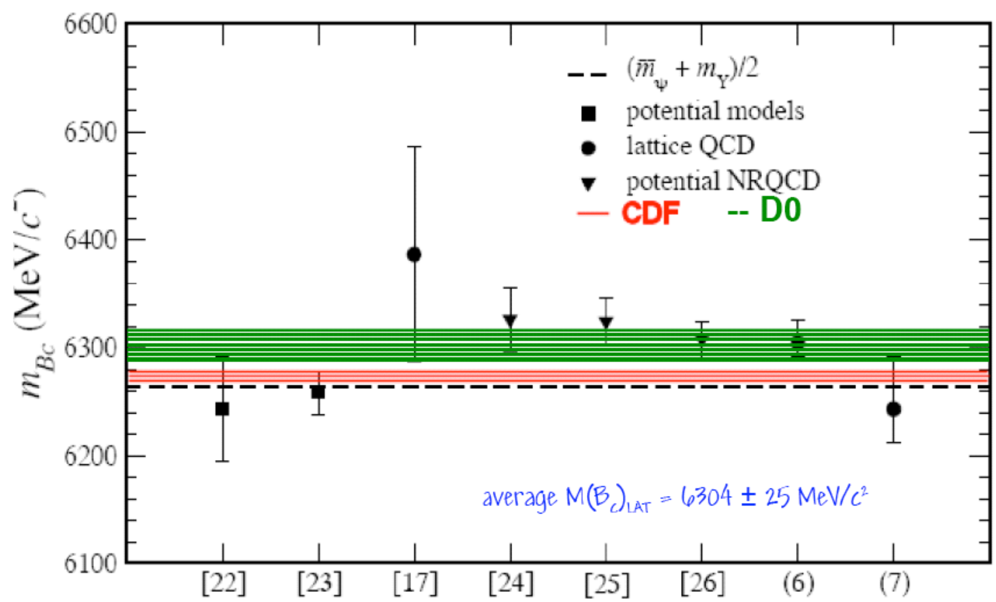
- B_c – unique meson as it contains two heavy quarks: bottom and anti-charm ($b\bar{c}$)
- Mass predictions:
  - NR potential models 6247 - 6286 MeV   Phys. Rev. D. 70, 054017 (2004)
  - lattice QCD 6304 +/- 12 $^{+18}_{-0}$ MeV   Phys. Rev. Lett. 94, 172001 (2005)



- Best mass measurement:

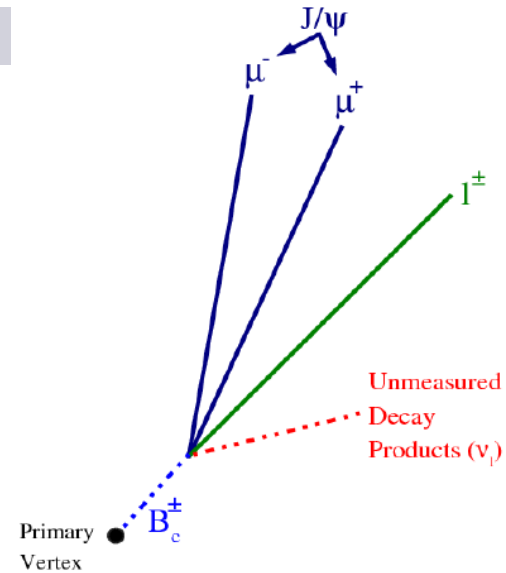
$$6275.6 \pm 2.9\ (\text{stat.}) \pm 2.5\ (\text{syst.})\ \text{MeV}/c^2$$





B_c Lifetime in $B_c \rightarrow J/\Psi$ lepton ($1\ fb^{-1}$)

http://www-cdf.fnal.gov/physics/new/bottom/080327.blessed-BC_LT_SemiLeptonic/



- Lepton can be either muon or electron

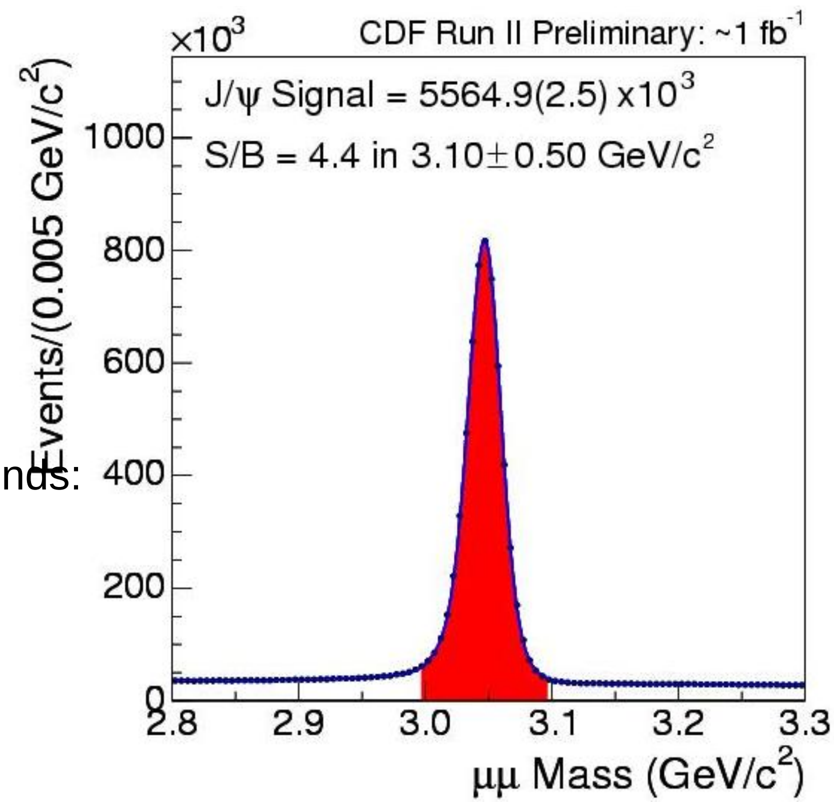
- Different contributions to total decay width:
  - c quark decays $B_c^+ \rightarrow B_s^0 \pi^+$
  - b quark decays $B_c^+ \rightarrow J/\psi \ell^+ \nu$
  - annihilation $B_c^+ \rightarrow \ell^+ \nu.$

- Lifetime expected ~1/3 of other B mesons (0.5ps compared to typical 1.5ps)

- Signal reconstruction from ~5.5 million J/Ψ
- Third lepton is vertexed with J/Ψ

- Partially reconstructed mode (missing neutrino)
  - use simulation to correct missing momentum

- Main challenge is understanding multiple backgrounds:
  - real J/Ψ + fake lepton
  - fake J/Ψ + real lepton
  - real J/Ψ + real lepton from bb events
  - prompt J/Ψ + μ



B_c Lifetime Results

- Most precise B_c lifetime measurement (same precision as DØ)

muon mode $c\tau_\mu = 179.1^{+32.6}_{-27.2}\ (\text{stat.})\ \mu\text{m},$

electron mode $c\tau_e = 121.7^{+18.0}_{-16.3}\ (\text{stat.})\ \mu\text{m}.$

- Combined:

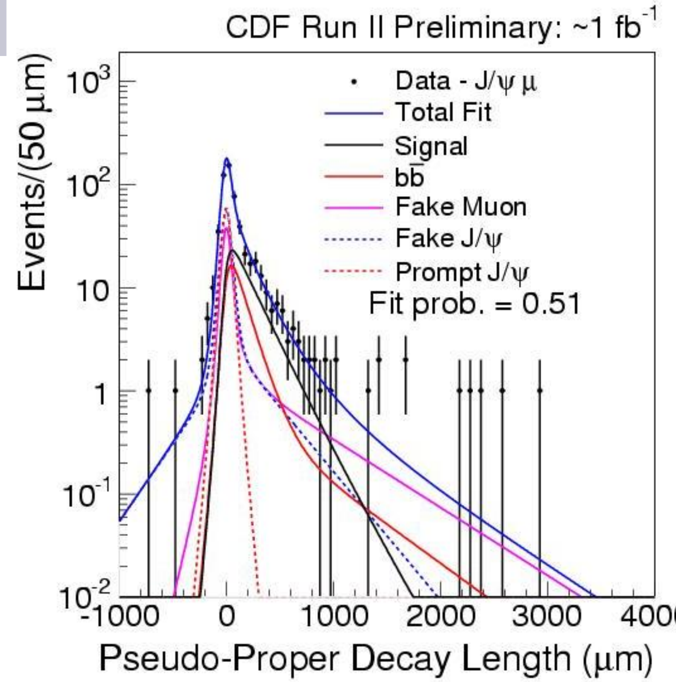
$$c\tau = 142.5^{+15.8}_{-14.8}\ (\text{stat.}) \pm 5.5\ (\text{syst.})\ \mu\text{m}.$$

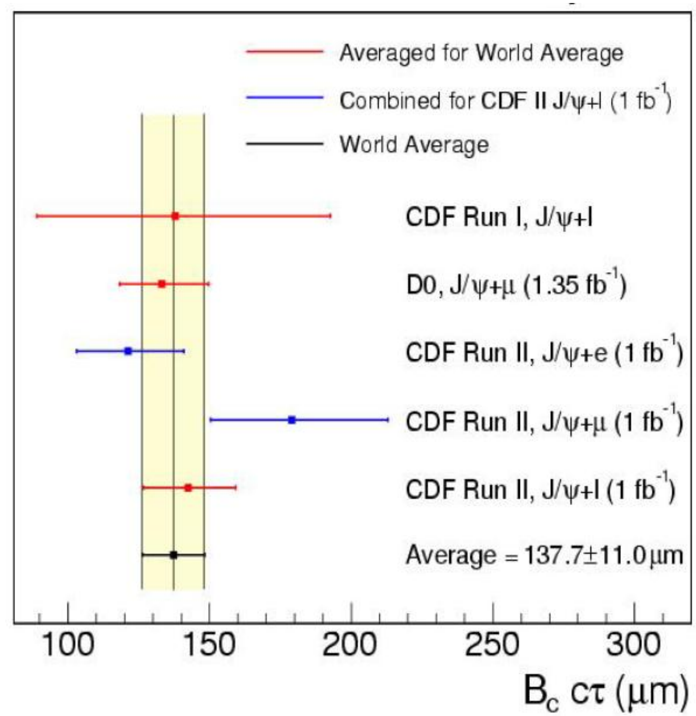
- Speaker's average (neglect correlations)

$\tau = 0.459 \pm 0.037$ ps

- Large theoretical uncertainties and model to model variations $\tau = 0.47 \div 0.59$ ps

- Expect CDF B_c lifetime measurement in fully reconstructed $B_c \rightarrow J/\Psi\ \pi$





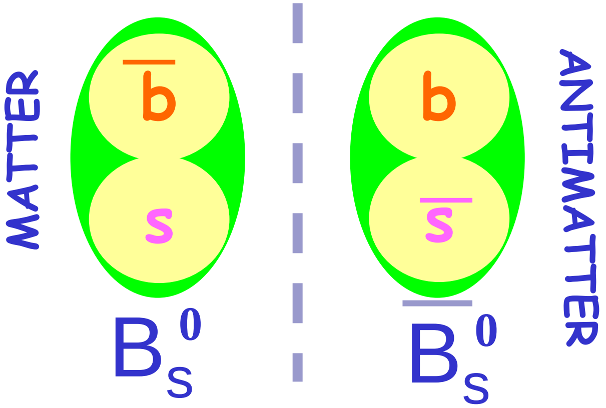
Neutral B_s System

- 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
  $\rightarrow$ mass eigenstates

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



- Different mass eigenvalues: $\Delta m_s = m_H - m_L \rightarrow$ B_s oscillates with frequency $\sim\Delta m_s$
  CDF $\Delta m_s = 17.77$ +/- 0.12 ps^{-1}
  DØ $\Delta m_s = 18.56$ +/- 0.87 ps^{-1}

- Mass eigenstates have different decay widths (different lifetimes)
  $\Delta\Gamma = \Gamma_L - \Gamma_H$

CP Violation in B_s System

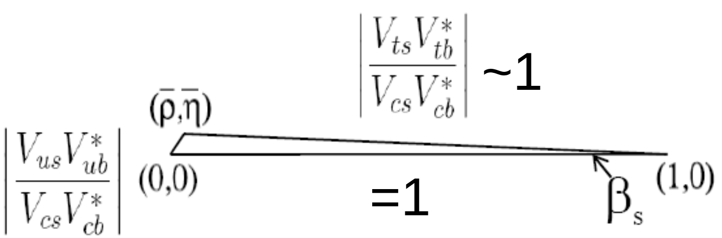
- Standard Model CP violation occurs through complex phases in the unitary CKM quark mixing matrix:

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

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

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

- Unitary matrix → $V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$

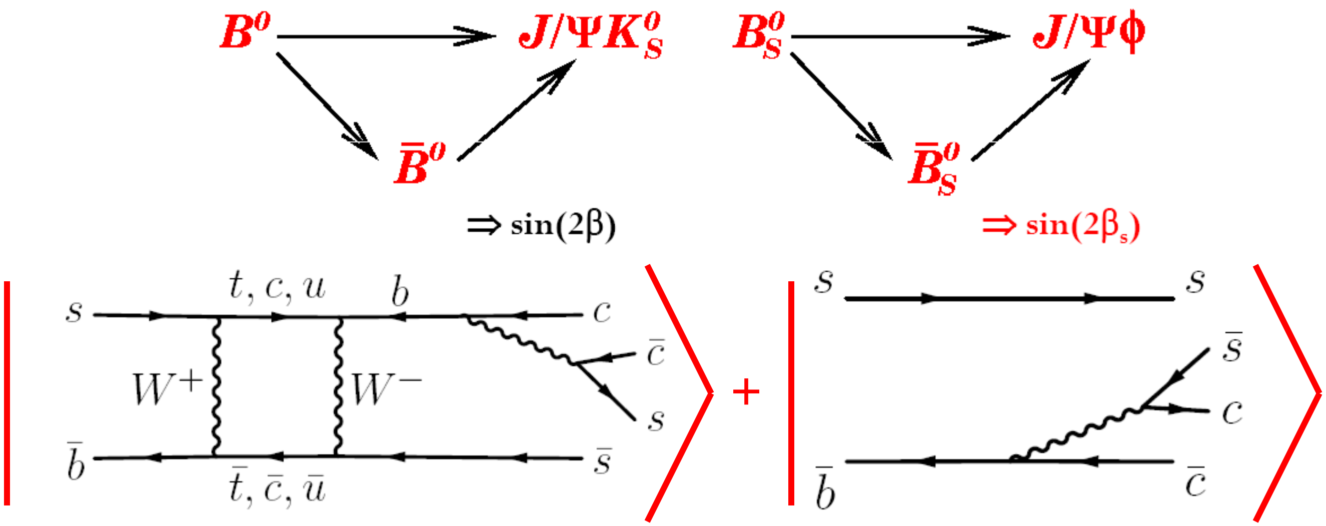


$\sim\lambda^2 \approx 0.05$

very small CPV phase β_s
accessible in $B_s \to J/\Psi\Phi$ decays

CP Violation in $B_s \rightarrow J/\Psi\Phi$ 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:

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

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

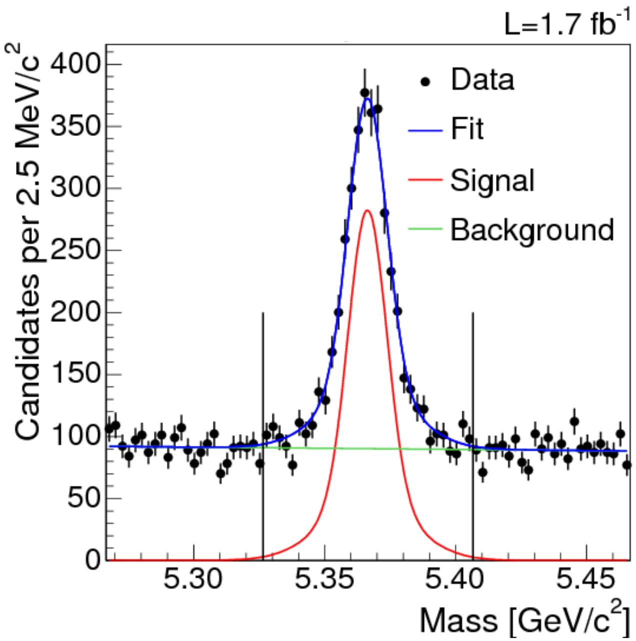
- If NP phase ϕ_s^{NP} dominates $\rightarrow$ $2\beta_s = -\phi_s^{\mathrm{NP}}$

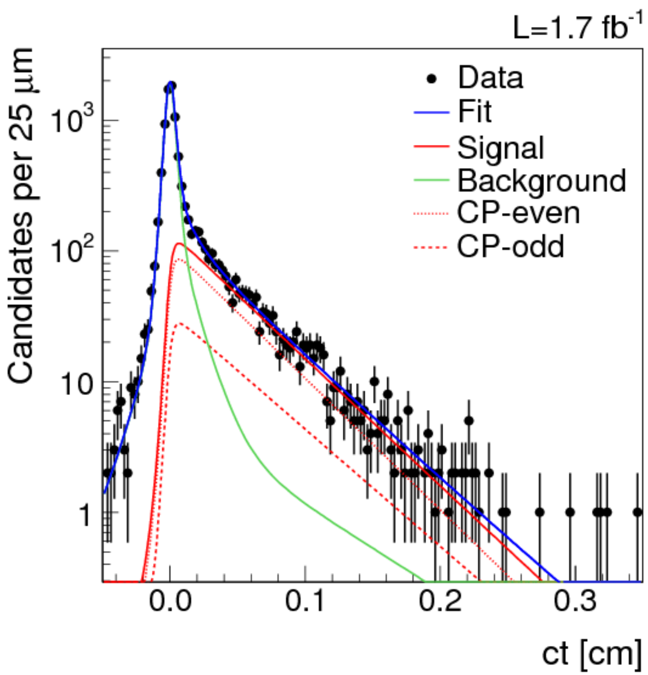
B_s Lifetime in $B_s \rightarrow J/\Psi\Phi$ Decays (1.7 fb^{-1}) **Phys.Rev.Lett. 100, 121803 (2008)**

~ 2500 signal events in ~1.7 fb-1

- B_s lifetime measurements from $B_s \rightarrow J/\Psi\Phi$ decays
- Measures average decay width $\Gamma_s = (\Gamma_L + \Gamma_H) / 2$

$$\tau_s = 1 / \Gamma_s = 1.52 \pm 0.04 \text{ (stat)} \pm 0.02 \text{ (syst) ps}$$





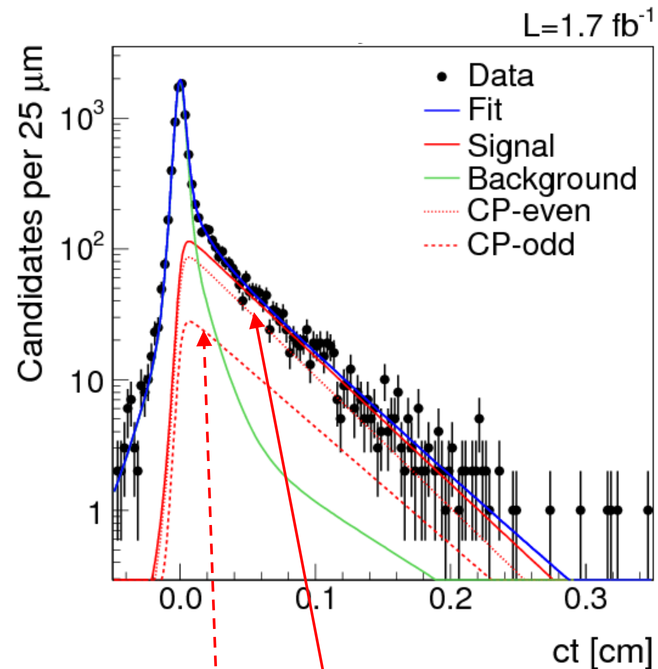
Width Difference $\Delta\Gamma$ in $B_s \rightarrow J/\Psi\Phi$ (1.7 fb-1) Phys.Rev.Lett. 100, 121803 (2008)

- Can also measure decay width $\Delta\Gamma$

- 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

L = 1 (p-wave) → CP odd



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

- At good approximation 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

$\Delta\Gamma = \Gamma_L - \Gamma_H = 0.08 \pm 0.06\ (stat) \pm 0.01\ (syst)\ ps^{-1}$

→ some sensitivity to CP violation phase β_s

- Determine B_s flavor at production (flavor tagging)

→ improve sensitivity to CP violation phase β_s

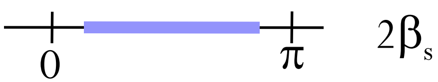
CP Violation Phase β_s in Tagged $B_s \to J/\Psi\Phi$ Decays (1.4 fb-1)

Phys. Rev. Lett. 100, 161802 (2008)

- First tagged analysis of $B_s \to J/\Psi\Phi$ (1.4 fb^{-1})
- Signal B_s yield ~2000 events with S/B ~ 1
- Irregular likelihood does not allow quoting point estimate
- Quote Feldman-Cousins confidence regions with frequentist inclusion of systematic uncertainties

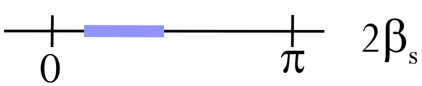
- 1D Feldman-Cousins procedure without external constraints:

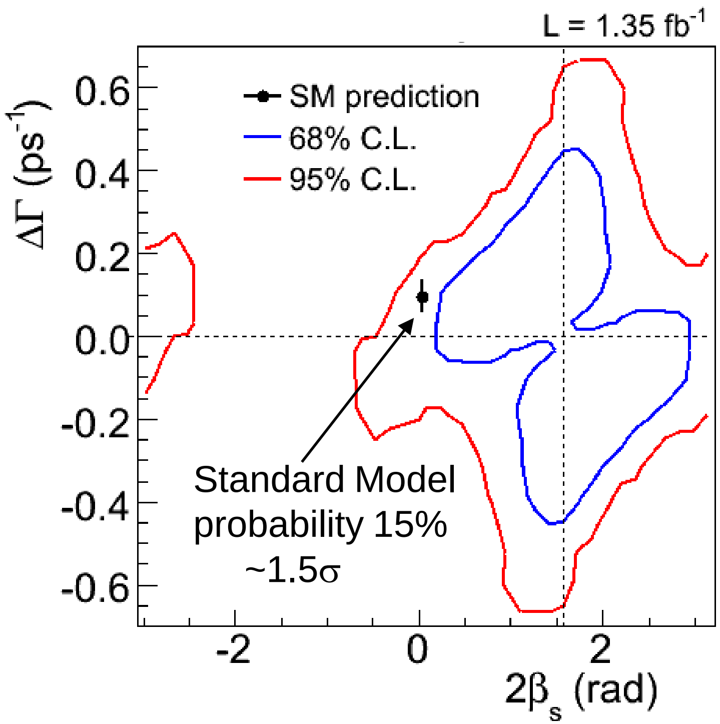
  $2\beta_s$ in [0.32, 2.82] at the 68% C.L.



- with external constraints (on strong phases, lifetime and $\Delta\Gamma$)

  $2\beta_s$ in [0.40, 1.20] at 68% C.L.





Comparison with DØ

arXiv:0802.2255

- DØ quotes the results in terms of $\phi_s = -2\beta_s$

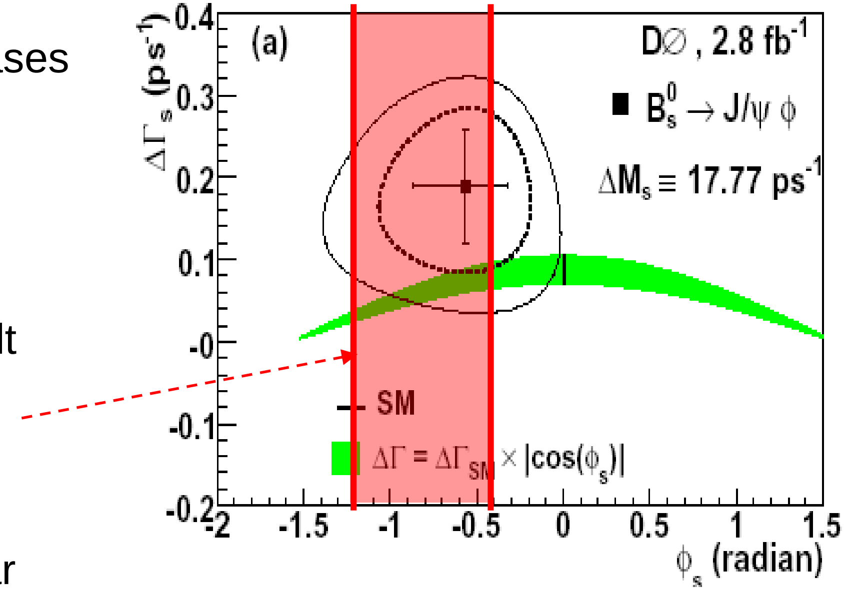
See talk by E. Fisk for DØ analysis

- DØ quotes a point-estimate with strong phases constrained from $B^0 \rightarrow J/\psi K^{*0}$

$$\phi_s = -0.57^{+0.24}_{-0.30}(\text{stat})^{+0.07}_{-0.02}(\text{syst})$$

- Can be compared to CDF constrained result

$2\beta_s \in [0.40, 1.20]$ @ 68% CL



- HFAG combined CDF + DØ result to appear very soon !

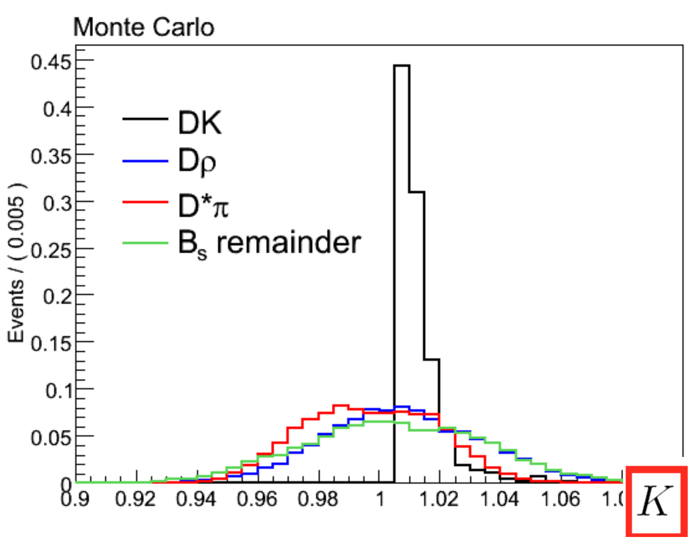
B_s Lifetime in Flavor Specific Decay $B_s \to D_s\,\pi\,X$

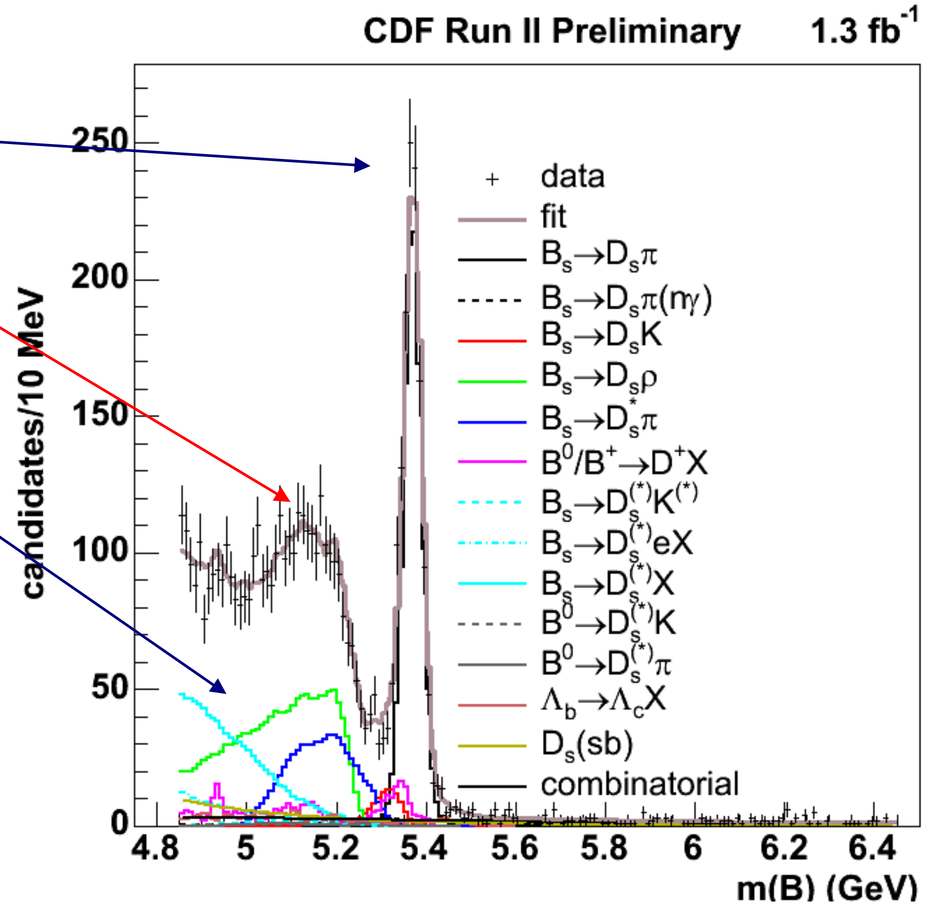
http://www-cdf.fnal.gov/physics/new/bottom/080207.blessed-bs-lifetime/

- Decay modes:
  - fully reconstructed $B_s \to D_s(\Phi\pi)\,\pi$ (~1100 events)
  - partially reconstructed (2200 events)

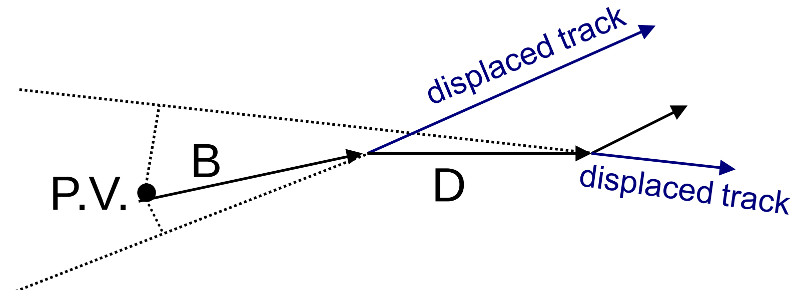
- Partially reconstructed modes ← use simulation to model mass distribution shapes and missing momentum:

$$ct = \frac{L_{xy} \cdot m_B^{rec}}{p_T} \cdot K$$

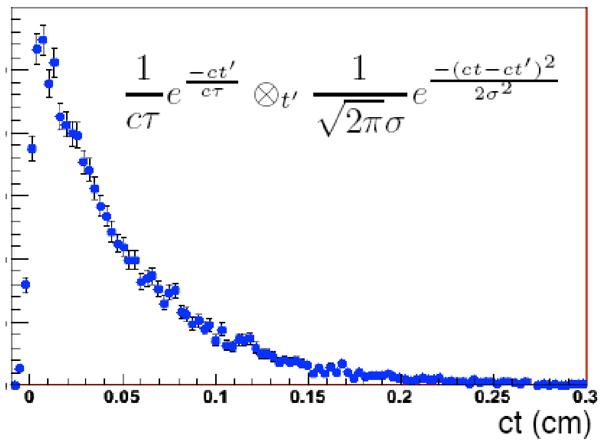




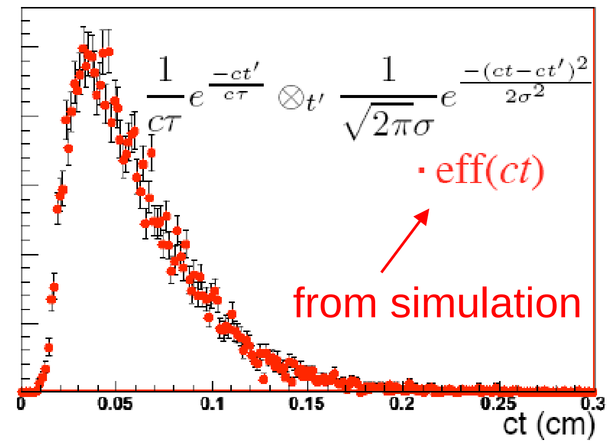
B_s Lifetime in $B_s \to D_s\, \pi\, X$ (cont)



- Data collected using displaced track trigger
  - two displaced tracks with 120 μm < d0 < 1mm
    - → lifetime bias corrected using simulation



trigger and analysis selection →



- Procedure tested and on control samples

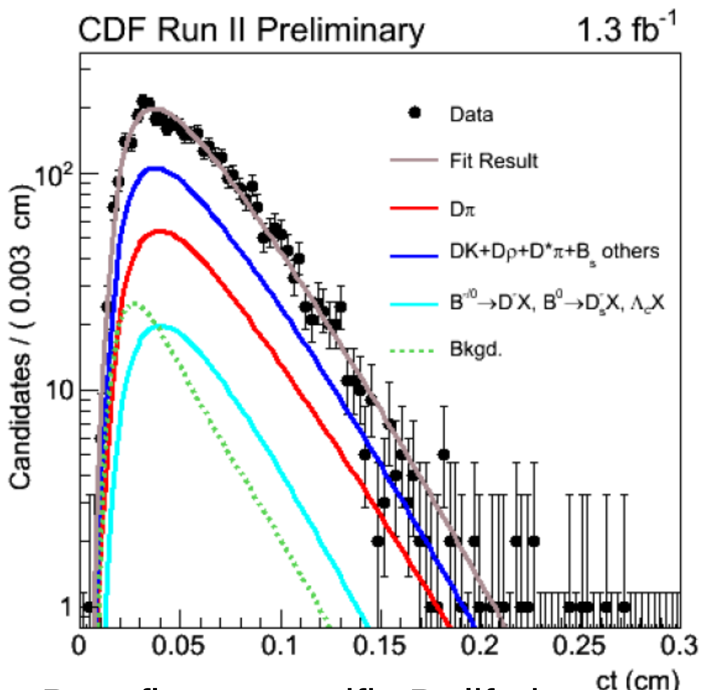
$B^0 \to D^-(K^+\pi^-\pi^-)\, \pi^+$

$B^0 \to D^{*-}(D^0(K^+\pi^-)\pi^-)\, \pi^+$

$B^+ \to D^0(K^+\pi^-)\, \pi^+$

- Found good agreement with world average

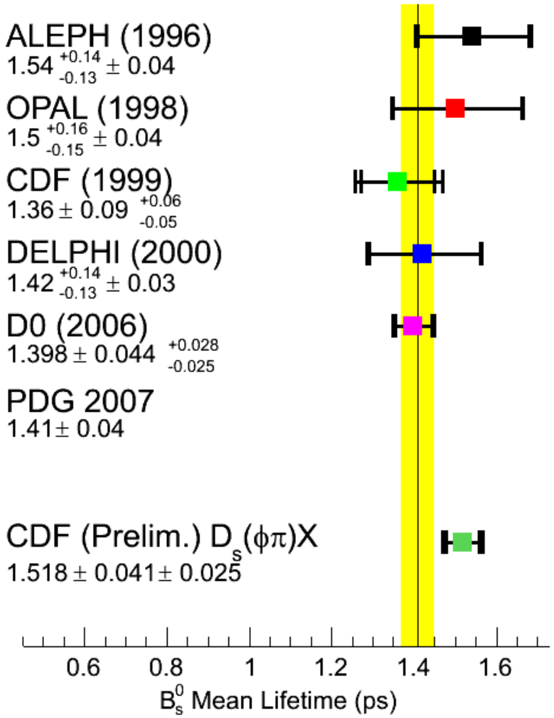
$B_s \rightarrow D_s \pi$ Lifetime Result



- Best flavor specific B_s lifetime:

$$\tau(B_s) = 1.518 \pm 0.041 \pm 0.025 \text{ ps}$$

- In good agreement with CDF and DØ results in $B_s \rightarrow J/\Psi\Phi$



- Note: flavor specific decays measure

$$\tau(B_s^0)_{\rm fs} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$

- Higher value will bring average closer to HQET prediction $\tau_s/\tau_d = 1.0$ +/- 0.02
- HFAG 2007: $\tau_s/\tau_d = 0.94$ +/- 0.02

Topics Not Covered

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

- Many other recent results not covered in this talk:

  - b baryons: Λ_b, Σ_b, Ξ_b
  - Best limits of rare decays:

    $B_s \rightarrow \mu\mu$, $B_s \rightarrow \mu\mu\Phi$, $B_s \rightarrow e\mu$, $B_s \rightarrow ee$, $D^0 \rightarrow \mu\mu$
  - CP asymmetry in semileptonic B decays
  - CP violation in charmless B and Λ_b two-body decays
  - CP asymmetry in $B^+ \rightarrow D^0 K^+$
  - Charm mixing
  - Simulation free lifetime measurement
  - $\Psi(2S)$ production, Y(1S), Y(2S) polarization
  - $B^0 \rightarrow J/\psi K^{*0}$ angular analysis
  - orbitally excited B mesons
  - b-b correlation

Conclusions

- Very rich B physics program at CDF

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

- Great Tevatron performance
  - → accumulate data fast
  - → expect 6-8 fb^{-1} by the end of Run 2

- Expect updates of many analyses

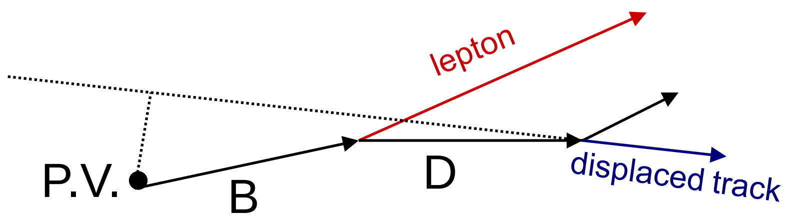
- Exciting time for flavor physics at Tevatron !

Backup Slides

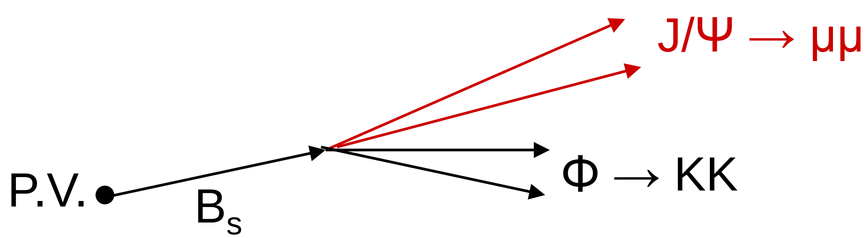
CDF B Physics Triggers

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

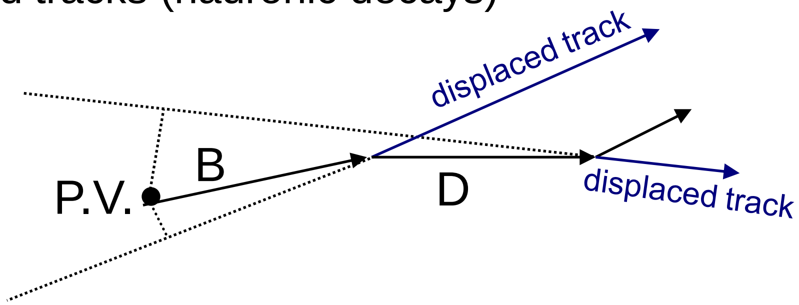
  - 4 GeV lepton + displaced track (semileptonic B decays)



  - di-muon (B → J/Ψ X, B → μμ)



  - two displaced tracks (hadronic decays)

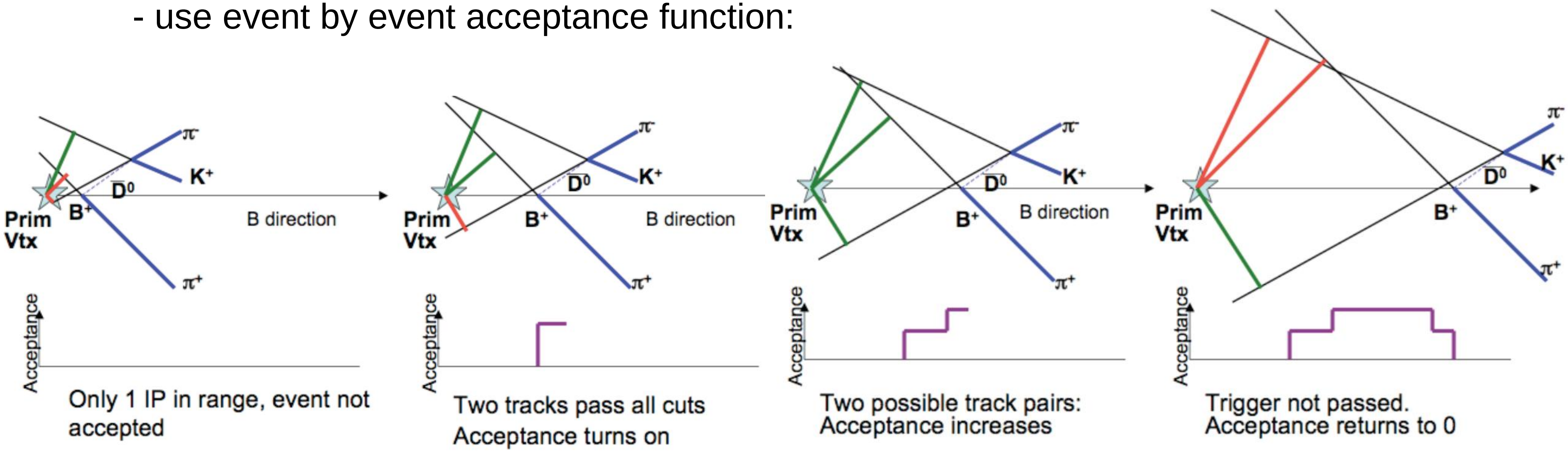


Simulation Free Lifetime Method in $B^+ \rightarrow D^0 \pi^+$ ($1fb^{-1}$)

- CDF has large sample of fully reconstructed decays of b hadrons collected by trigger which requires two displaced tracks with 120 mm < d0 < 1mm
  $\rightarrow$ in general, use simulation to correct for trigger induced lifetime biases

- Already good measurements of B_s (Λ_b lifetime measurement expected soon)
- Use alternative lifetime measurement techniques not based on simulation for better control of systematic uncertainties

- First lifetime measurement without use of simulation in trigger biased sample $B^+ \rightarrow D^0 \pi^+$ shows proof of principle
  - use event by event acceptance function:



Simulation Free B^+ Lifetime Results

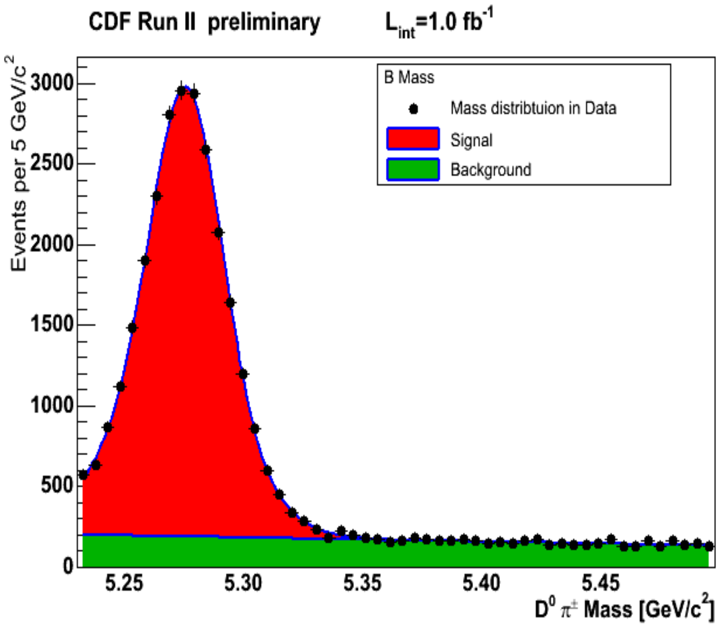
- 24200 +/- 200 signal events with S/B ~4.8

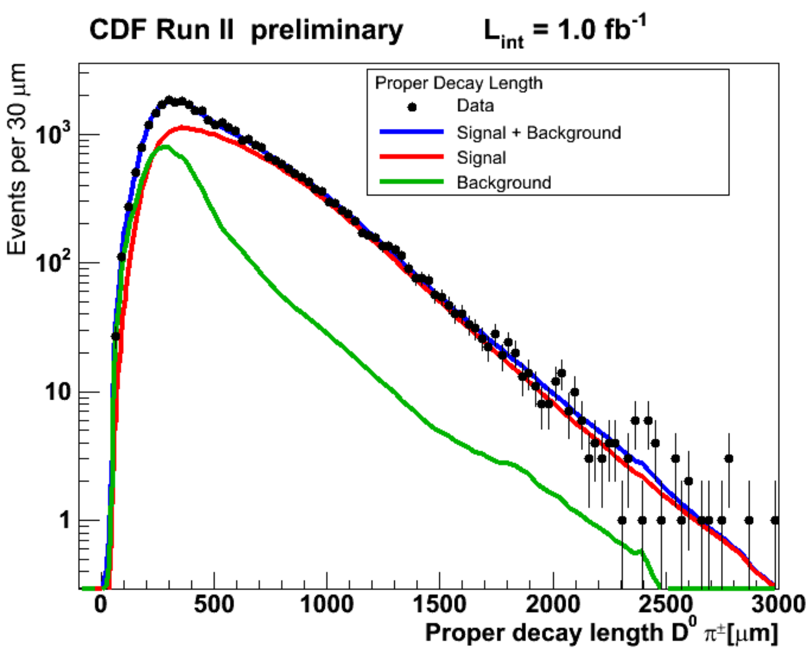
$\tau(B+) = 1.662 \pm 0.023$ (stat.) $\pm$ 0.013 (syst.) ps

- In good agreement with PDG average:
  1.638 $\pm$ 0.011 ps

- Method to be used in the future for better measurements of B_s and Λ_b lifetimes in trigger biased samples
  - with large data samples will also need better control of systematic uncertainties

- Important proof of principle for LHC experiments





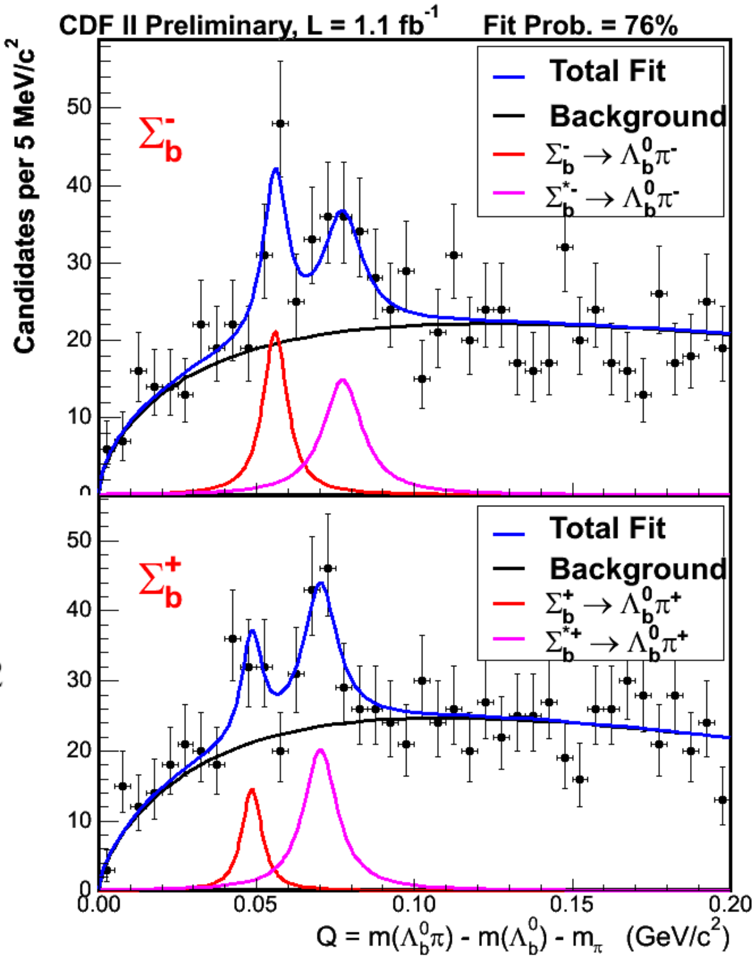
Σ_b Mass Measurement (1.1 fb^{-1})

PRL 99, 202001 (2007)

- Σ_b properties predicted by HQET, now tested by exp
- First observation of Σ_b and Σ_b* by CDF in 2007
- Reconstructed decay mode:

$$\Sigma_b^{(*)\pm} \to \Lambda_b^0 \pi^\pm$$
$$\Lambda_b^0 \to \Lambda_c^+ \pi^-$$
$$\Lambda_c^+ \to p K^- \pi^+$$

$$m_{\Sigma_b^+} = 5807.8^{+2.0}_{-2.2}\ (\text{stat.}) \pm 1.7\ (\text{syst.})\ \text{MeV}/c^2$$
$$m_{\Sigma_b^-} = 5815.2 \pm 1.0\ (\text{stat.}) \pm 1.7\ (\text{syst.})\ \text{MeV}/c^2$$
$$m_{\Sigma_b^{*+}} = 5829.0^{+1.6}_{-1.8}\ (\text{stat.})^{+1.7}_{-1.8}\ (\text{syst.})\ \text{MeV}/c^2$$
$$m_{\Sigma_b^{*-}} = 5836.4 \pm 2.0\ (\text{stat.})^{+1.8}_{-1.7}\ (\text{syst.})\ \text{MeV}/c^2$$



Ξ_b Mass Measurement (1.9 fb^{-1})

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

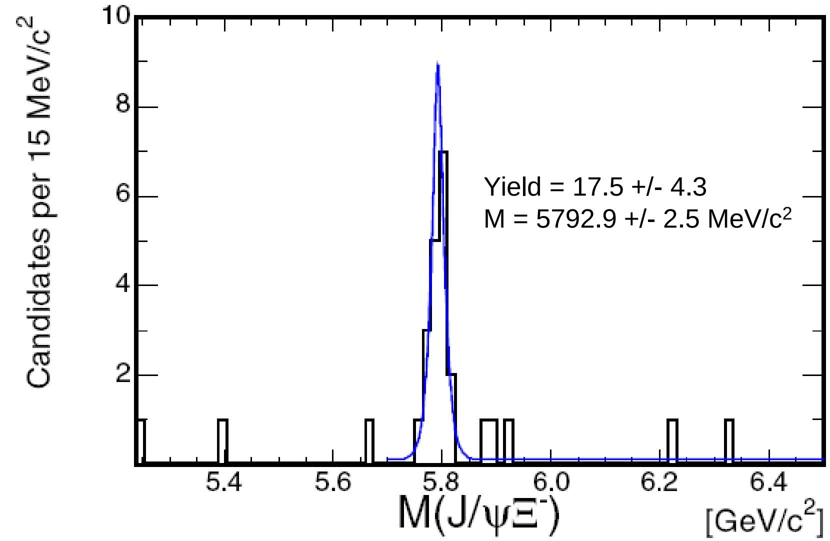
- Ξ_b (quark content: *bds*) $\rightarrow$ third observed b baryon after Λ_b and CDF's recent discovery of Σ_b

- Study b baryons $\rightarrow$ great way to test QCD which predicts $M(\Lambda_b) < M(\Xi_b) < M(\Sigma_b)$

- Decay mode

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

- Ξ tracked in silicon vertex detector for the first time at hadron collider

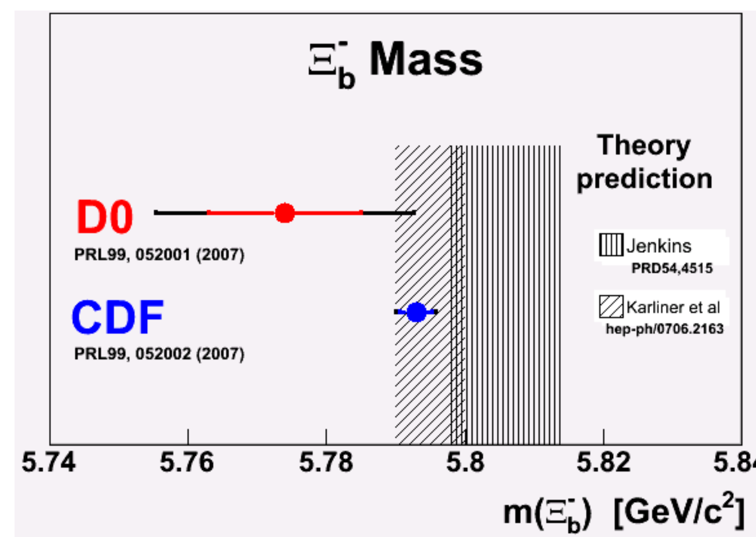


- Most precise measurement at 7.8σ significance

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

- Ξ_b can be measured in hadronic decays at CDF

- With more data will study other properties of Ξ_b



Branching Fractions and CP Asymmetry in $B^+ \to D^0 K^+$ (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:

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

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

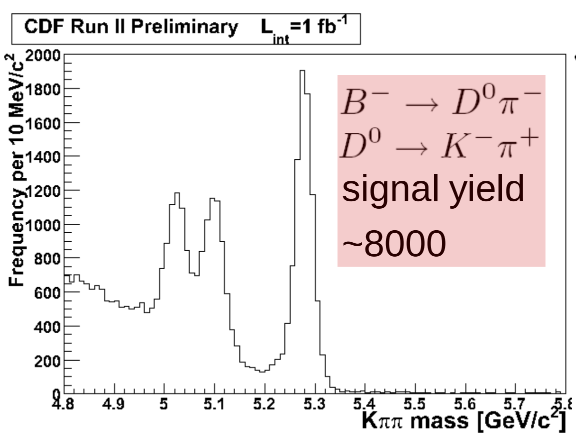
CP even eigenstate:

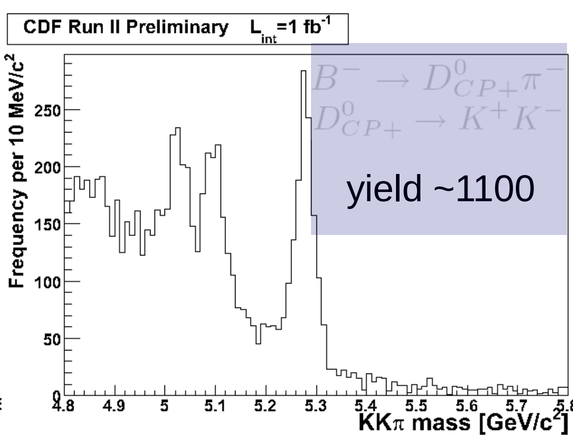
$$D^0_{CP+} \to K^+K^-$$

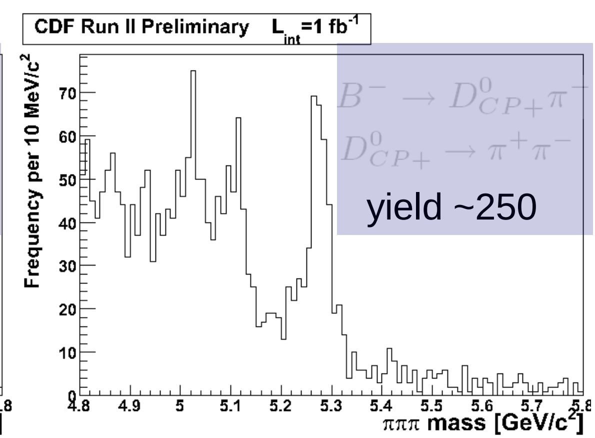
$$D^0_{CP+} \to \pi^+\pi^-$$

Flavor eigenstate:

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





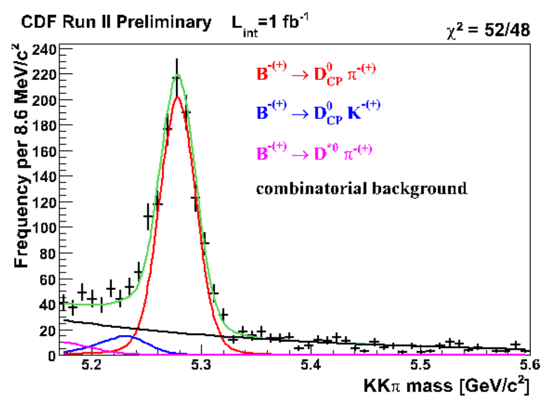


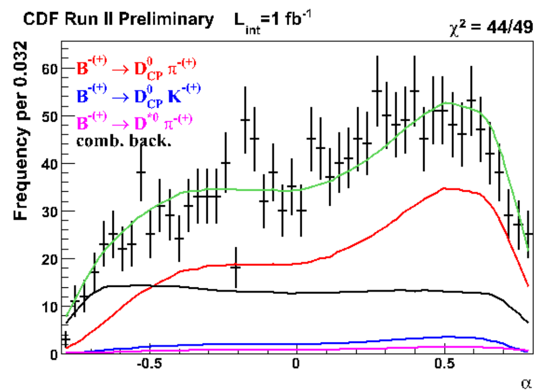
Branching Fractions and CP Asymmetry in $B^+ \to D^0 K^+$ (1 fb^{-1})

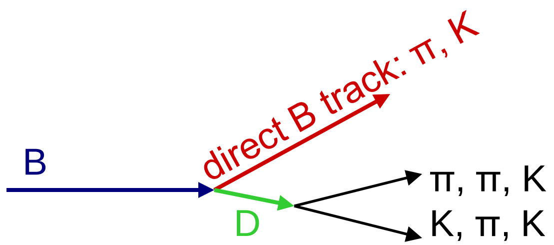
- Discriminating variables used to disentangle decay modes:

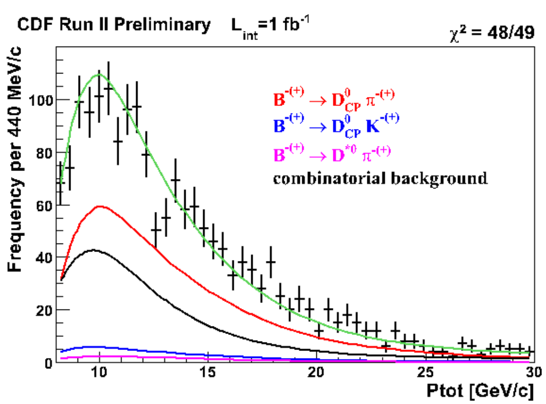
  - (D^0,track) invariant mass
  - momentum imbalance: $p_{tr} < p_{D^0}$ $\quad \alpha = 1 - p_{tr}/p_{D^0} > 0$
  - total momentum $\quad p_{tr} \geq p_{D^0}$ $\quad \alpha = -(1 - p_{D^0}/p_{tr}) \leq 0.$
  - ‘kaonness’ contains dE/dx information

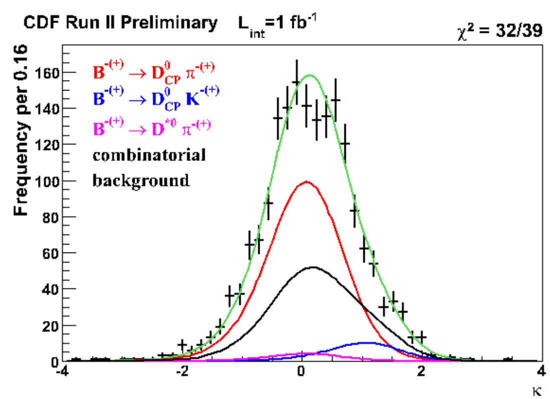
  of direct B track $\quad p_{tot} = p_t + p_{D^0}$











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

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

- Results:
  - ratio of branching fractions:

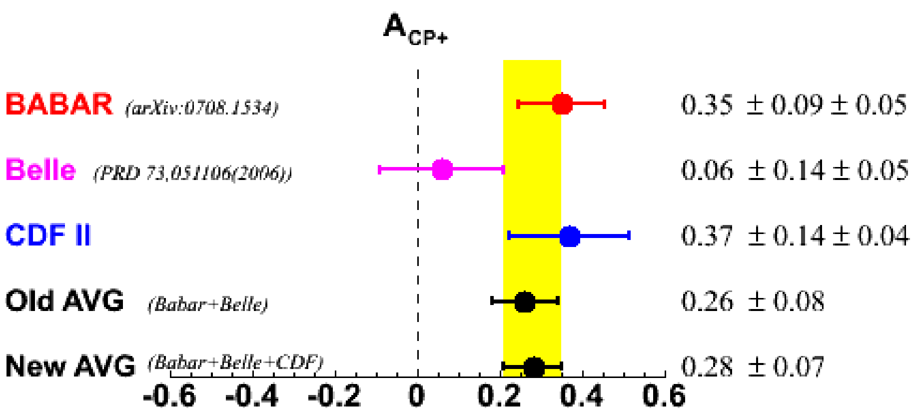
$$R = \frac{BR(B^- \to D^0 K^-) + BR(B^+ \to \overline{D}^0 K^+)}{BR(B^- \to D^0 \pi^-) + BR(B^+ \to \overline{D}^0 \pi^+)} = 0.0745 \pm 0.0043(stat.) \pm 0.0045(syst.)$$

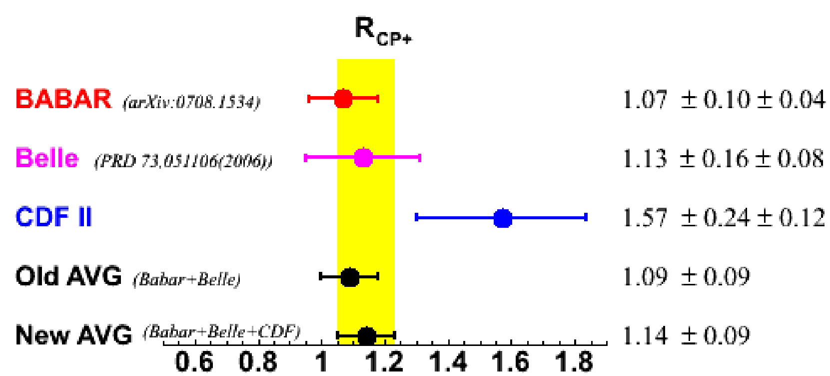
$$R_{CP+} = \frac{BR(B^- \to D^0_{CP+} K^-) + BR(B^+ \to D^0_{CP+} K^+)}{[BR(B^- \to D^0 K^-) + BR(B^+ \to \overline{D}^0 K^+)]/2} = 1.57 \pm 0.24(stat.) \pm 0.12(syst.)$$

  - direct CP asymmetry:

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

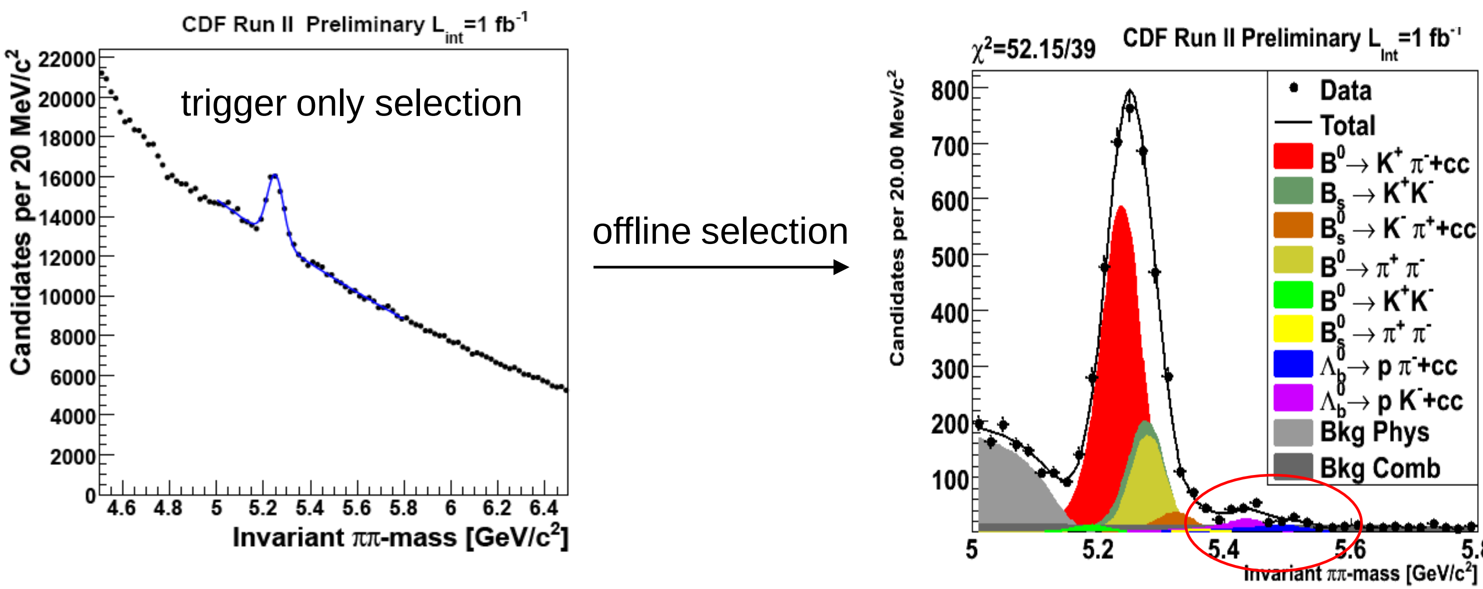
- Quantities measured for the first time at hadron colliders
- Results in agreement and competitive with B factories





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

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



- 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 $\Lambda_b \rightarrow p\,\pi(K)$

- Results:

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

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

- First CP asymmetry measurement in b baryon decays

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

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

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

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

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

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

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

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

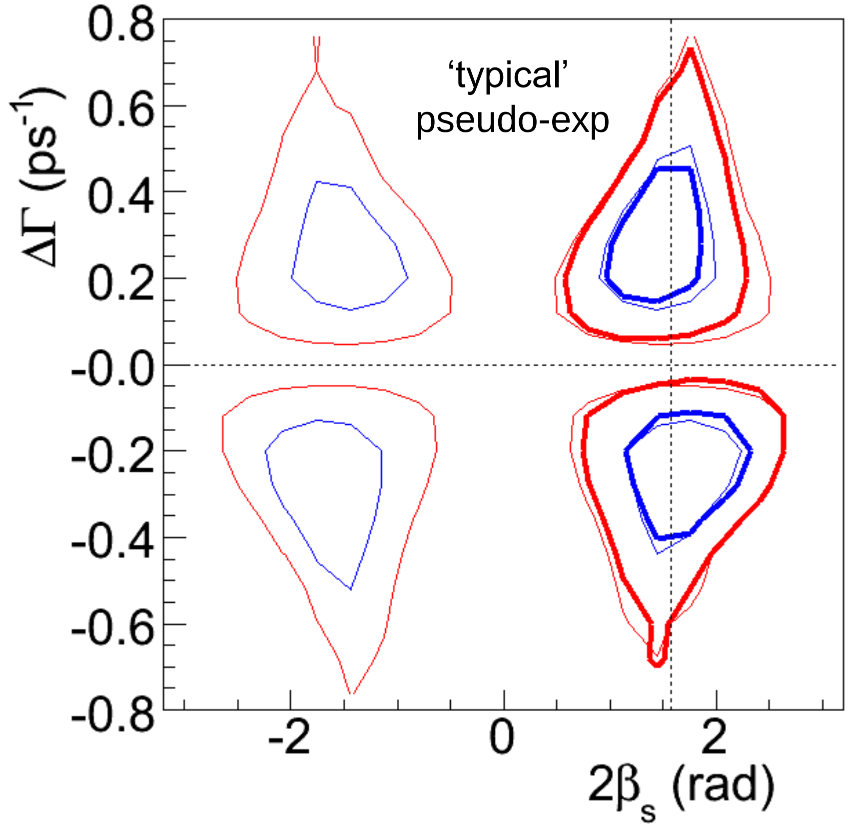
$$2\beta_s \to \pi - 2\beta_s$$
$$\Delta\Gamma \to -\Delta\Gamma$$
$$\delta_\parallel \to 2\pi - \delta_\parallel,$$
$$\delta_\perp \to \pi - \delta_\perp$$

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

pseudo experiment $2\beta_s$-$\Delta\Gamma$ likelihood profile



2Δlog(L) = 2.3 ≈ 68% CL — un-tagged

2Δlog(L) = 6.0 ≈ 95% CL — tagged

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:

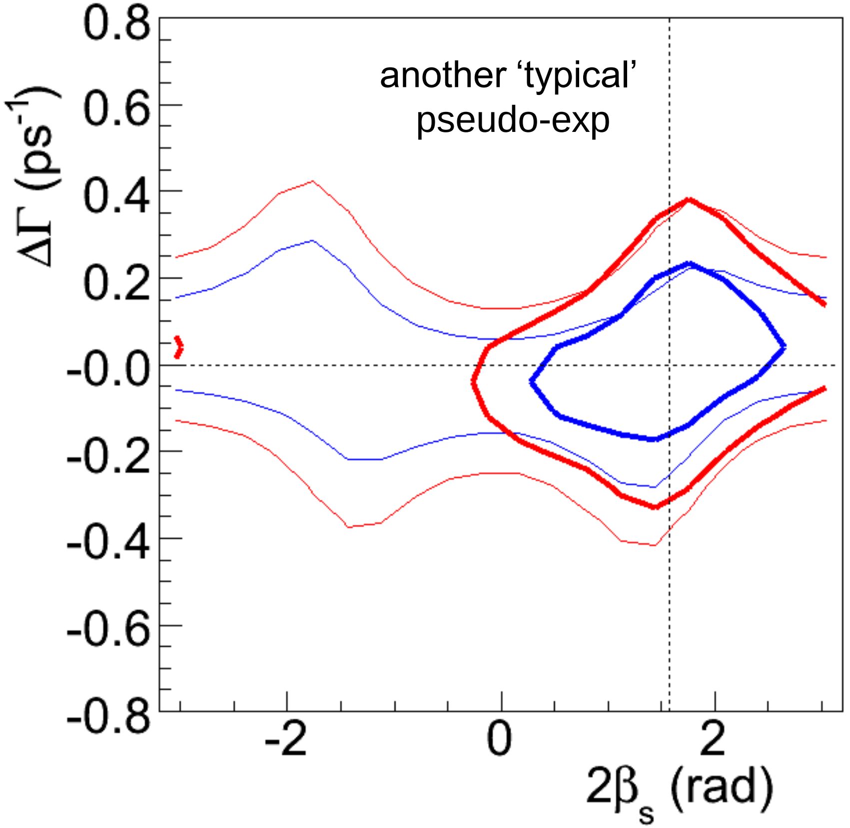
$$2\beta_s \rightarrow \pi - 2\beta_s$$
$$\Delta\Gamma \rightarrow -\Delta\Gamma$$
$$\delta_{\|} \rightarrow 2\pi - \delta_{\|},$$
$$\delta_{\perp} \rightarrow \pi - \delta_{\perp}$$

- Study expected effect of tagging using pseudo-experiments

- Improvement of parameter resolution is small due to limited tagging power (εD^2 ~ 4.5% compared to B factories ~30%)

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

pseudo experiment $2\beta_s$-$\Delta\Gamma$ likelihood profile



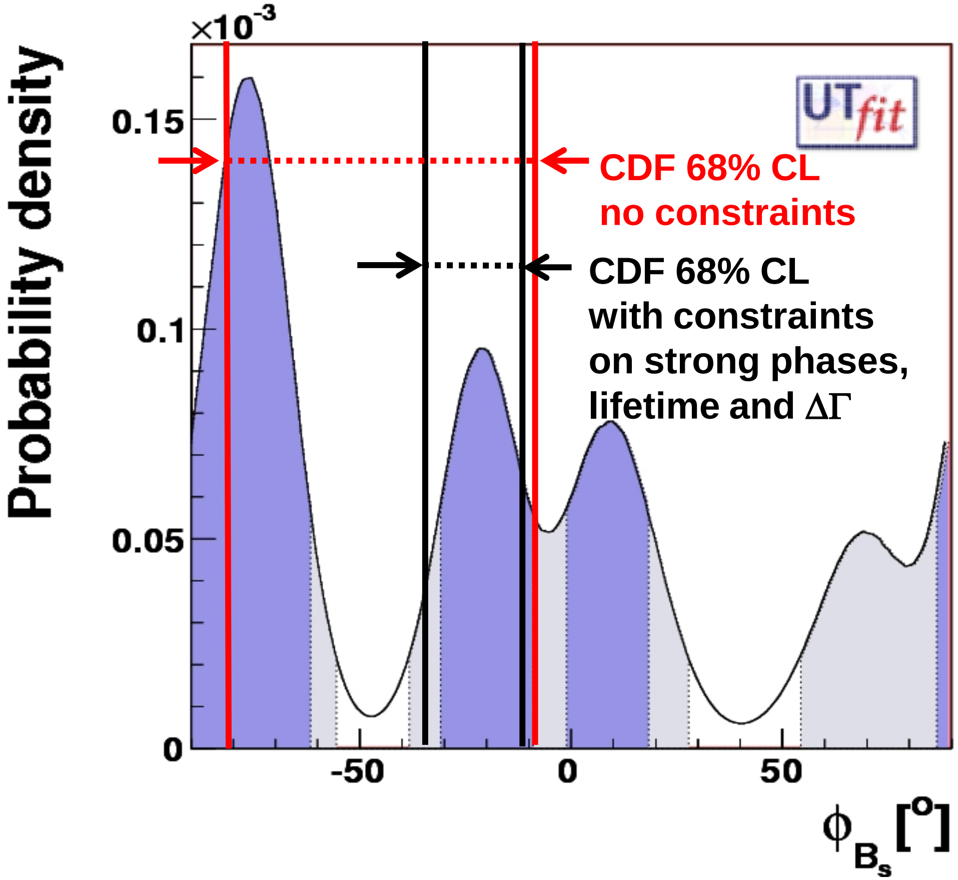
$2\Delta\log(L) = 2.3 \approx 68\%$ CL — un-tagged

$2\Delta\log(L) = 6.0 \approx 95\%$ CL — tagged

CDF Impact on Φ_s World Average

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

http://www.utfit.org/



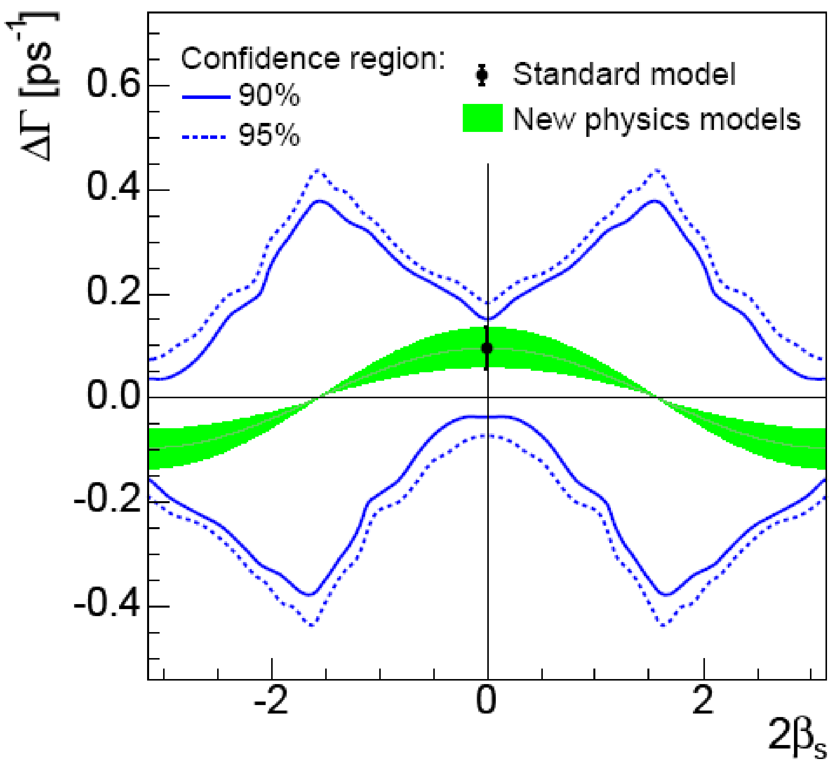
- CDF measurement suppresses large fraction of CP violation parameter space !

CP Violation Phase β_s in Un-tagged $B_s \rightarrow J/\Psi\Phi$ Decays (1.7 fb-1)

- 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%)

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



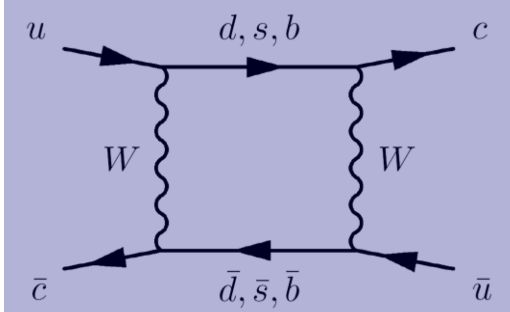
D^0 Mixing

arXiv:0712.1567

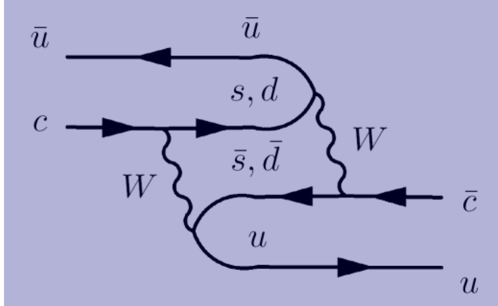
- After recent observation of fastest neutral meson oscillations in B_s system by CDF and DØ $\rightarrow$ time to look at the slowest oscillation of D^0 mesons ☺

- 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)

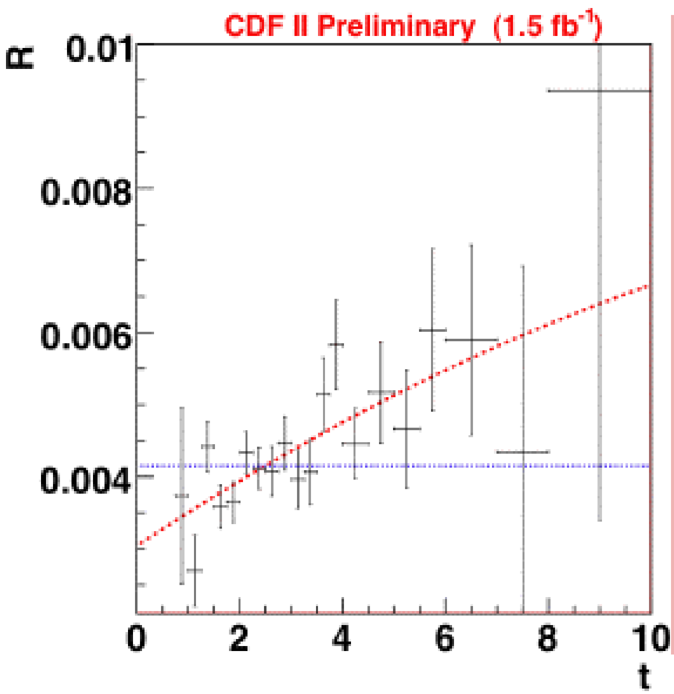
- CDF sees evidence for D^0 mixing at 3.8σ significance by comparing DCS $D^0 \rightarrow K^+\pi^-$ decay time distribution to CF $D^0 \rightarrow K^-\pi^+$ (confirms *BaBar*)
- Ratio of decay time distributions:

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

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

Rare Decays

- 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
- Best limits are set by CDF in various channels:

- 2.0 fb^{-1}

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

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 5.8 \times 10^{-8}\ (4.7 \times 10^{-8})$$ 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

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

- 0.36 fb^{-1}

$Br(D^0 \to \mu\mu) < 5.3 \times 10^{-7}$ (95%CL) **http://www-cdf.fnal.gov/physics/new/bottom/080228.blessed-d0-mumu/**

- Search for lepton flavor violation with 2fb^{-1} leads to best limits in $B_{s/d} \to e\mu$ channel:

$Br(B_s \to e\mu) < 2.0(2.6) \times 10^{-7}$

$Br(B_d \to e\mu) < 6.4(7.9) \times 10^{-8}$

http://home.fnal.gov/~wenzel/bsemu/bsemu.html