B_s Mixing Phase and CP Violation at Tevatron

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Outline

- B_s mixing
  - First measurement of $\sin 2\beta_s$ at TeVatron
  - Other B_s mixing phase related measurement
  - Outlook
- More B_s physics topics

Flavor mixing

- Flavor eigenstate ≠ Hamiltonian eigenstate
  - transition between meson and anti-meson exists
- Simplified Schroedinger equation describing mixing and decay

$$i\frac{d}{dt}\begin{pmatrix} B_q^0(t) \\ \overline{B_q^0}(t) \end{pmatrix} = (M - \frac{i}{2}\Gamma)\begin{pmatrix} B_q^0 \\ \overline{B_q^0} \end{pmatrix} \qquad \begin{pmatrix} M_{11} & M_{12} \\ M_{12}^* & M_{22} \end{pmatrix} ; \begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma_{22} \end{pmatrix}$$

- The mass and lifetime eigenstates (with $\Gamma_{12}/M_{12} << 1$)

$$|B_L> = p|B_q^0> + q|\overline{B}_q^0> \qquad \Delta m_q = m_H - m_L = 2|M_{12}^q|$$

$$|B_H> = p|B_q^0> - q|\overline{B}_q^0> \qquad \Delta\Gamma_q = \Gamma_L - \Gamma_H \cong -2|\Gamma_{12}^q|\,\mathrm{Re}(\frac{\Gamma_{12}^q}{M_{12}^q}) = 2|\Gamma_{12}^q|\cos(\varphi_s)$$

M_{12} and Γ_{12} are the focus of CDF & DØ experiments in the B_s system

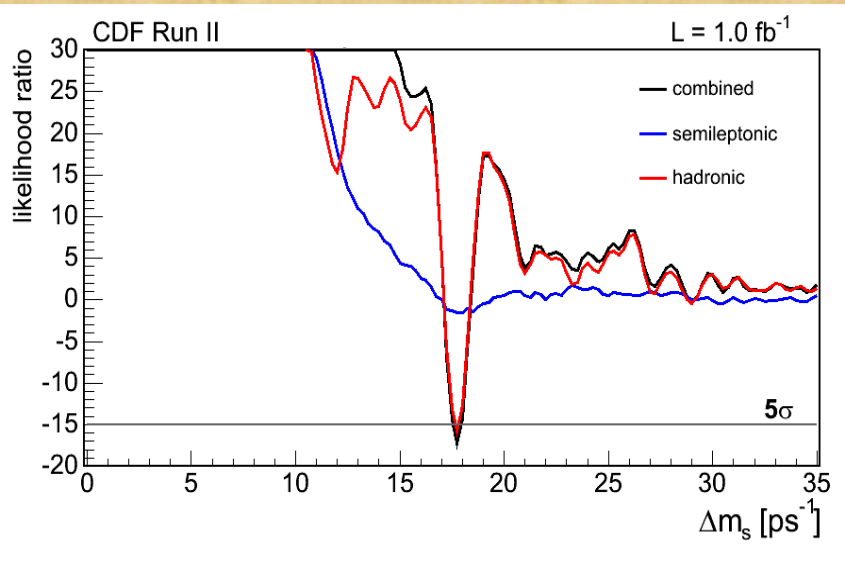
$|M_{12}|$ and Δm_s

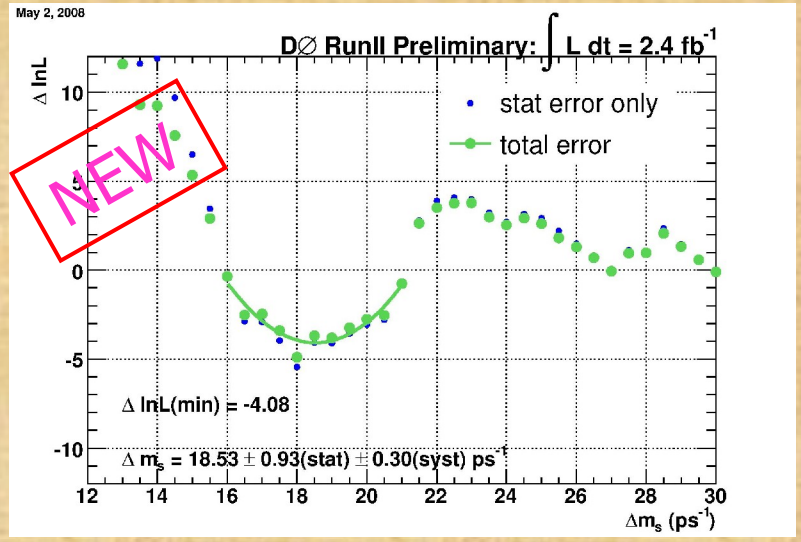
- Oscillation observed at CDF in 2006 with 1fb^{-1} of data
- Δm_s known with great precision:

$$\Delta m_s = 17.77 \pm 0.10(stat) \pm 0.07\, ps^{-1}$$

$$\frac{|V_{td}|}{|V_{ts}|} = 0.2060 \pm 0.0007(\exp)^{+0.0081}_{-0.0060}(theor)$$

- Comparision with SM prediction limited by lattice QCD uncertainty!





- 3σ significance (stat. only) obtained at DØ (2.4 fb^{-1})
- DØ note 5618:

$$\Delta m_s = 18.53 \pm 0.90(stat) \pm 0.30(syst)\ \ ps^{-1}$$

- Consistent with CDF result

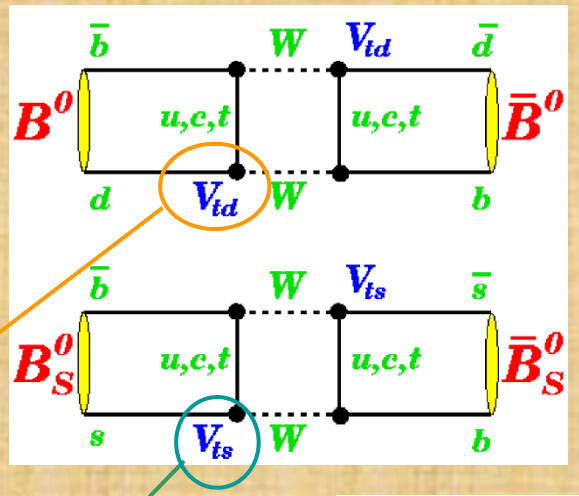
What about Mixing phase?

- In the SM phase of the mixing amplitude connected to the phase of CKM elements:

$$\Phi_M = \arg(V_{tb}V_{ts}^*)^2$$

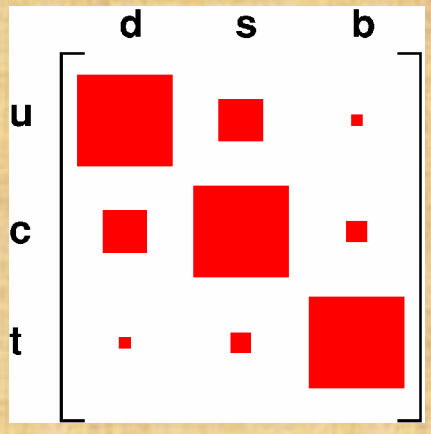
- In the Wolfenstain Parametrization (expanding in terms of $\lambda = \sin(\theta_c) \sim 0.23$ to $O(\lambda^5)$

  - η responsible for CP Violation $\Rightarrow \eta \neq 0$ implies CPV



$$V_{CKM} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + \frac{1}{2}A^2\lambda^5[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1 + 4A^2) & A\lambda^2 \\ A\lambda^3[1 - (1 - \frac{1}{2}\lambda^2)(\rho - i\eta)] & -A\lambda^2 + \frac{1}{2}A\lambda^4[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}A^2\lambda^4 \end{pmatrix} + O(\lambda^6)$$

Large CPV Suppressed CPV

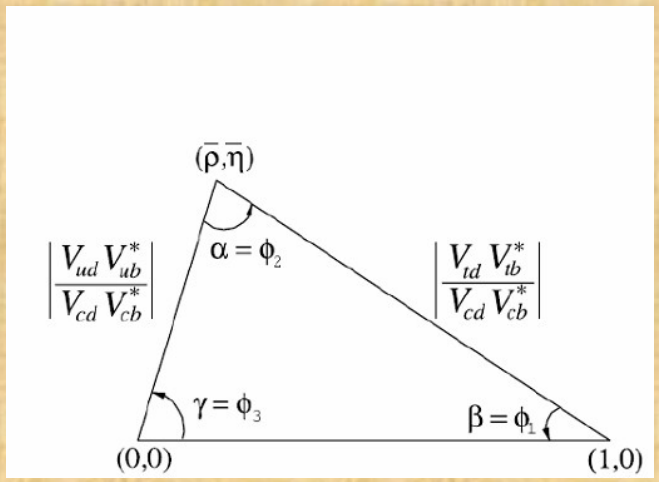


$\Rightarrow$ Standard Model does <u>not</u> predict values for CKM elements:

$\Rightarrow$ <u>CKM</u> hyerarchy implies small CP violation in B_s mixing

Unitarity triangle(s)

Unitarity Triangle

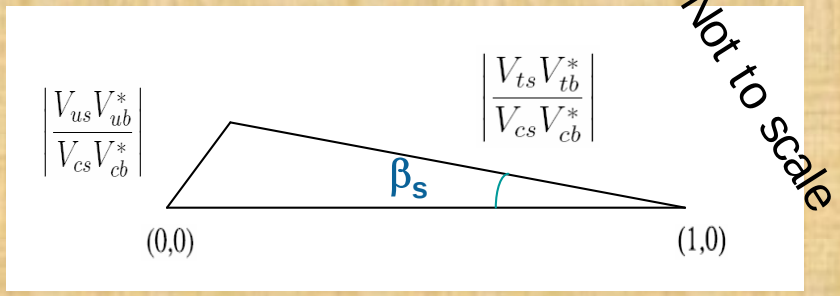


$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$$ß^{SM} = \arg -\frac{V_{tb}V_{tb}^*}{V_{cs}V_{cb}^*} \sim 0.75\ rad$$

β determines CP violation in interference of mixing and decay in b→ccs B_d transition

B_s Unitarity Triangle



$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

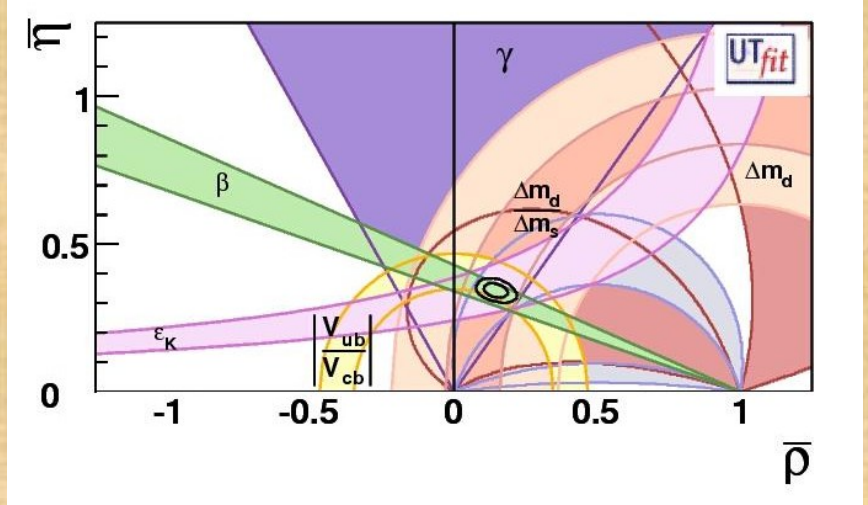
$$ß_S^{SM} = \arg -\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*} \sim 0.02\ rad$$

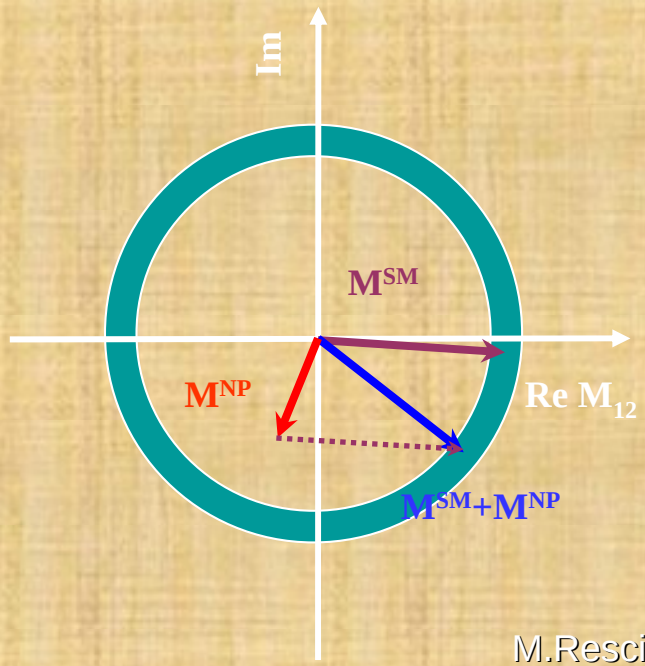
β_s determines CP violation in B_s case

⇒ Triangle not closing or large β_s would signal NP

New Physics in B_s mixing

- New Physics could likely contribute to $\Delta B=2$ transitions
- CKM fit including $\Delta ms/\Delta md$ (unfortunately) very successful
- But the picture is not complete until also the phase has been constrained





- Phase of the mixing amplitude is poorly determined
- Both are needed to constrain New Physics:

$$M_{12} = |M_{12}|\, e^{i\Phi_M} = |M_{12}|\, e^{-i2\beta_s}$$

Large value of CP Violation phase Φ_M is a clear sign of New Physics!

New Physics in B_s Mixing

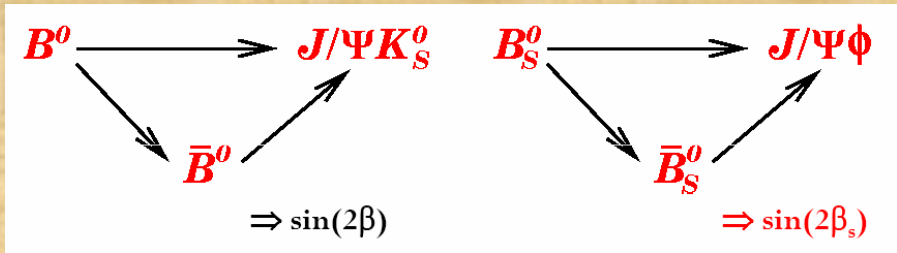
- If New Physics present in mixing amplitude:
  - $\boxed{F_s = F_s^{SM} + F_s^{NP} \sim F_s^{NP}}$ $[\Phi_s^{SM} \sim 0.004\ rad]$
  - Phase Φ_s can be measured directly using charge asymmetry in B_s semileptonic decays or through $\Delta\Gamma_s$ measurement
- CP violation phase β_s is also expected to be <u>small</u> in the Standard Model:
  - $\boxed{\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right) \sim 0.02\ \text{rad}}$
- <u>Same</u> New Physics phase F_s^{NP} would add to $\beta_s \Rightarrow$ $2\beta_s = 2\beta_s^{SM} - F_s^{NP}$
- if NP dominates $2\beta_s = -F_s$ $M_{12} = |M_{12}|\, e^{iF_M} = |M_{12}|\, e^{-i2\beta_s} = |M_{12}|\, e^{iF_s}$

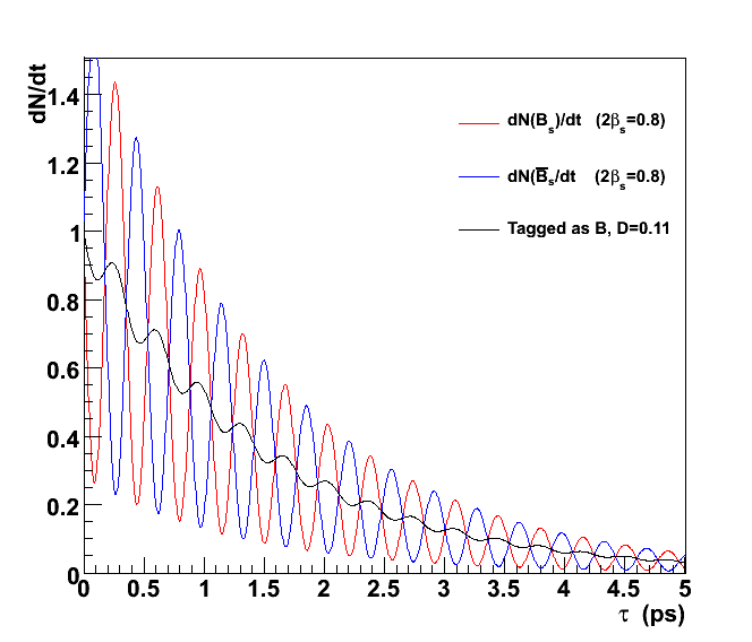
  $\Rightarrow$Large CP violation phase in $B_s \to J/\Psi\ \Phi$ decay is unequivocal sign of physics beyond the Standard Model

NB: CDF and DØ use different notations $2\beta_s(\text{CDF}) = -\phi_s(\text{DØ})$

CP violating time dependence

- Looking for CP violation in interference of decay with/without mixing
  - sin2β analog
- Contrary to the sin2β case B_s mixes much faster → cannot fit the asymmetry directly
- "Signal" appears as a time and CP dependent modulation of the exponential decay
  - In the SM the modulation is extremely tiny, the figure is exagerated
- Imperfect Tagging and experimental resolution on proer time makes life very hard
  - (typical dilution and no proper time smearing here)

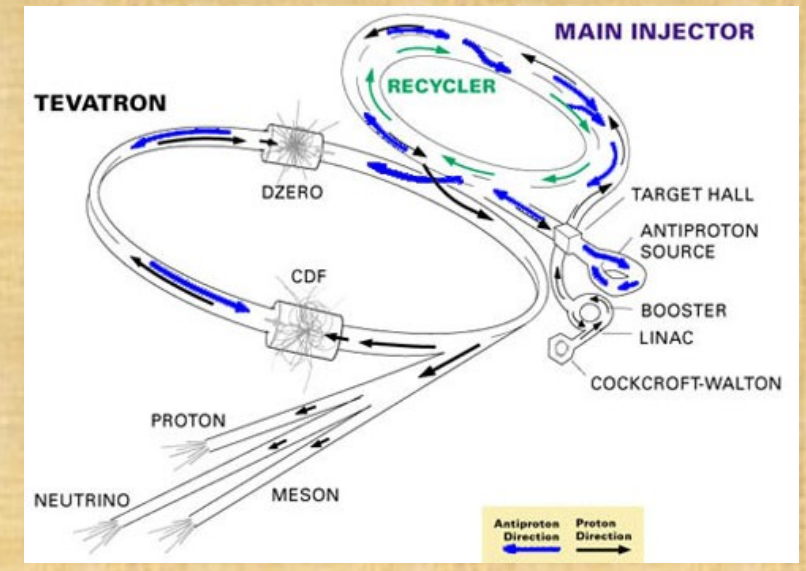


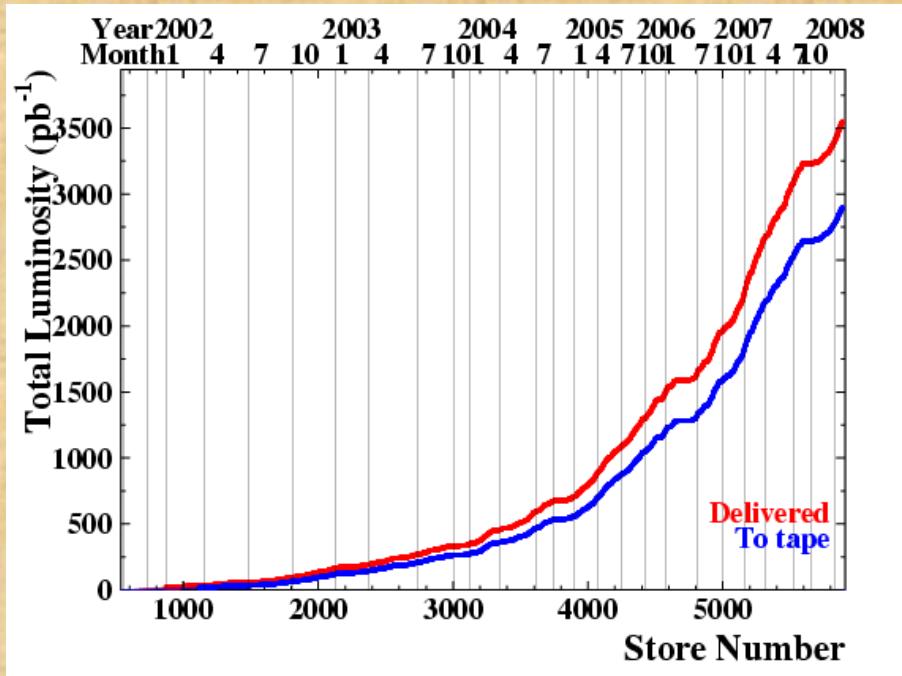


- $J/\Psi\phi$ is a mixture of CP eigenstate → need to be statistically separated through angular analysis

The Tevatron

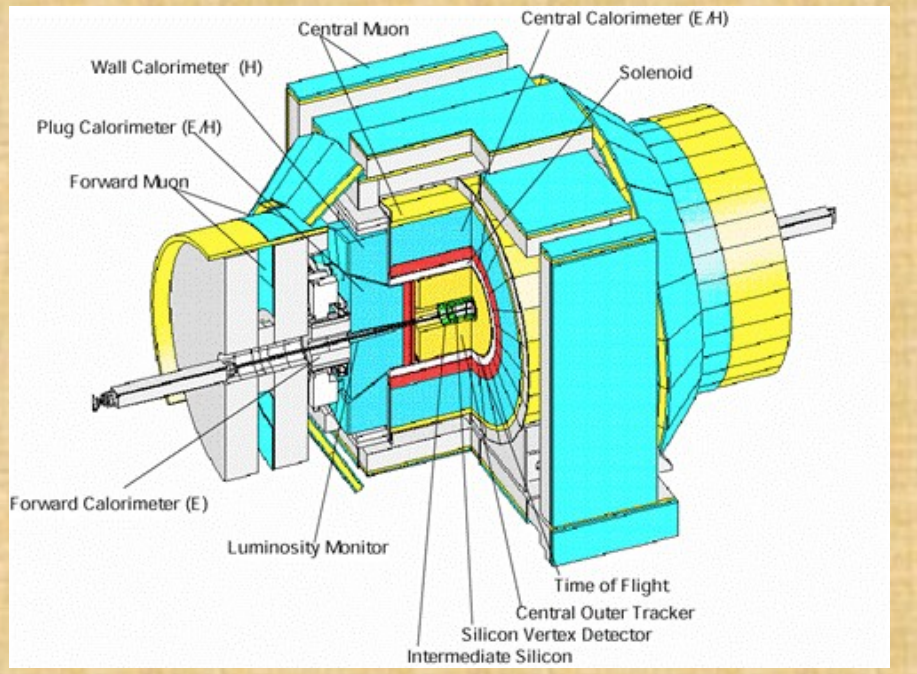
- $p\bar{p}$ collisions at 1.96 TeV
- Excellent Performance
- Peak Initial Luminosity recent record: 3.15 x 10^{32} cm^{-2} s^{-1}
- Challenge for Detectors, Triggers and Reconstructions





- Tevatron detectors are the only one to have currently access to sizeable numbers of B_s mesons
- The analyses presented in this talk span from 1.35 to 2.8 fb^{-1}
- Currently on tape > 3 fb^{-1}

Tevatron Detectors

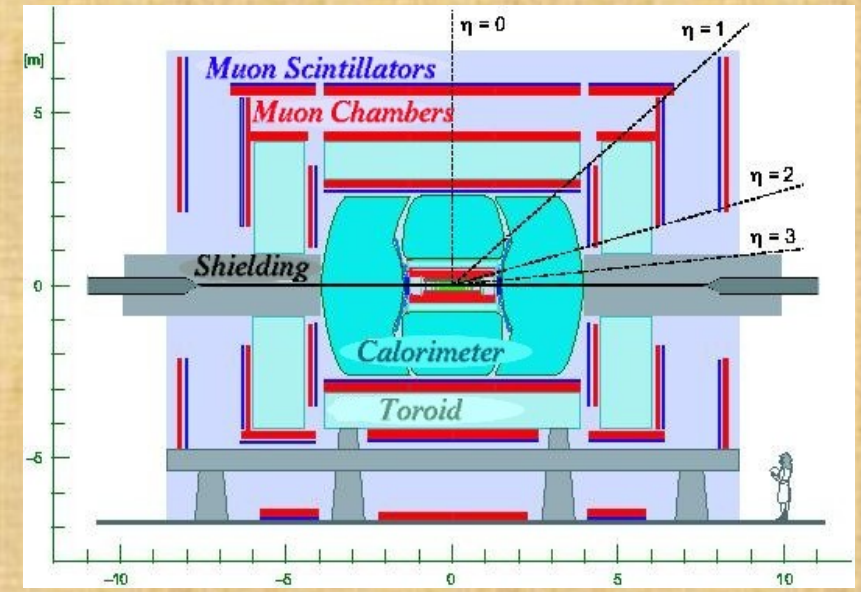


CDF II Detector

- Tracker: - Silicon Vertex Detector
  - Drift Chambers
- **Excellent Momentum Resolution**
- **Particle ID**: TOF and dE/dx
- Triggered Muon Coverage $|\eta|<1$

DØ Detector

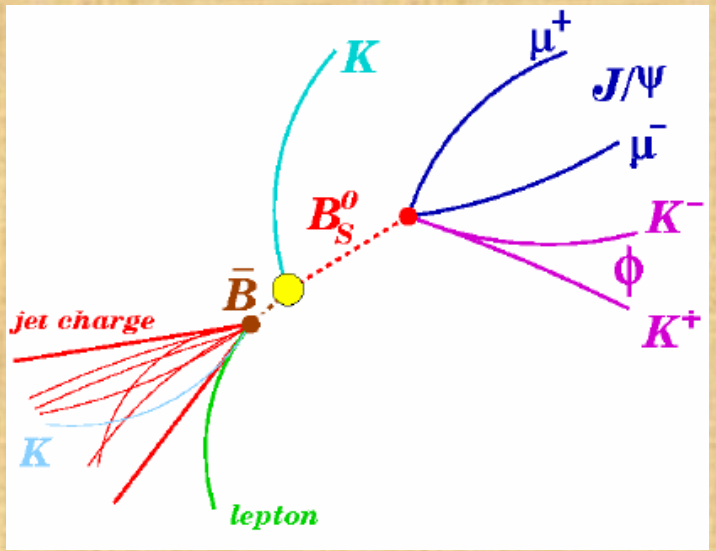
- **New L00** installed in 2006!
- Solenoid: 2T, weekly reversed polarity
- Excellent Calorimetry and electron ID
- **Triggered Muon Coverage** $|\eta|< 2.2$



Analysis Flow

1 Reconstruct decays from stable products:

- $B_s \rightarrow J/\Psi[\mu^+\mu^-]\ \Phi[K^+K^-]$
- $B_d \rightarrow J/\Psi[\mu^+\mu^-]\ K^{*0}[K^+\pi^-]$ (control sample)

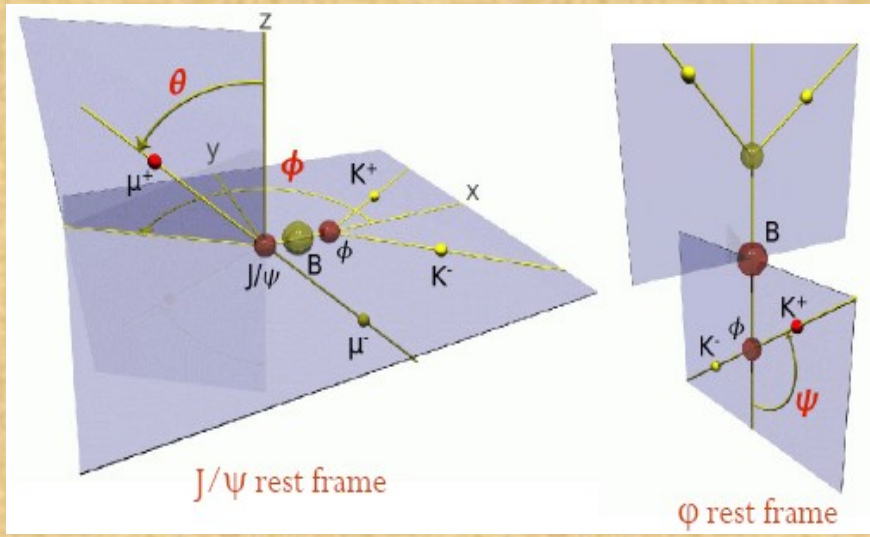


2. Measure lifetime $ct = m_B * L_{xy}/p_T$
   - Proper time resolution essential to resolve oscillations

3. Measure decay angles in transversity base:

$$\vec{w} = (\theta_T, F_T, \psi)$$

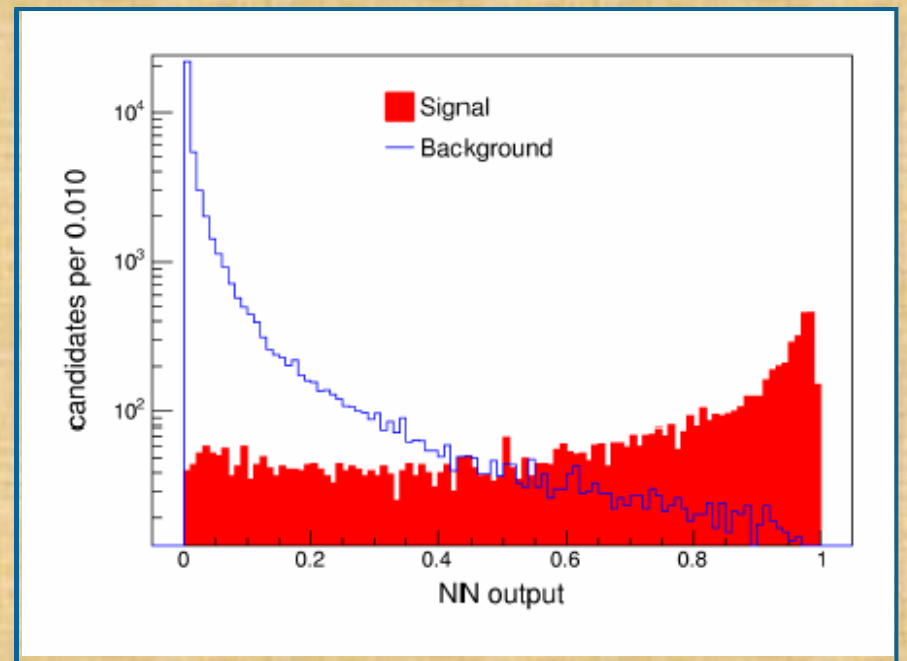
4. Identify $B_s / \overline{B}_s$ at production time:
   - Flavor Tagging (Tag decision ξ)



5. Perform maximum likelihood fit:
   - Likelihood in m, ct, w , ξ

Trigger/Signal selection

- **Trivial (?) trigger:**
  - Dimuons with invariant mass cuts around J/Ψ mass:
    - $P_{t\mu}$>1.5 GeV at low luminosity
    - Increasingly restrictive at higher luminosity
  - Significant bandwidth needed at high lumi (2E32 $cm^{-2}s^{-1}$)
    - 5 KHz (L1), 100 Hz (L2), 10 Hz (3)
- **Offline selection:**
  - CDF: Neural Network selection
  - DØ: cut based selection



NN Variables:

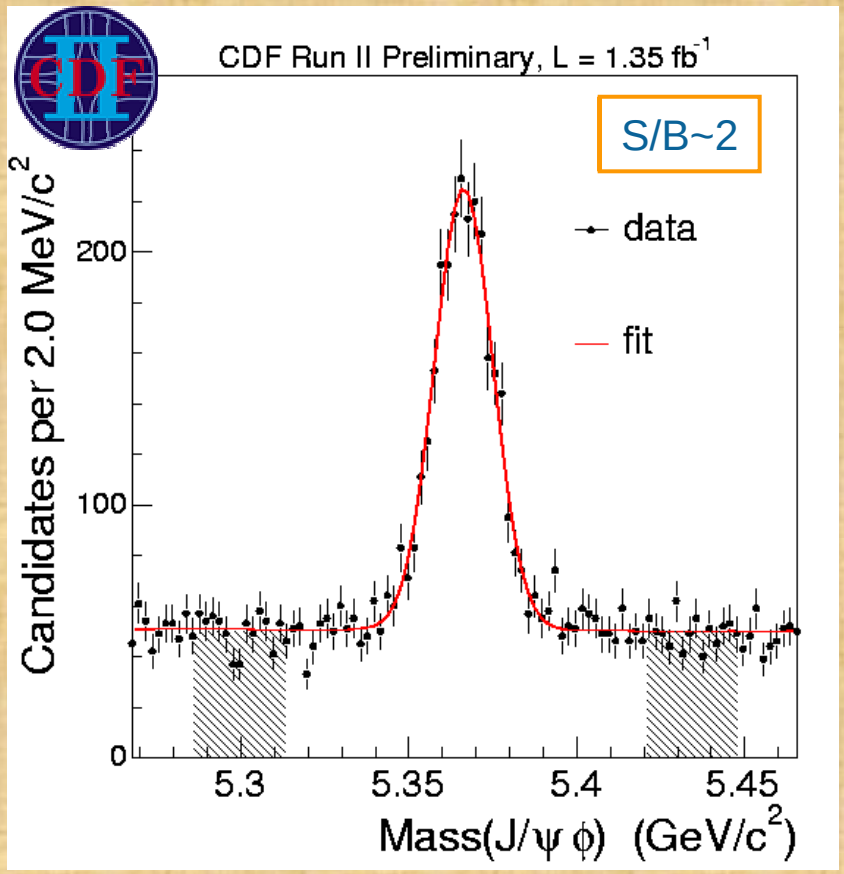
B_s: p_T and vertex quality

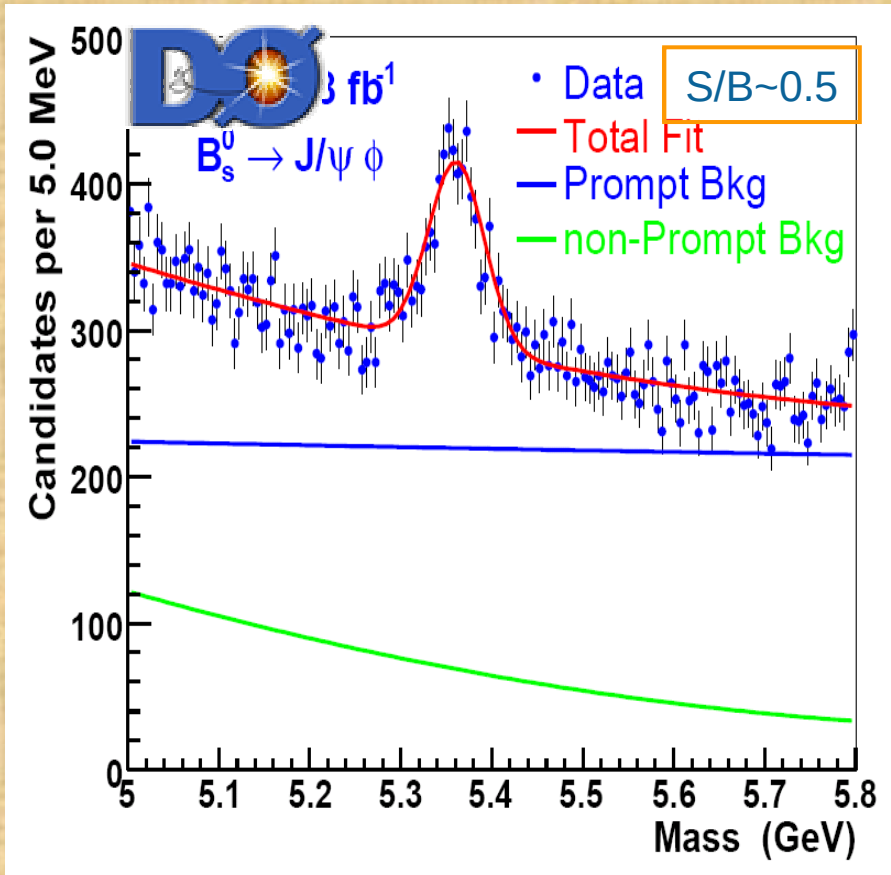
J/Ψ: p_T and vertex quality

F: mass and vertex quality

K^+/K^-: p_T and PID (TOF, dE/dx)

Signal





Signal Candidates:

- ~2000 in 1.35 fb^{-1} (Tagged analysis)
- ~2500 in 1.7 fb^{-1} (Untagged analysis)

Signal Candidates:

- ~2000 in 2.8 fb^{-1} (Tagged analysis)

P→VV decay rate (I)

$$\frac{d^4P(t,\vec{w})}{dtd\vec{w}} \propto A_0|^2 T_+ f_1(\vec{w}) + |A_\parallel|^2 T_+ f_2(\vec{w})$$
$$+|A_\perp|^2 T_- f_3(\vec{w}) + |A_\parallel||A_\perp| U_+ f_4(\vec{w})$$
$$+|A_0||A_\parallel|\cos(\mathrm{d}_\parallel) T_+ f_5(\vec{w})$$
$$+|A_0||A_\perp| V_+ f_6(\vec{w})$$

CP conserving strong phases

$$\mathrm{d}_\parallel = \arg(A_\parallel^* A_0)$$
$$\mathrm{d}_\perp = \arg(A_\perp^* A_0)$$

- Decay rate is a function of time, decay angles $\vec{w} = (\theta_T, F_T, \psi)$, initial B_s flavor and parameters $\Delta\Gamma_s$, β_s
- B_s decays into admixture of CP eigenstates (L=0,2 CP even; L=1 CP odd); 3 independent decay amplitude
- Using transverse polarization basis: A_0, $A_{//}$ CP even ; $A_\perp$ CP odd
  - ➢ <u>interference</u> terms allow sensitivity to CP violation in untagged (or poorly tagged) sample
- f_i (i=1,…,6) encode the different angular distributions

P→VV decay rate(II)

$$\frac{d^4P(t,\vec{w})}{dtd\vec{w}} \propto A_0|^2 T_+ f_1(\vec{w}) + |A_{||}|^2 T_+ f_2(\vec{w})$$
$$+|A_\perp|^2 T_- f_3(\vec{w}) + |A_{||}||A_\perp| U_+ f_4(\vec{w})$$
$$+|A_0||A_{||}|\cos(d_{||}) T_+ f_5(\vec{w})$$
$$+|A_0||A_\perp| V_+ f_6(\vec{w})$$

CP conserving strong phases

$$d_{||} = \arg(A_{||}^* A_0)$$
$$d_\perp = \arg(A_\perp^* A_0)$$

$$T_\pm = e^{-Gt} \times [\cosh(\Delta Gt/2) \mp \cos(2ß_s)\sinh(\Delta Gt/2)]$$
$$\mp \eta \sin(2ß_s)\sin(\Delta m_s t) \quad \eta = +1(-1) \text{ for } P(\bar{P})$$

$$U_\pm = \pm e^{-Gt} \times [\sin(d_\perp - d_{||})\cos(\Delta m_s t)$$
$$-\cos(d_\perp - d_{||})\cos(2ß_s)\sin(\Delta m_s t)$$
$$\pm\cos(d_\perp - d_{||})\sin(2ß_s)\sinh(\Delta\Gamma t/2)]$$

$$V_\pm = \pm e^{-Gt} \times [\sin(d_\perp)\cos(\Delta m_s t)$$
$$-\cos(d_\perp)\cos(2ß_s)\sin(\Delta m_s t)$$
$$\pm\cos(d_\perp)\sin(2ß_s)\sinh(\Delta Gt/2)]$$

Terms with Δm_s dependence flip sign with initial B_s flavor

Disappear summing $B_s + \bar{B}_s$

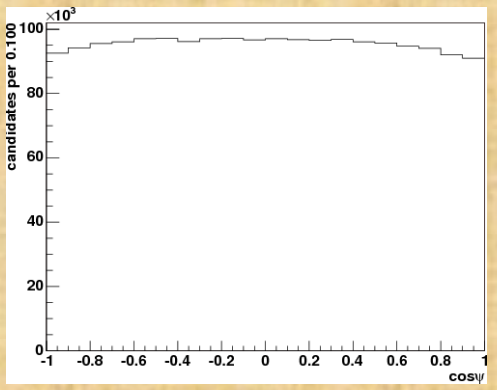
(untagged strategy)

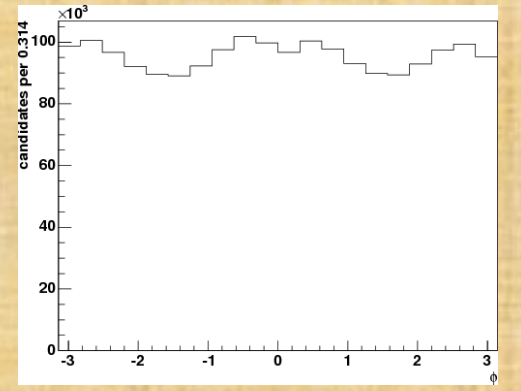
Sensitivity to $|\sin(2\beta_s)|$ remain in CP_{even} -CP_{odd} interference terms in triple differential decay rate

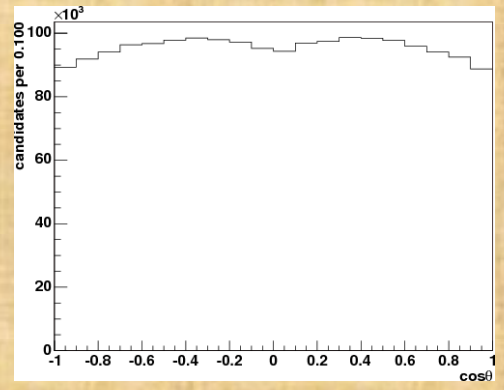
Angular acceptance

- Monte Carlo used to determine acceptance in transversity angles, two different approaches attempted: a) fitting to analytical model b) binned acceptance. Obtained equivalent results.

Acceptance

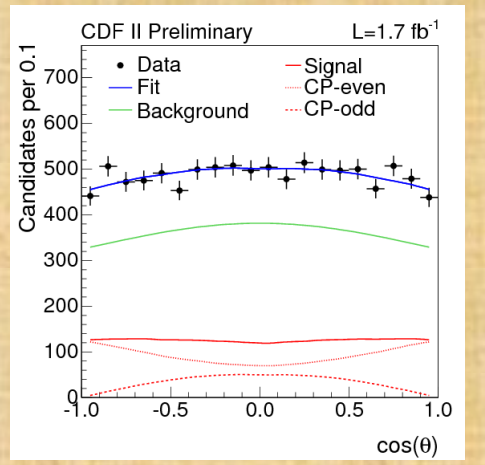


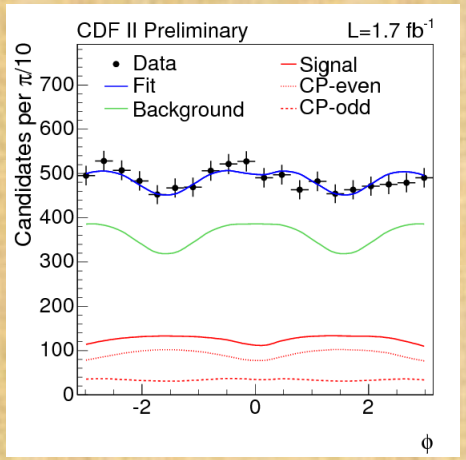


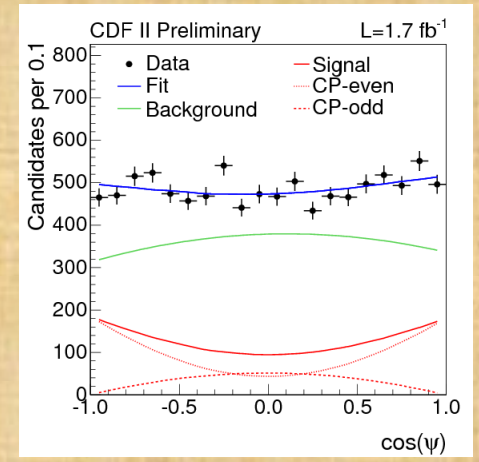


Data Fit Projections

uncorrected for detector sculpting

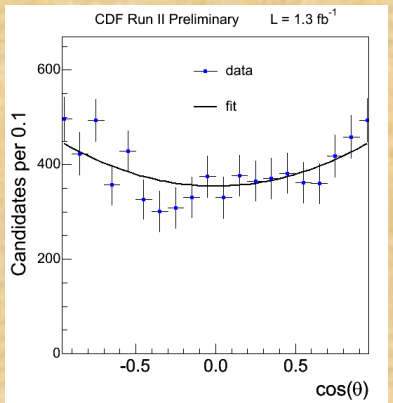


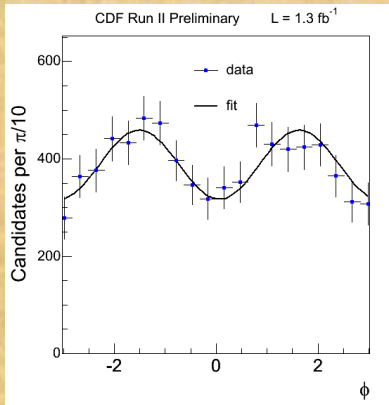


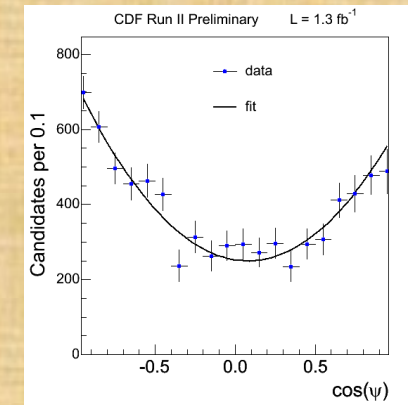


Polarization in $B_d \rightarrow J/\Psi K^{*0}$

- Acceptance corrected fit projections validates treatment of detector acceptance!







- <u>Results for $B^0 \rightarrow J/\Psi\ K^{*0}$</u> in good agreement with BaBar, competitive uncertainties!

CDF
www-cdf.fnal.gov/physics/new/bottom/070830.blessed-BdPsiKS

$$ct = 456 \pm 6\ (stat) \pm 6\ (syst)\ \mu m$$

$$|A_0(0)|^2 = 0.569 \pm 0.009\ (stat) \pm 0.009\ (syst)$$

$$|A_{\parallel}(0)|^2 = 0.211 \pm 0.012\ (stat) \pm 0.006\ (syst)$$

$$d_{\parallel} = -2.96 \pm 0.08\ (stat) \pm 0.03\ (syst)$$

$$d_{\perp} = +2.97 \pm 0.06\ (stat) \pm 0.01\ (syst)$$

Babar:
Phys. Rev. D 76, 031102 (2007)

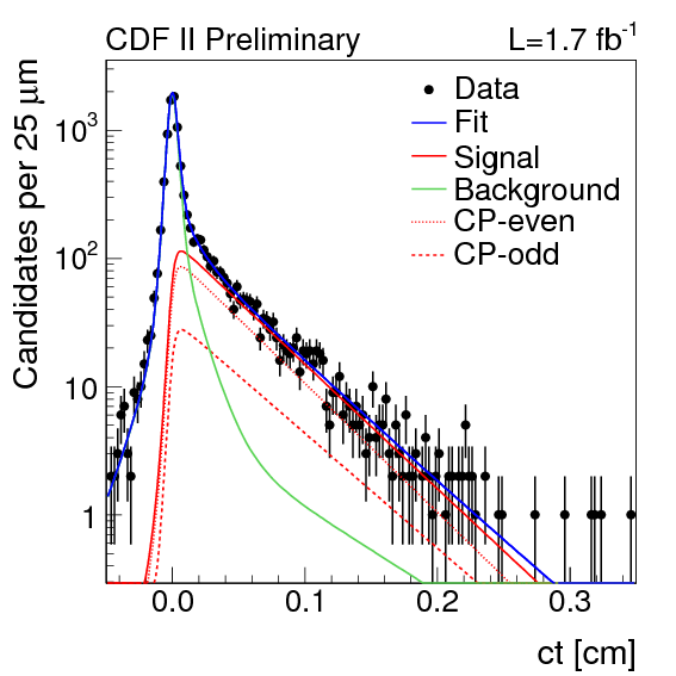
$$|A_0(0)|^2 = 0.556 \pm 0.009\ (stat) \pm 0.010\ (syst)$$

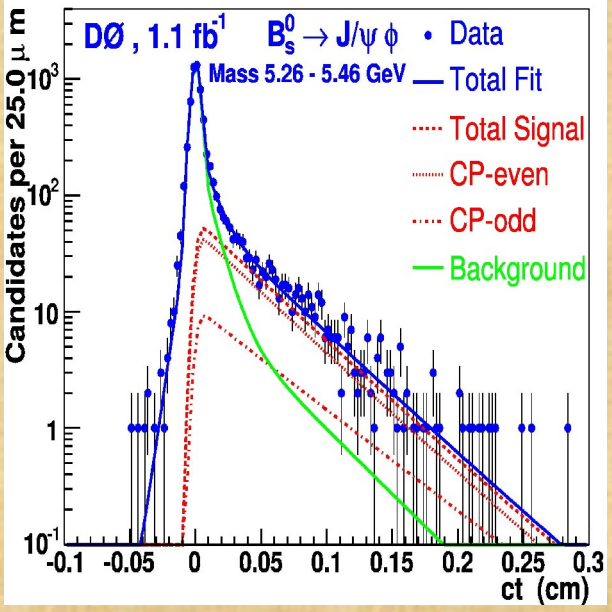
$$|A_{\parallel}(0)|^2 = 0.211 \pm 0.010\ (stat) \pm 0.006\ (syst)$$

$$d_{\parallel} = -2.93 \pm 0.08\ (stat) \pm 0.04\ (syst)$$

$$d_{\perp} = +2.96 \pm 0.05\ (stat) \pm 0.03\ (syst)$$

B_s average lifetime (β_s=0 case)





PRL 98, 121801 (2007)

$$t_s = 1.52 \pm 0.08(\text{stat})^{+0.01}_{-0.03}(\text{syst})\ \text{ps}$$

$$\Delta G_s = 0.12^{+0.08}_{-0.12}(\text{stat}) \pm 0.02(\text{syst})\ \text{ps}^{-1}$$

World Best $\Delta\Gamma_s$, Γ_s PRL 100, 121803 (2008)

Lifetime: $t_s = 1.52 \pm 0.04(\text{stat}) \pm 0.02(\text{syst})$ ps

Decay Width: $\Delta G_s = 0.08 \pm 0.06(\text{stat}) \pm 0.01(\text{syst})\ \text{ps}^{-1}$

Superseeded by recent 2.8 fb^{-1} result:

$$t_s = 1.53 \pm 0.06(stat) \pm 0.01(syst)\ \ ps$$

$$\Delta G_s = 0.14 \pm 0.07(stat)^{+0.01}_{-0.02}(syst)\ \ ps^{-1}$$

Nicely consistent with τ_d(PDG) = 1.530± 0.009 ps

Untagged J/Ψφ result ($\beta_s \neq 0$ case)

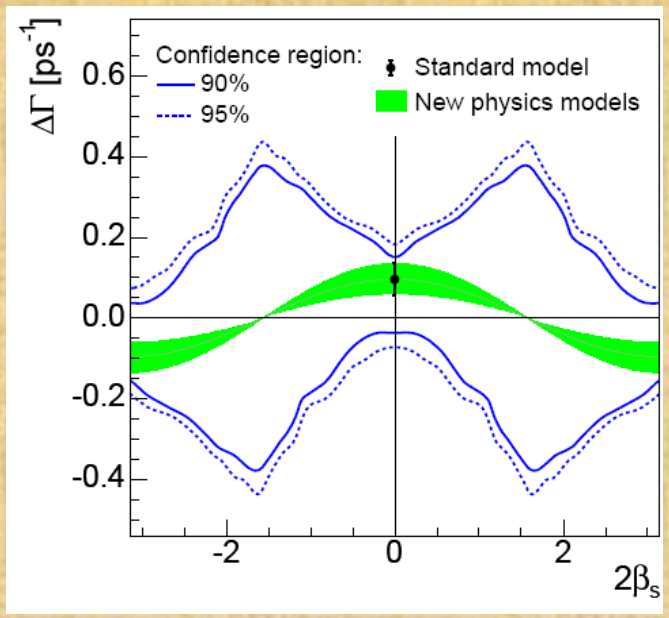
- Symmetry in the likelihood 4-fold ambiguity
- DØ quotes a point estimate:

$$\Rightarrow F_s = -2\beta_s = -0.79 \pm 0.56\ (\text{stat})^{+0.14}_{-0.01}\ (\text{syst})\ \text{rad}$$
$$\Rightarrow \Delta G_s = 0.17 \pm 0.09\ (\text{stat}) \pm 0.02\ (\text{syst})\ \text{ps}^{-1}$$

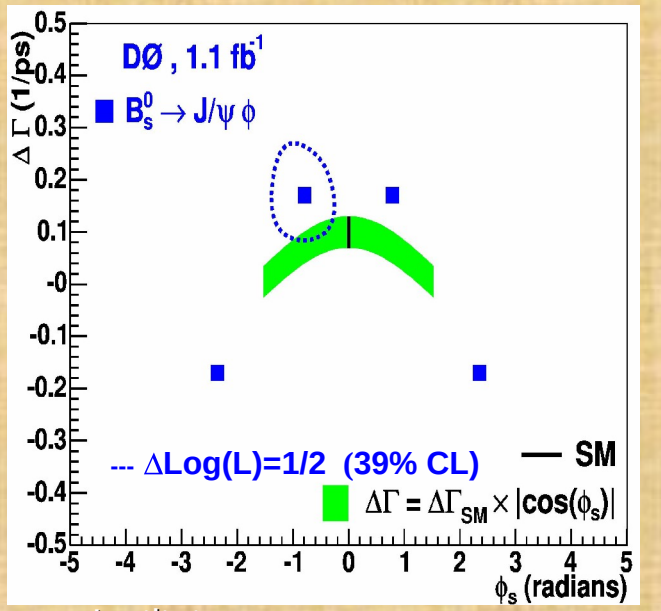
- CDF observes irregular likelihood and biases in fit

  ⇒ Feldman-Cousins confidence region: SM probability p_{value}=22% (1.2σ)

PRL 100, 121803 (2008) [arXiv:0712.2348]



PRL 98, 121801 (2007)



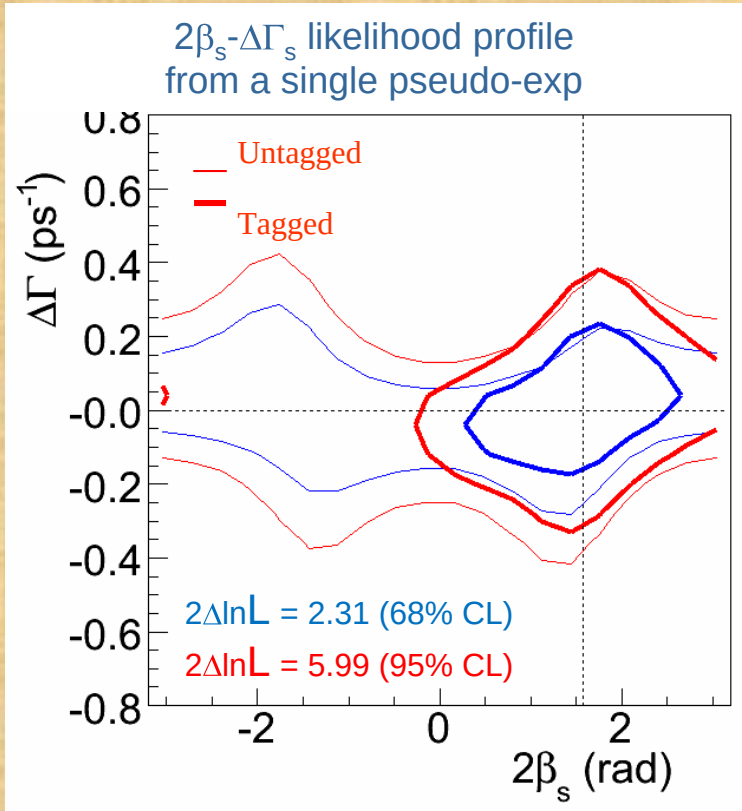
Introducing of Flavor tagging

$$2ß_s \rightarrow p - 2ß_s$$
$$\Delta G_s \rightarrow -\Delta G_s$$
$$d_{\|} \rightarrow 2p - d_{\|}$$
$$d_{\perp} \rightarrow p - d_{\perp}$$

- Tagging improves sensitivity to CP violation phase β_s (provided oscillation can be resolved)
- Removes two of the 4-fold ambiguity
- Still two exact mirror solution due to strong phase ambiguity remain

- Likelihood: with tagging, gain sensitivity to both $|\cos(2b_s)|$ and $\sin(2b_s)$, rather than only $|\cos(2b_s)|$ and $|\sin(2b_s)|$ (note absolute value)
- $\beta_s \leftrightarrow -\beta_s$ no longer a symmetry thanks to $\sin(\Delta m_s t)$ terms:

  $\Rightarrow$ 4-fold ambiguity reduced to <u>2-fold</u>



Flavor Tagging

Opposite Side Tagging

- Soft Lepton Taggers
- Jet Charge Tagger

OST's perform identically in $B_{u,d,s}$:
Calibrated in high statistics B^+/B^0 data

- Combined Performance:

  ✓Efficiency: $\varepsilon = 0.96 \pm 0.01$
  ✓Average Dilution: $D = 0.11 \pm 0.02$

Same Side Kaon Tagging

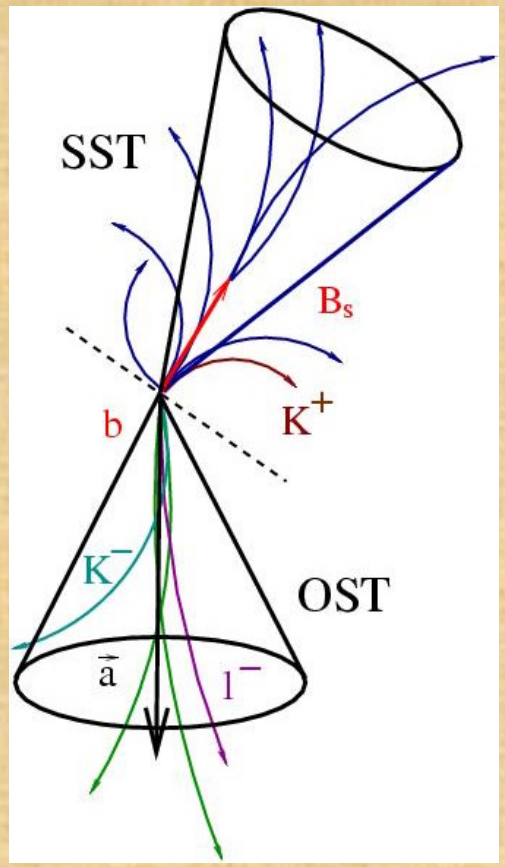
- Most powerful tagger available:

  ✓2–3 times more effective than combined OST

SSKT is different for B^0, B^+ and B_s:
SST needs to rely on MC simulation

- Performance:

  ✓Efficiency: $\varepsilon = 0.50 \pm 0.01$
  ✓ Average Dilution: $D = 0.27 \pm 0.04$



OST and SST combined independently
Overall $\varepsilon D^2 \sim 4\%$

DØ performance similar D~ 0.21 ε~ 1

CDF result

PRL 100, 161802 (2008)
arXiv:0712.2397 [hep-ex]

Perform an unbinned maximum likelihood fit to mass, ct and angles: 27 parameters total !

- Symmetries of the problem and low statistics means the likelihood contour does **not** have the correct coverage.
- Quoted confidence region is based on a modified Feldman Cousin profile-likelihood ratio ordering with inclusion of systematic uncertainties.

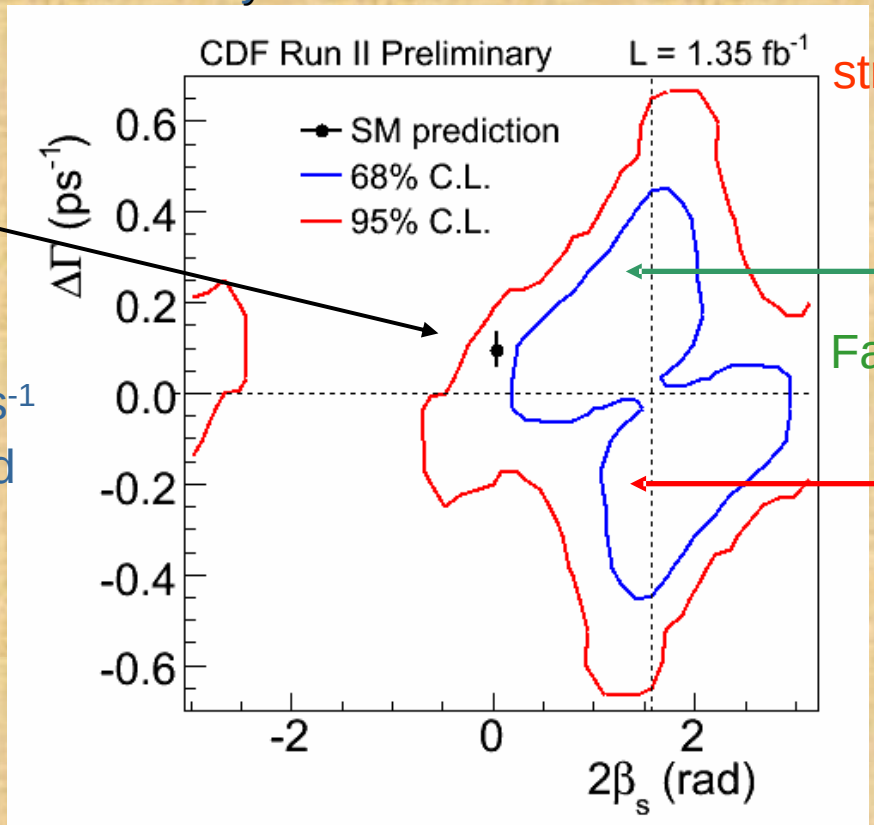
Standard Model expectations:

arXiv:hep-ph/0612167

$\Delta\Gamma_s = 0.096 \pm 0.039\ ps^{-1}$

$2\beta_s = 0.04 \pm 0.01$ rad

Standard Model p_{value} = 15% (1.5σ)



strong phases ambiguity:

$$\cos(d_\perp) < 0$$
$$\cos(d_\perp - d_\parallel) > 0$$

Favored by factorization and B_d analog

$$\cos(d_\perp) > 0$$
$$\cos(d_\perp - d_\parallel) < 0$$

Confidence Region Construction

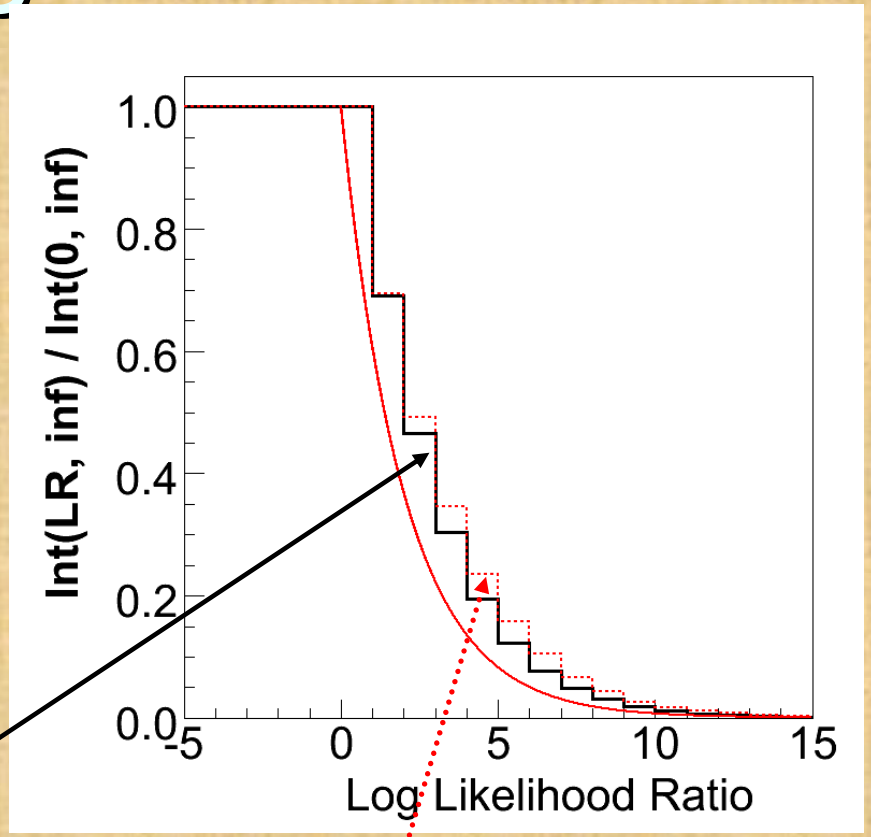
$$R(\Delta G_s, \beta_s) = \log \frac{L(\Delta \hat{G}_s, \hat{\beta}_s, \hat{\theta})}{L(\Delta G_s, \beta_s, \hat{\theta}')}$$

^ = parameters that maximize likelihood L

θ' = nuisance parameters which maximize L for a specific choice of $\Delta\Gamma_s, \beta_s$

Use pseudo–experiments to calculate:

$$p_{value} = \int_{Rdata}^{\infty} f(R, \Delta G_s, \beta_s) dR$$



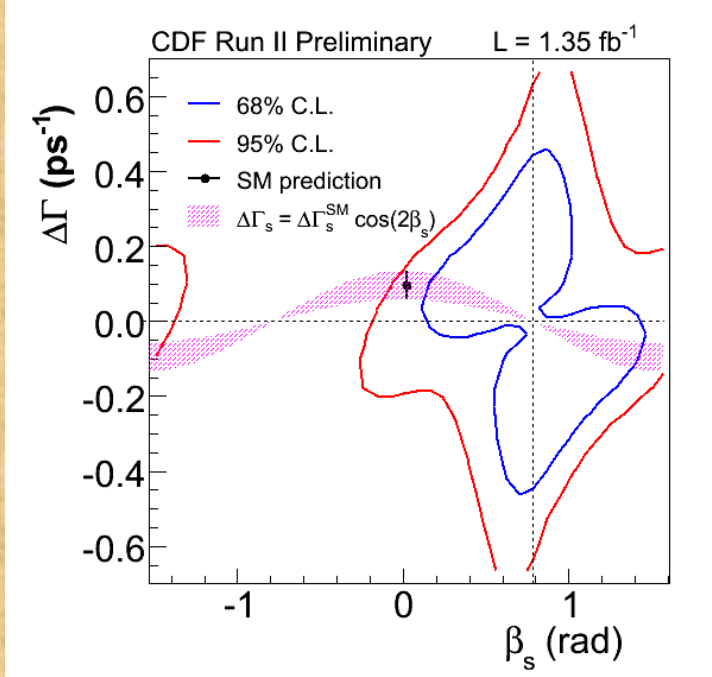
Guarantees the frequentistic coverage of the quoted C.L.
Takes into account non-asymptotic behaviour of likelihood, i.e. log(L) non-parabolic, and possibility of large fluctuation of likelihood shape from experiment-to-experiment

Include systematics via an additional coverage adjustment varying nuisance parameters within 5σ of their uncertainties and choosing worst case (higher P-value) to define the confidence regions

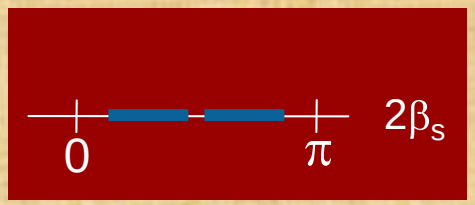
Adding information/Theory

$\Delta\Gamma_s$ is theoretically constrained:

- Input $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\Phi_s \approx 2|\Gamma_{12}|\cos(2\beta_s)$:
  [Γ_{12}=0.048±0.018 - Nierste, Lenz, hep-ph/0612167]

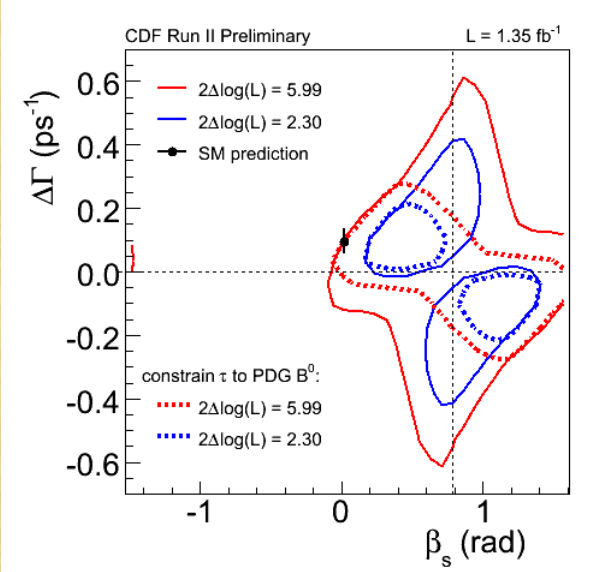


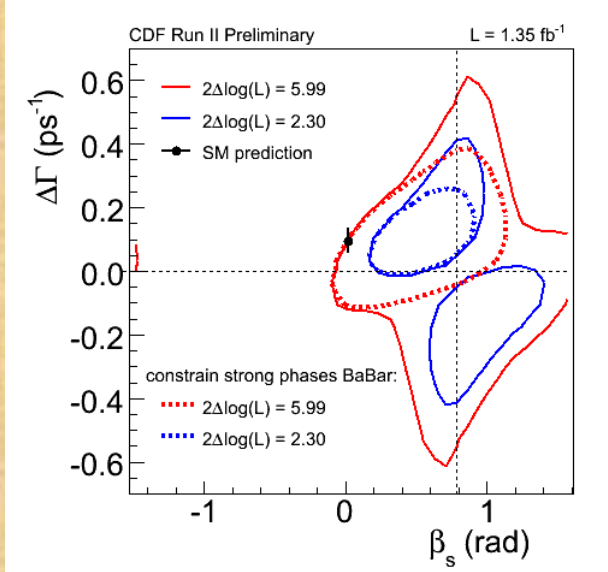
$2\beta_s$ in [0.24, 1.36] U [1.78, 2.90] at 68% C.L.

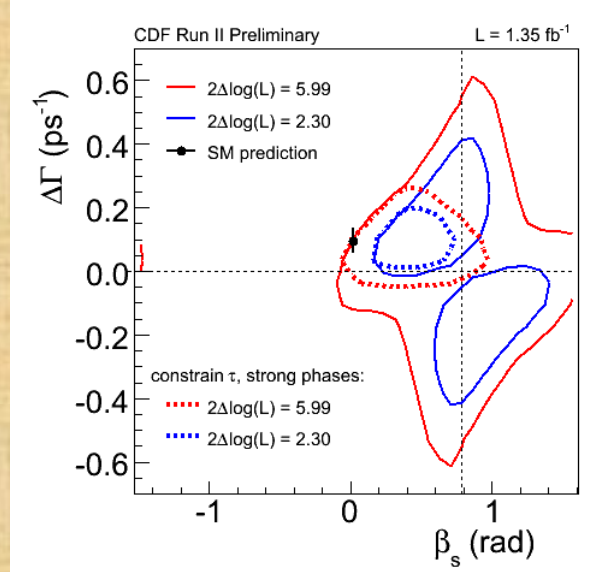


Adding information/Lifetime and strong phase constraints

- Contraint $\tau_s = \tau_d \pm 1\%$
- Constraint strong phase to $B_d \rightarrow J/\psi\ K^*$
- Both

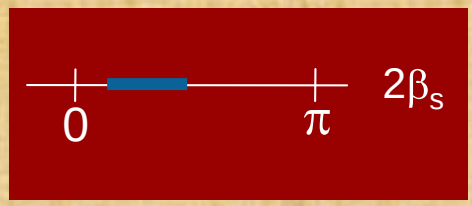






- Largest effect on $\Delta\Gamma_s$,and near $\beta_s = \pi/4$,likelihood near $\beta_s = 0$ not very sensitive (too bad)

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



DØ Result

arXiv: 0802.2255 [hep-ex]

- **DØ**: ~2000 B_s events with 2.8 fb^{-1}
- Assume strong phase as measured in $B_d \rightarrow J/\Psi K^*$ decays
- Combined Tagging Power $\Rightarrow \varepsilon D^2 = (4.68 \pm 0.54)\%$ (NEW)

$$t_s = 1.52 \pm 0.06\ (\text{stat}) \pm 0.01\ (\text{syst})\ \text{ps}$$

$$\Delta G_s = 0.19 \pm 0.07\ (\text{stat})^{+0.02}_{-0.01}\ (\text{syst})\ \text{ps}^{-1}$$

$$F_s = -2\beta_s = -0.57^{+0.24}_{-0.30}\ (\text{stat})^{+0.07}_{-0.02}\ (\text{syst})\ \text{rad}$$

FIT inputs:

Δm_s fixed to 17.77 ps^{-1}

Gaussian constraint on Strong phases:

$\delta_\perp - \delta_{||} = -0.46 \pm (\pi/5)$

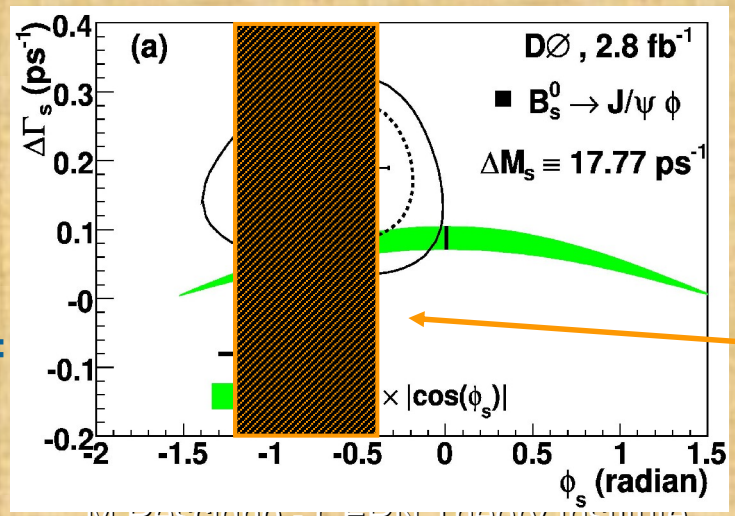
$\delta_\perp = +2.92 \pm (\pi/5)$

Standard Model expectations:

(arXiv:hep-ph/0612167)

$\Phi_s = -0.04 \pm 0.01$ rad

Standard Model p_{value} = 6.6%



90% C.L. contours:

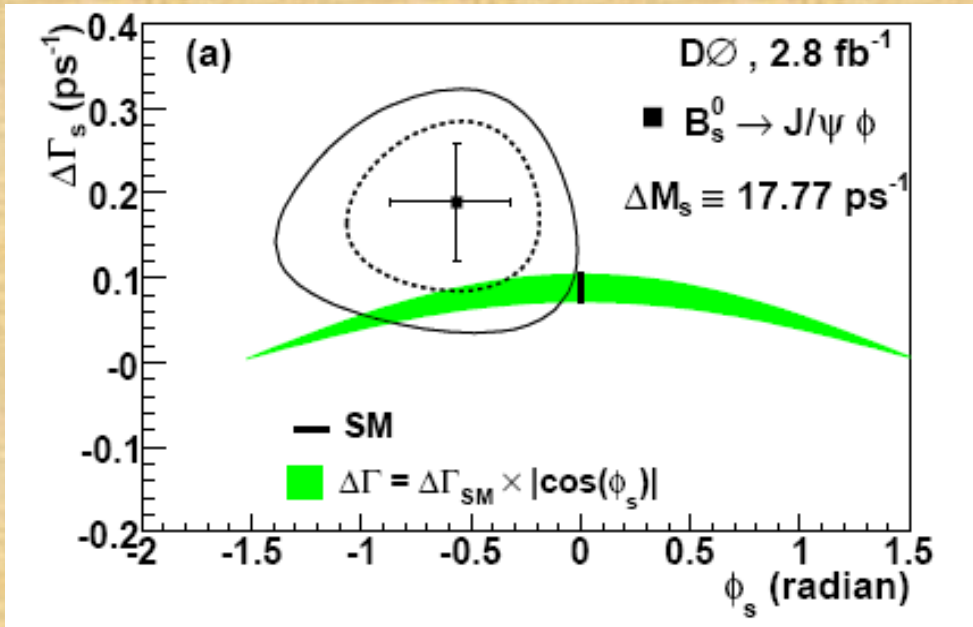
$-1.20 < 2\beta_s < 0.06$ rad

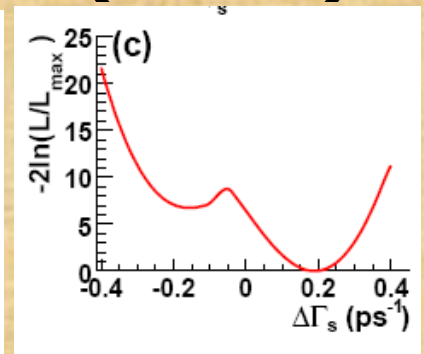
$0.06 < \Delta G_s < 0.30$ ps^{-1}

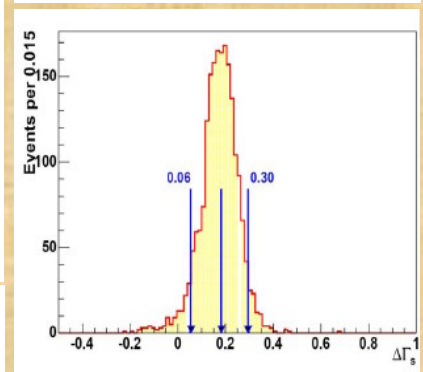
CDF 68% CL:

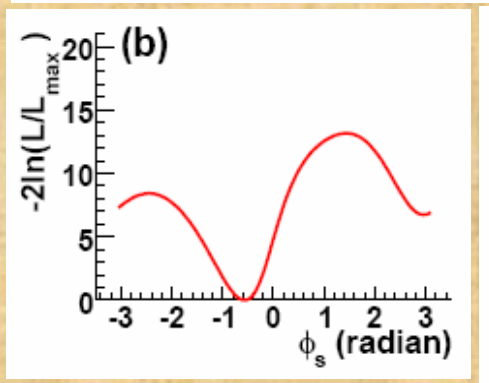
Constraining lifetime, strong phases and $\Delta\Gamma_s$

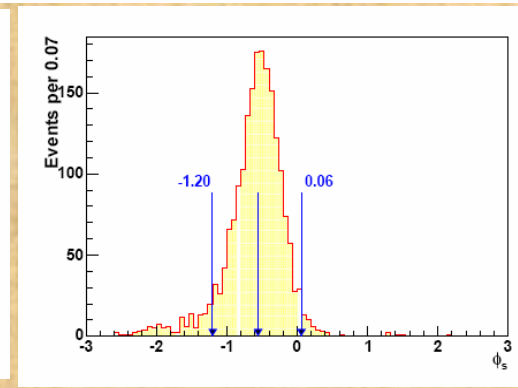
DØ Results (tails)











- 90% CL range from pseudoexperiment significantly different from what obtained from likelihood profile

$$-1.20 < \varphi_s < 0.06\ rad \quad \text{vs}$$

$$-1.10 < \varphi_s < -0.10\ rad$$

Additional ϕ_s related measurement at TeVatron and impact on New Physics

Charge Asymmetry

- if $M_{12}/\Gamma_{12} >> 1$

$$A^s_{SL} = \frac{\Delta G_s}{\Delta m_s} \tan F_s$$

- **DØ:** 1.3 fb^{-1} of data collected (B_s semileptonic decays):

$$A^s_{SL} = [2.45 \pm 1.93 \ (stat) \pm 0.35 \ (syst)] \times 10^{-2}$$

PRL 98, 151801 (2007)

- **CDF:** 1.6 fb^{-1} of data collected (dimuon charge asymmetry):

$$A^s_{SL} = 0.020 \pm 0.021 \ (stat) \pm 0.016 \ (syst) \pm 0.009 \ (inputs)$$

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

- **DØ:** 1.0 fb^{-1} of data collected (dimuon charge asymmetry):

$$A^s_{SL} = -0.0064 \pm 0.0101 \ (stat + syst)$$

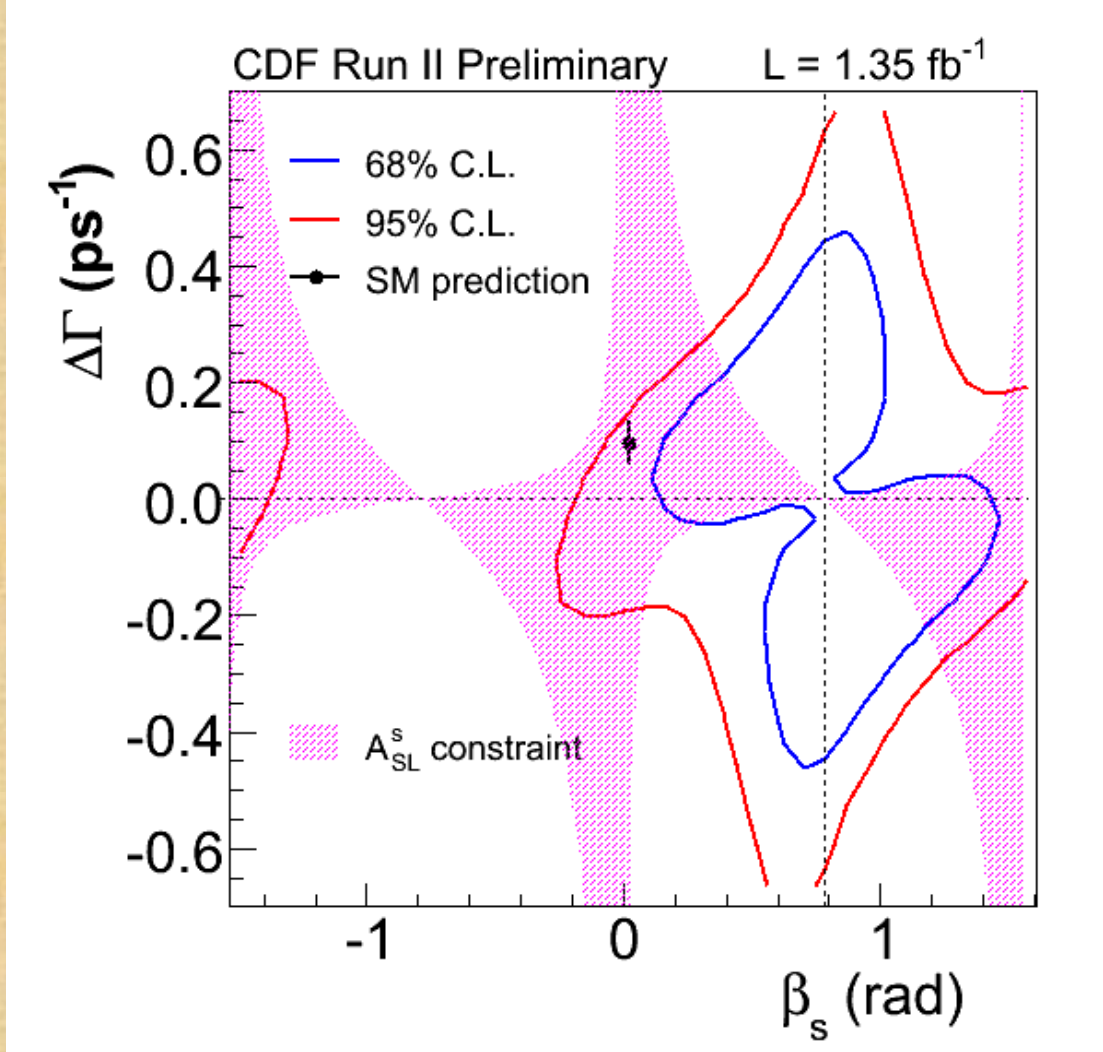
PRD 74, 092001 (2006)

- **Unofficial Tevatron combination:** using common/updated inputs

$$A^s_{SL} = -0.0054 \pm 0.0072 \ (stat + syst)$$

- Quite precise, compare with $A^d_{SL} = -0.0005 \pm 0.0055 \ (stat + syst)$

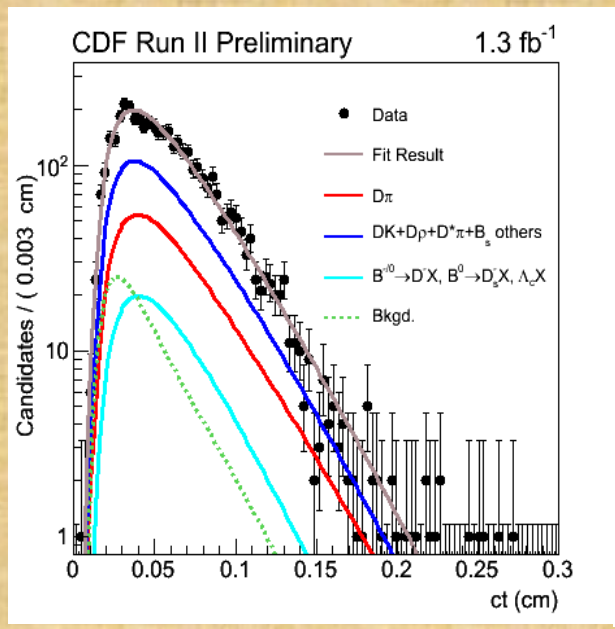
ASL_s constraint

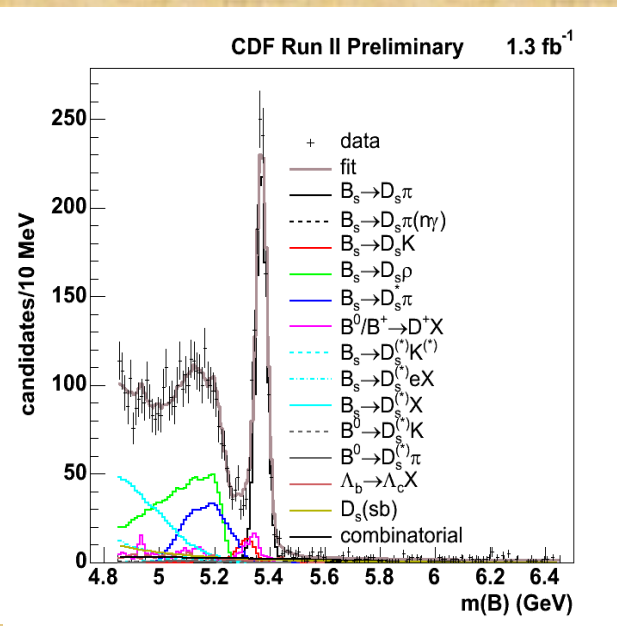


Flavor specific lifetime constraint

- Flavor specific modes: only accessible from either B_s or anti-B_s state
- Light and Heavy state contributes both 50% to the time evolution
- Fit to a single lifetime determine τ_{fs}
  - Expected higher than $1/\Gamma_s$
  - HQET : $\Gamma_s = \Gamma_d \pm O(1\%)$

$$\tau_{fs} = \frac{1}{\Gamma_s} \frac{1 + \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1 - \left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$$



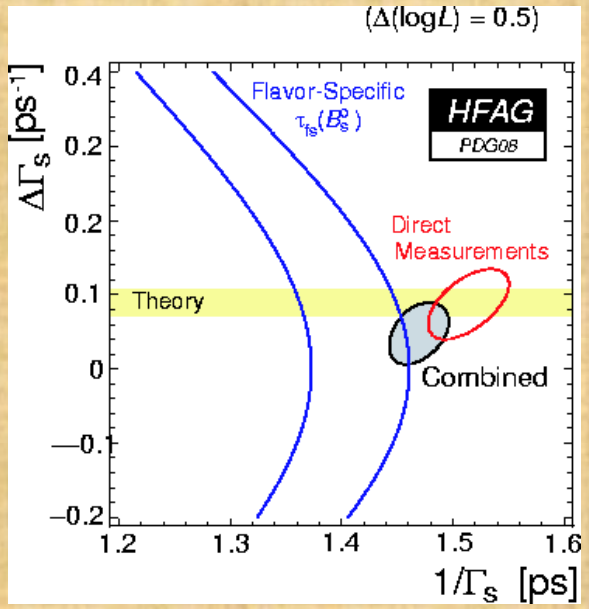


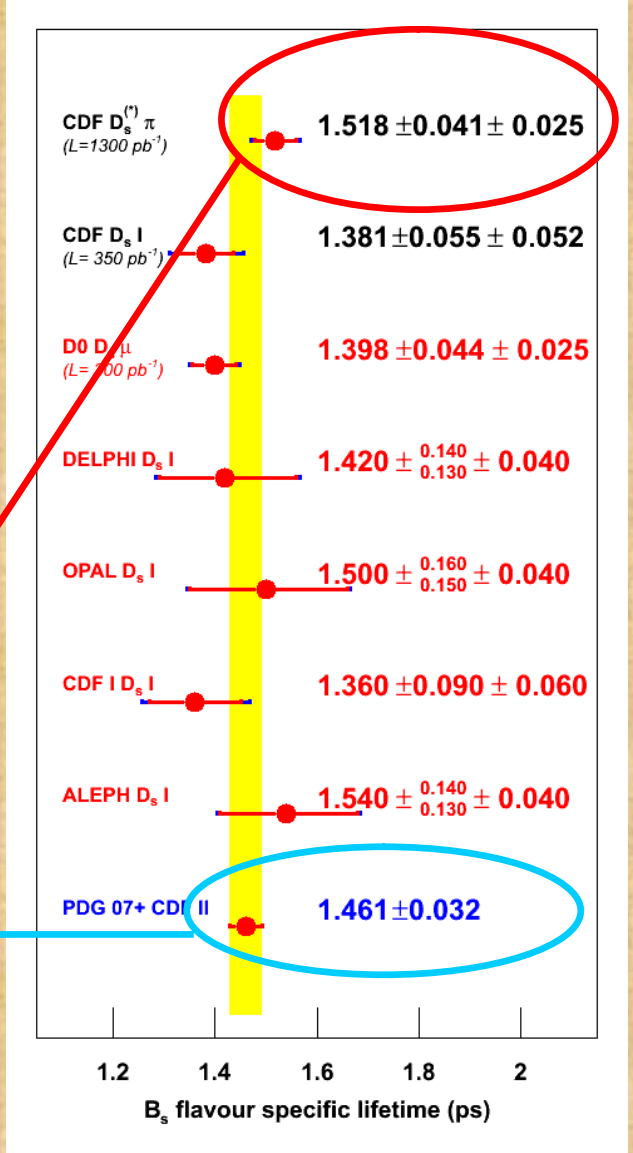
- Recent high precision measurement from CDF using $B_s \rightarrow D_s^{(*)}\pi + D_s^{(*)}\pi + D_s\rho$ final states using 1.3 fb-1
- $c\tau(B_s) = 455.0 \pm 12.2$ (stat.) ± 7.4 (syst.) μm

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

Flavor specific lifetime constraint

- PDG 08 average: 1.417 ± 0.042 ps
- Slightly lower than recent τ_s from $B_s \rightarrow J/\Psi\phi$ (1.52±0.04 ps) and τ_d

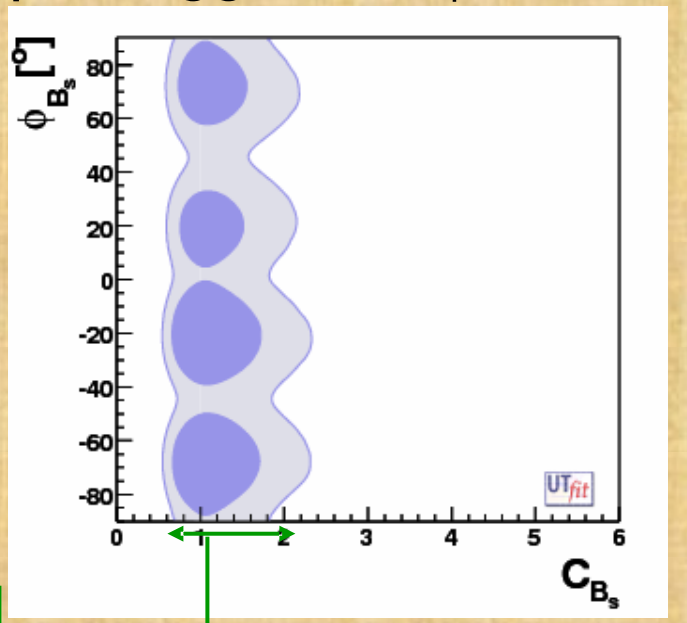




- CDF hadronic more consistent
- Naïve average PDG07+ CDFII
- Current precision on τ_{fs} can be translated in a constraint on $\Delta\Gamma_s < 0.16$ ps^{-1} at 1 σ

NP in Bs mixing

pre tagged $J/\Psi\phi$ status



UT$_{fit}$ inputs:

Δm_s measurement (CDF)

Lifetime τ_s (CDF and DØ)

$\Delta\Gamma_s$ (CDF on 200 pb^{-1})

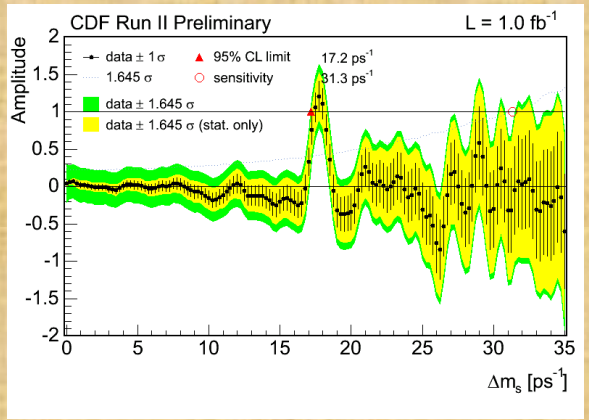
$\Delta\Gamma_s$ and Φ_s (DØ on 1.1 fb^{-1})

Semileptonic A_{SL} (DØ)

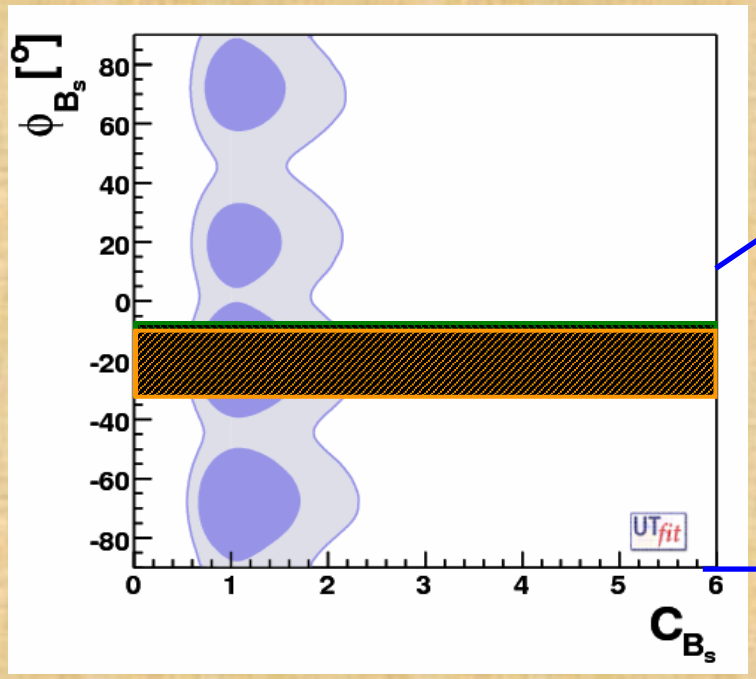
$\Delta m_s = C_{Bs} * \Delta m_s^{SM}$: Lattice-QCD dominated uncertainty

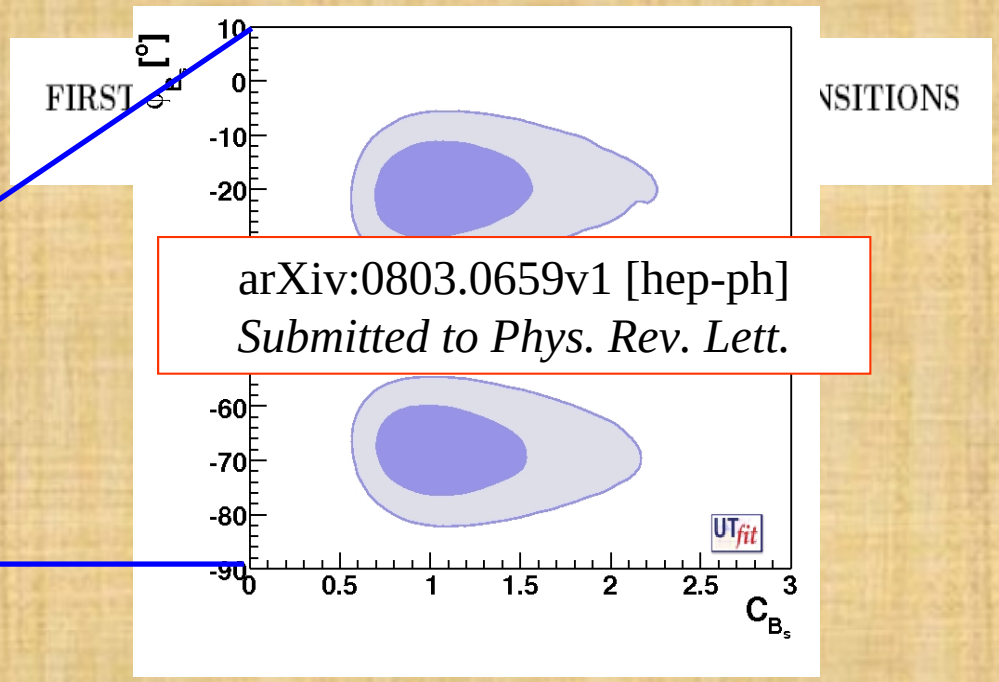
$$\frac{\langle B_s | H_{eff}^{full} | \bar{B}_s \rangle}{\langle B_s | H_{eff}^{SM} | \bar{B}_s \rangle} = C_{Bs}\, e^{2i\, F_{Bs}}$$

$\beta_s = \beta_s^{SM} - \Phi_{Bs}$: Experimentally dominated uncertainty



Effects of recent measurements





arXiv:0803.0659v1 [hep-ph]
Submitted to Phys. Rev. Lett.

Constraint:

✓ $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\Phi_s \approx 2|\Gamma_{12}|\cos(2\beta_s)$ with (Γ_{12}=0.048±0.018):

✓Strong phases from J/Ψ K^{*0} [hep-ex/0411016], B_d lifetime [PDG] and $\Delta\Gamma_s \approx 2|\Gamma_{12}|\cos(2\beta_s)$:

CDF: $2\beta_s \in$ **[0.40, 1.20] @ 68% C.L**

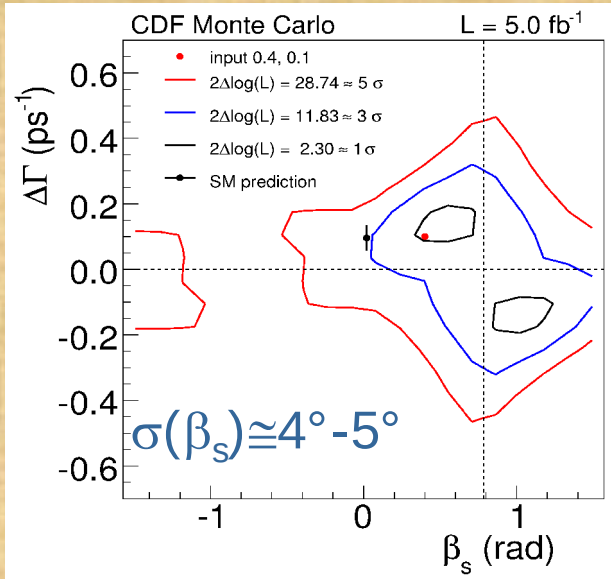
DØ: $2\beta_s = +0.46 \pm 0.28$

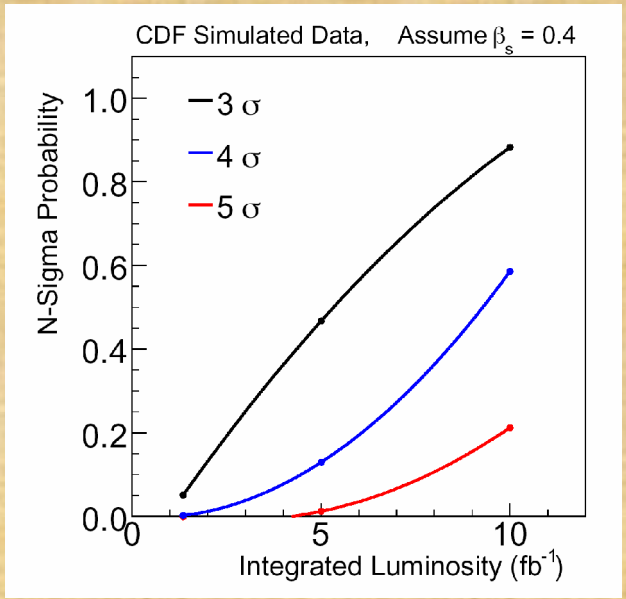
UTfit conclusions:

✓ NP phase 3σ from 0 (~-20°) with some approximation in the treatment of experimental result has been used

TeVatron experiments working towards a combination without approximations

Tevatron Outlook



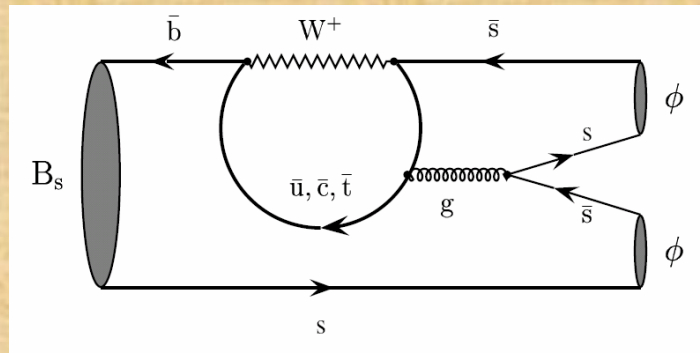


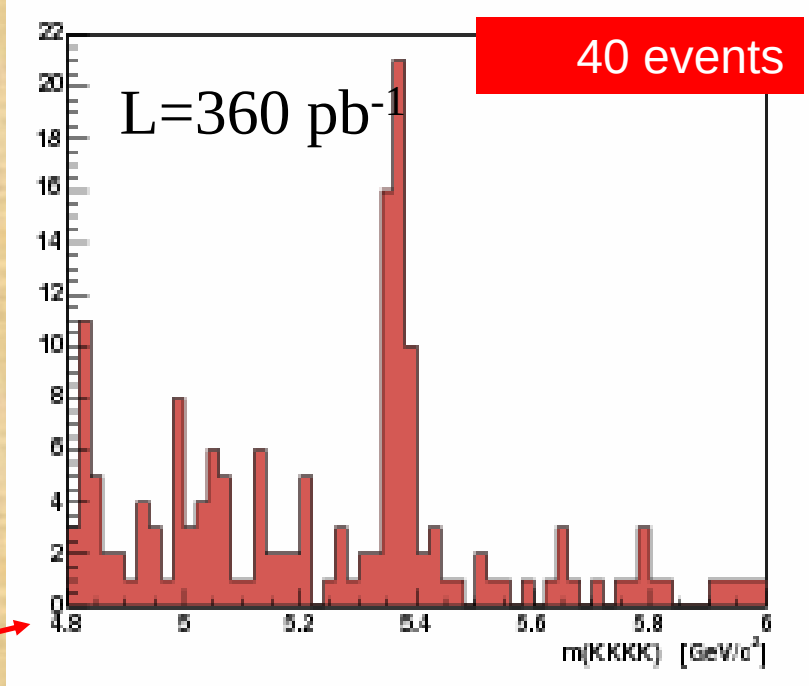
- With no analysis improvements, and no external constraints, but same signal yield and experimental resolution:
  - With 5(10) fb^{-1}each Tevatron experiment could reach a 3(5) σ significance if "fluctuation" is real
  - 10 fb^{-1} may also be viewed as a CDF+D0 combination with 5fb^{-1}
  - Expect >6 fb^{-1}/experiment if TeVatron stops in 2009 and ~8 fb^{--1}/ experiment if 2010 running approved
- May do better adding further signals (triggers) or better tagging (underway)

Selected B_s physics topics

- Difficult to select, peak just a few:
  - $B_s \rightarrow \phi\phi$
  - $B_{u(s)} \rightarrow DK$
  - $B_s \rightarrow hh$
  - $Bs \rightarrow \mu\mu$

$B_s \to \phi\phi$ signal at CDF



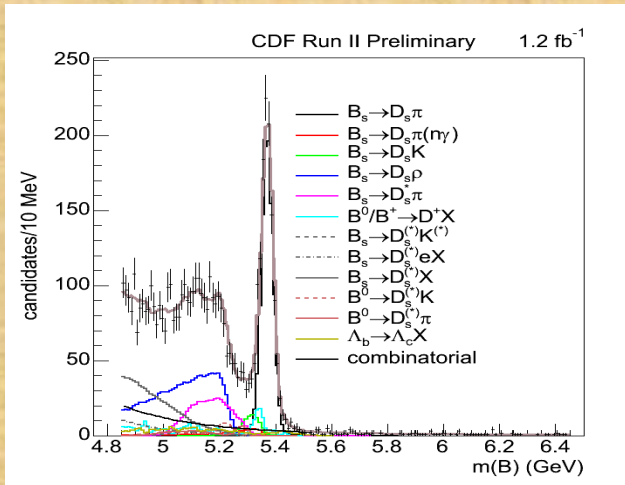


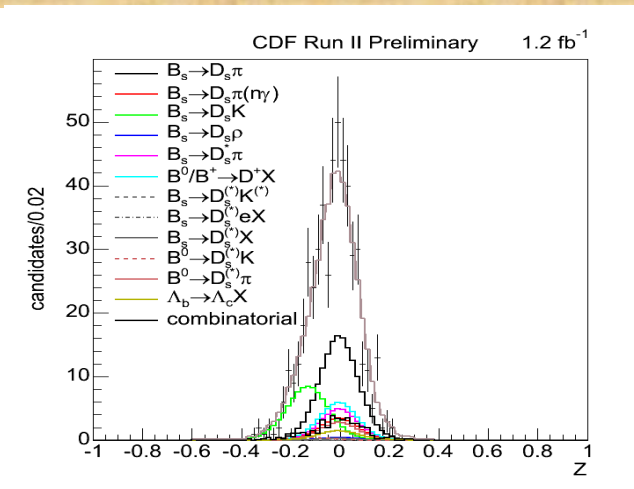
- Nice experimental signature
- b→s penguin dominated, measure ϕ_s to test new physics amplitude in penguin decays $\varphi_s^{c\bar{c}s} = \varphi_s^{s\bar{s}s}$
- ~40 events with 360 pb-1
- Need angular analysis similarly as J/Ψϕ
- Improved BR and first polarization with O(5%) uncertainties possible at CDF → polarization puzzle
- Unlikely testing for CP violation

- At LHCB with 2fb^{-1}:
- 3700 events collected
- $\sigma(\varphi_s^{s\bar{s}s}) = 0.11$!

$B_{d(s)} \rightarrow D_{(s)}K$ at CDF

- Theoretically clean method for measuring γ based on $B \rightarrow DK$ decays (interference of $b \rightarrow c$ and $b \rightarrow u$ decays)
- CDF has significant sample of these decays in all charged modes for B_u B_d and B_s mesons
- $Bs \rightarrow DsK$ time dependent rate (tagged) requires a lot of statistics



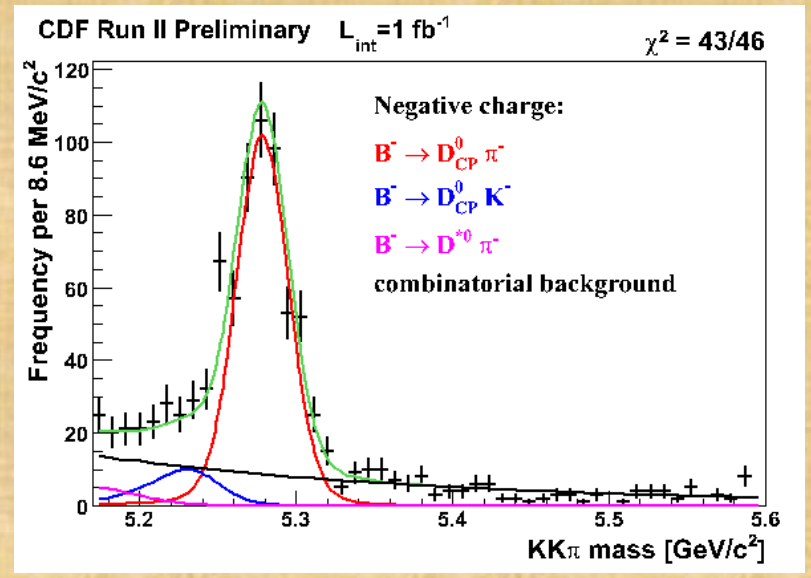


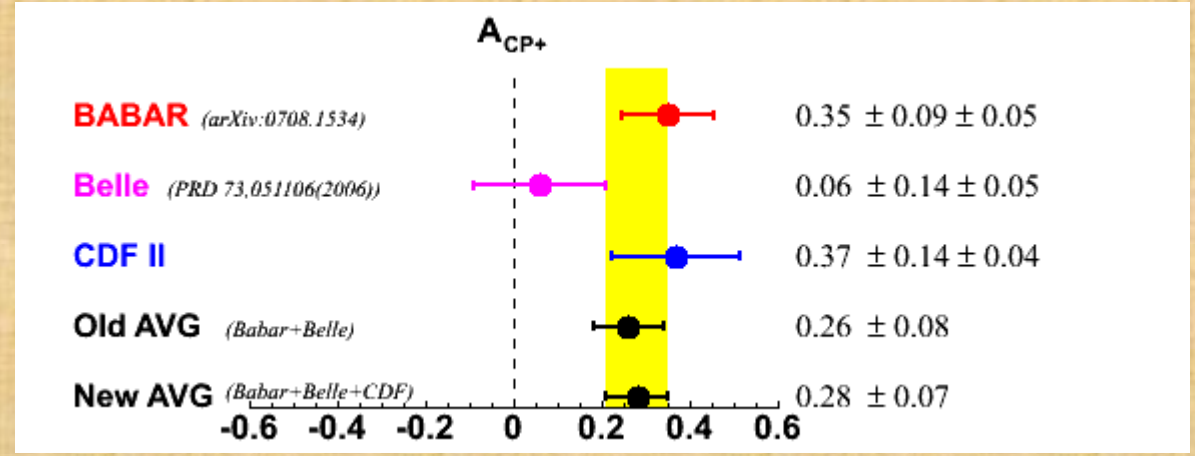
CDF has ~100 events in $1fb^{-1}$. signal significance 7.9 σ. BR measured, possible to measure lifetime [a way of testing for cos $2\beta_s$ sign Nierste:0801.0143 [hep-ph] γ measurement difficult…

$Br(B_s^0 \rightarrow D_s^{\pm}K^{+})/Br(B_s^0 \rightarrow D_s^{+}p^{-}) = 0.107 \pm 0.019(stat) \pm 0.008(sys)$.

$B^{\pm} \rightarrow DK^{\pm}$ at CDF

- Keep accumulating large number of $B^{\pm} \rightarrow DK^{\pm}$ events (this analysis ~120 $B \rightarrow D_{CP}K$ events)
- Cabibbo suppressed D^0 decays (CP+) firmly established: kinematics + PID separation

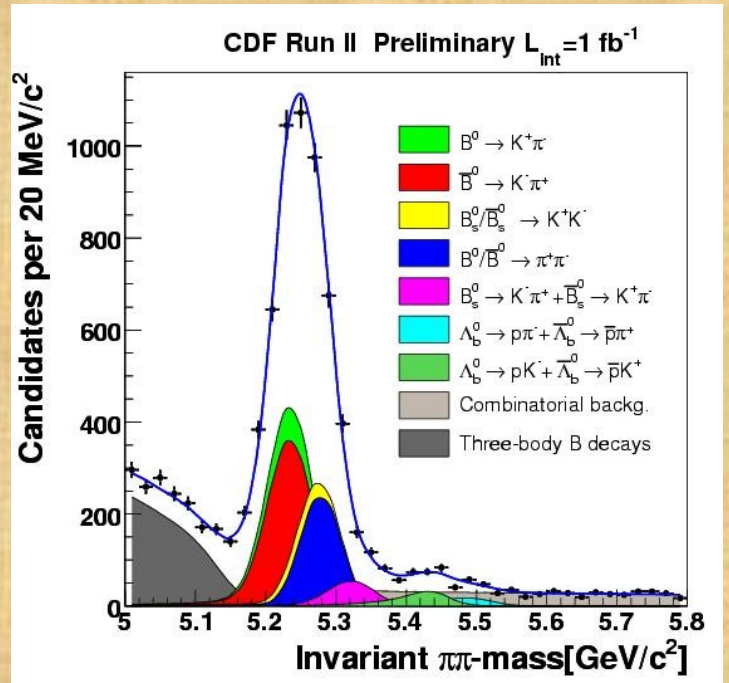




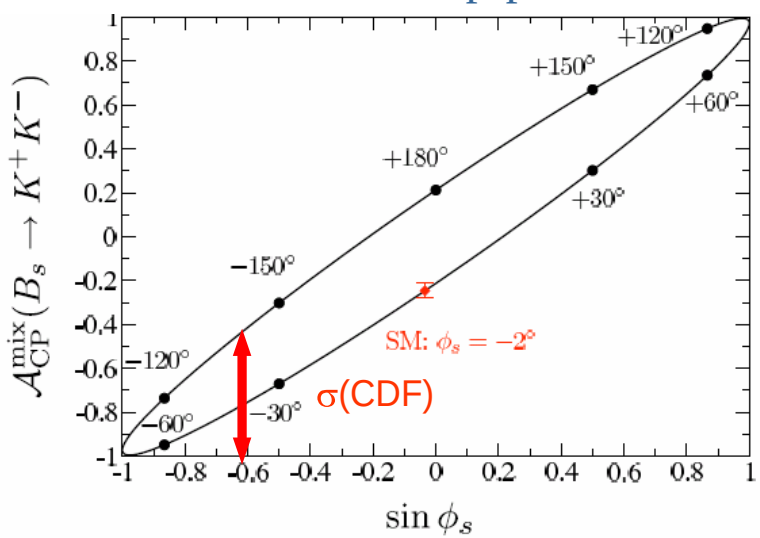
CDF contributing to "γ" via GLW method, a program for ADS method has been launched

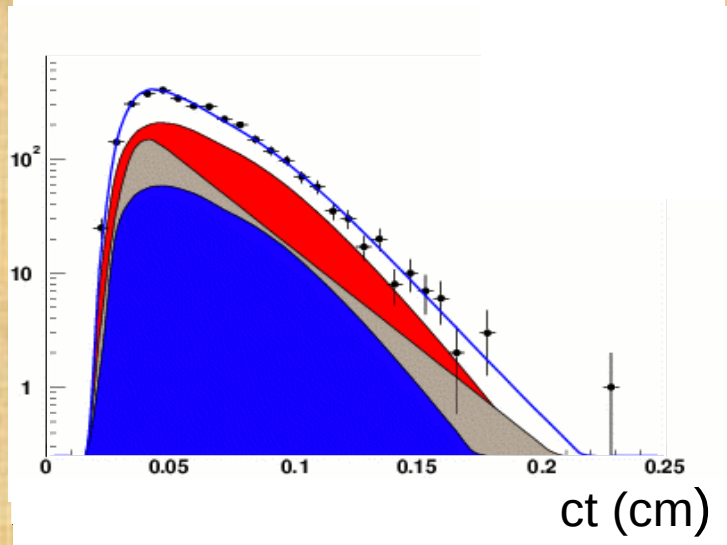
Lifetime and A_{CP} $B_s \rightarrow K^+ K^-$

- CDF has > 10^3 $B_s \rightarrow K^+K^-$ events in $1 fb^{-1}$
- Expect 25 μm in $B_s \rightarrow K^+K^-$ lifetime determination (measure τ_L in SM)
- May reach O(30%) ACP_{mix} at the end of Run II



Fleischer:0705.1121 [hep-ph]





Direct CP violation in $B_{s(d)}$ decays

- Direct CP asymmetry in a self tagging mode:

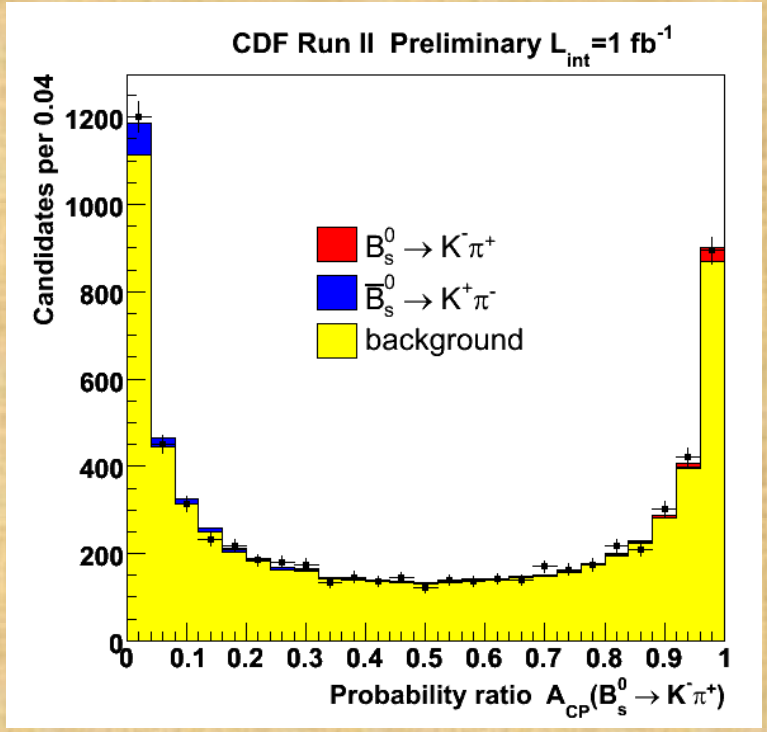
$$A_{CP} = \frac{N(\overline{B}_s^0 \to K^+ p^-) - N(B_s^0 \to K^- p^+)}{N(\overline{B}_s^0 \to K^+ p^-) + N(B_s^0 \to K^- p^+)}$$

- With 1fb^{-1} first observation of $B_s \to K\pi$ mode:

$$N(B_s^0 \to K^- p^+) = 230 \pm 34\ (stat) \pm 16\ (syst)\ [8s\ signif]$$

- First measurement of direct CP violation:

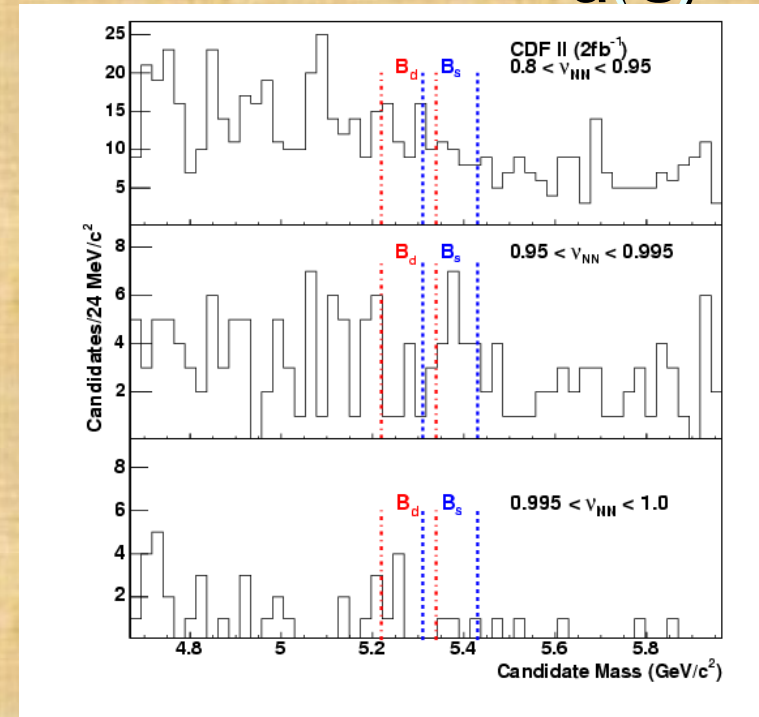
$$A_{CP}(B_s^0 \to K^- p^+) = 0.39 \pm 0.15\ (stat) \pm 0.08\ (syst)$$



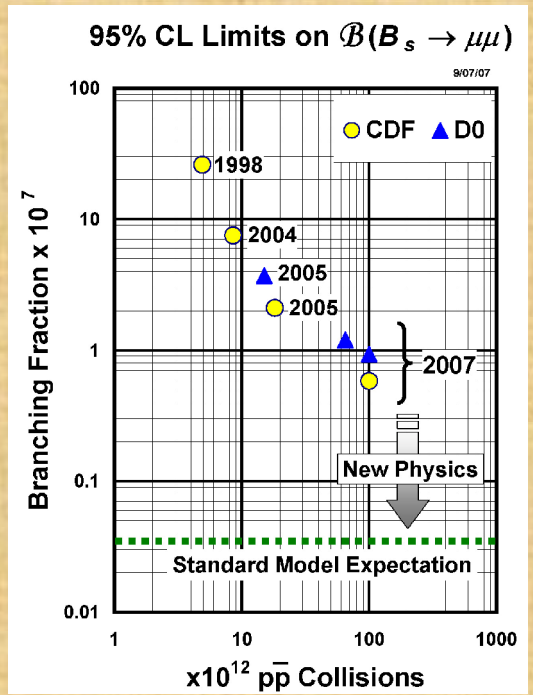
- A_{CP} is 2.5σ different from 0
- Compatible with expectation (~0.37) [H.J.Lipkin, Phys. Lett. B **621**, 126 (2005)]

- In addition:
  - high precision measurement ACP in $B_d \to K\pi$ $A_{CP} = 0.086 \pm 0.023 \pm 0.006$;
  - stringent upper limit on annhiilation dominated decays $B_d \to KK$ and $B_s \to \pi\pi$, b-barion two body decays

$B_{d(s)} \rightarrow \mu\mu$ search



- Improved analysis with Neural Netword selection (2fb^{-1})
- CDF UL extracted in 3 bins of NN + mass distribution
- CDF limit
  - $BR(B_s \rightarrow \mu\mu) < 5.8 \cdot 10^{-8}$ @ 95%C.L.
  - $BR(B_d \rightarrow \mu\mu) < 1.8 \cdot 10^{-8}$ @ 95% C.L.
- DØ limit
  - $BR(B_s \rightarrow \mu\mu) < 9.3 \cdot 10^{-8}$ @ 95% C.L.

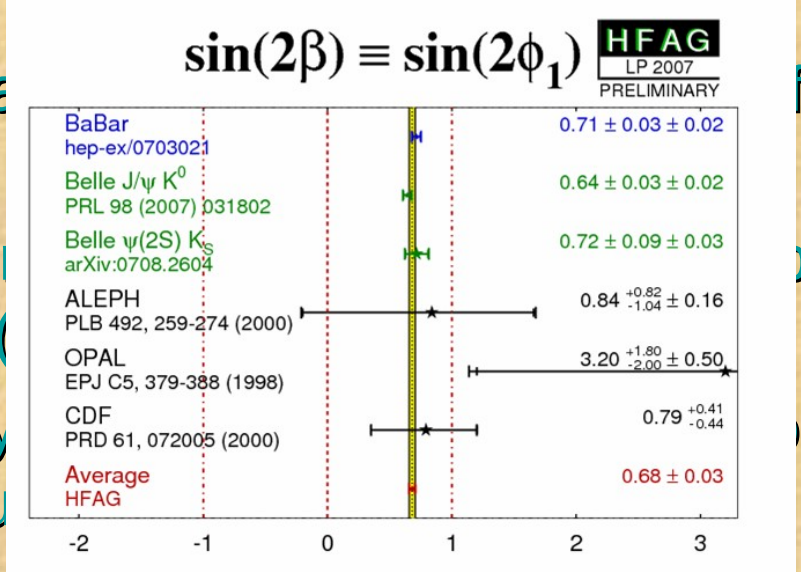


Analysis has improved faster than just luminosity until now

Even with no improvement will explore the region of low 10^{-8} $BR(B_s \rightarrow \mu\mu)$ in 2009 (6fb-1) → competition with LHC experiments?

Conclusions

- B(s) physics program at TeVatron very rich and promising:
- First ever fla f J/Ψφ rates this winter from
- Observe a (on towards large value of sin(
- Make B_s phy n and LHCb even more intrigu
- CDF update with > 2* statistics and DØ without constraints underway → TeVatron average
- Would be really nice to repeat 1999/2000 situation for sin2β!



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