β_s and $\Delta\Gamma_s$ Results from B_s --> J/ψ ϕ decays at D0 & CDF

Guillelmo Gomez-Ceballos
(Massachusetts Institute of Technology)

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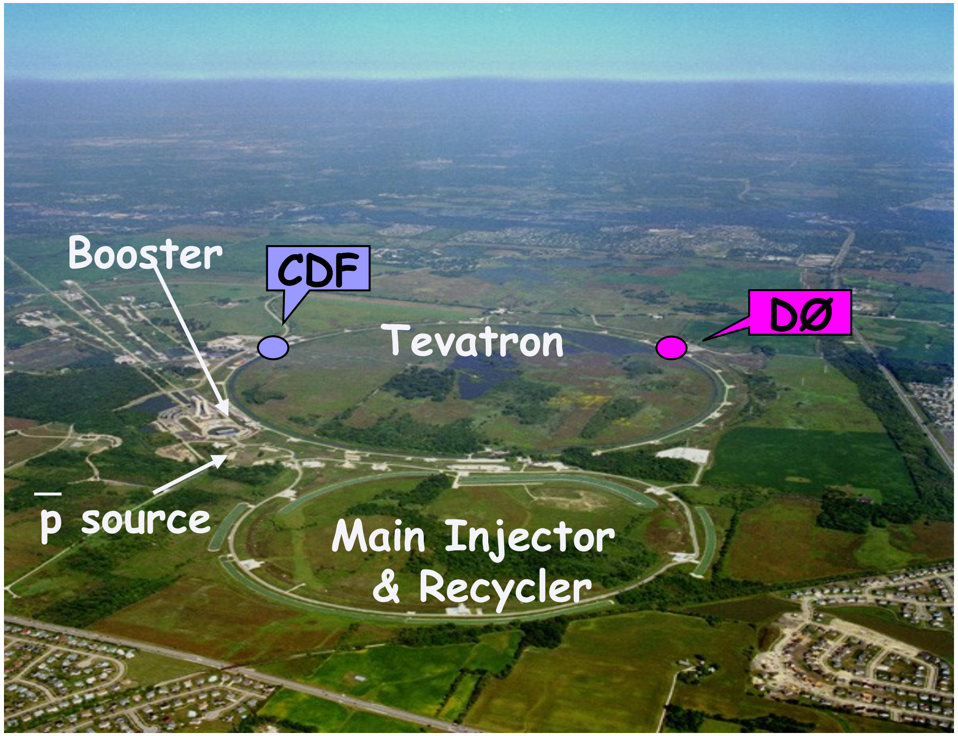
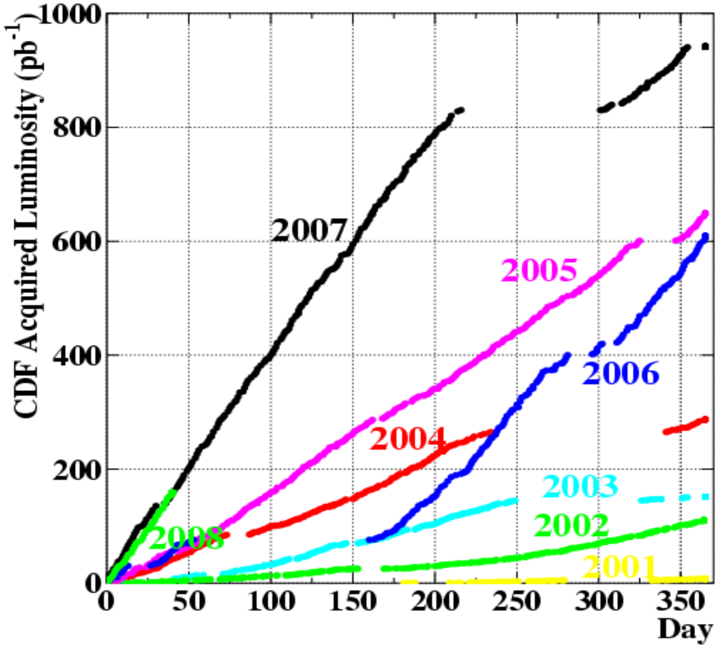
Tevatron

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

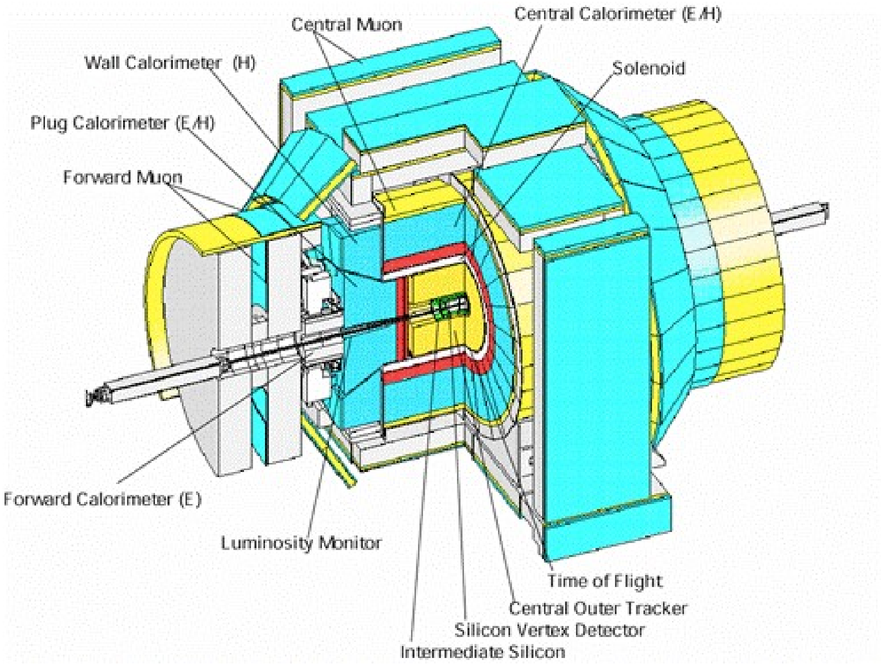
~3 fb^{-1} data on tape
Initial instantaneous luminosity 3.15x10^{32}cm^{-2}s^{-1}

- Approved running until 2009, possible 2010?





Tevatron Detectors

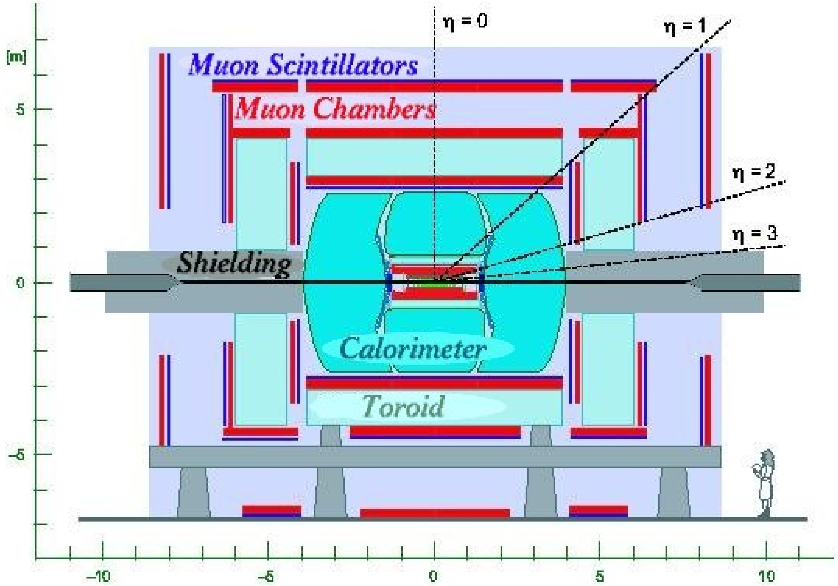


CDF II Detector

- Tracker: - Silicon Vertex Detector
  - Drift Chambers
- **Excellent Momentum and Vertex Resolution**
- **Particle ID**: TOF and dE/dx
- Triggered Muon Coverage $|\eta| < 1.0$

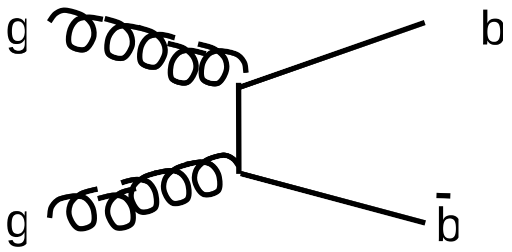
D∅ Detector

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

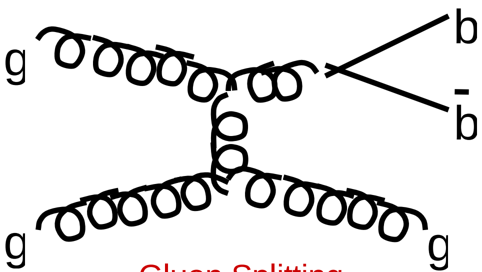


B Physics at the Tevatron

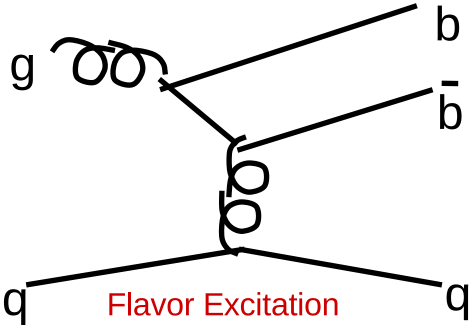
- Mechanisms for b production in $p\bar{p}$ collisions at 1.96 TeV



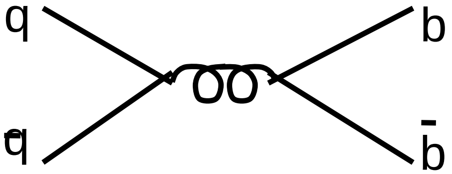
Flavor Creation (gluon fusion)



Gluon Splitting



Flavor Excitation



Flavor Creation (annihilation)

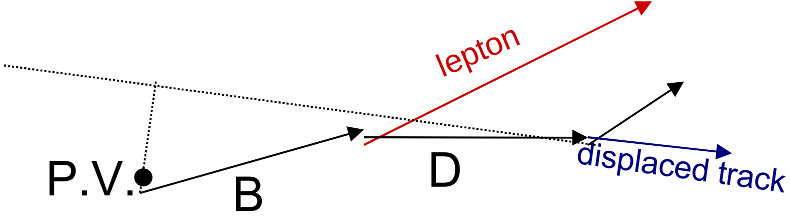
- At Tevatron, b production cross section is much larger compared to B-factories
  → Tevatron experiments CDF and DØ enjoy rich B Physics program

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

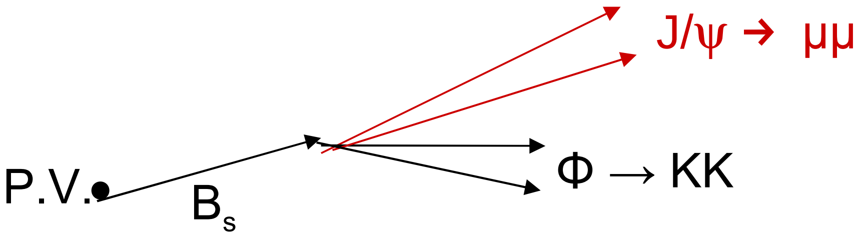
- Total inelastic cross section at Tevatron is ~1000 larger than b cross section
  → large backgrounds suppressed by triggers that target specific decays

Tevatron B Triggers

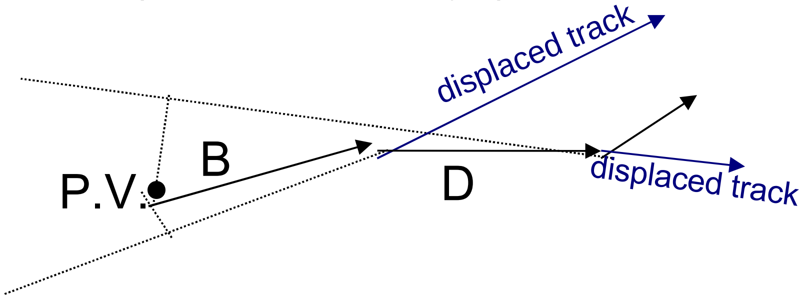
- Triggers designed to select events with topologies consistent with B decays:
  - single lepton (+ displaced track): D0 (CDF) --> semileptonic decays



  - di-lepton: D0 & CDF --> $B \rightarrow J/\psi X$, $B \rightarrow \mu\mu$, $B \rightarrow \mu\mu$ + hadron(s)



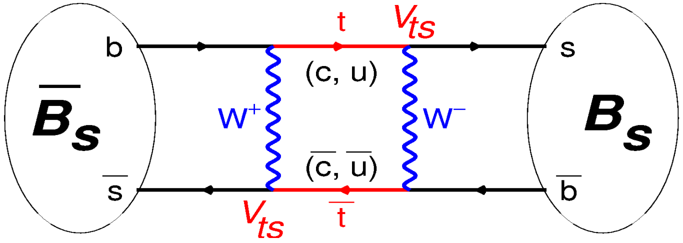
  - displaced tracks (hadronic decays): CDF

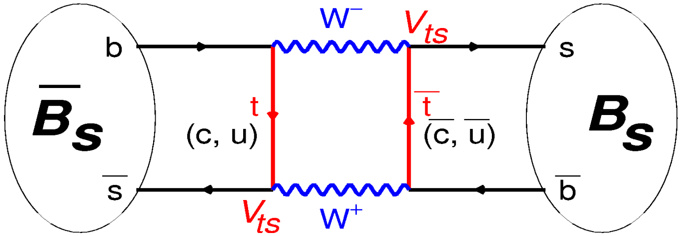


Neutral B_s System

Flavor eigenstates:

$$|B_s\rangle = (\bar{b}s); \quad |\bar{B}_s\rangle = (b\bar{s})$$





Pure B_s and $\bar{B}_s$ at production:

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

Mass eigeinstates are ($|p|^2+|q|^2=1$):

$$|B_H(t)\rangle = p|B_s(t)\rangle + q|\bar{B}_s(t)\rangle; \qquad |B_L(t)\rangle = p|B_s(t)\rangle - q|\bar{B}_s(t)\rangle$$

⇒ Different Masses:

$\Delta m_s = M_H - M_L \approx 2|M_{12}|$ defines the Mixing Oscillation Frequency

⇒ Different Lifetimes:

$\Delta\Gamma_s = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\Phi_s$,

CPV:

$\Phi_s^{SM} = \arg(-\frac{M_{12}}{\Gamma_{12}}) \approx 4\times10^{-3}$rad

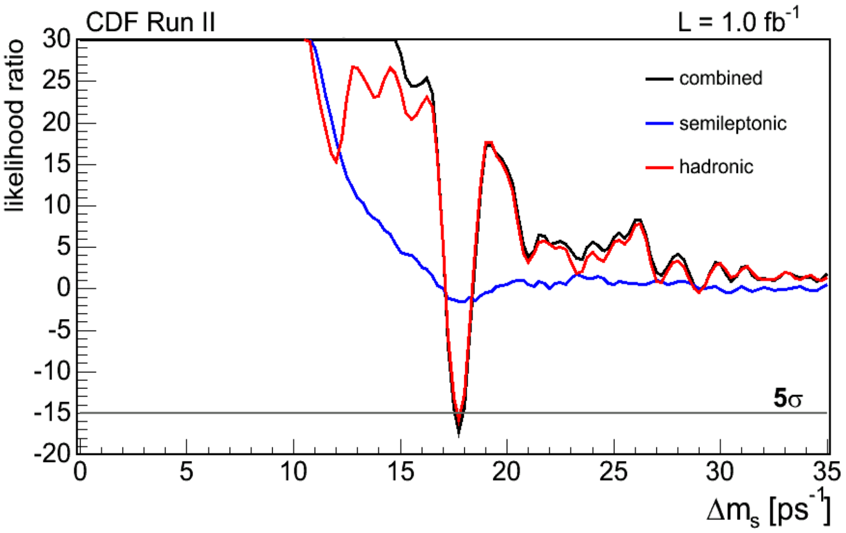
Small Phase expected in SM

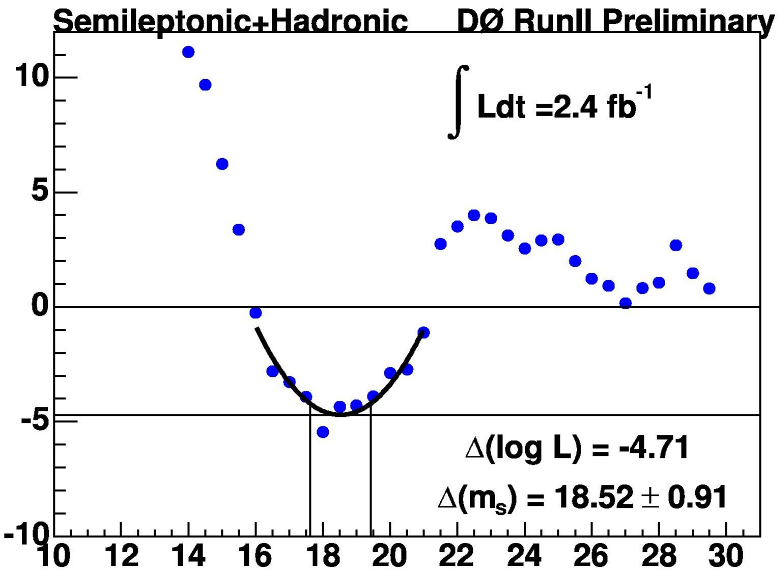
B_s Mixing Oscillation Magnitude

CDF: World First Observation (5σ)

- Integrated Luminosity: 1 fb^{-1}
- $\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$, $\xi = 1.210^{+0.047}_{-0.035}$ (lattice QCD)

$$\Delta m_s = 17.77 \pm 0.12\ \text{ps}^{-1}$$





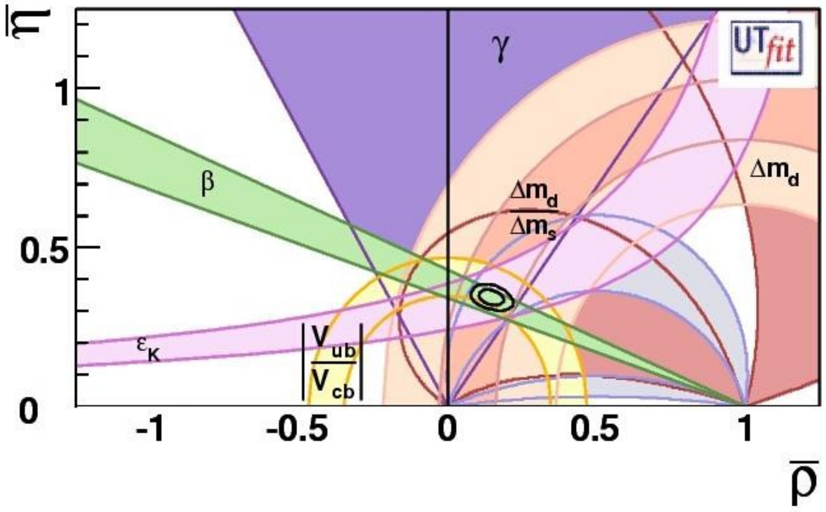
DØ: Evidence (3σ)

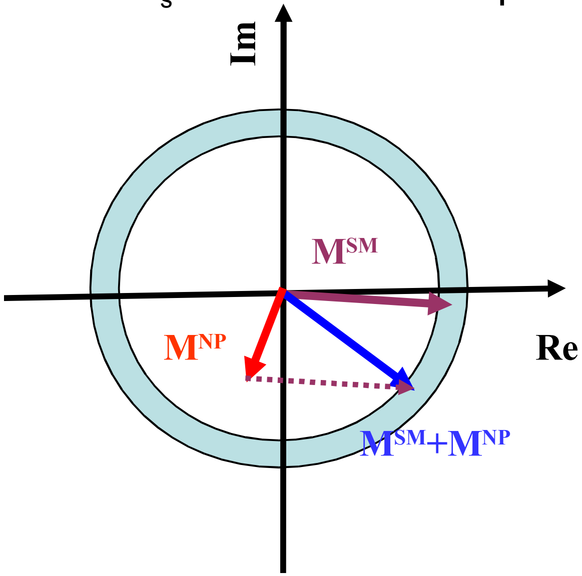
- Integrated Luminosity: 2.4 fb^{-1}
- First DØ measurement using a hadronic mode
- $\Delta m_s = 18.56 \pm 0.87\ \text{ps}^{-1}$
- Consistent with CDF result

CP Violation in B_s System

- B_s mixing oscillation is observed:
  - ✓ $\Delta m_s = M_H - M_L \approx 2|M_{12}|$ is well measured
  - ✓ Precisely determines $|M_{12}|$ in good agreement with the Standard Model

CDF: Δm_s = 17.77 +/- 0.12 ps^{-1}
DØ: Δm_s = 18.56 +/- 0.87 ps^{-1}





One of the few corners where large NP contributions can be found

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

$$\rightarrow M_{12} = |M_{12}|e^{i\phi_M}$$

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

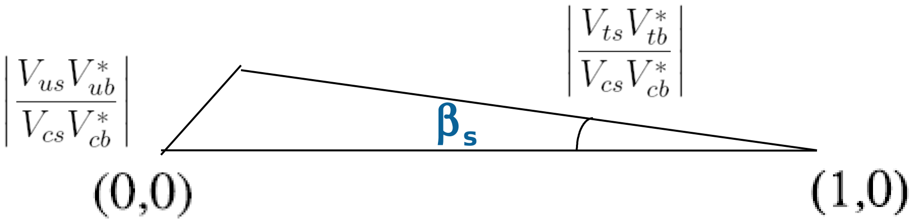
~~CP~~ in $B_s \to J/\Psi\ \Phi$ Decays

- CP Violation arises from the interference between mixing and decay:

$$\begin{tikzcd} B^0 \arrow[rr] \arrow[dr] & & J/\Psi K^0_S \\ & \bar{B}^0 \arrow[ur] & \end{tikzcd} \qquad \begin{tikzcd} B^0_S \arrow[rr] \arrow[dr] & & J/\Psi\phi \\ & \bar{B}^0_S \arrow[ur] & \end{tikzcd}$$

$\Rightarrow \sin(2\beta)$ $\qquad$ $\Rightarrow \sin(2\beta_s)$

- Unitarity Triangle in B_s System:



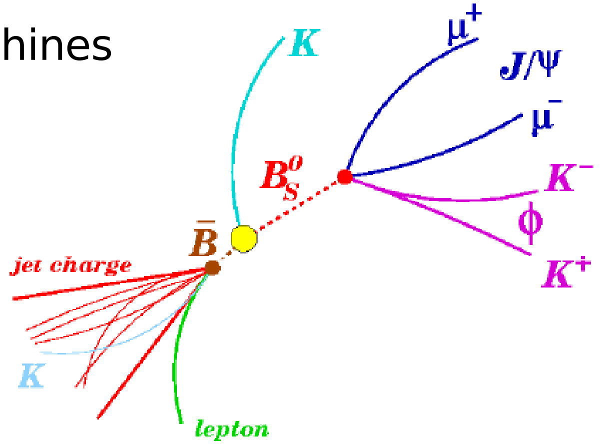
$$\boxed{V_{us}V^*_{ub} + V_{cs}V^*_{cb} + V_{ts}V^*_{tb} = 0}$$

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

$$2\beta_s^{SM} = 2\arg(-V_{ts}V^*_{tb} / V_{cs}V^*_{cb}) \approx 0.04 \pm 0.01 \quad \text{rad}$$

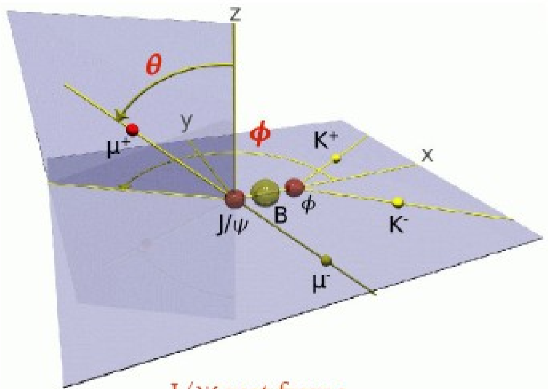
- Same New Physics affects the CPV phases as $\boxed{2\beta_s = 2\beta_s^{SM} - \Phi_s^{NP} \qquad \Phi_s = \Phi_s^{SM} + \Phi_s^{NP}}$
- If NP phase Φ_s^{NP} dominates $\Rightarrow$ $2\beta_s = -\Phi_s$

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

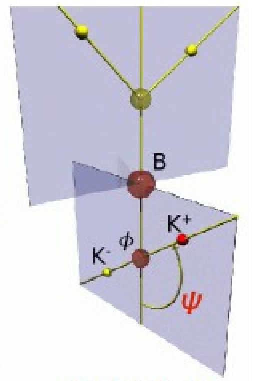


- Nice experimental signature for B physics at hadron machines
- Decays into an admixture of CP even (~75%) and CP odd (~25%)
- $CP|B_{L,H}\rangle \cong \pm|B_{L,H}\rangle \Rightarrow$ Mass and CP states are very close
- C-even ⇒ Different Parity ⇒ Separate CP contributions
- $B_s \to J/\Psi\Phi$ decays leads to three different angular momentum final states:
  - ✓ L=0 (S-wave), L=2 (D-wave) ⇒ P-even
  - ✓ L=1 (P-wave) ⇒ P-odd
- Angular Analysis to separate the different parity contributions
- Transversity Basis $w = (\theta,\ \Phi,\ \psi)$
- Sensitivity to $\Delta\Gamma_s$ and CP-Violation phase $2\beta_s$

  (also in untagged sample due to CP-even/CP-odd interference)



J/ψ rest frame



φ rest frame

Signal PDF for $B_s \to J/\Psi\ \Phi$

General decay rate formula:

$$\frac{d^4P(t,\vec{w})}{dtdw} \propto |A_0|^2\, T_+ f_1(\vec{w}) + |A_\parallel|^2\, T_+ f_2(\vec{w})$$

$$+ |A_\perp|^2\, T_- f_3(w) + |A_\parallel||A_\perp|\, U_+ f_4(w)$$

$$+ |A_0||A_\parallel| \cos(\delta_\parallel) T_+ f_5(w)$$

$$+ |A_0||A_\perp|\, V_+ f_6(w)$$

$$T_\pm = e^{-\Gamma t} \text{ x } [\cosh(\Delta\Gamma t/2) \mp \cos(2\beta_s)\sinh(\Delta\Gamma t/2)$$

$$\mp \eta \sin(2\beta_s)\sin(\Delta m_s t)],\ \eta = +1(-1) \text{ for } P(\bar{P})$$

$$U_\pm = \pm e^{-\Gamma t} \text{ x } [\sin(\delta_\perp - \delta_\parallel)\cos(\Delta m_s t)$$

$$-\cos(\delta_\perp - \delta_\parallel)\cos(2\beta_s)\sin(\Delta m_s t)$$

$$\pm \cos(\delta_\perp - \delta_\parallel)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

$$V_\pm = \pm e^{-\Gamma t} \text{ x } [\sin(\delta_\perp)\cos(\Delta m_s t)$$

$$-\cos(\delta_\perp)\cos(2\beta_s)\sin(\Delta m_s t)$$

$$\pm \cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma t/2)]$$

- B_s decays into mixture of CP eigeinstates: interference terms in general decay rate formula
- In the Transversity basis the vector meson polarization w.r.t the direction of motion is:

✓ Longitudinal ⇒ A_0 [CP even]
✓ Transverse and parallel to each other ⇒ $A_\parallel$ [CP even]
✓ Transverse and perpendicular to each other ⇒ $A_\perp$ [CP odd]

- Strong phases:

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

- Terms with Δm_s dependence flip sign for initial B_s flavor
- Untagged analysis are insensitive to $\Delta\Gamma_s$ and β_s signs ⇒ 4-fold ambiguity

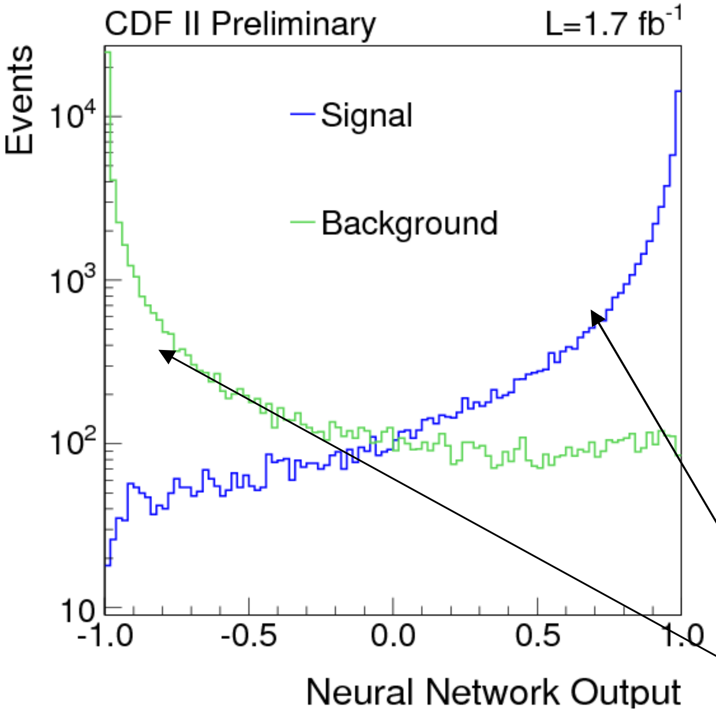
Experimental analysis:

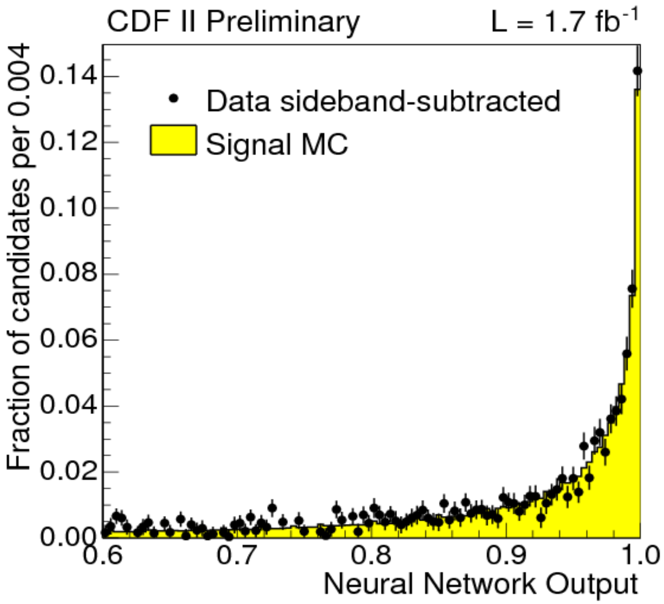
- * signal selection
  - untagged results
- * b-flavor tagging
  - tagged results

Selection of $B_s \to J/\psi\phi$ Decays

- D0 analysis: cut based approach
  - Variables not biasing lifetime distribution

    $p_t(\mu, K, J/\psi, \phi, B_s)$, $m(J/\psi, \phi)$, vertex fit probability $(J/\psi, \phi, B_s)$, $\mathrm{pid}(\mu, K)$
- CDF: multivariate techniques
  - All of them give similar performance, always better than cut based ones
  - Using the same variables as D0, but in a more sophisticated way
  - Neural Network frameworks were used

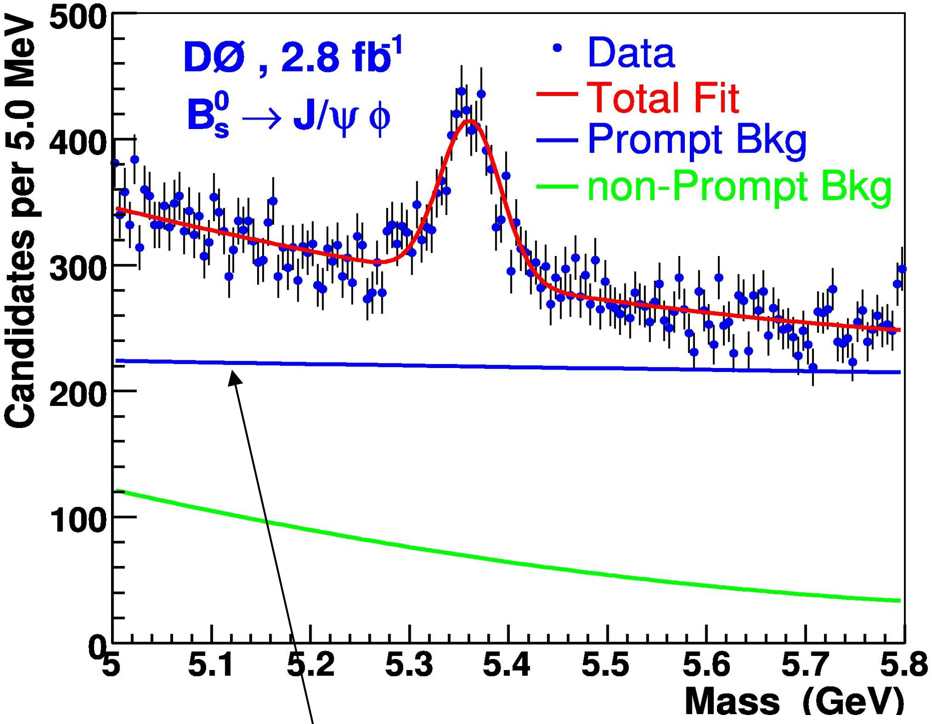


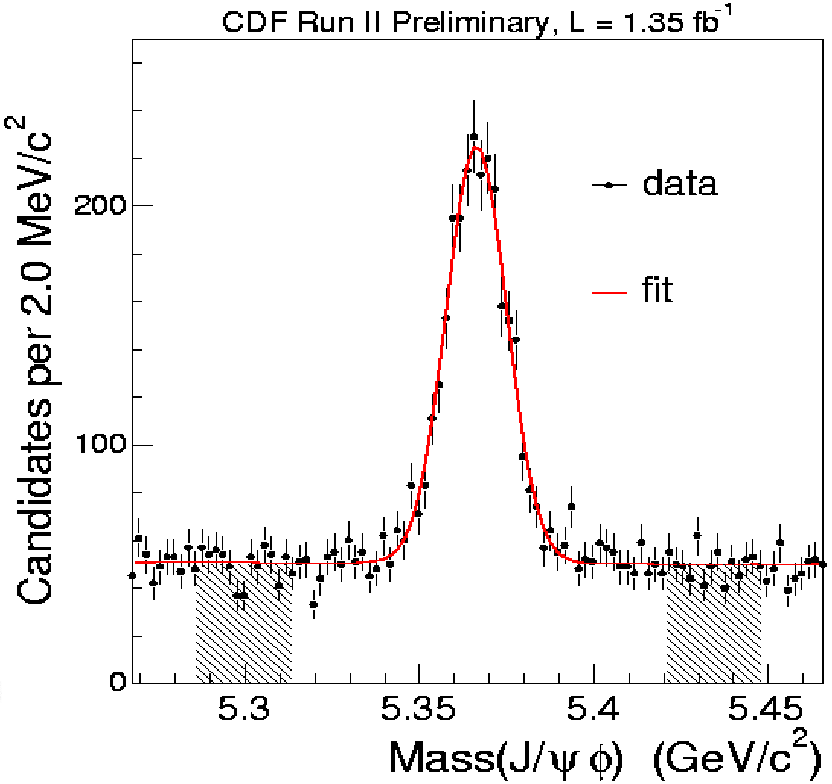


- Signal: MC simulation
- Background: B_s mass sidebands

Mass distributions on selected $B_s \to J/\psi\phi$ Decays

- D0 tagged analysis (2.8 fb^{-1}): ~2000 signal candidates with S/B~1/4
- CDF tagged analysis (1.3 fb^{-1}): ~2000 signal candidates with S/B~1/1



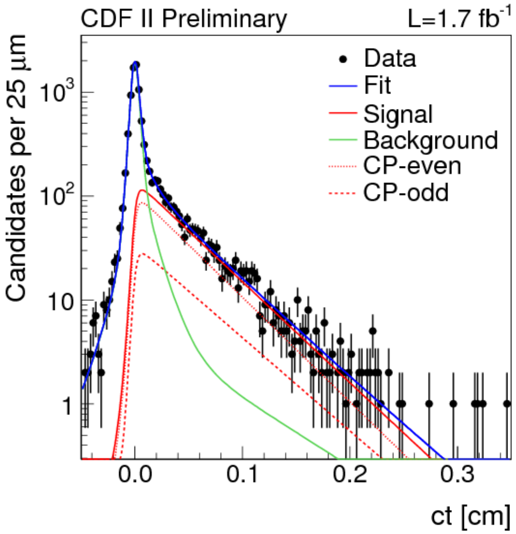


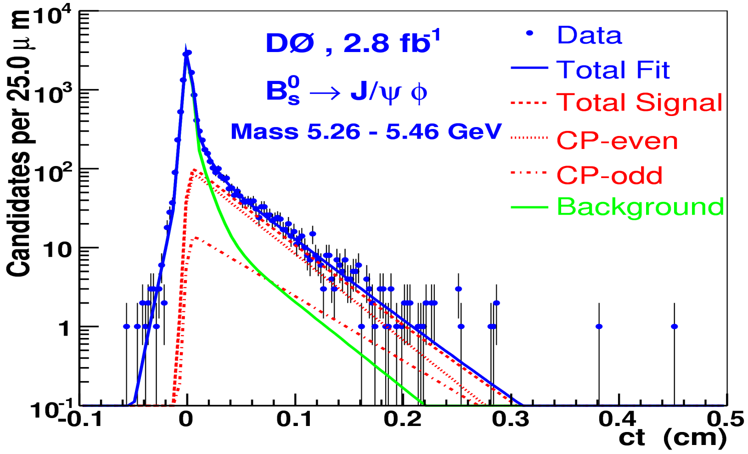
- Keep in mind most of the background is at t=0

B_s Lifetime and Decay Width

- Sizeable $\Delta\Gamma_s \Rightarrow$ CP-even and CP-odd contributions of the signal can be distinguished
- Results assuming no CP violation $\Rightarrow$ **β_s=0**

CDF: ~2500 signal events (1.7 fb^{-1}) **DØ:** ~2000 signal events (2.8 fb^{-1})





arXiv:0802.2255

World Best $\Delta\Gamma_s$ Measurements (arXiv: 0712.2348)

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

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

ct_s = 1.52 +/- 0.05(stat) +/- 0.01(syst) ps

$\Delta\Gamma_s$ = 0.19 +/- 0.07(stat) +/- 0.01(syst) ps

- $B^0 \to J/\Psi\ K^{*0}$: CDF validates treatment of detector acceptance!
  $\Rightarrow$ Results compatible and competitive with B Factories (see next slide)

Angular Analysis in $B^0 \rightarrow J/\psi K^{*0}$ Decays at CDF

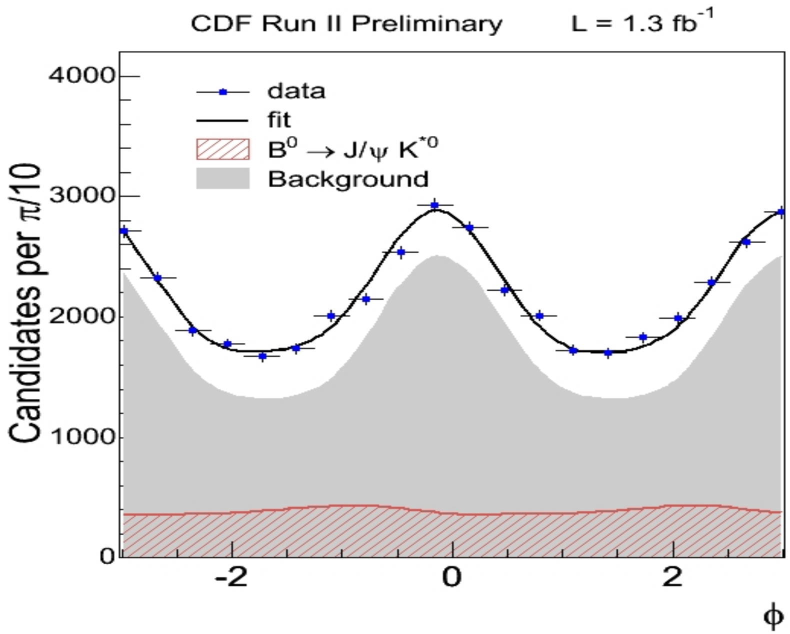
- Important analysis on its own
- Cross-check of B_s system

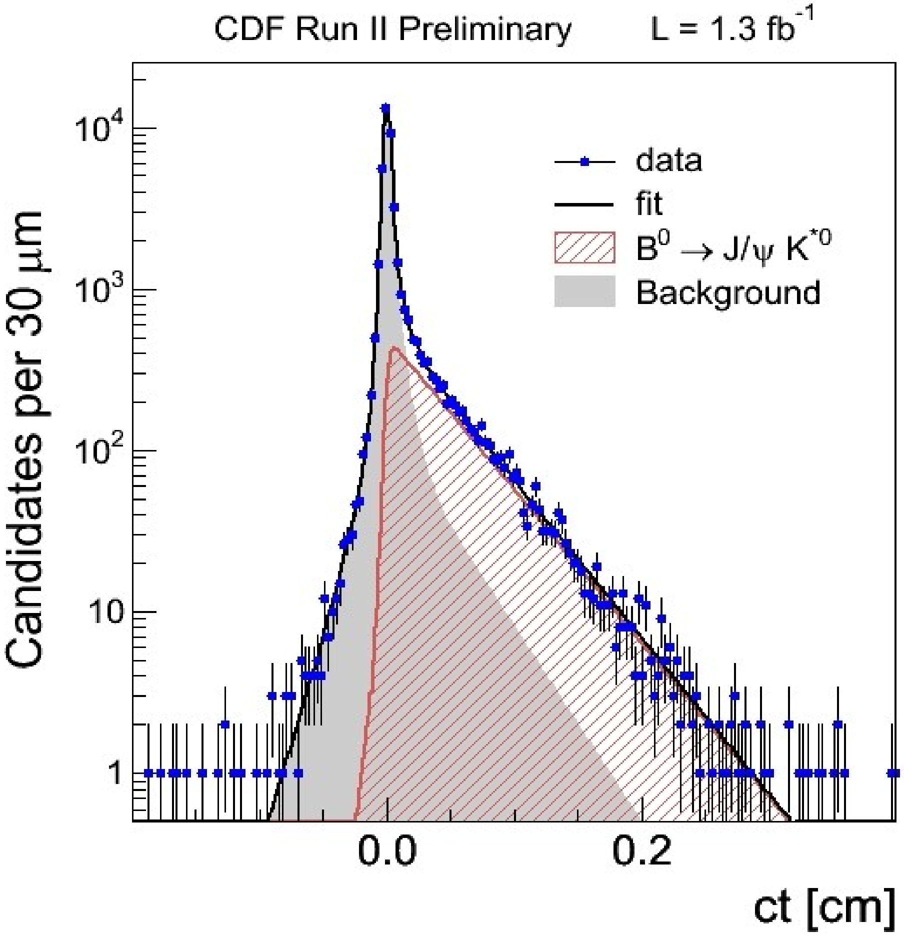
$|A_0|^2$ = 0.569 +/- 0.009 (stat) +/- 0.009 (syst)

$|A_{||}|^2$ = 0.211 +/- 0.012 (stat) +/- 0.006 (syst)

$\delta_{||}$ = -2.97 +/- 0.08 (stat) +/- 0.03 (syst)

$\delta_{\perp}$ = 2.97 +/- 0.06 (stat) +/- 0.01 (syst)

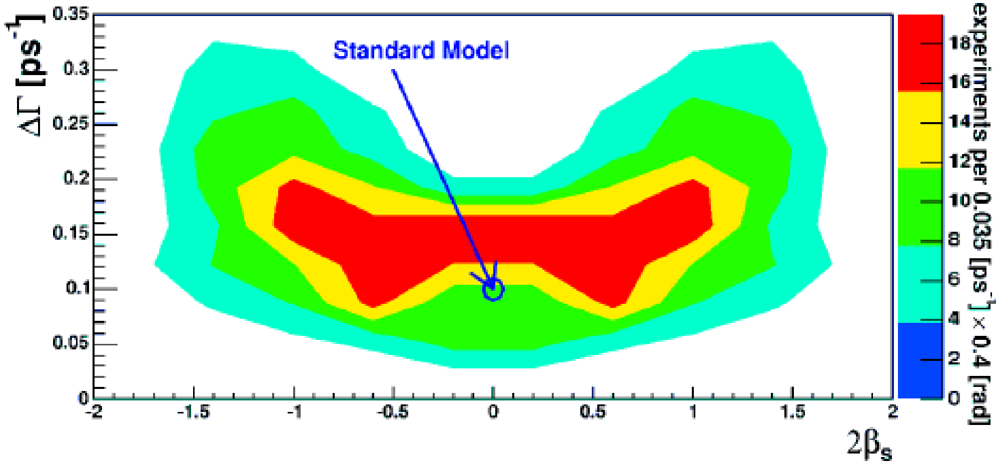




competitive with B factories

Untagged Analysis: Bias

- Biases due to low statistics
- Non-Gaussian estimates in pseudo-experiments
- Strong dependence on true values for biases on some fit parameters



Fits on simulated samples

generated with SM inputs for $\Delta\Gamma_s$ and β_s

⇒ Dependence on one parameter in the likelihood vanishes for some values of other parameters: Likelihood looses degrees of freedom

e.g., if $\Delta\Gamma=0$, δ is undetermined: $\cos(\delta_\perp)\sin(2\beta_s)\sinh(\Delta\Gamma_s t/2)$

~~CP~~ in Untagged $B_s \to J/\Psi\ \Phi$

- Allowing CP violation phase β_s to float in the fitter
- Symmetry in the likelihood 4-fold ambiguity
- **DØ** quotes a point estimate:

$$\Rightarrow \Phi_s = -2\beta_s = -0.79 \pm 0.56\ (\text{stat})^{+0.14}_{-0.01}\ (\text{syst})\ \text{rad}$$

$$\Rightarrow \Delta\Gamma_s = 0.17 \pm 0.09\ (\text{stat}) \pm 0.02\ (\text{syst})\ \text{ps}^{-1}$$

- **CDF** observes irregular likelihood and biases in fit

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

Standard Model expectations:

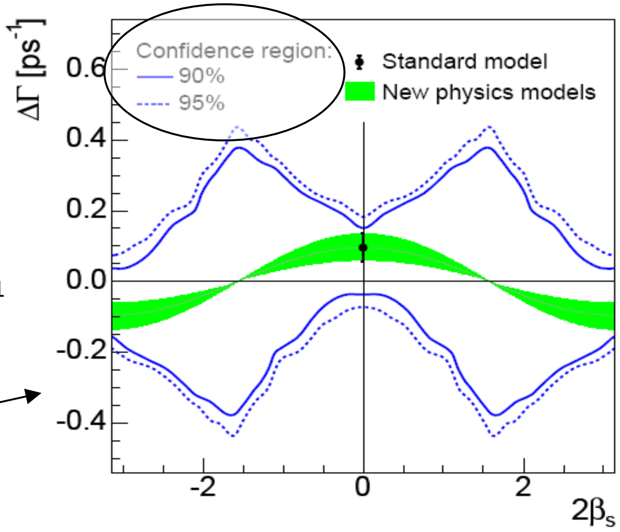
(arXiv:hep-ph/0612167)

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

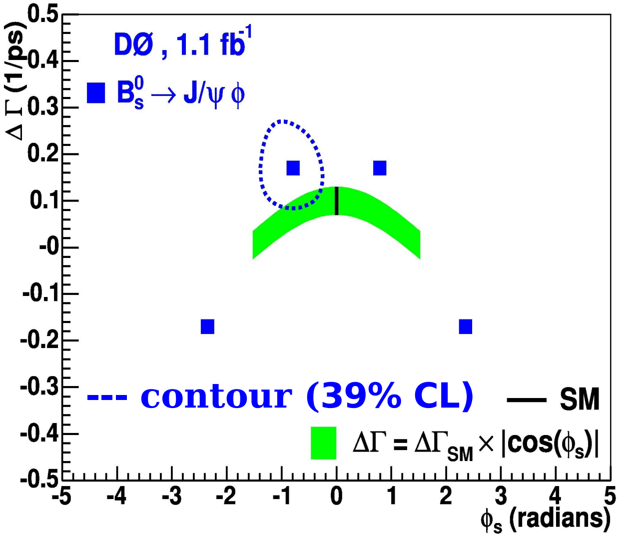
$2\beta_s = 0.04 \pm 0.01\ \text{rad}$

CDF

arXiv:0712.2348



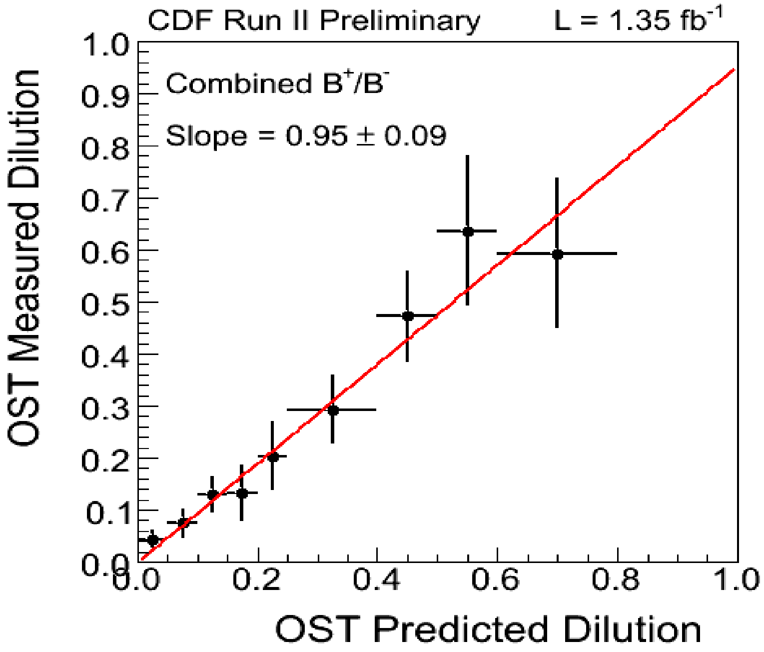
PRL 98, 121801 (2007)

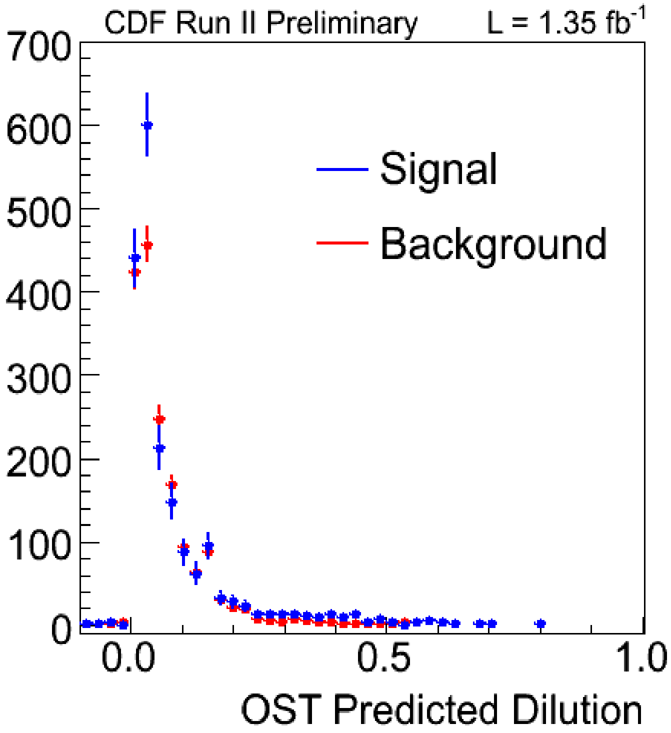


Flavor tagging

B Flavor Tagging, Opposite-Side

- Opposite -Jet-Charge-Tagging
  - sign of the weighted average charge of opposite B-Jet
- Soft-Lepton-Tagging (electron and muon)
  - identify soft lepton (e, μ) from semileptonic decay of opposite B
  - dilution due to b --> c decays and B oscillations

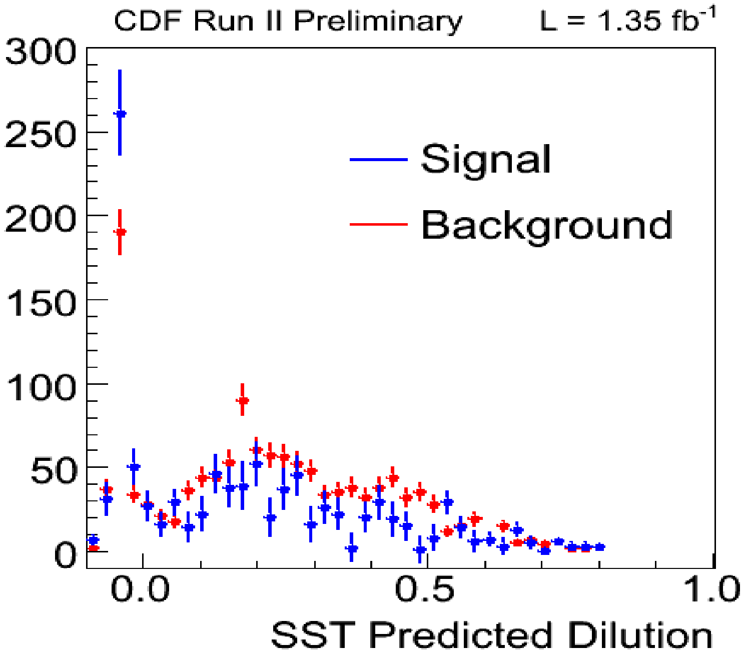


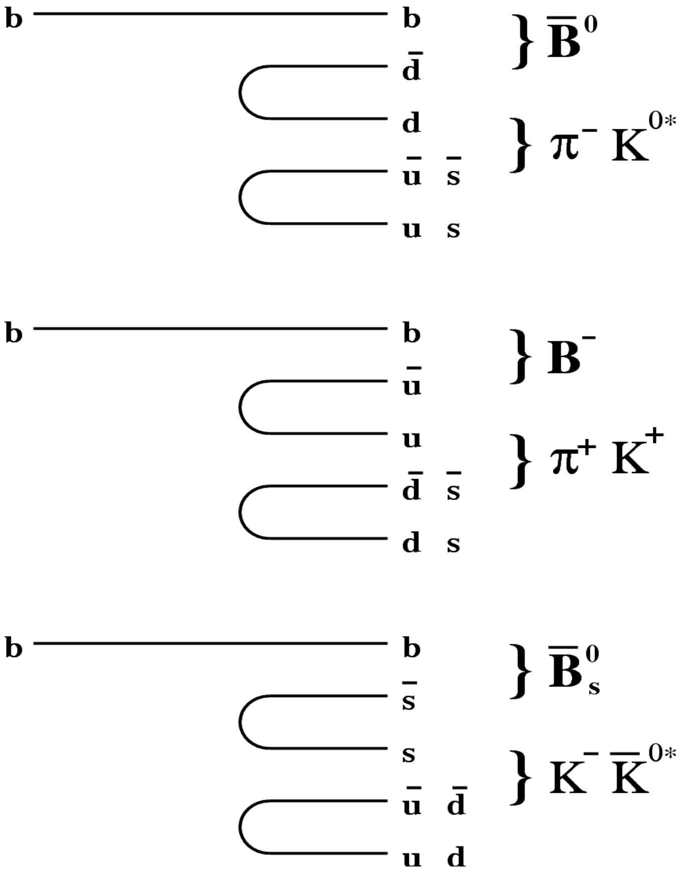


- Applicable to B^0, B^+ and B_s samples:
  - can use high statistics B^0 & B^+ to calibrate it
- Other b not always in the acceptance region

B Flavor Tagging, Same-Side (I)

- B fragmentation:
  - $B_{d/u}$ is likely to be accompanied close by a $\pi^{+/-}$
  - B_s is likely to be accompanied close by a K





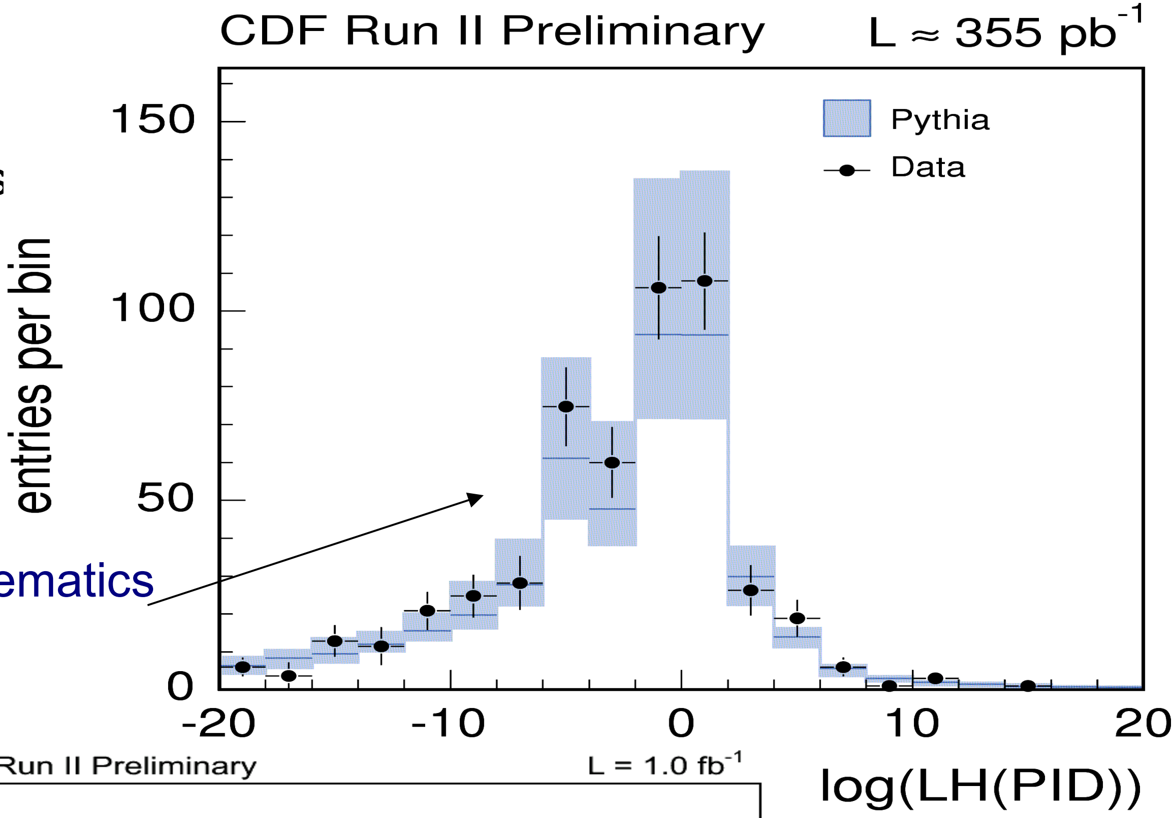
- Particle ID helps a lot to the tagging power
- No straightforward way to measure the tagger power
- Need to rely on MC, a lot of studies were performed!

Until B_s Mixing is(was) observed...

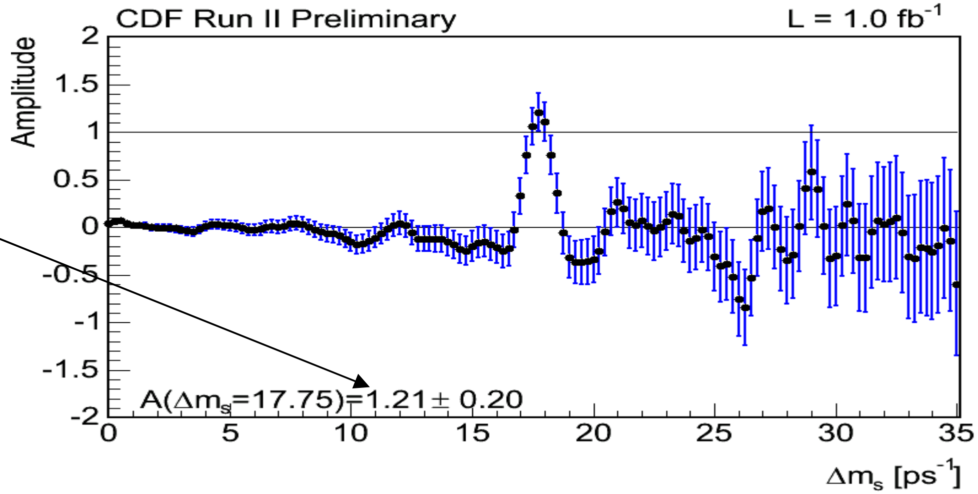
B Flavor Tagging, Same-Side (II)

Systematic studies:

Fragmentation Model
bb Production Mechanisms
B** content
Detector/PID resolution
Multiple interactions
PID content around B
Data/MC agreement



discrepancies covered by systematics



Correct calibration was confirmed later

B Flavor Tagging Performance

- Efficiency (ε): fraction of tagged candidates
- Dilution (D) = ($1 - 2\,p_w$), p_w: probability of giving wrong tagging decision
- $\varepsilon\,D^2$: maximum value, smaller statistical error

- CDF:
  - Opposite-side tagging: $\varepsilon \sim 96\%$, $D \sim 12\%$, $\varepsilon\,D^2 \sim 1.4\%$
  - Same-side tagging: $\varepsilon \sim 50\%$, $D \sim 27\%$, $\varepsilon\,D^2 \sim 3.6\%$
    - Calibrated only for 1.3 fb^{-1}
- D0:
  - Combined Same-side and Opposite-side tagging: $\varepsilon\,D^2 \sim 4.7\%$
    - Opposite-side tagging alone: $\varepsilon\,D^2 \sim 2.5\%$

Flavor Tagging Effect

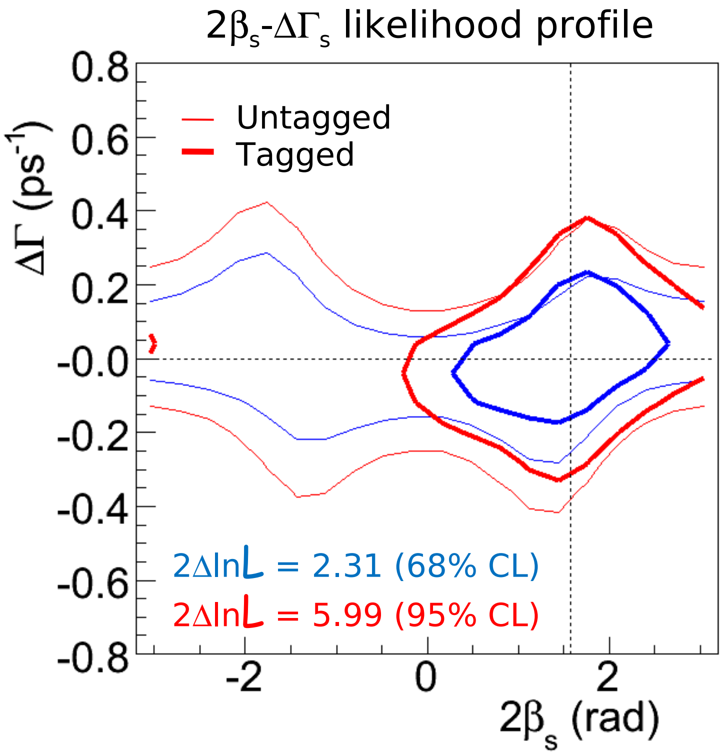
- Tagging improves sensitivity to CP violation phase β_s
- Exact symmetry present in signal probability distribution
- Two minima in the likelihood

$2\beta_s \leftrightarrow \pi - 2\beta_s$
$\Delta\Gamma_s \leftrightarrow -\Delta\Gamma_s$
$\delta_{||} \leftrightarrow \pi - \delta_{||}$
$\delta_{\perp} \leftrightarrow \pi - \delta_{\perp}$

- Check β_s-$\Delta\Gamma_s$ likelihood profile with Toy MC to understand tagging effect

- Likelihood: with tagging, gain sensitivity to both $|\cos(2\beta_s)|$ and $\sin(2\beta_s)$, rather than only $|\cos(2\beta_s)|$ and $|\sin(2\beta_s)|$ (note absolute value)
- $\beta_s \leftrightarrow -\beta_s$ is no longer a likelihood symmetry:

  $\Rightarrow$ 4-fold ambiguity reduced to <u>2-fold</u>
  $\Rightarrow$ allowed region for β_s is reduced to half



~~CP~~ in Tagged $B_s \to J/\Psi\ \Phi$

- First tagged analysis of $B_s \to J/\Psi\Phi$ decay arXiv: 0712.2397

Irregular likelihood does not allow quoting point estimate:

- ✓ Feldman-Cousins likelihood ratio ordering
- ✓ Systematics were taken into account

Standard Model expectations:

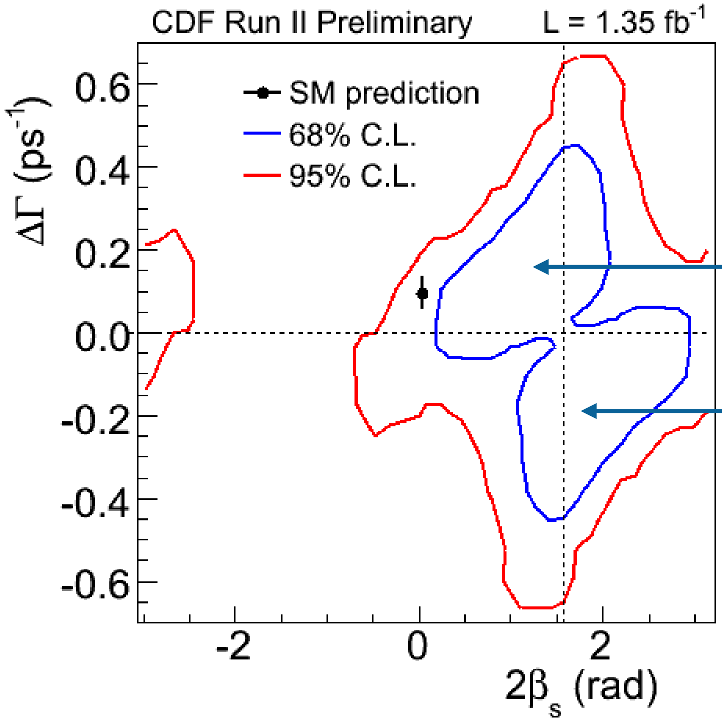
(arXiv:hep-ph/0612167)

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

$2\beta_s = 0.04 \pm 0.01$ rad

Standard Model

$p_{value} = 15\%\ (1.5\sigma)$



strong phases can separate the two minima

$cos(\delta_\perp) < 0$

$cos(\delta_\perp - \delta_{||}) > 0$

$cos(\delta_\perp) > 0$

$cos(\delta_\perp - \delta_{||}) < 0$

Δm_s constraint to $17.77 +/- 0.12\ \mathrm{ps}^{-1}$

~~CP~~ in Tagged $B_s \to J/\Psi\ \Phi$

1-dim Feldman-Cousins procedure on CP violation phase β_s

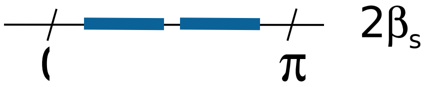
1. Without External Constraints:

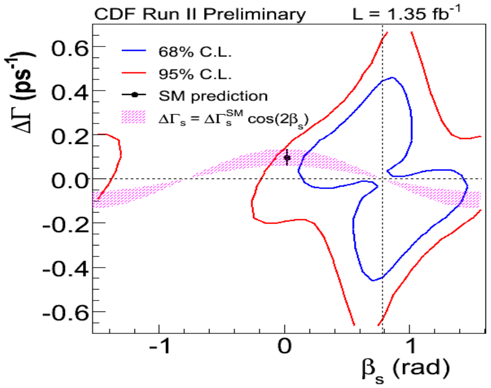
$2\beta_s$ in [0.32, 2.82] at the 68% C.L.

2. $\Delta\Gamma_s$ is theoretically constrained:

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

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

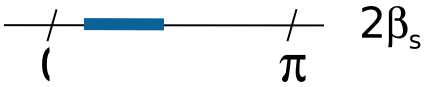




3. Strong phases from $B_d \to J/\Psi\ K^{*0}$ [PRD 71, 032005 (2005)],

B_s lifetime from B_d [PDG] and $\Delta\Gamma_s \approx 2|\Gamma_{12}|\cos(2\beta_s)$:

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



~~CP~~ in Tagged $B_s \to J/\Psi\ \Phi$

- Tagged analysis of $B_s \to J/\Psi\Phi$ decay from **DØ**

arXiv: 0802.2255

- Quoting point estimate:

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

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

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

FIT inputs:

Δm_s fixed to 17.77 ps^{-1} ← **CDF**

Gaussian constraint on Strong phases:

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

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

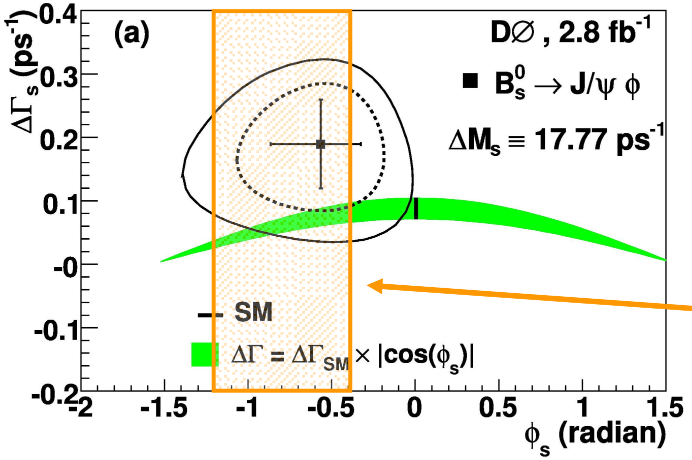
- Small change if the constraint is not included

Standard Model expectations:

(arXiv:hep-ph/0612167)

$$2\beta_s = 0.04 \pm 0.01\ \text{rad}$$

Standard Model p_{value} = 6.6%



90% C.L. contours:

$$-1.20 < 2\beta_s < 0.06\ \text{rad}$$

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

CDF 68% CL:

Constraining lifetime, strong phases and Γ_{12}

Conclusions

- Tevatron has a very active program in B Physics, with relevance in B_s sector
- Complementary and competitive with B Factories
- First $\sin(2B_s)$ results from D0 & CDF
  - D0 will release the likelihood scans with no strong phases constraints very soon
- Interesting $\sin(2\beta_s)$ fluctuation at Tevatron experiments:
  - exclude large negative values
  - both experiments
- Coming improvements:
  - Add more data, specially CDF
  - Better selection at D0

Constraints on β_s

New Physics in B_s mixing: **UTfit Group** (http://www.utfit.org/)

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

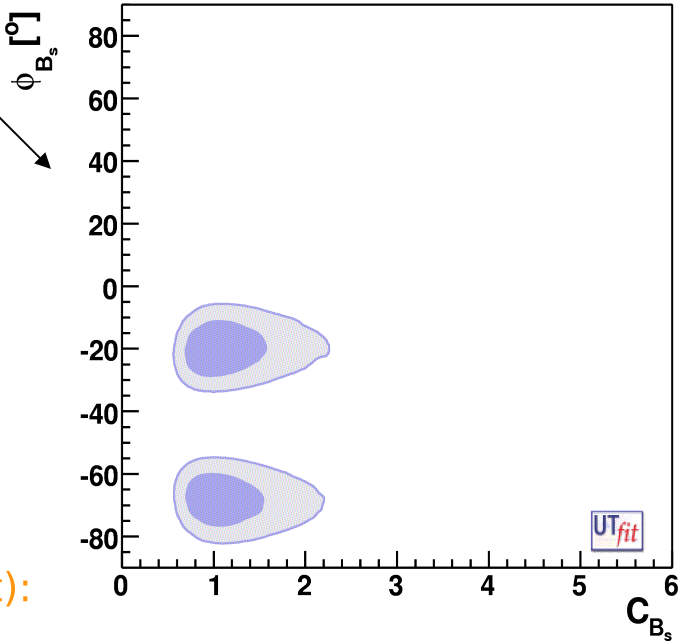
$\Delta m_s = C_{Bs} * \Delta m_s^{SM}$: Lattice-QCD dominated uncertainty

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

arXiv: 0802.2255

CDF input:
Tagged $B_s \rightarrow J/\Psi\, \Phi$ analysis

β_s expectation in SM (UTfit):
0.038 +/- 0.002



UTfit combination

D0 input:
Tagged $B_s \rightarrow J/\Psi\, \Phi$ analysis

Assumed Gaussian errors
for D0 inputs

Other **UT_{fit}** inputs:

Δm_s measurement (CDF)

Lifetime τ_s (all experiments)

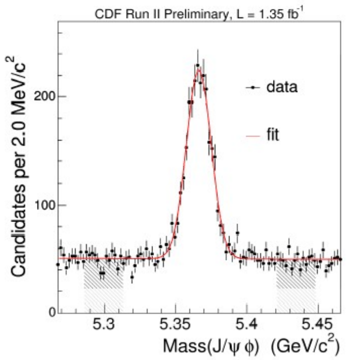
$\Delta\Gamma_s$ (CDF and D0)

A_{SL} (CDF and D0)

Back up

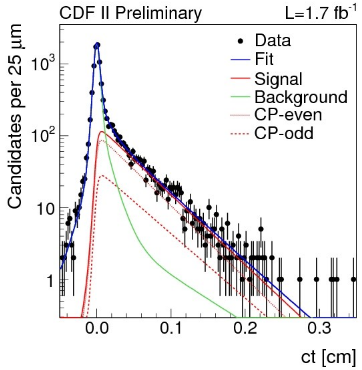
Signal PDF for $B_s \to J/\Psi\ \Phi$

$$P_s = P_M(\boxed{m \mid \sigma_m})\ P_L(\boxed{ct,}\ \boxed{w,}\ \boxed{\xi} \mid D,\ \boxed{\sigma_{ct}})\ P(\boxed{D})\ \varepsilon(w)$$



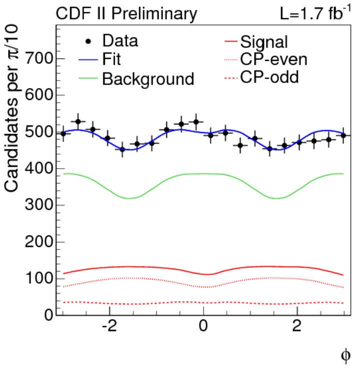
Mass:

discriminates signal against background



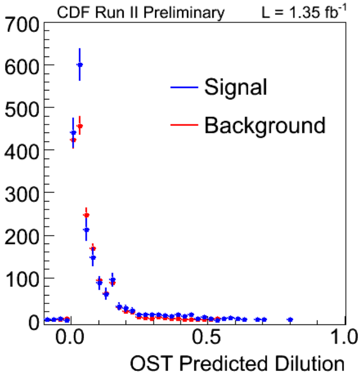
Decay-time:

determines lifetime of CP and flavor state



Angles:

separate CP-even from CP-odd final states



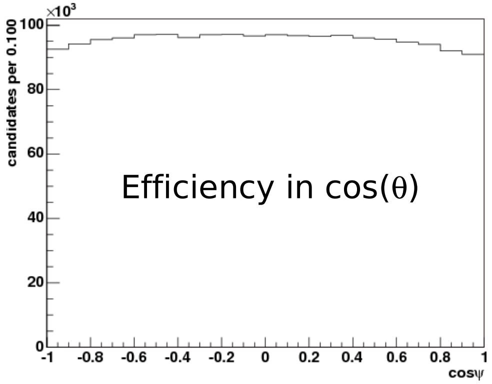
Tagging:

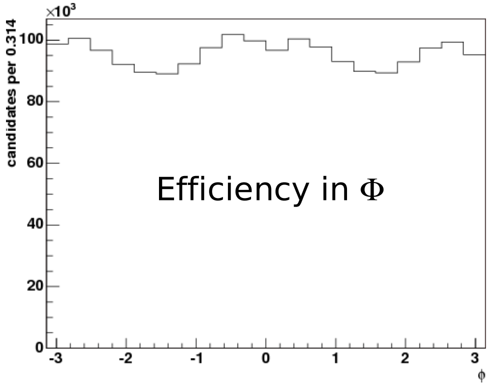
determine flavor of initial states

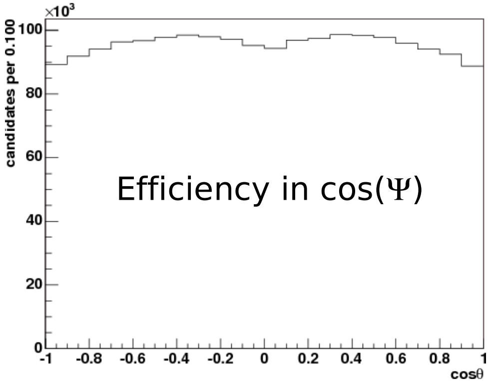
- $\varepsilon(w)$ is the sculpting of transversity angles due to detector acceptance

Detector Sculpting of Angles

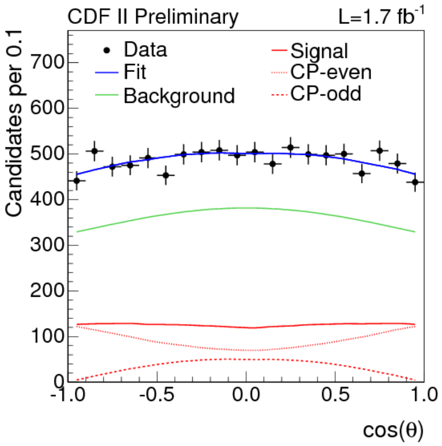
- Monte Carlo passed through detector simulation and to determine angular sculpting
  - Deviation from flat distribution indicates detector effects

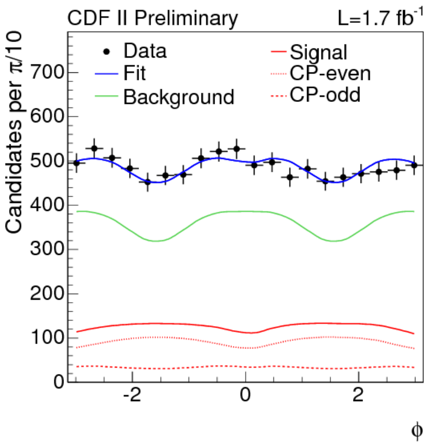

Efficiency in cos(θ)

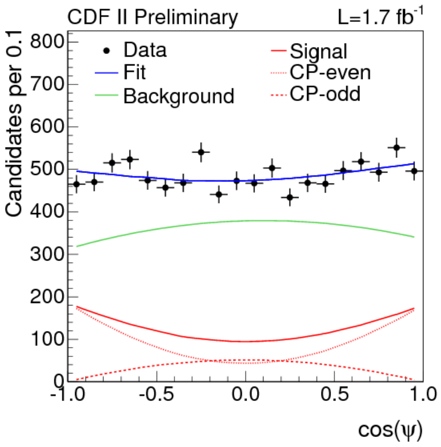

Efficiency in Φ


Efficiency in cos(Ψ)

- Data projections <u>uncorrected</u> for detector sculpting







Feldman-Cousins Procedure

Likelihood Ratio: $$R(\Delta\Gamma,\Phi) = \log \frac{L(\Delta\hat{\Gamma},\hat{\Phi},\hat{\theta})}{L(\Delta\Gamma,\Phi,\hat{\theta}')}$$

^ = parameters minimized by the likelihood L

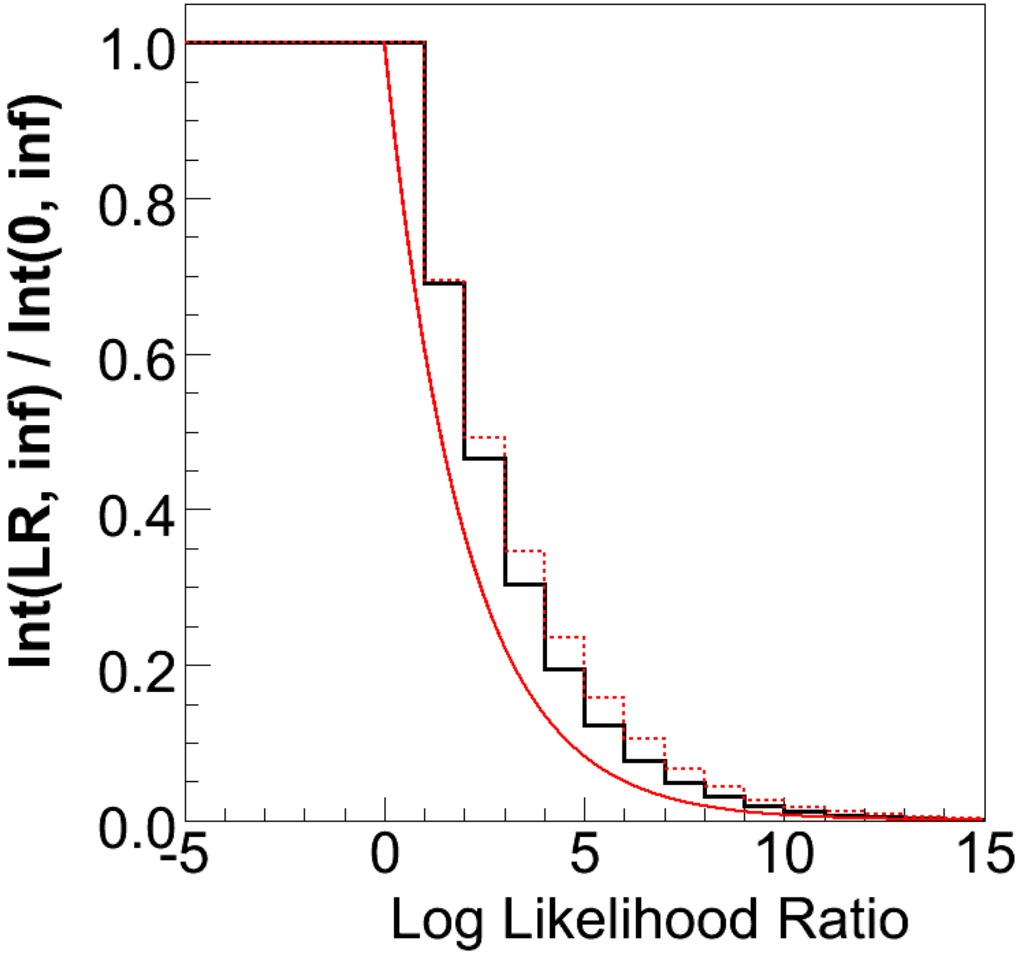
θ' = parameters which minimize L for a specific choice of $\Delta\Gamma$,Φ

- For a specific choice of $\Delta\Gamma$,Φ pseudo-exp are generated using θ'
- $p_{value} = \int_{Rdata}^{\infty} f(R,\Delta\Gamma,\Phi)dR$

Plug-In Method

Frequentist approach: probability to observe a result with $R \geq R_{data}$,
if $\Delta\Gamma$ and Φ are the values predicted by some model

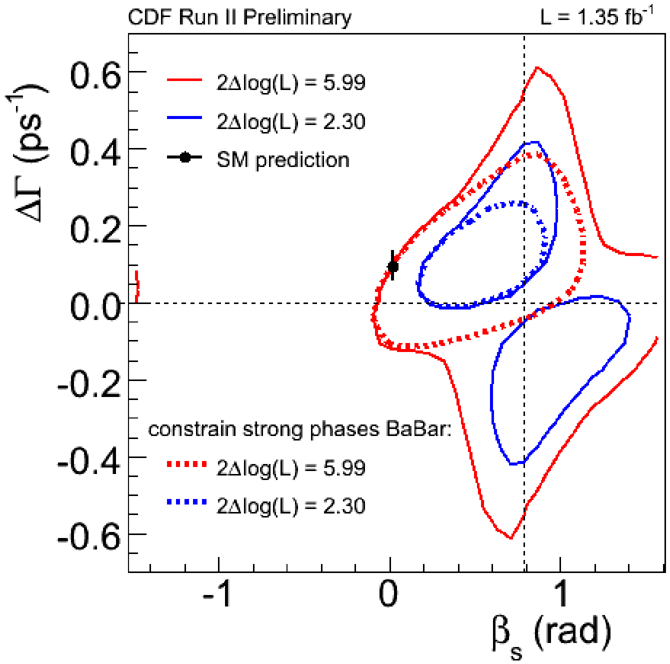
Feldman-Cousins Procedure



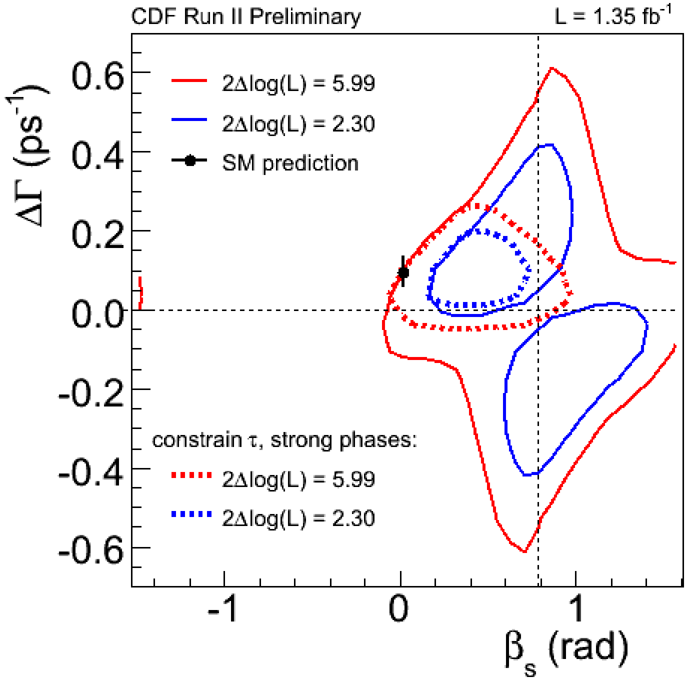
Constraints on Tagged $B_s \to J/\Psi\ \Phi$

- SU(3) flavor symmetry suggests that B_s and B^0 have similar lifetimes and strong phases
- Likelihood profiles with external constraints from B factories
- Underestimated confidence regions when using $2\Delta\ln\mathcal{L} = 2.31$ (5.99) to approximate 68% (95%) C.L. regions

constrain strong phases



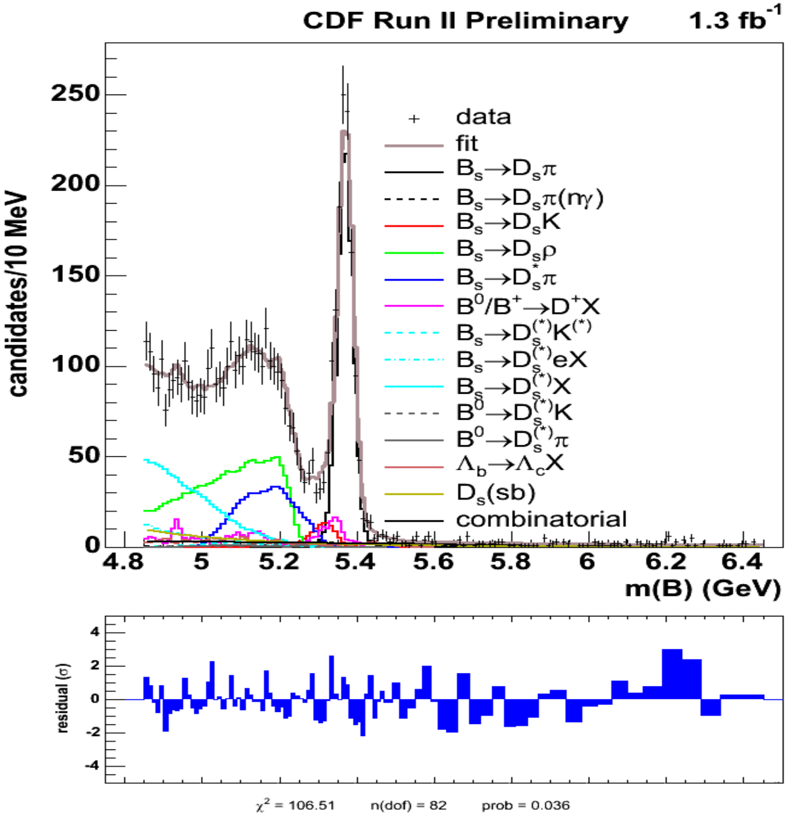
constrain lifetime and strong phases

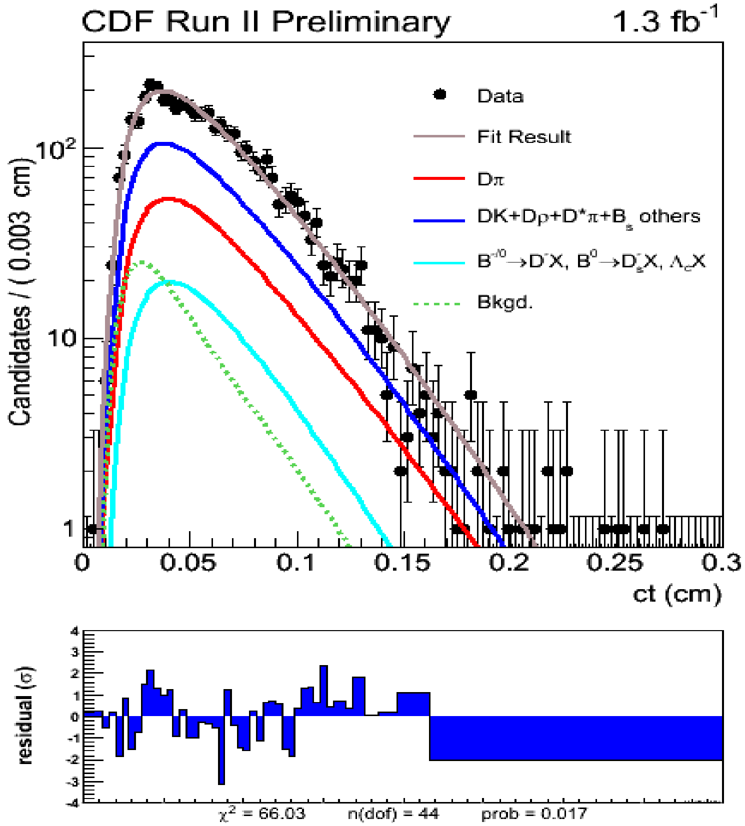


⇒ External constraints on strong phases remove residual 2-fold ambiguity

$B_s \rightarrow D_s\pi$ lifetime

cτ(Bs) = 455.0 ± 12.2 (stat.) ± 7.4 (syst.) μm





- ~1100 fully reconstructed B_s -> $D_s\pi$ decays
- ~2000 partially reconstructed B_s -> $D_s\pi/\rho$ decays

Charge Asymmetry

- CP Violation in mixing

- if $\Delta m_s / \bar{\Gamma}_s >> 1 \Rightarrow$ $\boxed{A_{SL}^s = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\Phi_s}$

- Combine these results with $B_s \rightarrow J/\Psi\Phi$ measurements to constrain phase β_s

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

$$\boxed{A_{SL}^s = 0.020 \pm 0.021 \text{ (stat)} \pm 0.016 \text{ (syst)} \pm 0.009 \text{ (inputs)}}$$

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

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

$$\boxed{A_{SL}^s = -0.0064 \pm 0.0101 \text{ (stat + syst)}}$$

PRD 74, 092001 (2006)

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

$$\boxed{A_{SL}^s = [2.45 \pm 1.93 \text{ (stat)} \pm 0.35 \text{ (syst)}] \times 10^{-2}}$$

PRL 98, 151801 (2007)