Recent *B* Physics Results from CDF

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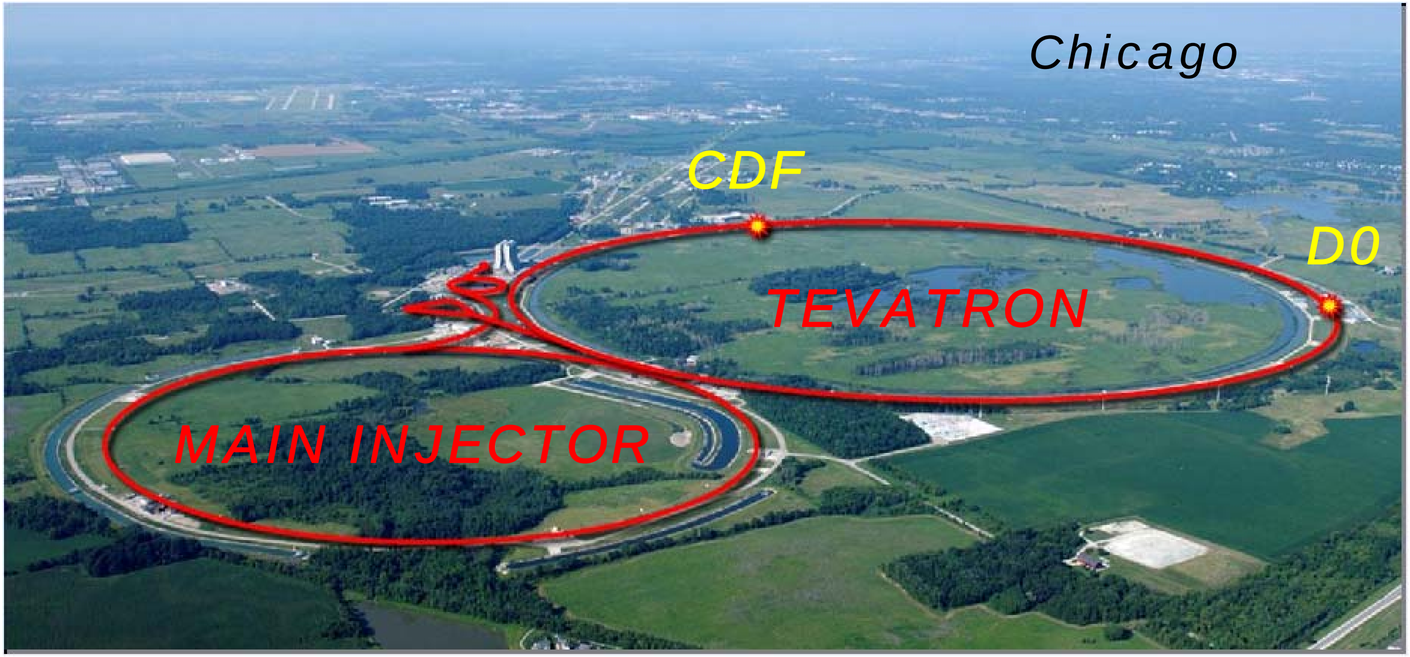
Outline

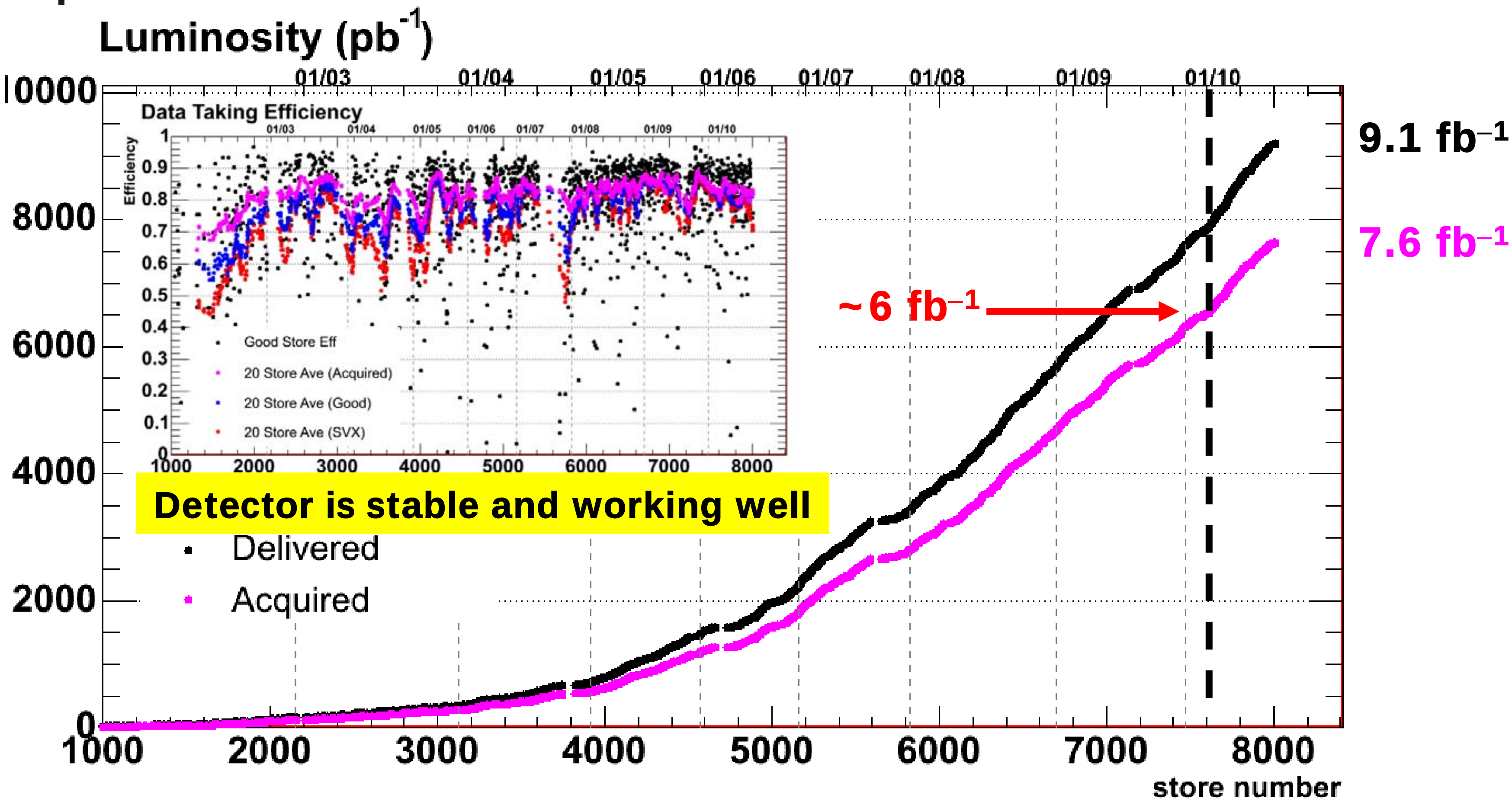
- Updated Measurement of the CP Violating Phase β_s in $B_s \to J/\psi\,\phi$
- and others

Tevatron Run II



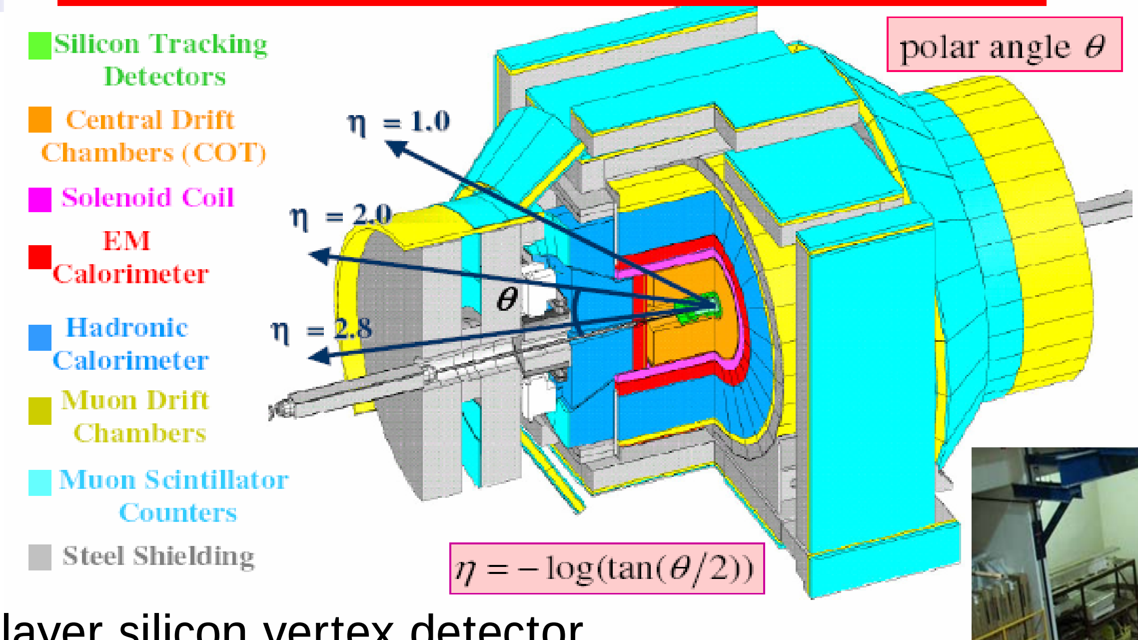
- No longer the world's highest-energy particle collider…
- Proton-antiproton collisions at sqrt(s) = 1.96 TeV
- Tevatron is performing really well
  - Peak luminosity: ~ 4.0×10^{32} cm^{-2} s^{-1}

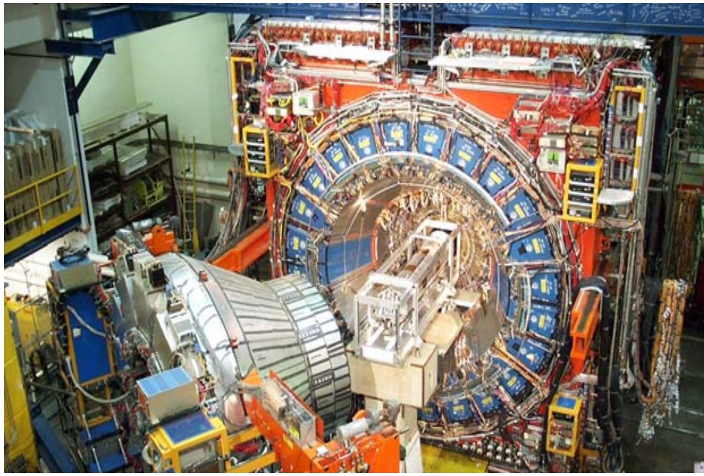
Luminosity



Luminosity (pb-1)
10000
8000
6000
4000
2000
0
1000
2000
3000
4000
5000
6000
7000
8000
store number
01/03
01/04
01/05
01/06
01/07
01/08
01/09
01/10
Data Taking Efficiency
Efficiency
Good Store Eff
20 Store Ave (Acquired)
20 Store Ave (Good)
20 Store Ave (SVX)
Detector is stable and working well
Delivered
Acquired
9.1 fb−1
7.6 fb−1
~6 fb−1

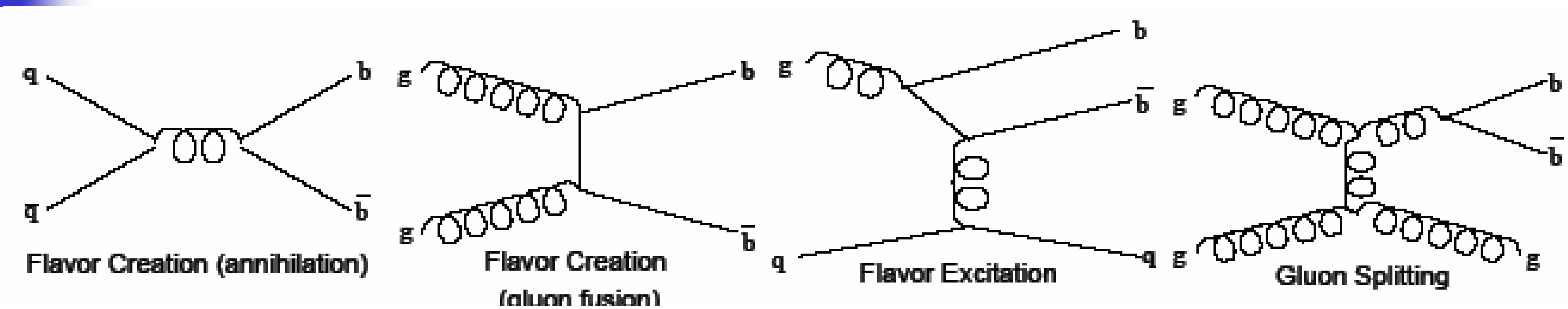
CDF II Detector

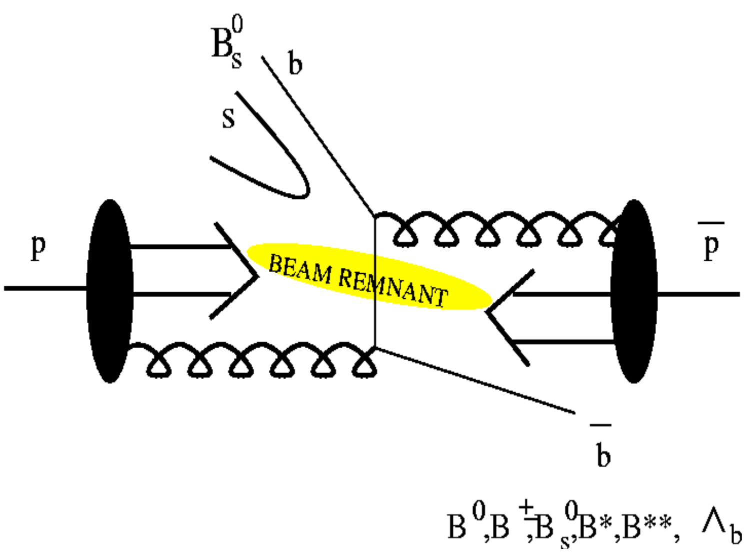




- 8 layer silicon vertex detector
- 8 super layer drift chamber
- 1.4T solenoid
- Good particle identification (K, π)
- Central/Wall/Plug calorimeters
- Scintillator+drift chamber muon detectors

B Production at Tevatron

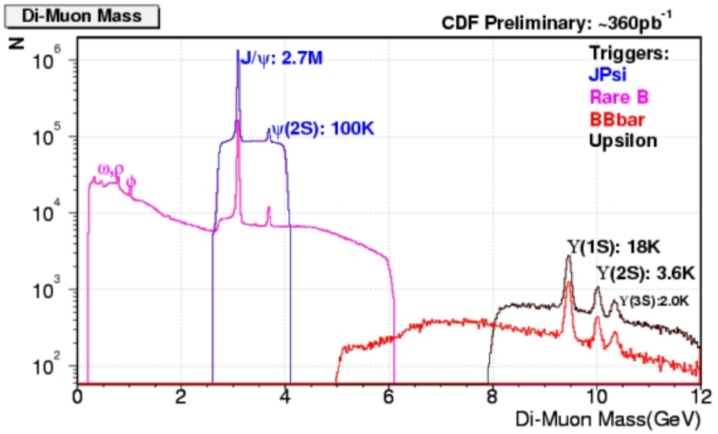


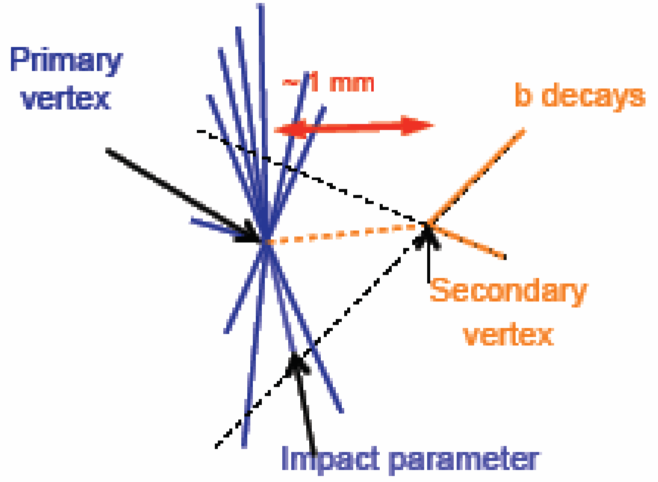


- Tevatron is a source of all *B*-hadron species
  - B_d, B_u, B_c, B_s, and Λ_b
- σ_b = 29.4 ± 0.6 ± 6.2 μb ($|\eta|<1$) (CDF)
- Huge cross sections compared to the B-factories, but proportionally large backgrounds as well

Triggers for *B* Physics

- Since $\sigma(bb) << \sigma(pp)$, events have to be selected with specific triggers.
- Trigger requirements: large bandwidth, background suppression, dead-time-less
  - Single-/Di-lepton : J/ψ modes
    - High p_T lepton or two leptons with lower p_T
  - Lepton + displaced track : semileptonic sample
    - $p_T(e/\mu)$ > 4 GeV/c
    - p_T(Trk) > 2 GeV/c
    - 120 μm < d0(Trk) < 1 mm
  - Two displace tracks : hadronic sample
    - p_T(Trk) > 2 GeV/c
    - 120 μm < d0(Trk) < 1 mm
    - Σp_T > 5.5 GeV/c





CKM Matrix and Unitarity Triangles

CKM Matrix
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{1}{2}A^2\lambda^5[1-2(\rho+i\eta)] & 1-\frac{1}{2}\lambda^2-\frac{1}{8}\lambda^4(1+4A^2) & A\lambda^2 \\ A\lambda^3[1-(1-\frac{1}{2}\lambda^2)(\rho+i\eta)] & -A\lambda^2+\frac{1}{2}A\lambda^4[1-2(\rho+i\eta)] & 1-\frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

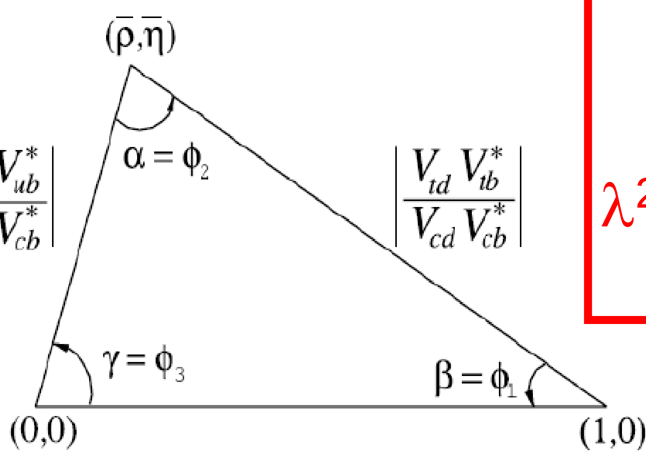
Unitarity Relations

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

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

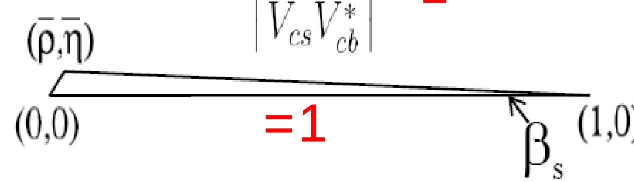
Unitarity Triangles

$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right|$ $\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right|$



$\left|\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right| \sim 1$

$\lambda^2 \sim \left|\frac{V_{us}V_{ub}^*}{V_{cs}V_{cb}^*}\right|$

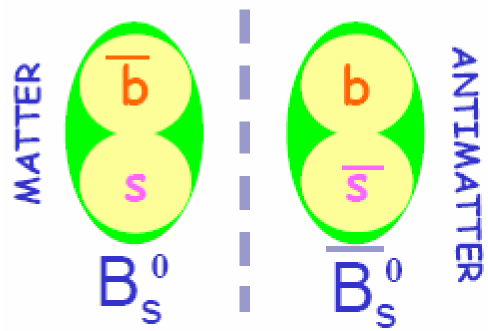


- Small CP violation phase β_s accessible in $B_s \to J/\psi\,\phi$ decays

Neutral B_s System

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

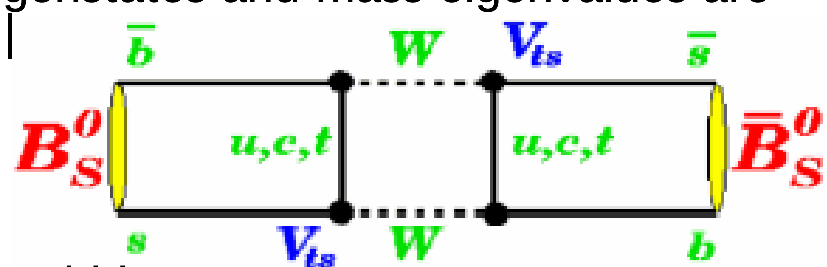
$$i\frac{d}{dt}\begin{pmatrix}|B_s^0(t)\rangle\\ |\bar{B}_s^0(t)\rangle\end{pmatrix} = \left(\mathbf{M}-\frac{i}{2}\Gamma\right)\begin{pmatrix}|B_s^0(t)\rangle\\ |\bar{B}_s^0(t)\rangle\end{pmatrix}$$



- Diagonalize mass (M) and decay (Γ) matrices
  $\rightarrow$ mass eigenstates:

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

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



  - Mass eigenstates have different decay widths

$$\Delta\Gamma = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\phi_s \quad \text{where} \quad \phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4\times 10^{-3}$$

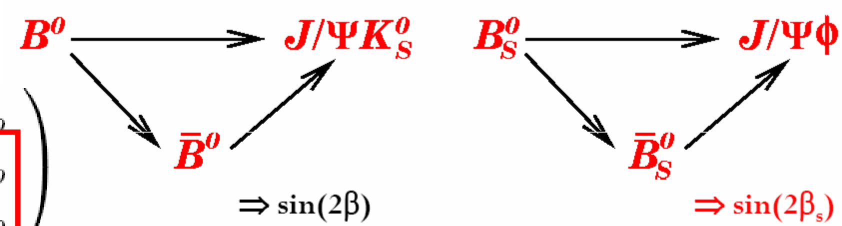
CP Violation in $B_s \to J/\psi\, \phi$ Decays

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

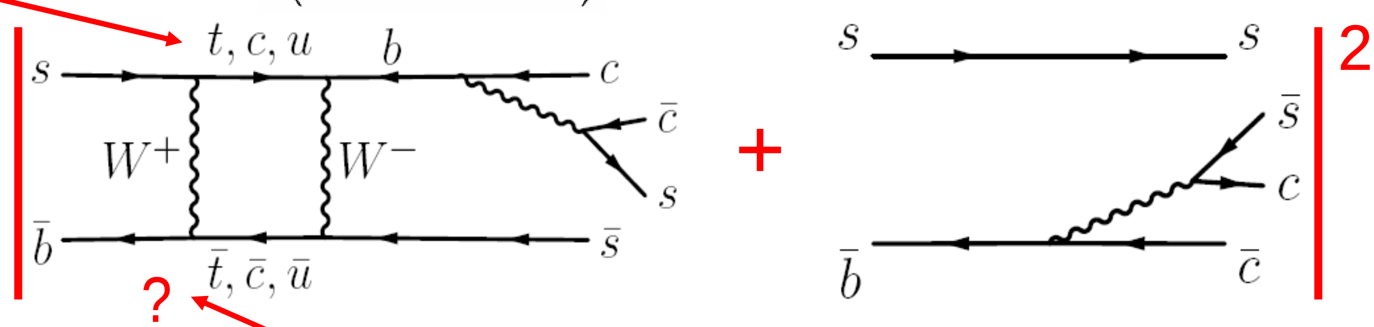
$$\beta_s^{SM} = \arg\left(-V_{ts}V_{tb}^{*}/V_{cs}V_{cb}^{*}\right) \approx 0.02$$

Dominant contribution from top quark

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



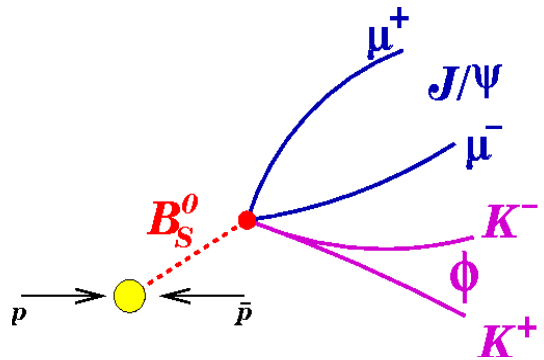
Decay rate ~

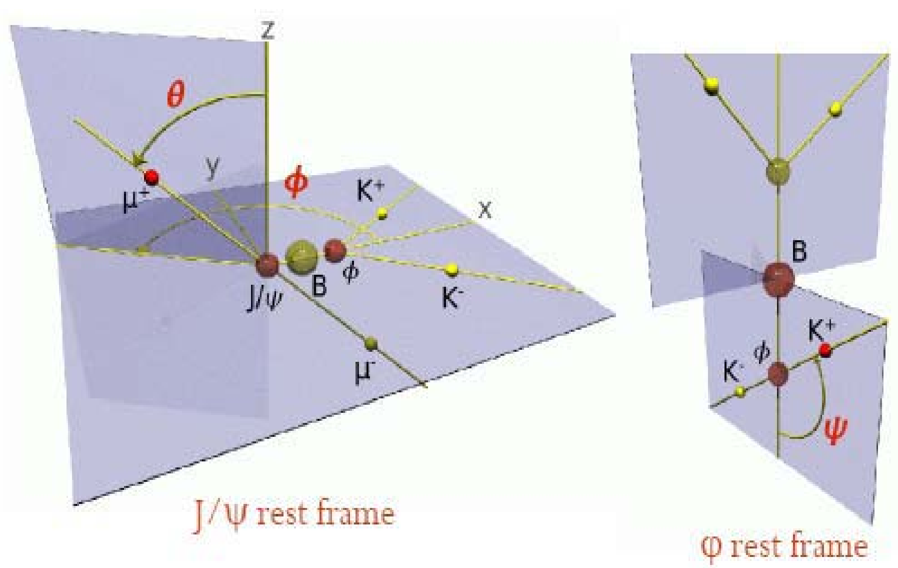


New physics particles?

- CP violation phase β_s in SM is predicted to be very small, $O(\lambda^2)$
- New physics particles running in the mixing diagram may enhance β_s
  - large $\beta_s \to$ clear indication of New Physics!

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

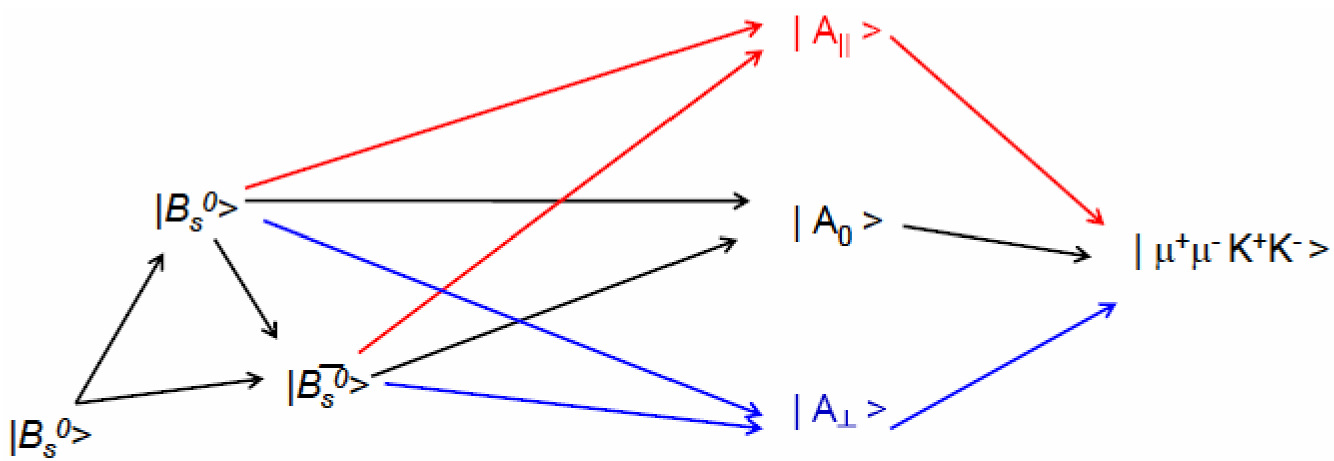




- Measurements:
  - B_s lifetime τ_s
  - B_{sH} and B_{sL} decay width difference $\Delta\Gamma_s$
  - CP violating phase β_s
- Three different angular momentum final states:
  - L=0, 2 $\to$ CP even
    - Short lived or light B_s
  - L=1 $\to$ CP odd
    - Long lived or heavy B_s
- Three decay angles $\vec{\rho} = (\theta, \phi, \psi)$ describe directions of final decay products: $\mu^+\mu^-K^+K^-$

Transversity Basis

- Use “tansversity basis” in which the vector boson polarizations w.r.t. direction of motion are either
  - Transverse ($\perp$ perpendicular to each other) $\rightarrow$ CP odd
  - Transverse (|| parallel to each other) $\rightarrow$ CP even
  - Longitudinal (0) $\rightarrow$ CP even
- Corresponding amplitudes: $A_\perp$, $A_{||}$, and A_0
  (A. S. Dighe *et al.*, Phys. Lett. B369, 144 (1996))



Decay Rate

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

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

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

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

- $B_s \to J/\psi\,\phi$ decay rate as a function of time, decay angles, and initial B_s flavor

Time dependence terms

Angular dependence terms

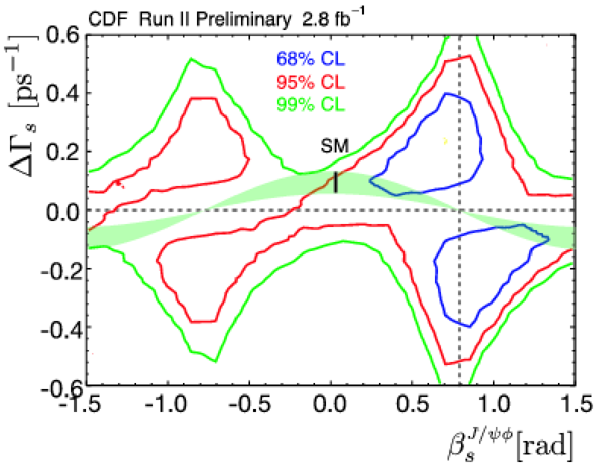
Terms with β_s dependence

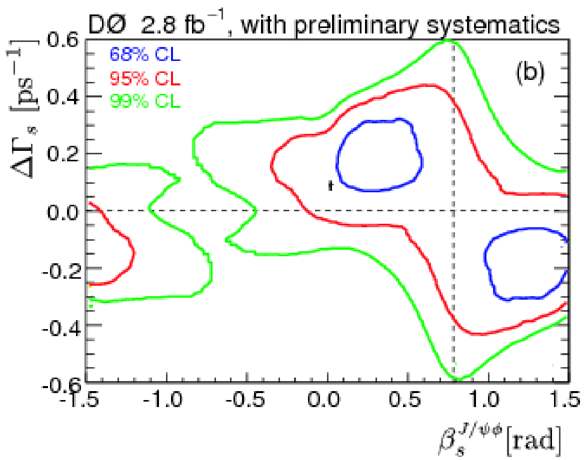
terms with Δm_s dependence present if initial state of B meson (B vs anti-B) is determined (flavor tagged)

Strong phases:
$$\delta_\parallel \equiv \mathrm{Arg}(A_\parallel(0)A_0^*(0))$$
$$\delta_\perp \equiv \mathrm{Arg}(A_\perp(0)A_0^*(0))$$

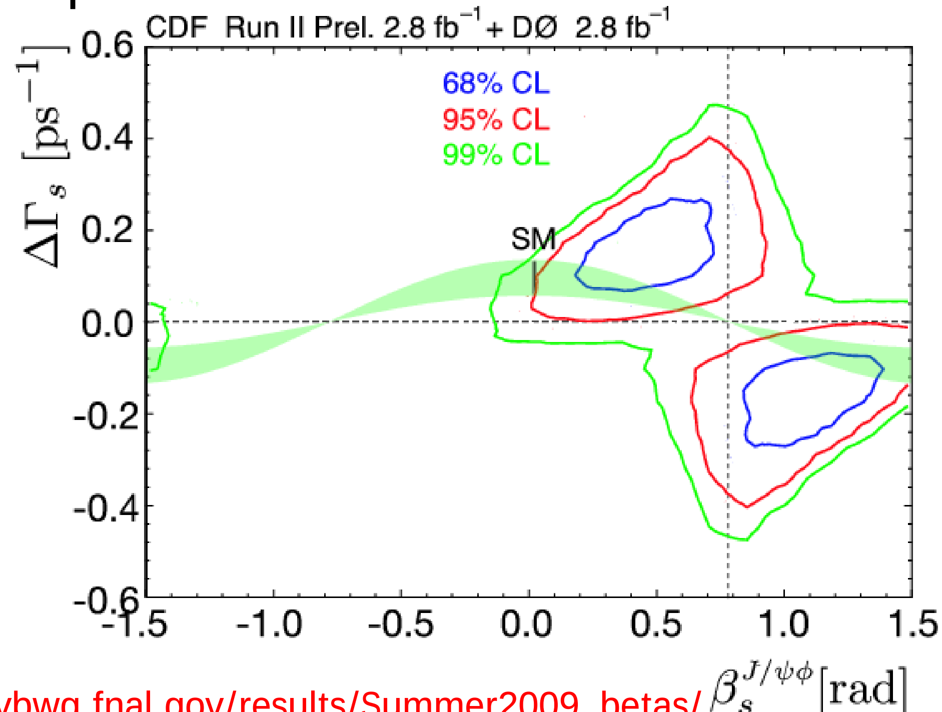
- Identification of B flavor at production (flavor tagging) $\to$ better sensitivity to β_s

Previous Result





- Both CDF and D0 showed ~1.5σ deviations from SM in the same direction
- Combined result shows 2.1σ deviation from SM expectation

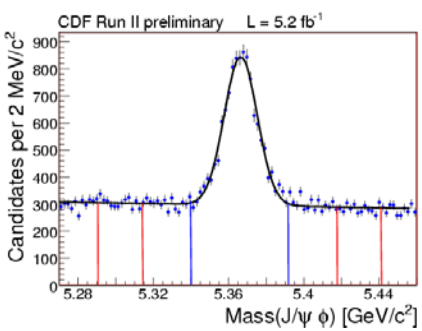


http://tevbwg.fnal.gov/results/Summer2009_betas/

Analysis Components

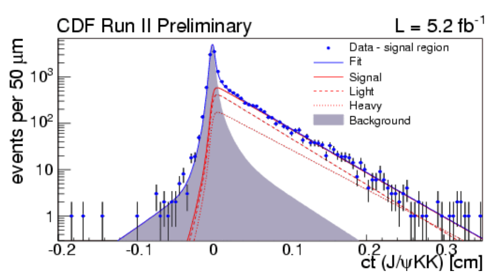
- Multi-dimensional likelihood fit

$$f_s\, P_s\left(m \middle| \sigma_m\right) P_s\left(t, \vec{\rho}, \xi \middle| \mathcal{D}, \sigma_t\right) P_s\left(\sigma_t\right) P_s\left(\mathcal{D}\right)$$



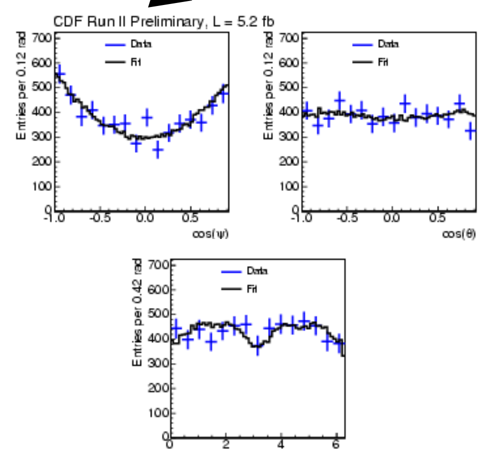
Mass

Discriminates signal against background



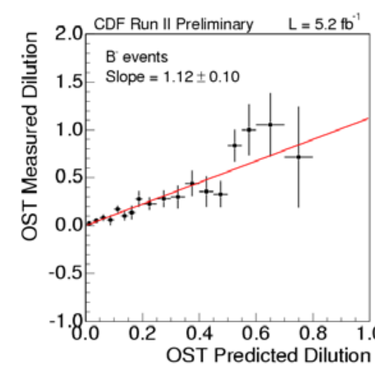
Decay-time

Determines lifetime of each mass eigenstate



Angles

Separates CP-even from CP-odd final states

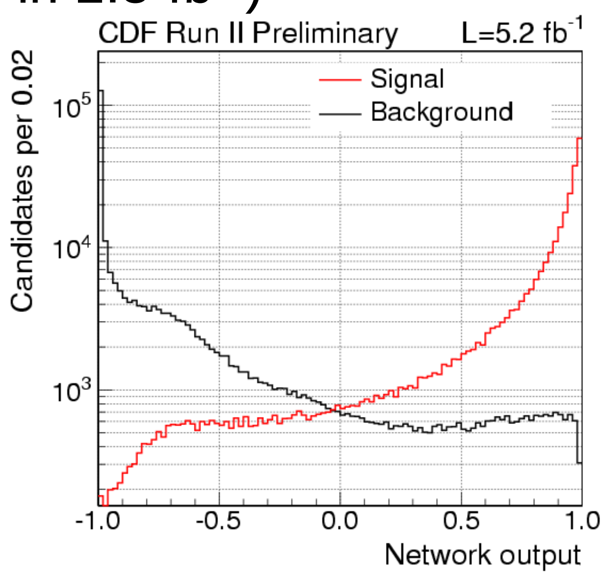


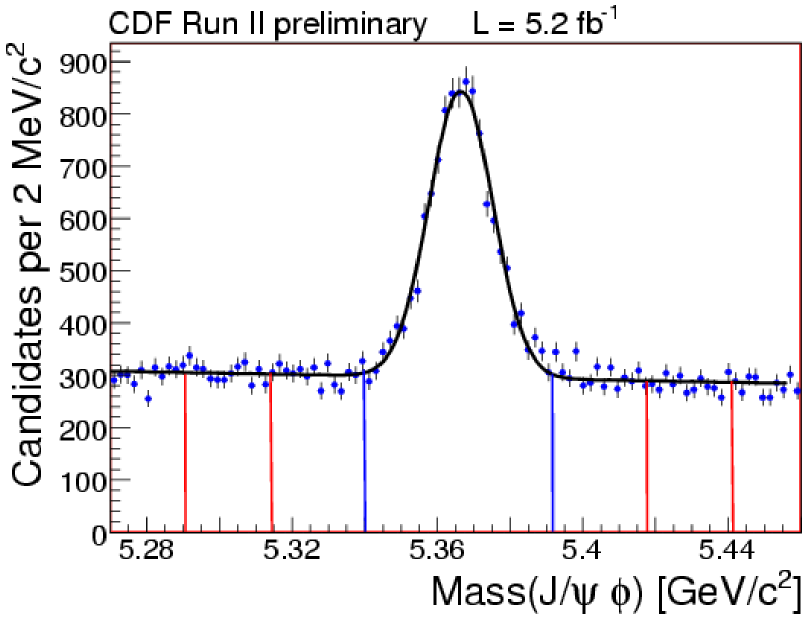
Tagging

Determines flavor of initial Bs state

Signal Reconstruction

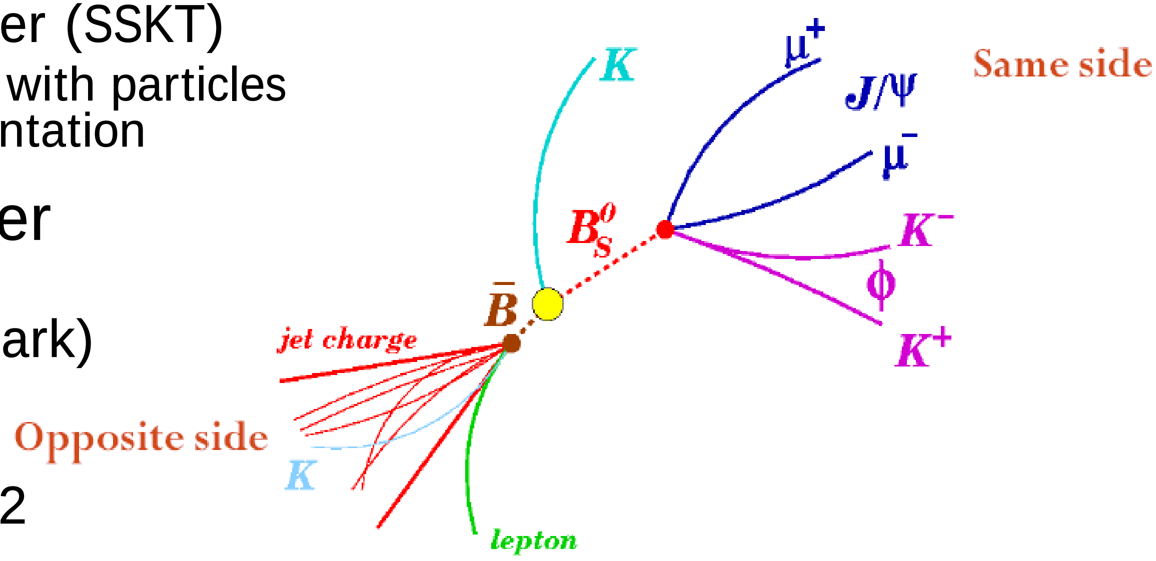
- Reconstruct $B_s^0 \rightarrow J/\psi\, \phi$ in 5.2 fb^{-1} of data from sample selected by di-muon trigger
  - Combine kinematic variables with particle ID information (dE/dx, TOF) in neural network to discriminate signal from background
  - Yield of ~6500 signal B_s events with S/B ~ 1 (compared to ~3150 in 2.8 fb^{-1})





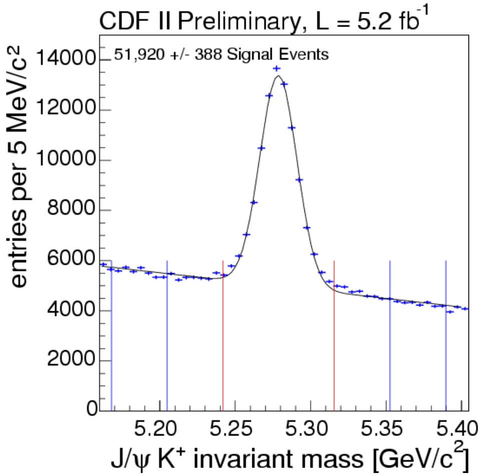
Flavor Tagging

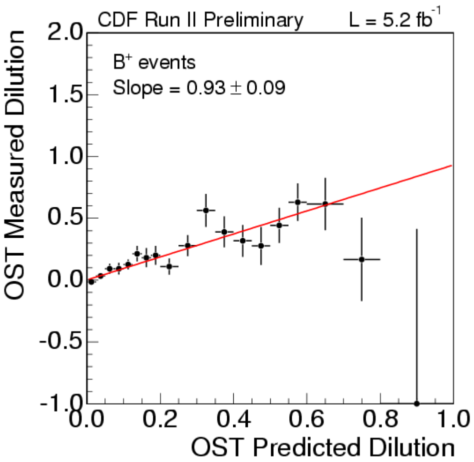
- At Tevatron, *b* quarks mainly produced in pairs of bottom anti-bottom
  → flavor of the *B* meson at production inferred with:
  - Opposite Side Tagger (OST)
    - Exploits decay products of other *b*-hadron in the event
  - Same Side Kaon Tagger (SSKT)
    - Exploits correlations with particles produced in fragmentation
- Output of flavor tagger
  - Flavor decision (*b*-quark or anti-*b*-quark)
  - Probability that the decision is correct: $P = (1 + \text{Dilution}) / 2$

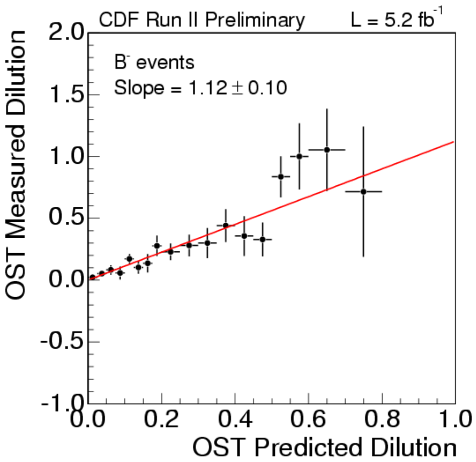


Opposite Side Tagging Calibration and Performance

- OST combines opposite side lepton and jet charge information in a NN
- Initially calibrated using a sample of inclusive semileptonic *B* decays
  - Predicts tagging probability on event-by-event basis
- Re-calibrated using ~52000 $B^{\pm} \to J/\psi\, K^{\pm}$ decays
  - OST efficiency = $94.2 \pm 0.4\%$, OST dilution = $11.5 \pm 0.2\%$ (correct tag probability ~56%)
  - Total tagging power = 1.2%



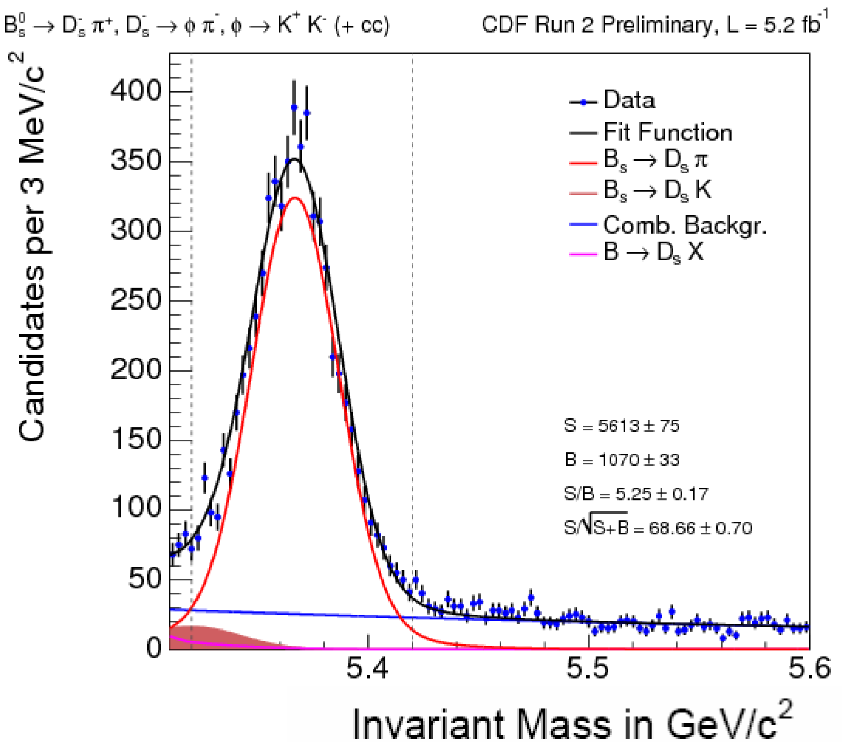




Same Side Tagging Calibration

$$P_{Sig}(ct|\sigma_{ct}, \xi = \xi_D \cdot \xi_P, D) = \frac{1}{N} \cdot \left[\frac{1}{\tau} e^{-\tilde{t}/\tau} \cdot (1 + \xi \mathcal{A} D \cdot \cos(\Delta m_s \tilde{t}))\right] \otimes \mathcal{G}(c\tilde{t}|\sigma_{ct}) \cdot \epsilon(ct|\sigma_{ct})$$

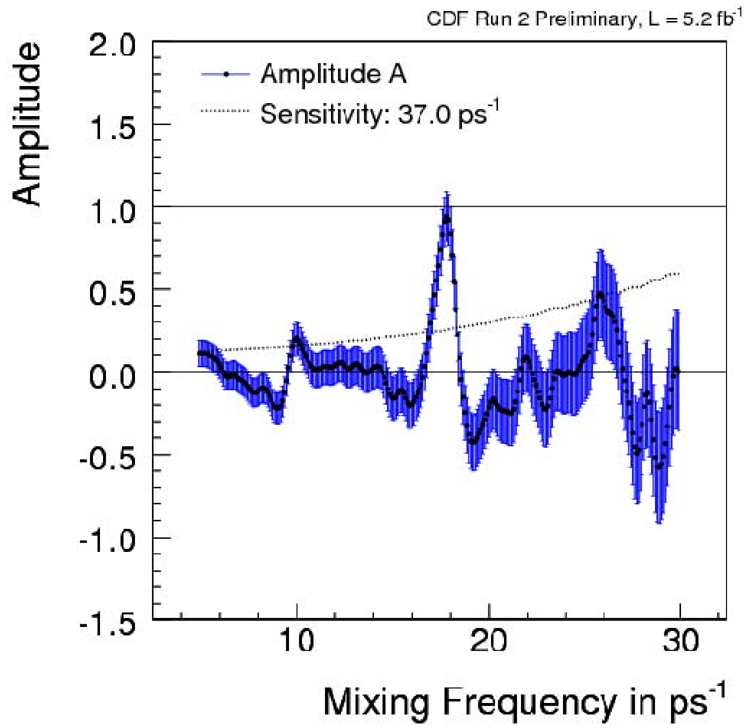
- Event-by-event predicted dilution based on simulation
- Calibrated with 5.2 fb^{-1} of data
- Simultaneously measuring the B_s mixing frequency Δm_s and the dilution scale factor $\mathcal{A}$
  - D: event-by-event predicted dilution
  - ξ: tagging decision = +1, -1, 0 for B_s, $\bar{B}_s$, and un-tagged events
- Fully reconstructed B_s decays selected by displaced track trigger



Decay Channel	S
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to \phi\pi^-$	5613 ± 75
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to K^* K^-$	2761 ± 53
$B_s^0 \to D_s^- \pi^+,\ D_s^- \to (3\pi)^-$	2652 ± 52
$B_s^0 \to D_s^- (3\pi)^+,\ D_s^- \to \phi\pi^-$	1852 ± 43
Sum	**12877 ± 113**

Same Side Tagging Performance

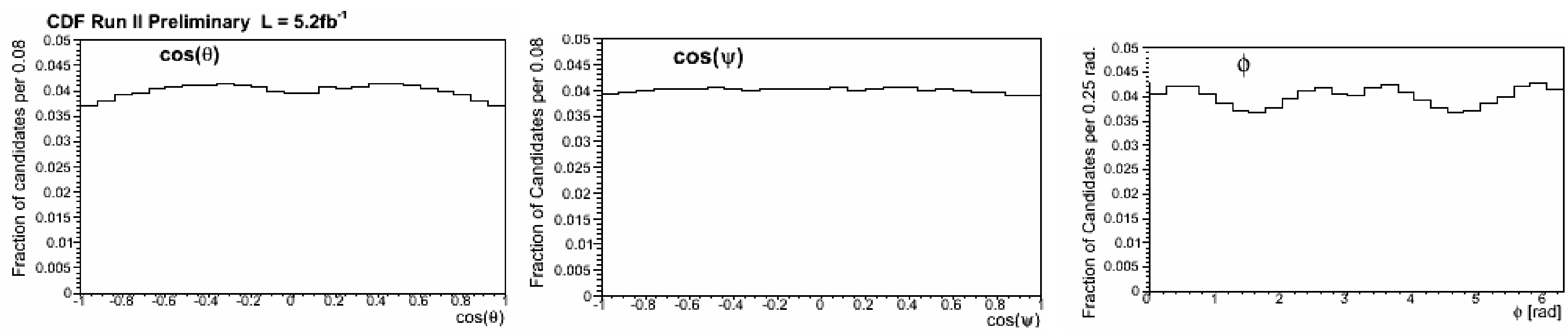
- B_s oscillation frequency measured
  $$\Delta m_s = (17.79 \pm 0.07)\ \mathrm{ps}^{-1}$$ (statistical error only)
- In good agreement with the published CDF measurement with 1 fb^{-1}
  (Phys. Rev. Lett. 97, 242003 (2006), Phys. Rev. Lett. 97, 062003 (2006))
  $$\Delta m_s = 17.77\ \pm 0.10\ (\mathrm{stat})\ \pm 0.07\ (\mathrm{syst})\ \mathrm{ps}^{-1}$$
  - used as external constraint in β_s measurement
- Dilution scale factor (amplitude) in good agreement with 1:
  $$\mathcal{A} = 0.94 \pm 0.15\ (stat.) \pm 0.13\ (syst.)$$
- Largest systematic uncertainty from decay time resolution modeling
- Total SSKT tagging power:
  $$\varepsilon \mathcal{A}^2 D^2 = (3.2 \pm 1.4)\ \%$$



Detector Angular Efficiency

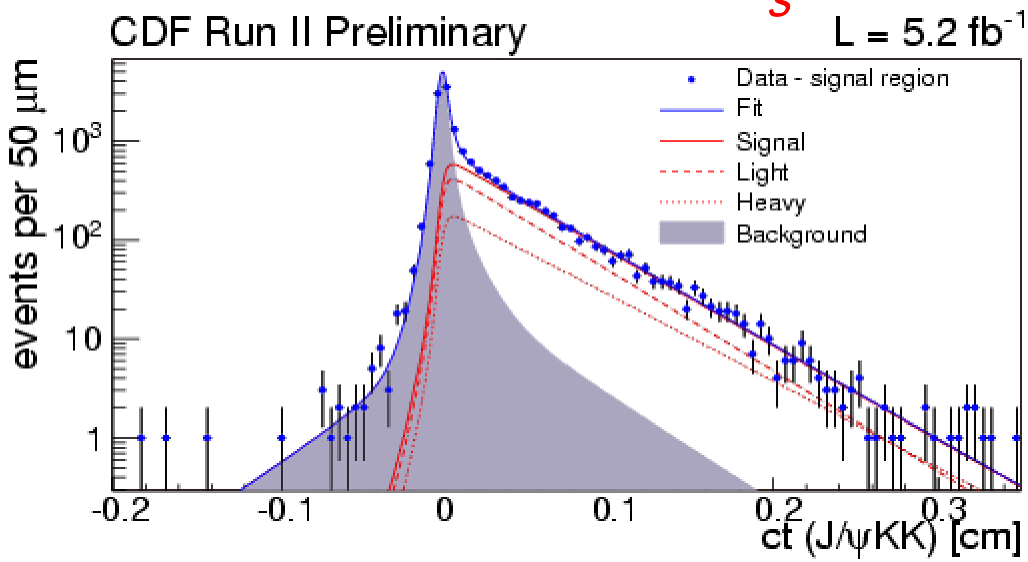
- CP-even and CP-odd final states have different angular distributions $\rightarrow$ use angles $\rho = (\theta, \phi, \psi)$ to statistically separate CP-even and CP-odd components
- Detector acceptance distorts the angular distributions
  $\rightarrow$ determine 3D angular efficiency function from simulation and account for this effect in the fit

CDF Simulation of Detector Angular Sculpting



B_s Lifetime and Decay Width Difference

- Assuming no CP violation ($\beta_s = 0$) obtain most precise measurements of lifetime τ_s and decay width difference $\Delta\Gamma_s$



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

$$\tau_s = 1.53 \pm 0.025 \text{ (stat.) } \pm 0.012 \text{ (syst.) ps}$$

$$\Delta\Gamma = 0.075 \pm 0.035 \text{ (stat.) } \pm 0.01 \text{ (syst.) } ps^{-1}$$

compared to PDG 2009 averages:

$\tau_s = 1.472^{+0.024}_{-0.026}$ ps

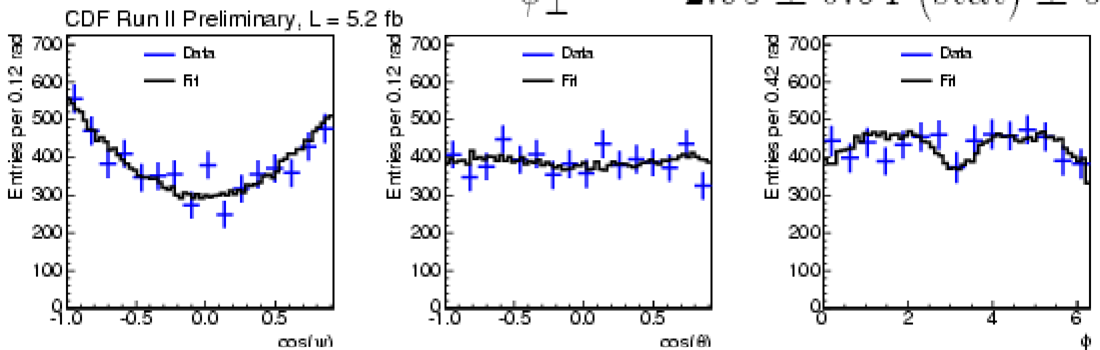
$\Delta\Gamma_s = 0.062^{+0.034}_{-0.037}$ ps^{-1}

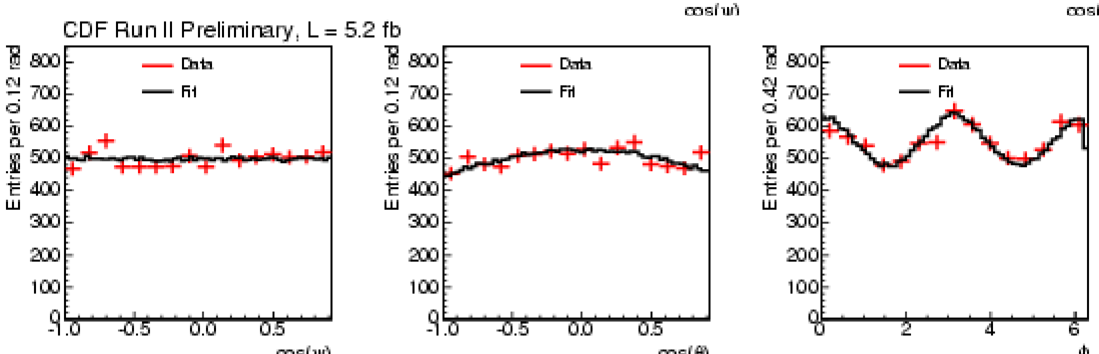
Polarization Amplitudes

- Most precise measurement of polarization amplitudes

$$
\begin{aligned}
|A_{\parallel}(0)|^2 &= 0.231 \pm 0.014\ (\text{stat}) \pm 0.015\ (\text{syst.}) \\
|A_0(0)|^2 &= 0.524 \pm 0.013\ (\text{stat}) \pm 0.015\ (\text{syst.}) \\
\phi_{\perp} &= 2.95 \pm 0.64\ (\text{stat}) \pm 0.07\ (\text{syst.}).
\end{aligned}
$$

Signal fit projections

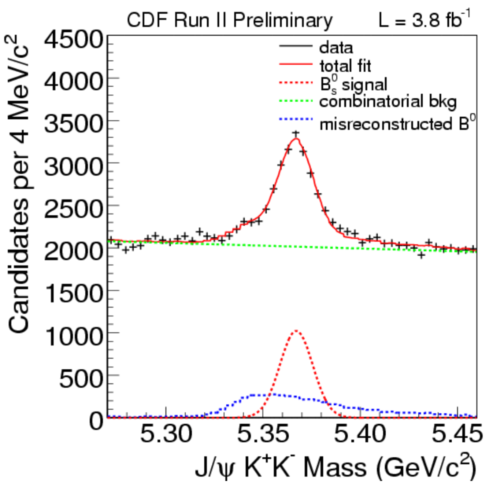


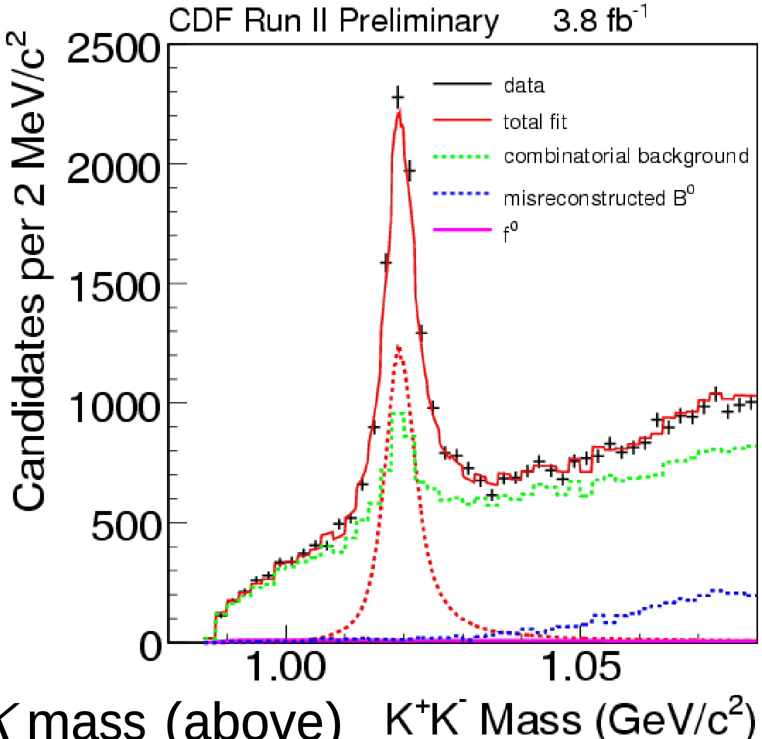


Background fit projections

S-wave Contamination

- Potential contamination of $B_s \to J/\psi\, \phi$ signal by:
  - $B_s \to J/\psi\, KK$ (KK non-resonant) and $B_s \to J/\psi\, f^0$ where KK and f^0 are S-wave states
- Predicted up to 15% contamination of total sample (~6% of signal) could bias towards SM value of β_s



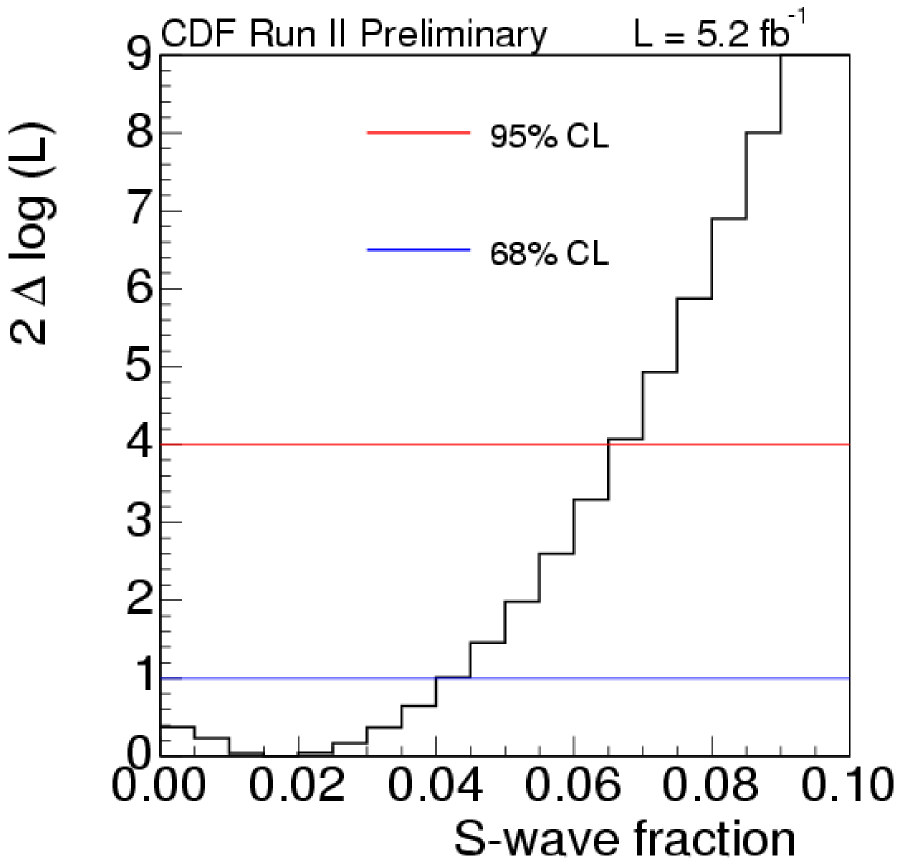


- Invariant KK mass (above)
  - Combinatorial background from B_s sidebands
  - B^0 reflections modelled from MC
  - Fractions fixed from B_s mass fit (left)

Inclusion of *S*-wave *KK* Component

- *S*-wave *KK* component has been added to full-angular, time-dependent likelihood fit.
- Both f^0 and non-resonant *KK* are considered flat in mass within the small selection window, ϕ meson mass is modeled by asymmetric, relativistic Breit-Wigner.
- J/ψ *KK* (f0) is pure CP odd state
- *KK* mass is not a fit parameter

The fitted fraction of *KK S*-wave contamination in the signal is: < 6.7% at the 95% CL

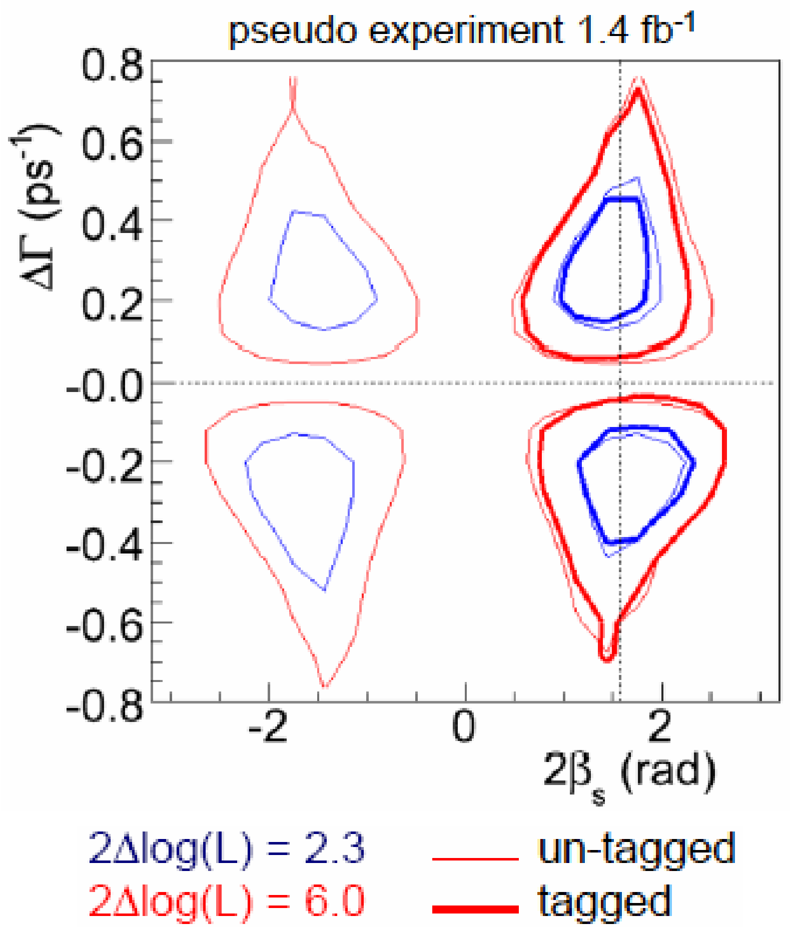


CP Violating Phase β_s in Tagged $B_s \to J/\psi\,\phi$ Decays

- Without the *S*-wave, the likelihood function is symmetric under the transformation

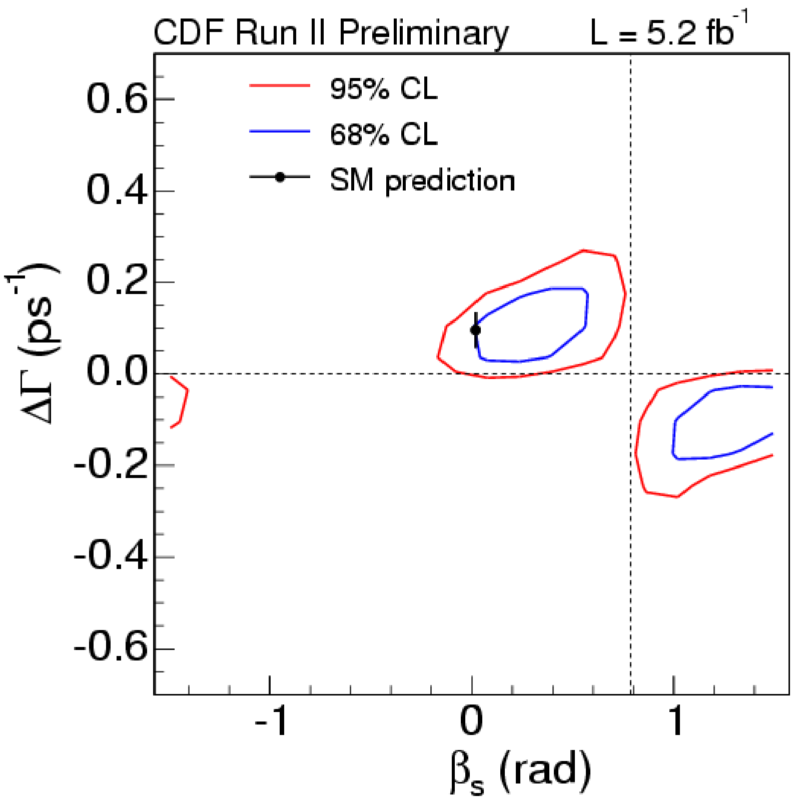
$$2\beta_s \to \pi - 2\beta_s \qquad \Delta\Gamma \to -\Delta\Gamma$$
$$\delta_{\parallel} \to 2\pi - \delta_{\parallel} \qquad \delta_{\perp} \to \pi - \delta_{\perp}$$

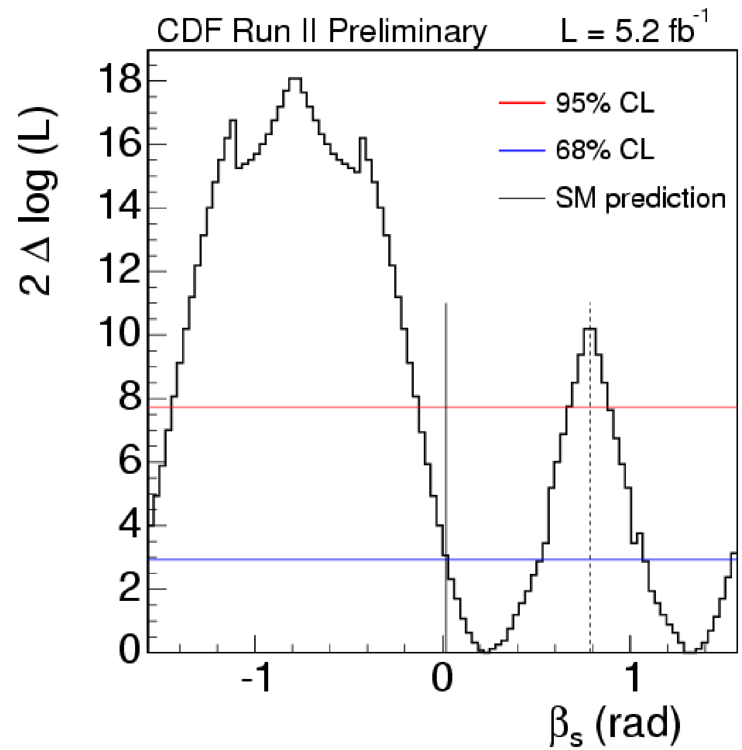
- Study expected effect of tagging using pseudo-experiments
  - Improvement of parameter resolution is small due to limited tagging power
    - εD^2 ~ 4.5% compared to *B*-factories ~30%
  - However, $\beta_s \to -\beta_s$ no longer a symmetry $\to$ 4-fold ambiguity reduced to 2-fold ambiguity
  - Adding the *S*-wave "slightly" breaks the symmetry due to asymmetric ϕ mass shape
  - Symmetry still valid with good approximation…



New CDF Measurement of β_s

P-value for SM point: 44%
(~0.8σ deviation)





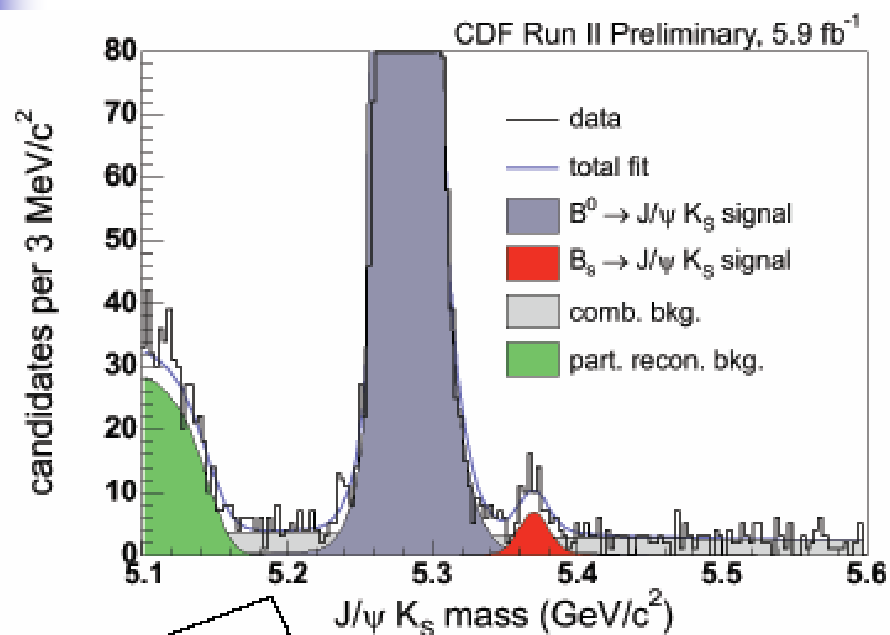
68% CL: $[0.0, 0.5] \cup [1.1, 1.5]$
95% CL: $[-0.1, 0.7] \cup [0.9, \pi/2]$
$\cup [-\pi/2, -1.5]$

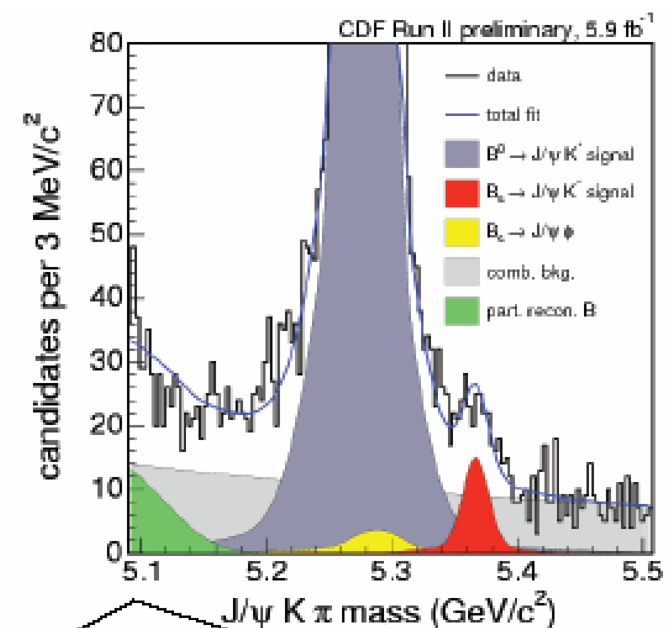
Other New Results

- $B_s^0 \to J/\psi K_s^0$
  - CP eigenstate, lifetime measures $\tau(B_s^{heavy})$
  - Can be used to extract CKM angle γ

    (R. Fleischer, Eur. Phys. J. **C10**, 299 (1999))
- $B_s^0 \to J/\psi K^{*0}$
  - Admixture of CP final states. Estimate penguin contribution to $J/\psi\ \phi$
  - A large sample can be used to measure sin($2\beta_s$) as a complementary mode to $B_s^0 \to J/\psi\ \phi$
- Procedure
  - Reconstruct the signal modes in B_s^0 and B^0 samples from 6 fb^{-1} of CDF di-muon triggered data
  - Apply binned likelihood fits to mass distributions to extract signal yield fractions between B_s^0 and B^0 modes
  - Finally, measure $f_s\,BR(B_s^0 \to J/\psi K^{(*)0}{}_{(s)})\ /\ f_d\,BR(B^0 \to J/\psi K^{(*)0}{}_{(s)})$

First Observation of $B_s^0 \rightarrow J/\psi K_s^0$ and $B_s^0 \rightarrow J/\psi K^{*0}$





Yields: B_s^0: **64 ± 14**, B^0: **5954 ± 79**

BR($B_s \rightarrow J/\psi K^*$) = (3.5 ± 0.6 (stat.) ± 0.4 (syst.) ± 0.4 (frag.) ± 0.4 (PDG)) . 10^{-5}

7.2σ significance w.r.t. null hypothesis

Yields: B_s^0: **151 ± 25**, B^0: **9530 ± 110**

BR($B_s \rightarrow J/\psi K^*$) = (8.3 ± 1.2 (stat.) ± 3.3 (syst.) ± 1.0 (frag.) ± 0.4 (PDG)) . 10^{-5}

8σ significance w.r.t. null hypothesis

Summary

- Tevatron is operating well. Better than ever!
  - CDF is ready to run for FY2011. $\int L dt$ ~ 12 fb^{-1} is expected.
  - Possibly Run III (2012~2014). ~ 16 fb^{-1}?

- Successful application of multivariate analysis techniques, even for *B* physics.

- No signs of physics beyond SM? But search continues actively.
  - β_s analysis is now consistent with SM within ~1σ.

- Stay tuned for interesting results from CDF in the near future!
  - Search for new physics in Bs mixing at CDF has potential to observe/exclude wide range of non-SM mixing phase values

Backup Slides

Systematic Uncertainties

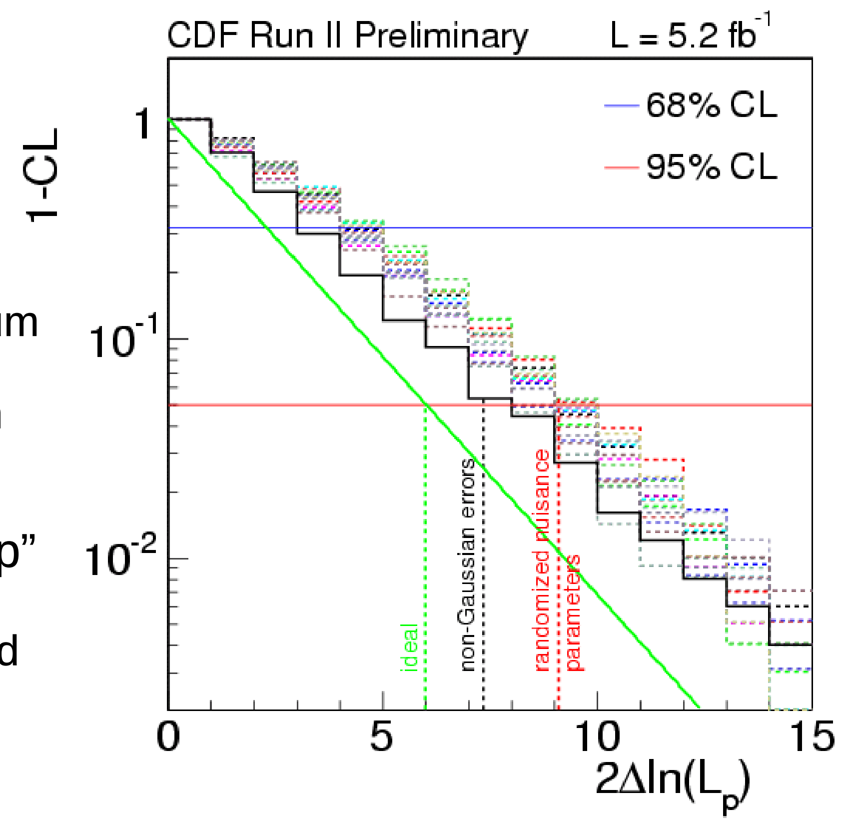
Systematic	$\Delta\Gamma$	$c\tau_s$	$\lvert A_\parallel(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\phi_\perp$
Signal efficiency:					
Parameterisation	0.0024	0.96	0.0076	0.008	0.016
MC reweighting	0.0008	0.94	0.0129	0.0129	0.022
Signal mass model	0.0013	0.26	0.0009	0.0011	0.009
Background mass model	0.0009	1.4	0.0004	0.0005	0.004
Resolution model	0.0004	0.69	0.0002	0.0003	0.022
Background lifetime model	0.0036	2.0	0.0007	0.0011	0.058
Background angular distribution:					
Parameterisation	0.0002	0.02	0.0001	0.0001	0.001
$\sigma(c\tau)$ correlation	0.0002	0.14	0.0007	0.0007	0.006
Non-factorisation	0.0001	0.06	0.0004	0.0004	0.003
$B^0 \to J/\psi K^*$ crossfeed	0.0014	0.24	0.0007	0.0010	0.006
SVX alignment	0.0006	2.0	0.0001	0.0002	0.002
Mass error	0.0001	0.58	0.0004	0.0004	0.002
$c\tau$ error	0.0012	0.17	0.0005	0.0007	0.013
Pull bias	0.0028		0.0013	0.0021	
Totals	0.01	3.6	0.015	0.015	0.07

Dilution Scale Factor Systematic Uncertainties

Modification	Systematic Uncertainty
Proper decay time resolution scaling	0.11
Resolution model	0.06
Cabibbo reflection	0.03
Cabibbo fraction	negligible
Mass window	negligible
Selection of upper side band	negligible
Λ_b template	negligible
$\Delta\Gamma/\Gamma$	negligible
Mean Lifetime	negligible
Trigger Composition	negligible
Signal Mass Model	negligible
Total	**0.13**

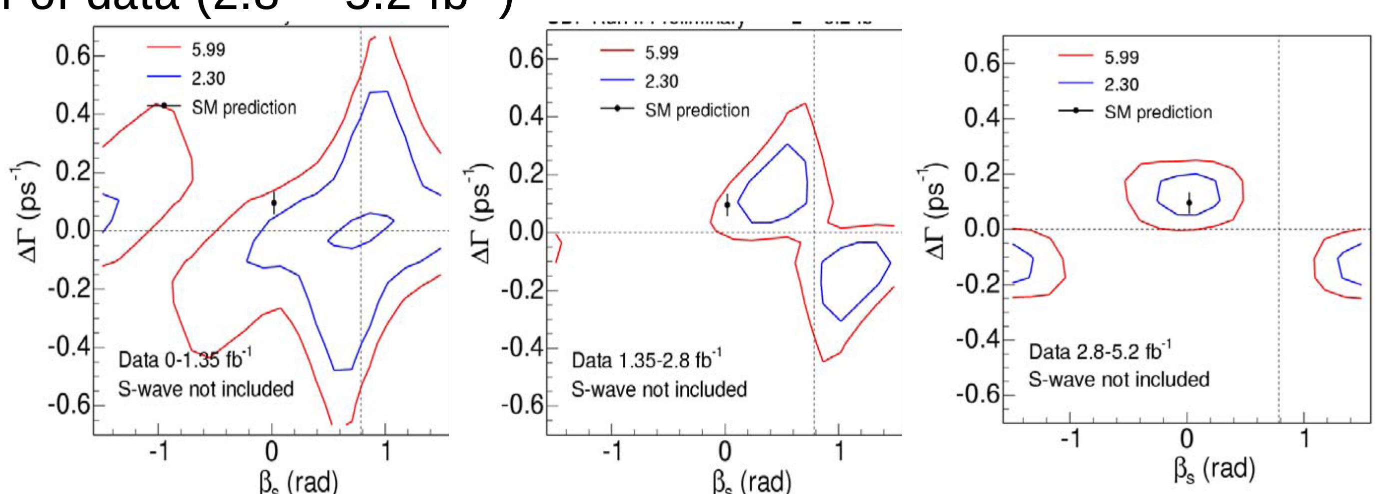
Non-Gaussian Regime

- Pseudo-experiments show that we are still not in perfect Gaussian regime
  $\rightarrow$ quote confidence regions instead of point estimates
  - In ideal case (high statistics, Gaussian likelihood), to get the 2D 68% (95%) C.L. regions, take a slice through profiled likelihood at 2.3 (6.0) units up from minimum
  - In this analysis integrated likelihood ratio distribution (black histogram) deviates from the ideal $\chi 2$ distribution (green continuous curve)
- Using pseudo-experiments establish a “map” between Confidence Level and 2Δlog(L)
  - All nuisance parameters are randomly varied within $\pm 5\sigma$ from their best fit values and maps of CL vs 2Δlog(L) re-derived
  - To establish final confidence regions use most conservative case

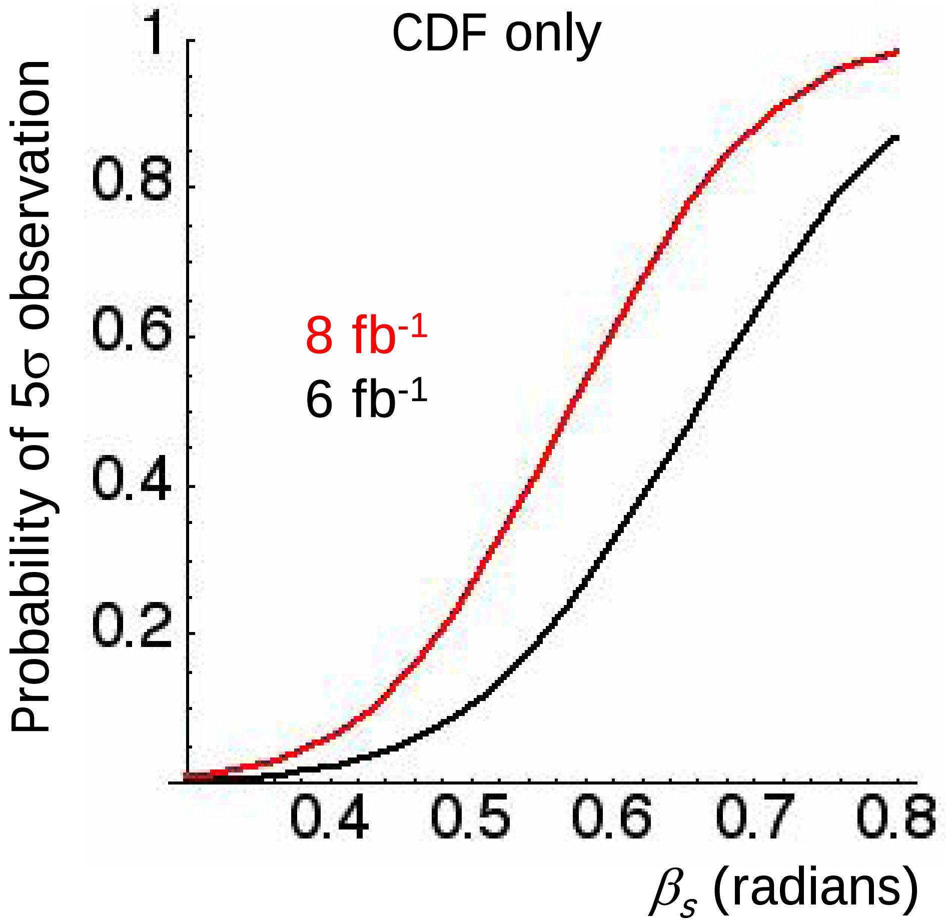


Comparison Between Different Data Periods

- Divide 5.2 fb^{-1} sample in three sub-samples corresponding to three public releases:
  - 0 ~ 1.4 fb^{-1} (initial result released at the end of 2007, Phys. Rev. Lett. **100**, 161802 (2008))
  - 1.4 ~ 2.8 fb^{-1} (added for 2008 ICHEP update)
  - 2.8 ~ 5.2 fb^{-1} (added for this update)
- Previous results reproduced with updated analysis
- Clearly, improved agreement with the SM expectation comes from the second half of data (2.8 ~ 5.2 fb^{-1})



β_s Sensitivity



CP Asymmetry in Semileptonic *B* Decays

- 1.6 fb^{-1} of data
  - $A_{SL} = 0.0080 \pm 0.0090 \text{ (stat)} \pm 0.0068 \text{ (syst)}$
  - $A^s_{SL} = 0.020 \pm 0.021 \text{ (stat)} \pm 0.016 \text{ (syst)} \pm 0.009 \text{ (inputs)}$