(Recent) *B* Physics at the Tevatron

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Motivation

Why the huge matter-antimatter asymmetry in the universe?

Why *B* Physics? *It's got it all!*

- Electroweak symmetry breaking → determines flavor structure
  CKM matrix, CP violation, FCNC's
- QCD Modeling: production, spectroscopy, masses, lifetimes, decays
  → Challenges lattice gauge, Heavy Quark Effective Theory, strong symmetries
- Searches for new physics → rare decays & departures in

Why at the Tevatron?

- Produce heavier states not accessible anywhere else:

$\bar{b}\,s$ $\bar{b}\,c$ $d\,\bar{b}$ $s\,\bar{b}$ $b\,u\,d$ $b\,u\,u$ $b\,u\,u$

$\boxed{B_s^0,}$ $B_c,$ $B^{**},$ $B_s^{**},$ ... $\Lambda_b,$ $\Sigma_b,$ $\Xi_b,$ ...

→ Complementary to $\Upsilon(4S)$ *B* factories

$\bar{b}\,d$ $B_d^0,$ B^+ $\bar{b}\,u$

Motivation

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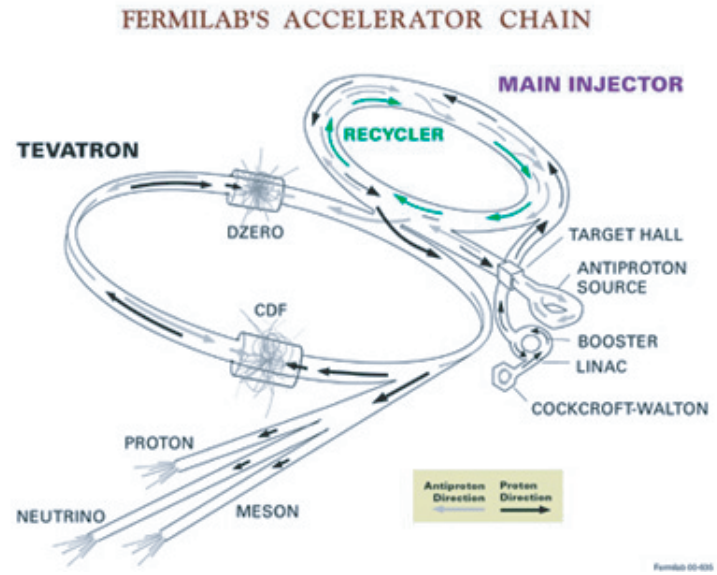
Why at the Tevatron?

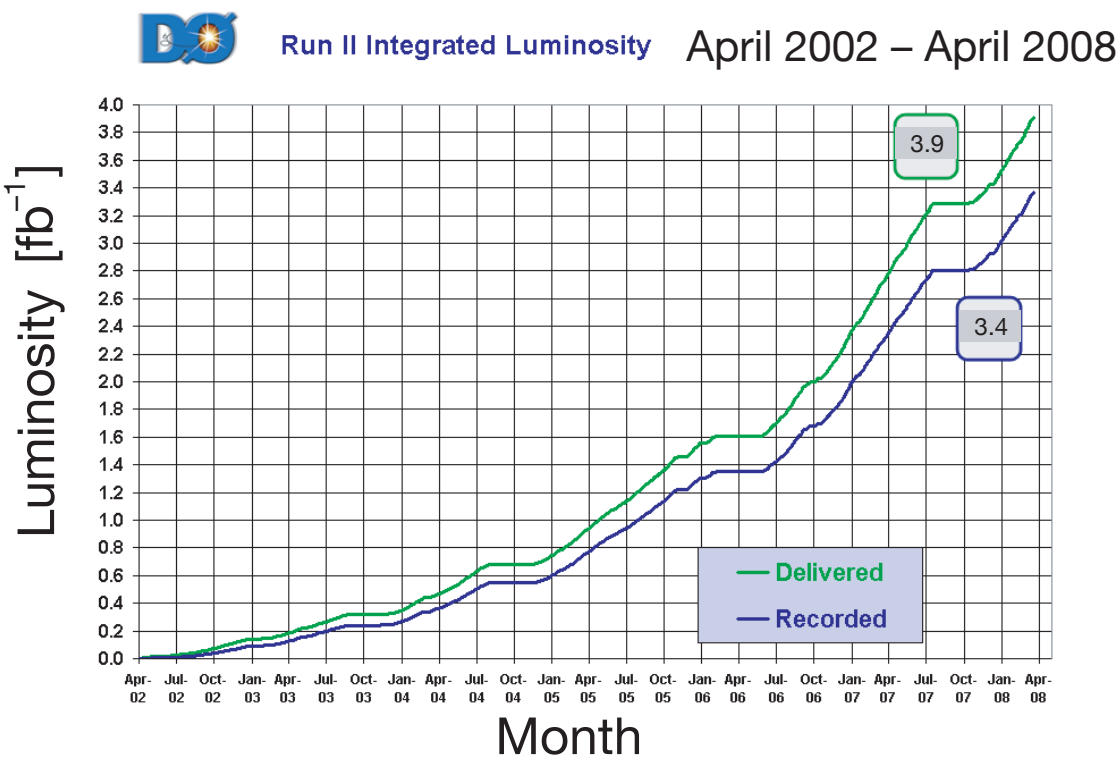
- Produce heavier states not accessible anywhere else: B_s^0, B_c, B^{**}, B_s^{**}, Λ_b, Ξ_b, Σ_b ...
  → Complementary to $\Upsilon(4S)$ *B* factories
- Huge production rate (but also huge backgrounds: triggers for specific target decays)
  → Precision, rare decays, can also be competitive with *B* factories in some B^+ and B_d^0 decays

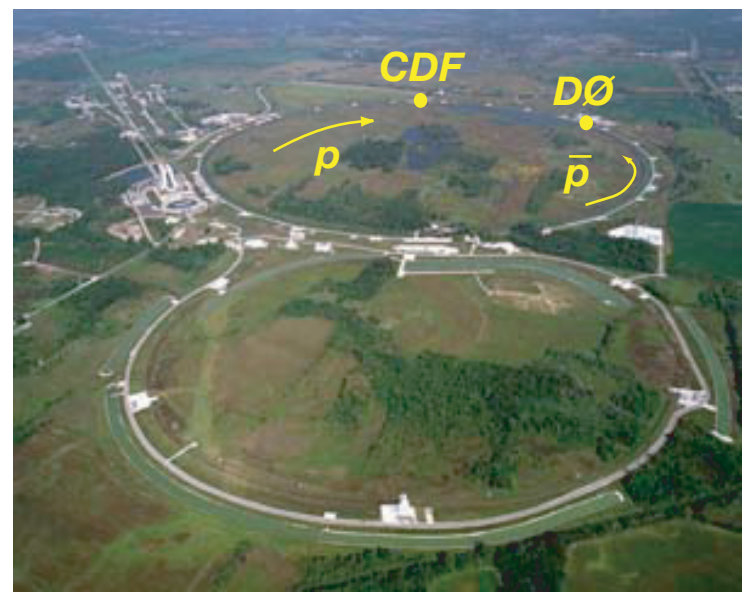
Tevatron

- $p\bar{p}$ collisions at 1.96 TeV
- Tevatron running with peak luminosities of 300 x 10^{30} cm^{-2} s^{-1}

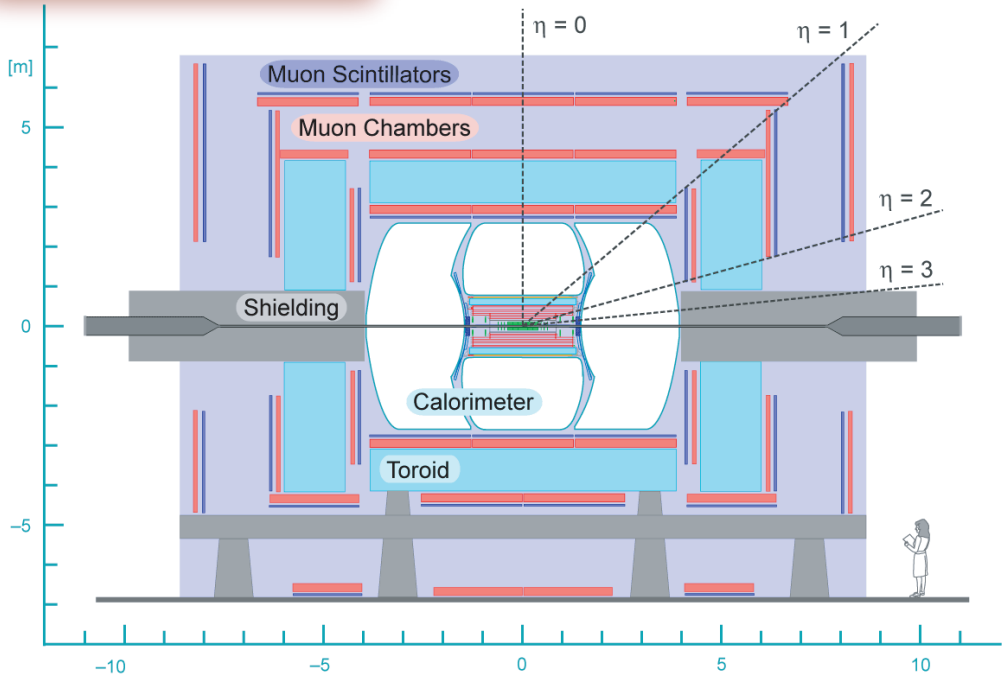
  Up to 10 interactions per x-ing!
- Delivered ~3.9 fb^{-1} , recorded ~3.4 fb^{-1}, data analyses with up to 2.8 fb^{-1} !

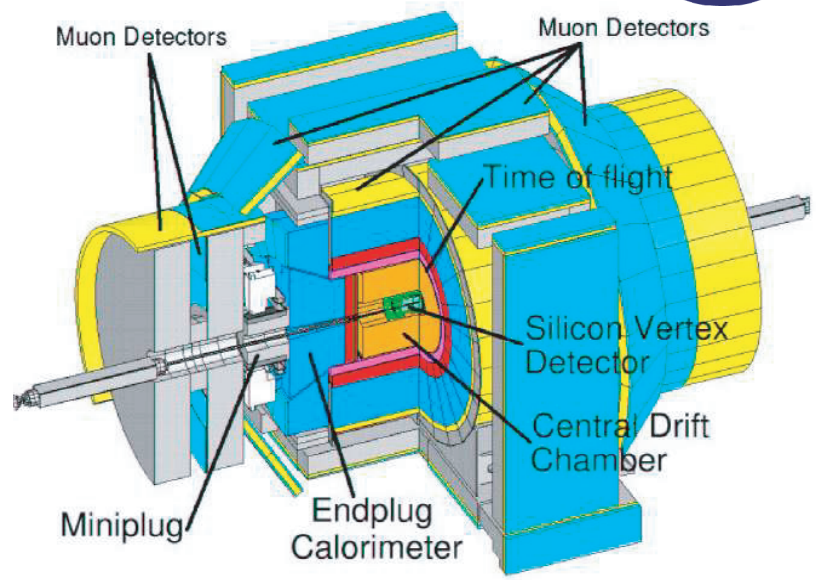






Detectors





Relevant for B physics:

DØ Tracker: excellent coverage & vertexing

- Silicon & scintillating fiber
- Small radii, but extending to |□| < 2
- New Layer 0 silicon on beam pipe in 2006, improving impact para. resol.

Triggered muon coverage: |□| < 2

E.g.triggers: dimuons, *single muons*, track displacement @ L2

CDF Tracker: excellent mass resolution & vertexing

- Silicon, Layer 00
- Large radii drift chamber, many hits, excellent momentum resolution
- dE/dx (and TOF): particle id

Triggered muon coverage: |□| < 1

E.g.triggers: dimuons, lepton + displ. track, *two displaced tracks*

B^0-$\bar{B}^0$ Mixing and Oscillations

Neutral B^0 Mesons

All different!

Weak Eigenstates propagate according to Schrodinger:

$$i\frac{d}{dt}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}$$

Diagonalize

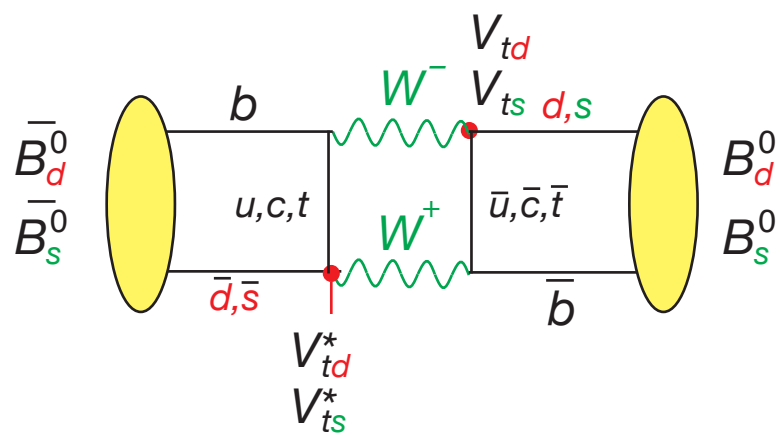
CP Eigenstates: $|B^{odd}\rangle = |B^0\rangle + |\bar{B}^0\rangle$ $\quad |B^{even}\rangle = |B^0\rangle - |\bar{B}^0\rangle$

Mass Eigenstates: $|B^H\rangle = p|B^0\rangle + q|\bar{B}^0\rangle$ $\quad |B^L\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$

Heavy *Light*

Mass Difference:

$$\Delta m = M_H - M_L \sim 2|M_{12}|$$



slow oscillation

fast oscillation

Conversion of matter to anti-matter

B_s^0-$\bar{B}_s^0$ Mixing and Oscillations

Weak Eigenstates propagate according to Schrodinger:

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Heavy *Light*

For the B_s^0 meson:

$$\Delta m_s = M_H - M_L \sim 2|M_{12}|$$

$$\Delta\Gamma_s^{CP} = \Gamma_{even} - \Gamma_{odd} \sim 2|\Gamma_{12}|$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|\cos\phi_s$$

Tiny for B_d^0 meson, but not for B_s^0 ! eigenstates propagate with different lifetimes!

$$\Gamma_s = \frac{\Gamma_L + \Gamma_H}{2} \quad ; \quad \tau_s = \frac{1}{\Gamma_s}$$

$$\phi_s^{SM} = \arg\left[-\frac{M_{12}}{\Gamma_{12}}\right] \sim 0.004 \text{ in SM}$$

B_s^0-$\bar{B}_s^0$ Mixing and Oscillations

Weak Eigenstates propagate according to Schrodinger:

$$i\frac{d}{dt}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix}\begin{pmatrix} B_s^0 \\ \bar{B}_s^0 \end{pmatrix}$$

Diagonalize

Probe *entire* matrix!

CP Eigenstates: $|B_s^{odd}\rangle = |B_s^0\rangle + |\bar{B}_s^0\rangle \quad |B_s^{even}\rangle = |B_s^0\rangle - |\bar{B}_s^0\rangle$

Mass Eigenstates: $|B_s^H\rangle = p|B_s^0\rangle + q|\bar{B}_s^0\rangle \quad |B_s^L\rangle = p|B_s^0\rangle - q|\bar{B}_s^0\rangle$

Heavy *Light*

For the B_s^0 meson: Whole new window for new physics!

$\Delta m_s = M_H - M_L \sim 2|M_{12}|$ Sensitive to new physics

$\Delta\Gamma_s^{CP} = \Gamma_{even} - \Gamma_{odd} \sim 2|\Gamma_{12}|$ Not sensitive to new physics

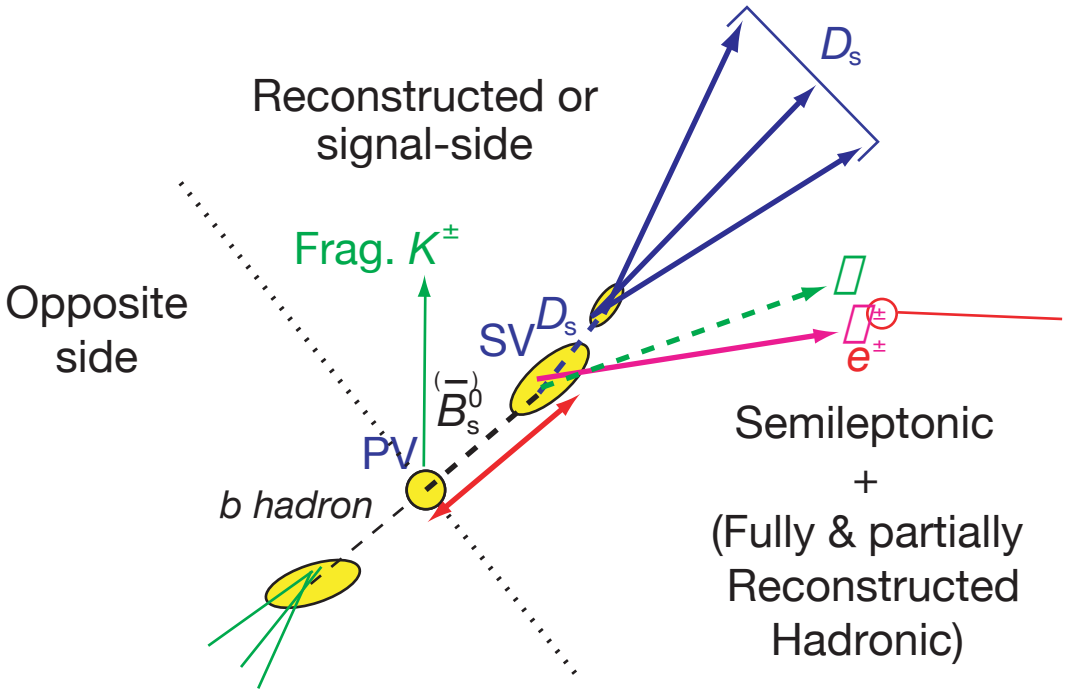
$\Delta\Gamma_s = \Gamma_L - \Gamma_H \sim 2|\Gamma_{12}|\cos\phi_s$ *Very* sensitive to new physics

$\phi_s^{SM} = \arg\left[-\frac{M_{12}}{\Gamma_{12}}\right] \sim 0.004$ in SM

$\Gamma_s = \frac{\Gamma_L + \Gamma_H}{2}$; $\tau = \frac{1}{\Gamma_s}$

B_s^0: Δm_s , Frequency of Oscillations

DØ: first two-sided limit: $17 < \Delta m_s < 21$ ps @ 90% CL
Now: new update of measurement of Δm_s



- Flavor (B_s^0 or $\bar{B}_s^0$) at production
  - Opposite-side flavor tagging
  - Same-side flavor tagging
- Flavor at decay
- Did it oscillate? ("mixed" or "unmixed")
- Measure decay length

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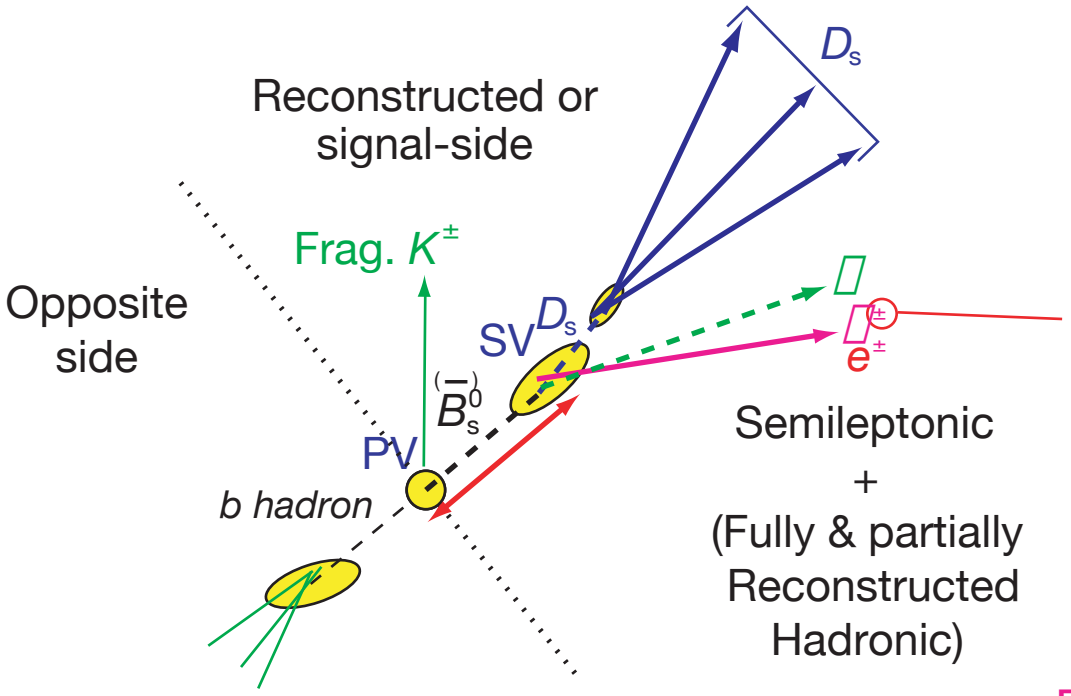

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  - Same-side flavor tagging
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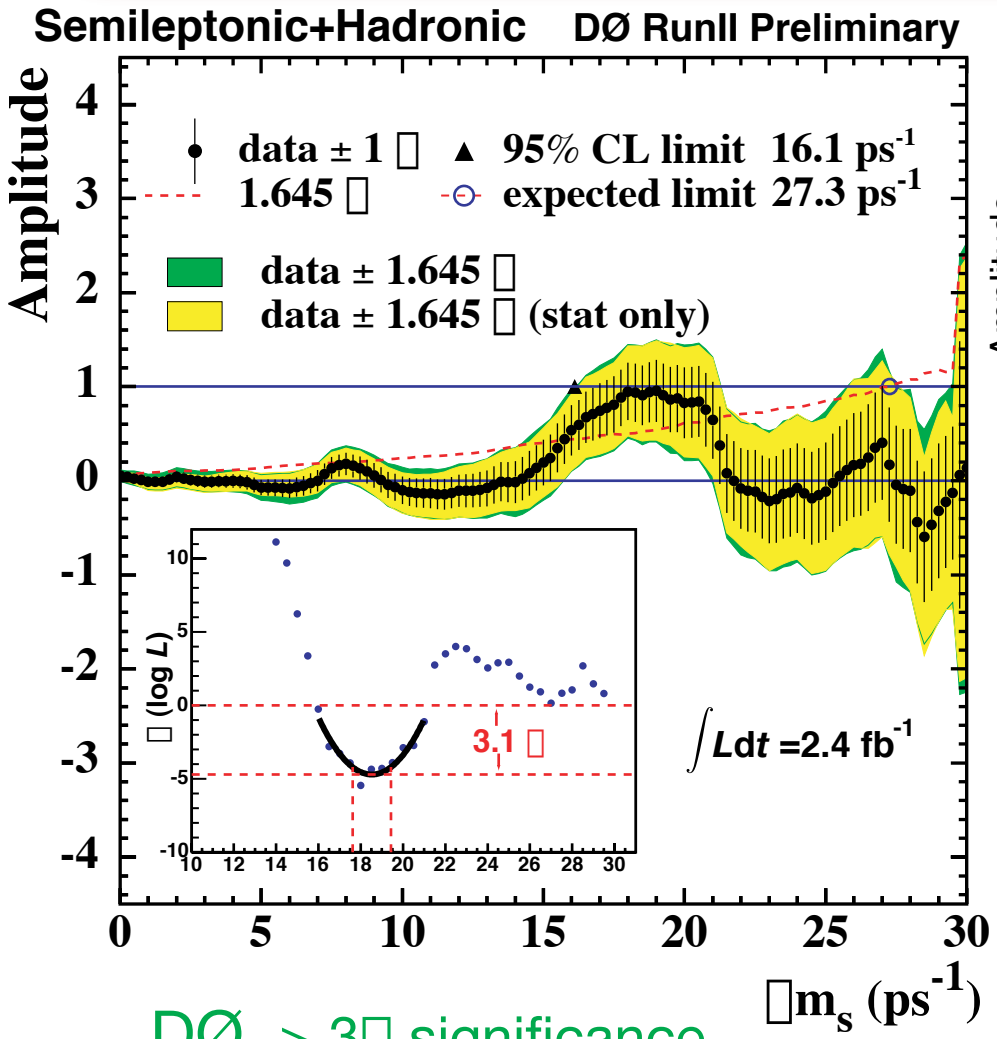
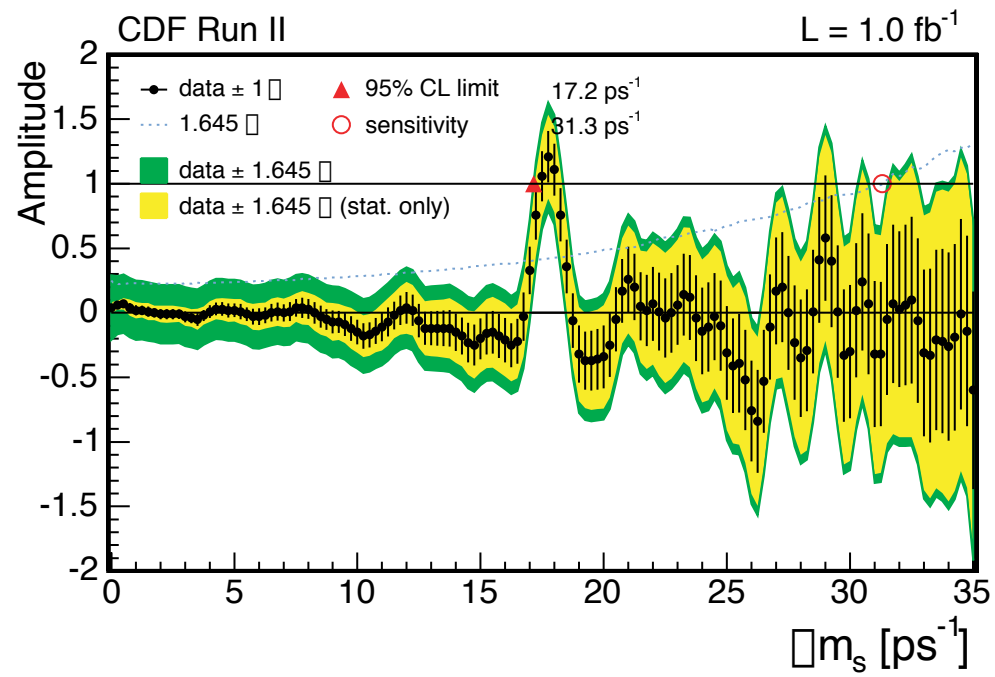
Purity of flavor tag

$$\mathrm{Prob}^{unmix,mix}(x) = \frac{K}{2c\tau_{B_s}} \exp(-\frac{Kx}{c\tau_{B_s}})(1 \pm (1-2\eta)\mathcal{A}\cos(\Delta m_s Kx/c))$$

Amplitude

B_s^0: Δm_s , Frequency of Oscillations





- Power of hadronic $B_s^0 \to D_s \pi(X)$ decay mode & two-displaced track trigger

DØ, > 3□ significance

$\Delta m_s = 18.56 \pm 0.87\ \mathrm{ps}^{-1}$

DØ Note 5474

CDF, > 5□ significance

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

PRL 97, 242003 (2006)

CP Violation

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

- CP violation in SM occurs in only one place: complex phases in unitary CKM matrix; new physics: plenty of new phases!!

(e.g., 43 in MSSM!)

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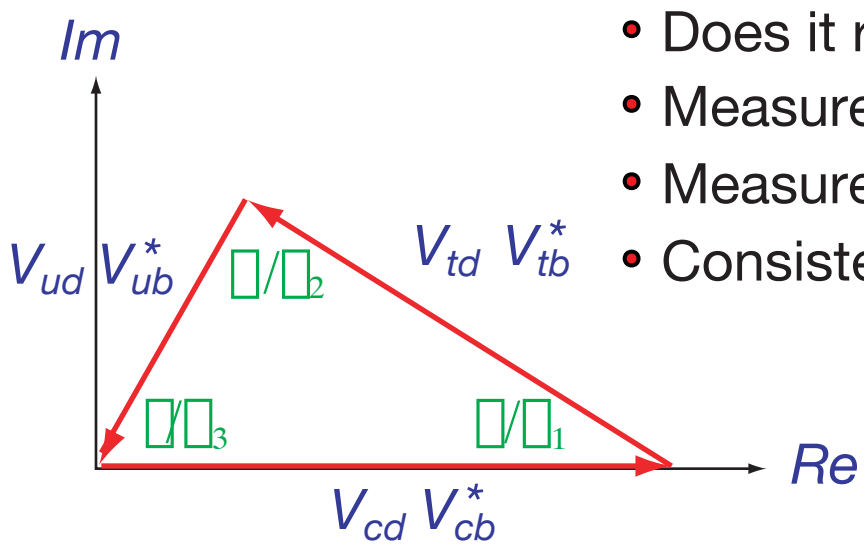
B_d unitarity condition

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



- Does it return to zero?
- Measure lengths of all sides
- Measure all three angles
- Consistent?

CP Violation

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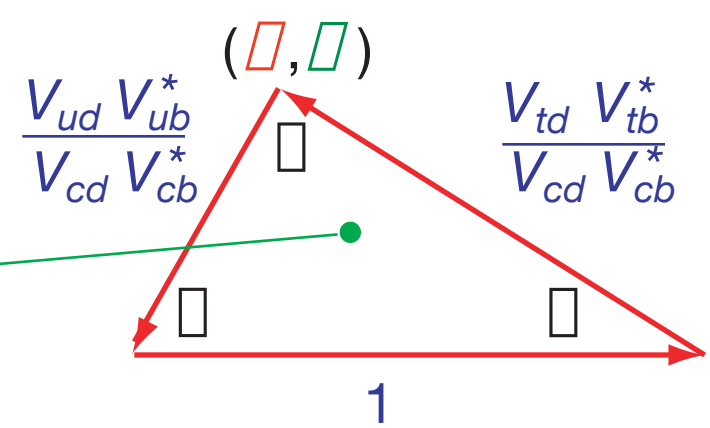
Golden mode, *B* factories

$$\begin{tikzcd} B^0 \arrow[rr] \arrow[dr, "\text{mix}"'] & & J/\psi K_S^0 \\ & \bar{B}^0 \arrow[ur, "\text{mix}"'] & \end{tikzcd}$$

$\sin 2\beta$

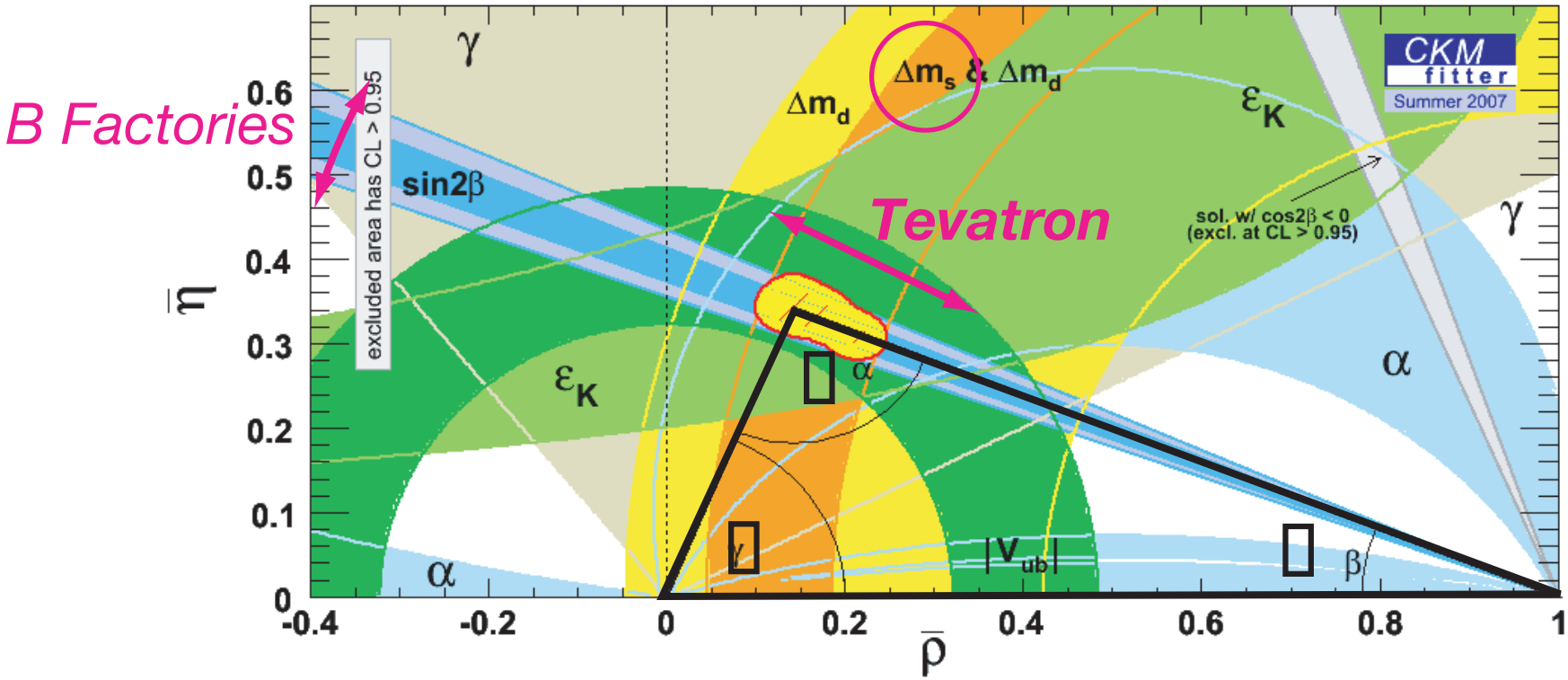
CP violation through interference of diagrams with and w/o mixing



Area of triangle prop. to level of CP violation

B_s^0: Δm_s , Frequency of Oscillations

$$\frac{\Delta m_s}{\Delta m_d} \rightarrow V_{td}$$



Window on to new physics not open very wide!

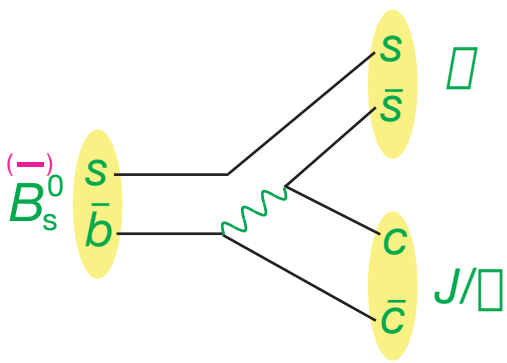
$\Delta\Gamma_s$ and τ_s

First assuming no *CP* violation in B_s mixing

Mass and CP eigenstates the same

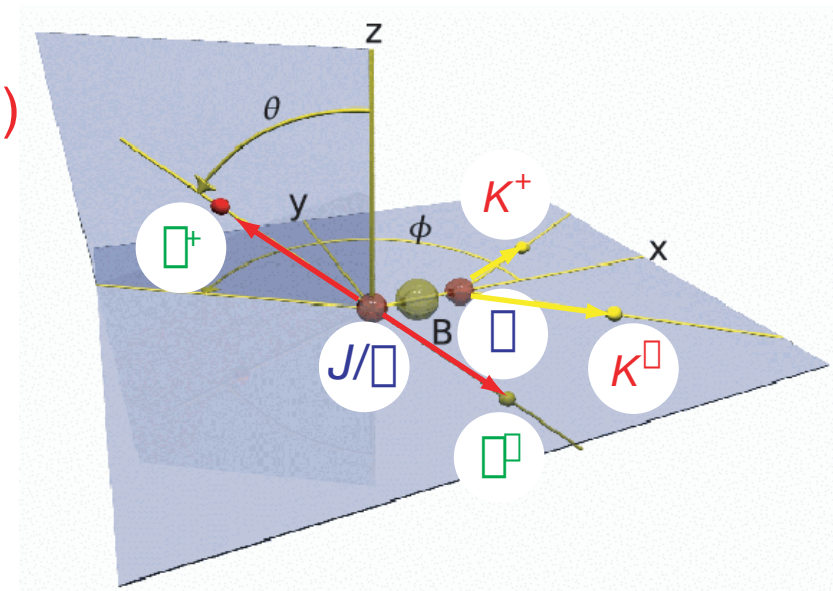
- Heavy (*H, CP-odd*) and Light (*L, CP-even*) B_s states

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \; ; \qquad \Gamma_s = (\Gamma_L + \Gamma_H)/2 \; ; \qquad \tau_s = \frac{1}{\Gamma_s}$$



Not "flavor-specific", predicted to be more *CP*-even than odd

- Decays into two vector mesons that are either *CP*-odd (L=1) or *CP*-even (L=0,2)
- Time-dependent angular distributions allow separation of components
- Simultaneous fit to lifetime and and three angles



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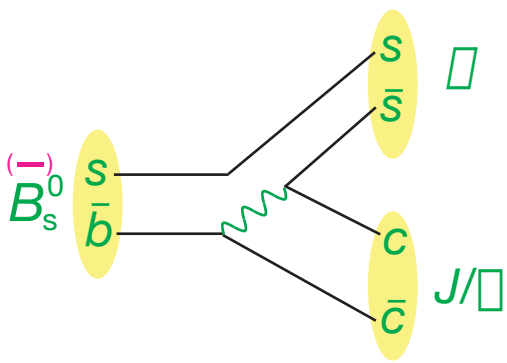

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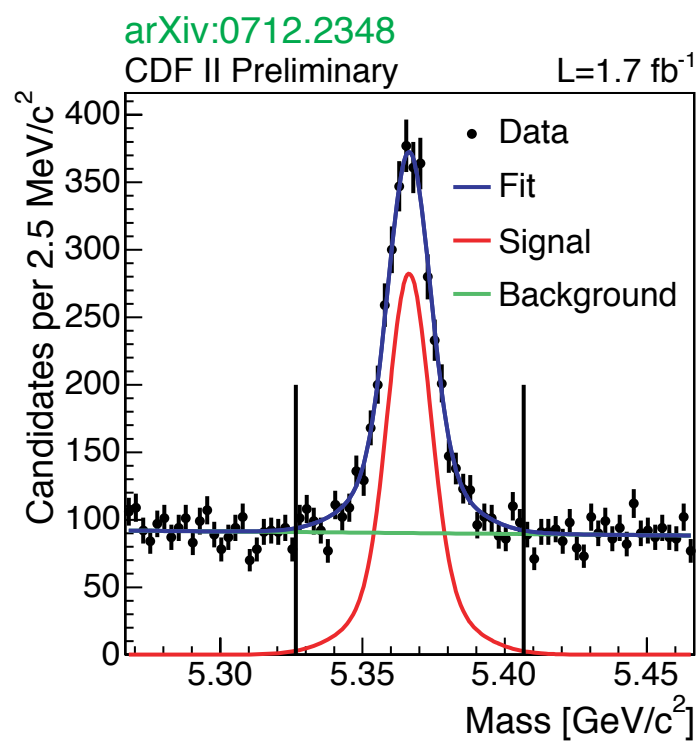

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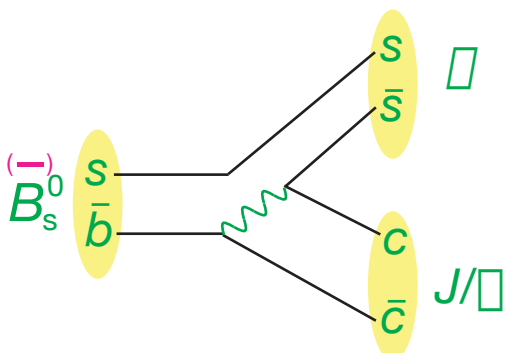
$\Delta\Gamma_s$ and τ_s

First assuming no *CP* violation in B_s mixing

Mass and CP eigenstates the same

- Heavy (*H, CP-odd*) and Light (*L, CP-even*) B_s states

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \; ; \qquad \Gamma_s = (\Gamma_L + \Gamma_H)/2 \; ; \qquad \tau_s = \frac{1}{\Gamma_s}$$



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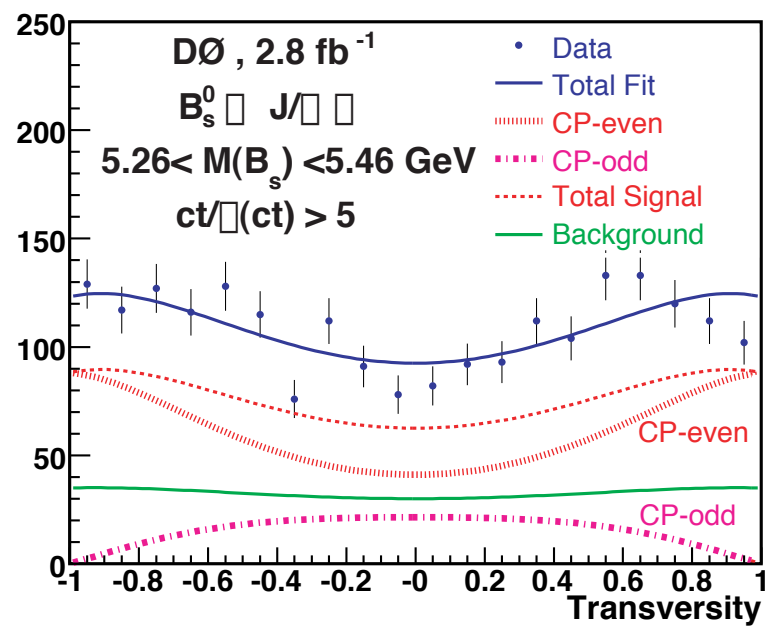
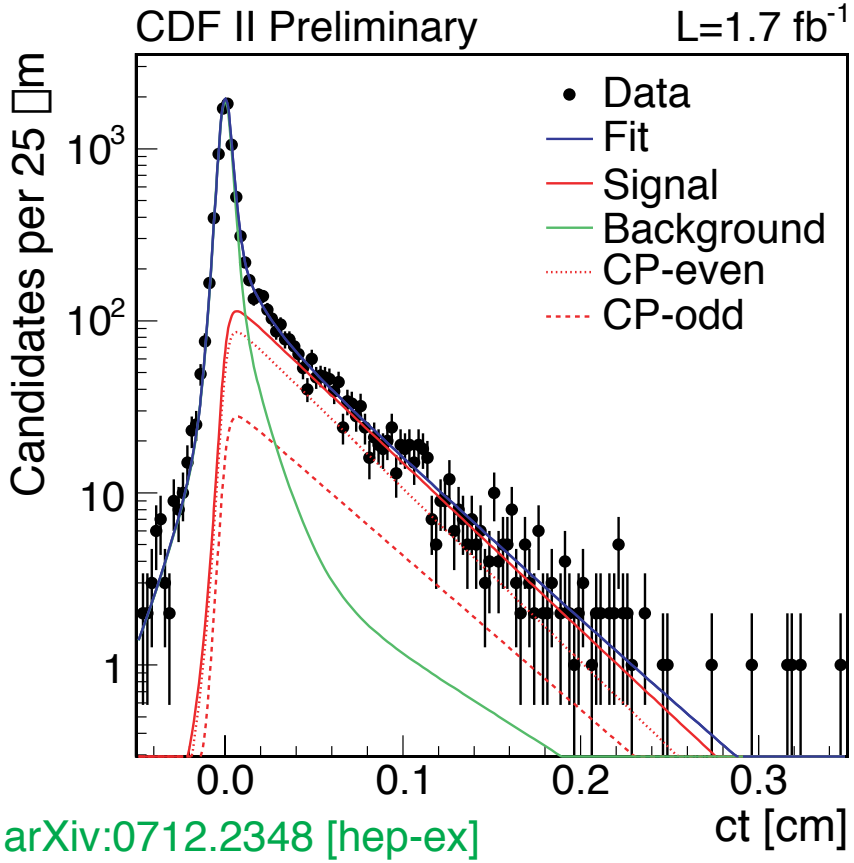


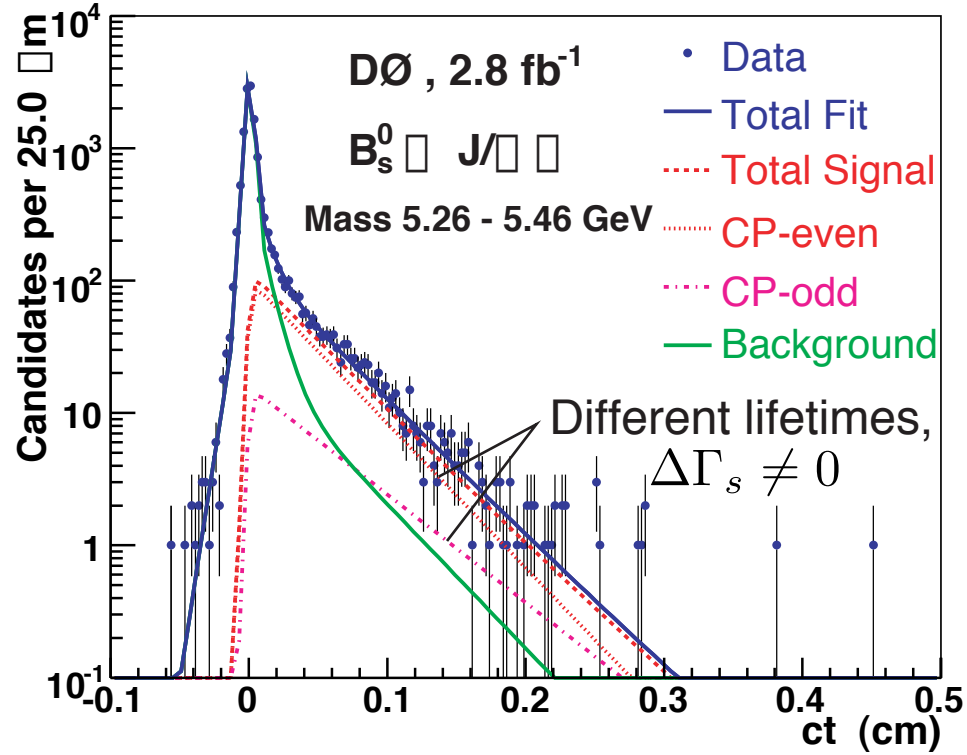
□□$_s$ and □$_s$

First assuming no *CP* violation in B_s mixing, □$_s$ = 0

Mass and CP eigenstates the same



arXiv:0712.2348 [hep-ex]



arXiv:0802.2255 [hep-ex]

$$\Delta\Gamma_s = 0.076^{+0.059}_{-0.063} \pm 0.006\,\mathrm{ps}^{-1}$$

$$\bar{\tau}_s = 1.52 \pm 0.04 \pm 0.02\,\mathrm{ps}$$

$$\Delta\Gamma_s = 0.14 \pm 0.07\,\mathrm{ps}^{-1}$$

$$\bar{\tau}_s = 1.53 \pm 0.05 \pm 0.01\,\mathrm{ps}$$

$$\bar{\tau}_s = \frac{1}{\Gamma_s} = \frac{2}{\Gamma_H + \Gamma_L}$$

c.f. $\Delta\Gamma_s^{SM,pred} = 0.088 \pm 0.017\,\mathrm{ps}^{-1}$ (hep-ph/0612167)

CP Violation

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

- CP violation in SM occurs in only one place: complex phases in unitary CKM matrix; new physics: plenty of new phases!!

B_d unitarity condition

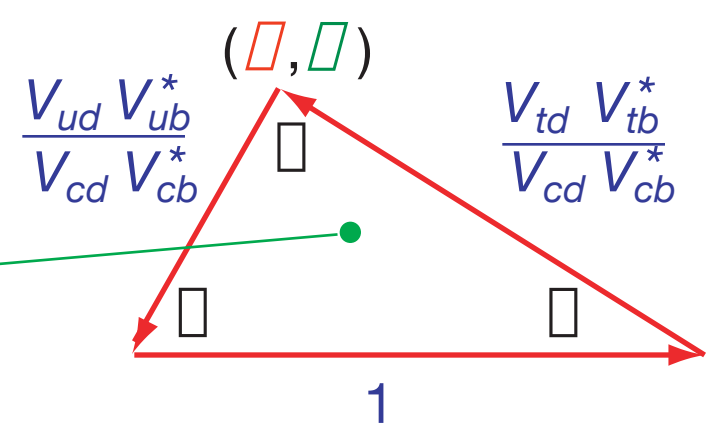
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

Golden mode, *B* factories

$$\begin{tikzcd} B^0 \arrow[rr] \arrow[dr, "\text{mix}"'] & & J/\psi K_S^0 \\ & \bar{B}^0 \arrow[ur, "\text{mix}"'] & \end{tikzcd}$$

$\sin 2\beta$

CP violation through interference of diagrams with and w/o mixing



Area of triangle prop. to level of CP violation

CP Violation in B_s^0 System

Explore new part of matrix!

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

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B_s unitarity condition

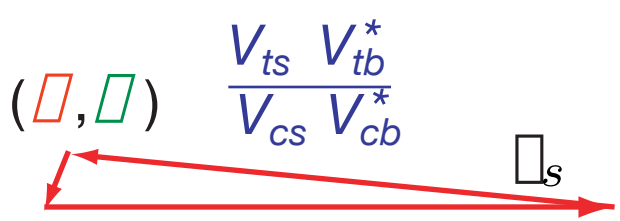
$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

$$\beta_s^{SM} = \arg[-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*]$$

$$\approx 0.02$$

Tiny!

"Squashed" Triangle



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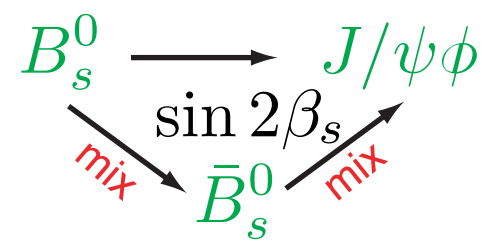
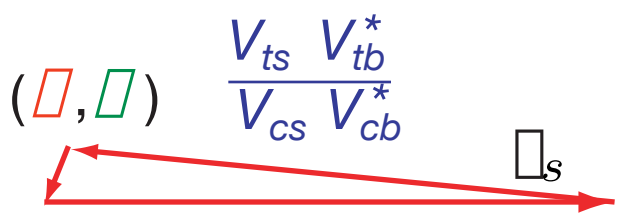
Golden mode, **Tevatron**



"*Squashed*" *Triangle*



CP violation through interference of diagrams with and w/o mixing

CP Violation in B_s^0 System

- How could new physics affect these phases?

$$2\beta_s^{SM} = 2\arg[-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*] \rightarrow \underbrace{2\beta_s^{SM}}_{\sim 0.04} - \phi_s^{NP}$$

$$\phi_s^{SM} = \arg[-M_{12}/\Gamma_{12}] \rightarrow \underbrace{\phi_s^{SM}}_{\sim 0.004} + \phi_s^{NP}$$

Subtracts from one, adds to other

- Both DØ and CDF also measure/observe the phase responsible for CP violation in $B_s^0 \rightarrow J/\psi\phi$ decays

$$\underbrace{\phi_s}_{\text{DØ}} = \underbrace{-2\beta_s}_{\text{CDF}} \approx \underbrace{\phi_s^{NP}}_{\text{If large}}$$

- Use flavor tagging to identify initial flavor, B_s^0 or $\bar{B}_s^0 \rightarrow J/\psi\phi$ (and known value of Δm_s)

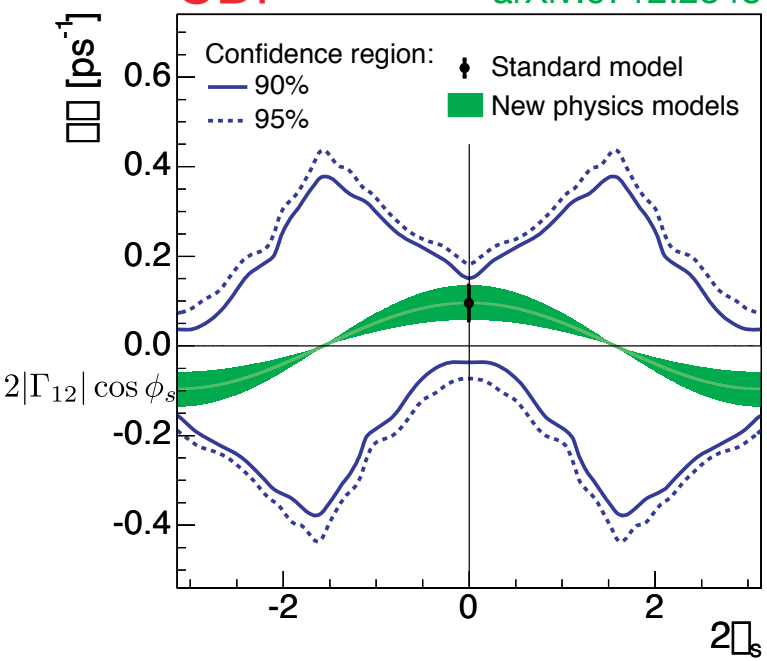
Flings the window open wide...

CP Violation in $B_s^0 \to J/\square\square$

- Even without initial state flavor tagging, have sensitivity to $\phi_s = -2\beta_s$

CDF

arXiv:0712.2348



DØ

PRL 98 , 121801 (2007)

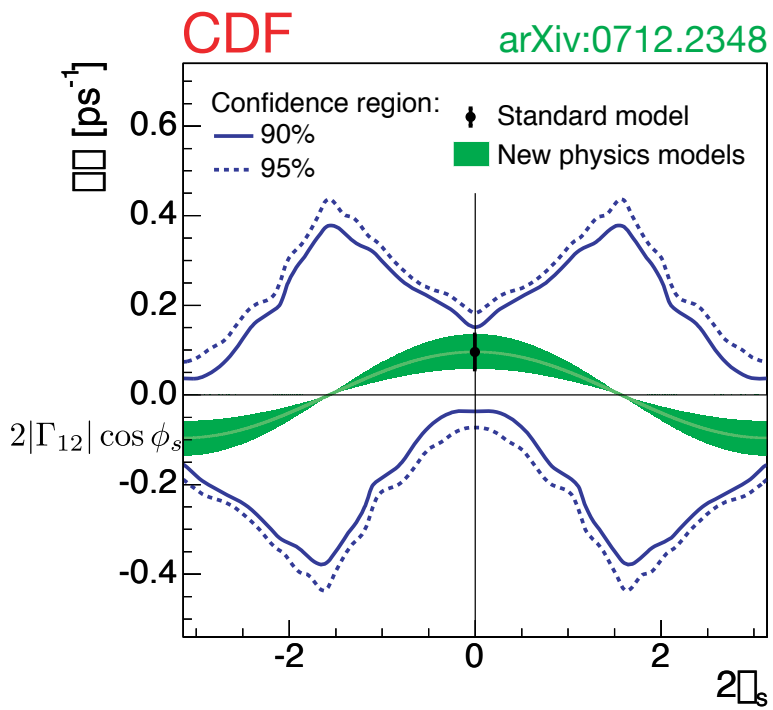
$$\phi_s = -0.79 \pm 0.56^{+0.14}_{-0.01}$$

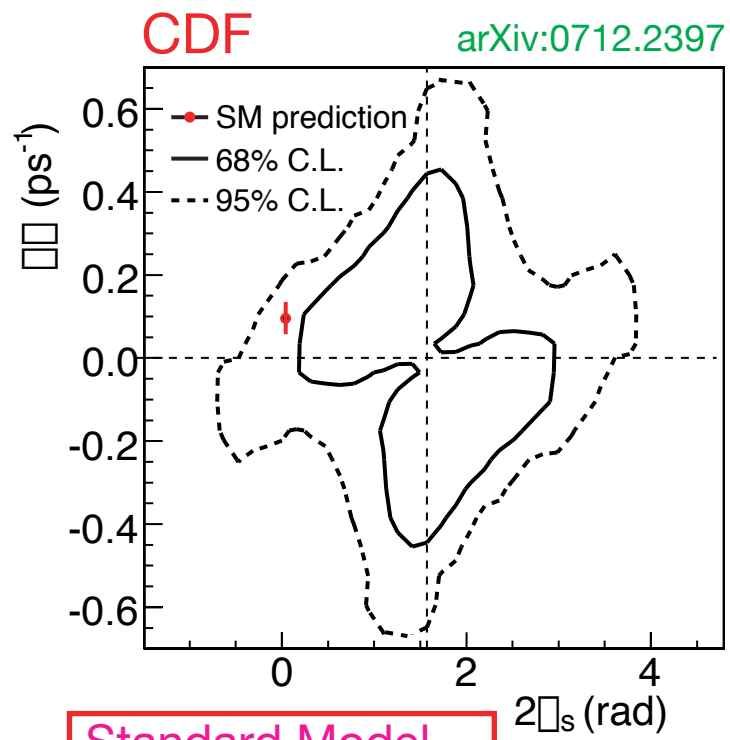
For one of the ambiguities

- But 4-fold ambiguity, reduce to 2-fold with flavor tagging...

CP Violation in $\overset{(-)}{B}{}^0_s \to J/\square\square$

- Now using initial state flavor tagging:





Standard Model Probability = 6.6%, ~1.5□

- Remaining ambiguities:

$$2\beta_s^{J/\psi\phi} \to \pi - 2\beta_s^{J/\psi\phi} \qquad \Delta\Gamma_s \to -\Delta\Gamma_s$$

Strong phases
(relative phases between polarization amplitudes)

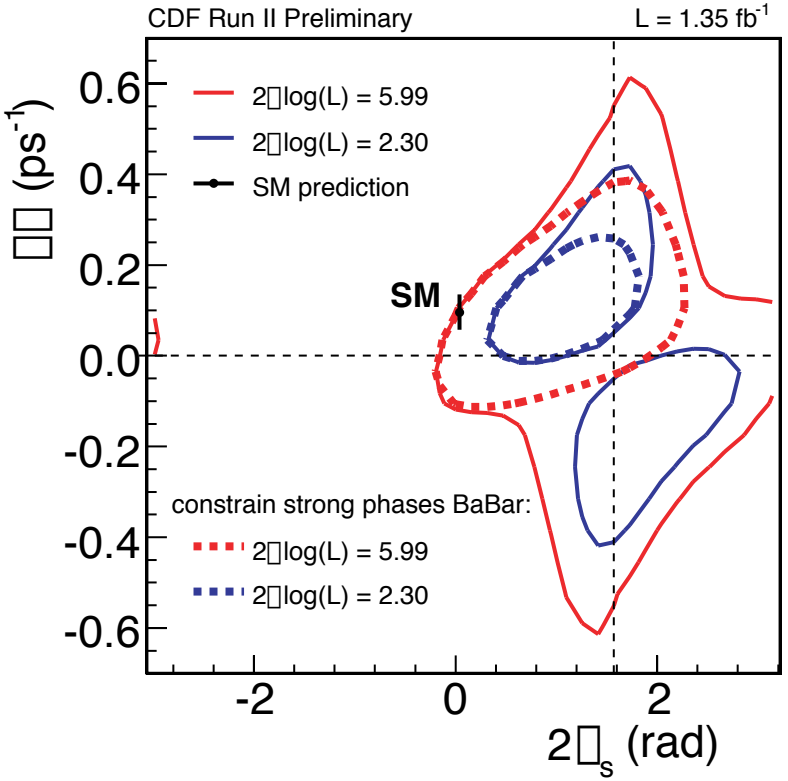
$$\delta_{\parallel} \to 2\pi - \delta_{\parallel} \qquad \delta_{\perp} \to \pi - \delta_{\perp}$$

CP Violation in $B_s^0 \to J/\psi\phi$

- Now using initial state flavor tagging, constrain strong phases

CDF

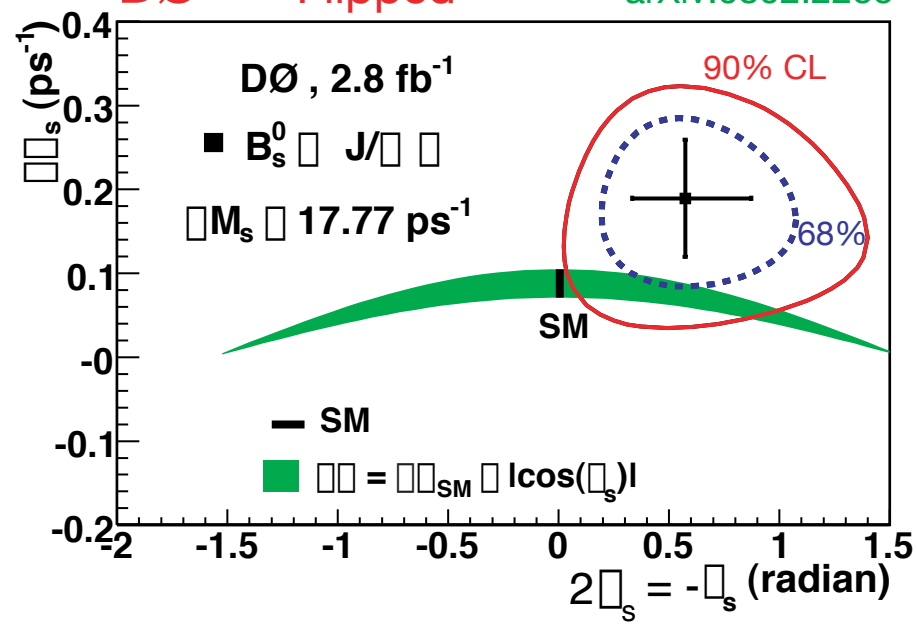
arXiv:0712.2397



Confidence regions underestimated using 2□log*L*

DØ "Flipped"

arXiv:0802.2255



Standard Model Probability = 6.6%, ~1.8□

- Ambiguities:

$$2\beta_s^{J/\psi\phi} \to \pi - 2\beta_s^{J/\psi\phi} \qquad \Delta\Gamma_s \to -\Delta\Gamma_s$$

Constrain based on B_d^0 observations

$$\cancel{\delta_{\parallel} \to 2\pi - \delta_{\parallel}} \qquad \cancel{\delta_{\perp} \to \pi - \delta_{\perp}}$$

CP Violation in B_s^0 Mixing: Other Handles?

- Measured semileptonic asymmetries:

$$a_{SL}^s = \frac{\Gamma(\bar{B}_s^0 \to f) - \Gamma(B_s^0 \to \bar{f})}{\Gamma(\bar{B}_s^0 \to f) + \Gamma(B_s^0 \to \bar{f})} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$$

- DØ, 1.3 fb^{-1}, PRL 98, 151801 (2007)

$$N(B_s^0 \to D_s^- \mu^+ \nu)$$

vs.

$$N(\bar{B}_s^0 \to D_s^+ \mu^- \bar{\nu})$$

+

- DØ, 1 fb^{-1}, PRD 74, 092001 (2006)

$$N(b\bar{b} \to \mu^+\mu^+ X)$$

vs.

$$N(b\bar{b} \to \mu^-\mu^- X)$$

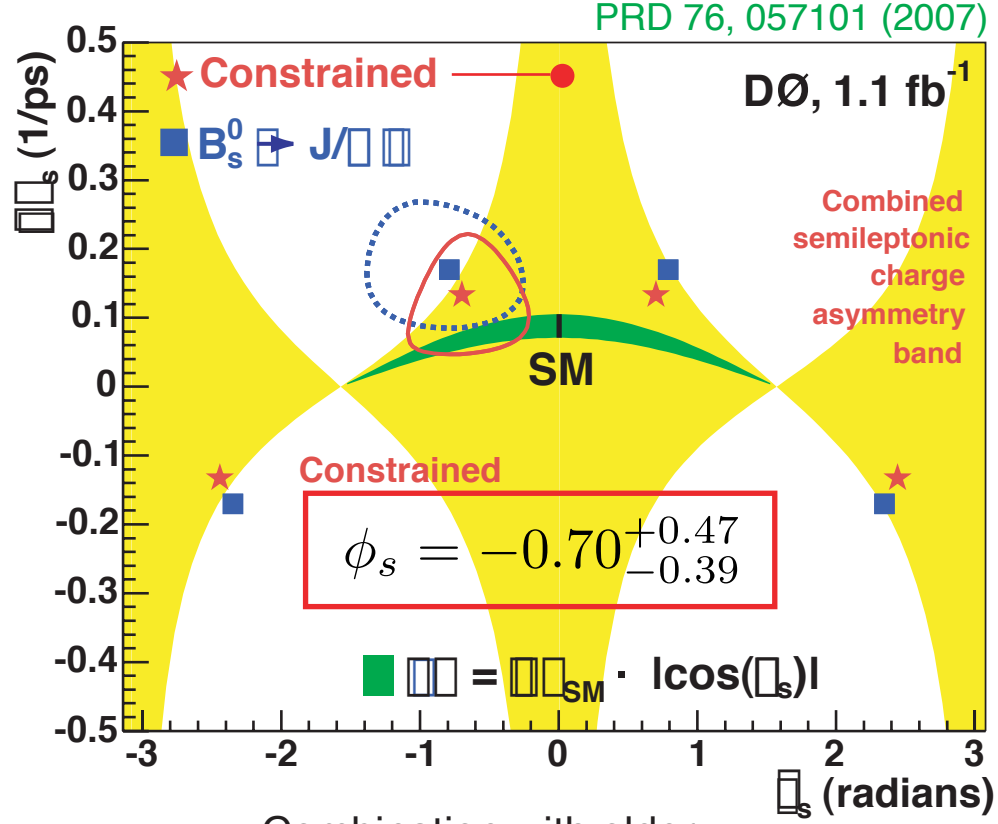
||

$$a_{SL}^s = 0.0001 \pm 0.0090$$

PRD 76, 057101 (2007)

Regular flipping of polarity of solenoid (tracking) and toroid (muons) magnets essential for controlling systematic uncertainties

PRD 76, 057101 (2007)



Combination with older DØ analysis before flavor tagging

CP Violation in B_s^0 Mixing: Other Handles?

- Measured semileptonic asymmetries:

$$a_{SL}^s = \frac{\Gamma(\bar{B}_s^0 \to f) - \Gamma(B_s^0 \to \bar{f})}{\Gamma(\bar{B}_s^0 \to f) + \Gamma(B_s^0 \to \bar{f})} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$$

- DØ, 1.3 fb^{-1}, PRL 98, 151801 (2007)

$$N(B_s^0 \to D_s^- \mu^+ \nu)$$
vs.
$$N(\bar{B}_s^0 \to D_s^+ \mu^- \bar{\nu})$$

+

- DØ, 1 fb^{-1}, PRD 74, 092001 (2006)

$$N(b\bar{b} \to \mu^+\mu^+ X)$$
vs.
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||

$$a_{SL}^s = 0.0001 \pm 0.0090$$

PRD 76, 057101 (2007)

- CDF, 1.6 fb^{-1}, CDF Note 9015

$$N(b\bar{b} \to \mu^+\mu^+ X)$$
vs.
$$N(b\bar{b} \to \mu^-\mu^- X)$$

New

$$a_{SL}^s = 0.020 \pm 0.021 \pm 0.018$$

Regular flipping of polarity of solenoid (tracking) and toroid (muons) magnets essential for controlling systematic uncertainties

CP Violation in B_s^0 Mixing: Other Handles?

- Flavor-specific B_s^0 lifetime
  - Know flavor at time of decay from charge of decay product

    $B_s^0 \to D_s^- \mu^+ \nu \quad B_s^0 \to D_s^- \pi^+$
  - 50% CP-even, 50% CP-odd at time $t = 0$

$$\tau_{fs}(B_s^0) = \frac{1}{\Gamma_s} \frac{1 + (\Delta\Gamma_s/2\Gamma_s)^2}{1 - (\Delta\Gamma_s/2\Gamma_s)^2}$$

$$\neq \bar{\tau}_s = \frac{1}{\Gamma_s}$$

CP Violation in B_s^0 Mixing: Other Handles?

- Flavor-specific B_s^0 lifetime
  - Know flavor at time of decay from charge of decay product

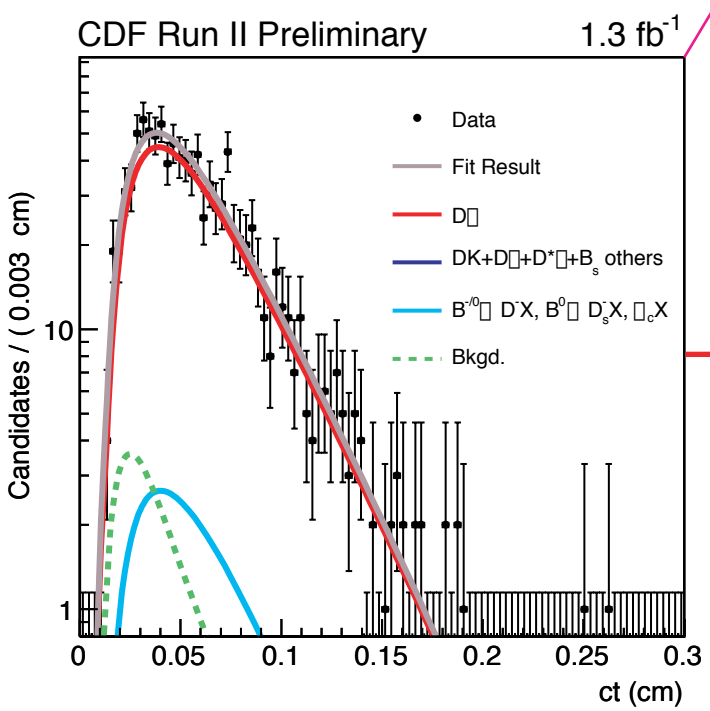
$$B_s^0 \to D_s^- \mu^+ \nu \quad B_s^0 \to D_s^- \pi^+ (\pi^0)$$

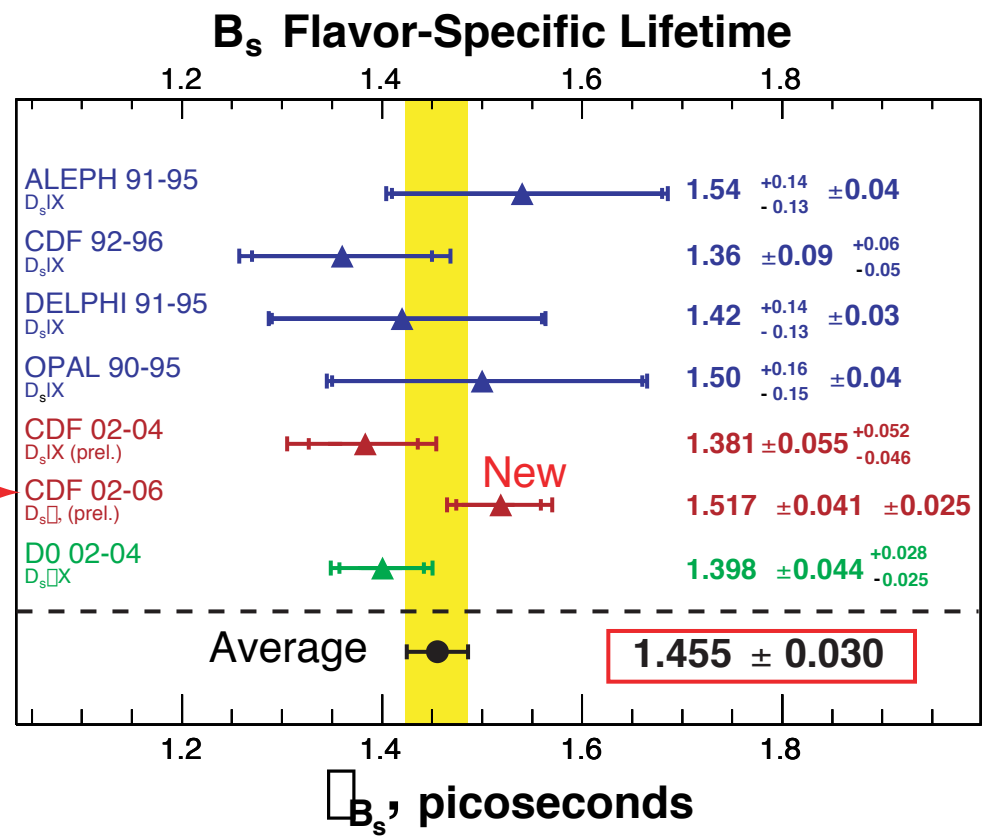
  - 50% CP-even, 50% CP-odd at time $t = 0$

$$\tau_{fs}(B_s^0) = \frac{1}{\Gamma_s} \frac{1 + (\Delta\Gamma_s/2\Gamma_s)^2}{1 - (\Delta\Gamma_s/2\Gamma_s)^2}$$

$$\neq \bar{\tau}_s = \frac{1}{\Gamma_s}$$

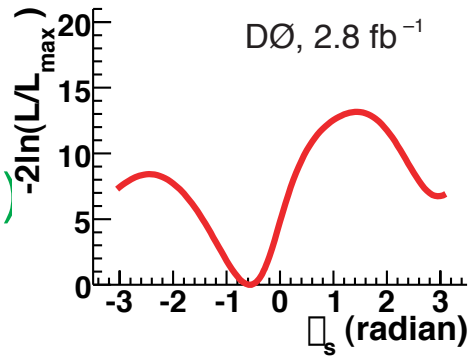
- CDF, 1.6 fb^{-1}, CDF Note 9015





CP Violation in B_s^0 : Combination

- In $B_s^0 \to J/\psi\phi$ flavor-tagged analyses, in $(\Delta\Gamma_s, \phi_s)$ space, CDF has ~1.5 deviation from SM, DØ ~1.8 deviation, consistent with each other
- Need to be careful, non-parabolic log(*L*), multiple correlations (best is simply more data!!)

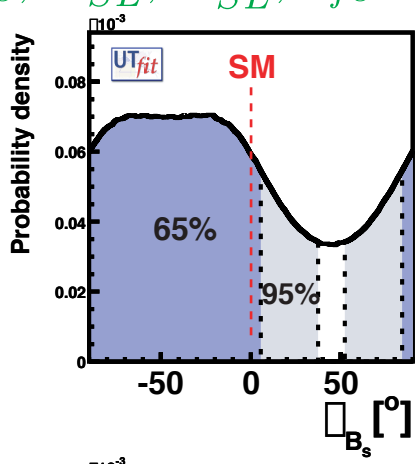


CP Violation in B_s^0: Combination

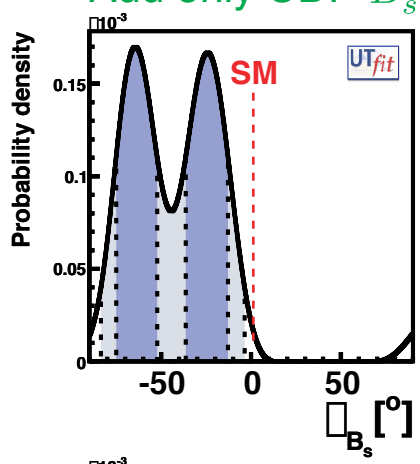
- In $B_s^0 \to J/\psi\phi$ flavor-tagged analyses, in $(\Delta\Gamma_s, \phi_s)$ space, CDF has ~1.5□ deviation from SM, DØ ~1.8□ deviation, consistent with each other

UTfit group, arXiv:0803.0659:

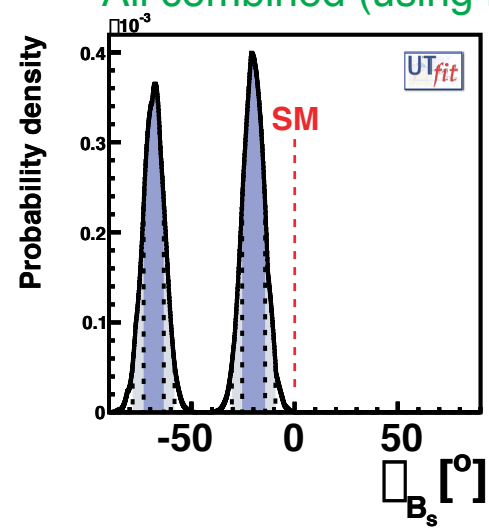
$\Delta m_s,\ A_{SL}^s,\ A_{SL}^{\mu\mu},\ \tau_{fs}$



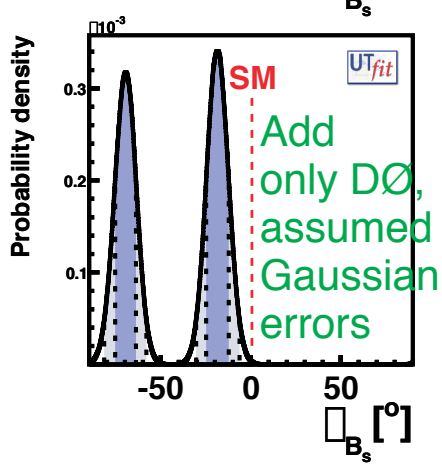
Add only CDF $B_s^0 \to J/\psi\phi$

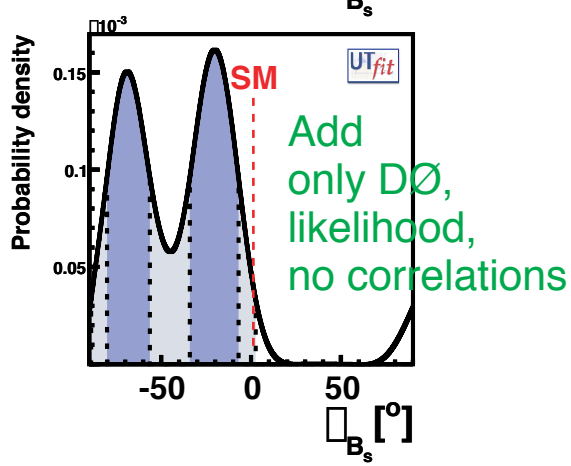


All combined (using DØ Gauss. assumption)



> 3□ deviation from SM





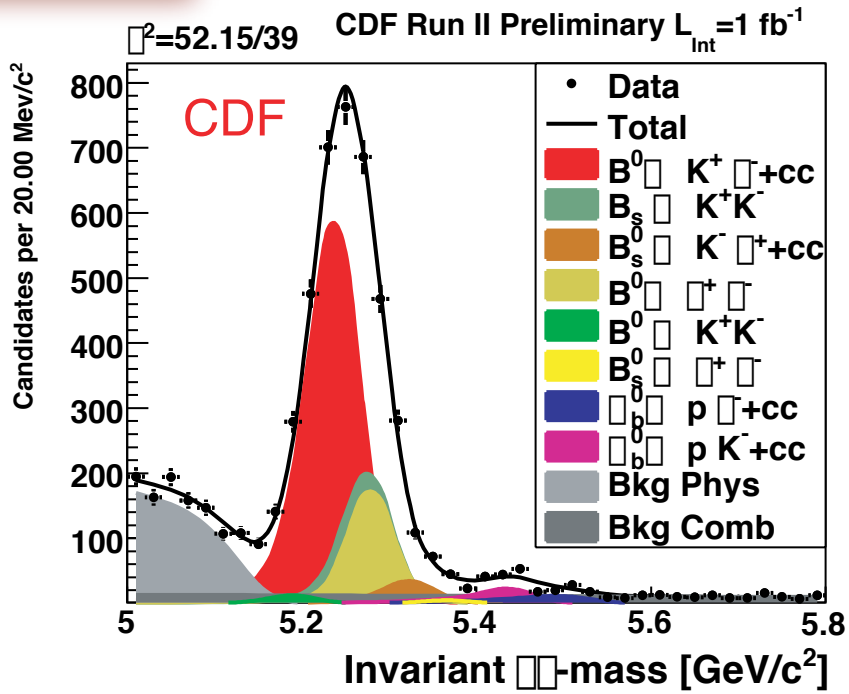
- Intriguing, results from DØ, CDF with more data coming soon; CDF+DØ+HFAG also working on combin.

Direct *CP* Violation in *b* Hadrons

- Direct (not through mixing) *CP* violation expected to be large in some *b* hadron decays, including B_s^0 mesons and *b* baryons
- Measure asymmetry: f = final state

$$A_{CP} = \frac{N(\bar{B} \to \bar{f}) - N(B \to f)}{N(\bar{B} \to \bar{f}) + N(B \to f)}$$

- CDF: *Br*'s and asymmetries of two-body charmless states, $B \to hh^{(\prime)}$
  - Two displaced-track trigger
  - Separate decays using mass, momentum imbalance of products, dE/dx particle id



$$A_{CP}(B^0 \to K^+\pi^-) = -0.086 \pm 0.023 \pm 0.009$$

Competitive w/ *B* Factories

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

2.5, can be used to measure in CKM triangle

Direct *CP* Violation in *b* Hadrons

- Direct (not through mixing) *CP* violation expected to be large in some *b* hadron decays, including B_s^0 mesons and *b* baryons
- Measure asymmetry: f = final state

$$A_{CP} = \frac{N(\bar{B} \to \bar{f}) - N(B \to f)}{N(\bar{B} \to \bar{f}) + N(B \to f)}$$

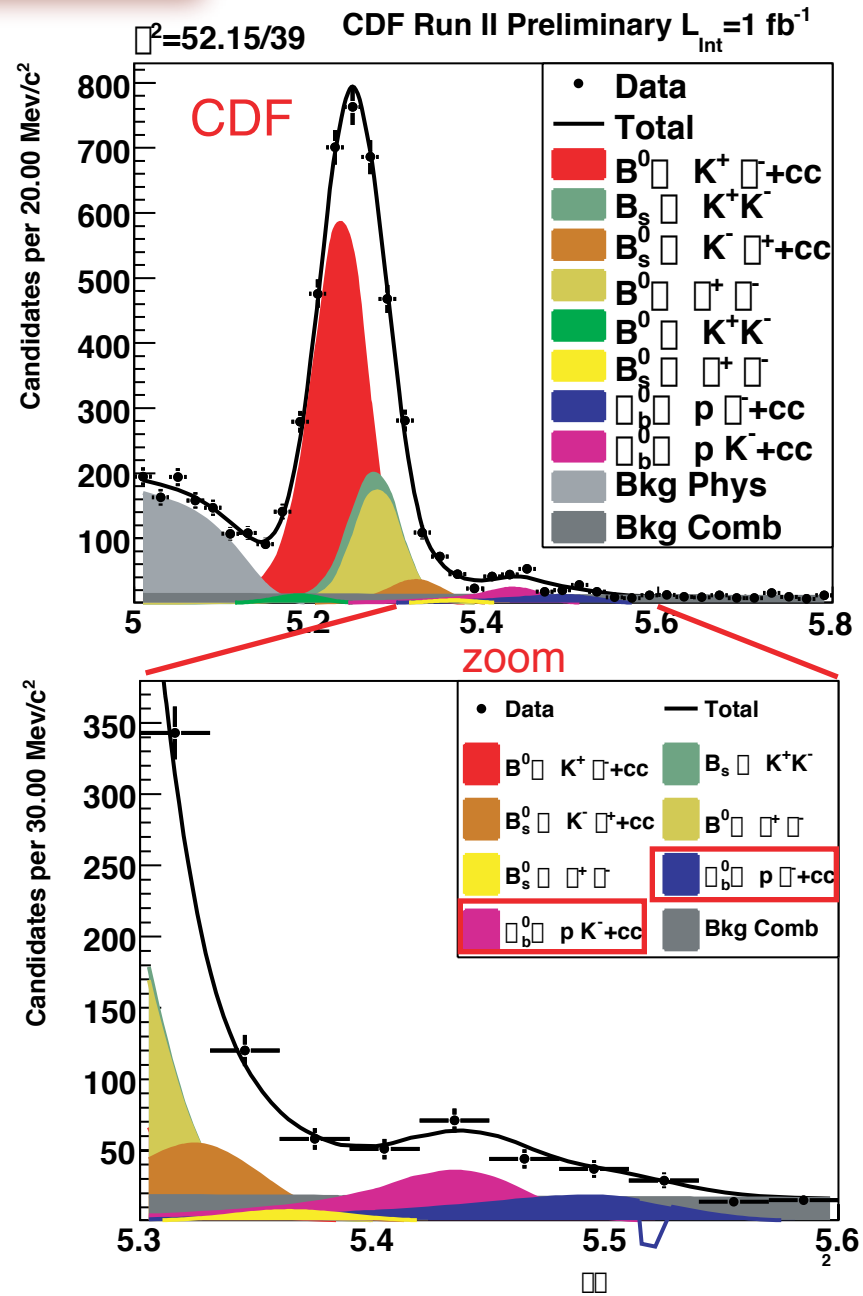
- CDF: *Br*'s and asymmetries of two-body charmless states, $B \to hh^{(\prime)}$

CDF Note 9092

$$A_{CP}(\Lambda_b^0 \to p\pi^-) = 0.03 \pm 0.17 \pm 0.05$$

$$A_{CP}(\Lambda_b^0 \to pK^-) = 0.37 \pm 0.17 \pm 0.03$$

- Expectations, asymmetry ~30%
- First *CP* asymmetry measurement in *b* baryon decays



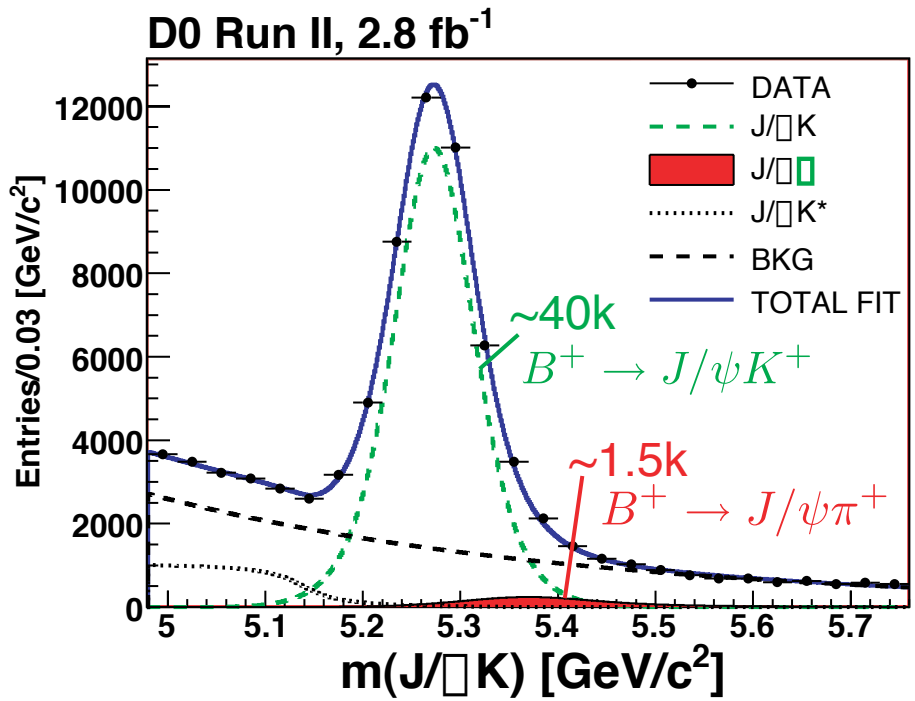
Direct *CP* Violation in *b* Hadrons

- DØ: Small (~1%) CP asymmetry expected in SM for $B^+ \to J/\psi K^+$
- Again, frequent solenoid and toroid polarity reversals essential to control charge asymmetry systematic uncertainties
- Correct for K^+/K^- asymmetry

arXiv:0802.3299

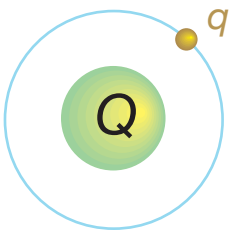
$$A_{CP}(B^+ \to J/\psi K^+) = +0.0075 \pm 0.0061 \pm 0.0027$$

- < 1% precision, factor ~2 better than current world average



Spectroscopy

Hydrogen atom of strongly interacting systems



Orbitally Excited *B* Mesons

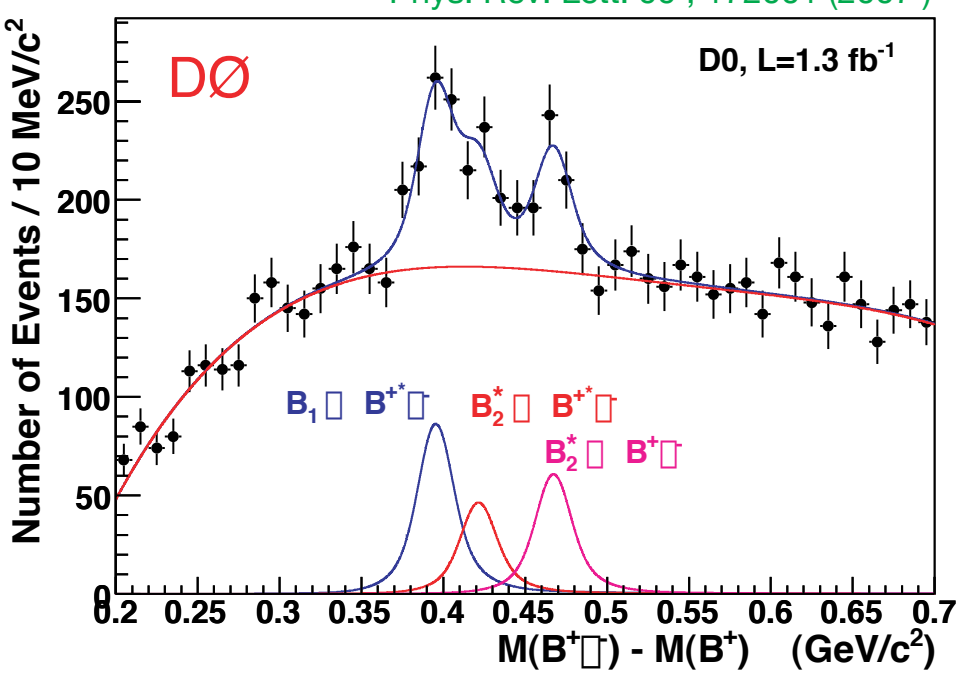
$L = 1$

$\vec{j}_q = \vec{s}_q + L$	$\vec{J} = \vec{s}_Q + \vec{j}_q$		
$j_q = 1/2$	$J = 0, 1$	B_0^*, B_1'	B_{s0}^*, B_{s1}'
$j_q = 3/2$	$J = 1, 2$	B_1, B_2^*	B_{s1}, B^*

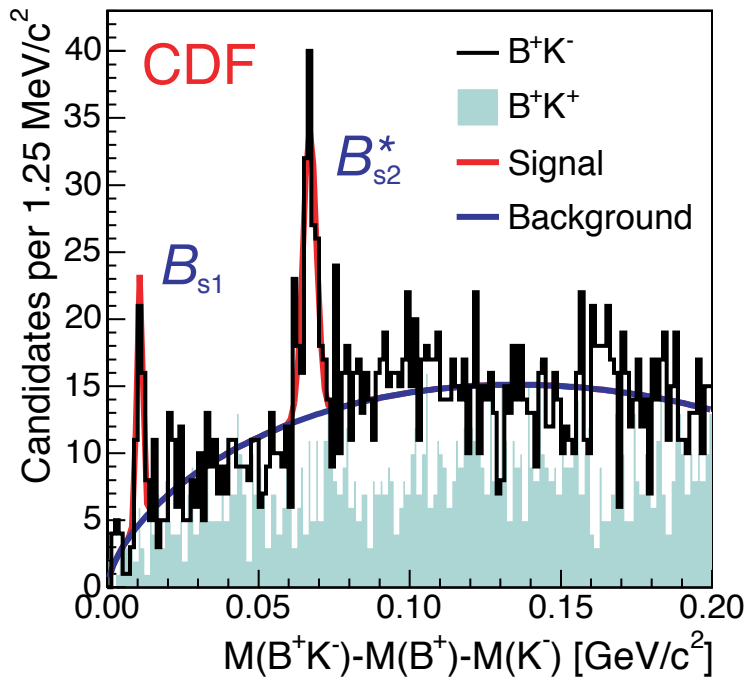
Collectively referred to as: B^{**} B_s^{**}

Two will be narrow,
two will be wide

Phys. Rev. Lett. 99 , 172001 (2007)



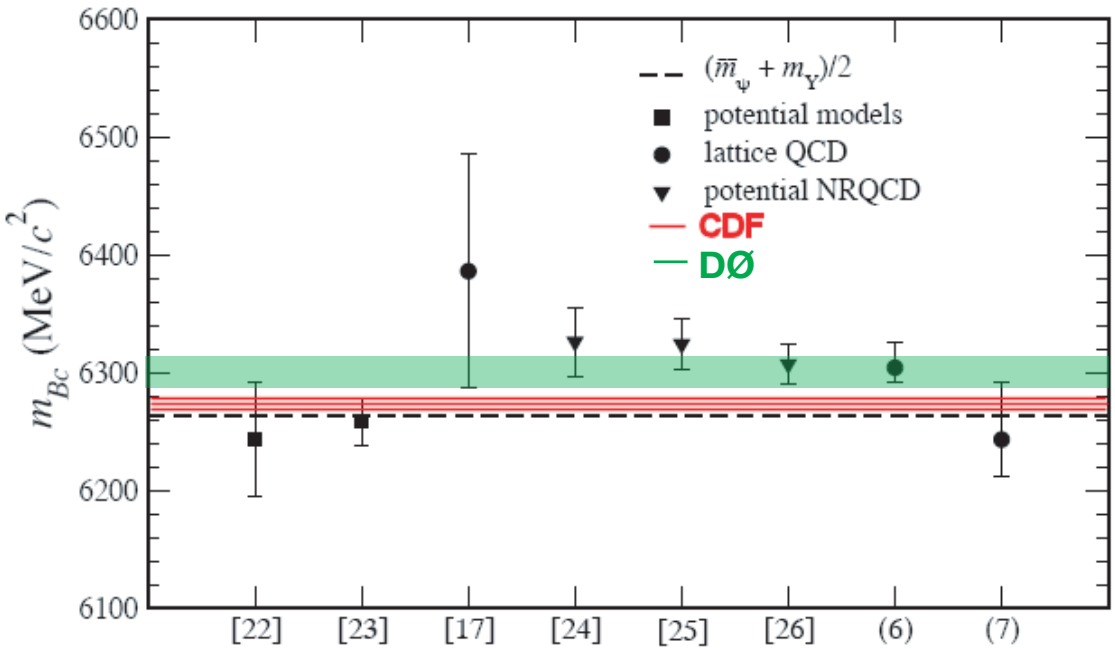
CDF Run 2 arXiv:0710.4199 1.0 fb^{-1}

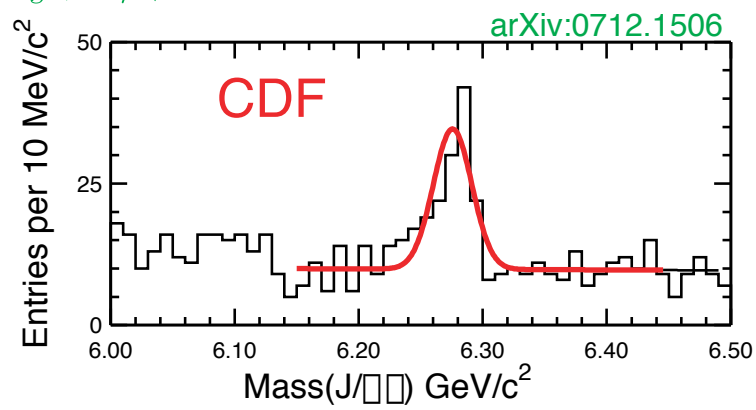


- First separation of individual states
- Comparisons to theory in backup slides

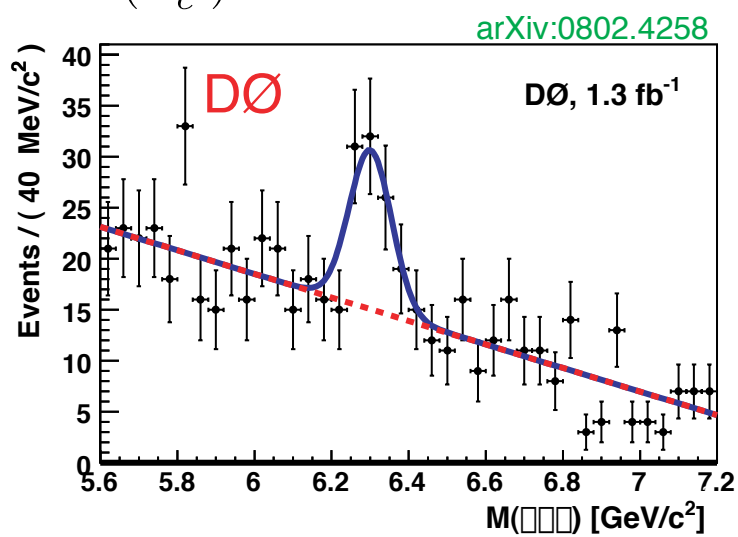
Spectroscopy: B_c Meson

- Unique in that it contains two *different* heavy quarks
- Decays: via b quark $B_c^+ \to B_s^0 \pi^+;\ B_s^0 \ell^+ \nu$
  via c quark $B_c^+ \to J/\psi \pi^+;\ J/\psi D_s^+;\ J/\psi \ell^+ \nu$
  annihilation $B_c^+ \to \ell^+ \nu$





$$m(B_c^+) = 6275.6 \pm 2.9 \pm 2.5\,\mathrm{MeV}$$



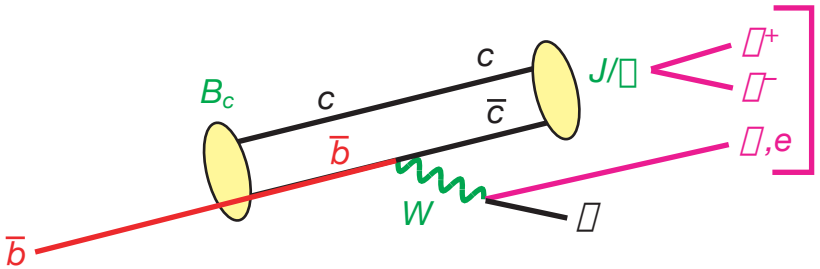
$$m(B_c^+) = 6300 \pm 14 \pm 5\,\mathrm{MeV}$$

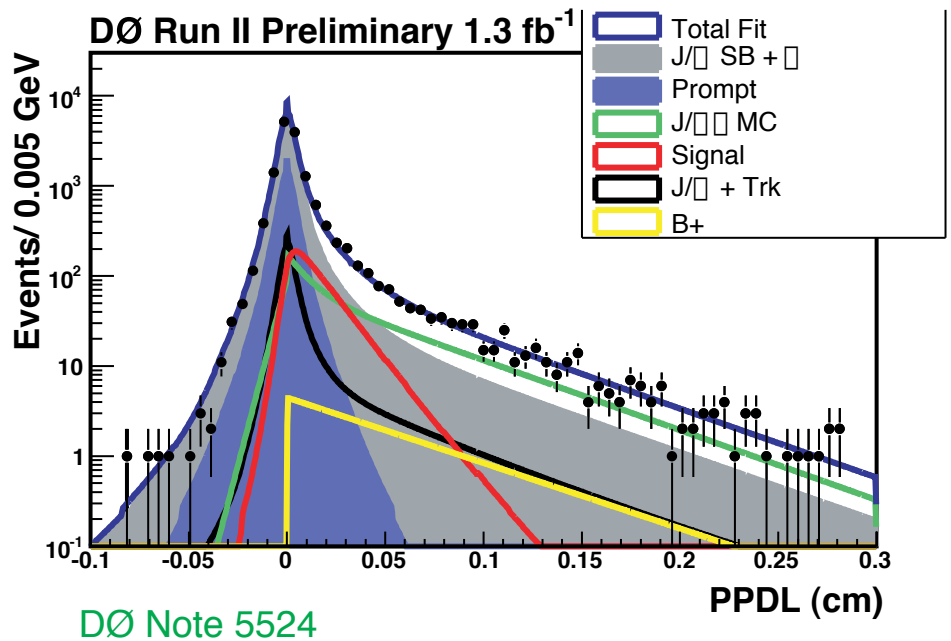
Spectroscopy: B_c Meson

Lifetime

- Unique in that it contains two *different* heavy quarks
- Decays: via b quark $B_c^+ \to B_s^0\pi^+;\ B_s^0\ell^+\nu$ Γ_b
  via c quark $B_c^+ \to J/\psi\pi^+;\ J/\psi D_s^+;\ J/\psi\ell^+\nu$ Γ_c
  annihilation $B_c^+ \to \ell^+\nu$ Γ_{annih}

Lifetime expected to be much shorter than other b hadrons (~1/3)





- DØ: simultaneous fit to mass templates and lifetime models
- CDF: normalization floats, includes semi-electronic decay

CDF: 080327.blessed-BC_LT_SemiLeptonic

$$\tau(B_c) = 0.475^{+0.053}_{-0.049} \pm 0.018\,\mathrm{ps}$$

DØ Note 5524

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

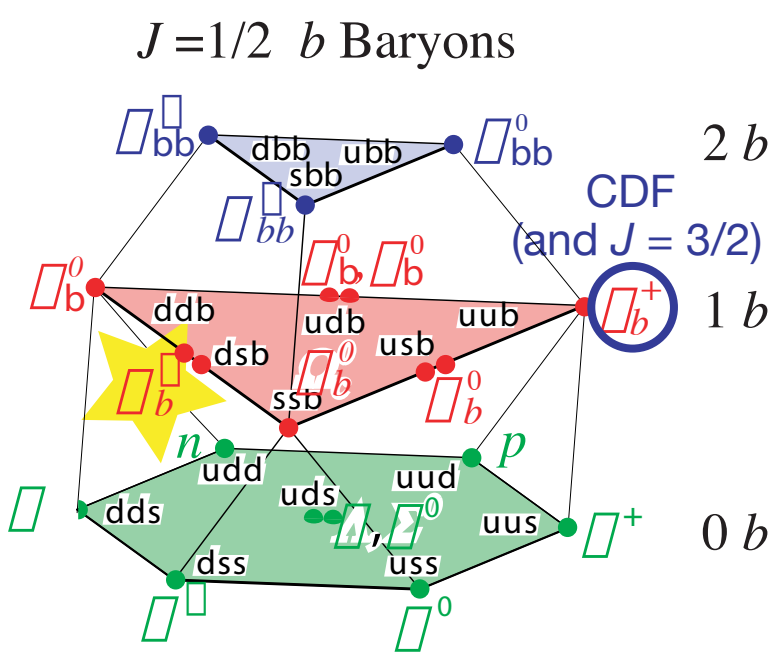
New world average, including CDF Run 1 pub:

$$\tau_{ave}(B_c) = 0.460 \pm 0.037\,\mathrm{ps}$$

- c.f. theory prediction hep-ph/0308214

$$\tau(B_c) = 0.48 \pm 0.05\,\mathrm{ps}$$

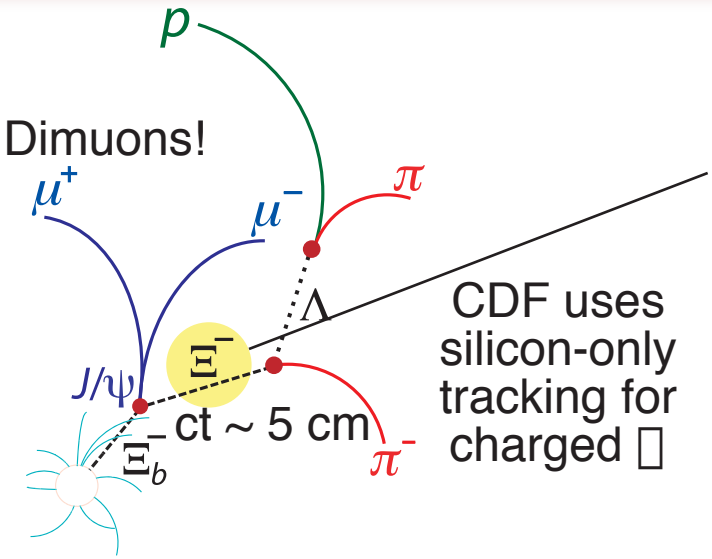
Spectroscopy: New Ω_b Baryon

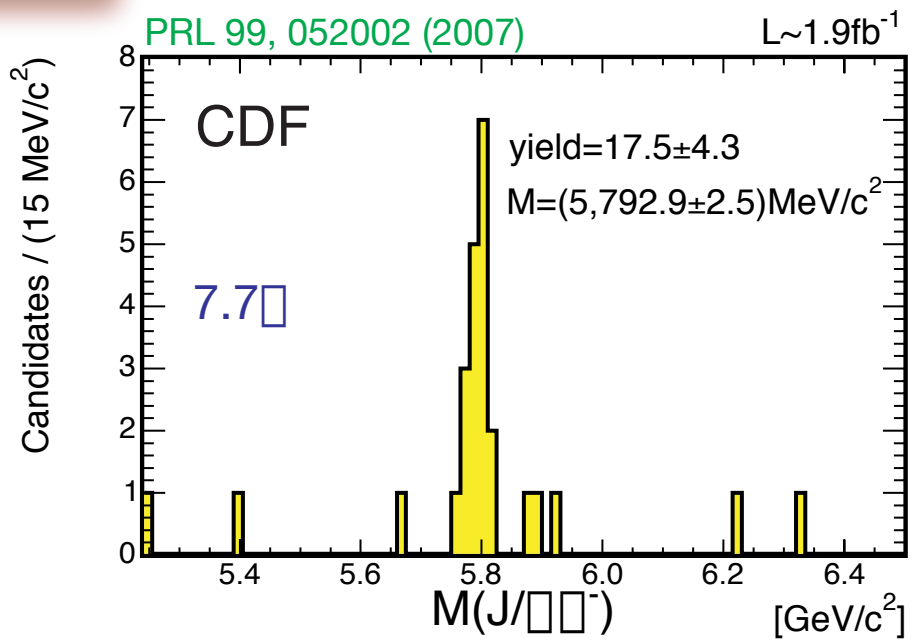


"Strangely Beautiful Baryon"

"Triple-Scoop Baryon"

Spectroscopy: New Ξ_b Baryon





CDF

$$M(\Xi_b) = 5792.9 \pm 2.4 \pm 1.7\,\mathrm{MeV}$$

DØ

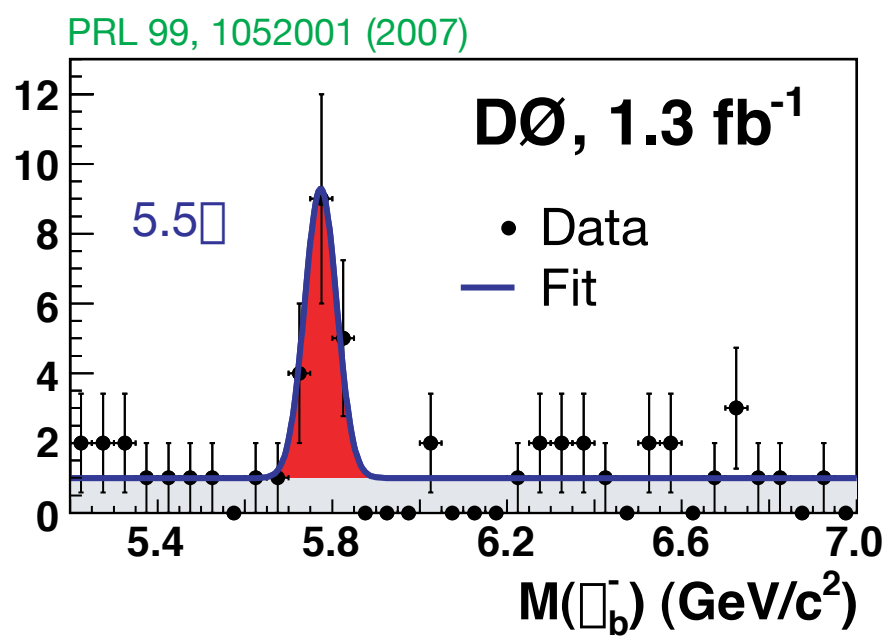
$$M(\Xi_b) = 5774 \pm 11 \pm 15\,\mathrm{MeV}$$

- Theory prediction:

  $$M(\Xi_b) = 5795 \pm 5\,\mathrm{MeV}$$

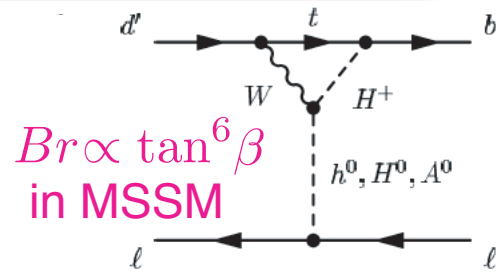
  hep-ph/0706.2163

- Plus production rates; next step: lifetime



Rare Decays: Another window on to New Physics

- Excellent window into new physics, forbidden at tree level, highly suppressed in SM

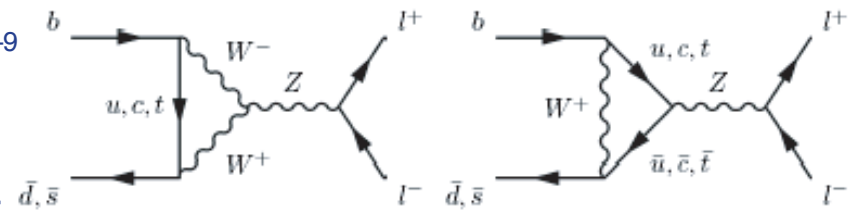


$Br \propto \tan^6\beta$ in MSSM

Predicted:

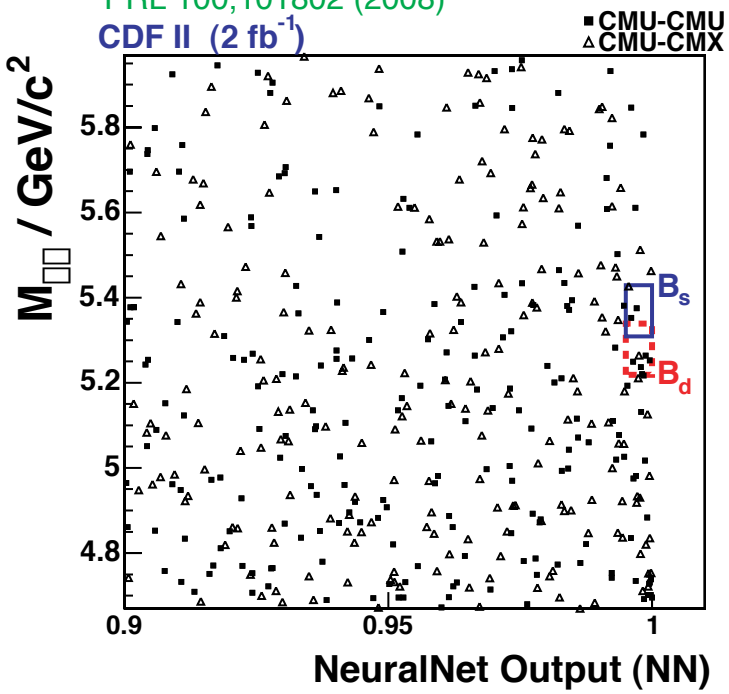
$Br(B_s \to \mu^+\mu^-) = (3.4 \pm 0.5) \times 10^{-9}$

$Br(B_d \to \mu^+\mu^-)$ suppressed by another factor of $|V_{td}/V_{ts}| \sim 0.04$



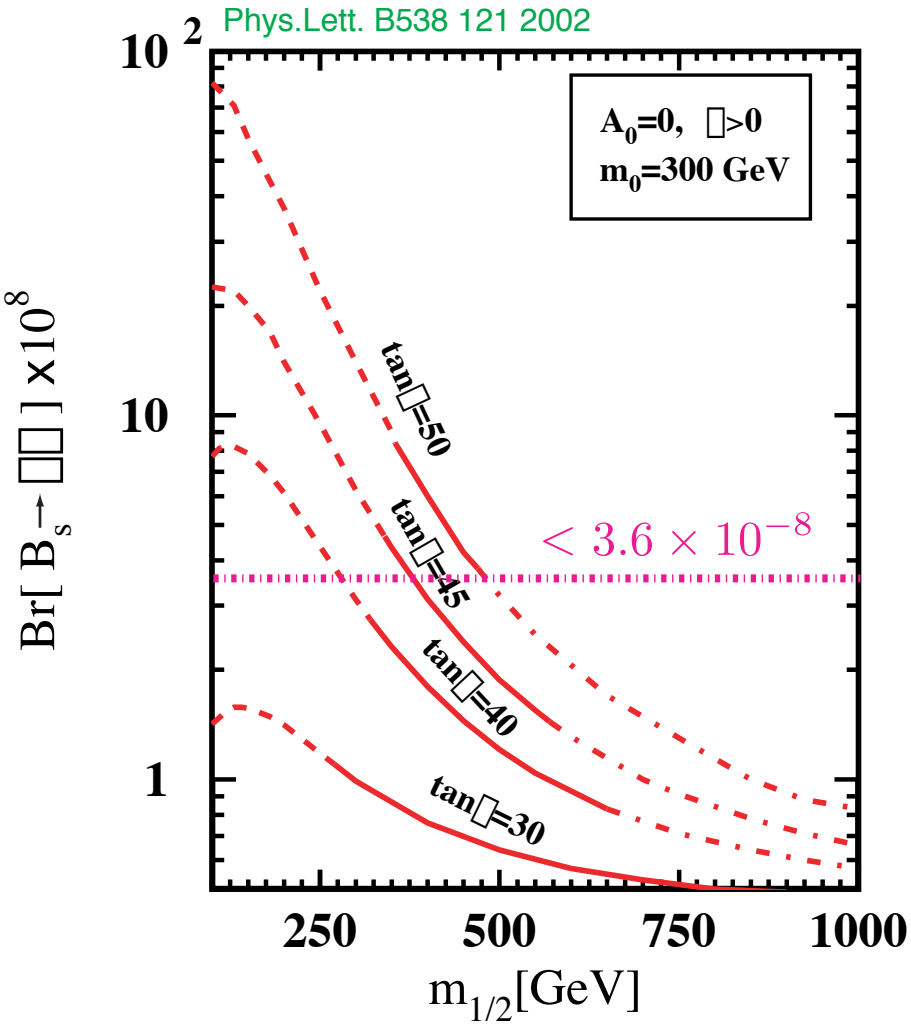
	$Br(B_s^0 \to \mu^+\mu^-)$ @ 90% CL	$Br(B_d^0 \to \mu^+\mu^-)$ @ 90% CL
CDF PRL 100,101802 (2008)	$< 4.7 \times 10^{-8}$	$< 1.5 \times 10^{-8}$
DØ DØ Note 5344	$< 7.3 \times 10^{-8}$	
New HFAG average	$< 3.6 \times 10^{-8}$	

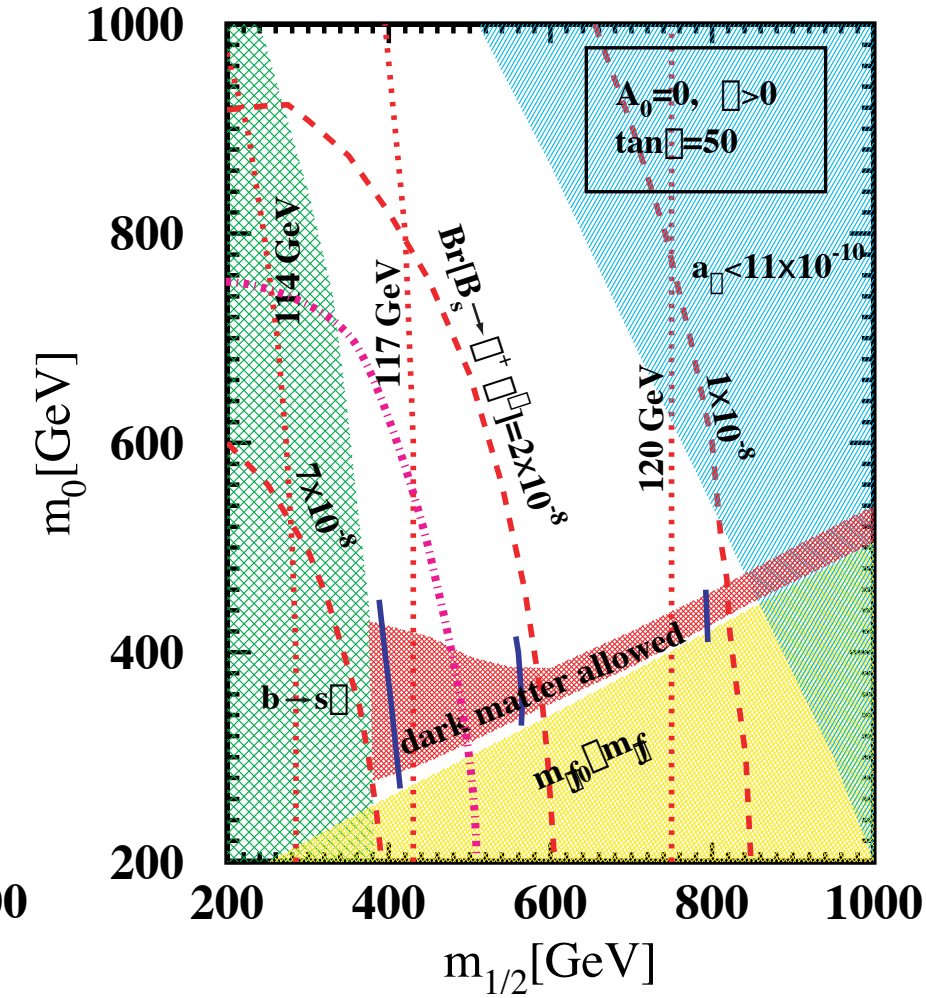
PRL 100,101802 (2008)



Rare Decays: Another window on to New Physics

Phys.Lett. B538 121 2002





Regrets...

- $b - \bar{b}$ correlations
- $\psi(2S)$ production & cross section
- Σ_b observations
- $\Upsilon(1S), \Upsilon(2S)$ polarization

- $Br(B_s^0 \to D_s^{(*)} D_s^{(*)})$ for $\Delta\Gamma_s^{CP}$
- CP asymmetry in $B^+ \to D_{CP}^0 K^+$
- Angular analysis of $B_d^0 \to J/\psi K^{*0}$

- Rare charm FCNC limits
- $D^0 - \bar{D}^0$ mixing
- $D^0 \to \mu^+\mu^-$ limits

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

DØ: http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm

Conclusions & Prospects

- Diverse physics program at the Tevatron resulting in continued large gains in understanding of *B* physics
- Complementary to and competitive with the *B* factories
- B_s^0 system and CP studies opening a powerful new window: possibly already providing hints of new phenomena?

- Renaissance of spectroscopy (and properties) as new heavy states continue to flood in
- Continue to push on rare decays

- Tevatron doing very well, expect to at least *double* our data-set by the end of running

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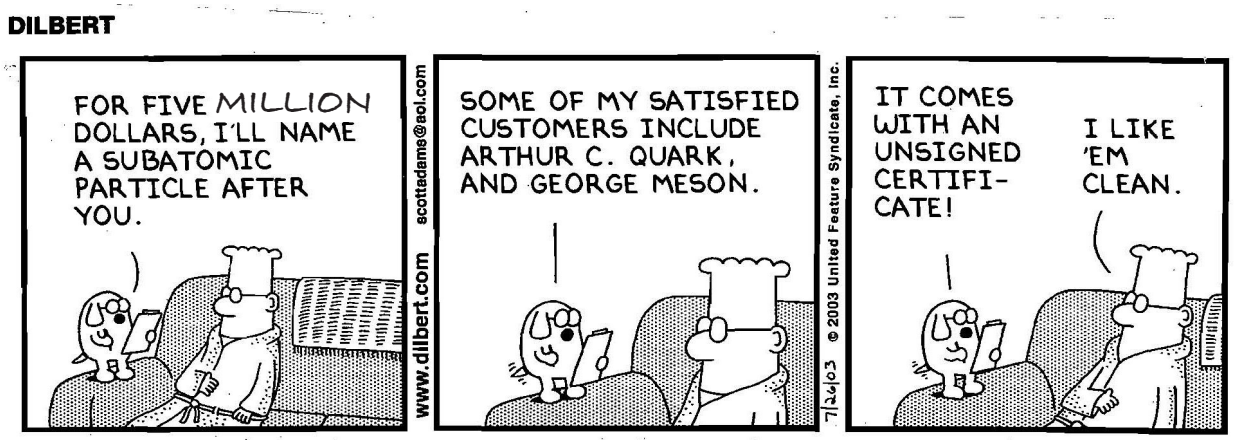

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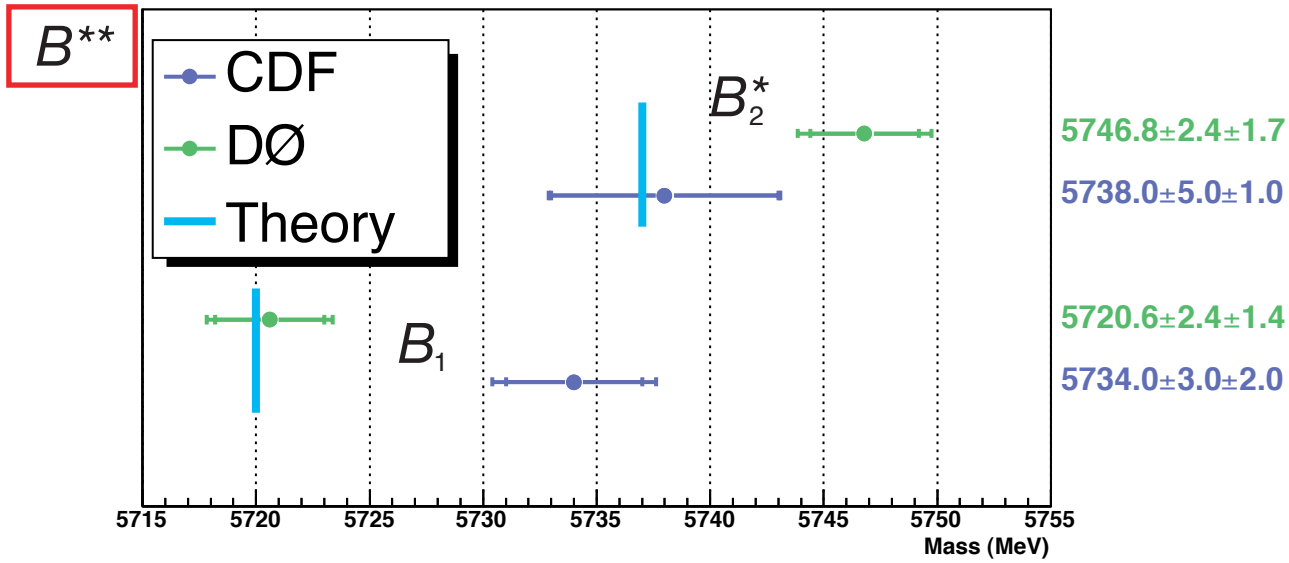
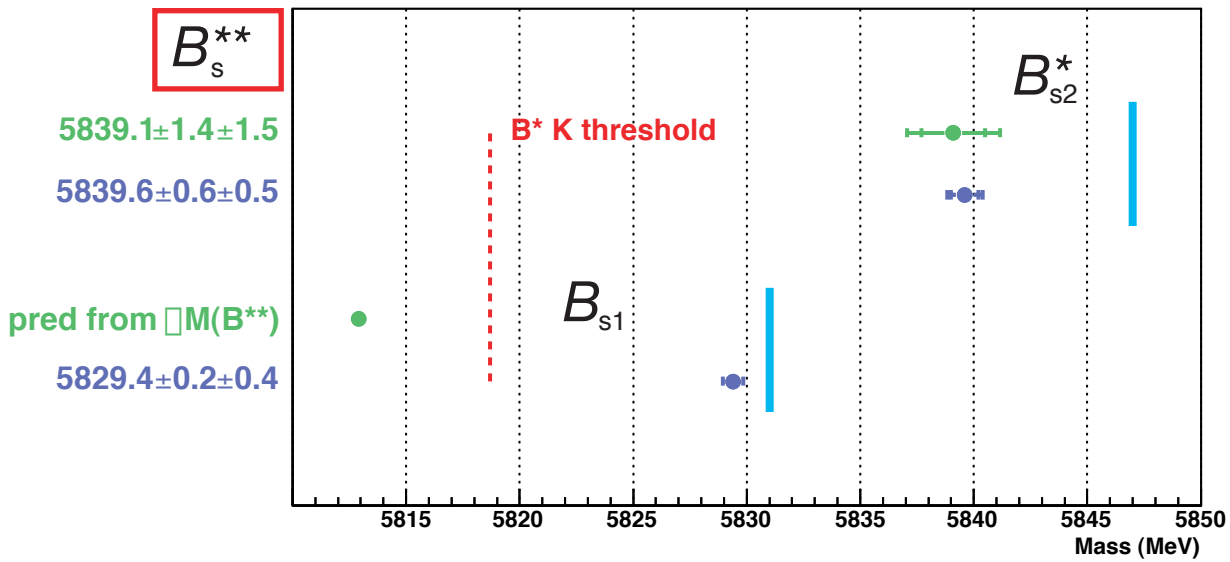
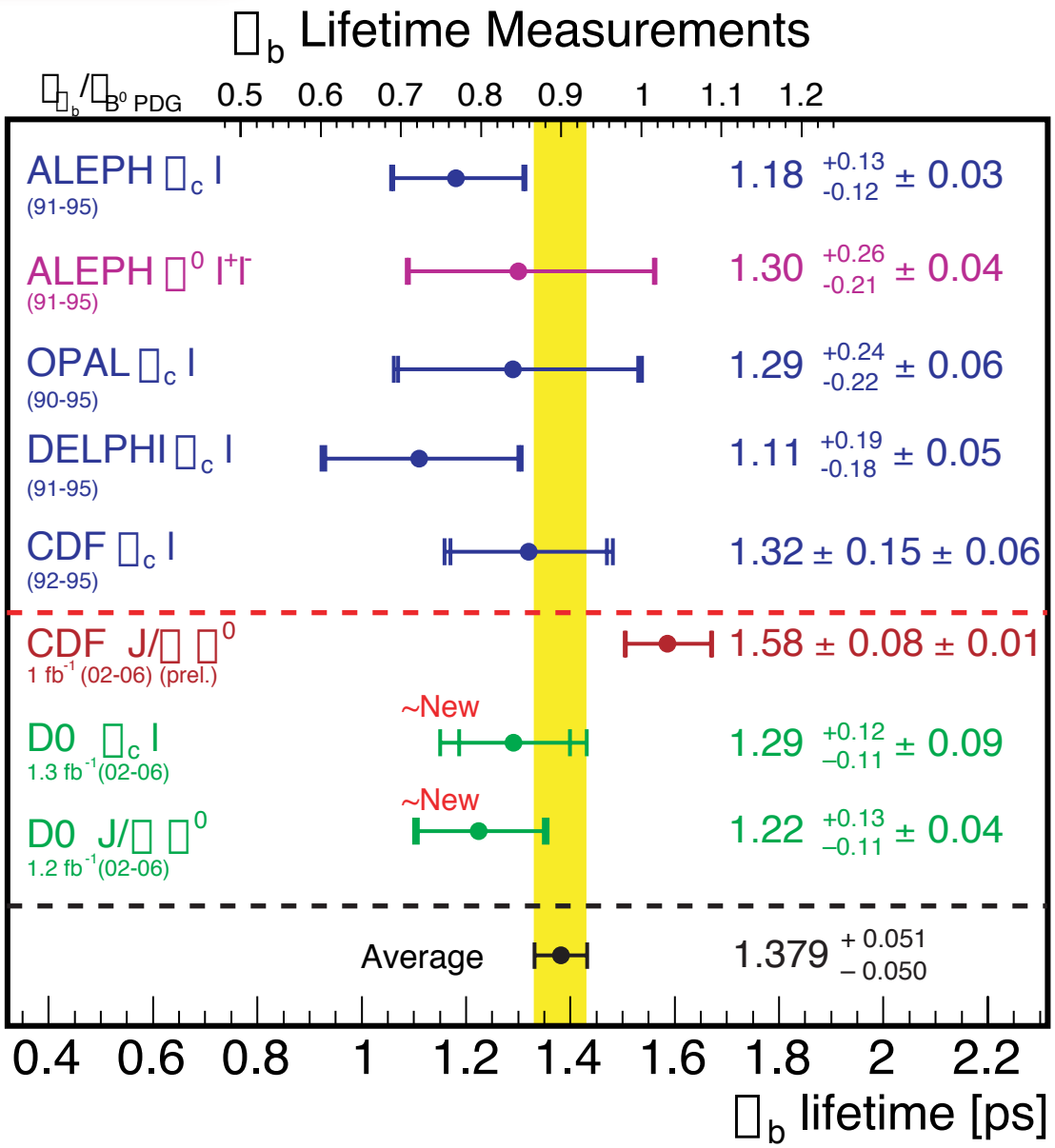




Theory: Matsuki, et al., hep-ph/0605019

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