Measurements of the B_s Mixing Phase at CDF

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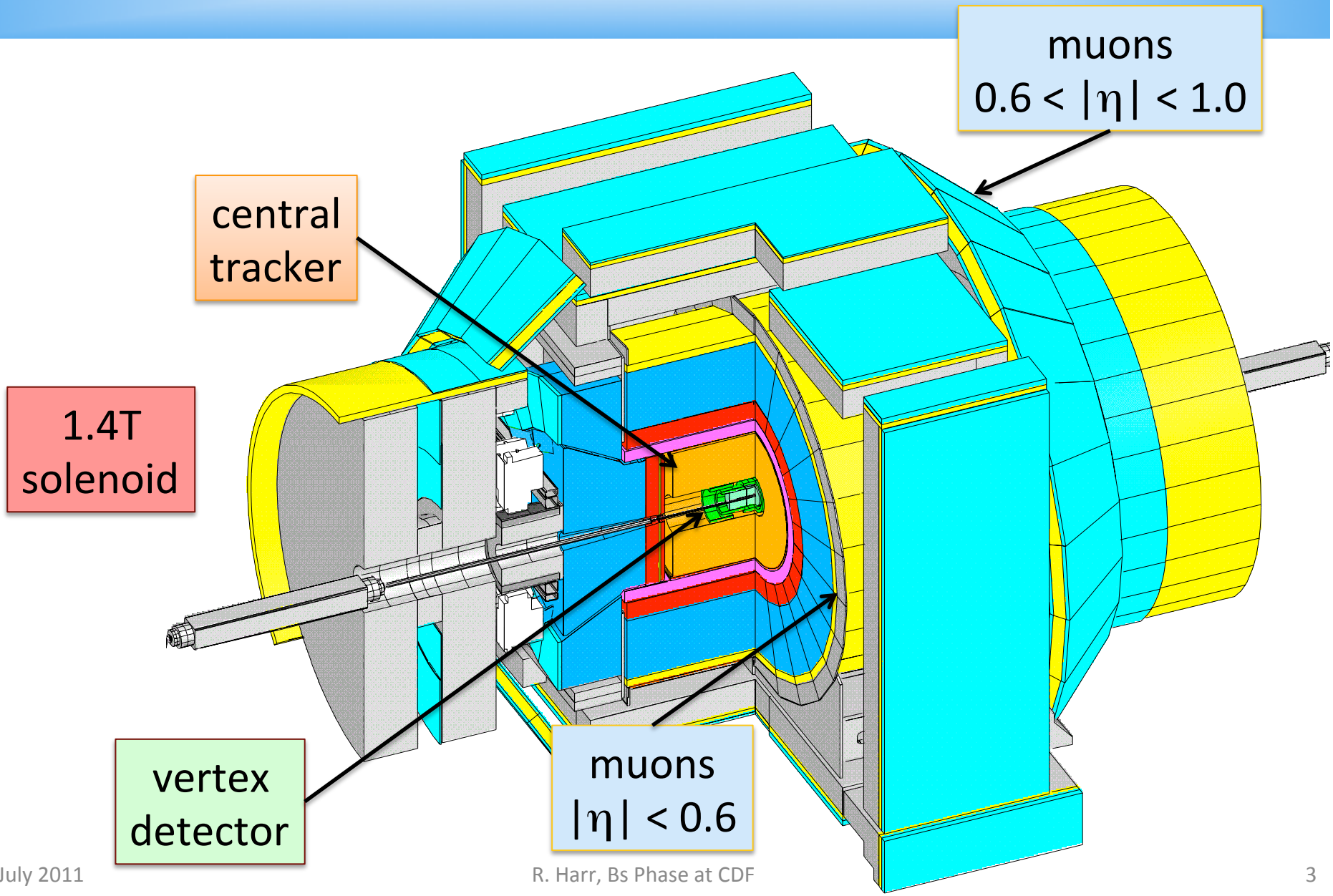
Outline

- Status of the CP violation in $B_s \rightarrow J/\psi\ \phi$ analysis
- $B_s \rightarrow J/\psi\ f_0(980)$ branching fraction and lifetime
- Measurement of χ_b
- CP violation in $B_s \rightarrow \phi\ \phi$
- Summary

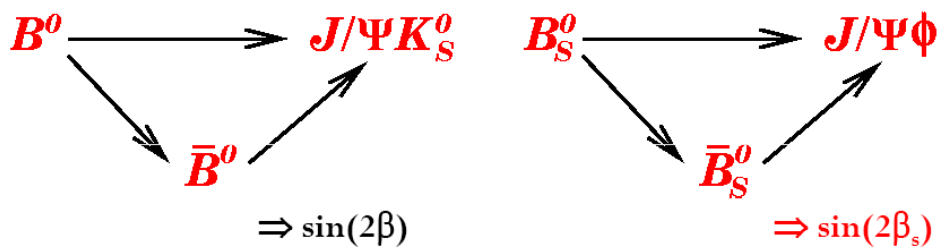
The CDF Detector



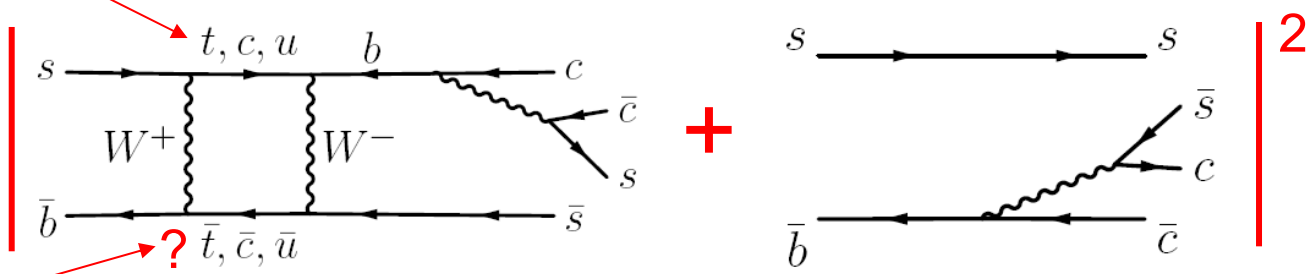
$B_S \rightarrow J/\psi\ \phi$

CP Violation in $B_s \rightarrow J/\psi\ \phi$ Decays

dominant contribution from top quark



Decay rate ~



New Physics particles ?

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

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

SM predicts tiny CP violation in B_s mixing.

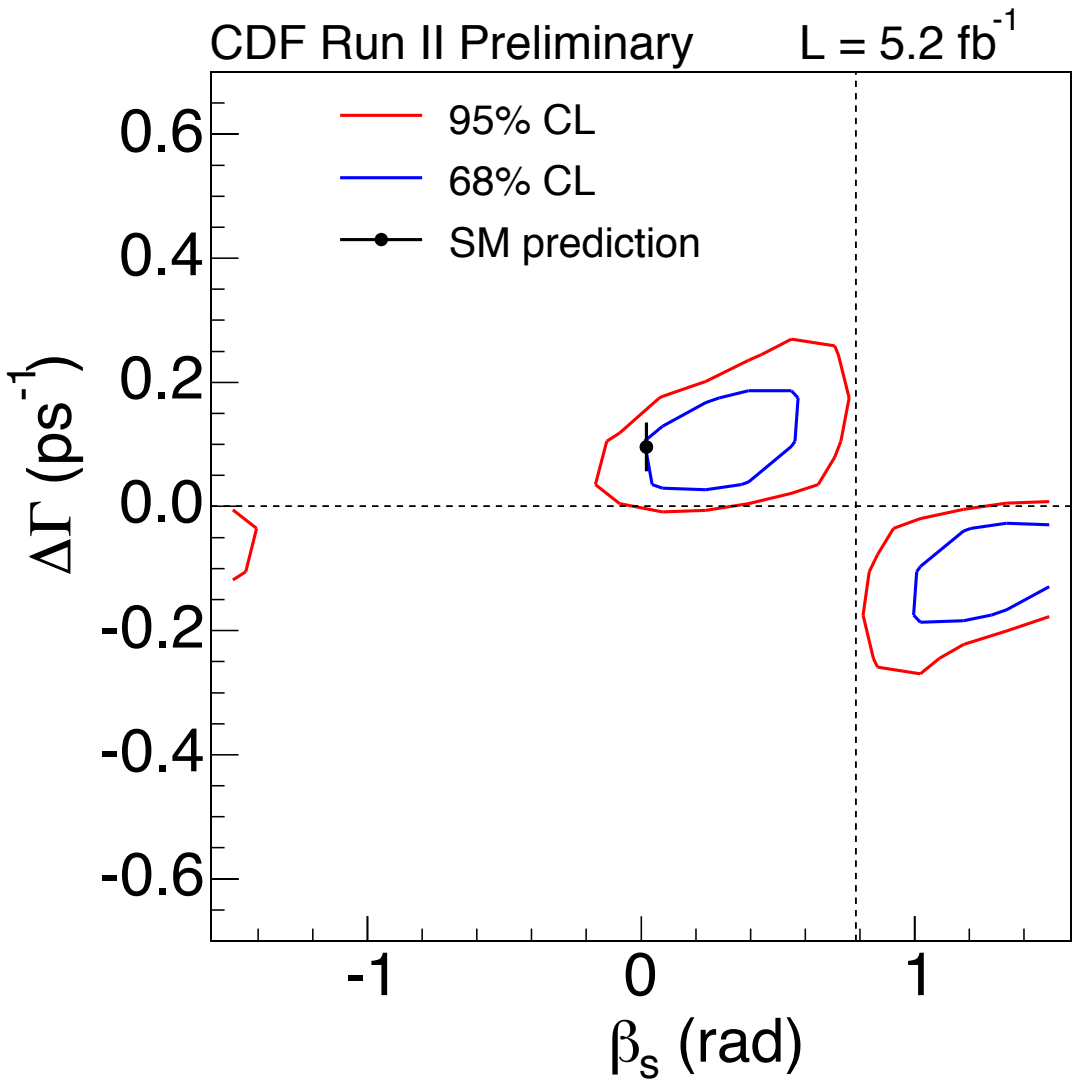
New physics can have a detectable effect.

Current Status

CDF and D0 originally had ~2σ inconsistencies with SM prediction, were more consistent with each other..

CDF 5.2 fb^{-1} result (summer 2010) is more consistent with SM, difference is ~1σ

An update with (7+) fb^{-1} data set is in progress.

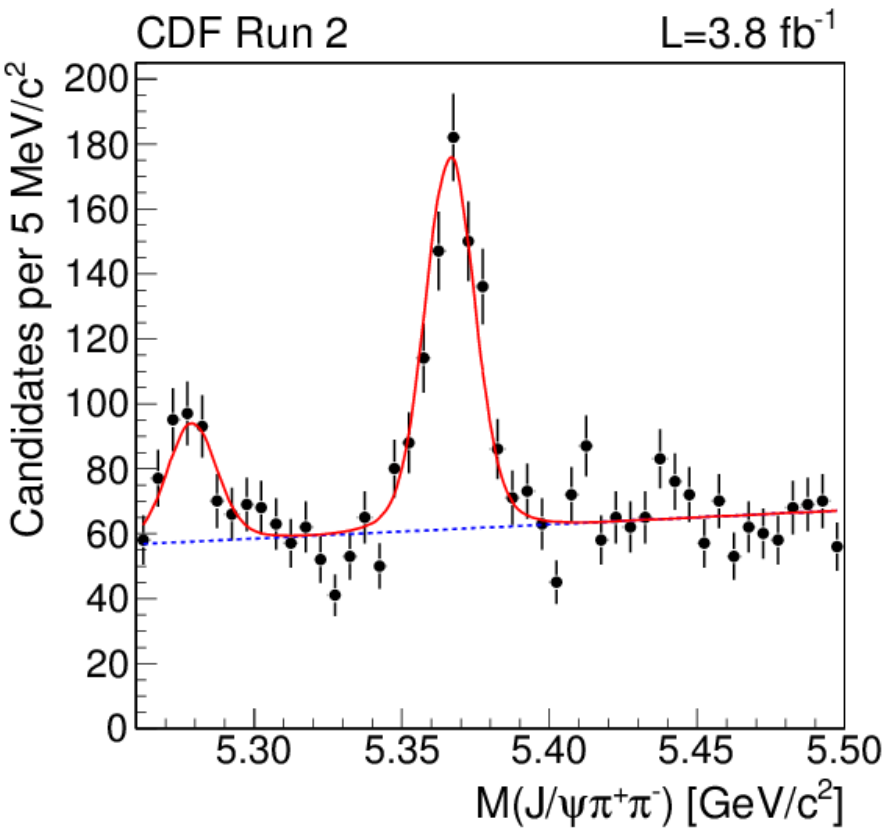


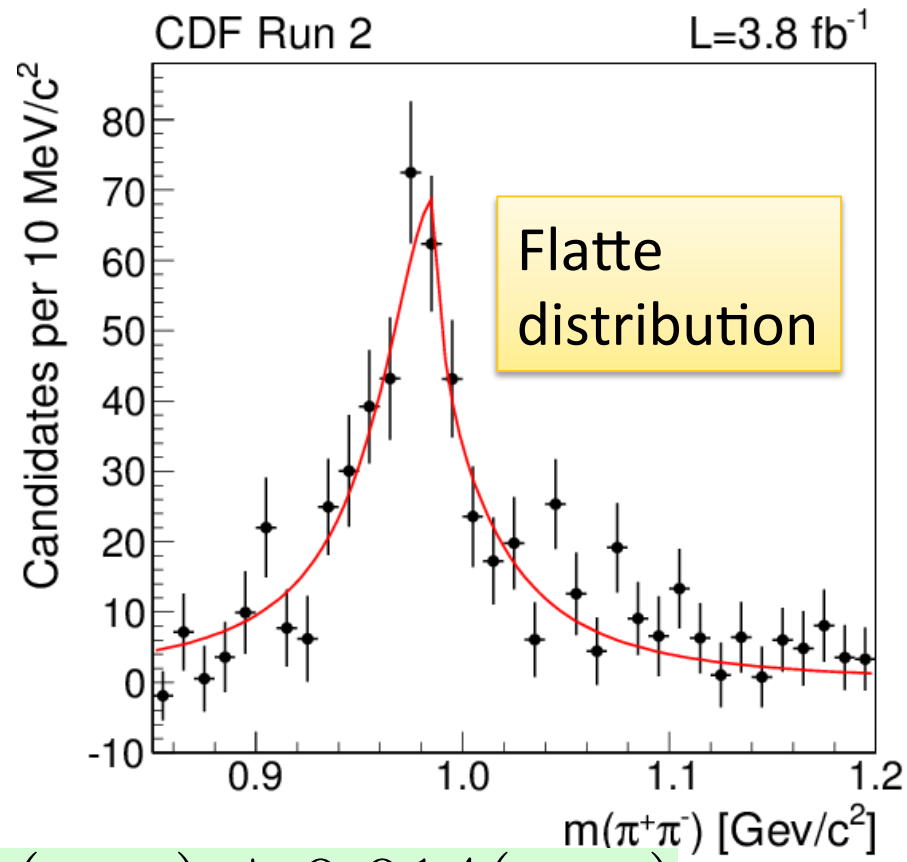
$B_S \rightarrow J/\psi\, f_0(980)$

Interest in $B_s \rightarrow J/\psi\, f_0(980)$

- This is a P → V S decay.
- The decay is S-wave
  - may effect the $B_s \rightarrow J/\psi\, \phi$ analysis when $f_0 \rightarrow K^+K^-$.
- Measure the B.F. to help constrain effects in $J/\psi\, \phi$.
- Additionally, this final state is CP odd, and neglecting direct CP violation, comes only from B_H eigenstate.
  - Lifetime gives $\tau_{H.}$
  - Can be used to measure CP violation without angular analysis.

CDF Observation of $B_s \rightarrow J/\psi\, f_0(980)$





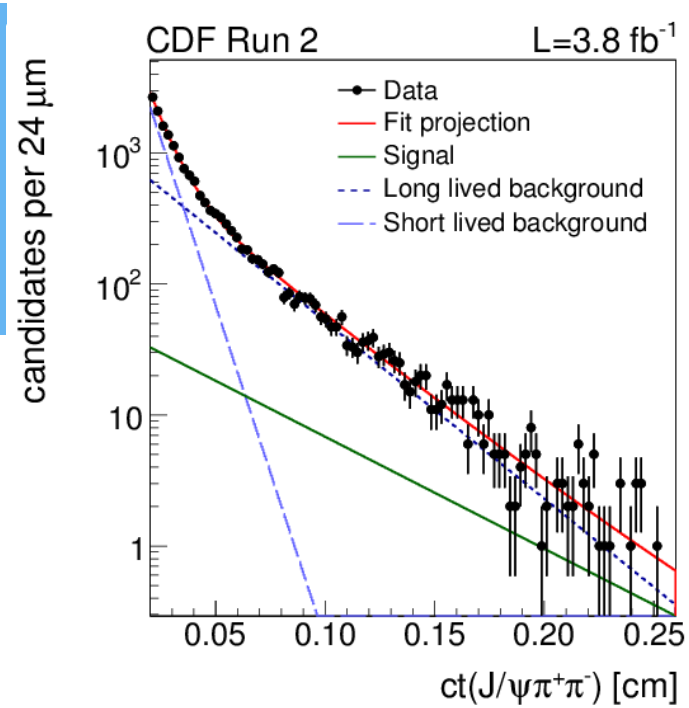
$$R_{f_0/\phi} = 0.257 \pm 0.020(\text{stat}) \pm 0.014(\text{syst})$$

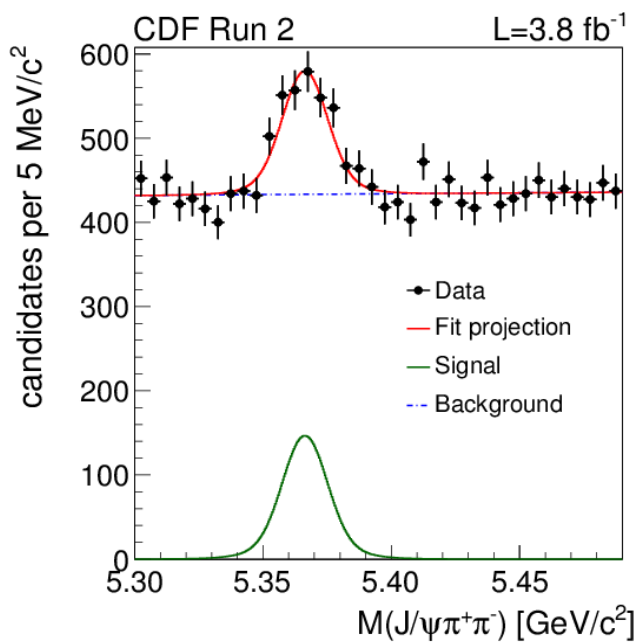
$$\mathcal{B}(B_s^0 \rightarrow J/\psi f_0(980))\mathcal{B}(f_0(980) \rightarrow \pi^+\pi^-) =$$
$$(1.63 \pm 0.12(\text{stat}) \pm 0.09(\text{syst}) \pm 0.50(\text{pdg})) \times 10^{-4}$$

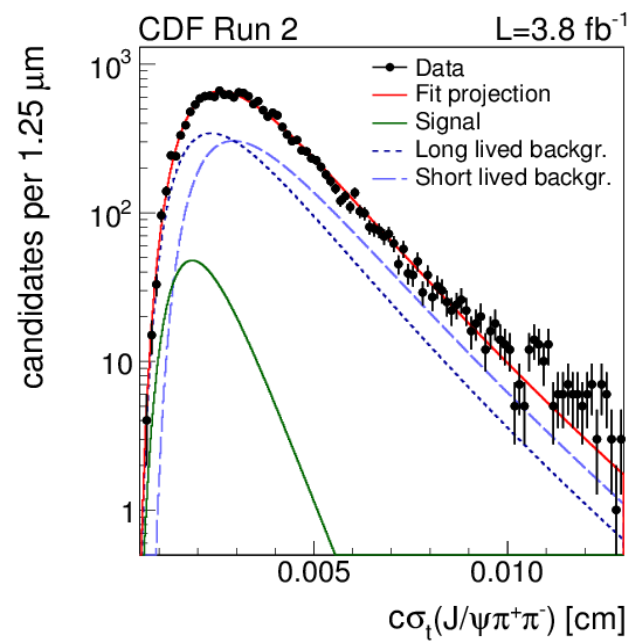
Lifetime in $B_s \rightarrow J/\psi\, f_0(980)$

In the absence of CP violation, measures the lifetime of B_H state.

Simultaneous fit to mass, decay time, and decay time error.



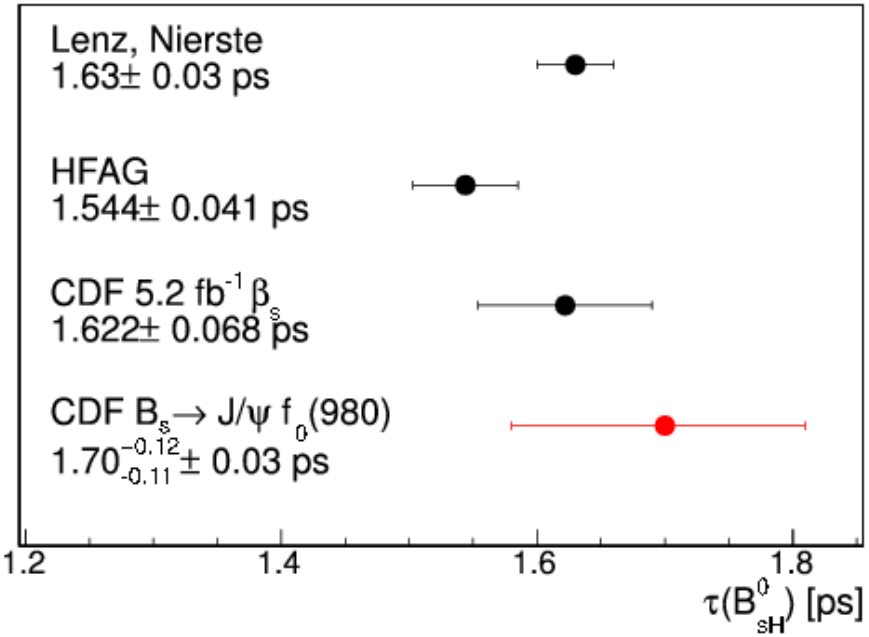




First Lifetime Measurement

$$\tau(B_s^0 \to J/\psi f_0(980)) = 1.70^{+0.12}_{-0.11}(\text{stat}) \pm 0.03(\text{syst})\ \text{ps}$$

- Interpret as first direct measurement of τ_H
- Compares well to indirect measurements of τ_H, and theoretical predictions.



MEASUREMENT OF $\overline{\chi}_B$

$\overline{\chi}$

- $\overline{\chi}$ is the average mixing probability

$$\overline{\chi}_b = \frac{\Gamma(B^0 \to \bar{B}^0 \to \ell^+ X)}{\Gamma(B \to \ell^\pm X)} = f_d \chi_d + f_s \chi_s$$

- And is related to R:

$$R = \frac{N^{++} + N^{--}}{N^{OS}}$$

- Difference in average $\overline{\chi}$ from LEP (0.1259±0.0042) and Tevatron (0.147±0.011)

CDF Run I: PRD 69, 012002 (2004)

Relation of R to $\overline{\chi}$

- R has contributions from mixing, and other decay processes such as
  - b → c → μ decays
  - b → ψX, b → χ_cX, and other b → $c\overline{c}$ q decays
- We account for these effects with a parameter *f*, determined from simulation to be *f*=0.176±0.011
- We obtain the relation:

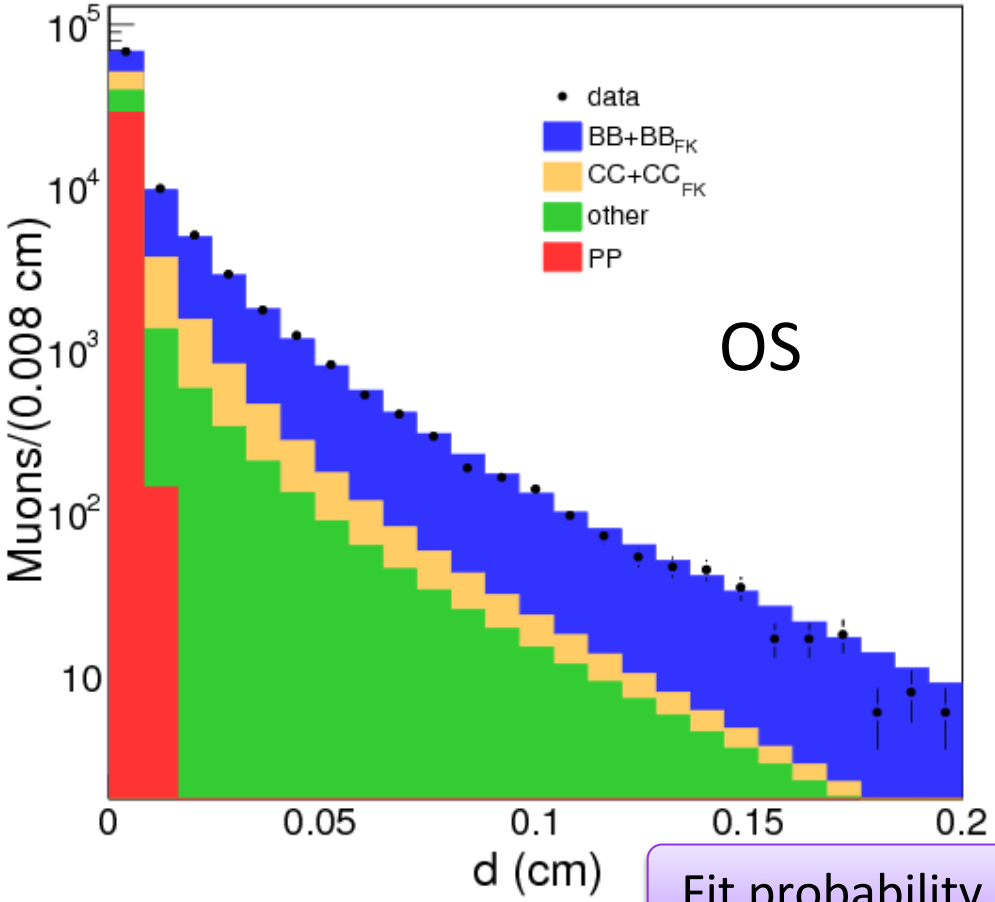
$$R = \frac{f\left[\overline{\chi}^2 + (1-\overline{\chi})^2\right] + 2\overline{\chi}(1-\overline{\chi})(1-f)}{(1-f)\left[\overline{\chi}^2 + (1-\overline{\chi})^2\right] + 2\overline{\chi}(1-\overline{\chi})f}$$

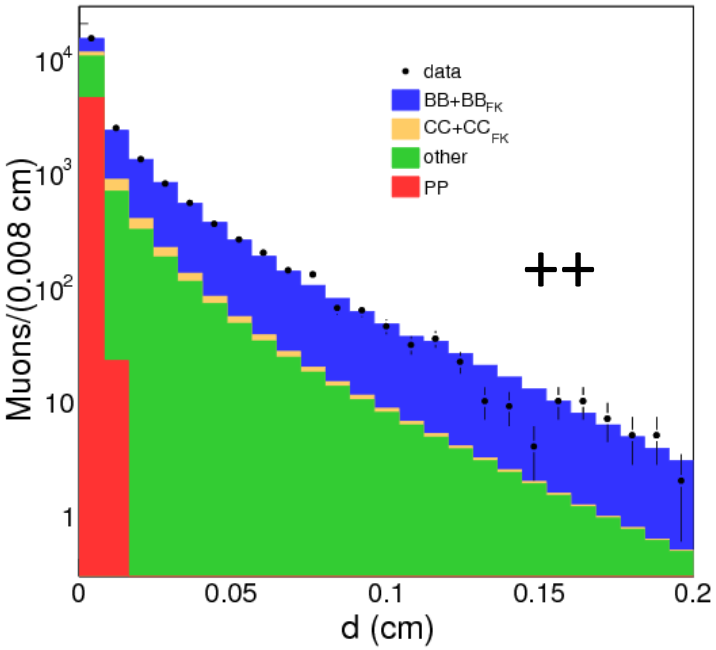
$\bar{\chi}$ Measurement

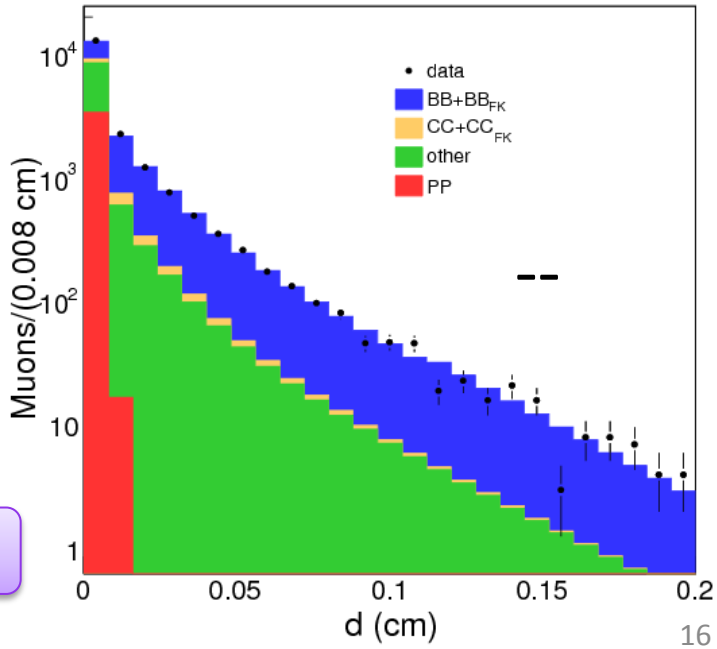
- Use dimuon triggered data from 1.44/fb of int. lumi.
- Same selection requirements as described for A_{SL} measurement.
- Require that both muons have a hit in one of the two innermost silicon layers
  - Removes a large fraction of poorly understood events
  - Reduces overall statistics.
- Fit the OS, ++, and – impact parameter distributions simultaneously
- Determine R from $b\bar{b}$ component of the fit.

Fit Results

1D projections of 2D fits







Fit probability 78.5%

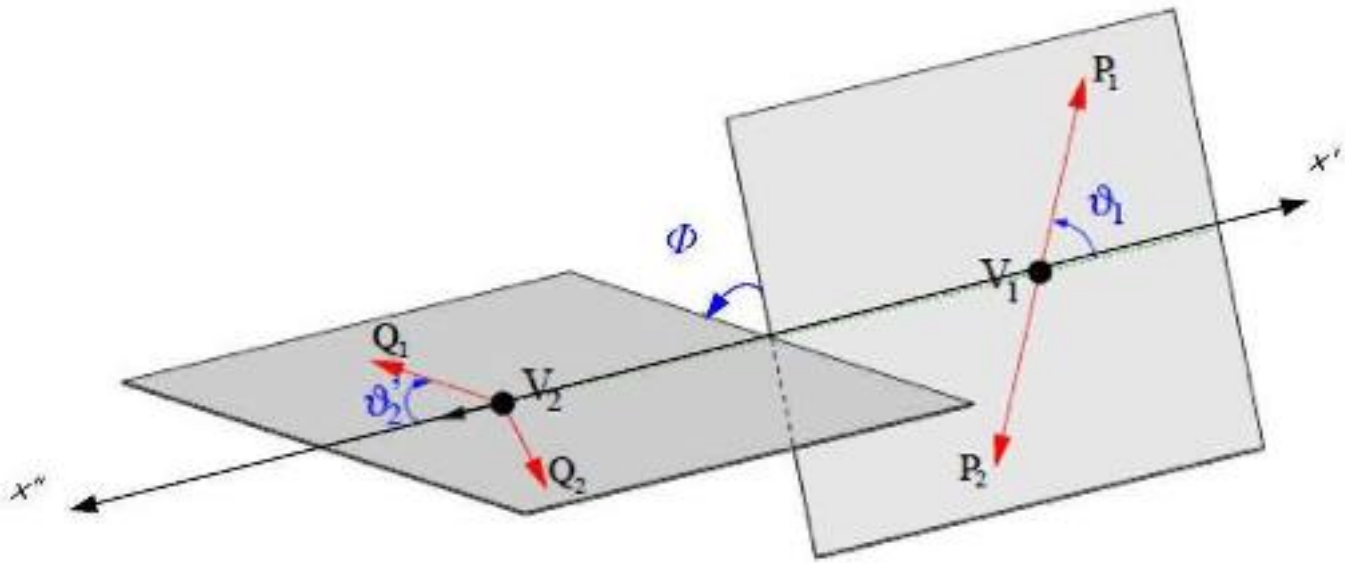
$\overline{\chi}$ Result

- R=0.467±0.008 (stat only)
- Varying the templates within their uncertainties yields a systematic error of 0.007
- R = 0.467±0.011 (stat and syst)
- Yields $\overline{\chi}$ = 0.126 ± 0.008
  (0.005 is due to R and 0.006 to *f*)
- Compare to LEP average $\overline{\chi}$ = 0.1259 ± 0.0042

$B_S \rightarrow \phi\,\phi$

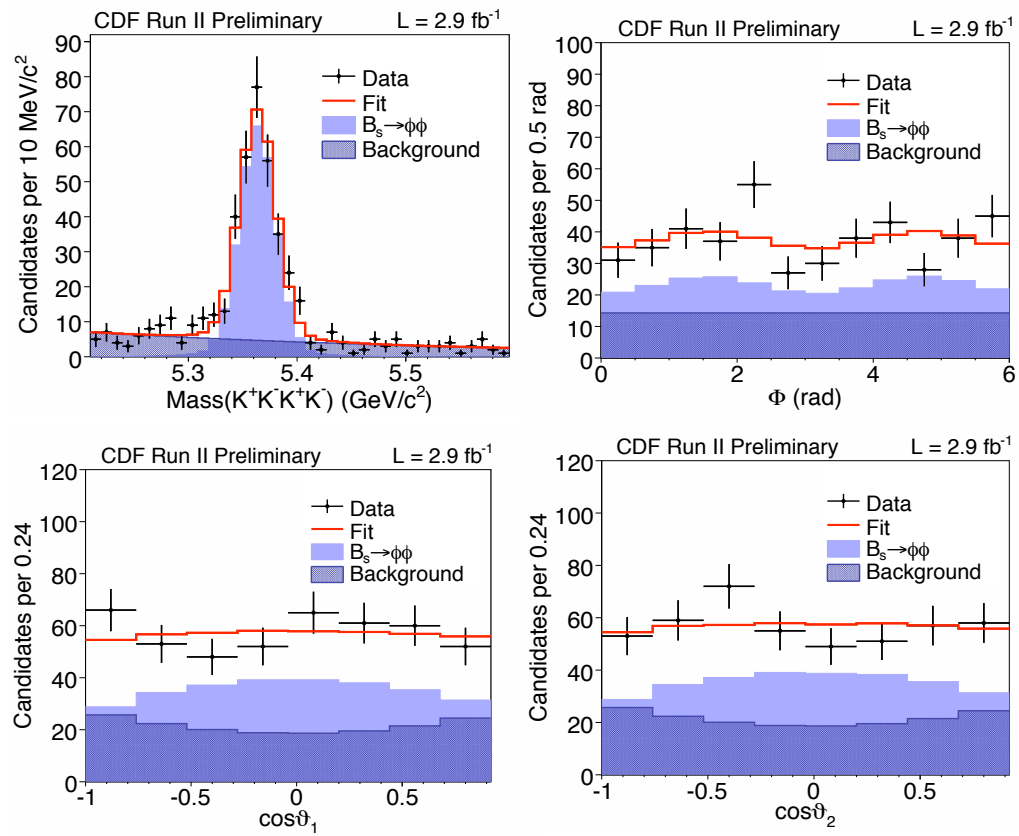
Angular Variables

- This is a P → V V decay
  - We use the helicity frame with variables ϕ, θ_1, θ_2



Fit Data from 2.9 fb^{-1} of Lumi.

- Combined fit to mass and angular variable dists.



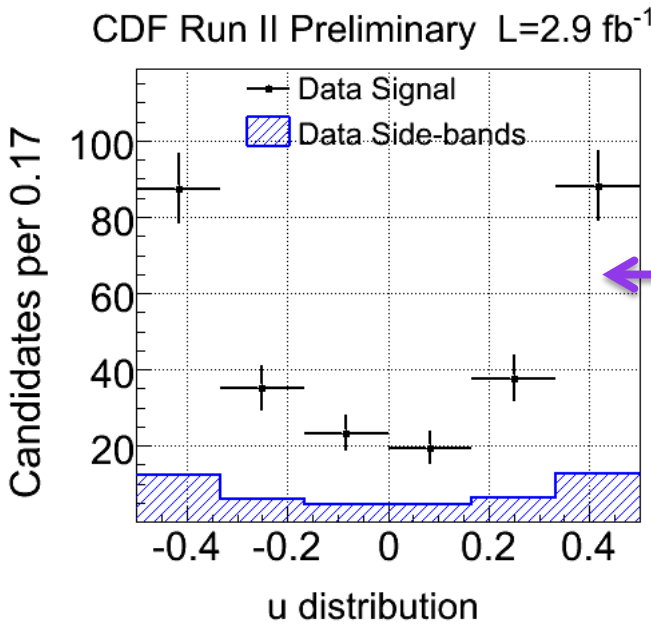
arXiv: 1107.4999

$|A_0|^2$ = 0.348±0.041 (stat) ± 0.021 (syst)
$|A_{||}|^2$ = 0.287±0.043 (stat) ± 0.011 (syst)
$|A_{perp}|^2$ = 0.365±0.044 (stat) ± 0.027 (syst)
$\cos\delta_{||}$ = $-0.91^{+0.15}_{-0.13}$ (stat) ± 0.009 (syst)

f_L = 0.348±0.041 (stat) ± 0.021 (syst)
f_T = 0.652±0.041 (stat) ± 0.021 (syst)

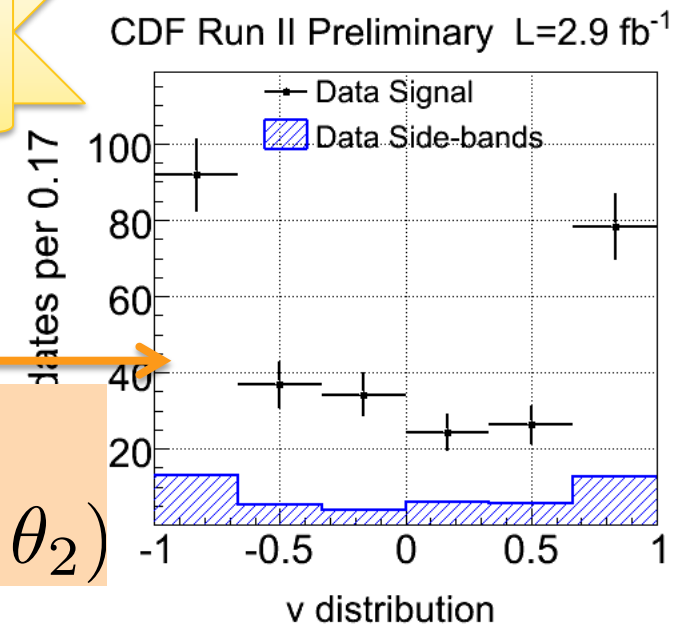
Triple Product Asymmetries

New
arXiv: 1107.4999



$$u = \sin\phi\cos\phi$$

$$v = \sin\phi \times \mathrm{sign}\left(\cos\theta_1 \cos\theta_2\right)$$



- TP asym. is T odd → violates CP under CPT cons.
- NP enters in interfer. betwn CP even and odd amplitudes
- Result is consistent with zero (SM expectation)

First measurement

A_u = -0.007 ± 0.064 (stat) ± 0.018 (syst)
A_v = -0.120 ± 0.064 (stat) ± 0.016 (syst)

Datta and London, Int. J. Mod. Phys. A 19, 2505 (2004)

Summary

- The new $\overline{\chi}$ result is in agreement with the LEP measurements, possibly settling a long standing difference.
- First measurement of triple products in $B_s \rightarrow \phi\phi$ decays, consistent with SM expectation of zero.
- First measurement of lifetime in B_s decay to CP odd eigenstate $B_s \rightarrow J/\psi\, f_0$
- Update in progress for $B_s \rightarrow J/\psi\, \phi$ analysis

BACKUP

The Fit Function (for completeness)

$$L = \prod_i \prod_j \left[\ell_{ij}^{n(i,j)} \frac{e^{-\ell_{ij}}}{n(i,j)!} \right]$$

$$\begin{aligned}
\ell_{ij} = & BB^{XS} \cdot S_b^{XS}(i) \cdot S_b^{XS}(j) + BB_{FK}^{XS} \cdot S_b(i) \cdot S_b(j) \\
& + \left(CC + CC_{FK}^{XS}\right) \cdot S_c(i) \cdot S_c(j) + PP^{XS} \cdot S_p(i) \cdot S_p(j) \\
& + \frac{1}{2} \left[BP^{XS} \cdot (S_b(i) \cdot S_p(j) + S_p(i) \cdot S_b(j)) \right. \\
& + CP^{XS} \cdot (S_c(i) \cdot S_p(j) + S_p(i) \cdot S_c(j)) \\
& \left. + BC^{XS} \cdot (S_b(i) \cdot S_c(j) + S_c(i) \cdot S_b(j)) \right]
\end{aligned}$$

$$\frac{1}{2} \left[\frac{(CP - BP)^2}{CP + BP + (0.14 \cdot BP)^2} + \frac{(BC - 0.046 \cdot BB)^2}{BC + (0.046)^2 \cdot BB + (0.013 \cdot BB)^2} \right]$$

$$\begin{aligned}
CP^{LS} &= (1.05 \pm 0.05) \cdot CP^{OS} & CP^{++} &= (1.2 \pm 0.1) \cdot CP^{--} \\
BP^{LS} &= (0.87 \pm 0.07) \cdot BP^{OS} & BP^{++} &= (1.15 \pm 0.05) \cdot BP^{--} \\
BC^{LS} &= BC^{OS} & BC^{++} &= BC^{--}
\end{aligned}$$

Fit Results

$|A_0|^2 = 0.348 \pm 0.041\ (\text{stat}) \pm 0.021\ (\text{syst})$
$|A_{||}|^2 = 0.287 \pm 0.043\ (\text{stat}) \pm 0.011\ (\text{syst})$
$|A_{perp}|^2 = 0.365 \pm 0.044\ (\text{stat}) \pm 0.027\ (\text{syst})$
$\cos\delta_{||} = -0.91^{+0.15}_{-0.13}\ (\text{stat}) \pm 0.009\ (\text{syst})$

$f_L = 0.348 \pm 0.041\ (\text{stat}) \pm 0.021\ (\text{syst})$
$f_T = 0.652 \pm 0.041\ (\text{stat}) \pm 0.021\ (\text{syst})$

CDF Public Note 10064