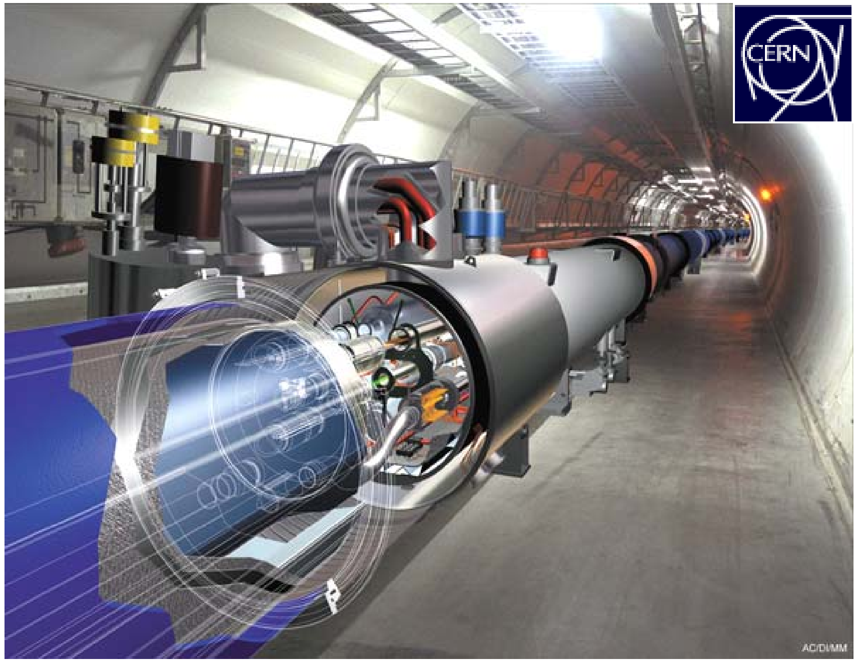
A_{SL} $\Delta\Gamma_s$ ϕ_s

Sergey Burdin (University of Liverpool)
on behalf of the DØ Collaboration



- Definitions
- DØ detector
- DØ measurements of A_{SL}, $\Delta\Gamma_s$, ϕ_s
- Combination of the results
- Conclusion

B Mixing Theory

- **Decay of two-body system** $i\frac{d}{dt}\begin{pmatrix}|B(t)\rangle \\ |\bar{B}(t)\rangle\end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2}\end{pmatrix}\begin{pmatrix}|B(t)\rangle \\ |\bar{B}(t)\rangle\end{pmatrix}$
- **B mixing depends on $|M_{12}|$, $|\Gamma_{12}|$ and phase $\phi \approx \arg(-M_{12}/\Gamma_{12})$**
  - $\phi_s = O(|V_{us}|^2(m_c/m_b)^2) \sim 4 \cdot 10^{-3} = 0.2^o$ (SM)
- **Two mass eigenstates**
  - Light $|B_L\rangle = p|B^0\rangle + q|\bar{B}^0\rangle$
  - Heavy $|B_H\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$
  - Masses $M_{L,H}$ and widths $\Gamma_{L,H}$ — B_s
    - ✓ $\Delta m = M_H - M_L \approx 2|M_{12}|$ (SM: $\sim 20 ps^{-1}$)
    - ✓ $\Delta\Gamma = \Gamma_L - \Gamma_H \approx - \Delta m\, Re(\Gamma_{12}/M_{12}) = 2|\Gamma_{12}| \cos\phi$ (SM: $\sim 0.1 ps^{-1}$)
    - ✓ $\Delta\Gamma/\Delta m \approx |\Gamma_{12}/M_{12}| = O((m_b/M_W)^2)$ (SM: $\sim 5 \cdot 10^{-3}$)
  - $a_{fs} = A_{SL} = Im(\Gamma_{12}/M_{12}) = |\Gamma_{12}/M_{12}| \sin\phi \approx \Delta\Gamma/\Delta m \tan\phi$ (SM: $\sim 2 \cdot 10^{-5}$)
    - ✓ CP asymmetry in flavor-specific B decays
    - ✓ measures CP violation in mixing

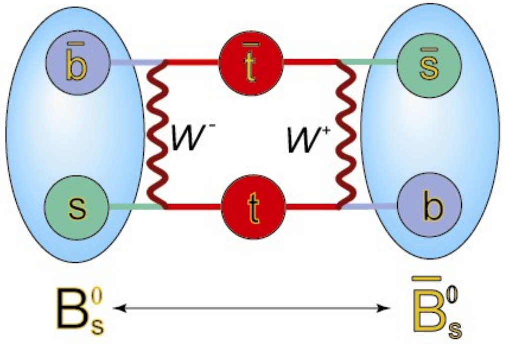
Search for New Physics in Boxes

- **Small effect on Γ_{12}**
  - Γ_{12} stems from tree-level decays

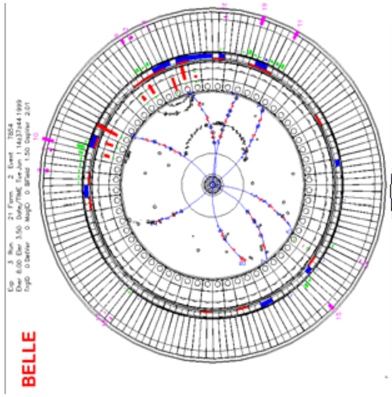
- **M_{12} is very sensitive to virtual effects of new heavy particles**
  → $\Delta m \approx 2|M_{12}|$ can change
  - $\Delta m_s = 17.77 \pm 0.10(\text{stat.}) \pm 0.07(\text{syst.})\, ps^{-1}$ (CDF) agrees with SM → no strong effects

- **as well as $\phi \approx \arg(-M_{12}/\Gamma_{12})$**
  - $|\Delta\Gamma| = \Delta\Gamma_{SM}\,|\cos\phi|$ is depleted
  - $|a_{fs}|$ is enhanced
    - ✓ up to $5 \cdot 10^{-3}$ (Nierste)

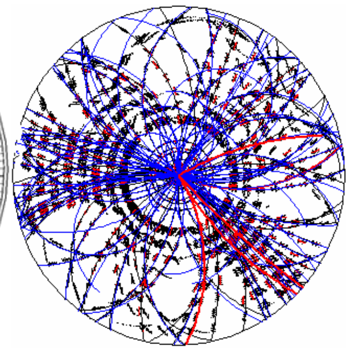
- **Currently Tevatron is the best place for measurements of the B_s properties**
  - Large B cross-section
  - Production of all B species
  - Large boost of B mesons
  - But large background

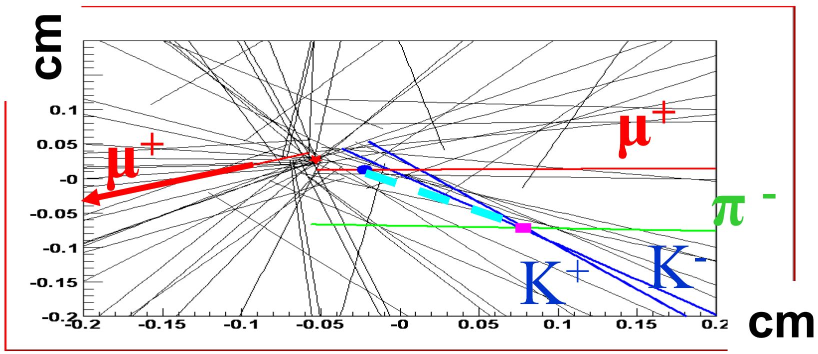


BELLE



CDF

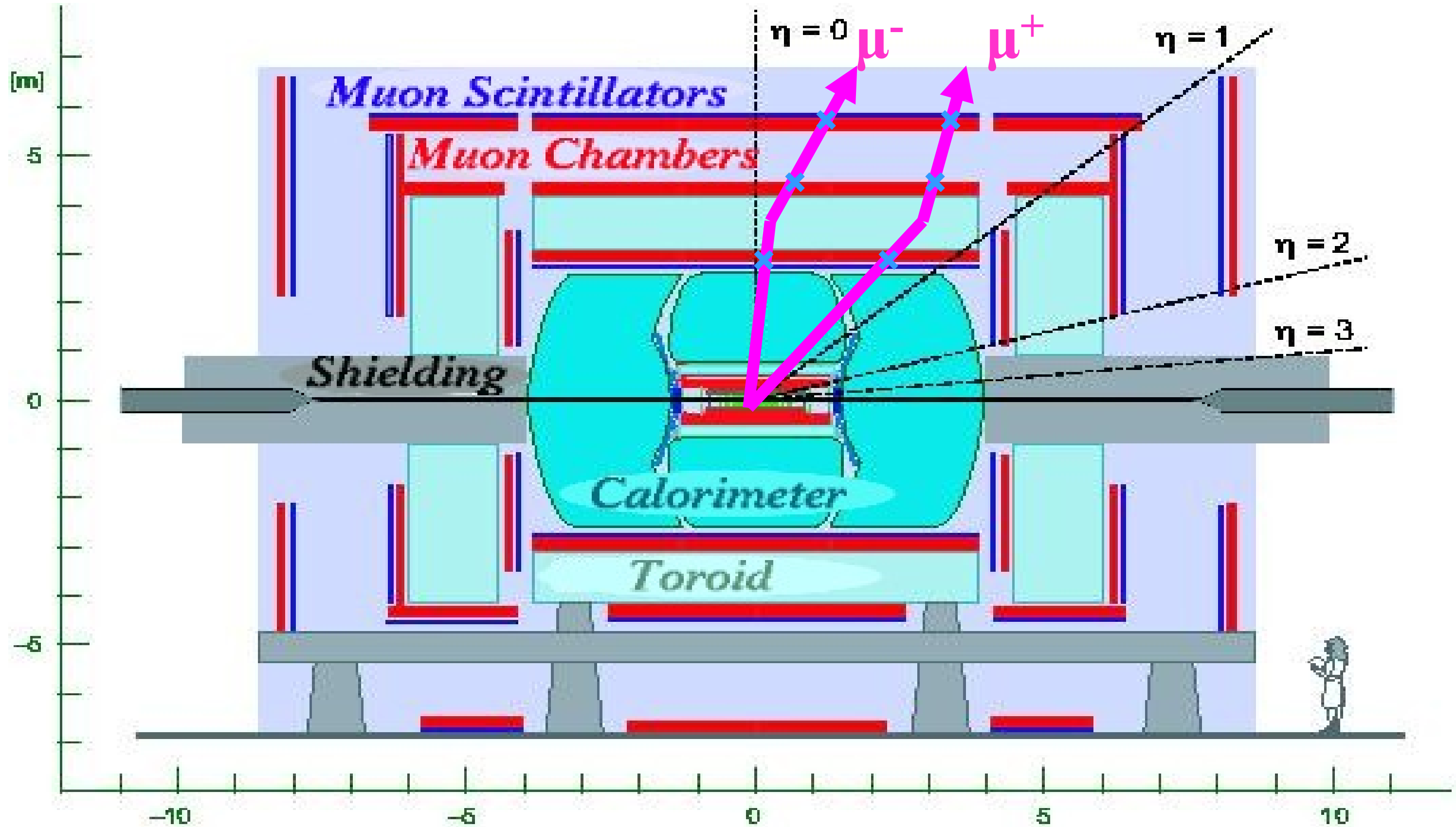




DØ

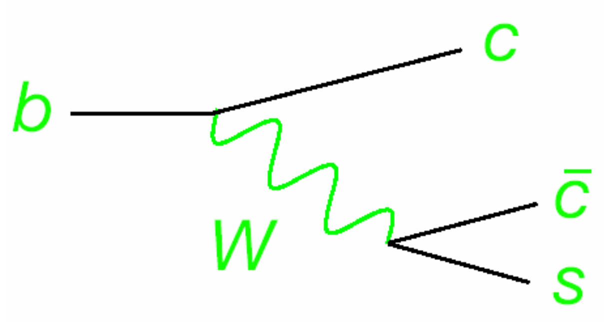
DZero Detector

- Spectrometer : Fiber and Silicon Trackers in 2 T Solenoid
- Energy Flow : Fine segmentation liquid Ar Calorimeter and Preshower
- Muons : 3 layer system & absorber in Toroidal field
  - Toroid and solenoid polarities are being reversed regularly → low systematic error in muon charge asymmetry
- Hermetic : Excellent coverage of Tracking, Calorimeter and Muon Systems

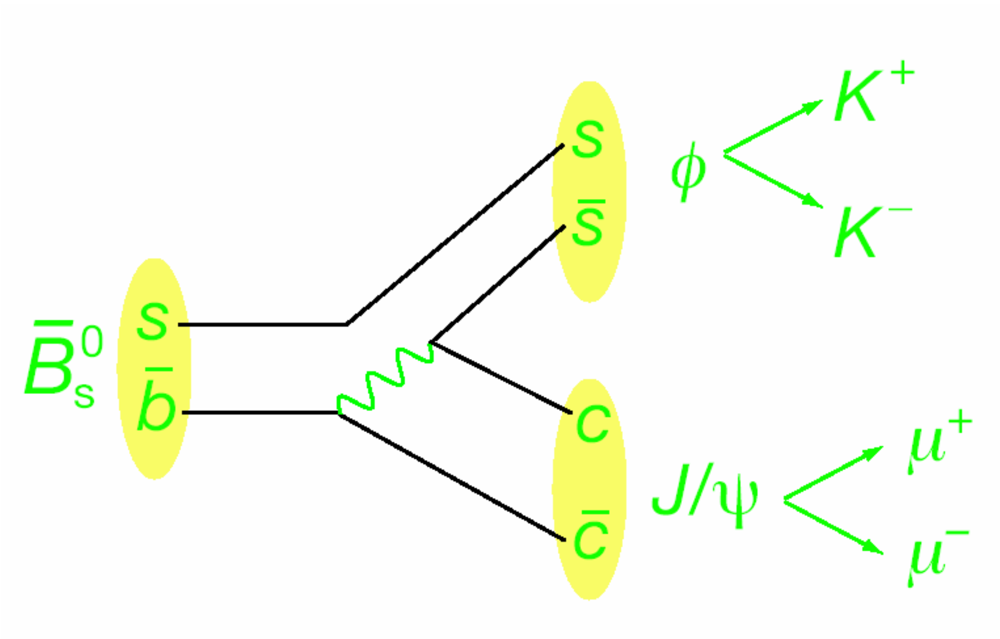


$\Delta\Gamma_s$ and ϕ_s from $B_s \rightarrow J/\psi\ \varphi$

- Γ_{12} dominated by decay $b \rightarrow c\bar{c}s$ from decays into final states common to both $B^0_s(\bar{b}s)$ and $\bar{B}^0_s(b\bar{s})$



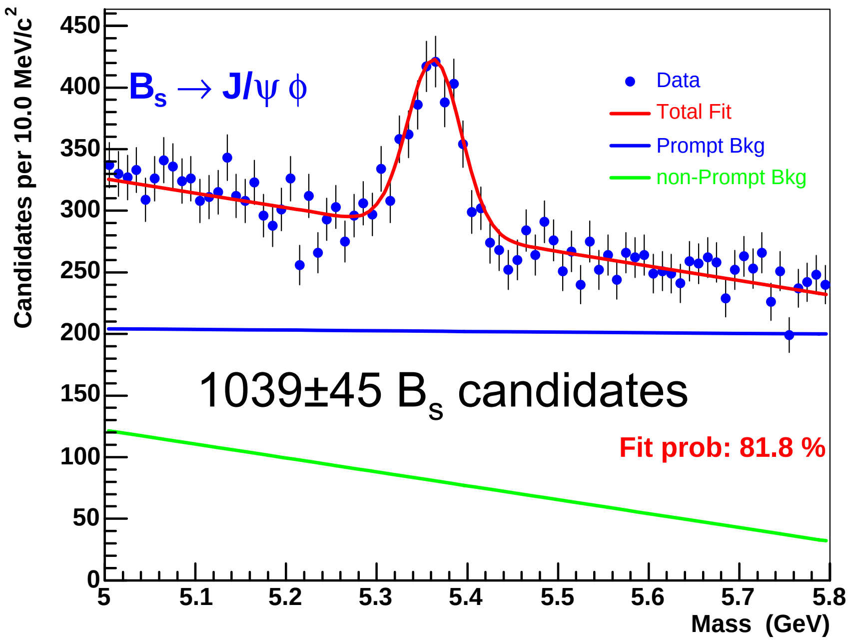
$B_s \rightarrow J/\psi\ \varphi$

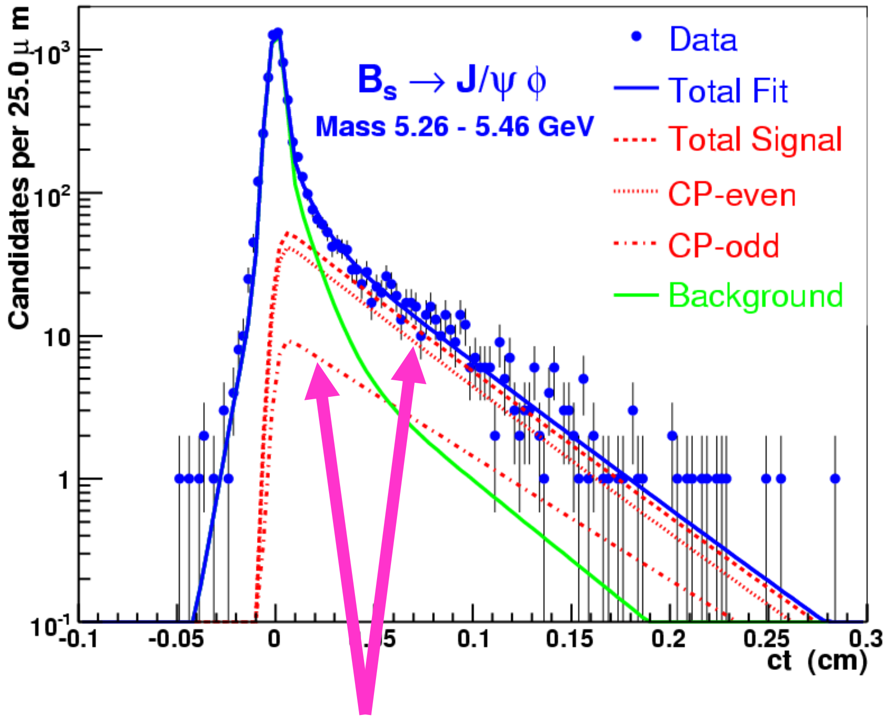


- A mix of CP-even and CP-odd states could be separated using angular distributions of J/ψ and φ decay products
- Simultaneous fit to lifetimes

$\Delta\Gamma_s$ and ϕ_s from $B_s \rightarrow J/\psi\ \varphi$

- **1 fb^{-1} data sample**





Different lifetimes of the two mass eigenstates

$$\bar{\tau}_{Bs} = 1.52 \pm 0.08^{+0.01}_{-0.04}\ \text{ps}$$

$$\Delta\Gamma_s\Big|_{\phi_s \equiv 0} = 0.12^{+0.08}_{-0.10}\ {}^{+0.03}_{-0.04}\ \text{ps}^{-1}$$

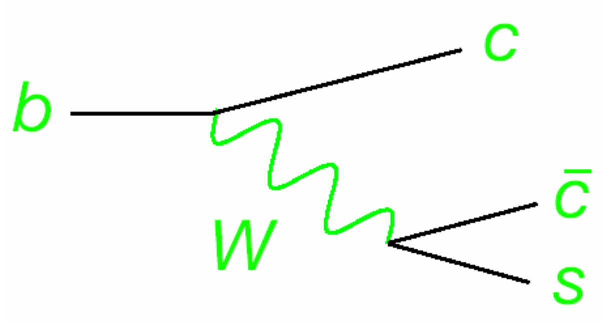
$$\Delta\Gamma_s\Big|_{free\ \phi_s} = 0.17^{+0.09}_{-0.09}\ \text{ps}^{-1}$$

$$\phi_s\Big|_{fixed\ \tau_{Bs}} = -0.92 \pm 0.47$$

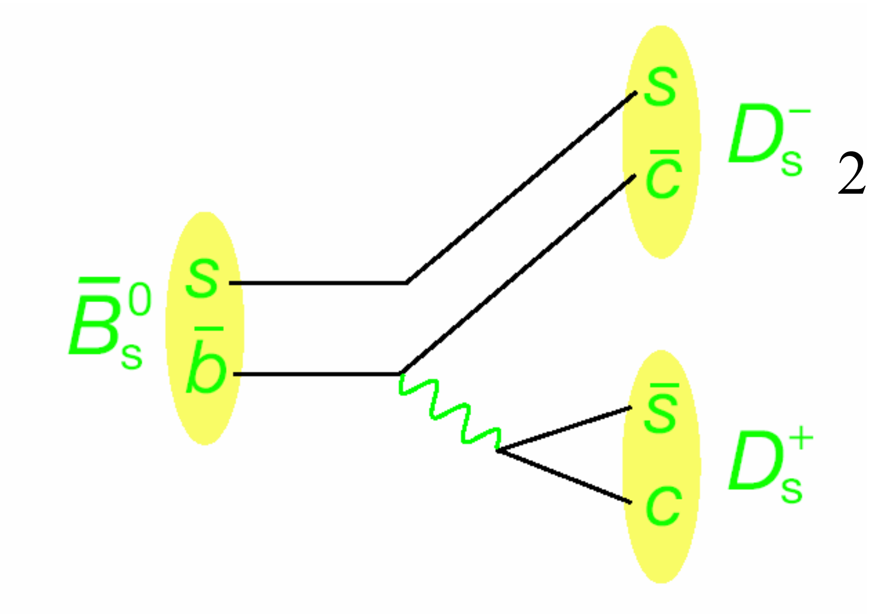
$$\phi_s = -0.79 \pm 0.56$$

$\Delta\Gamma_s$ from $B_s \rightarrow D^{(*)+}_s D^{(*)-}_s$

- Γ_{12} dominated by decay $b \rightarrow c\bar{c}s$ from decays into final states common to both $B^0_s(\bar{b}s)$ and $\bar{B}^0_s(b\bar{s})$
- $\Delta\Gamma_{CP} = 2|\Gamma_{12}| = \Gamma(B_s^{even}) - \Gamma(B_s^{odd})$



- $B_s \rightarrow D^+_s D^-_s$ is pure CP even
- $B_s \rightarrow D^{(*)+}_s D^{(*)-}_s$ inclusive is also CP even with 5% (?) theoretical uncertainty



$$2Br\left(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}\right) \approx \frac{\Delta\Gamma_{CP}}{\Gamma}\left(1 + O\left(\frac{\Delta\Gamma}{\Gamma}\right)\right)$$

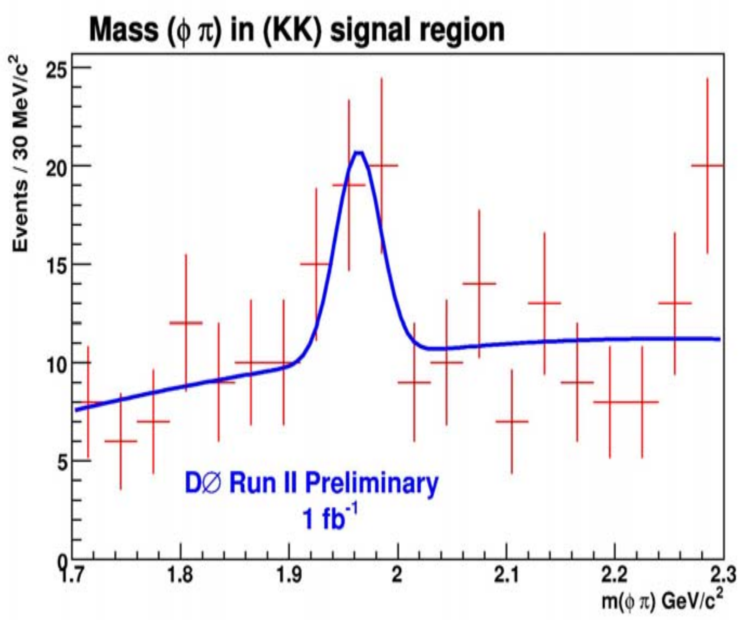
I.Dunietz, R.Fleischer, U.Nierste hep-ph/0012219

- $\phi = 0 \rightarrow \Delta\Gamma_S = \Delta\Gamma_{CP}$

$Br(B^0_s \to D^{(*)+}_s D^{(*)-}_s)$

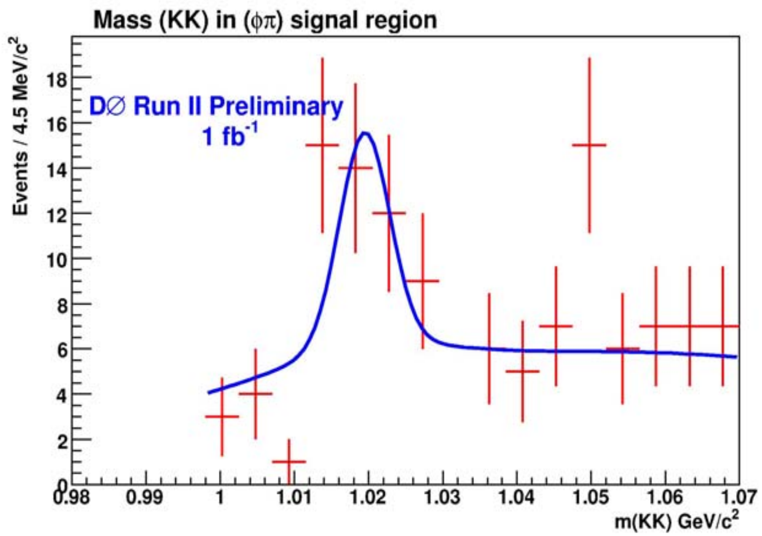
- 19.3 ± 7.8 signal candidates
- Backgrounds

$B \to D_s^{(*)+} D_s^{(*)-} K X$	0.44 ± 0.30
$B_s^0 \to D_s^{(*)+} D_s^{(*)-} X$	suppressed
$B_s^0 \to \mu \nu D_s^{(*)} \phi X$	1.27 ± 1.14
$c\bar{c} \to \mu \phi D_s^{(*)}$	lifetime cuts

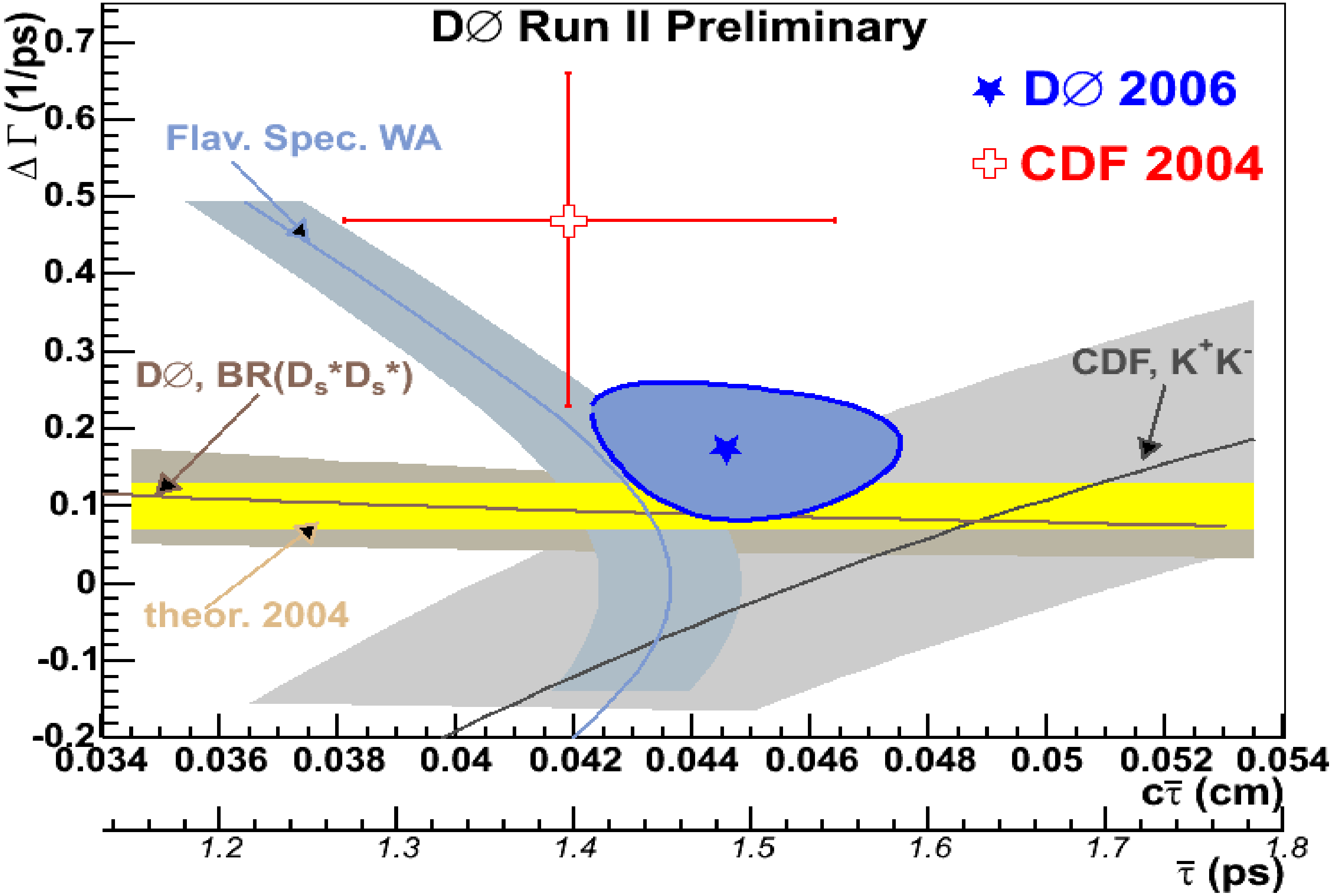


- $Br(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) =$
  $= 0.071 \pm 0.032\ (\text{stat})\ ^{+0.029}_{-0.025}\ (\text{syst})$

$$\Delta\Gamma_{CP}/\Gamma(B_s^0) = 0.142 \pm 0.064(\text{stat})^{+0.058}_{-0.050}(\text{syst})$$



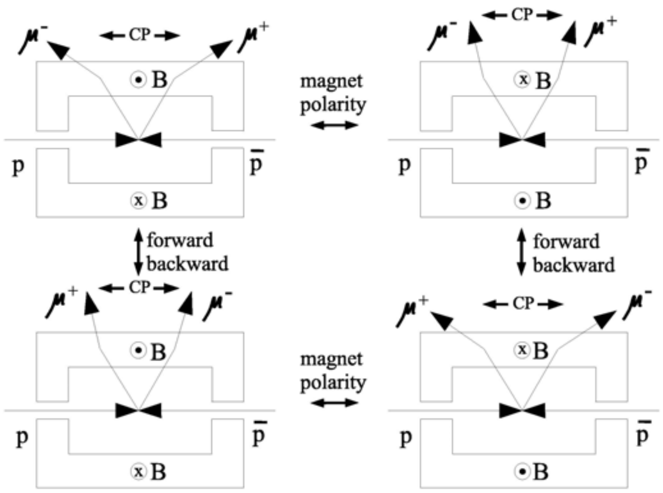
$\Delta\Gamma_s$ VS. $\bar{\tau}_s$

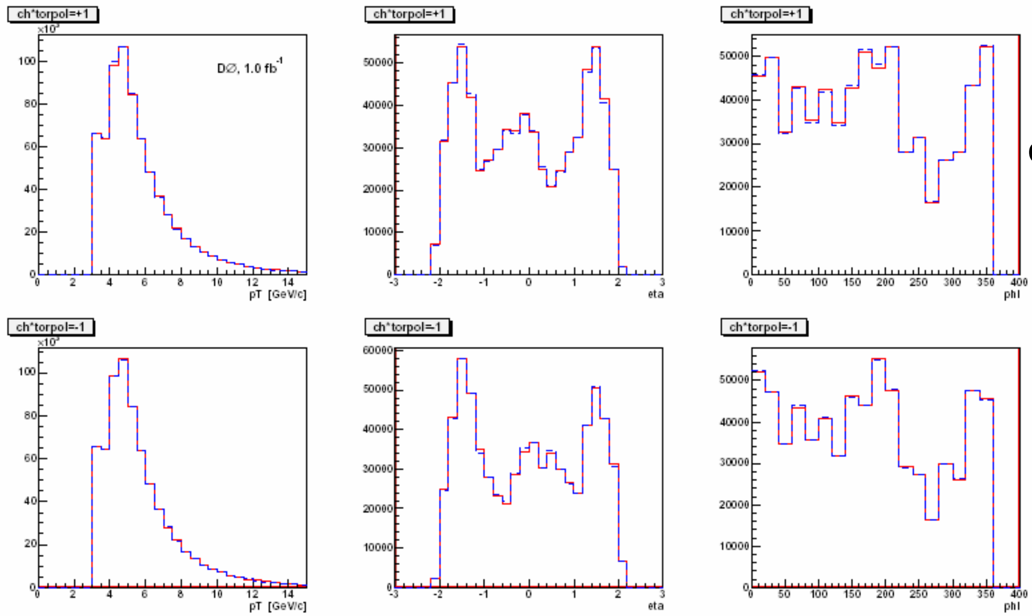


Same-Sign Dimuon Asymmetry

$$A_{SL} = \frac{N(b\bar{b} \to l^+ l^+ X) - N(b\bar{b} \to l^- l^- X)}{N(b\bar{b} \to l^+ l^+ X) + N(b\bar{b} \to l^- l^- X)} = \frac{f_d Z_d A_{SL}^d + f_s Z_s A_{SL}^s}{f_d Z_d + f_s Z_s}$$

$$Z_q = \frac{1}{1-y_q^2} - \frac{1}{1-x_q^2} \qquad x_q = \frac{\Delta m_q}{\Gamma_q} \qquad y_q = \frac{\Delta\Gamma_q}{2\Gamma_q}$$





q×pol=+1

q×pol=-1

$1 fb^{-1}$, ~3M dimuon events

Few processes contribute to same-sign samples (no charge asymmetry in first order)

Magnet polarities are reversed regularly → helps to study detector effects

Result on Same-Sign Dimuon Asymmetry (hep-ex/0609014)

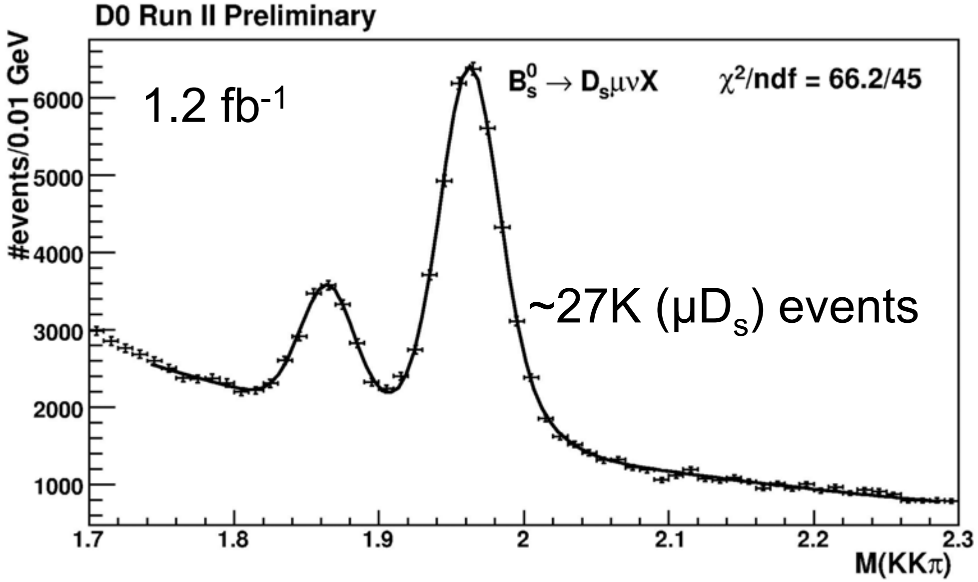
- **Dimuon charge asymmetry**
  - A=-0.0028±0.0013(stat.)±0.0009(syst.)
- **CP-violating parameter**

$$\frac{\Re\left(\varepsilon_{B^0}\right)}{1+\left|\varepsilon_{B^0}\right|^2} = \frac{A_{SL}^d}{4} = -0.0023 \pm 0.0011(\text{stat.}) \pm 0.0008(\text{syst.})$$

  - assuming $A_{SL}^s = 0$
- **Preliminary result is used in rest of the talk for combinations**
  - A_{prelim}=-0.0013±0.0012(stat.)±0.0008(syst.)
  - Using $A_{SL}^d = +0.0011 \pm 0.0055$ from CLEO and B-factories
  - → $A_{SL}^s = -0.0076 \pm 0.0102$
  - Combinations will be updated soon

Asymmetry in Semileptonic B_s Decays

- Integrated asymmetry in large sample $B_s \rightarrow X\mu^+ D_s^- (\rightarrow \varphi\pi^-)$



$$A_{SL}^{\text{int}} = \frac{N(B_s \rightarrow \mu^+ D_s) - N(B_s \rightarrow \mu^- D_s)}{N(B_s \rightarrow \mu^+ D_s) + N(B_s \rightarrow \mu^- D_s)} = \frac{1}{2}\frac{x_s^2}{1+x_s^2} A_{SL}^s \cong \frac{1}{2} A_{SL}^s$$

$$A_{SL}^s = +0.0245 \pm 0.0193 \pm 0.0035$$

Combined DØ Result on A_{SL}^{s}

- A_{SL} from same-sign dimuon sample (preliminary)

$$A_{SL}^{s} = -0.0076 \pm 0.0102$$

- A_{SL} from $B_s \rightarrow \mu D_s X$ sample

$$A_{SL}^{s} = +0.0245 \pm 0.0193 \pm 0.0035$$

- Combination of both DØ results

$$A_{SL}^{s} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan(\phi_s) = -0.0007 \pm 0.0090$$

- constrains the $\Delta\Gamma_s$ and ϕ_s measurements

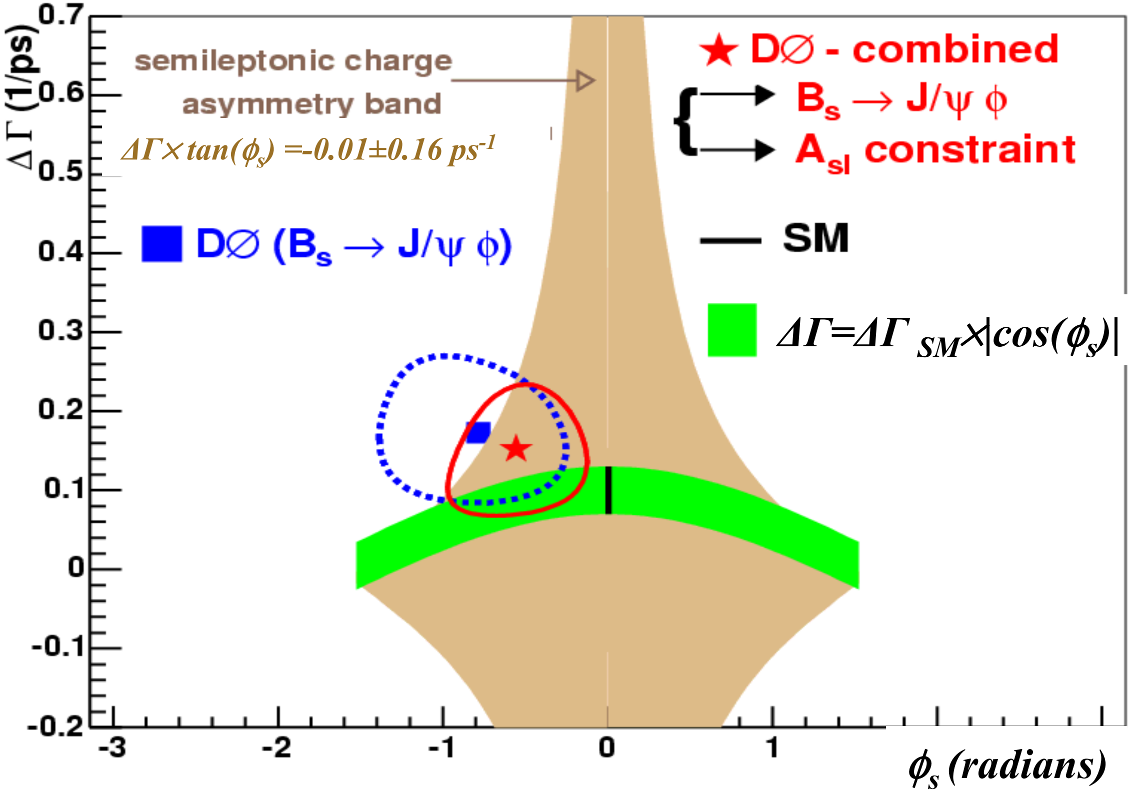
$$\Delta\Gamma_s \tan(\phi_s) = A_{SL}^{s} \Delta m_s = -0.01 \pm 0.16 \text{ ps}^{-1}$$

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

Combined DØ Result on $\Delta\Gamma_s$ & ϕ_s

$$\Delta\Gamma_s = 0.17^{+0.10}_{-0.09}\ \text{ps}^{-1}$$

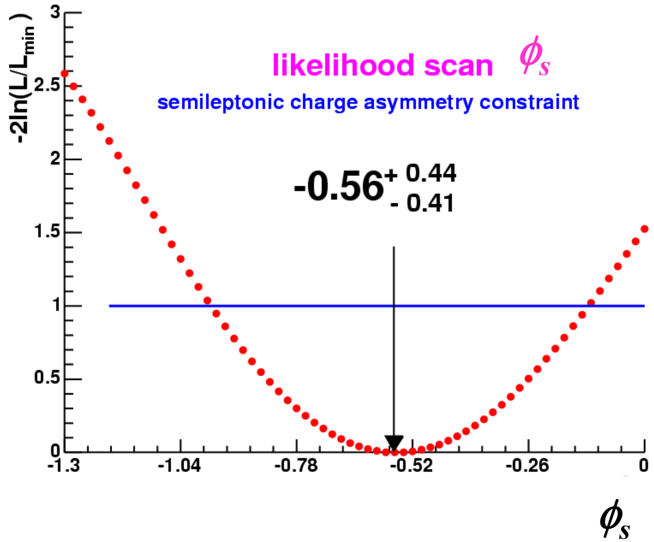
$$\phi_s = -0.79^{+0.53}_{-0.60}$$



With constraint from A_{SL}^{s}

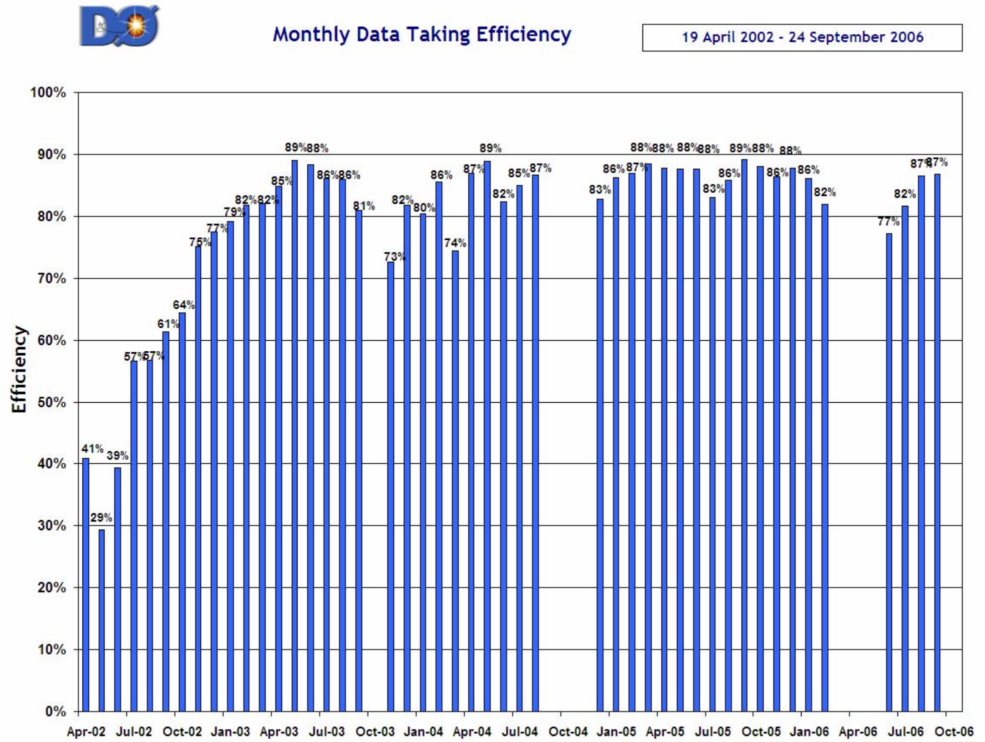
$$\Delta\Gamma_s = 0.15^{+0.09}_{-0.08}\ \text{ps}^{-1}$$

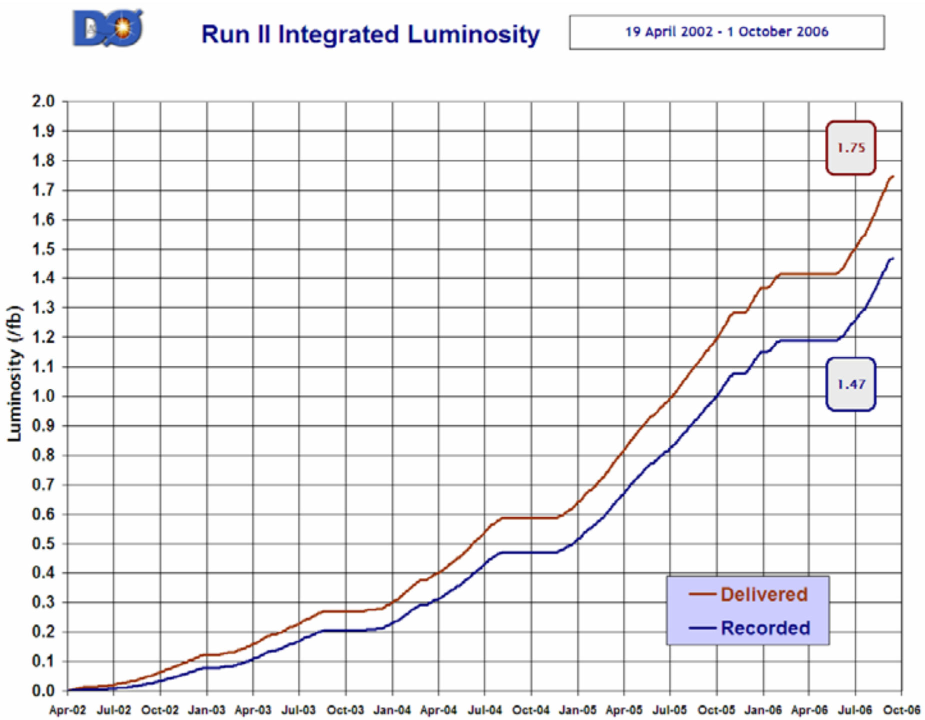
$$\phi_s = -0.56^{+0.44}_{-0.41}$$



DØ Operation

- DØ fully recovered after complicated shutdown
- 50% more data is available





Conclusion

- **DØ is performing a complex study of key parameters of the B_s system at Tevatron**
  - **Exciting progress in the $\Delta\Gamma_s$ measurements**
  - **First results on CPV in $B_s - \overline{B}_s$ mixing**
    - ✓ **Flavour specific asymmetry A^s_{SL}**
    - ✓ **CPV mixing phase ϕ_s from $B_s \rightarrow J/\psi\ \varphi$**
    - ✓ **Constraints on ϕ_s from two measurements of A^s_{SL}**
- **New results are coming**
- **Stay Tuned**

Backup Slides

Background in the same-sign dimuon sample

- Sources of background.

Background	Cut
Cosmic Rays	Timing requirement
$K^{\pm}$ and $\pi^{\pm}$ decays	$p_T > 3.0$ GeV/c
Punch through	Muons must traverse toroid
Wrong sign, $W^{\pm}$, Z decay	$p_T < 15.0$ GeV/c

Systematic errors in the same-sign dimuon asymmetry analysis

Source of Error	ΔA
$K^{\pm}$ Decay + prompt μ	0.00068
Sample Normalization	0.00018
Misreconstructed charge	0.00015
Detector	0.00015
Cosmic Rays	0.00010
Punch through	0.00001
Total	0.00074

- Largest source of systematics from $K^{\pm}$ decays.
  - Difference in inelastic interaction length for K^{+} vs. K^{-}.
  - Presence of $S = -1$ baryons (Λ, Σ, Y^{*}).
  - Correction: -0.0028 ± 0.0007.

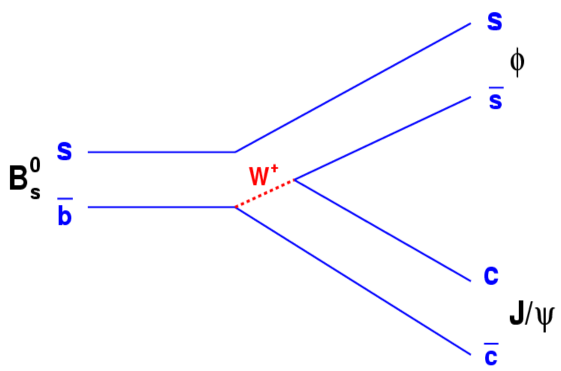
Systematic errors in the Bs semileptonic asymmetry analysis

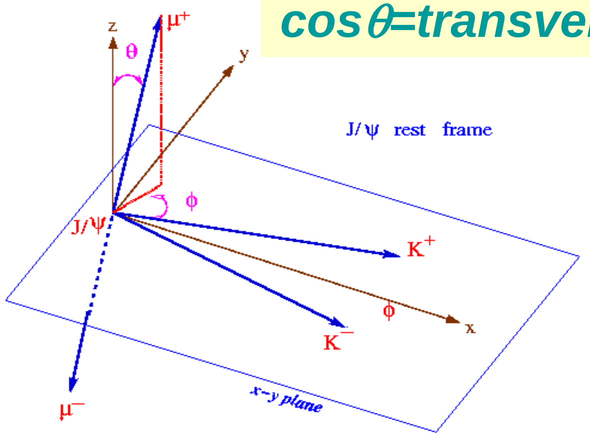
Source	ΔA
Mass fitting	0.0027
Sample composition	0.0022
$\pi^{\pm}$ interactions	0.0004
Contribution from A^d_{SL}	0.0002
Total	0.0035

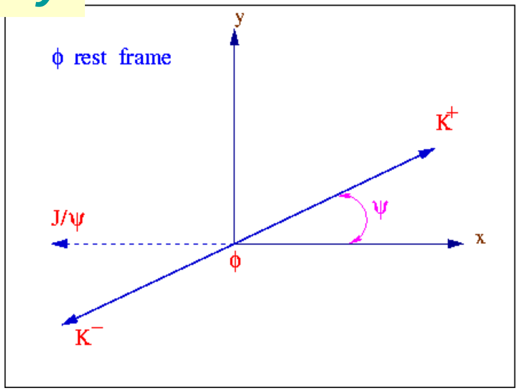
Scalar → Vector Vector

- B_s → V1 + V2 ($J/\psi + \phi$) i.e. Spin 0 → 1+1 L= 0,1,2
- L = 0 and 2 corresponds to CP even; L=1 CP odd
- Angular distribution can be written in terms of helicity $H = \frac{\vec{s}\cdot\vec{p}}{|\vec{s}|\,|\vec{p}|}$

- Most suitable coordinate bases: Transversity basis
  - Transversity basis is convenient for separation of CP-even and CP-odd components of the decay amplitude
  - Polar coordinates in this basis are defined in "J/ψ rest frame" and "ϕ rest frame"







Angular Distribution

Decay amplitude

$$\frac{d^3\Gamma(t)}{dt\, d\cos\theta\, d\varphi\, d\cos\psi} \propto$$

$$2|A_0(0)|^2\, \mathcal{T}_+\, \cos^2\psi(1-\sin^2\theta\cos^2\varphi)$$

$$+\ |A_\parallel(0)|^2\, \mathcal{T}_+\, \sin^2\psi(1-\sin^2\theta\sin^2\varphi)$$

$$+\,|A_\perp(0)|^2\, \mathcal{T}_-\, \sin^2\psi\sin^2\theta$$

$$+\,\frac{1}{\sqrt{2}}|A_0(0)||A_\parallel(0)|\cos(\delta_2-\delta_1)\, \mathcal{T}_+\, \sin 2\psi\sin^2\theta\sin 2\varphi$$

$$+\left\{\frac{1}{\sqrt{2}}|A_0(0)||A_\perp(0)|\cos\delta_2\, \sin 2\psi\sin 2\theta\cos\varphi\right.$$

$$\left.-|A_\parallel(0)||A_\perp(0)|\cos\delta_1\, \sin^2\psi\sin 2\theta\sin\varphi\right\}\frac{1}{2}\left(e^{-\Gamma_H t}-e^{-\Gamma_L t}\right)\sin(\delta\phi)$$

$$\mathcal{T}_+ = \tfrac{1}{2}\left\{(1+cos\delta\phi)e^{-\Gamma_L t}+(1-cos\delta\phi)e^{-\Gamma_H t}\right\}$$

$$\mathcal{T}_- = \tfrac{1}{2}\left\{(1-cos\delta\phi)e^{-\Gamma_L t}+(1+cos\delta\phi)e^{-\Gamma_H t}\right\}$$

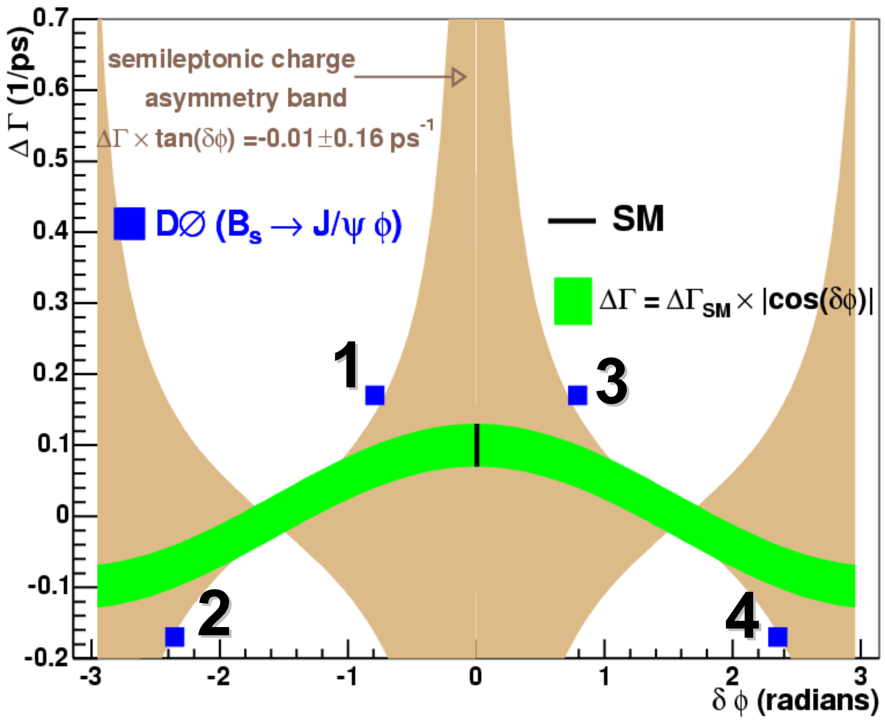
- ✓$\delta\phi$ → **CP-violating weak phase ; in SM ~0.3**
- ✓δ_1 δ_2 → **CP-conserving strong phase ; ~ |π| and 0**
- ✓$A_0(0)$, $A_{||}(0)$ → **CP-even linear polarization amplitude at t=0**
- ✓$A_\perp(0)$ → **CP-odd linear polarization amplitude at t=0**

Sign Ambiguity

Observable	BSW [a]	Soares [b]	Cheng [c]
$\frac{\lvert A_{\parallel}(0)\rvert}{\lvert A_0(0)\rvert}$	0.81	0.82	0.75
$\frac{\lvert A_{\perp}(0)\rvert}{\lvert A_0(0)\rvert}$	0.41	0.89	0.55
δ_1	π	π	π
δ_2	0	0	0

a: M. Bauer, B. Stech and M. Wirbel, Z. Phys. C29 (1985) 637 and Z. Phys. C34 (1987) 103.
b: J.M. Soares, Phys. Rev. D53 (1996) 241.
c: H.-Y. Cheng, Z. Phys. C69 (1996) 647.

1. $\cos(\delta_1) = -0.987 \quad \cos(\delta_2) = 0.765 \quad \Delta\Gamma = 0.17 \quad \delta\phi = -0.79$
2. $\cos(\delta_1) = -0.987 \quad \cos(\delta_2) = 0.765 \quad \Delta\Gamma = -0.17 \quad \delta\phi = 2.35$
3. $\cos(\delta_1) = 0.987 \quad \cos(\delta_2) = -0.765 \quad \Delta\Gamma = 0.17 \quad \delta\phi = 0.79$
4. $\cos(\delta_1) = 0.987 \quad \cos(\delta_2) = -0.765 \quad \Delta\Gamma = -0.17 \quad \delta\phi = -2.35$



For almost all theoretical models solution **1** is the most favorable solution from data set we have used to measure the observables

BUT

We have three more equally probable solutions from the same data set depends what choice you make for δ_1 δ_2 & $\Delta\Gamma$

Due to

Angular distribution equation

DØ $Br(B^0_s \rightarrow D^{(*)+}_s D^{(*)-}_s)$

- **Semileptonic D_s decays (need trigger)**

$$B^0_s \rightarrow D_s^{(*)+}(\phi\mu^+\nu)D_s^{(*)-}(\phi\pi^-)$$

- **Normalize to** $B^0_s \rightarrow D_s^{(*)+}(\phi\pi^+)\mu^-\nu$

- **Measure ratio** $R = \dfrac{Br(B^0_s \rightarrow D_s^{(*)+}D_s^{(*)-}) \cdot Br(D_s \rightarrow \phi\mu\nu)}{Br(B^0_s \rightarrow \mu\nu D_s^{(*)-})}$