DØ results on CP violation phase in B_s system

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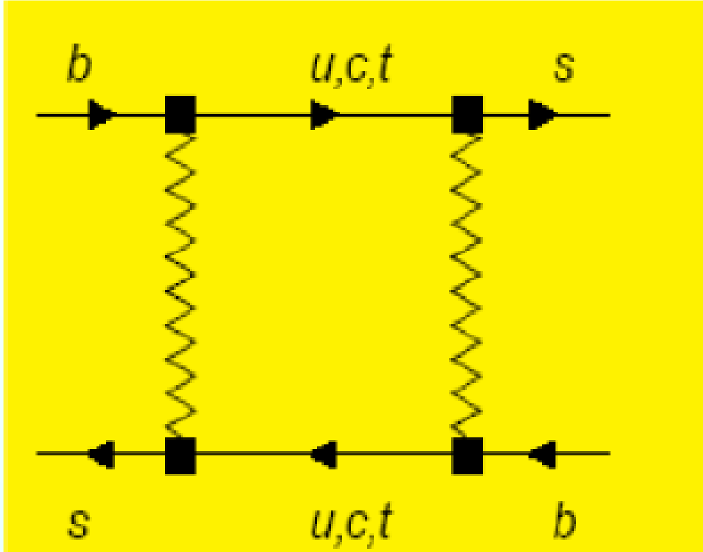
CP violation in B_s system

- Contrary to any other system, B_s is strongly mixed;
- Two physical states B_s^H (heavy) and B_s^L (light) have distinct masses and lifetimes:



$$\Delta m_s = m_H - m_L \approx 2|M_{12}|;$$
$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \approx 2|\Gamma_{12}|\cos\phi_s;$$
$$\phi_s = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right);$$

M_{12} and Γ_{12} are elements of complex mass matrix $(M - i\,\Gamma/2)$ of B_s system;

ϕ_s- CP violating phase;

Open window for New Physics

- **SM model predicts very small value for CP phase ϕ_s:**

$$\phi_s(\mathrm{SM}) = O(|V_{us}|^2 m_c^2/m_b^2) \sim 5\cdot 10^{-3} = 0.3^o$$

  - **GIM suppression factor (m_c^2/m_b^2);**
  - **Additional suppression by $|V_{us}|^2 \sim \lambda^2$ (λ=0.22 - Wolfenstein parameter);**
- **New physics contributions can lift these suppressions;**
- **Small SM value of ϕ_s simplifies detection of NP contributions;**

First measurement of ϕ_s

- **DØ experiment performs the first measurement of ϕ_s in different processes:**
  - **From the time dependence of polarization amplitudes in**

$$\boxed{B_s \to J/\psi\,\varphi}$$

  - **From the time-integrated di-muon charge asymmetry:**

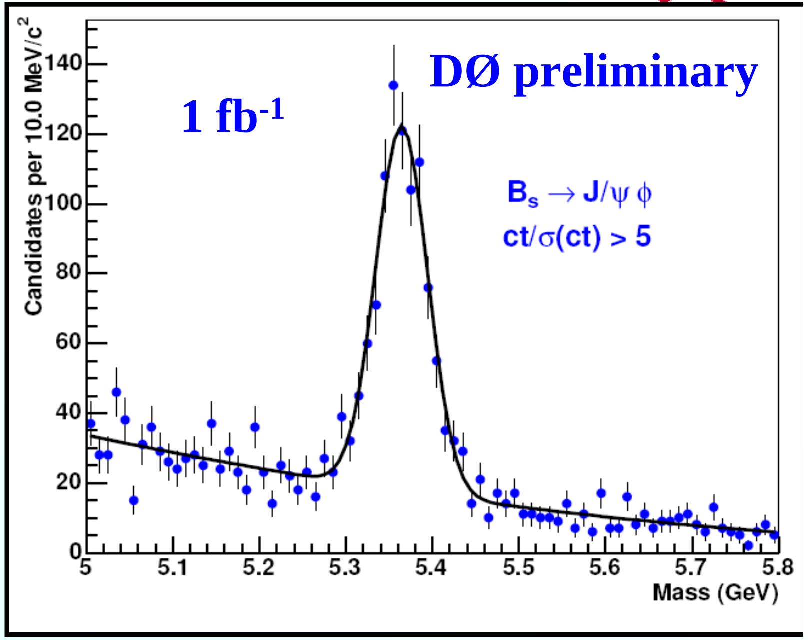
$$\boxed{A_{SL} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}}$$

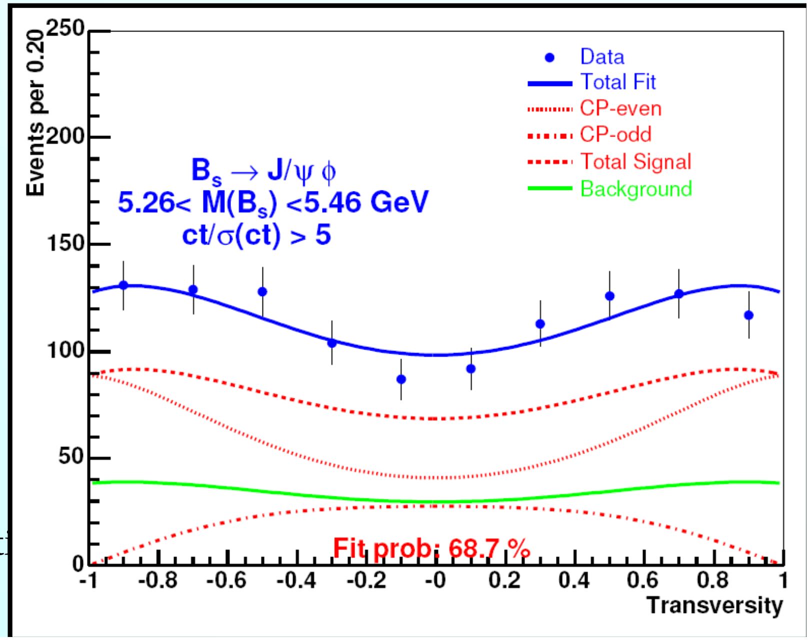
  - **From time-integrated charge asymmetry of $B_s \to \mu\nu D_s$ decay:**

$$\boxed{A_{SL}^{unt} = \frac{N(B_s \to \mu^+ D_s X) - N(B_s \to \mu^- D_s X)}{N(B_s \to \mu^+ D_s X) + N(B_s \to \mu^- D_s X)}}$$

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

- **Clean signal selection;**
- **Final state is mostly CP-even state with small CP-odd contribution;**
- **They produce different angular distributions of polarization amplitudes A_0, $A_{\parallel}$ (CP-even) and $A_{\perp}$ (CP-odd);**
- **Time evolution of these amplitudes depends on lifetime difference $\Delta\Gamma_s$ and CP-violation phase ϕ_s**





Results from $B_s \to J/\psi\ \varphi$

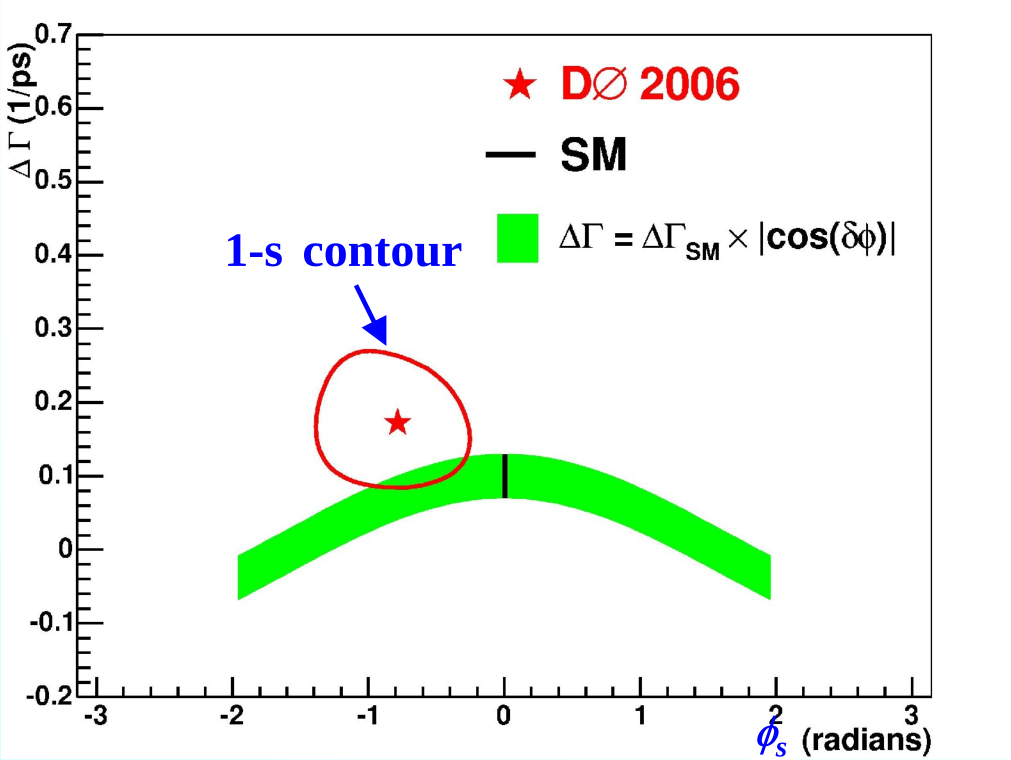
- **Dzero Conference note 5144**

$$\boxed{\begin{aligned} \Delta\Gamma_s &= 0.17 \pm 0.09 \pm 0.03\ \mathrm{ps}^{-1} \\ \phi_s &= -0.79 \pm 0.56 \pm 0.01 \end{aligned}}$$

- **Most precise direct measurement of $\Delta\Gamma_s$;**
- **First measurement of ϕ_s**
- **Consistent with the SM prediction:**

$$\Delta\Gamma_s = 0.10 \pm 0.03\ \mathrm{ps}^{-1}$$

$$\phi_s \cong 0.005$$



Dimuon Charge Asymmetry

- **Charge asymmetry of muons from B decays depends on the CP violation phase:**

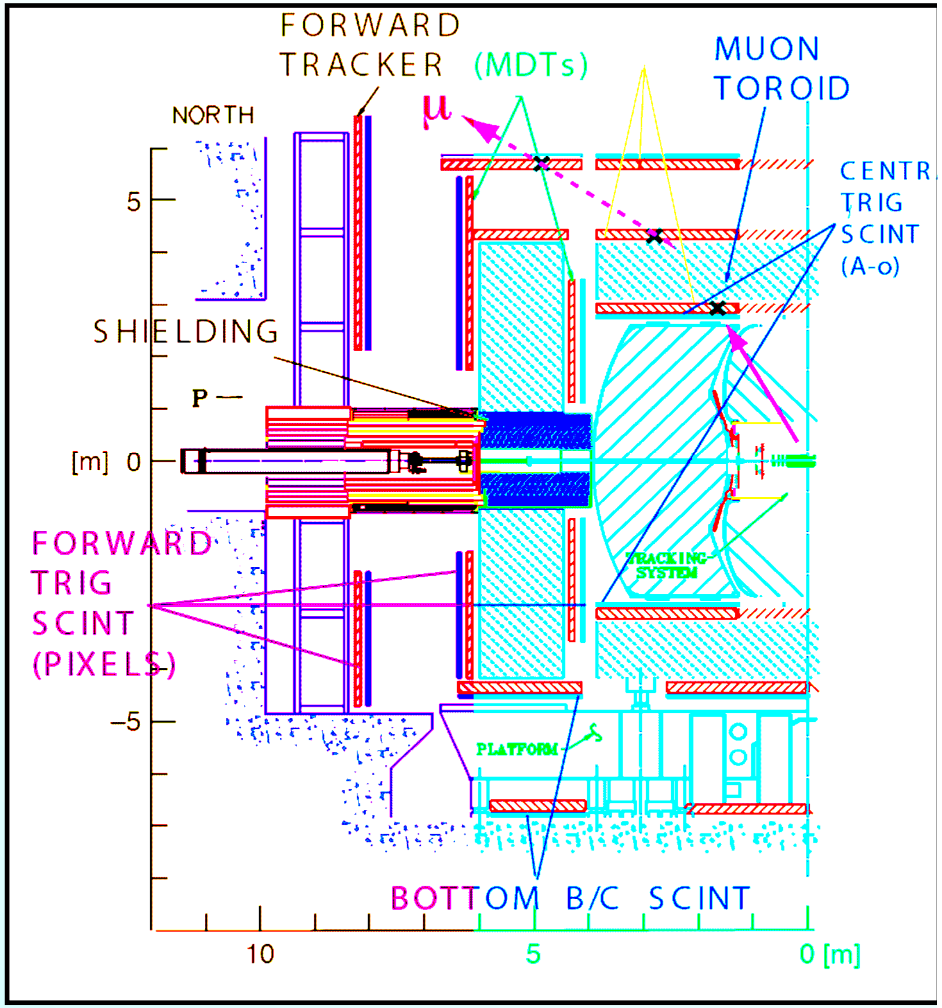
$$A_{SL} = \frac{N(\bar{B} \to l^+ X) - N(B \to l^- X)}{N(\bar{B} \to l^+ X) + N(B \to l^- X)} = \frac{\Delta\Gamma}{\Delta m}\tan(\phi)$$

- **Non-zero A_{sl} corresponds to CP violation in mixing;**
- **The only type of CP violation not observed yet in B decays;**
- **At Tevatron, the dimuon charge asymmetry is measured - better control of systematics:**

$$A = \frac{N(b\bar{b} \to l^+ l^+ X) - N(b\bar{b} \to l^- l^-)}{N(b\bar{b} \to l^+ l^+ X) + N(b\bar{b} \to l^- l^-)} = A_{SL}$$

Dimuon events in DØ

- **~5 Mln of same sign dimuon events collected (1 fb^{-1}) ;**
- **Excellent muon system with very low punch-through;**
- **Strong suppression of cosmic background;**
- **Regular reversal of magnets polarities - reduced detector systematics;**



Results

- The most precise measurement of A_{sl} obtained (DØ conference note 5042):

$$\boxed{A_{SL}(\text{Dzero}) = (-4.4 \pm 4.0(stat) \pm 2.8(syst)) \times 10^{-3}}$$

- To be compared with A_{sl}^{d} results from B-factories:

$$\boxed{\begin{aligned} A_{SL}^{d}(\text{Belle}) &= \left(-1.1 \pm 7.9(stat) \pm 7.0(syst)\right) \times 10^{-3} \\ A_{SL}^{d}(\text{Babar}) &= \left(+1.6 \pm 5.4(stat) \pm 3.8(syst)\right) \times 10^{-3} \end{aligned}}$$

- Both B_d and B_s contribute to the measured A_{SL}(Dzero);
- Combination of these results provides important information on CP violation in B_s system;

Asymmetry in semileptonic B_s decays

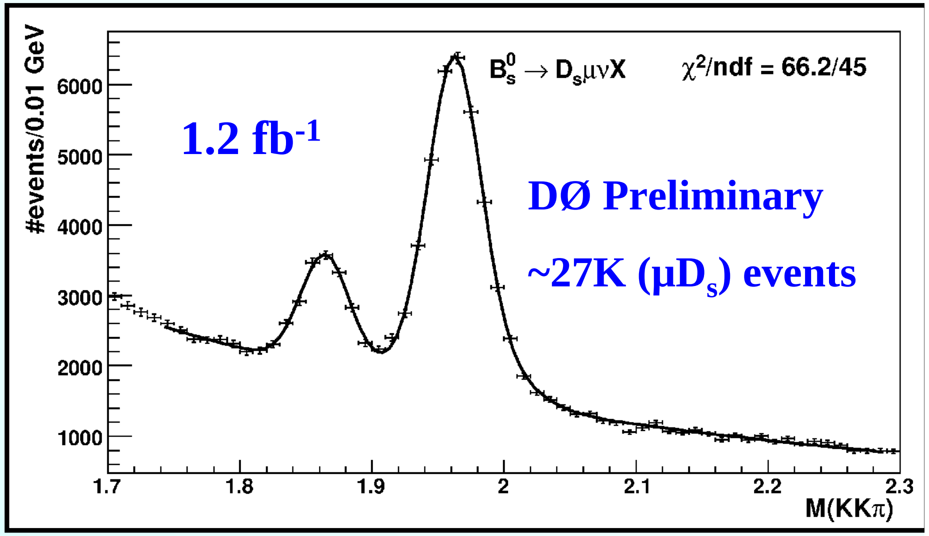
- A_{SL}^s can also be obtained from time-integrated charge asymmetry in semileptonic decays $B_s \to \mu\nu D_s$:

$$A_{SL}^{unt} = \frac{N(B_s \to \mu^+ D_s) - N(B_s \to \mu^- D_s)}{N(B_s \to \mu^+ D_s) + N(B_s \to \mu^- D_s)}$$

$$= \frac{1}{2}\frac{x_s^2}{1+x_s^2} A_{SL}^s \cong \frac{1}{2} A_{SL}^s;$$

$$x_s = \Delta m_s / \Gamma_s >> 1$$

(U.Nierste hep-ph/0406300)



- Large sample of decays $B_s \to \mu\nu D_s$ with $D_s \to \varphi\pi$ was collected by DØ;

Results

- **Analysis is similar to the measurement of A_{SL} in same sign dimuon events;**
- **Exploits the reversal of magnet polarities, which cancels the detector effects;**
- **First measurement of $A_{SL}{}^{s}$ for B_s meson (DØ conference note 5143):**

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

Combined value of A_{SL}^{s}

- **Both DØ results on A_{SL} can be combined together:**
  - **(DØ Conference note 5189);**
  - **A_{SL}^{d} value from b-factories is used;**

$$A_{SL}^{s} = \frac{\Delta\Gamma_s}{\Delta m_s}\tan(\phi_s) = -0.0007 \pm 0.0091$$

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

$$(\text{assuming } \Delta m_s = 17.3 \pm 0.3\ \mathrm{ps}^{-1}, \text{CDF})$$

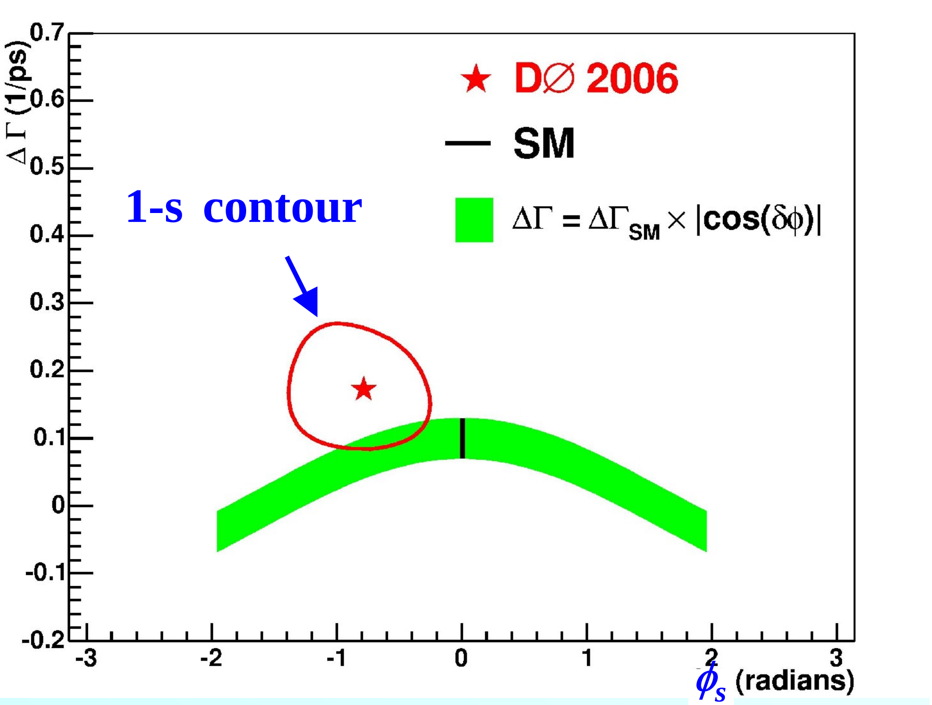
Constraints on $\Delta\Gamma_s$ and ϕ_s

- We have two constraints (both from DØ) on $\Delta\Gamma_s$ and ϕ_s:
- From charge asymmetry:

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

- From analysis of $B_s \to J/\psi\ \varphi$:

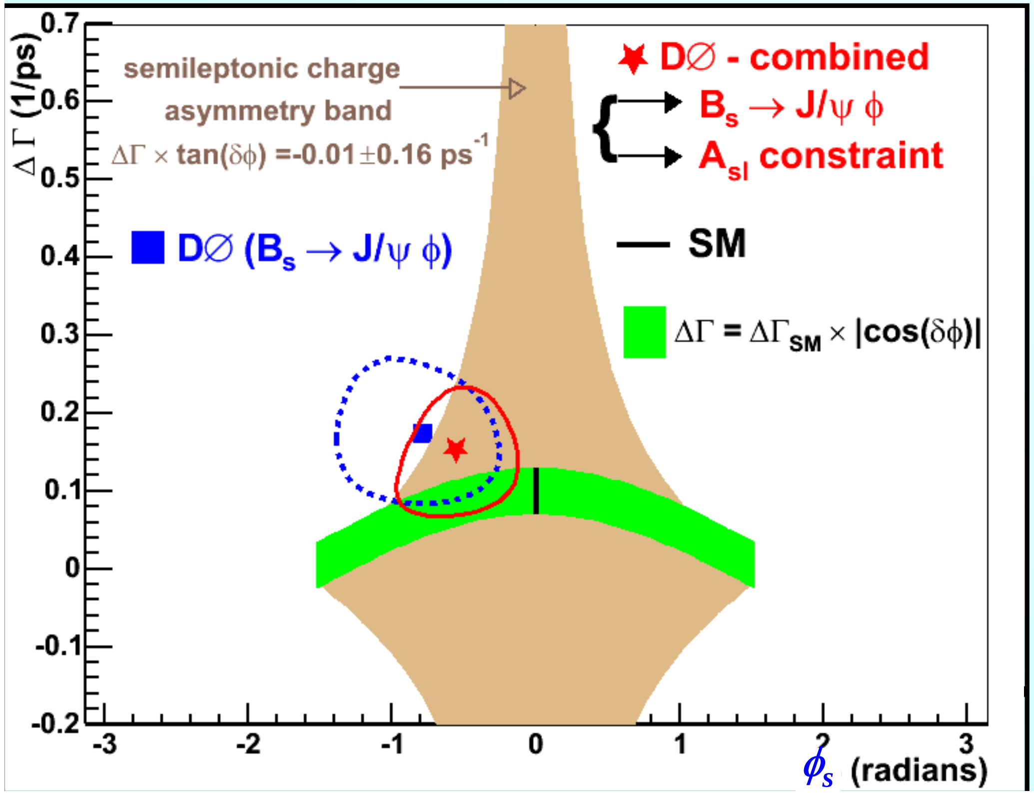
$$\Delta\Gamma_s = 0.17 \pm 0.09 \pm 0.03\ \mathrm{ps}^{-1}$$
$$\phi_s = -0.79 \pm 0.56 \pm 0.01$$

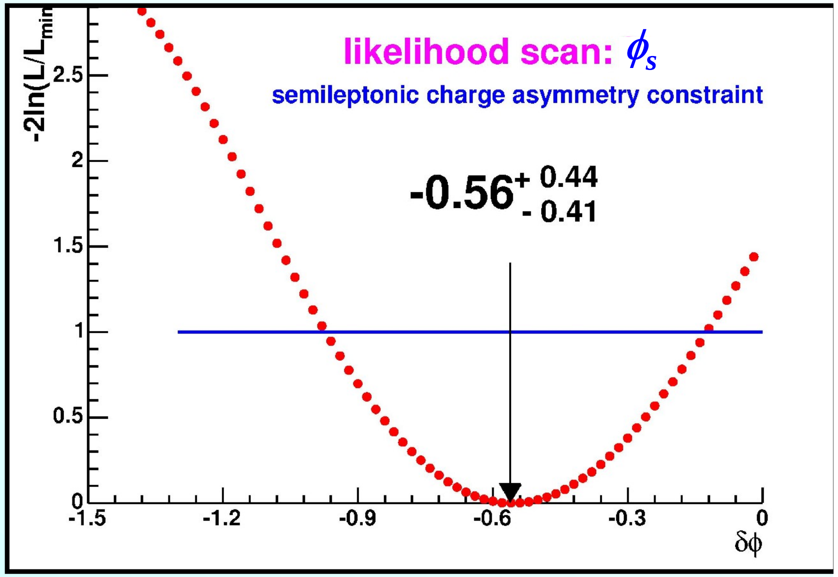


$\Delta\Gamma_s$ versus ϕ_s

- **Combination of results from A_{SL} and from $B_s \to J/\psi\ \varphi$ improves the precision of ϕ_s :**

$$\boxed{\Delta\Gamma_s = 0.15^{+0.09}_{-0.08}\ ps^{-1};\quad \phi_s = -0.56^{+0.44}_{-0.41}}$$





Conclusions

- **DØ delivered first ever results on CP violation phase in B_s system;**
- **First measurement of CP phase in $B_s \to J/\psi\ \varphi$:**

$$\boxed{\begin{aligned} \Delta\Gamma_s &= 0.17 \pm 0.09 \pm 0.03\ \mathrm{ps}^{-1} \\ \phi_s &= -0.79 \pm 0.56 \pm 0.01 \end{aligned}}$$

- **Most precise measurement of charge dimuon asymmetry:**

$$\boxed{A_{SL}(\mathrm{Dzero}) = (-4.4 \pm 4.0(stat) \pm 2.8(syst)) \times 10^{-3}}$$

- **First measurement of $A_{SL}{}^{s}$:**

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

Conclusions

- **Results on A_{SL}^{d} from B-factories (Babar, Belle, Cleo) can be combined with Dzero results giving:**

$$\boxed{A_{SL}^{s} = \frac{\Delta\Gamma_s}{\Delta m_s}\tan(\phi_s) = (-0.7 \pm 9.1)\times 10^{-3}}$$

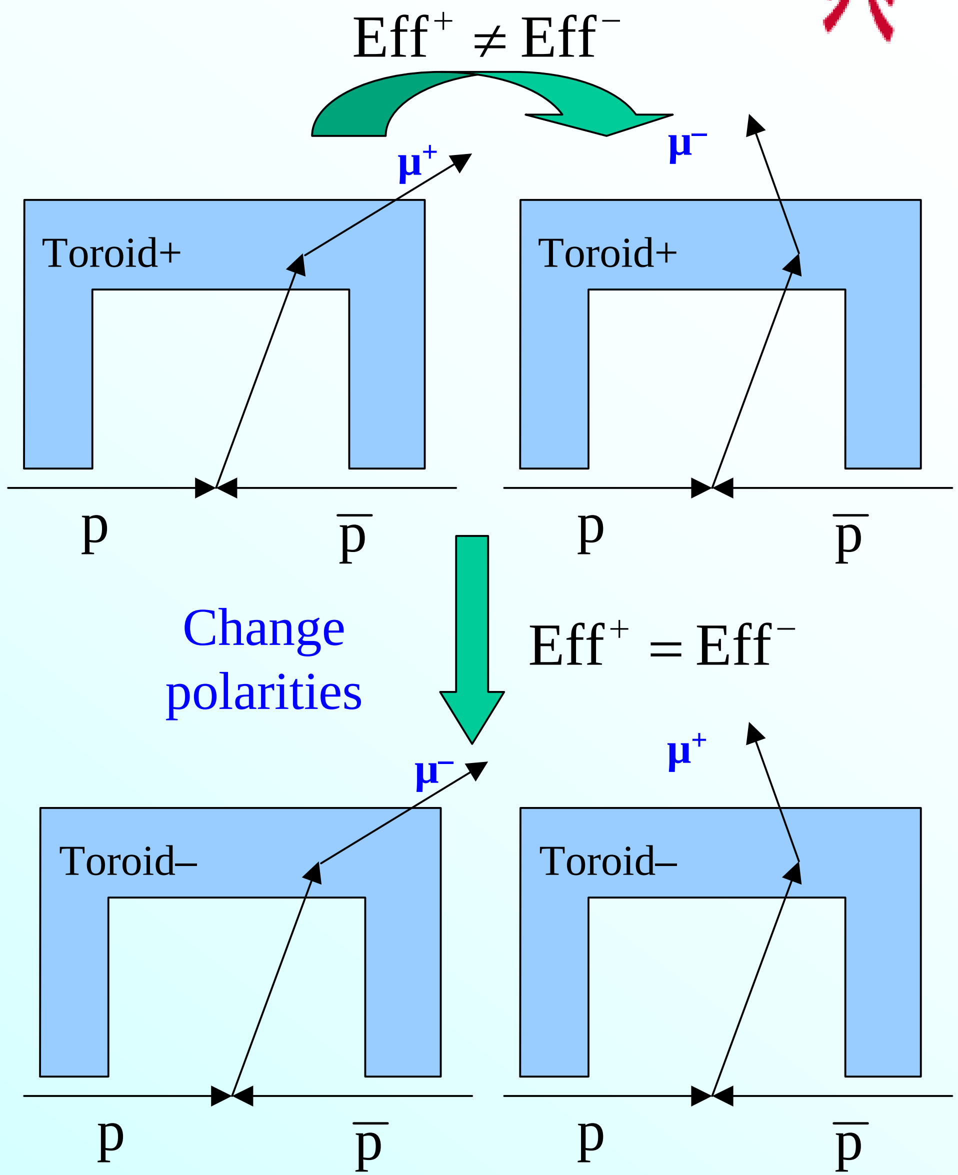
- **Combining all results together we get:**

$$\boxed{\Delta\Gamma_s = 0.15^{+0.09}_{-0.08}\ ps^{-1};\quad \phi_s = -0.56^{+0.44}_{-0.41}}$$

- **Result on CP phase consistent with SM prediction;**

BACKUP SLIDES

- **Changing magnet polarities cancel detector effects in chrge asymmetry of muon reconstruction;**
- **Significant reduction in systematics achieved;**



Combination of DØ results

- A_{SL} in dimuon events at Tevatron can be expressed as:

$$A_{SL} = \frac{f_d Z_d A_{SL}^d + f_s Z_s A_{SL}^s}{f_d Z_d + f_s Z_s};\ Z_q = \frac{x_q^2}{1+x_q^2};\ x_q = \frac{\Delta M}{\Gamma}$$

(Grossman, Nir, Raz, hep-ph/0605028, assuming ΔG/G<<1)

- DØ extracted A_{SL}^d assuming A_{SL}^s=0;
- Rewriting it in general form:

$$A_{SL}(\mathrm{Dzero}) = A_{SL}^d + \frac{f_s Z_s}{f_d Z_d} A_{SL}^s$$

- Using A_{SL}^d measured at b-factories (Babar, Belle, Cleo) we get:

$$A_{SL}^s = (-7.6 \pm 10.2) \times 10^{-3} \text{ (from Dzero dimuon analysis)}$$

- Combining it with A_{SL}^s from semileptonic decays

$$A_{SL}^s = (+24.5 \pm 19.3) \times 10^{-3} \text{ (from Dzero semileptonic } B_s \text{ decays)}$$

- we get:

$$A_{SL}^s = \frac{\Delta\Gamma}{\Delta M} \tan(\phi_s) = (-0.6 \pm 9.0) \times 10^{-3}$$