Δm_s, Γ_s, A_{SL}, at the Tevatron

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Beauty 2009 7th September 2009

B Mixing and Oscillations

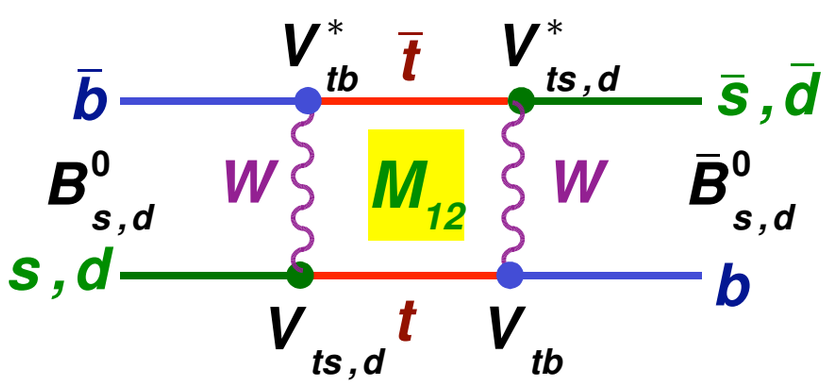
$$i\frac{d}{dt}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}$$

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

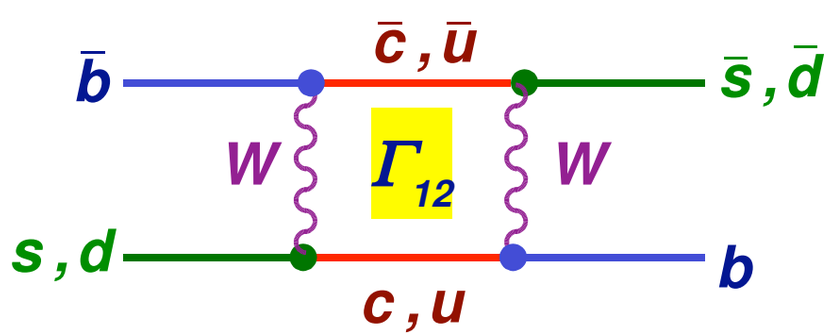
Mass Eigenstates: $|B^H\rangle = p|B^0\rangle + q|\bar{B}^0\rangle \quad |B^L\rangle = p|B^0\rangle - q|\bar{B}^0\rangle$

- Mass Difference: $\Delta m = M_H - M_L \sim 2|M_{12}|$ directly probes V_{td} and V_{ts} in oscillations of B_d & B_s

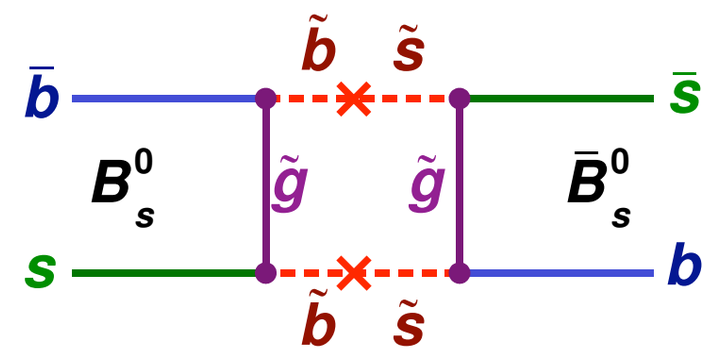
$$\Delta m_d \propto |V_{tb}^* V_{td}|^2$$
$$\Delta m_s \propto |V_{tb}^* V_{ts}|^2$$



Sens. to NP

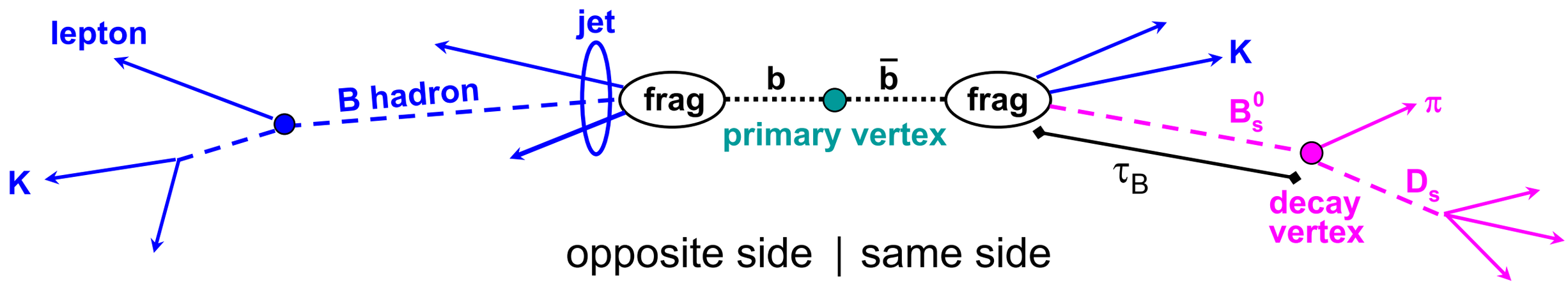


less sens. to NP



SUSY

Flavour Tagging



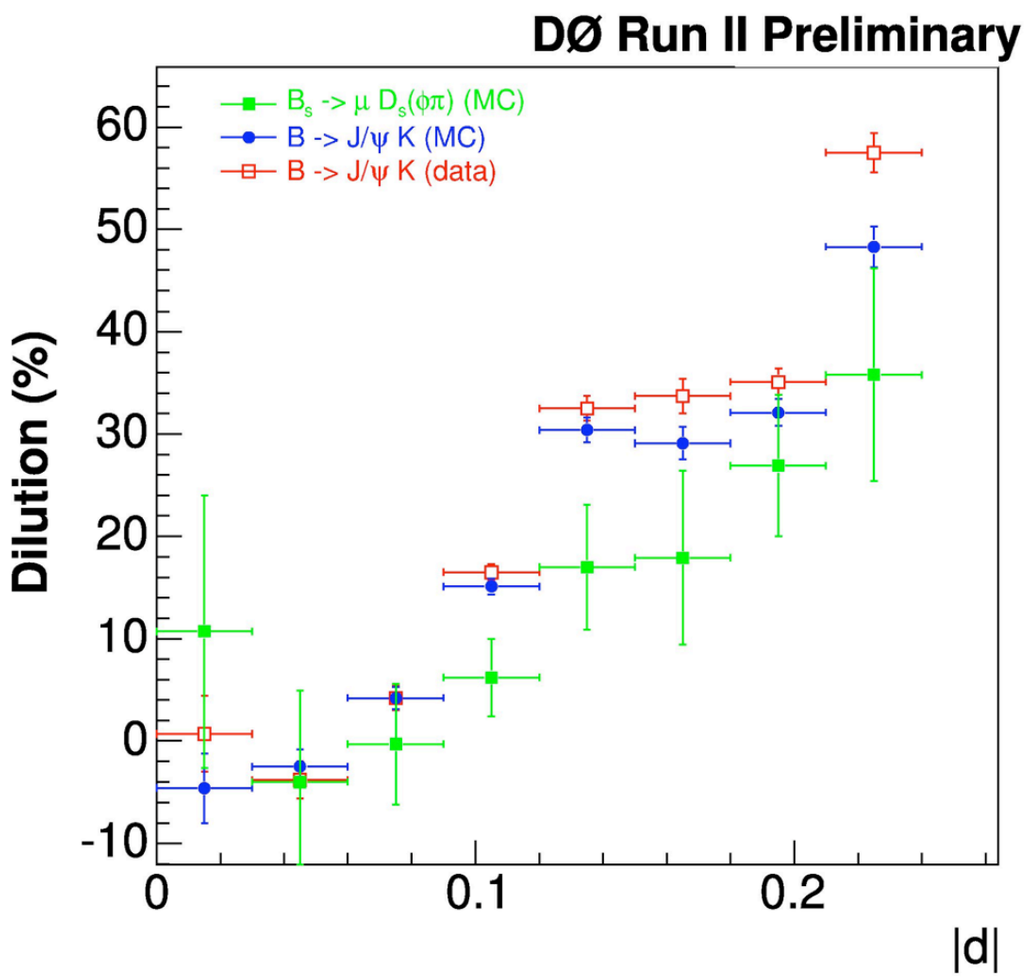
opposite side | same side

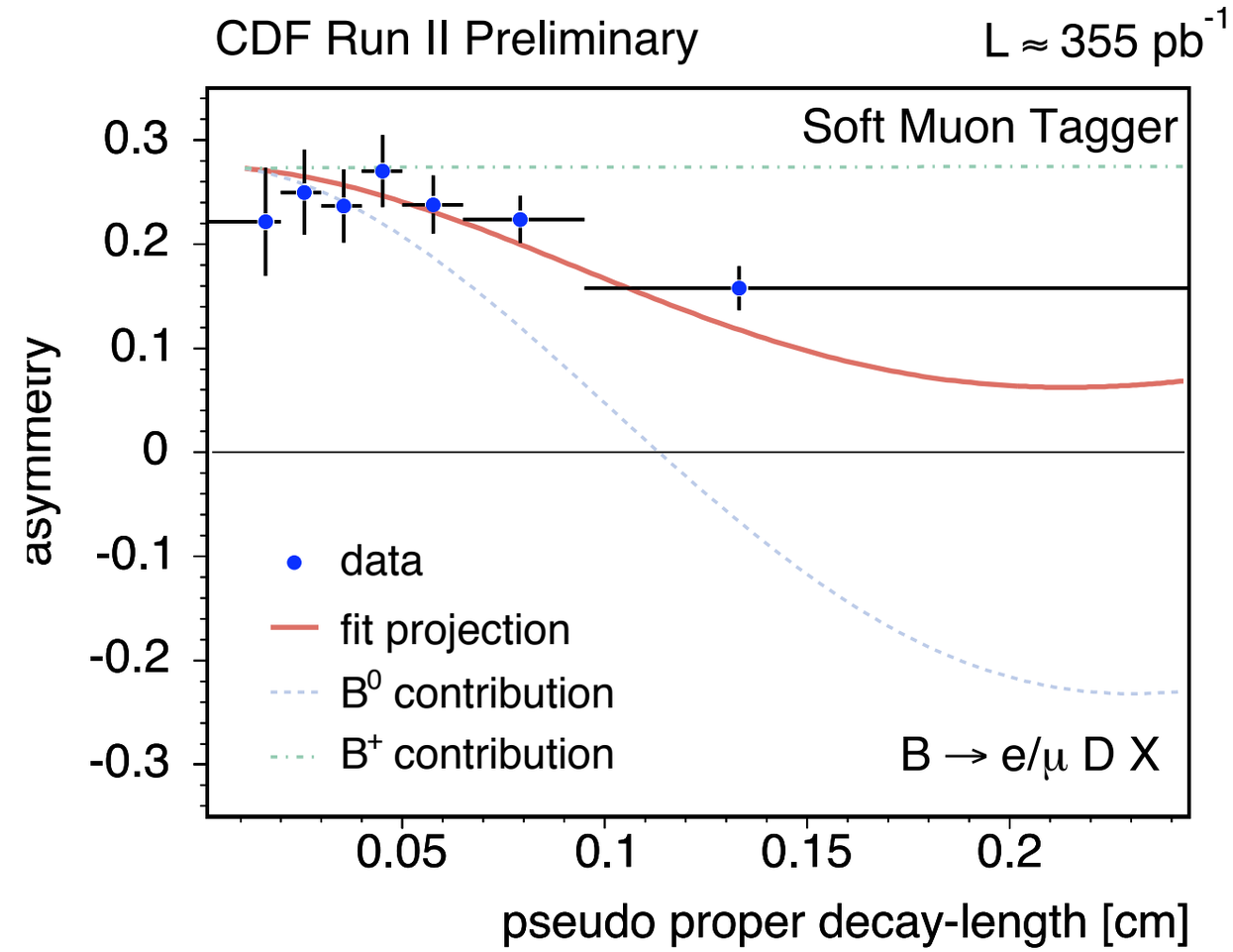
1. Measurement of production flavour
   - OS kaon flavour
   - SS kaon flavour
   - lepton flavour $b \to X l^-$, but $b \to c \to x l^+$
   - Jet Charge multivariate

2. Measurement of decay flavour
   - lepton or flavour specific final state

3. Measurement of Proper Time
   - depends on resolution of tracking system

Flavour tagging II

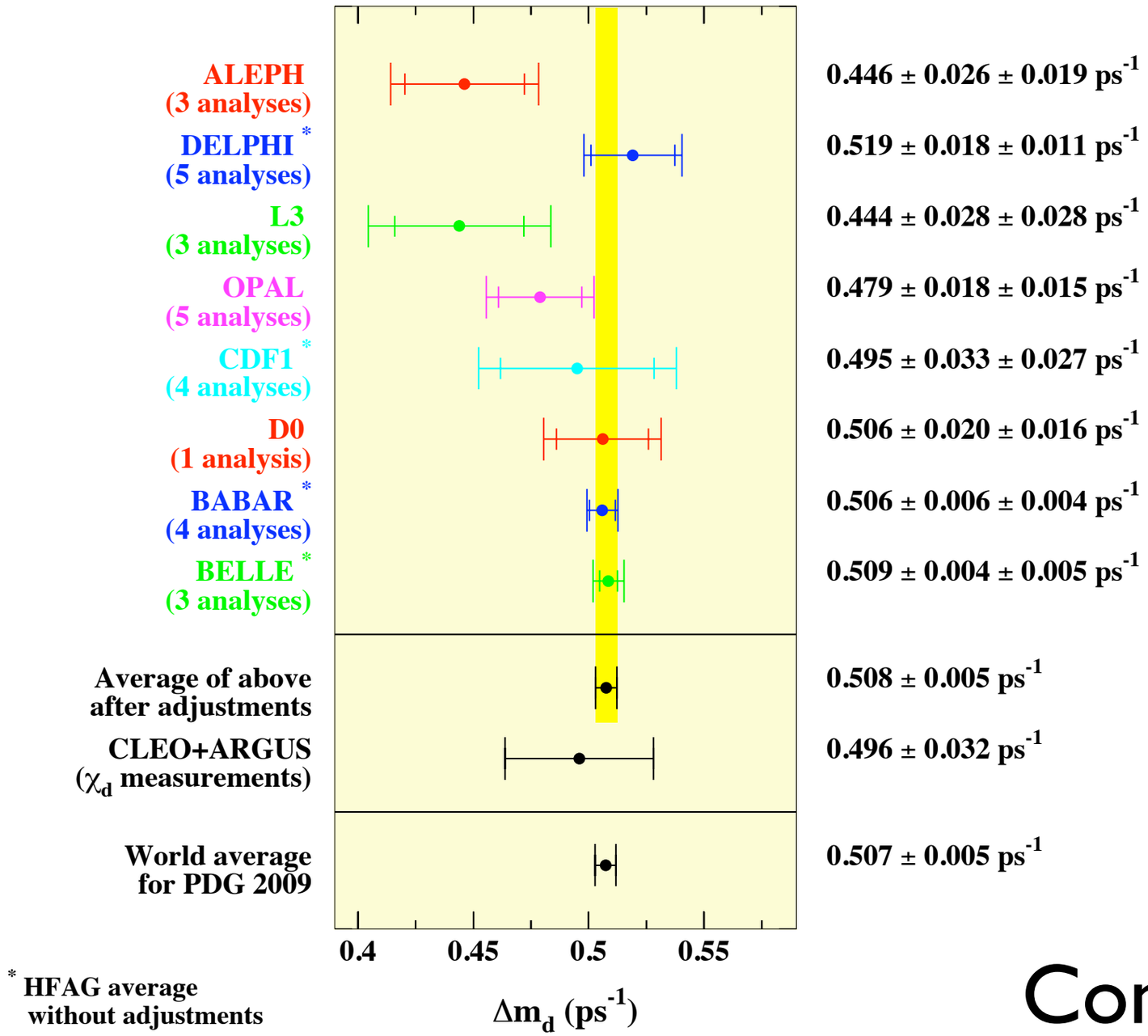




- Combine multiple tagging techniques with NN, etc.
- Check results with B_d mixing and B^+ decays

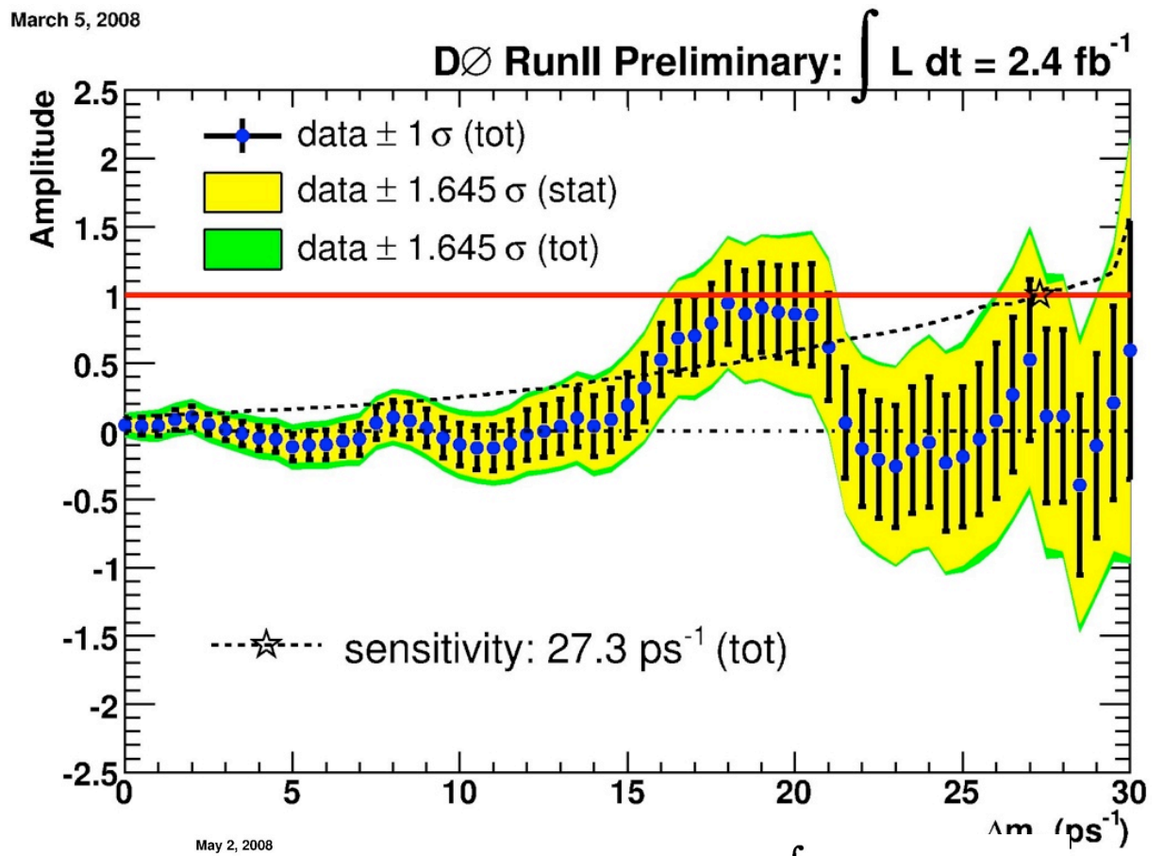
$$\langle \text{significance} \rangle = \sqrt{\frac{\epsilon D^2}{2}} \frac{S}{\sqrt{S+B}} \exp\left[\frac{-(\Delta m \sigma_t)^2}{2}\right]$$

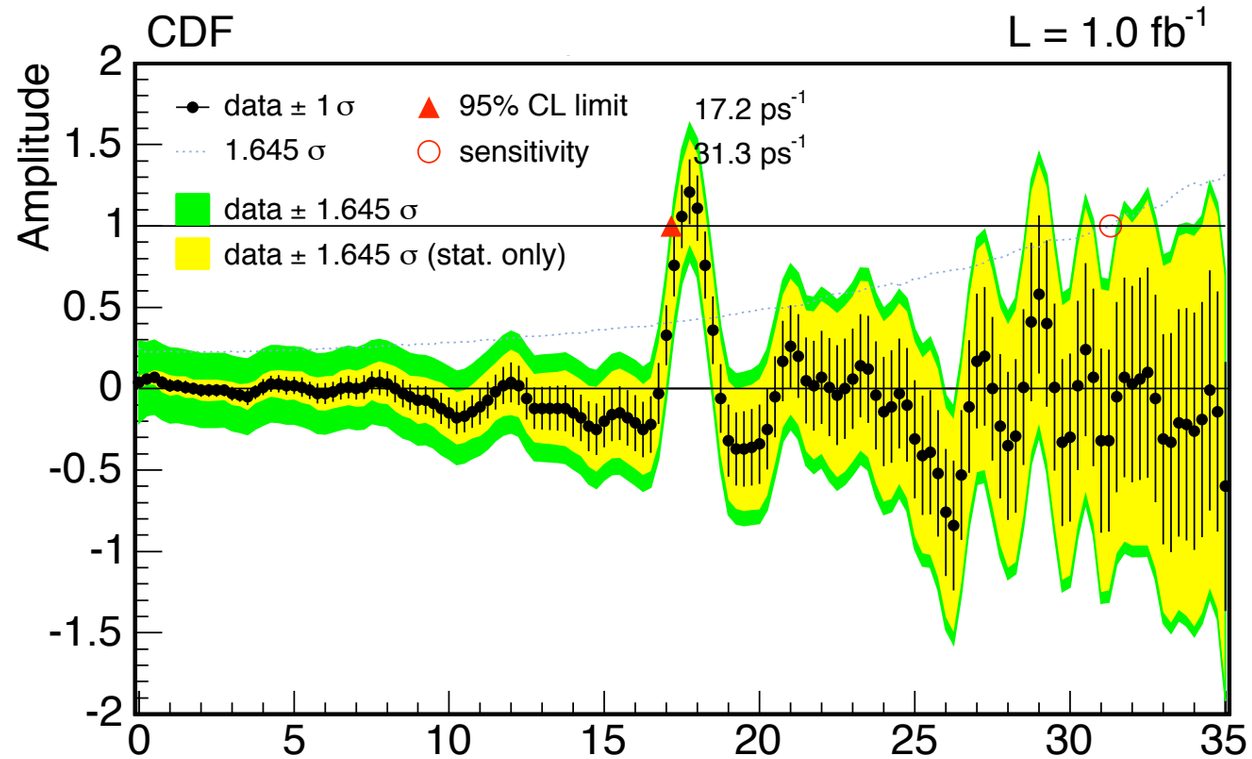
m_d

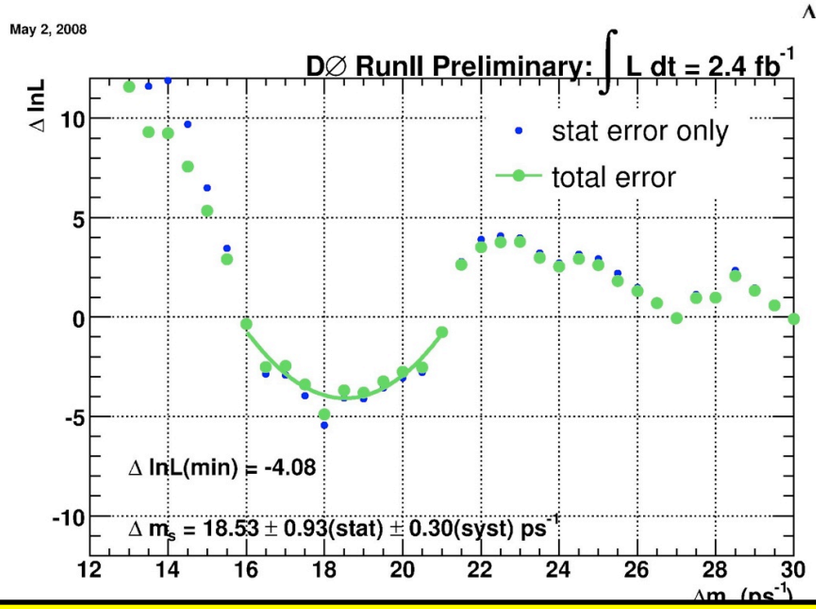


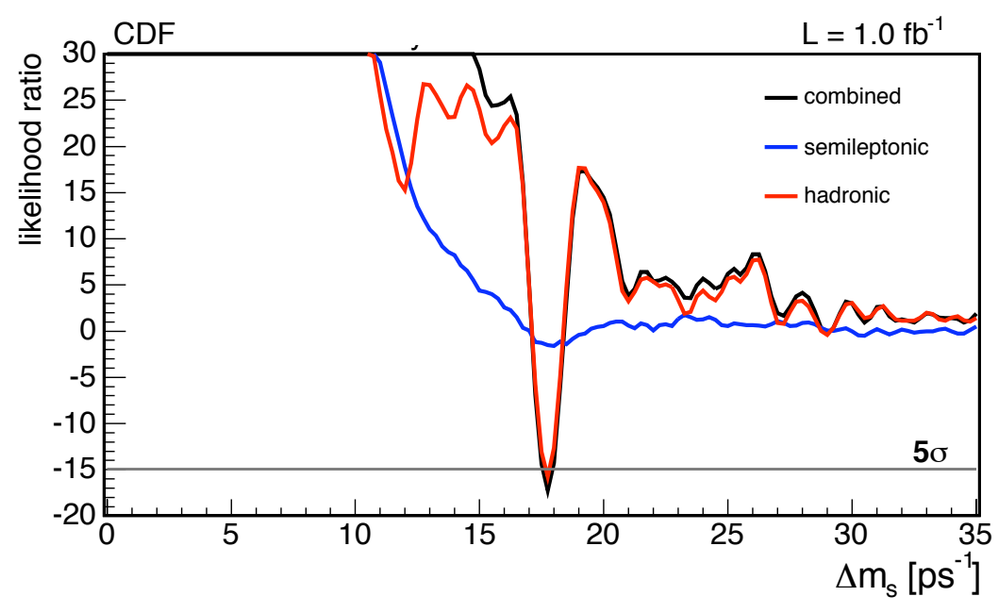
Consistent with B Factories

Δm_s Measurements









DØ: 2.9 σ significance
$\Delta ms = 18.53 \pm 0.93(stat) \pm 0.30(syst)\ ps^{-1}$

CDF: >5σ significance
$\Delta ms = 17.77 \pm 0.10(stat) \pm 0.07(sys)$

Vts & Vtd

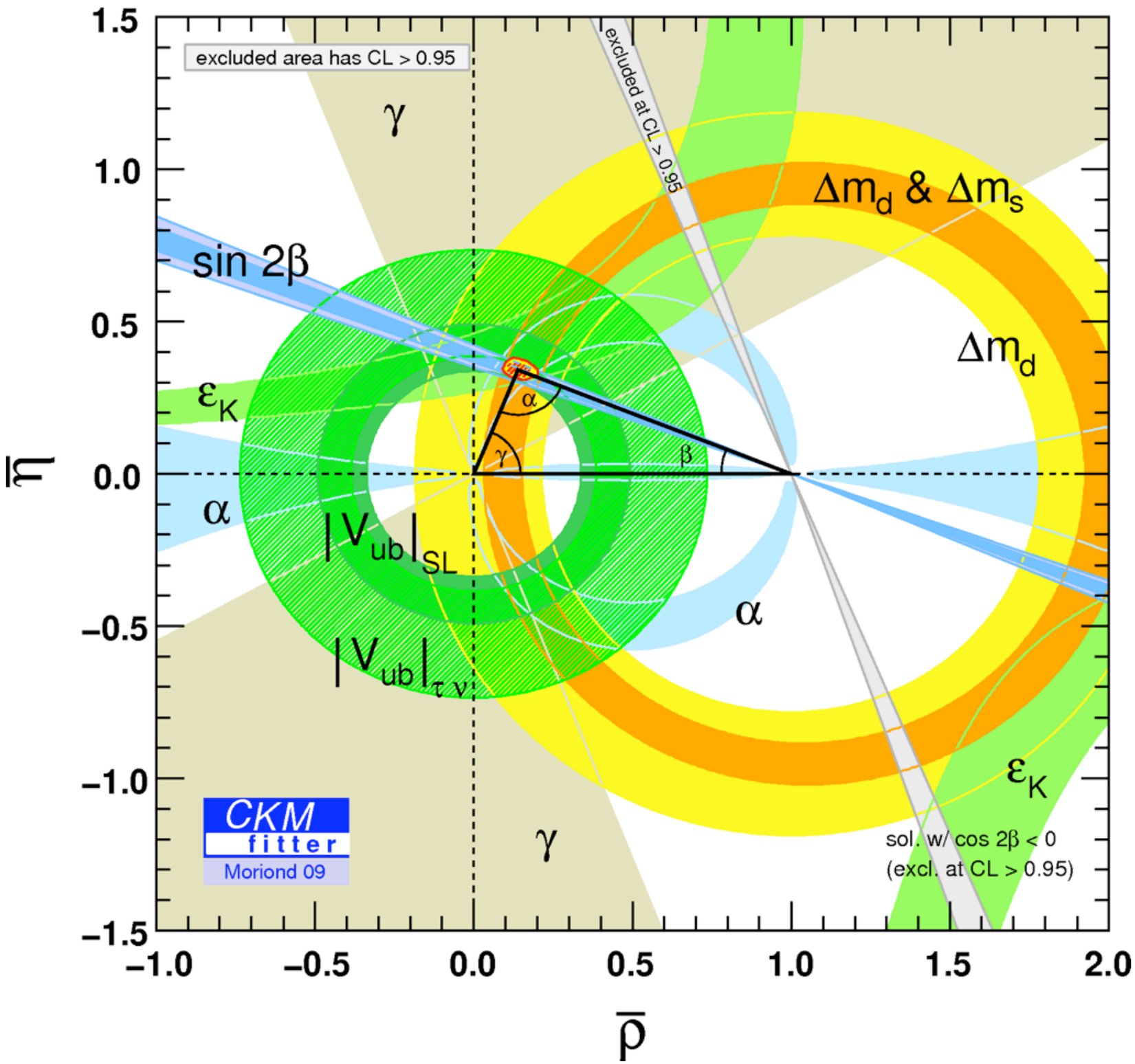
$$\left|\frac{V_{td}}{V_{ts}}\right|^2 = \xi^2 \left(\frac{\Delta m_d}{\Delta m_s}\right)\left(\frac{M_{B_s}}{M_{B_d}}\right)$$

D0: 0.2018 ±0.0053(exp) ± 0.0010(Δmd) +0.0078-0.0058(ξ)
CDF: 0.2060 ±0.0007(exp) ± 0.0010(Δmd) +0.0080-0.0060(ξ)

Ave: 0.2059 ±0.0007(exp) ± 0.0010(Δmd) +0.0080-0.0060(ξ)

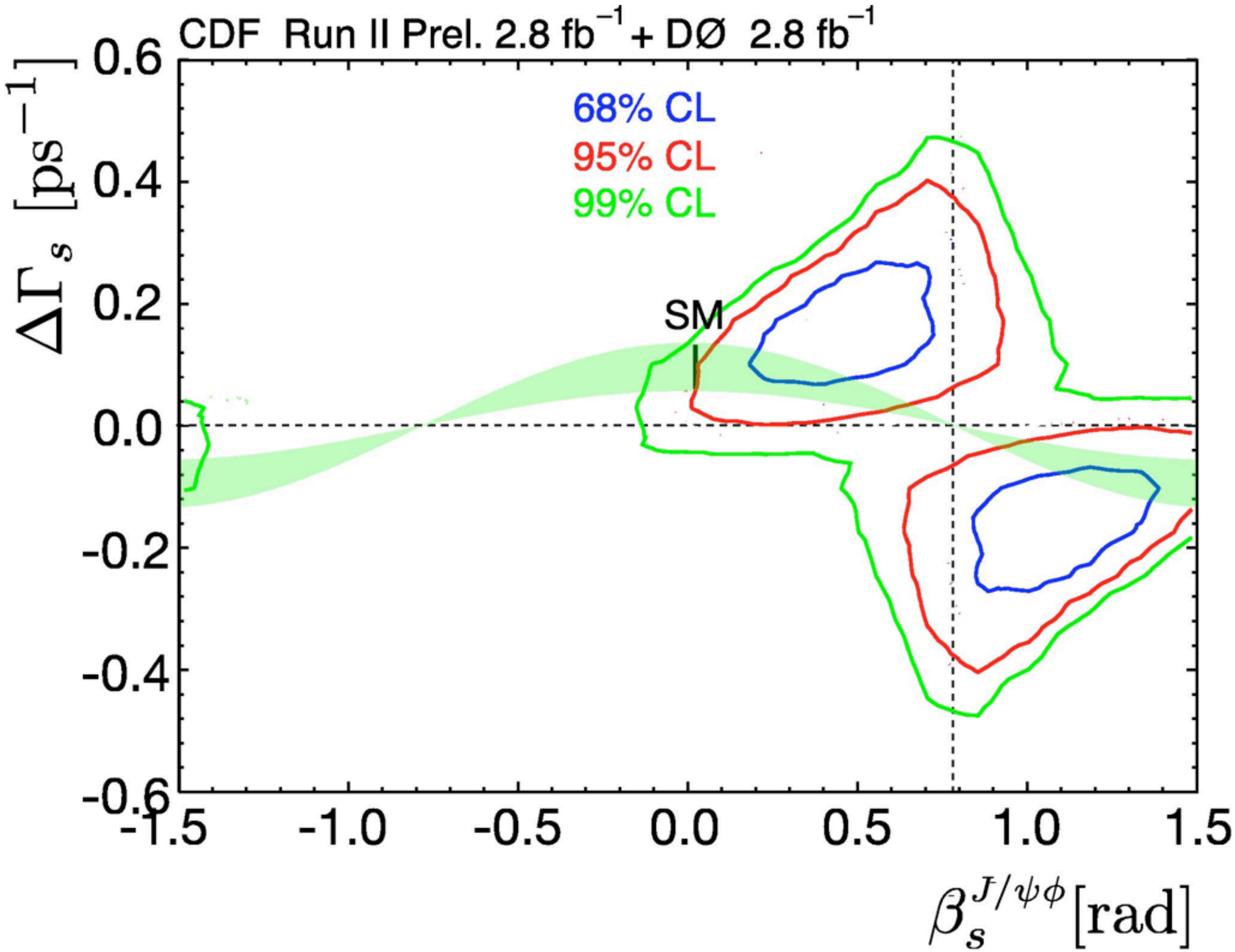
- Uncertainty driven by theoretical calculation of ξ.
- Full Uncertainties (added in naive quadrature)
  - D0 - 4.3% CDF - 3.5%
  - Require theoretical improvements to progress here...

Last Word on Oscillations

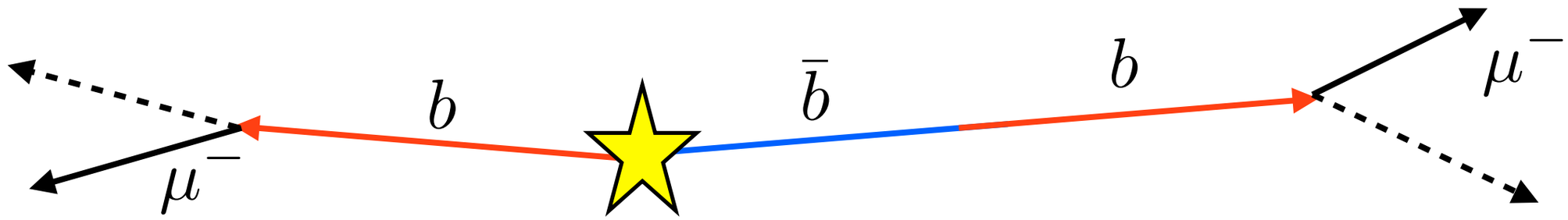


CP Violation

Karen Gibson's Talk



a_{sl}: Dimuons



- Like sign muons indicate an event with mixing
- Measure the Charge asymmetry

$$A^{\mu\mu} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$

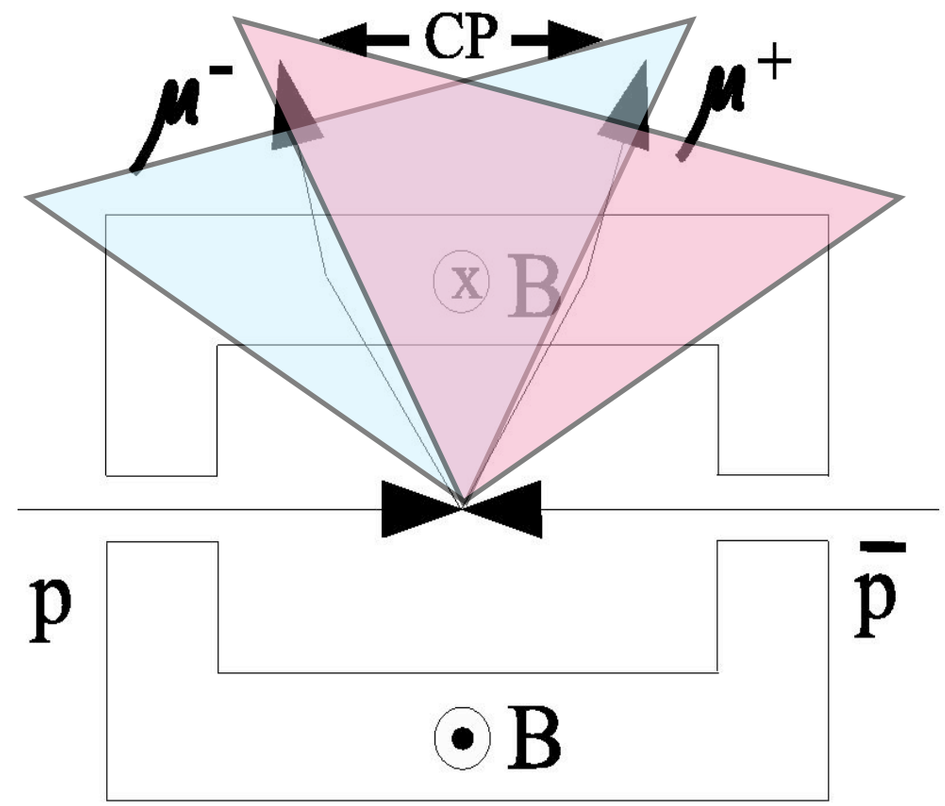
direct-direct	$b \to \mu^-,$	$\bar{b} \to \mu^+$
direct-indirect	$b \to \mu^-,$	$\bar{b} \to \bar{c} \to \mu^+$
direct-prompt	$b \to \mu^-,$	$c \to \mu^+$
prompt-prompt	$c \to \mu^+,$	$\bar{c} \to \mu^-$
$\mu - K^\pm$ decay	$K^- N \to Y\pi$	

Dimuon

$$A^{\mu\mu} = \frac{1}{4f}\left[A^d_{sl} + \frac{f_s\,\langle\chi_s\rangle}{f_d\,\langle\chi_s\rangle}A^s_{sl}\right]$$

- f - contribution from fakes
- χ - mixing probability
- $f_{s,d}$ - fraction of $B_{s,d}$ events

Acceptance



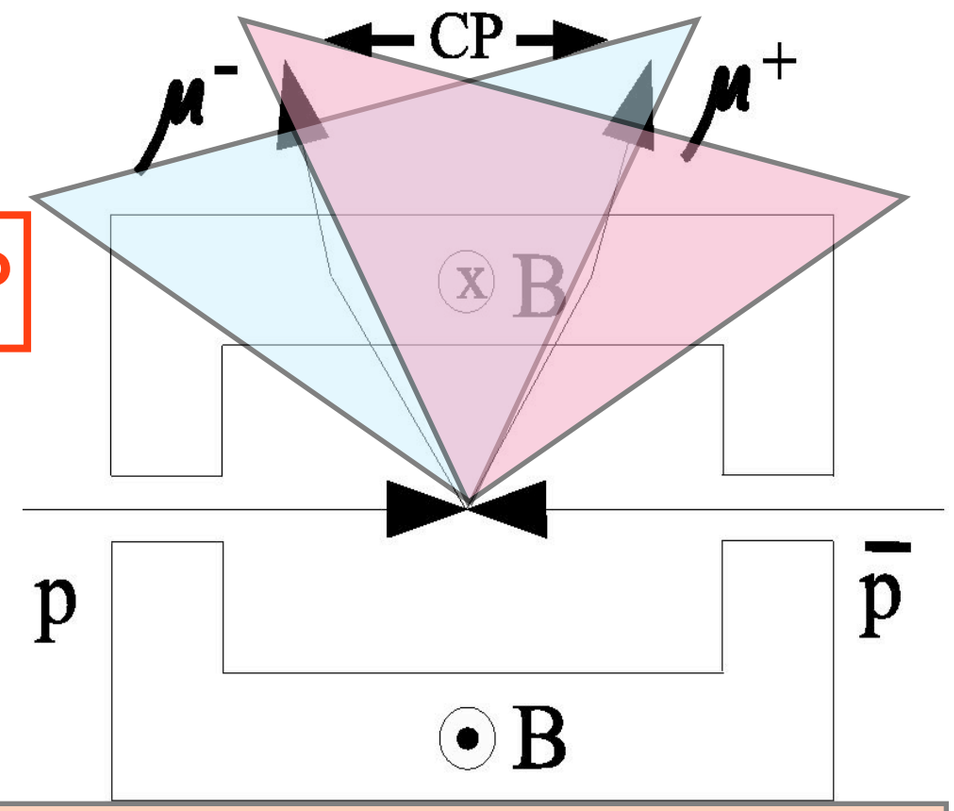
Dimuon

$$A^{\mu\mu} = \frac{1}{4f}\left[A^d_{sl} + \frac{f_s\,\langle\chi_s\rangle}{f_d\,\langle\chi_s\rangle}A^s_{sl}\right]$$

B-factories/LEP

$$A^d_{sl} = -0.0047 \pm 0.0046$$

Acceptance



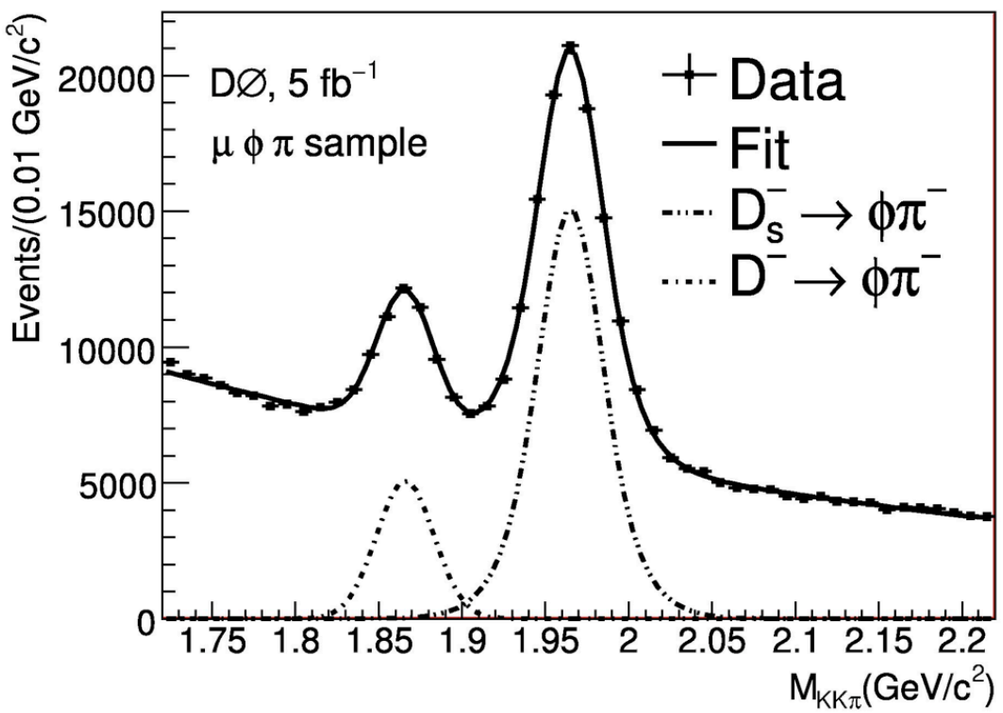
CDF	$A^{\mu\mu}$	$= 0.0080 \pm 0.0090\,(\text{stat}) \pm 0.0068\,(\text{syst})$
CDF/HFAG	A^s_{sl}	$= 0.026 \pm 0.021\,(\text{stat}) \pm 0.017\,(\text{syst})$

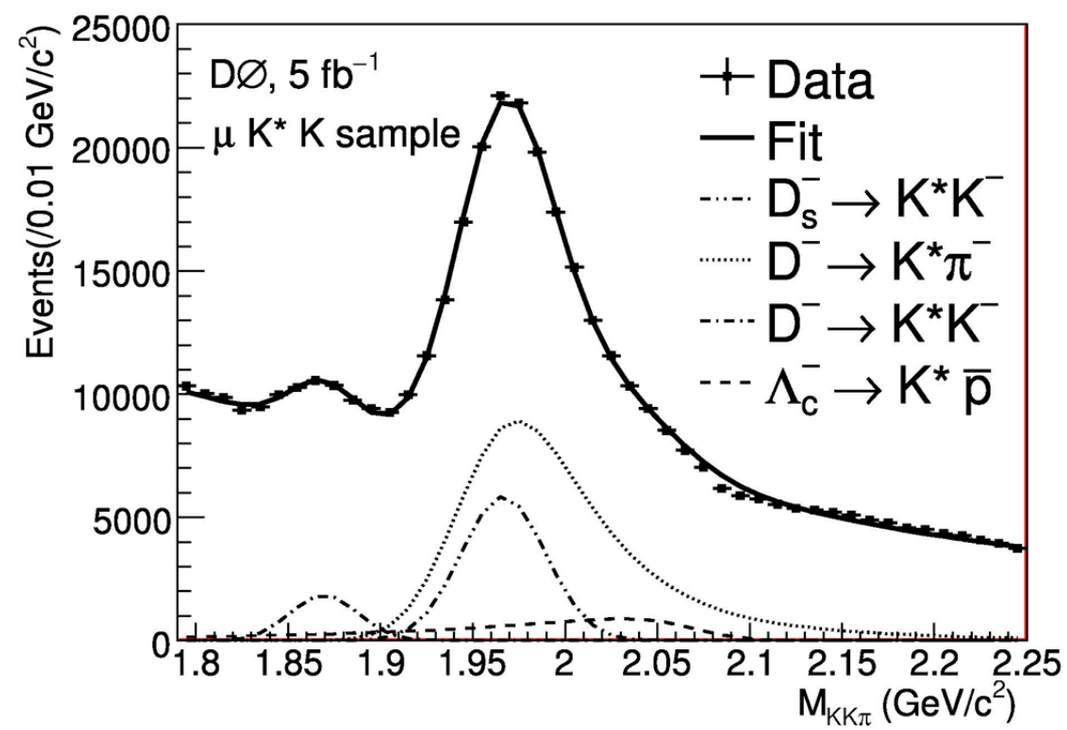
DØ	$A^{\mu\mu}$	$= -0.0028 \pm 0.0013\,(\text{stat}) \pm 0.0090\,(\text{syst})$
DØ/HFAG	A^s_{sl}	$= -0.006 \pm 0.006\,(\text{stat}) \pm 0.008\,(\text{syst})$

$B_s \to D_s^- \mu^+ \nu X$ decays

$$a^s_{fs} = \frac{\Gamma_{\overline{B_s}(t)} - \Gamma_{B_s(t)}}{\Gamma_{\overline{B_s}(t)} + \Gamma_{B_s(t)}} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$$

- New time dependent analysis
  - Removes dependence on B_d result
  - Two reconstructed Decays



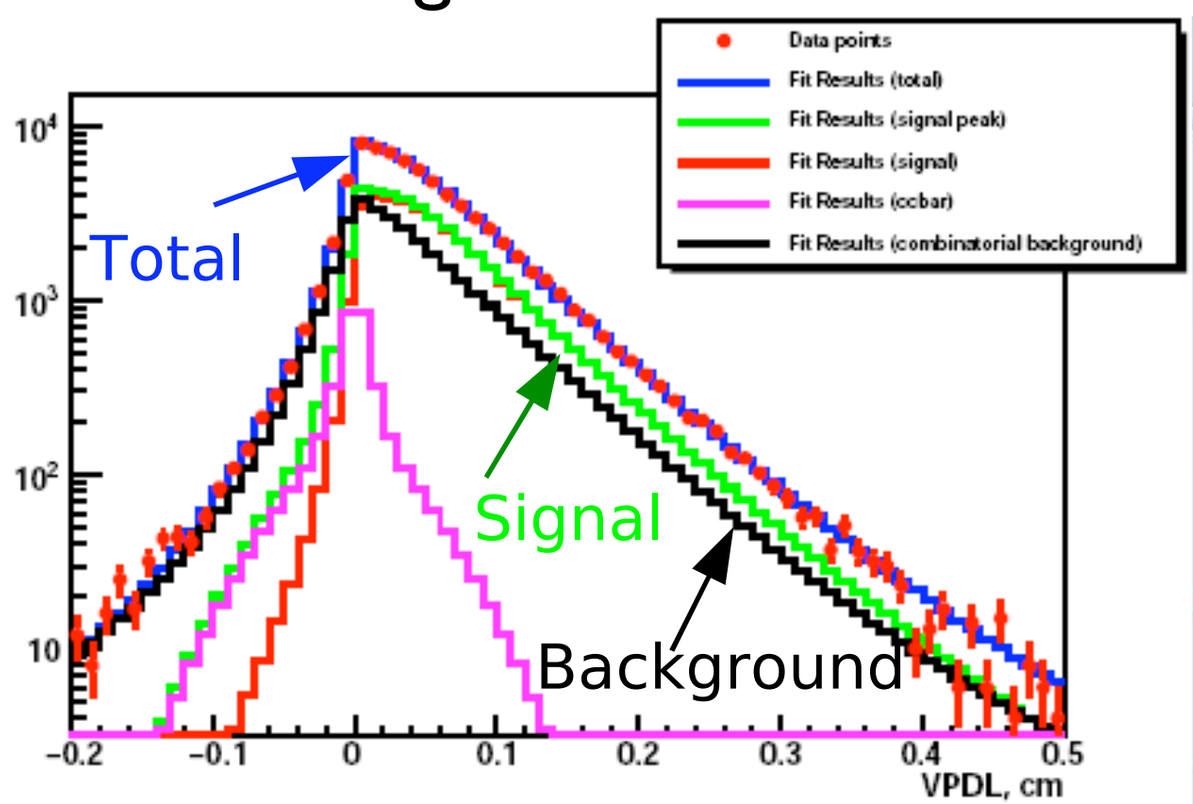


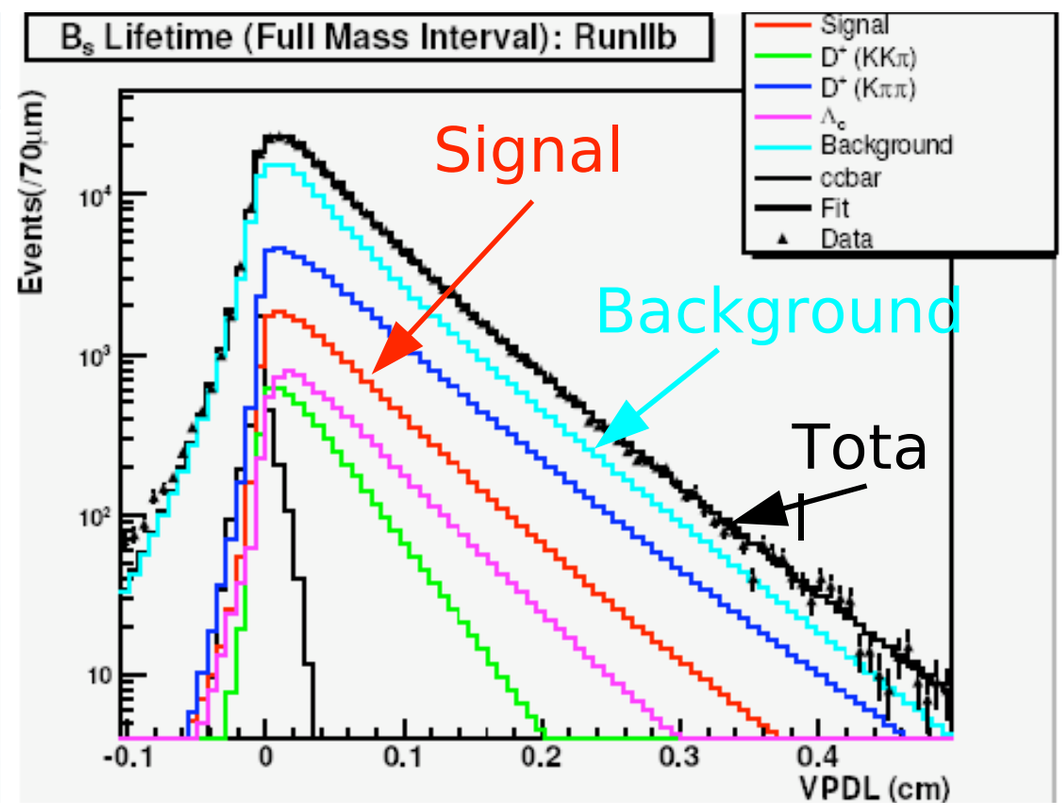
$$D_s^- \to \phi\pi^-; \qquad \phi \to K^+K^-$$
$$D_s^- \to K^{0*}K^-; \qquad K^{0*} \to K^+\pi^-$$

$B_s \to D_s^- \mu^+ \nu X$ decays

$$\Gamma_{B_s(t)\to\bar{f}} = N_f \left|\bar{A}_{\bar{f}}\right|^2 \left(1 - a^s_{fs}\right) \exp\left[-\Gamma_s t \frac{\cosh\left(\Delta\Gamma_s t/2\right) - \cos\left(\Delta m_s t\right)}{2}\right]$$

- Unbinned likelihood fit
  - depends on tagging, decay length, decay length resolution, and background fractions
- Extract Signal Amounts

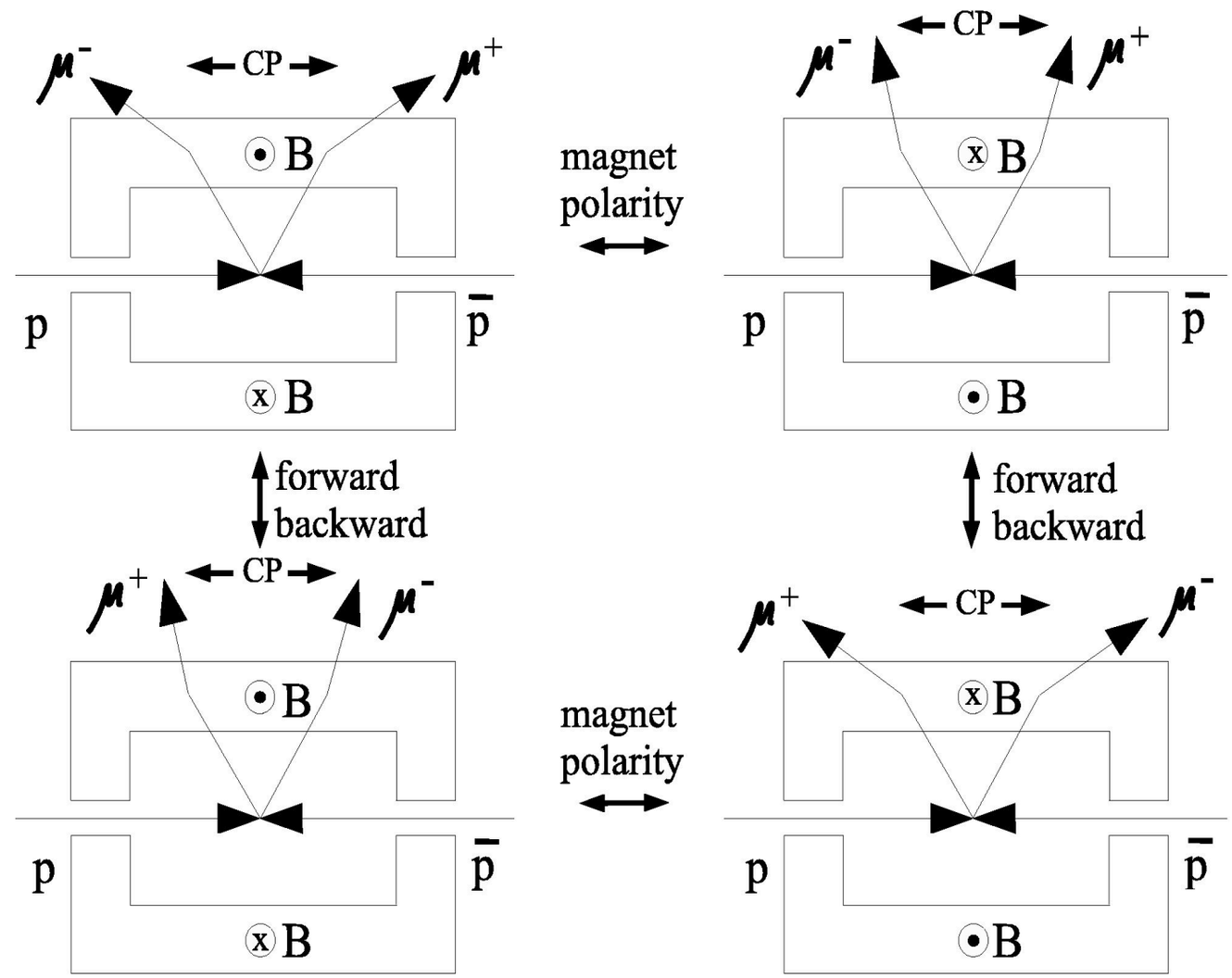




$B_s \rightarrow D_s^- \mu^+ \nu X$ decays

$$n_q^{\beta\gamma} = \frac{1}{4} N e^{\beta} (1 + qA)(1 + q\gamma A_{fb}) (1 + \gamma A_{\rm det})(1 + q\beta\gamma A_{\beta\gamma q})(1 + \beta\gamma A_{\beta\gamma})$$

- Use detector to solve acceptance issues
  - A - a_{sl} - charge asymmetry
  - A_β - Toroid Asymmetry
  - A_γ - North/South detector (A_{det})
  - $A_{q\gamma}$ - Beam related (A_{fb})
  - $A_{q\beta}$ - toroid efficiency
  - $A_{\beta\gamma}$ - forward backward toroid asymmetries
  - $A_{q\beta\gamma}$ - range out asymmetries (A_{ro})
- Have eight samples based on charge of muon, solve.



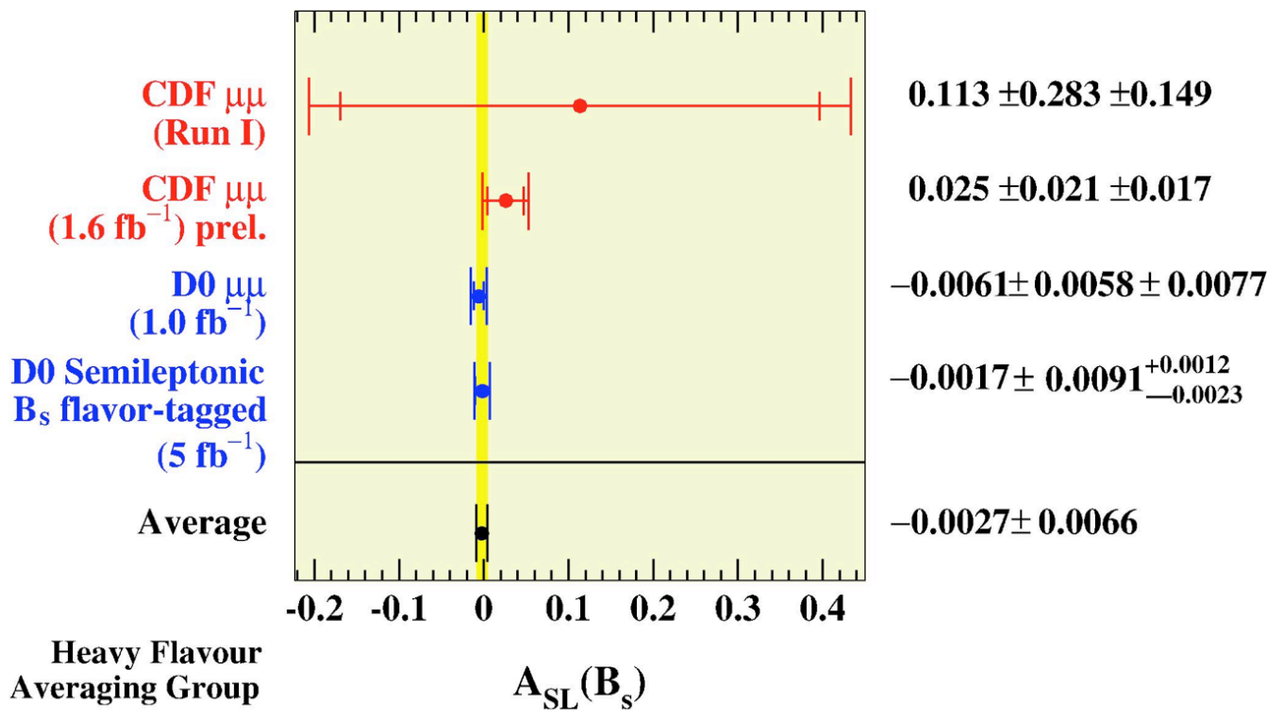
$B_s \to D_s^- \mu^+ \nu X$ decays

Asymmetries with statistical uncertainties			
	$\mu^+\phi\pi^-$	$\mu^+K^{0*}K^-$	Combined
$a^s_{fs} \times 10^3$	-7.0 ± 9.9	20.3 ± 24.9	-1.7 ± 9.1
$a^d_{fs} \times 10^3$	-21.4 ± 36.3	50.1 ± 19.5	40.5 ± 16.5
$a^{\text{bkg.}}_{fs} \times 10^3$	-2.2 ± 10.6	-0.1 ± 13.5	-3.1 ± 8.3
$A_{fb} \times 10^3$	-1.8 ± 1.5	-2.0 ± 1.5	-1.9 ± 1.1
$A_{\text{det}} \times 10^3$	3.2 ± 1.5	3.1 ± 1.5	3.1 ± 1.1
$A_{\text{ro}} \times 10^3$	-36.7 ± 1.5	-30.2 ± 1.5	-33.3 ± 1.1
$A_{\beta\gamma} \times 10^3$	1.1 ± 1.5	0.2 ± 1.5	0.6 ± 1.1
$A_{q\beta} \times 10^3$	4.3 ± 1.5	2.0 ± 1.5	3.1 ± 1.1

$$A^s_{fs} = \left[-1.7 \pm 9.1\,(\text{stat})\,\frac{+1.2}{-2.3}\,(\text{sys})\right] \times 10^{-3}$$

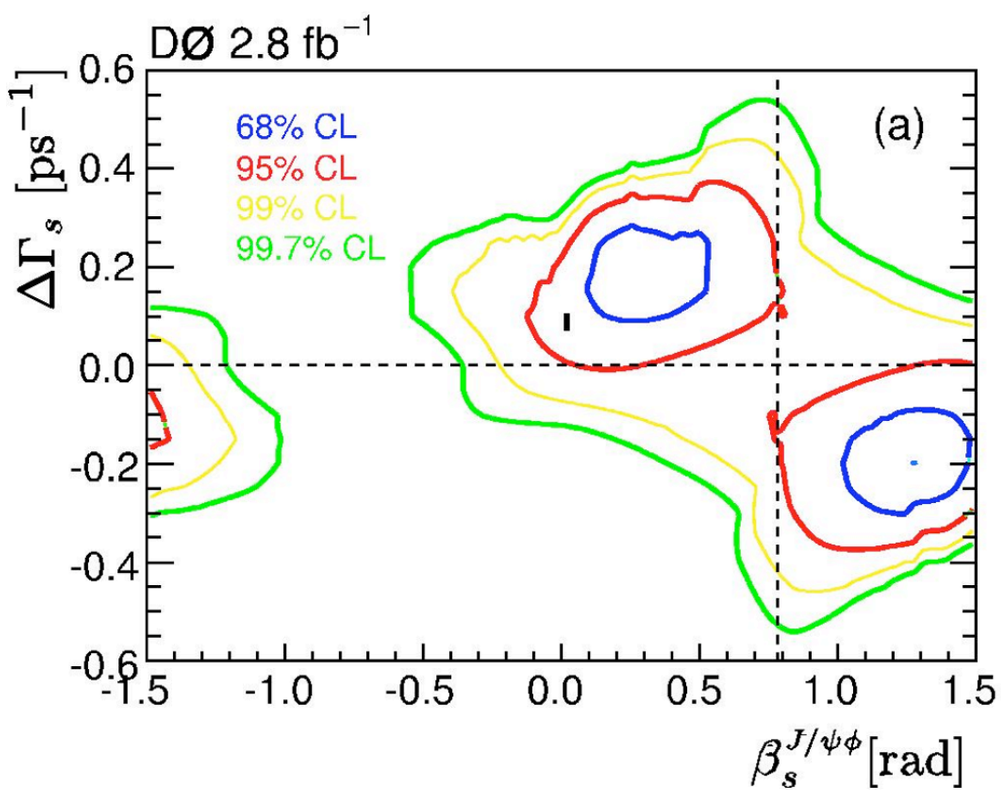
Factor 2 improvement over previous result.

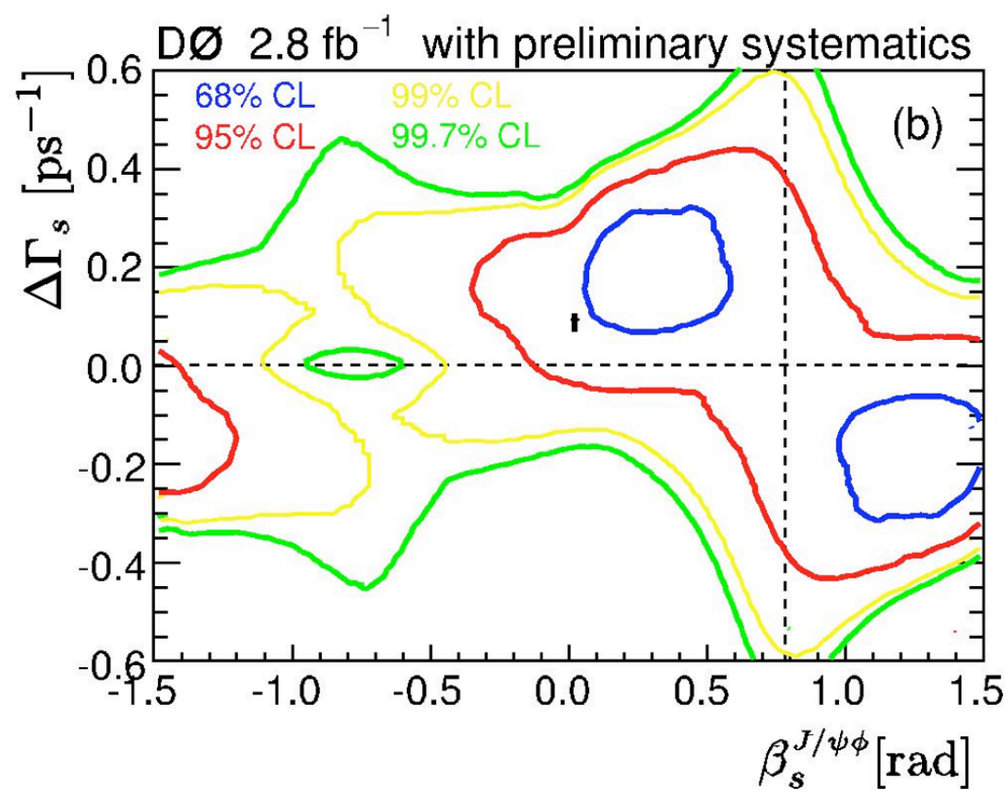
DØ Combination with J/Ψϕ



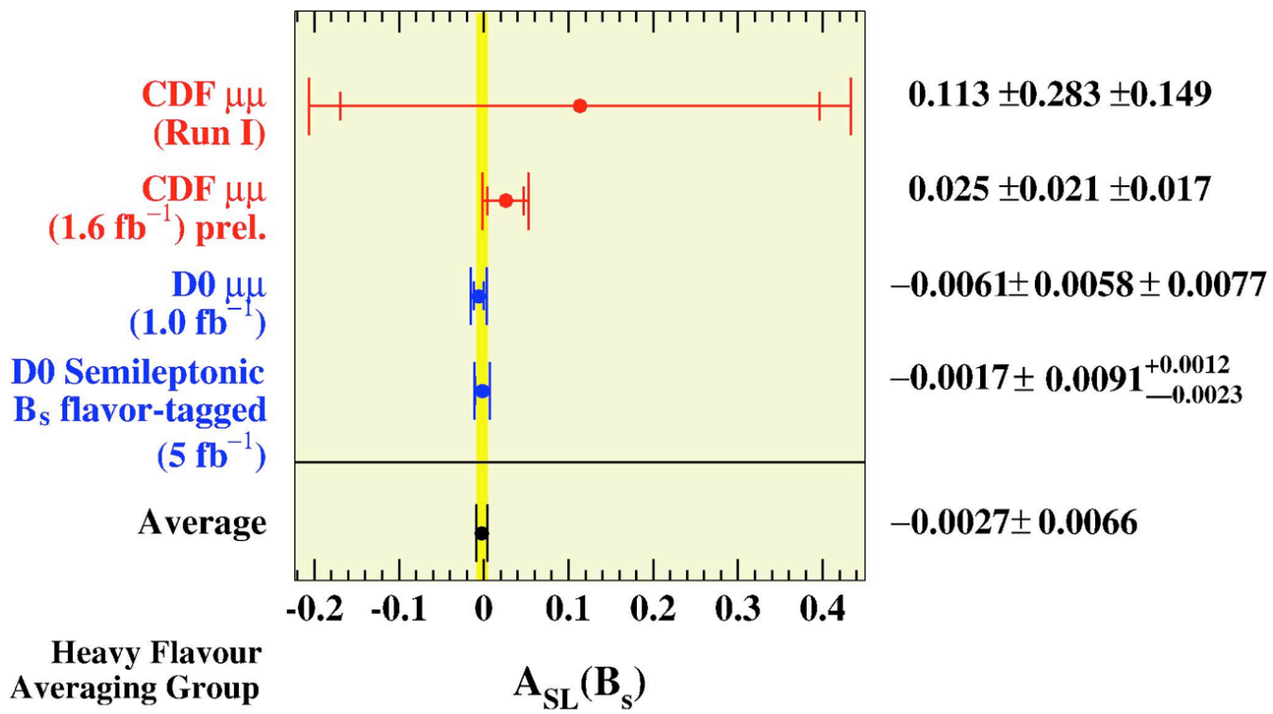
- Combine the two A_{sl} results and combine with the J/Ψϕ result (D0 only)

$$a^s_{fs} = \frac{\Gamma_{\overline{B_s}(t)} - \Gamma_{B_s(t)}}{\Gamma_{\overline{B_s}(t)} + \Gamma_{B_s(t)}} = \frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s$$





DØ Combination with J/Ψϕ



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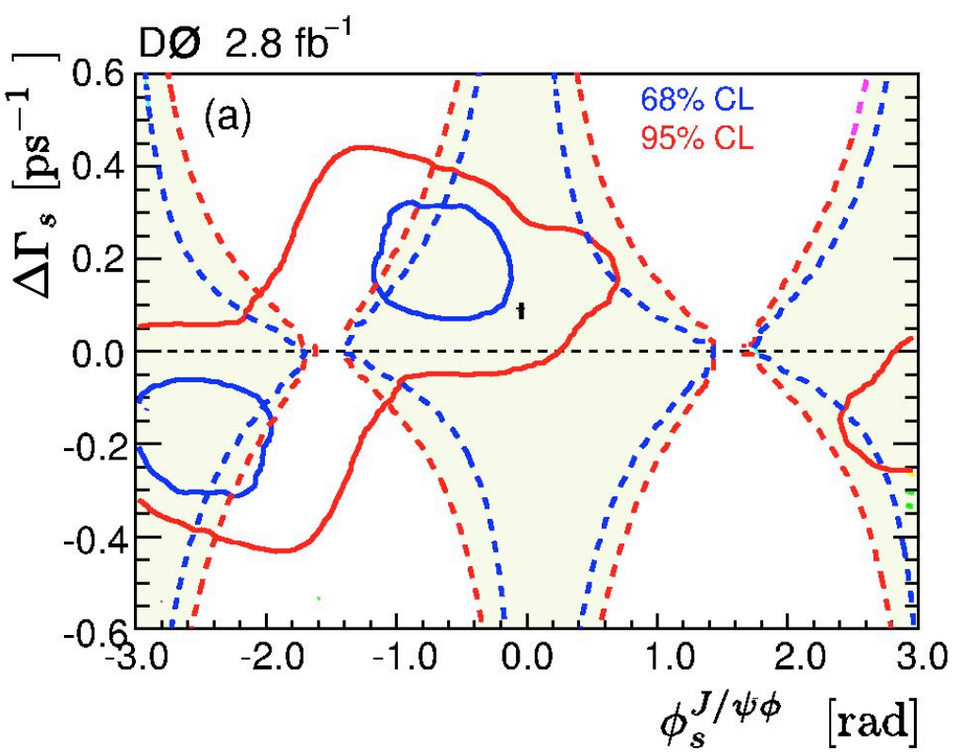
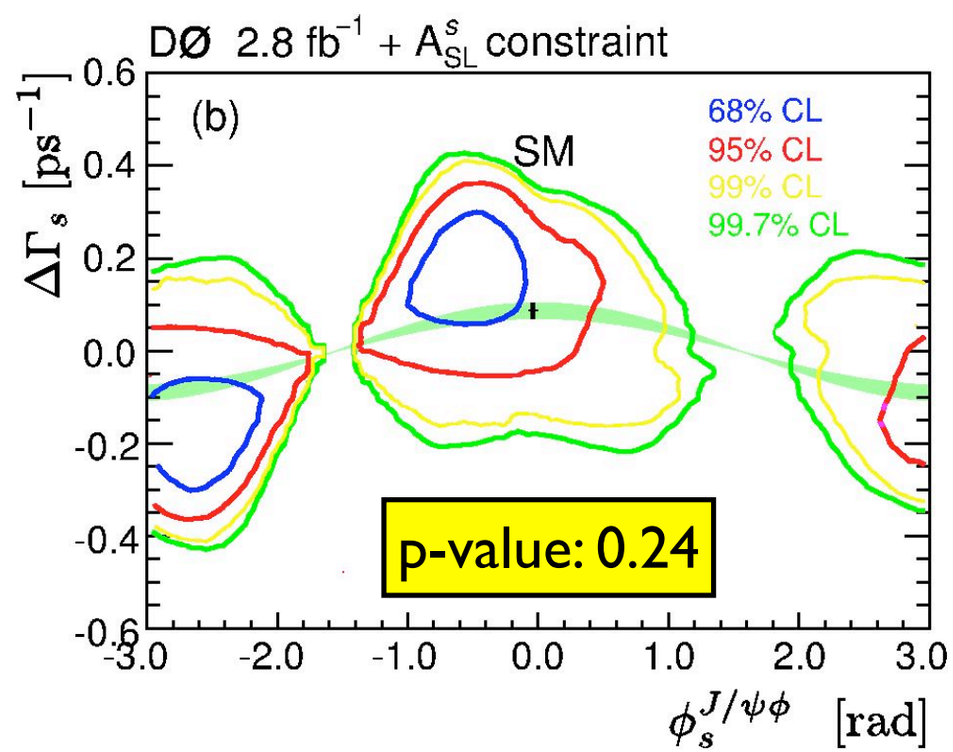
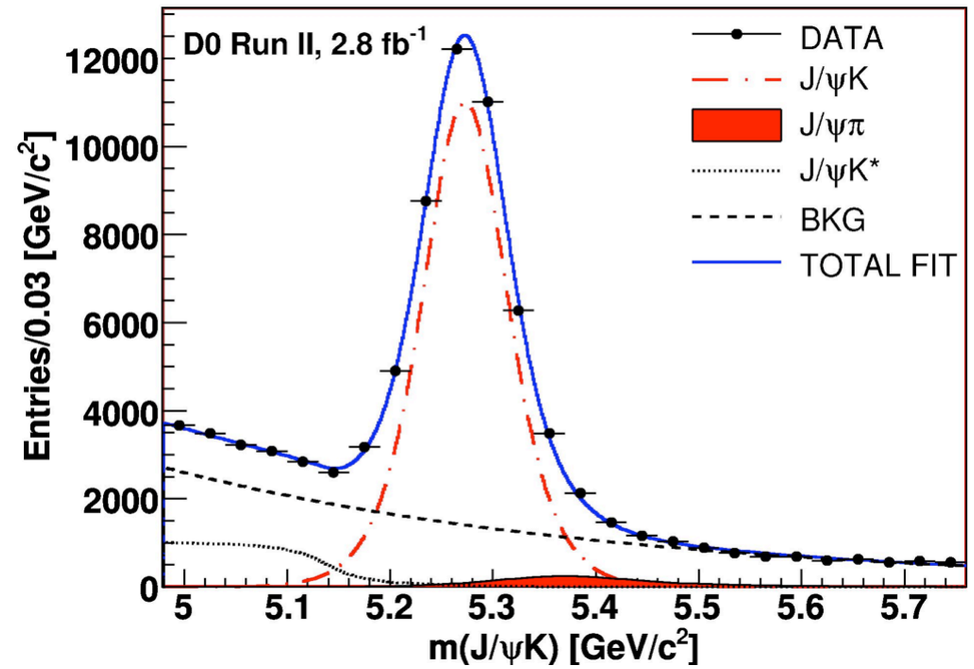


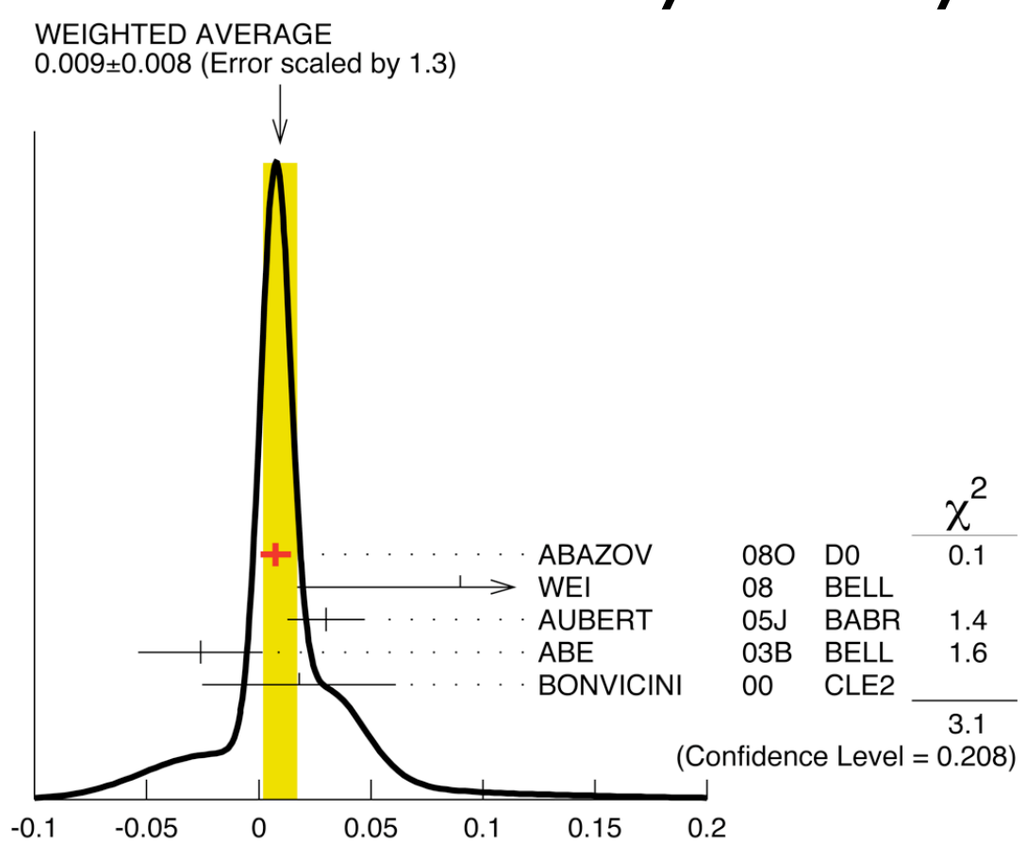


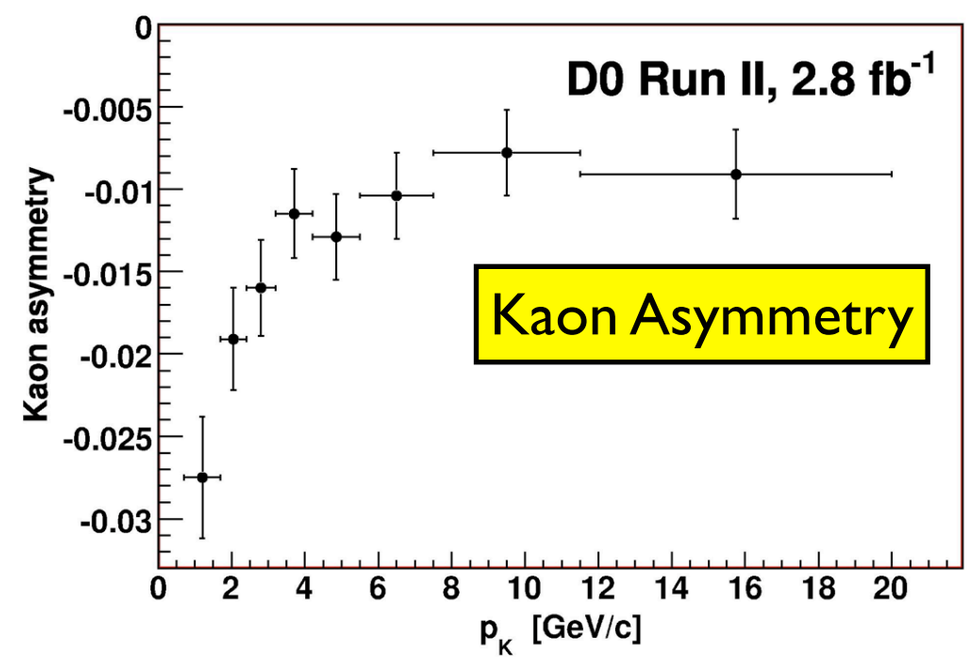
Aside: $B^+ \rightarrow J/\Psi K^+$ Decays

$$A_{CP}\left(B^+ \rightarrow J/\Psi K^+\right) = -0.0075 \pm 0.0061\,(\text{stat}) \pm 0.027\,(\text{sys})$$
$$A_{CP}\left(B^+ \rightarrow J/\Psi \pi^+\right) = -0.09 \pm 0.08\,(\text{stat}) \pm 0.03\,(\text{sys})$$

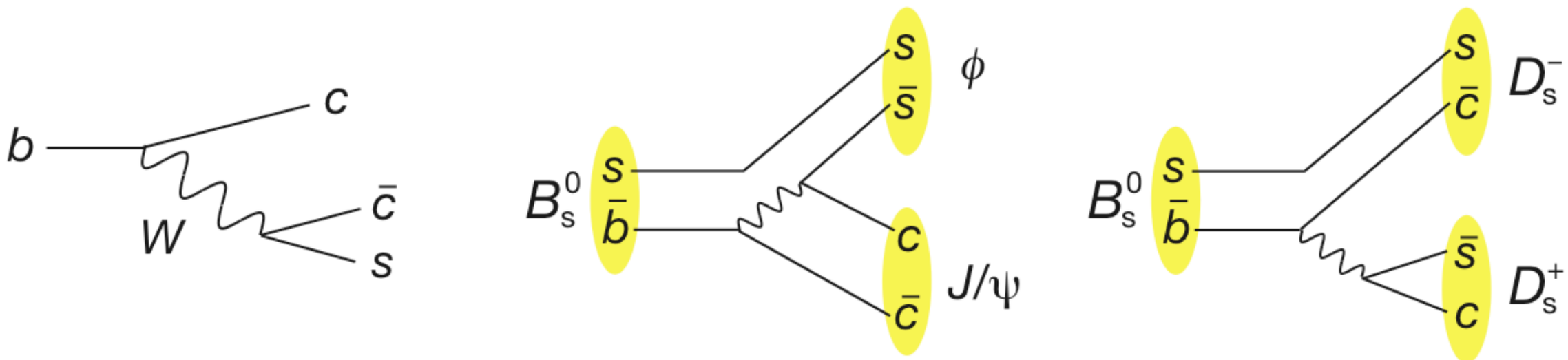
- Makes use of same detector model to solve for detector asymmetries
- Subtract Kaon asymmetry







$B_s \to D^{(*)}_s D^{(*)}_s$



- $B_S \to D_s^{(*)} D_s^{(*)}$ is almost a pure CP-even (theory assumptions)

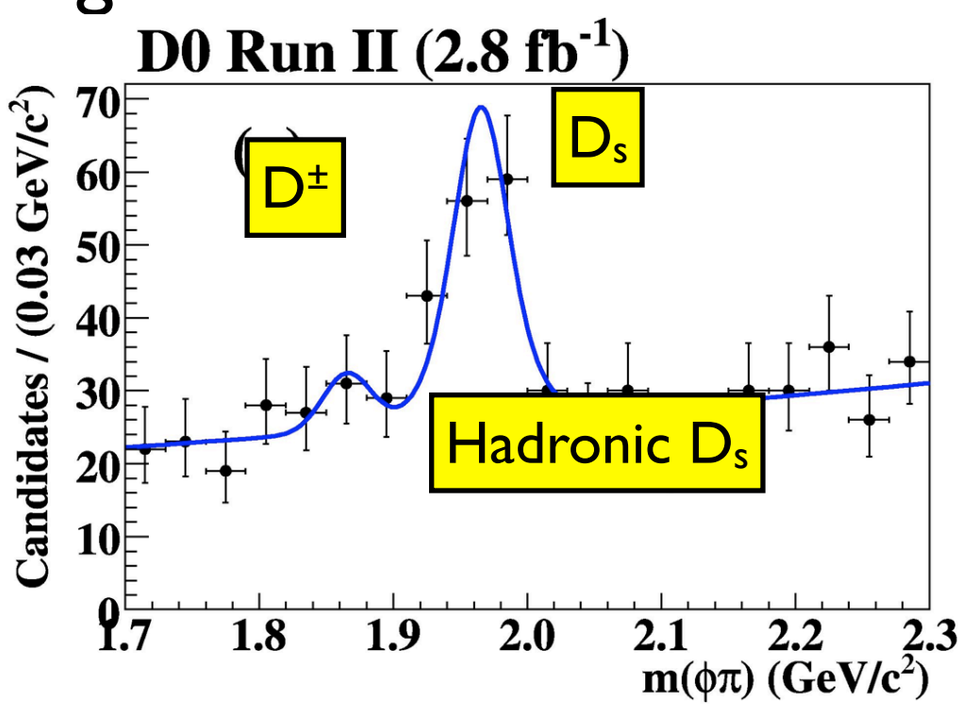
$$\frac{\Delta\Gamma_s^{\mathrm{CP}}}{\Gamma_s} \simeq \frac{2\mathcal{B}\left(B_s \to D_s^{(*)} D_s^{(*)}\right)}{1 - \mathcal{B}\left(B_s \to D_s^{(*)} D_s^{(*)}\right)}$$

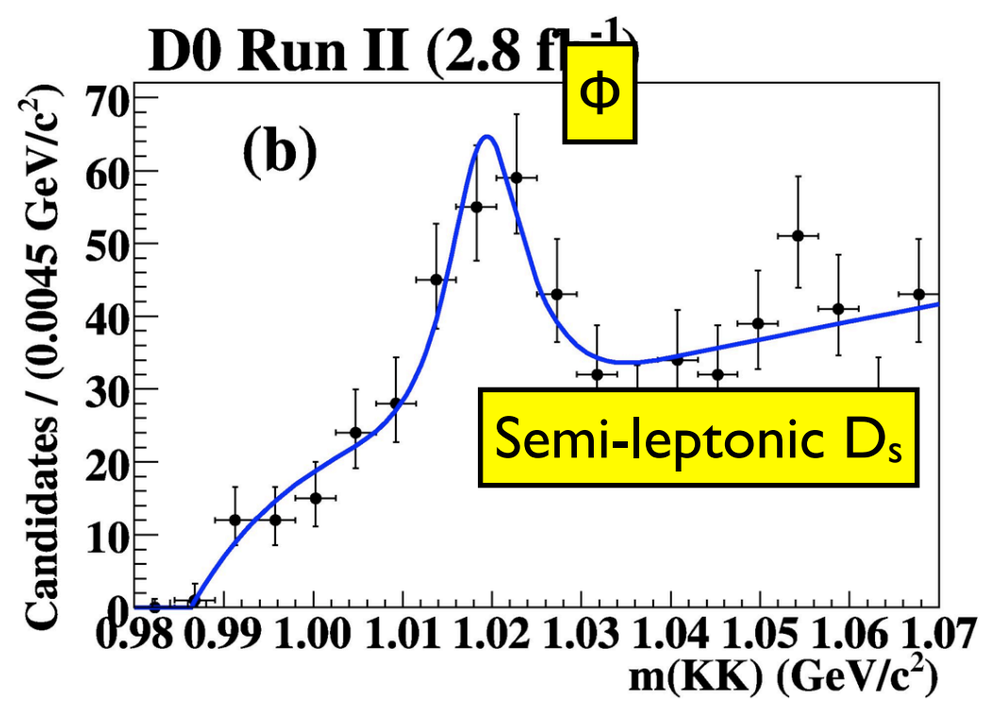
- Select events in both the hadronic & semi-leptonic channels:

$$D_s \to \phi\pi \qquad \text{where } \phi \to K^+K^-$$
$$D_s \to \phi\mu\nu \qquad \text{where } \phi \to K^+K^-$$

$B_s \to D^{(*)}_s D^{(*)}_s$

- Fit to 2-dim. distribution m(φπ) of hadronic D_s vs. m(KK) of semi-leptonic Ds. 4 components:
  - Correlated D_sD_s signal,
  - (2×) uncorrelated D_s signal with D_s background,
  - correlated D_sD_s background
  - cc, $B_s \to D_s^{(*)}\varphi\mu\nu$, $B_s \to D_s^{(*)}D_s^{(*)}KX$)
- Signal template extracted from $B_s \to D_s^{(*)}\mu\nu$ by removing peaking backgrounds





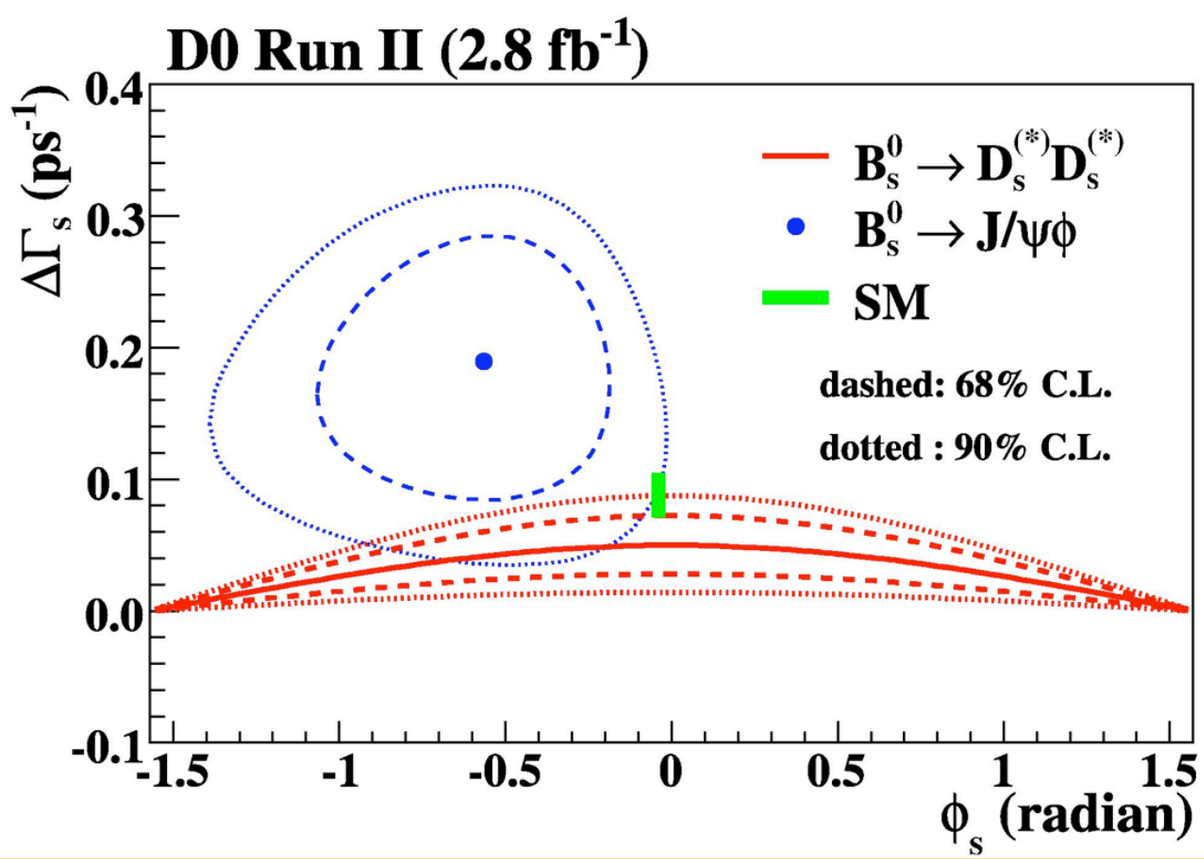
26.6 ± 8.4 signal events (3.2σ)

Extraction of $\Delta\Gamma_s^{CP}/\Gamma_s$

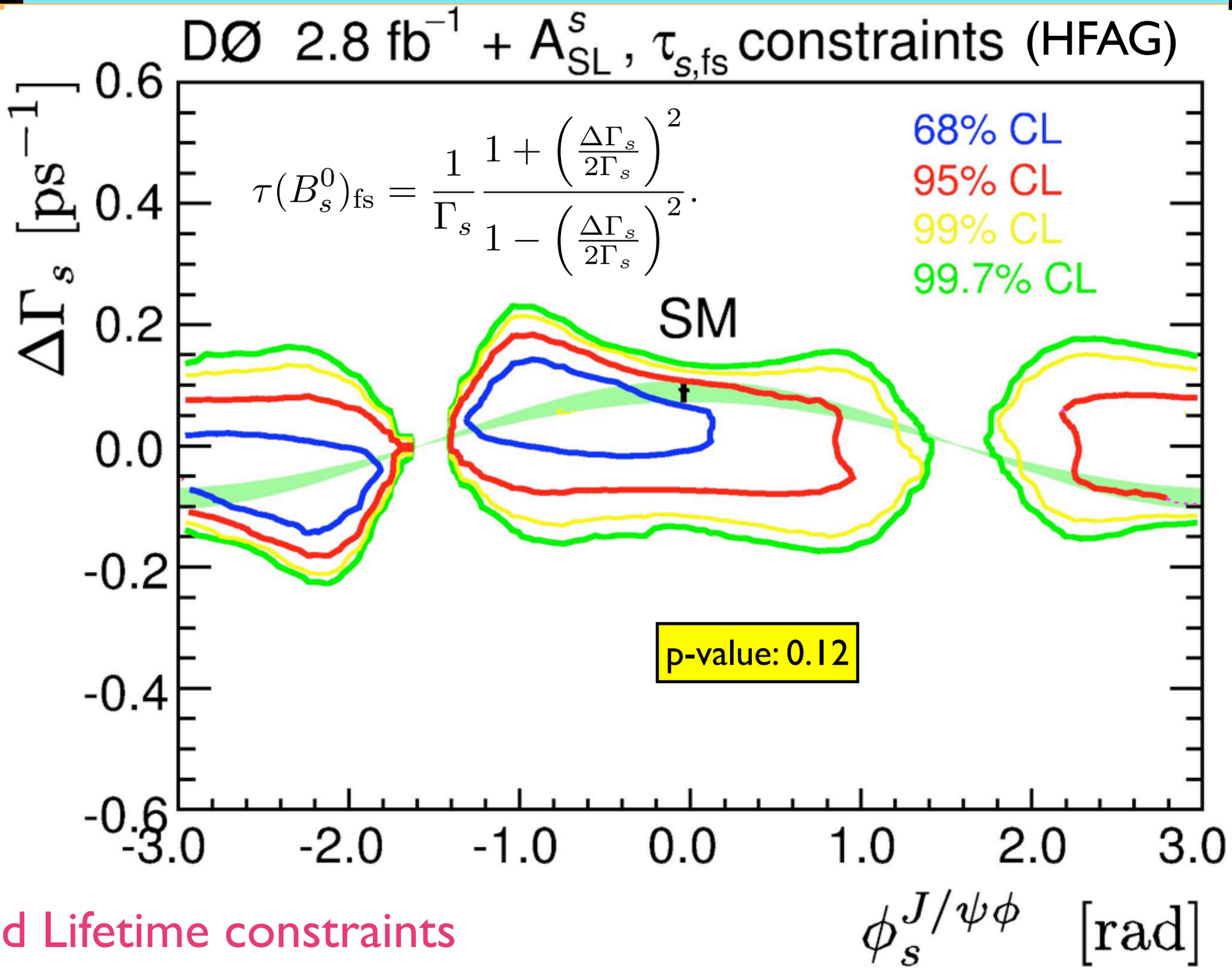
$$\mathcal{B}\left(B_s \to D_s^{(*)} D_s^{(*)}\right) = 0.035 \pm 0.010\,(\text{stat}) \pm 0.008\,(\text{exp syst}) \pm 0.007\,(\text{ext syst})$$

- Using heavy quark hypothesis (Phys. Lett. B316 (1993) 567) and assuming no CP-odd component obtain $\Delta\Gamma_s^{CP}$:

$$\frac{\Delta\Gamma_s^{\text{CP}}}{\Gamma_s} \simeq \frac{2\mathcal{B}\left(B_s \to D_s^{(*)} D_s^{(*)}\right)}{1 - \mathcal{B}\left(B_s \to D_s^{(*)} D_s^{(*)}\right)} = 0.072 \pm 0.021\,(\text{stat}) \pm 0.022\,(\text{syst})$$

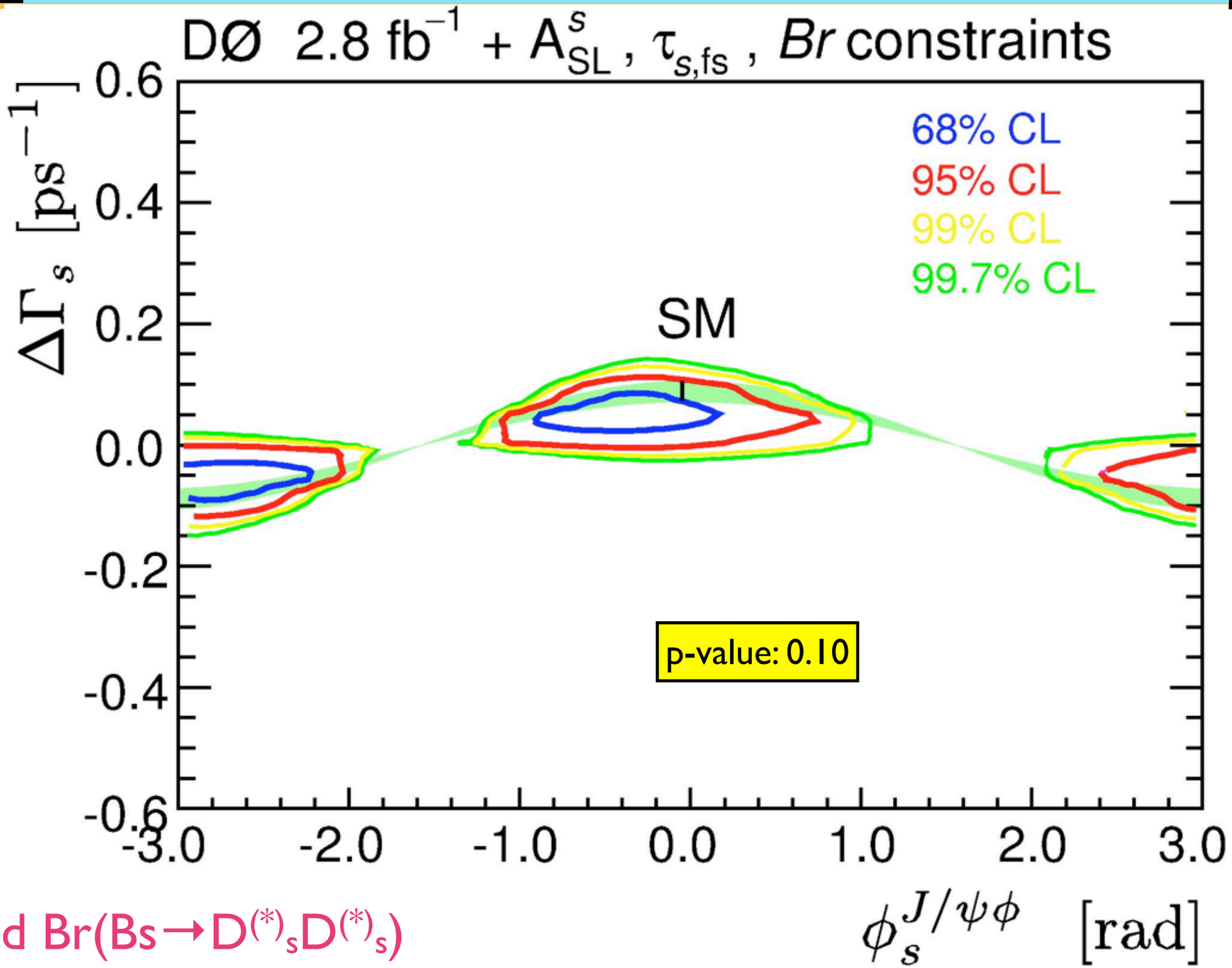


Combination of Results



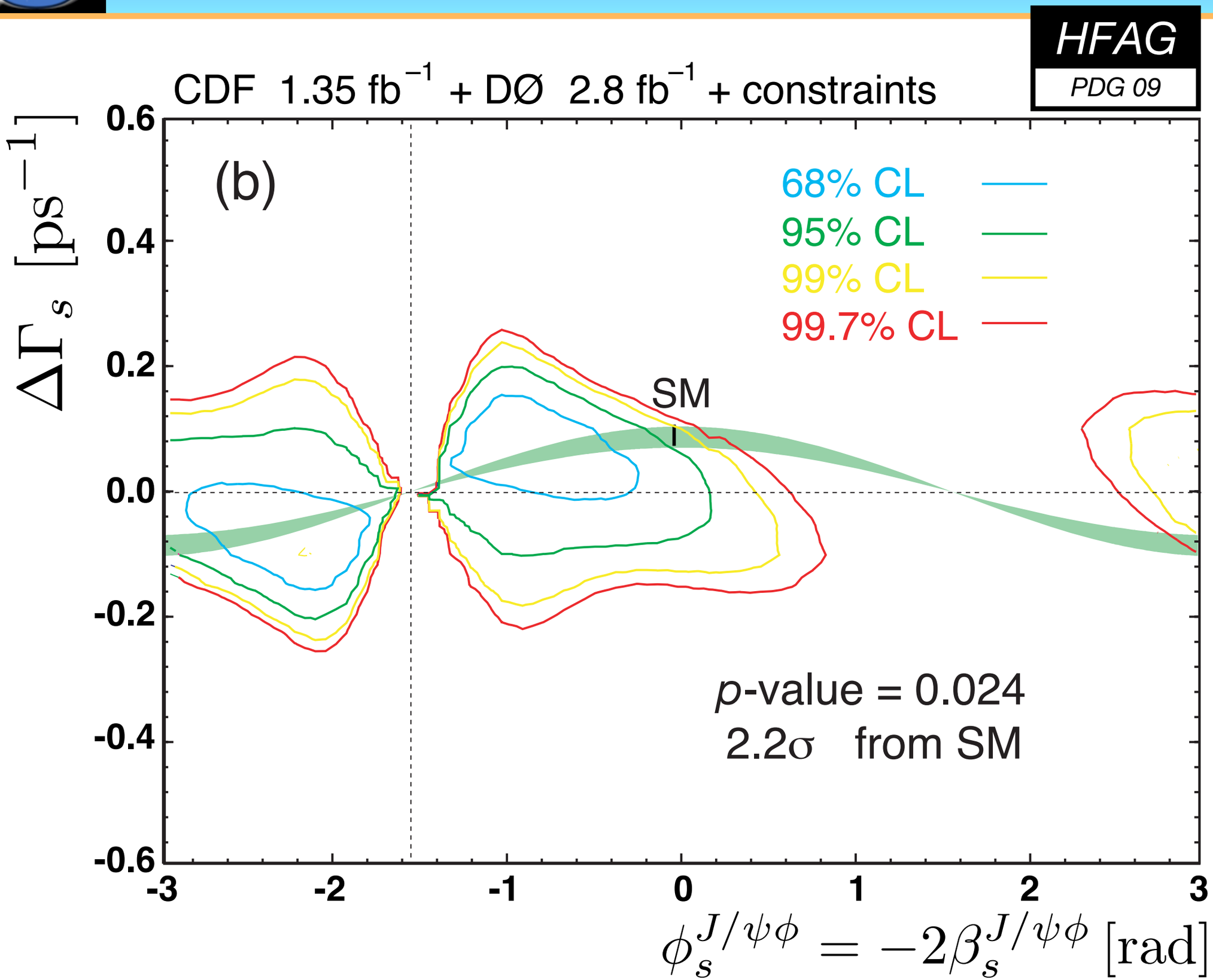
- Add Lifetime constraints

Combination of Results



- Add Br(Bs→$D^{(*)}_s D^{(*)}_s$)

HFAG with published results



Last Words

B_s Mixing Observation essentially unchanged.....
(Largely limited by theory, expect to be confirmed by LHC)

Tevatron has extensive programme of CP violation measurements in B_s, B_d, and B^+.

- Make the most of advantages of high production cross sections and detector choices.
- Expect updates to A_{sl} in di-muons, B^+, etc. in the near future
- Additional data pouring in ... Expect many improvements over next couple of years.