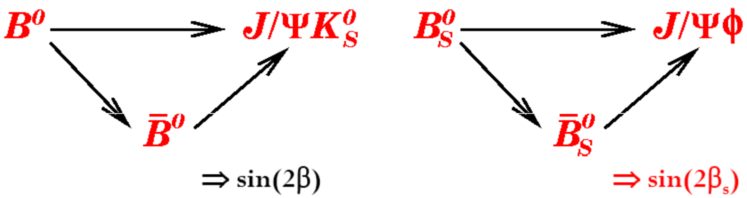
TEVATRON: THE LAST ROUND

Aurore Savoy-Navarro, CNRS-IN2P3, France

Bs-CPV remaining puzzles: comparison between CDF and D0

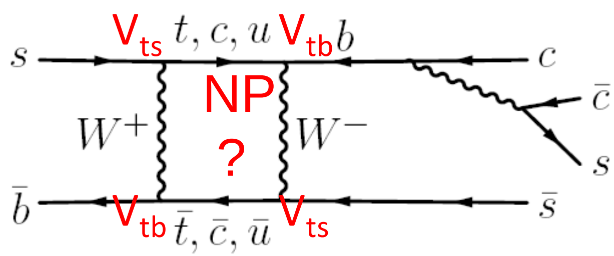
Miniworkshop on BSM at the LHC era, KIAS, Seoul, Korea, March 10, 2011

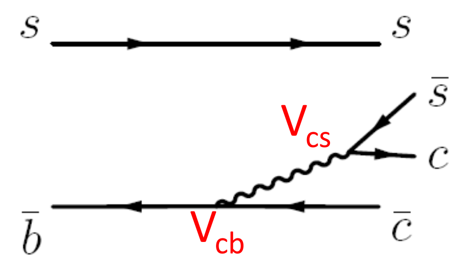
Search for New Physics in Bs Mixing

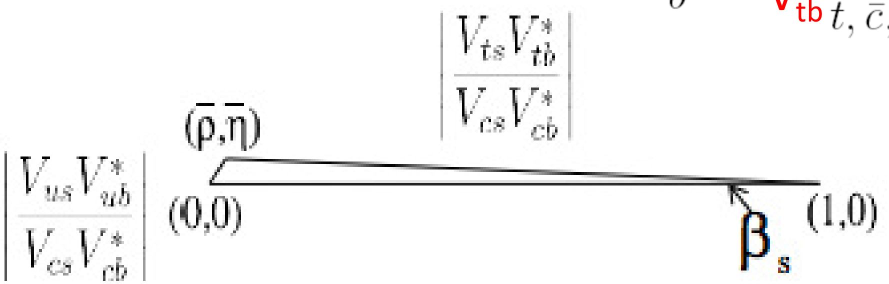


Analogously to the neutral Bo system, CP Violation in Bs system occurs through interference of decays with or without mixing

Dominant top quark contribution







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

- *CP* violation phase β_s in SM is predicted to be very small, *$O(\lambda^2)$*
- New physics particles running in the mixing diagram may enhance *β:* large β_s => clear indication of New Physics

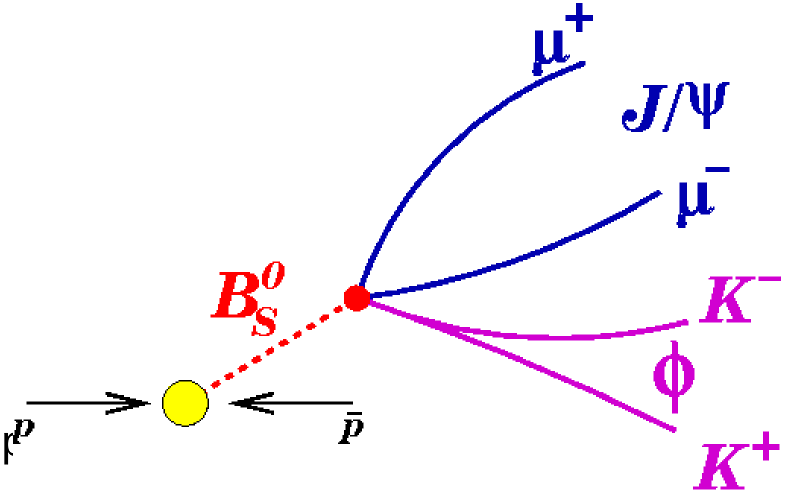
Bs→J/Ψφ is golden mode, but additional experimental complications:

J/ψϕ: a mix of CP-even and CP-odd eigenstates, treat them separately

B_s oscillates ~ 35 times faster than B^0

sin2β~0.7, sin2β_s expected about 20 times smaller

$B_s \rightarrow J/\Psi\Phi$ Decays



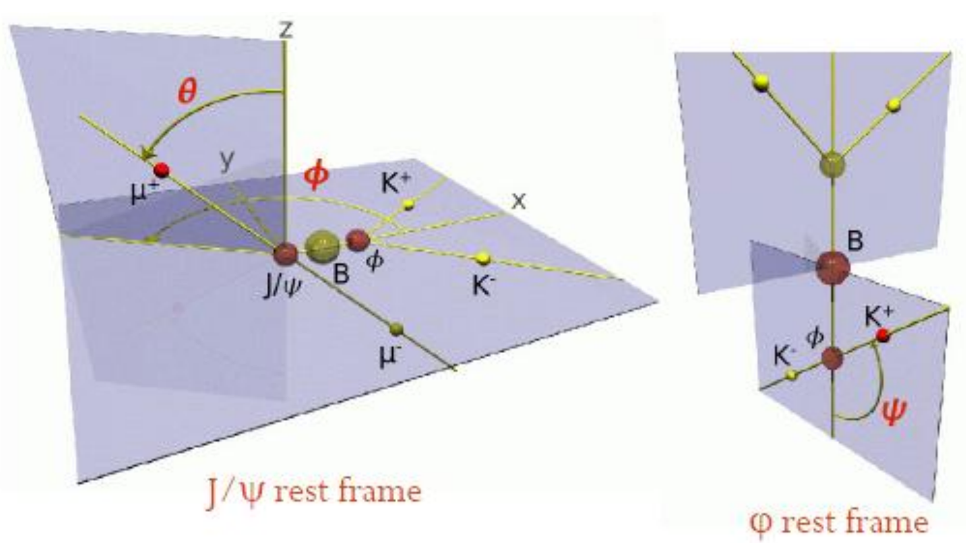
- Extremely physics rich decay mode

- Can measure lifetime, decay width difference $\Delta\Gamma$ and *CP* violating phase β_s

- Decay of B_s (spin 0) to J/Ψ (spin 1) and Φ (spin 1) angular momentum final states:

$L = 0$ (s-wave), 2 (d-wave) → *CP even* (= short lived or light B_s if no *CPV*)

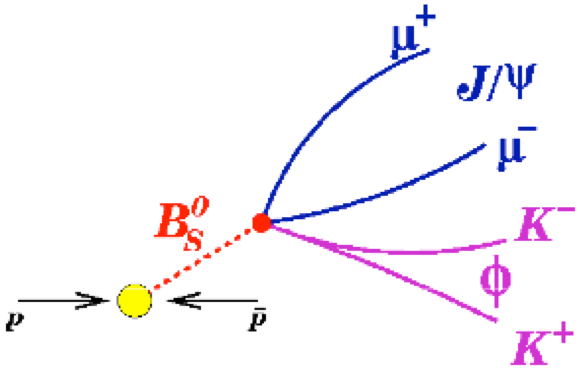
$L = 1$ (p-wave) → *CP odd* (= long lived or heavy B_s if no *CPV*)



- Three decay angles $\vec{\rho} = (\theta, \phi, \psi)$ describe directions of final decay products $\mu^+ \mu^- K^+ K^-$

CURRENT ANALYSIS OUTLINE

Reconstruct Bs→J/ψ(→μ+μ-) φ(→K+K-)



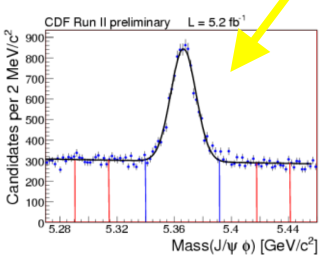
DIMUONS TRIGGER

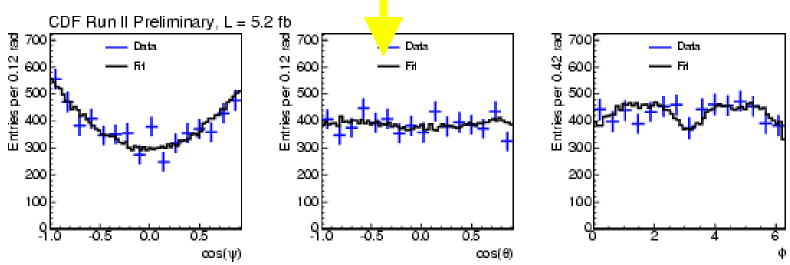
NN SELECTION

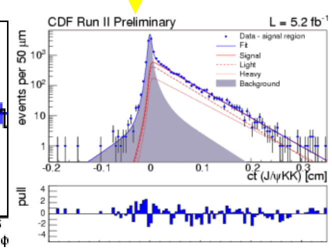
Simultaneous mass, angular, time dependent, flavour tagged fit:

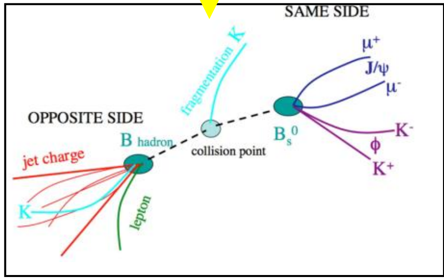
$$f_s P_s(m|\sigma_m) P_s(t, \vec{\rho}, \xi | \mathcal{D}, \sigma_t) P_s(\sigma_t) P_s(\mathcal{D})$$

Bs mass fit to Separate signal from background	Angular separation of CP eigenstates	Time dependence of decay	Flavour tagging to separate Bs and Anti-Bs decays



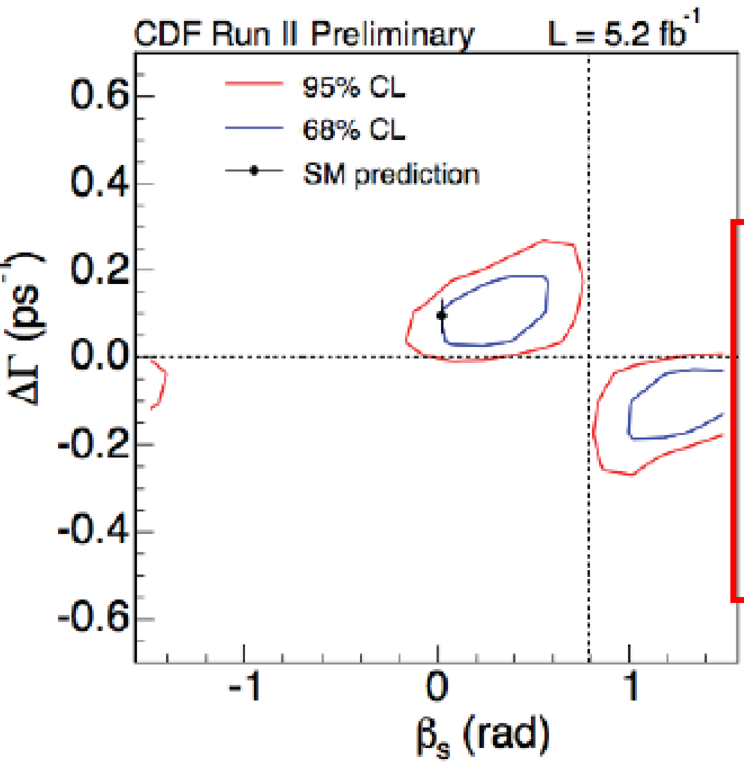






N.B. All based on quantities directly derived from data!!

RESULTS and 2011 PROSPECTS



Flavour tagged fit with sin2βs set to 0 (i.e. SM)

PDG value: $\tau_s = 1.47^{+0.026}_{-0.027}$ ps

$$c\tau_s = 458.6 \pm 7.5\ (\text{stat.}) \pm 3.6\ (\text{syst.})\ \mu\text{m}$$

$$\Delta\Gamma = 0.075 \pm 0.035\ (\text{stat.}) \pm 0.01\ (\text{syst.})\ ps^{-1}$$

$$|A_{\parallel}(0)|^2 = 0.231 \pm 0.014\ (\text{stat}) \pm 0.015\ (\text{syst.})$$

$$|A_0(0)|^2 = 0.524 \pm 0.013\ (\text{stat}) \pm 0.015\ (\text{syst.})$$

$$\phi_{\perp} = 2.95 \pm 0.64\ (\text{stat}) \pm 0.07\ (\text{syst.})$$

World's more precise single measurement of Bs lifetime and decay width difference

P-value for SM point: 44% ***(0.8σ dev.)***

[0.02,0.52]U[1.08,1.55] 68% C.L.

[-0.13,0.68]U[0.89,π/2]U [-π/2, -1.44] 95% C.L.

- ***Agreement with SM expectation increases with higher statistics***
- ***β_s and $\Delta\Gamma$ allowed parameter space greatly reduced***

Prospects for 2011:

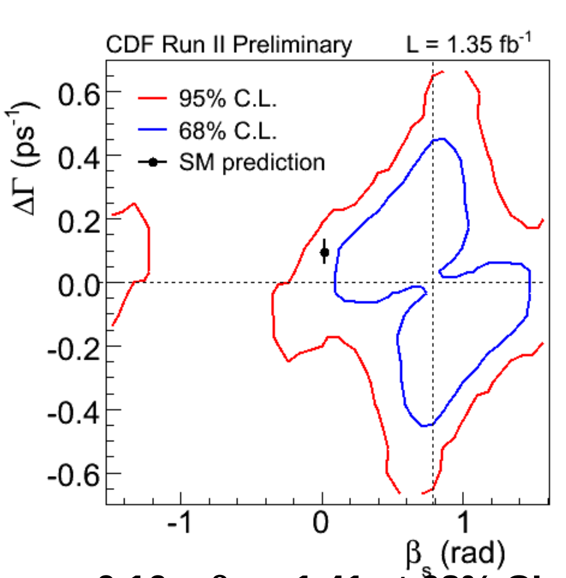
- Doubling the statistics on dimuons data
- Add new data from other processes and triggers

Evolution of the Results with increased data set

- Agreement with SM expectation increases with higher statistics

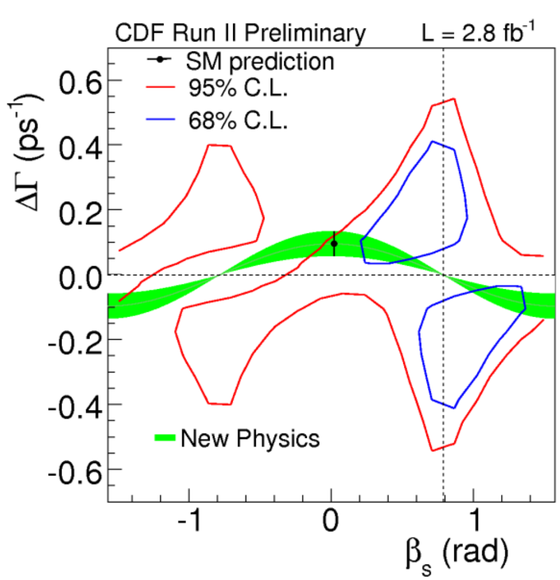
- β_s and $\Delta\Gamma$ allowed parameter space greatly reduced

Initial result released at the end of 2007, ~2000 signal events



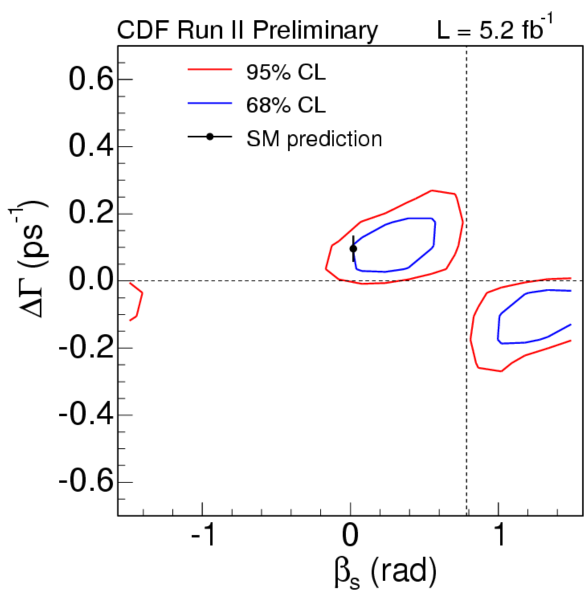
$0.16 < \beta s < 1.41$ at 68% CL

2008 ICHEP update with sub-optimal PID and tagging ~3150 signal events



$0.28 < \beta s < 1.29$ at 68% CL

ICHEP 2010 update
With improved analysis
~6500 signal events

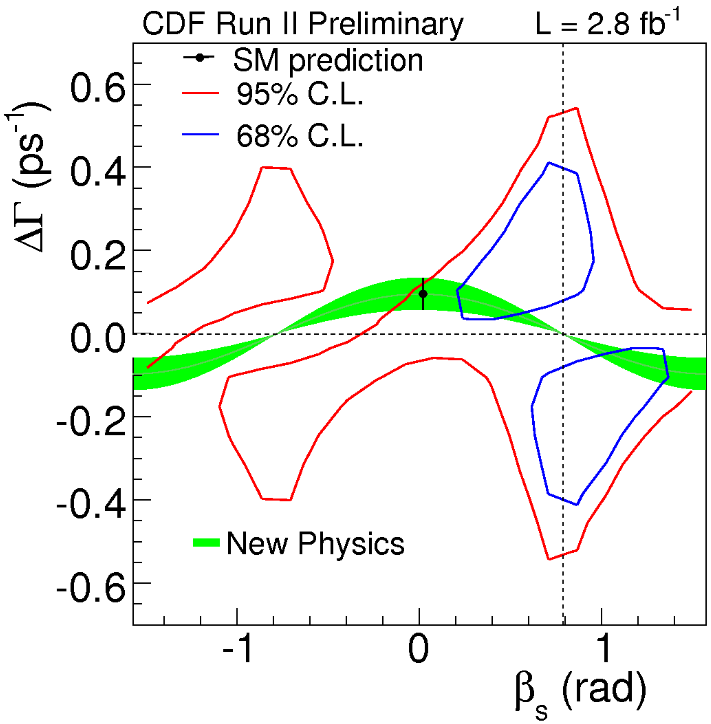


[0.02, 0.52] U [1.08, 1.55] at 68% CL

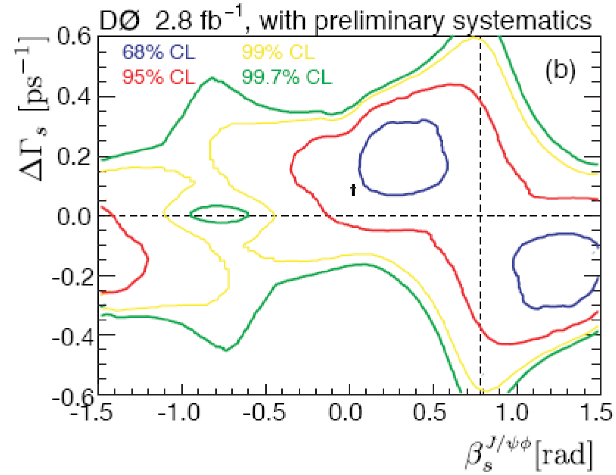
Agreement with SM: → **15% (1.5σ)** → **7% (~1.8σ)** → **44%~0.8σ**

Mixing phase – *results & prospects*

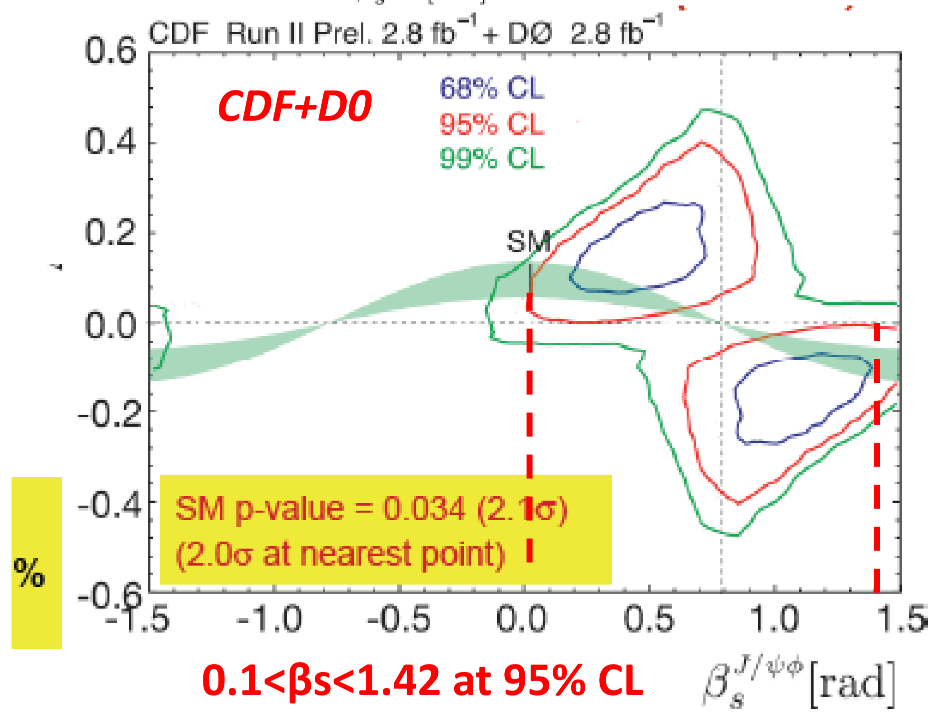
Results in 2009



CDF only: SM p-value: 7% (1.8σ)

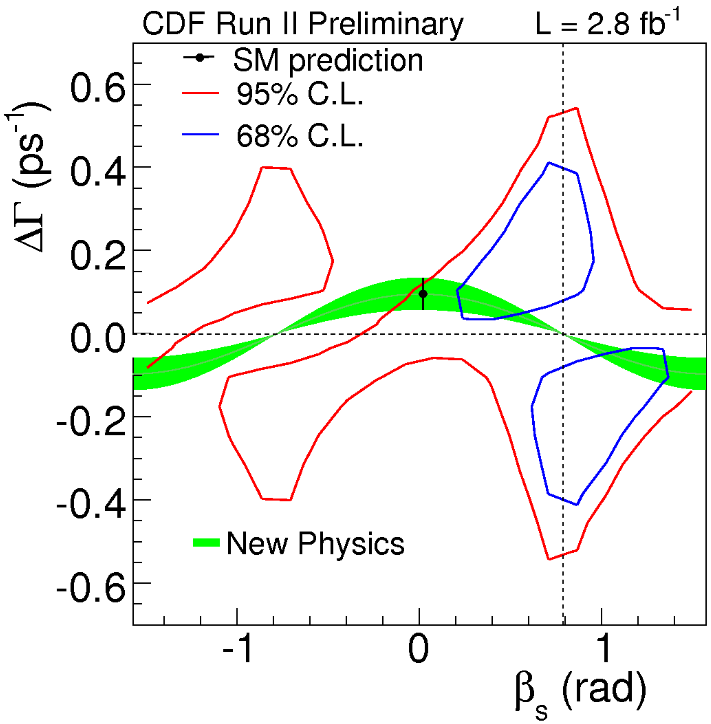


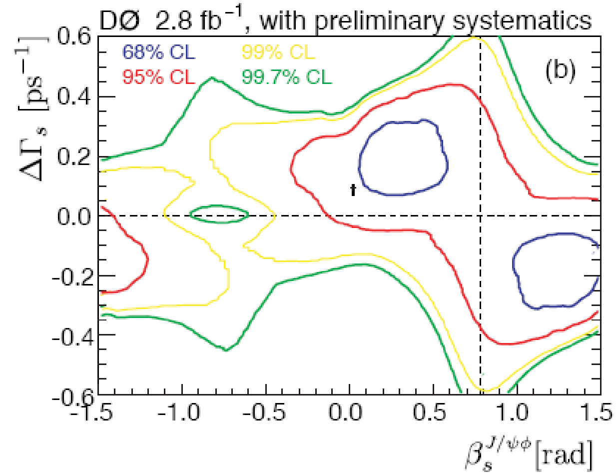
CDF and D0 combined =>
Assuming SM the probability of observing a fluctuation as or larger than observed in the data is 3.4% (2.1σ)



0.1<βs<1.42 at 95% CL

Mixing phase – *results & prospects*

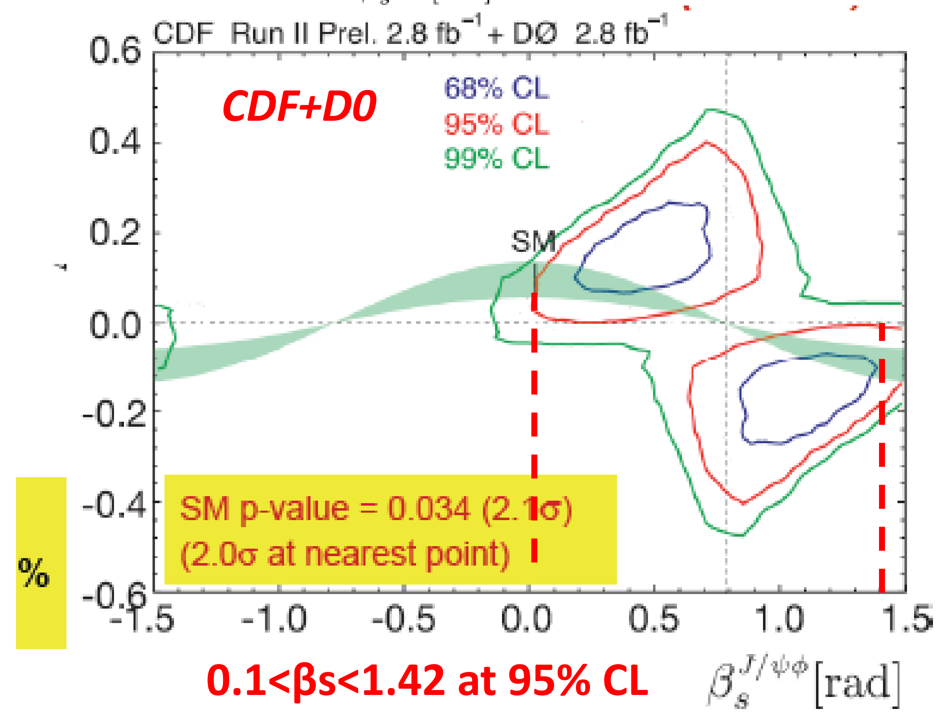




Results in 2009

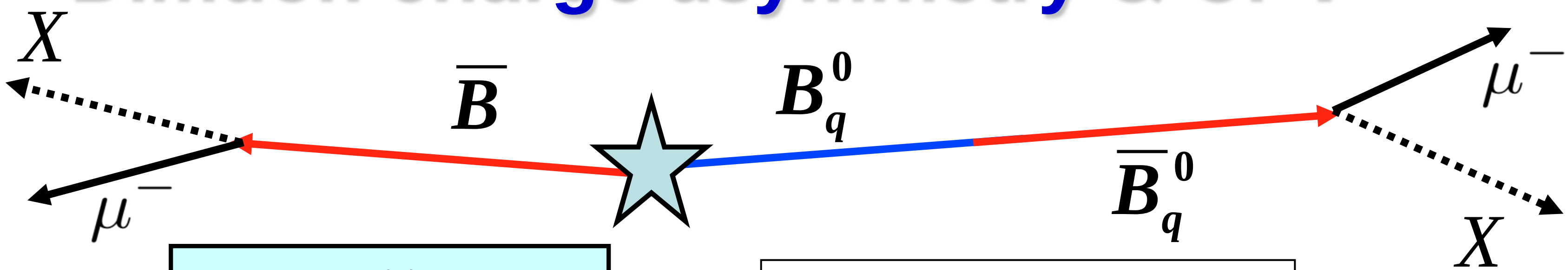
CDF only: SM p-value: 7% (1.8σ)

CDF and D0 combined =>
Assuming SM the probability of observing a fluctuation as or larger than observed in the data is 3.4% (2.1σ)



0.1<βs<1.42 at 95% CL

Dimuon charge asymmetry & CPV



$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

N_b^{++} (N_b^{--}) – number of same-sign $\mu^+\mu^+$ ($\mu^-\mu^-$) events from $B \to \mu X$ decay

- Both B_d and B_s contribute in A^b_{sl} at Tevatron :

$$A_{sl}^b = (0.506 \pm 0.043) a_{sl}^d + (0.494 \pm 0.043) a_{sl}^s$$

B_d contribution

B_s contribution

- a^q_{sl} is the charge asymmetry of "wrong sign" semileptonic B^0_q ($q = d,s$) decays and is related to CP violating phase

$$a_{sl}^q \equiv \frac{\Gamma(\overline{B}_q^0 \to \mu^+ X) - \Gamma(B_q^0 \to \mu^- X)}{\Gamma(\overline{B}_q^0 \to \mu^+ X) + \Gamma(B_q^0 \to \mu^- X)}; \quad q = d, s$$

$$a_{sl}^q = \frac{\Delta\Gamma_q}{\Delta M_q} \tan(\phi_q)$$

SM prediction

- SM predicts very small values of ϕ_q and $A^b{}_{sl}$:

$$\phi_d^{SM} = -0.091^{+0.026}_{-0.038}$$
$$\phi_s^{SM} = 0.0042 \pm 0.0014$$
$$A_{sl}^{b,SM} = (-2.3^{+0.5}_{-0.6}) \times 10^{-4}$$

A. Lenz, U. Nierste, J. High Energy Phys. 0706, 072 (2007)

  – These values are below current experimental sensitivity

- New physics contribution can significantly change these values

$$\phi_d = \phi_d^{SM} + \phi_d^{NP}$$
$$\phi_s = \phi_s^{SM} + \phi_s^{NP}$$

Non-zero $A^b{}_{sl}$ would indicate the presence of new physics

---

Remark:

$\phi_s^{SM} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right) \approx 4x10^{-3}$ and $\beta_s^{SM} = \arg(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) \approx 0.02$

$2\beta_s = 2\beta_s^{SM} - \phi_s^{NP}$ & $\phi_s = \phi_s^{SM} + \phi_s^{NP} \longrightarrow 2\beta_s = -\phi_s^{NP} = -\phi_s$

Measurement strategy

- Measure two raw asymmetries (include μ's from all sources):

raw dimuon charge asymmetry

$$A \equiv \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = (0.564 \pm 0.053)\%$$

raw inclusive muon charge asymmetry

$$a \equiv \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)} = (0.955 \pm 0.003)\%$$

- Both asymmetries contain contributions from A^b_{sl} and detector-related background asymmetries

$$A = K\, A^b_{sl} + A_{bkg}$$

$$a = k\, A^b_{sl} + a_{bkg}$$

  – contribution from A^b_{sl} to a is strongly suppressed by k=0.041±0.003
- Determine background contributions A_{bkg} and a_{bkg} using data with minimal input from simulation
- Exploit the correlation of background content in raw asymmetries to reduce the uncertainty on A^b_{sl}

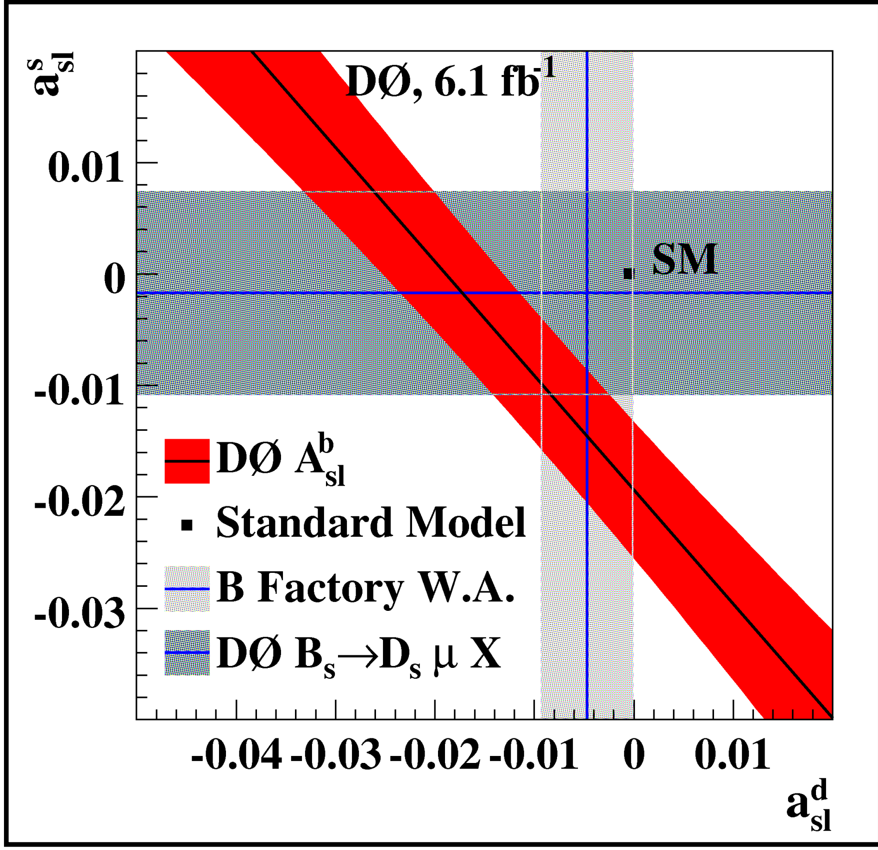
Evidence for an anomalous like-sign charge asymmetry

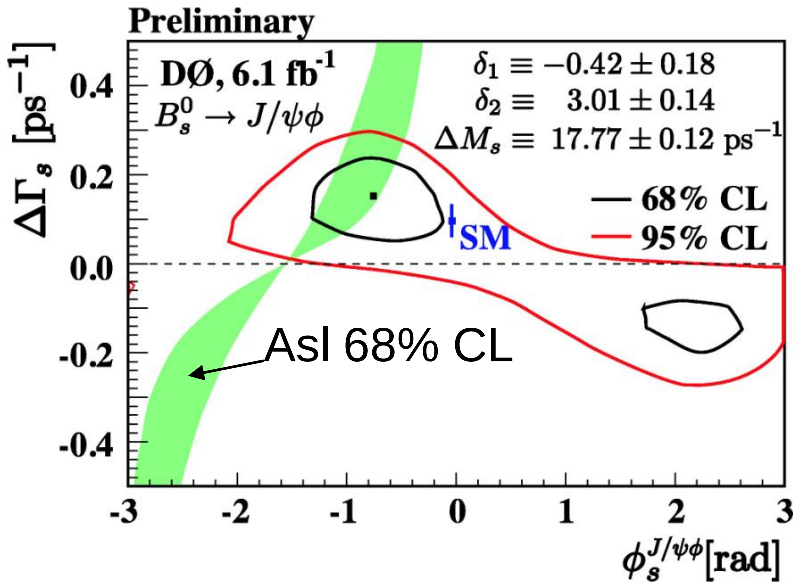
$$A^b_{sl} = (-0.957 \pm 0.251\,(\text{stat}) \pm 0.146\,(\text{syst}))\%$$

- This result differs from the SM prediction by ~3.2 σ
- A^b_{sl} produces a band in a^d_{sl} v.s. a^s_{sl} plane:

$$A^b_{sl} = (0.506 \pm 0.043)a^d_{sl} + (0.494 \pm 0.043)a^s_{sl}$$

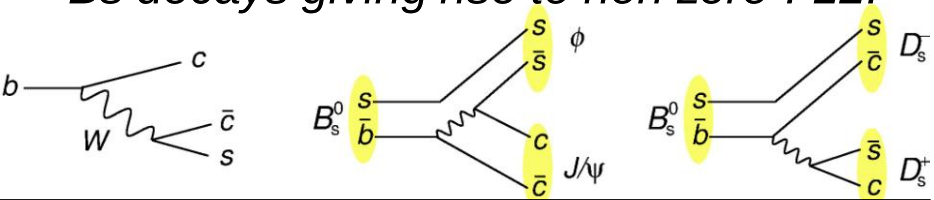
- Obtained result agrees well with other measurements of a^d_{sl} and a^s_{sl}

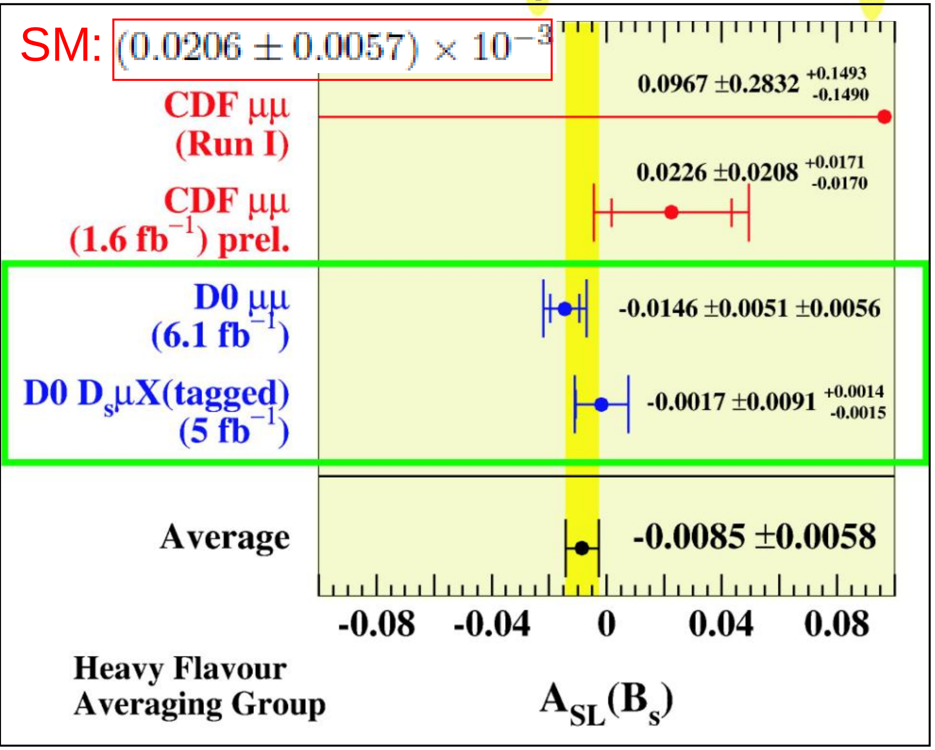


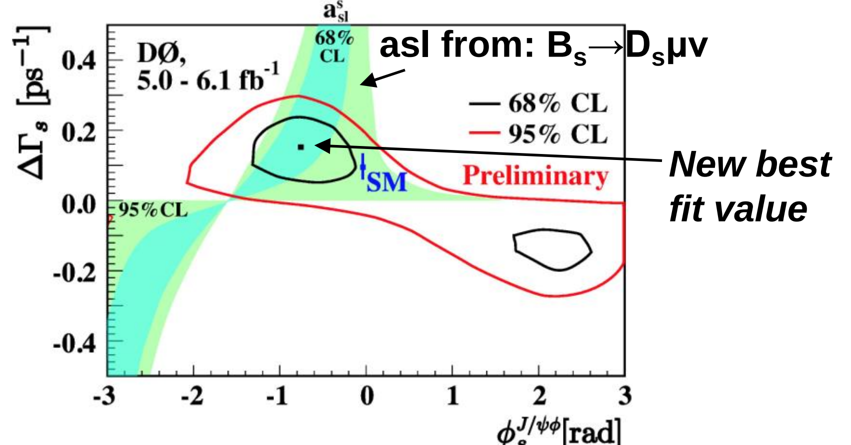


Combining results on $\Delta\Gamma_s$ and CPV phase

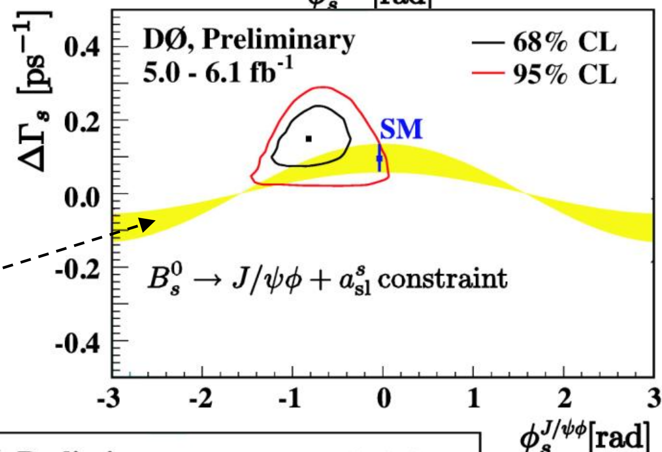
Bs decays giving rise to non zero Γ12:

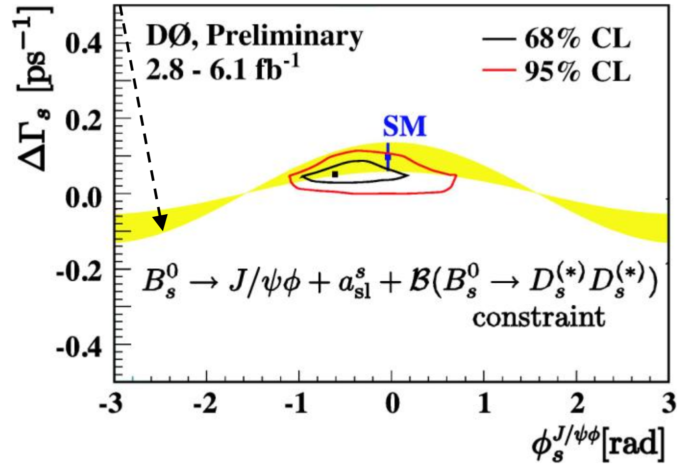






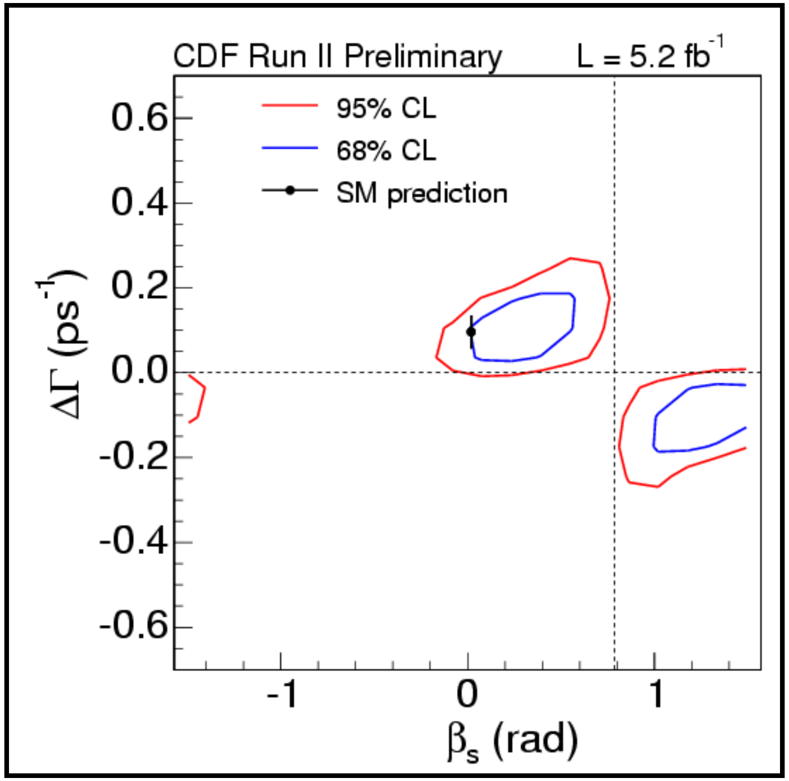
Region allowed in NP models given by: $\Delta\Gamma_s = 2|\Gamma_{12}|\cos\varphi_s$





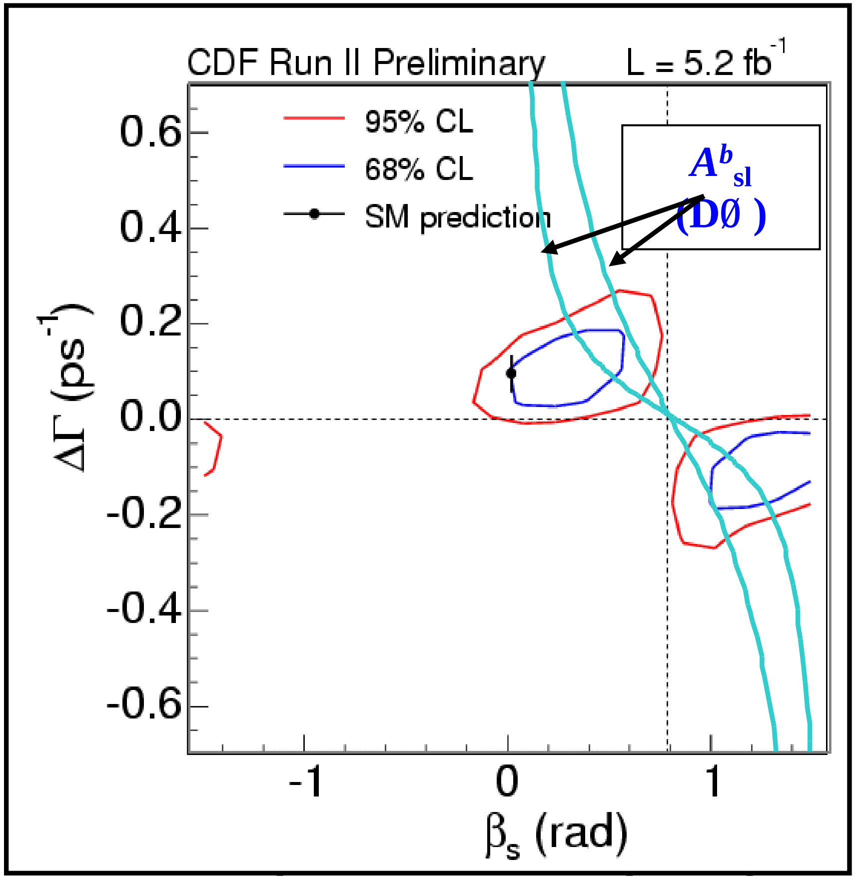
New a_{sl} measurement & asl from $B_s \to D_s \mu\nu$ => constraints on $\Delta\Gamma_s$ & $\Phi_s^{J/\Psi\varphi}$ consistent with the new results from $B_s \to J/\Psi\varphi$. When combining p-value at SM point is: 7.5%. When adding $Br(B_s \to D_s^* D_s^*)$ p-value decreases to 6%

Mixing phase – *results & prospects*

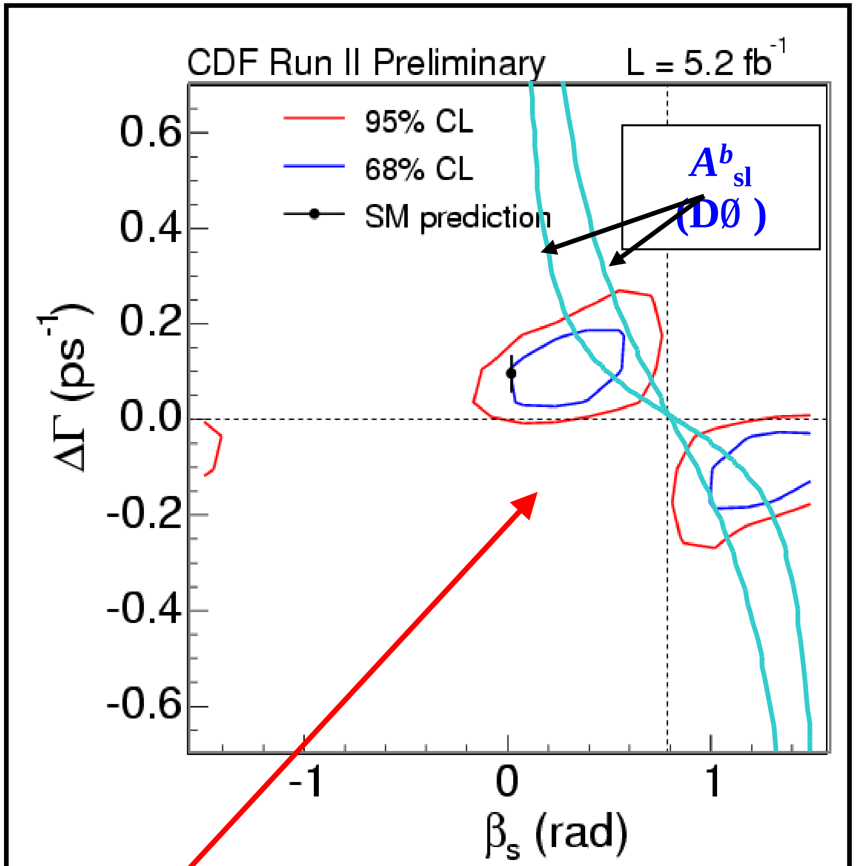


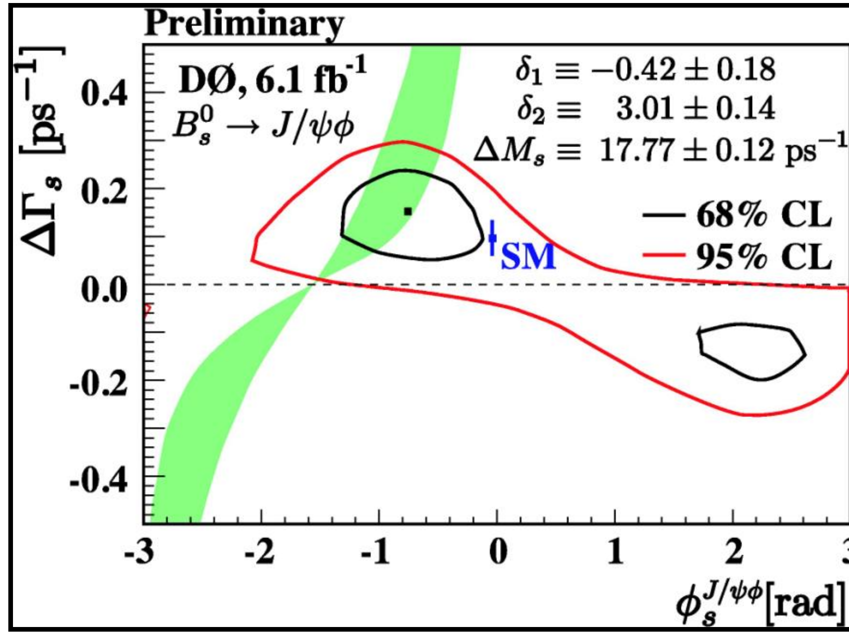
NEW: p-value is 44% (0.8 σ)

Mixing phase – *results & prospects*



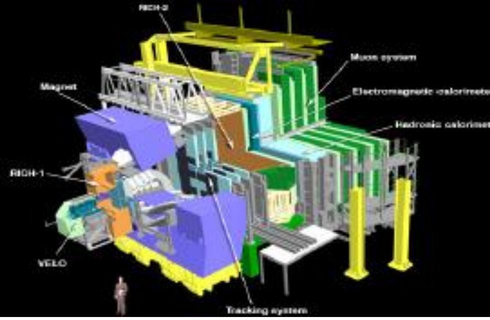
Mixing phase – *results & prospects*





Results of CDF and DØ are consistent within ~1σ

REALLY??????!!



Untagged angular analysis of $B_s^0 \to J/\psi\phi$ (ϕ_s fixed to 0) [LHCb-CONF-2011-002]

Luminosity used in this talk $\sim 35 - 36\,\mathrm{pb}^{-1}$

$$\begin{aligned}
\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.679 \pm 0.036(\mathrm{stat}) \pm 0.027(\mathrm{sys}) \\
\Delta\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.077 \pm 0.119(\mathrm{stat}) \pm 0.021(\mathrm{sys}) \\
|A_0|^2 &= 0.528 \pm 0.040(\mathrm{stat}) \pm 0.028(\mathrm{sys}) \\
|A_\perp|^2 &= 0.263 \pm 0.056(\mathrm{stat}) \pm 0.014(\mathrm{sys}) \\
\delta_\parallel\ (\mathrm{rad}) &= 3.14 \pm 0.52(\mathrm{stat}) \pm 0.13(\mathrm{sys})
\end{aligned}$$

(new results presented by Leroy at LaThuile)

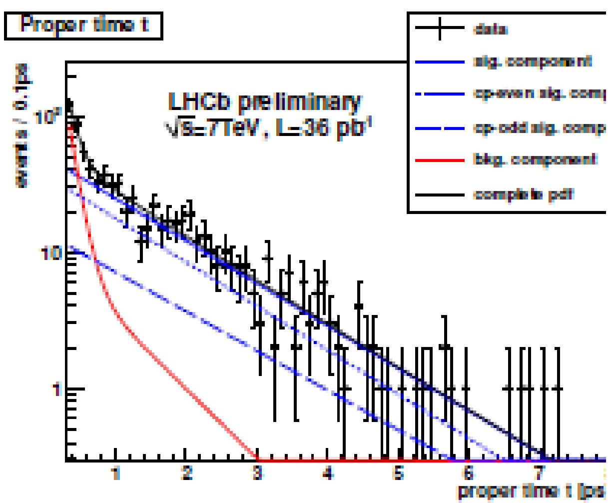
LHCb will be soon competitive in 2011

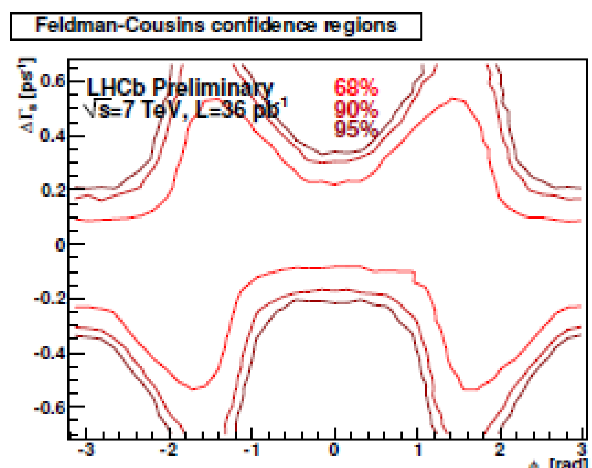
CDF note 10206:

$$\begin{aligned}
\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.653 \pm 0.011(\mathrm{stat}) \pm 0.005(\mathrm{syst}) \\
\Delta\Gamma_s\ (\mathrm{ps}^{-1}) &= 0.075 \pm 0.035(\mathrm{stat}) \pm 0.010(\mathrm{syst}) \\
|A_0|^2 &= 0.524 \pm 0.013(\mathrm{stat}) \pm 0.015(\mathrm{syst})
\end{aligned}$$

- Compatible with world best measurements
- Systematic uncertainties $<$ statistical ones
- Will be competitive in 2011

Untagged angular analysis of $B_s^0 \to J/\psi\phi$ (ϕ_s floating)





Coverage-adjusted two-dimensional profile likelihood of $\Delta\Gamma_s - \phi_s$