Mixing and Mixing-Related Asymmetries in the B System at the Tevatron

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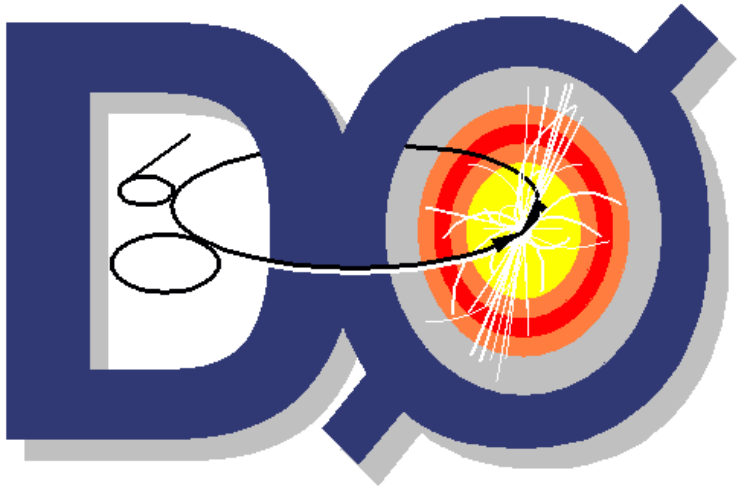
CKM 2012

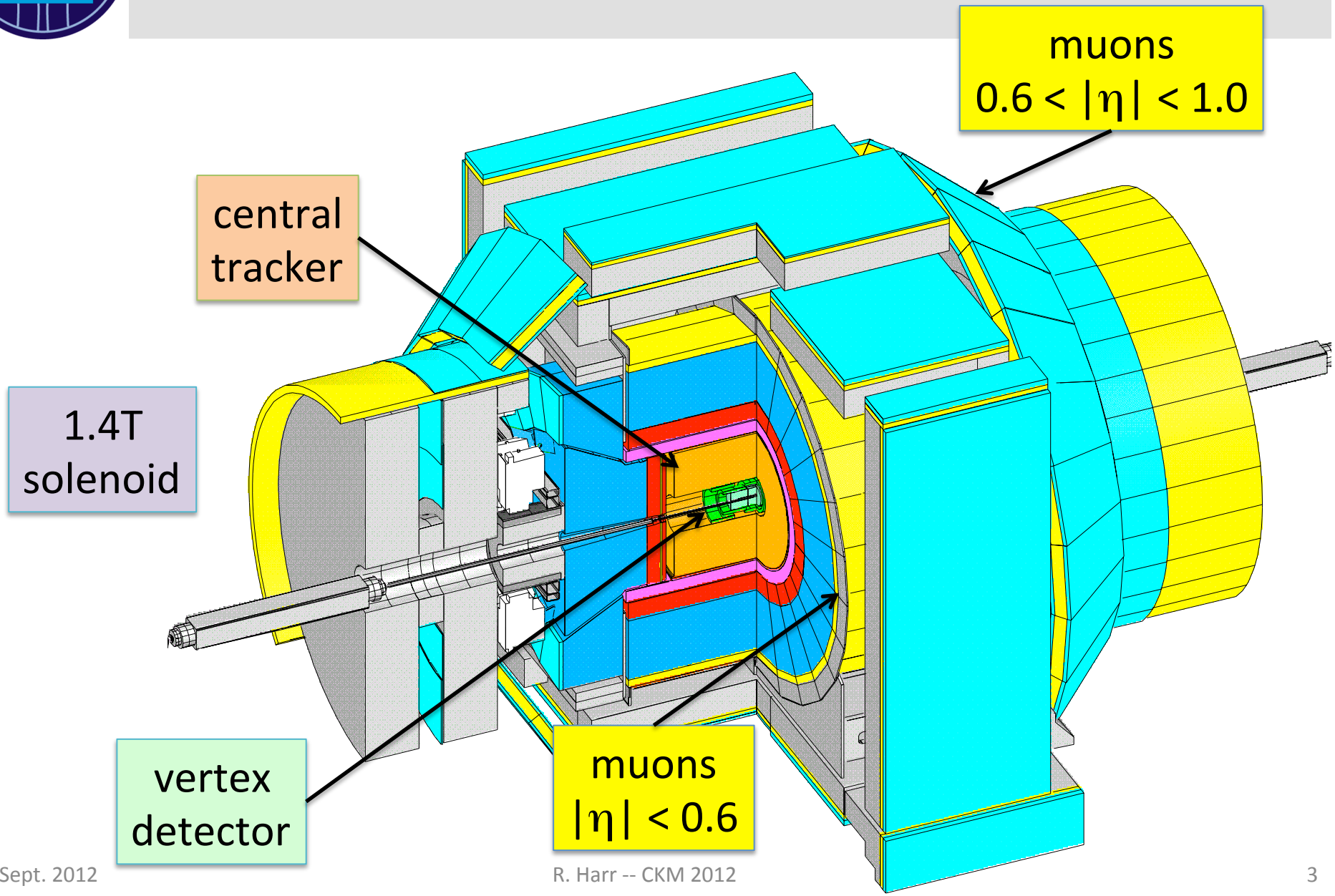
Outline

- The CDF and D0 detectors
- a_{sl} in $B_s \rightarrow D_s \mu X$ decays
- $B_s \rightarrow D_s^{(*)+} D_s^{(*)-}$ branching fractions
- CP violation in $B_s \rightarrow J/\psi\, \phi$
  - disentagling S- and D-wave components
- Summary

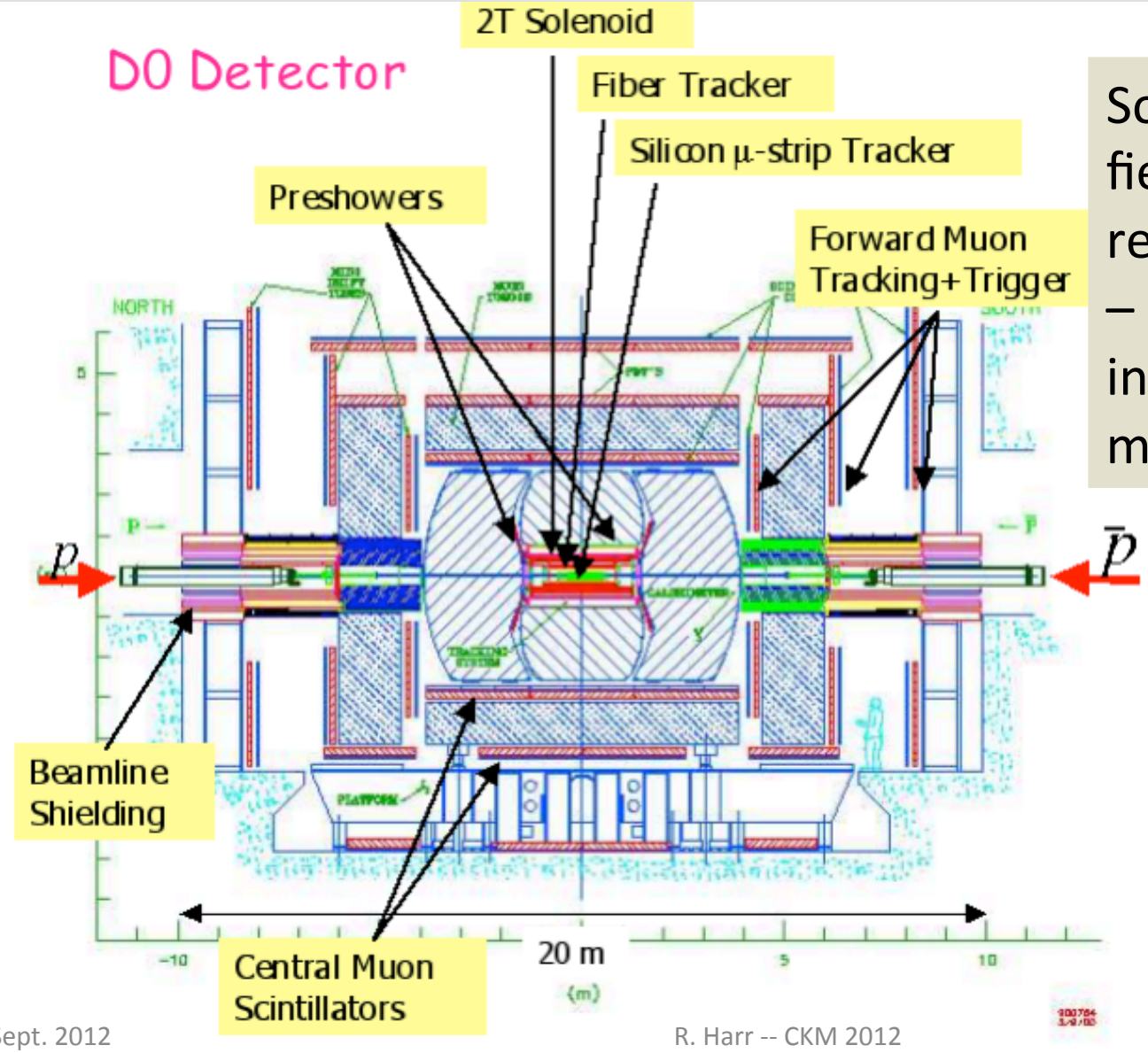


Most results use the full Run 2 dataset.

The CDF Detector



D0 Detector



Solenoid and toroid fields reversed periodically – used in asymmetry measurements

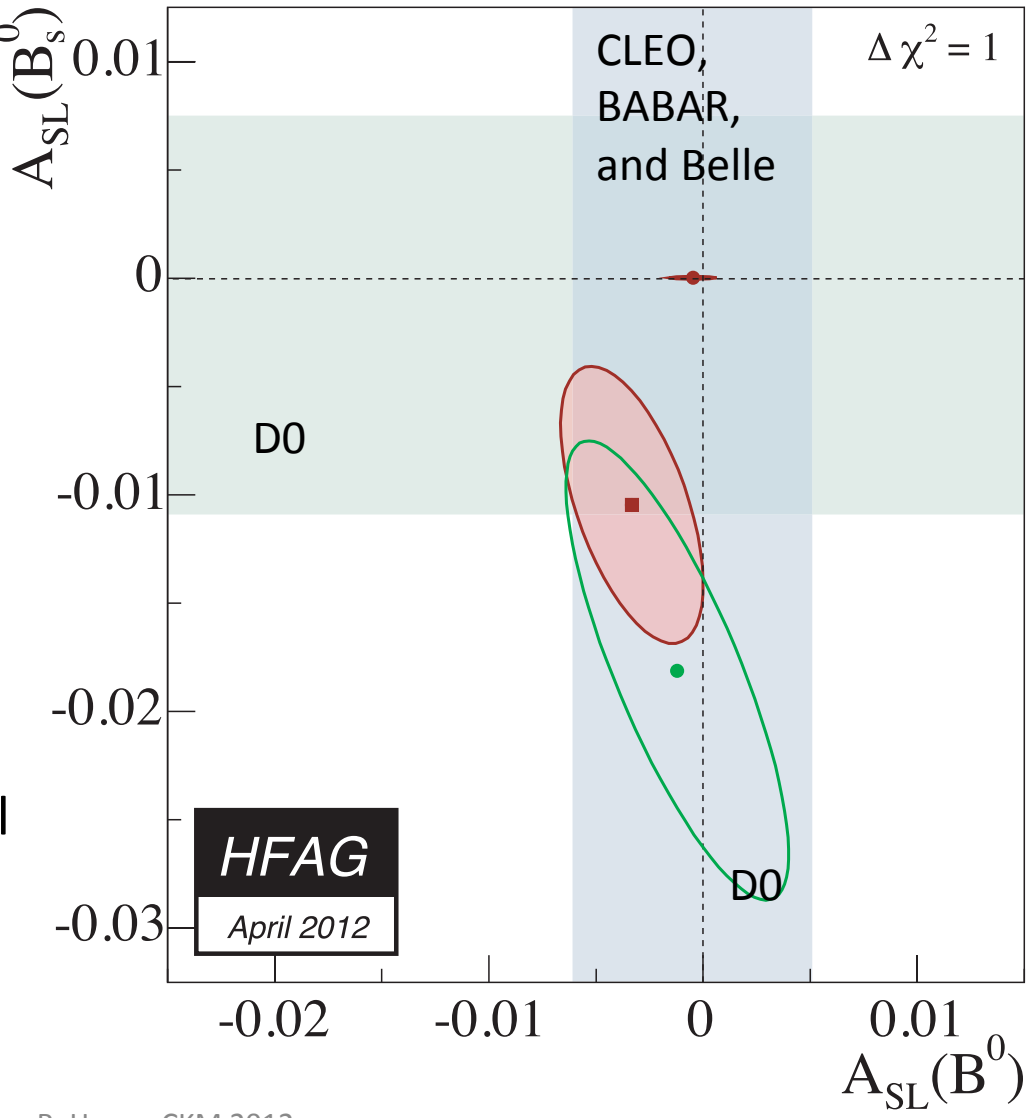
results based on single muon and dimuon triggers

Heavy Flavor Triggers

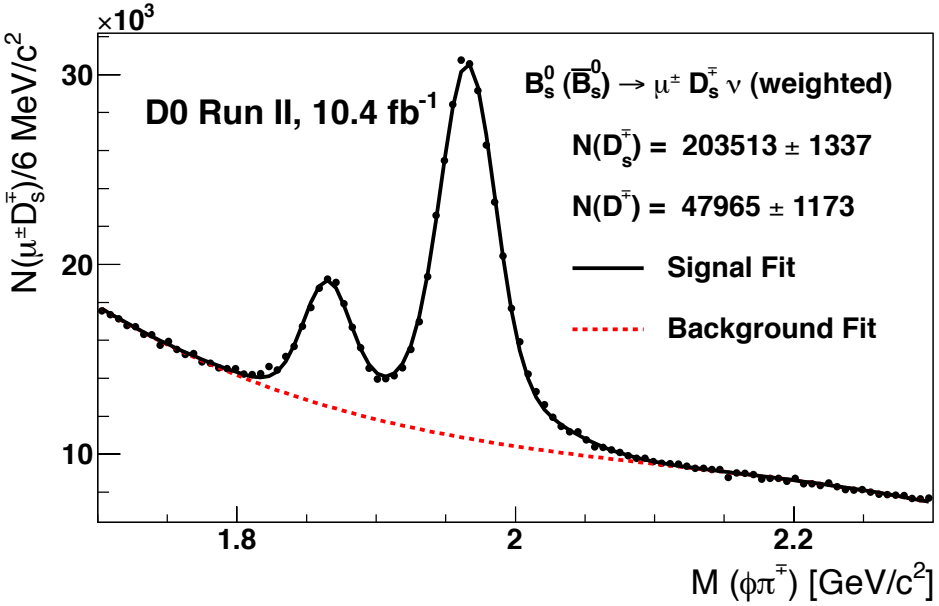
- single muon trigger (D0 only)
  - muon p_T > 2GeV/c, p > 3GeV/c
- dimuon trigger (CDF and D0)
  - for decays with $J/\psi \rightarrow \mu\mu$
  - muon p_T > 1.5 GeV/c, $|\eta|$ < 1.0 (CDF)
  - muon p_T > 2 GeV/c, $|\eta|$ < 2 (D0)
- displaced vertex trigger (CDF only)
  - for hadronic charm and bottom decays
  - 2 tracks, opposite charge, p_T > 2.0 GeV/c
  - impact parameters 100μm < d < 1000μm

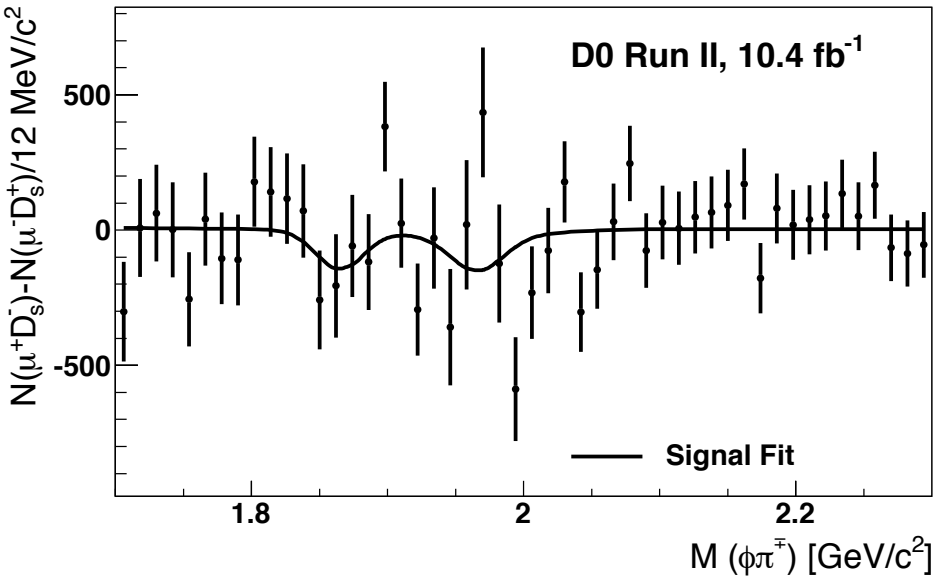
Status of A_{sl}

- D0 like-sign dimuon asymmetry result 3.9σ from standard model.
- SM point from [arXiv:1102.4274]
- D0 has new measurements of $A_{sl}(B^0)$ and $A_{sl}(B^0_s)$.



A_{sl} in $B_s \rightarrow D_s \mu X$ decays



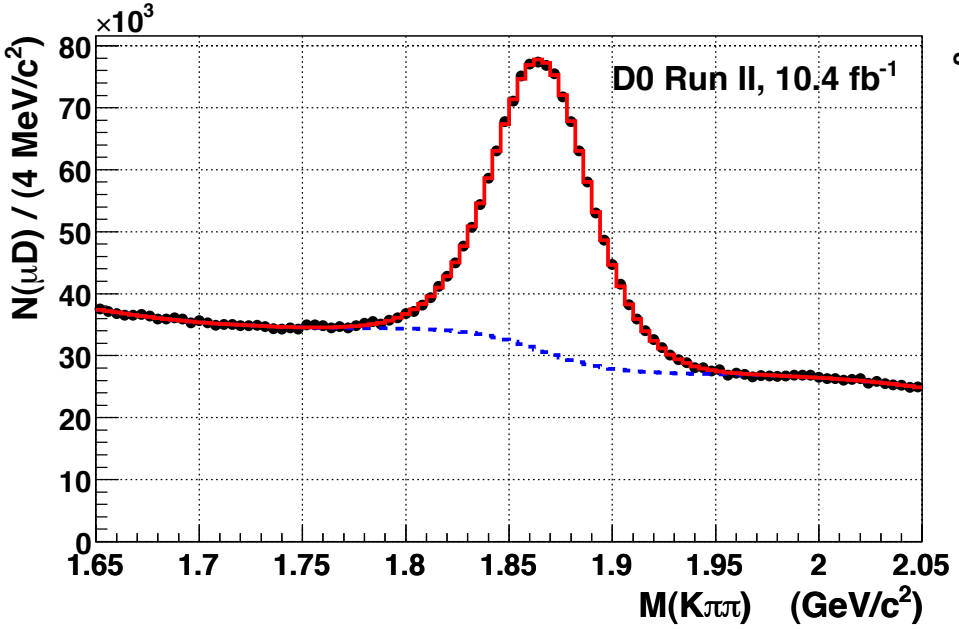


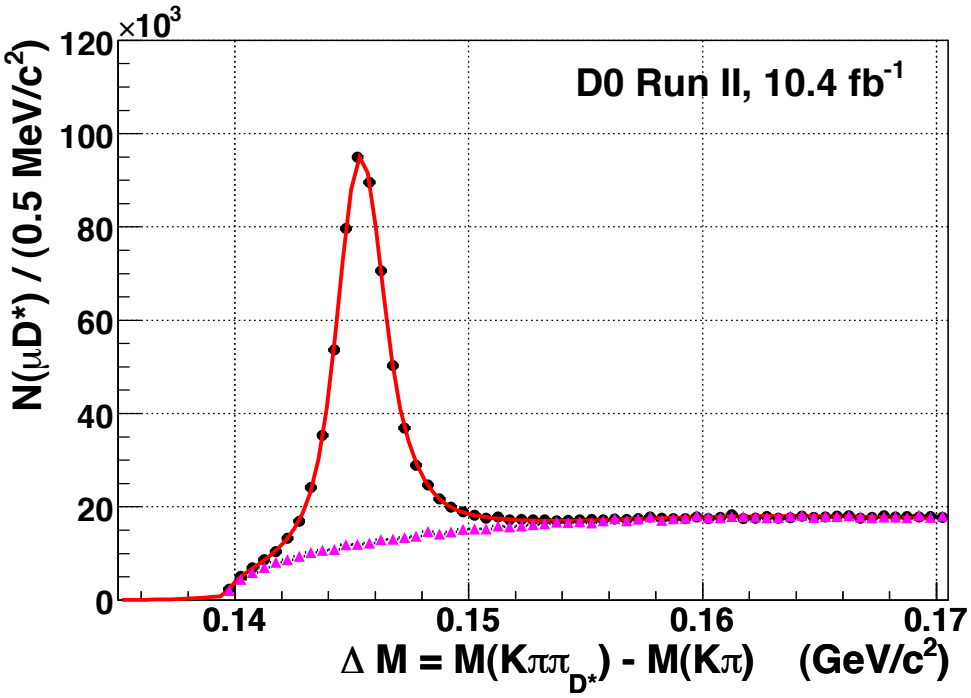
Using $D_s \rightarrow \phi\pi$, after all corrections:

$$A_{sl}(B_s^0) = (-1.08 \pm 0.72 \pm 0.17)\%$$

arXiv:1207.1769

A_{sl} in $B^0 \rightarrow D^{(*)-}\mu X$ decays



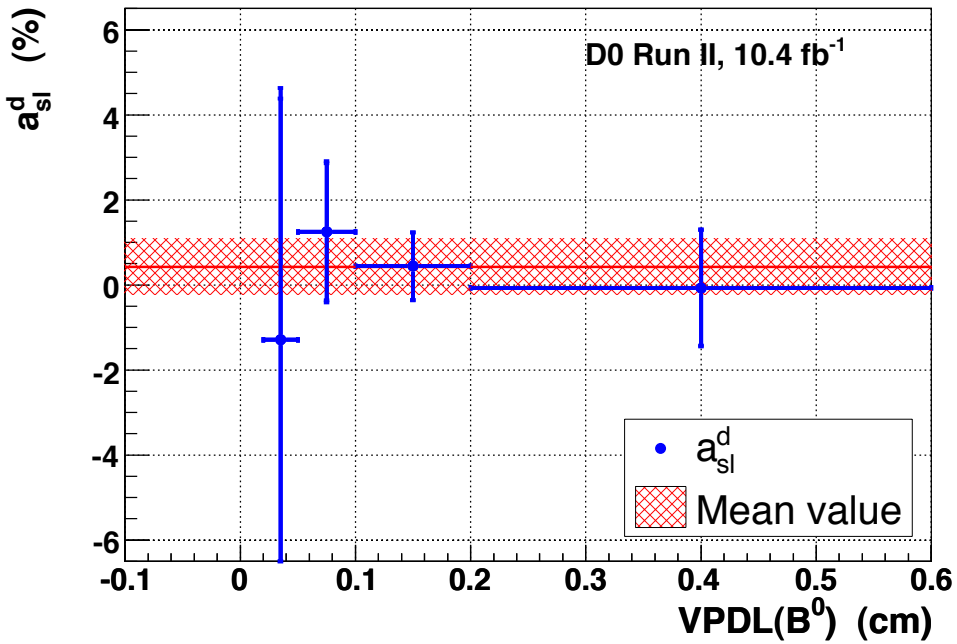


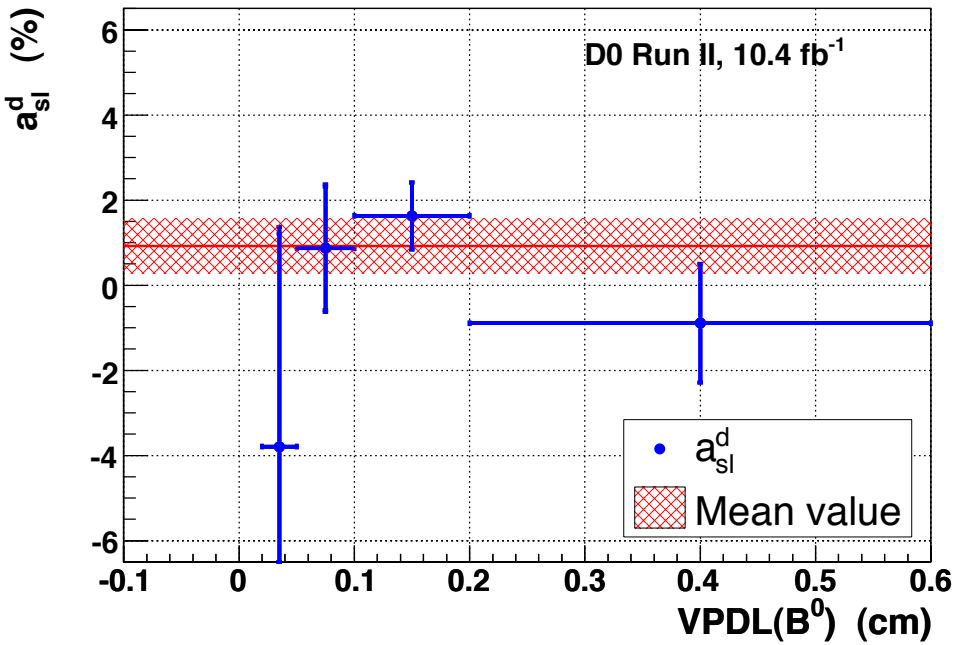
D^- signal for μD events

D^* mass difference signal for μD^* events

Asymmetries calculated in bins of VPDL, corrected, and averaged

Final Asymmetries





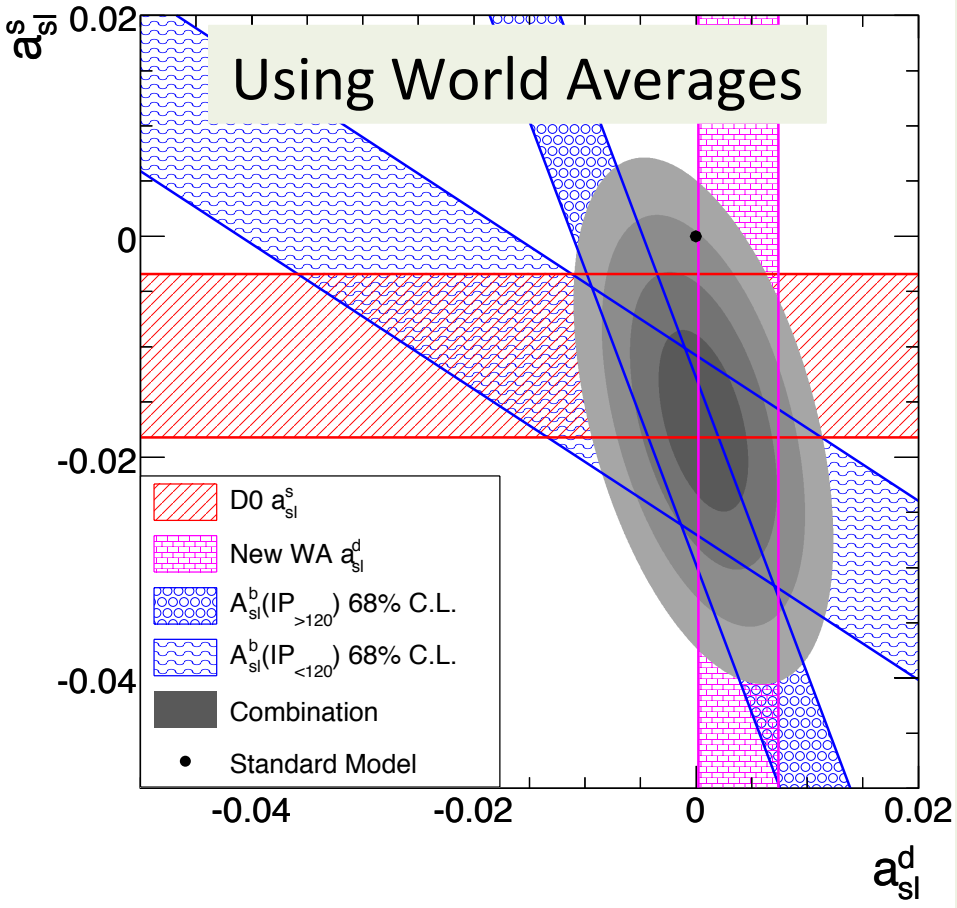
μD events

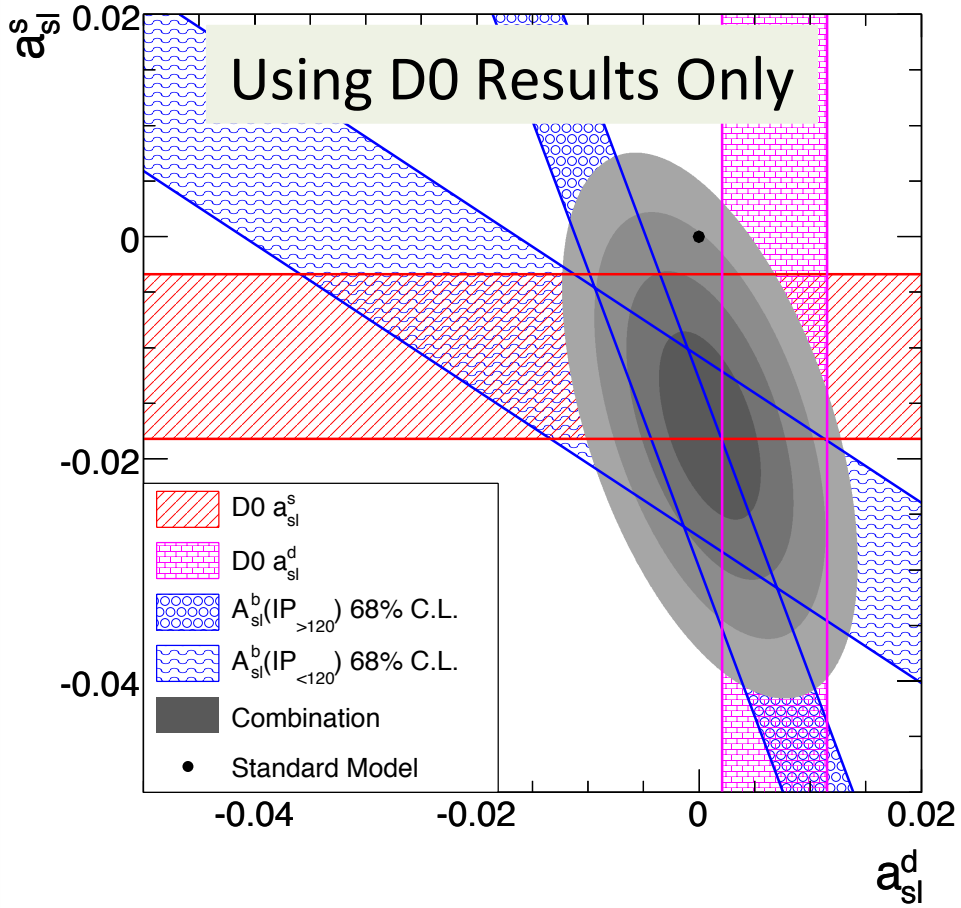
μD^* events

$$A_{sl}(B^0) = (0.68 \pm 0.45 \pm 0.14)\%$$

arXiv:1208.5813

Updated 2D Asymmetry Plo



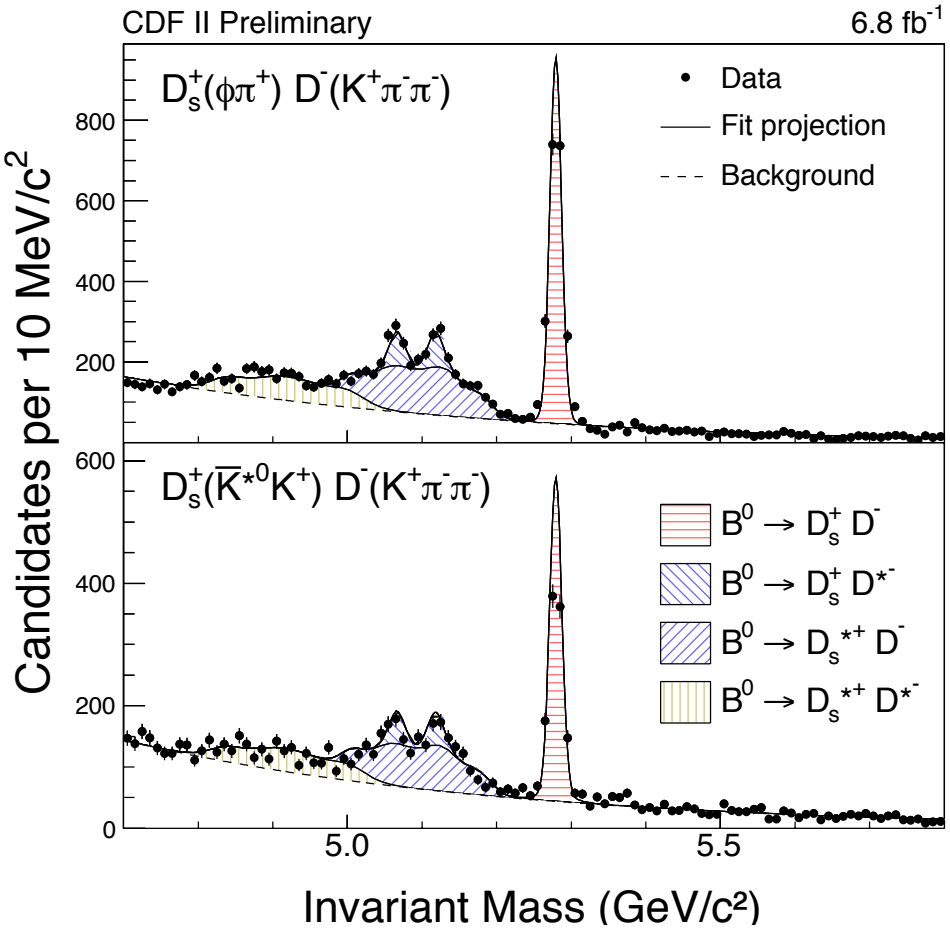


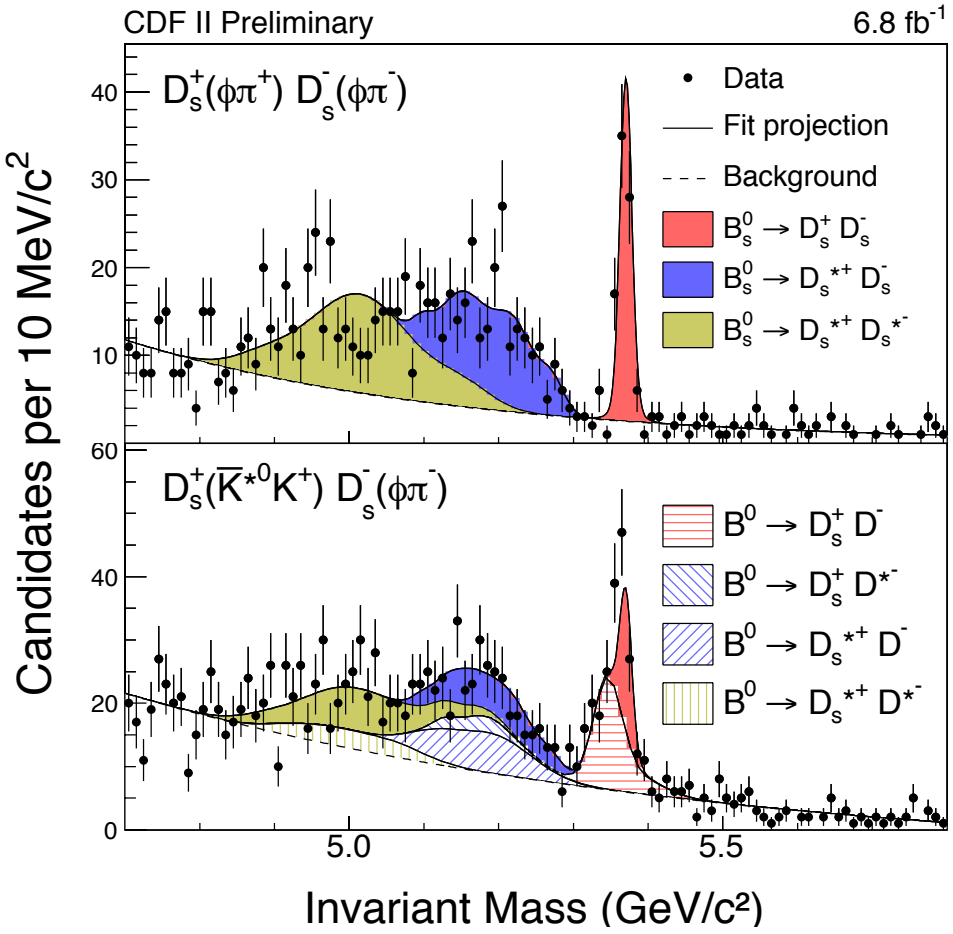
Global fit still lies about 3σ from SM point.

$B_s \rightarrow D_s^{(*)+} D_s^{(*)-}$ B.F.

- Decays are primarily CP even
- One of the major contributions to $\Delta\Gamma_s$
- Poorly measured or unmeasured B.F.s
- Reconstruct $D_s \rightarrow \phi\pi$ and K^*K
- D_s^* reconstructed as satellite peak (missing γ, π^0)
- Normalize to $B^0 \rightarrow D_s^{(*)+} D^{(*)-}$ reconstructed similarly
- Constrain with multiple fits

$B_s \rightarrow D_s^{(*)+} D_s^{(*)-}$ Mass Plots





[Phys. Rev. Lett. 108, 201801 (2012)]

Results

$$\begin{aligned}
\mathcal{B}(B_s^0 \to D_s^+ D_s^-) &= (0.49 \pm 0.06 \pm 0.05 \pm 0.08)\% \\
\mathcal{B}(B_s^0 \to D_s^{*\pm} D_s^{\mp}) &= (1.13 \pm 0.12 \pm 0.09 \pm 0.19)\% \\
\mathcal{B}(B_s^0 \to D_s^{*\pm} D_s^{*\mp}) &= (1.75 \pm 0.19 \pm 0.17 \pm 0.29)\% \\
\mathcal{B}(B_s^0 \to D_s^{(*)+} D_s^{(*)-}) &= (3.38 \pm 0.25 \pm 0.30 \pm 0.56)\%
\end{aligned}$$

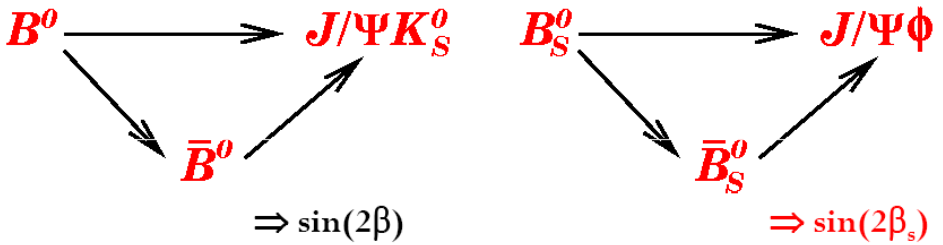
Assuming that this is the only major contribution to the width difference we estimate:

$$\Delta\Gamma_s^{D_s D_s}/\Gamma_s = (6.99 \pm 0.54 \pm 0.64 \pm 1.20)\%$$

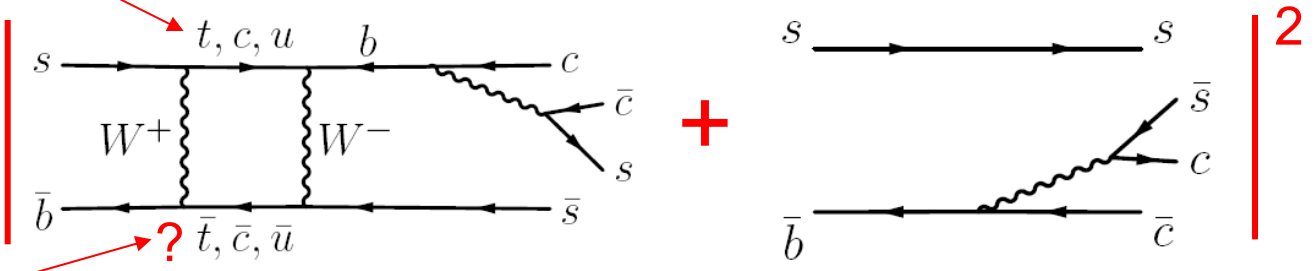
less than the world average of about 14%, indicating other major contributions exist.

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

dominant contribution from top quark



Decay rate ~



New Physics particles ?

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

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

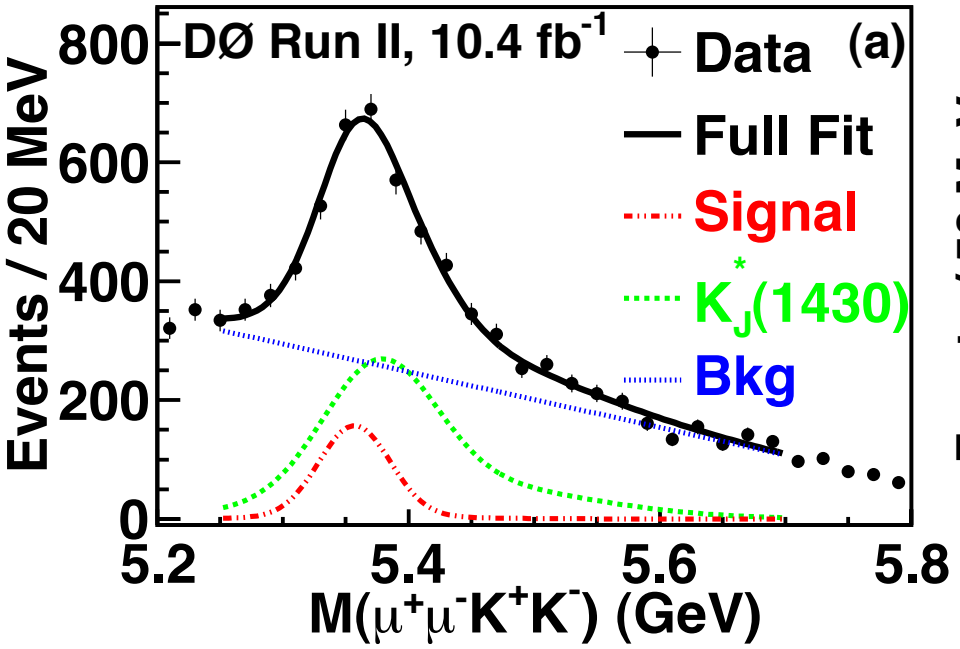
SM predicts tiny CP violation in B_s mixing.

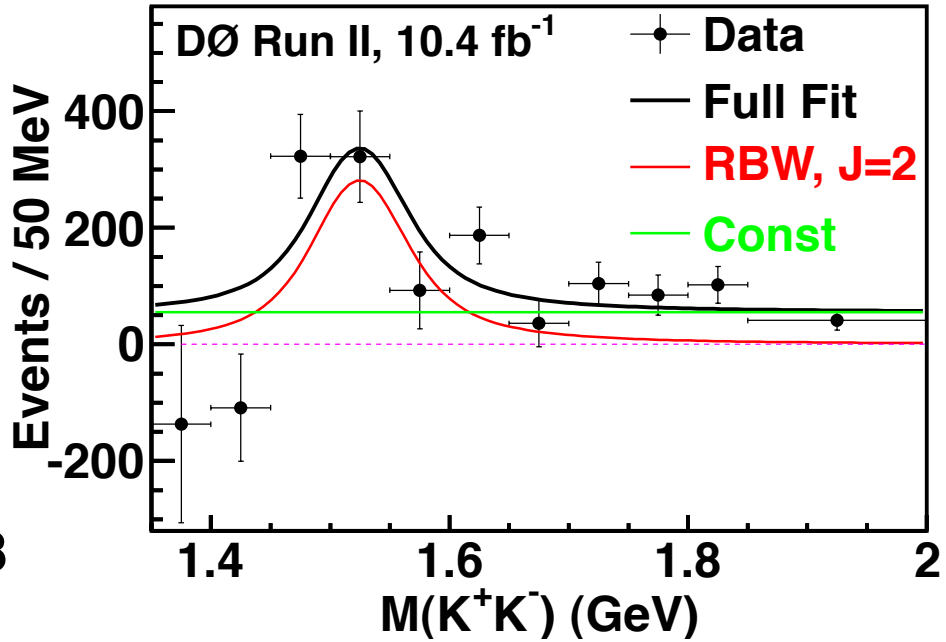
New physics can be the dominant effect.

Related Modes

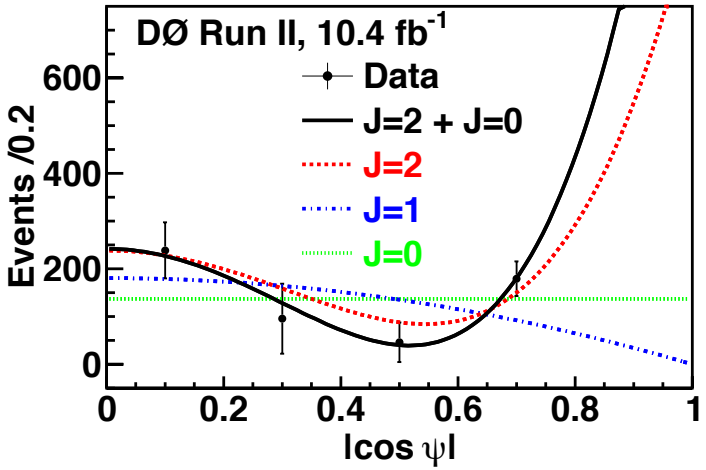
- CDF and D0 determined the B.F. of $B_s \rightarrow J/\psi\, f_0(980)$ where $f_0(980) \rightarrow \pi^+\pi^-$
  - When $f_0 \rightarrow K^+K^-$ could be a background in $B_s \rightarrow J/\psi\, \phi$
  - B.F.s measured by LHCb, Belle, CDF, and D0 are consistent
  - Decay is CP odd: CDF measured lifetime in this mode, should be equal to τ_H
- D0 measured B.F. of $B_s \rightarrow J/\psi\, f_2(1525)$
  - Possibly another way to measure β_s

$B_s \rightarrow J/\psi\, f_2(1525)$ Results





$$R_{f_2'/\phi} = 0.22 \pm 0.05 \pm 0.04$$



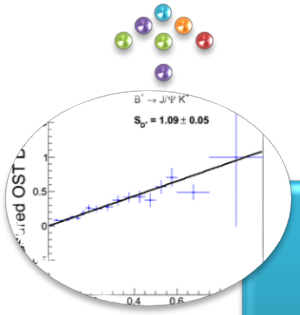
Confirms LHCb observation.

Analysis at a Glance

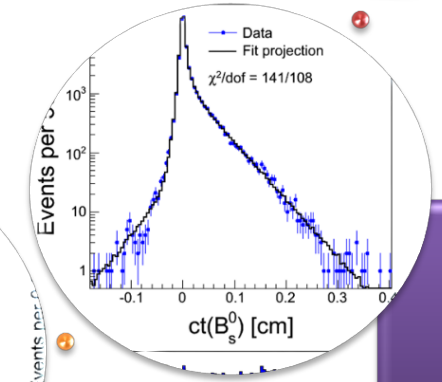
Very complex likelihood fit, 11 physical parameter 35 nuisance:
use mass, angles, decay-time and production flavor distributions

Dimuon trigger

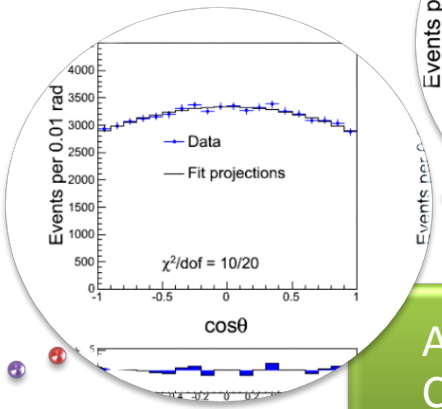
Offline selection



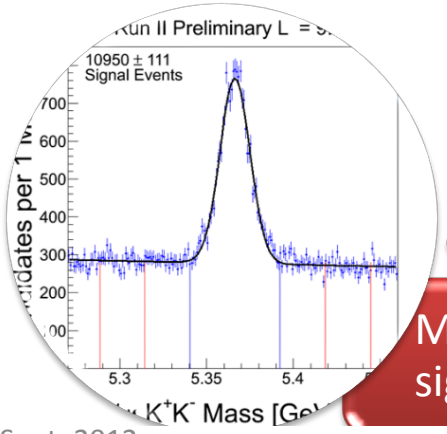
Flavor tagging to separate B from $\bar{B}$



Decay time to know time evolution



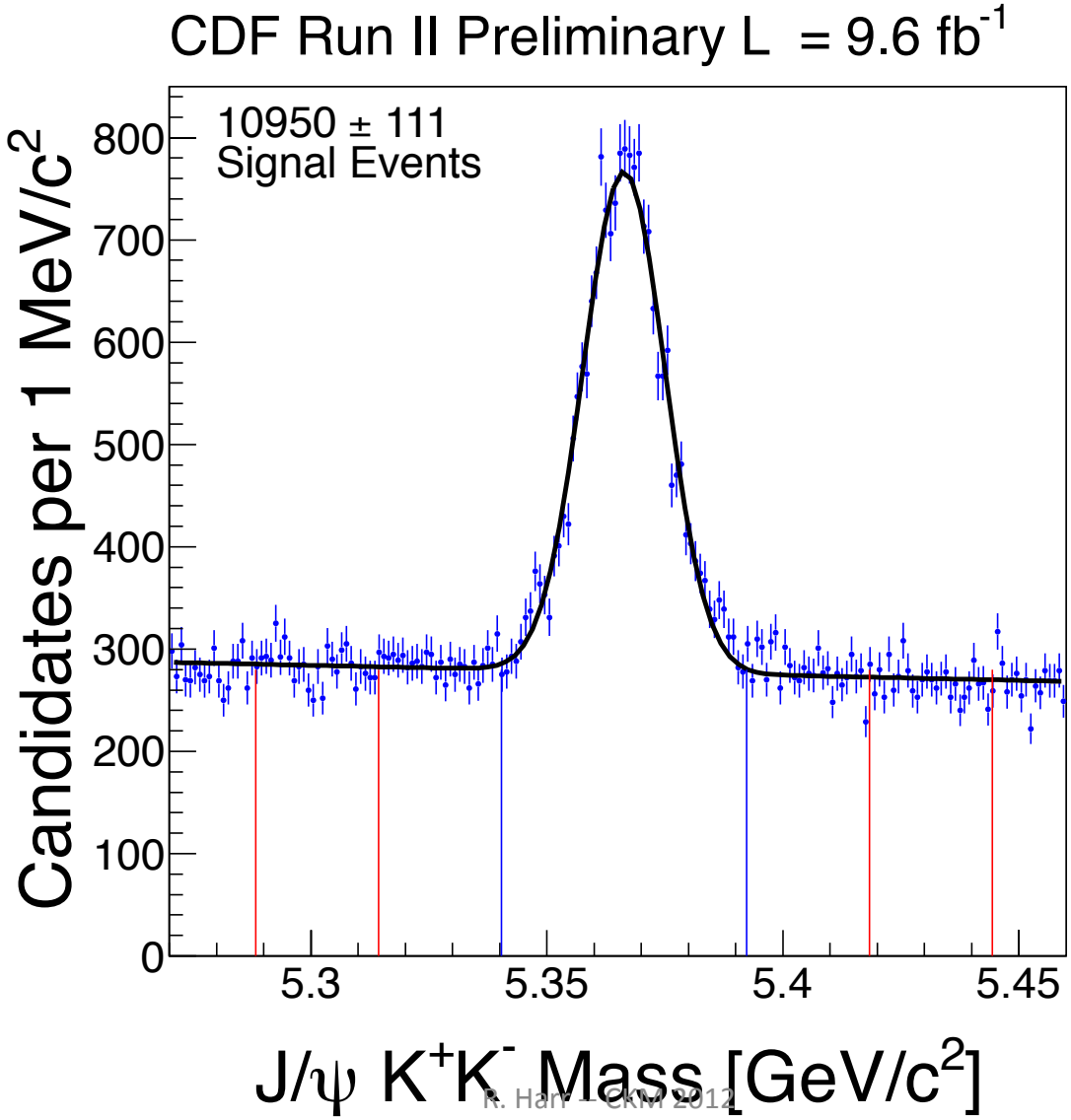
Angles to separate CP-even/odd



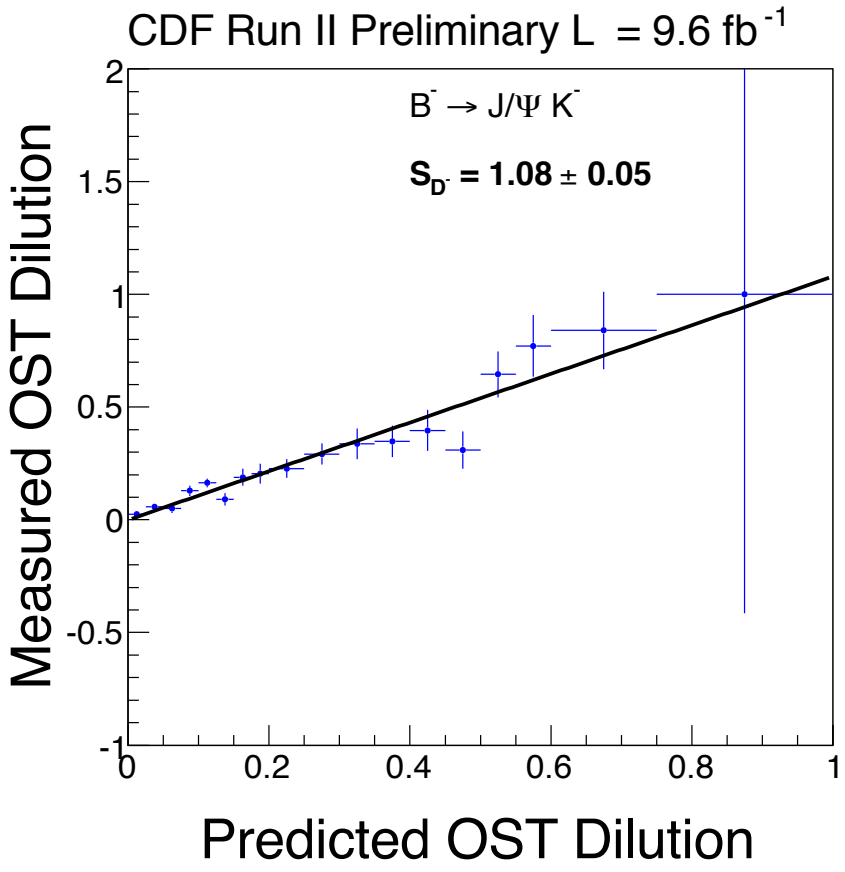
Mass to separate signal from bckg

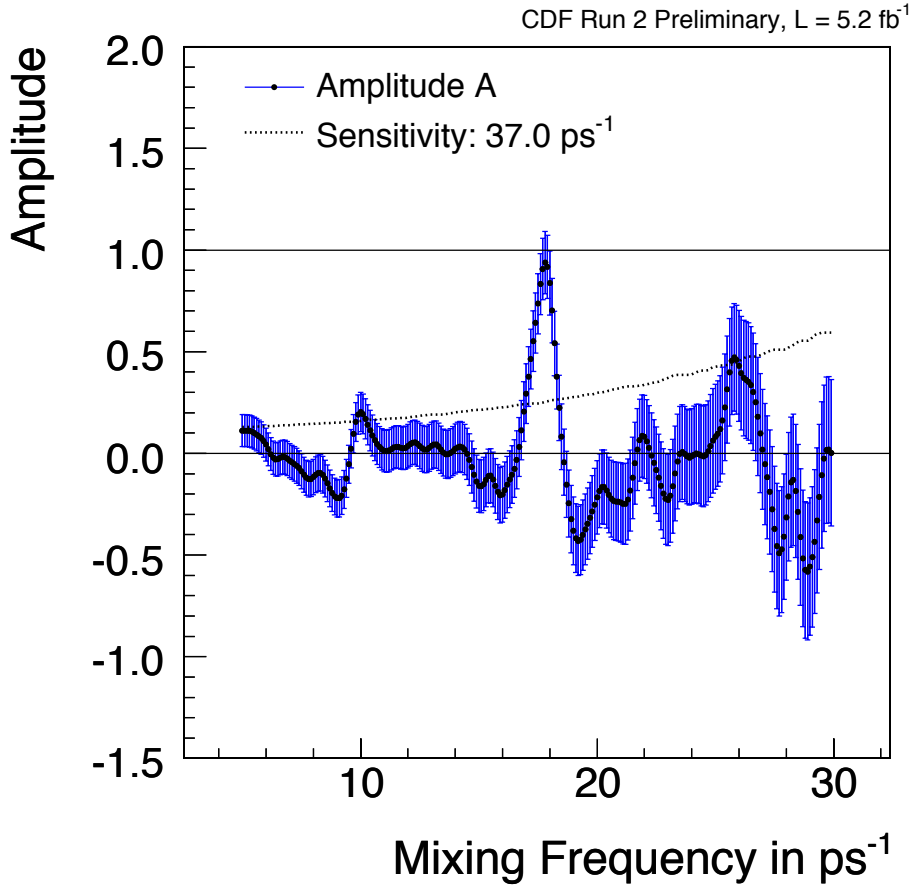
CDF Public Note 10778

Mass Projection



Tagging

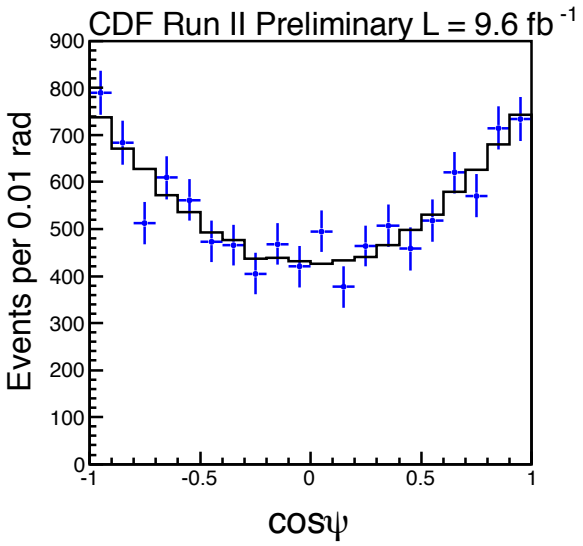


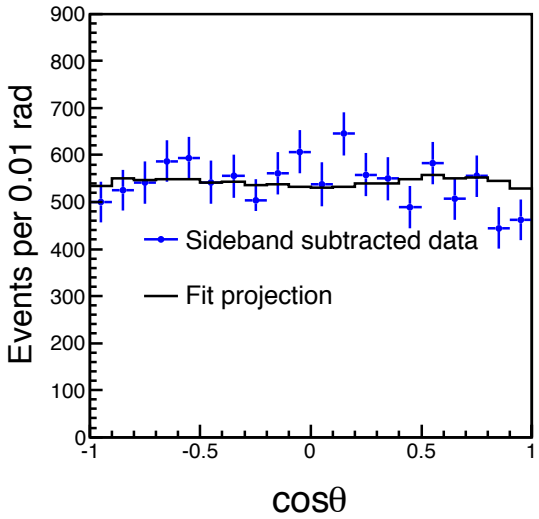


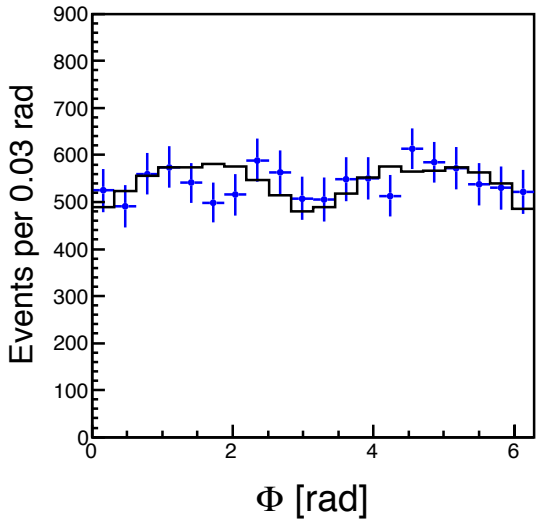
Opposite side tagging calib. for 9.6fb^{-1}

Same side kaon tagging calibrated for 5.2fb^{-1}

Angular Projections







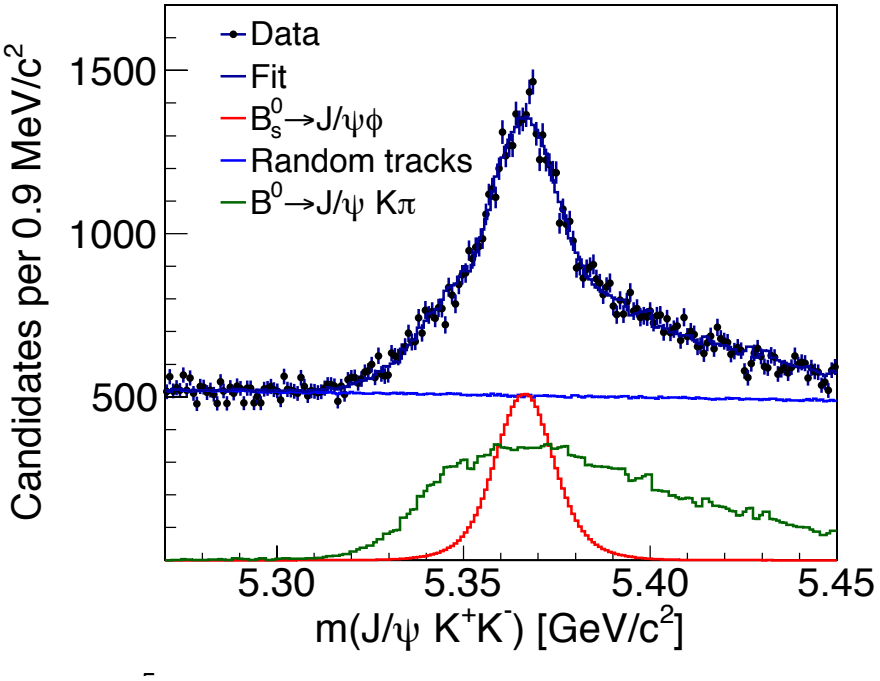
Assuming SM value for CP phase

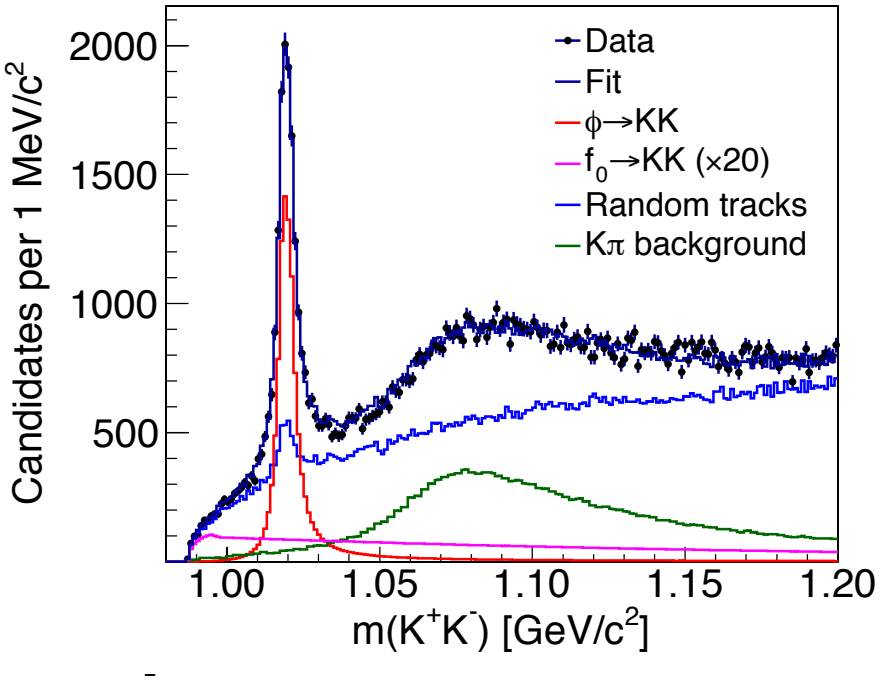
$$\begin{aligned}
\tau_s &= 1.528 \pm 0.019 \pm 0.009\,\mathrm{ps} \\
\Delta\Gamma_s &= 0.068 \pm 0.026 \pm 0.007\,\mathrm{ps}^{-1} \\
|A_0(0)|^2 &= 0.512 \pm 0.013 \pm 0.017 \\
|A_{\parallel}(0)|^2 &= 0.229 \pm 0.010 \pm 0.014 \\
\delta_{\perp} &= 2.79 \pm 0.53 \pm 0.15
\end{aligned}$$

S-Wave Component

- S-wave decay could leak into signal range and effect phase measurement. Different amounts seen:
  - LHCb: (2.2 ± 1.4)% in [1.008,1.032] GeV (La Thuile 2012)
  - D0: (17.3 ± 3.6)% in [1.010,1.030] GeV (8/fb PRD)
  - ATLAS: (2 ± 3)% in [1.008,1.032] GeV (ICHEP 2012)
  - CDF: <5.6% @ 95%CL in [1.009,1.028] GeV (this result)
- CDF performed a detailed analysis of K^+K^- mass spectrum from threshold to 1.2 GeV/c^2.
  - gives enough lever arm to study wide distributions

S-Wave Analysis

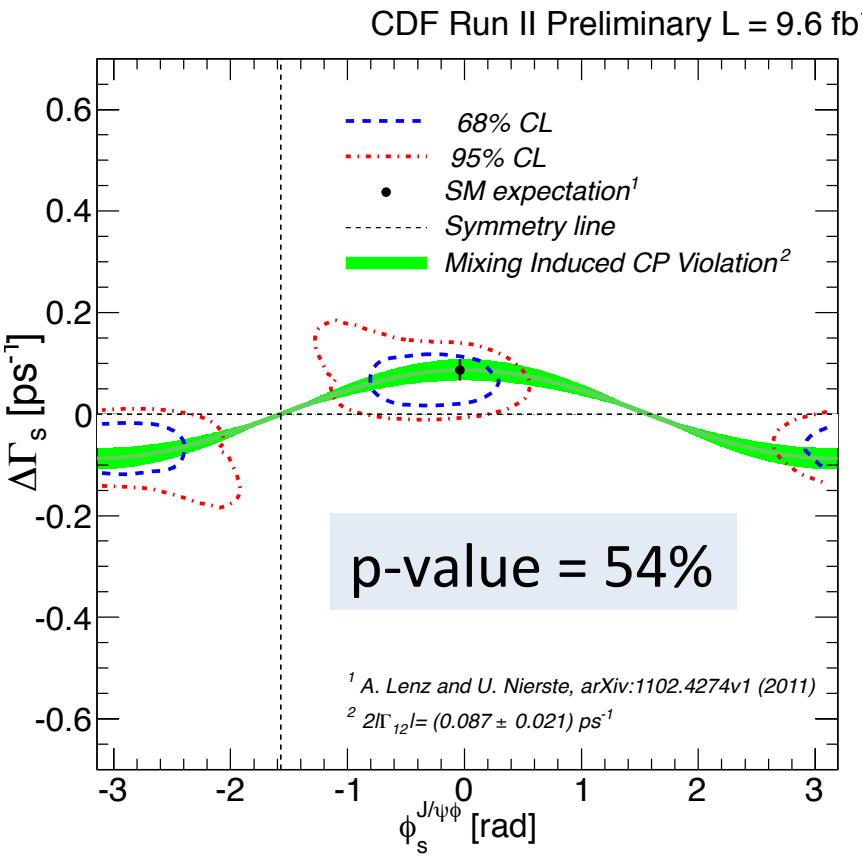


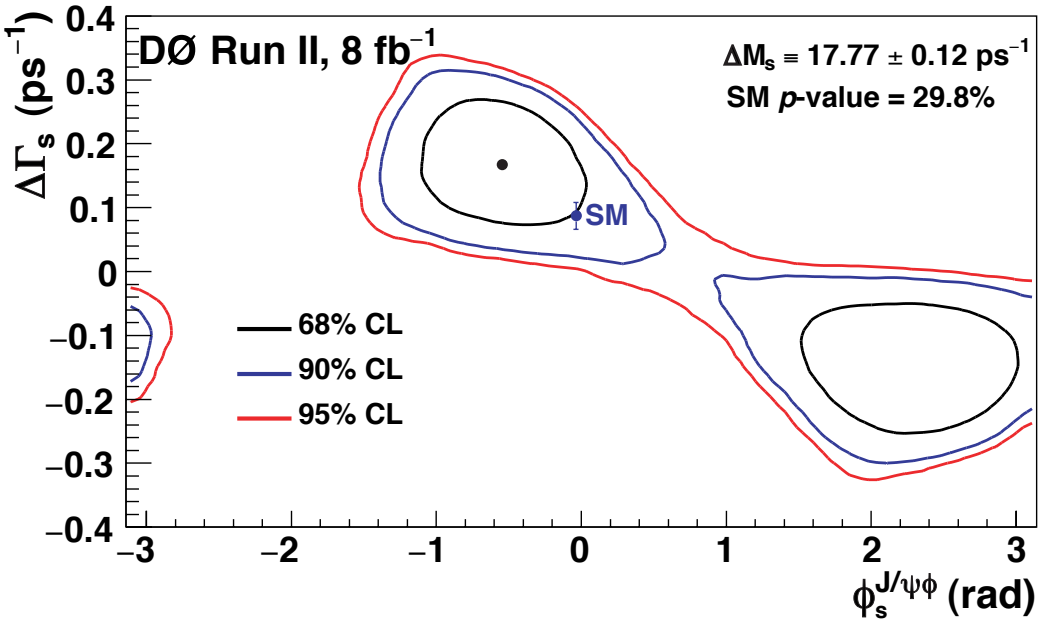


Backgrounds include:
$B_s \to J/\psi\, f_0(980)$ with $f_0 \to K^+K^-$
$B^0 \to J/\psi\, K\pi$ with π misidentified as K,
including S and P wave interference

f_0 S-wave (0.8 ± 0.2)%
B^0 bkg: (8.0 ±0.2)%
in [1.009,1.028]GeV

$\Delta\Gamma_s$ Versus CP Phase

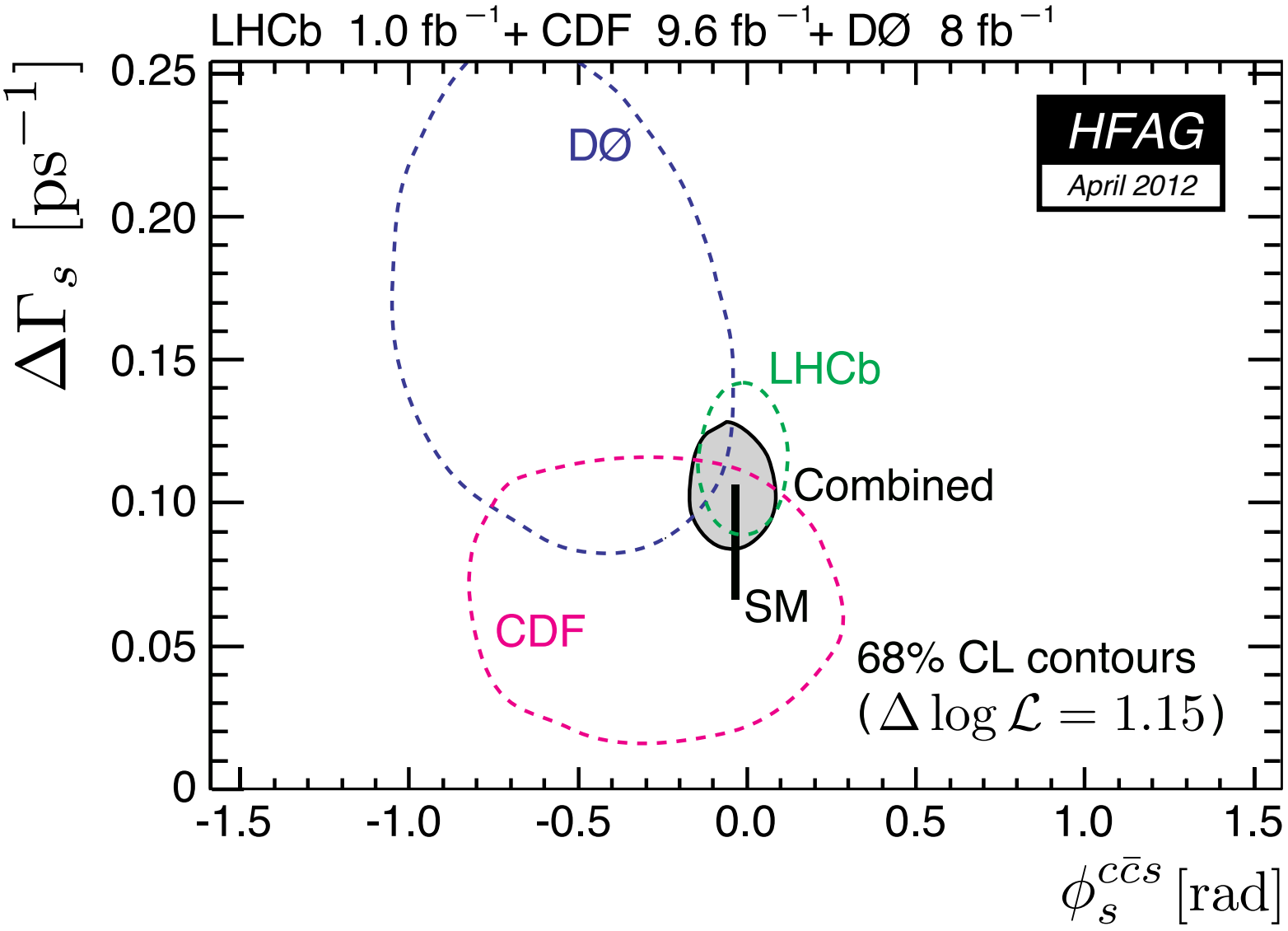




arXiv:1208.2967

Phys. Rev. D 85, 032006 (2012)

HFAG: $\Delta\Gamma_s$ versus CP phase



Summary

- D0 and CDF results with the full run II dataset.
- A_{sl} measurements remain about 3σ from SM
- CP violation in $B_s \rightarrow J/\psi\,\phi$ is tending to SM pred.
  - $B_s \rightarrow J/\psi\, f_0(980)$ and $B_s \rightarrow J/\psi\, f_2(1525)$ modes explored.
  - Detailed KK mass study indicates that B^0 background could be worse than expected.
- More results are in the pipeline