

# Heavy Flavor at the Tevatron

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# Outline

- Very brief history
- Recent results
  - Upsilon polarization
  - charm asymmetries
  - $\chi_b(3P)$  state
- Possible future measurements
  - cross sections
  - $a_{SL}$  (incl. recent dimuon asymmetry and  $B_s \rightarrow J/\psi \phi$  with full statistics)
  - $A_{FB}$  for charm and bottom

# Disclaimer

- This talk has not been vetted by the Tevatron groups.
- Opinions are my own.
- Mistakes, errors, misrepresentations are my own.

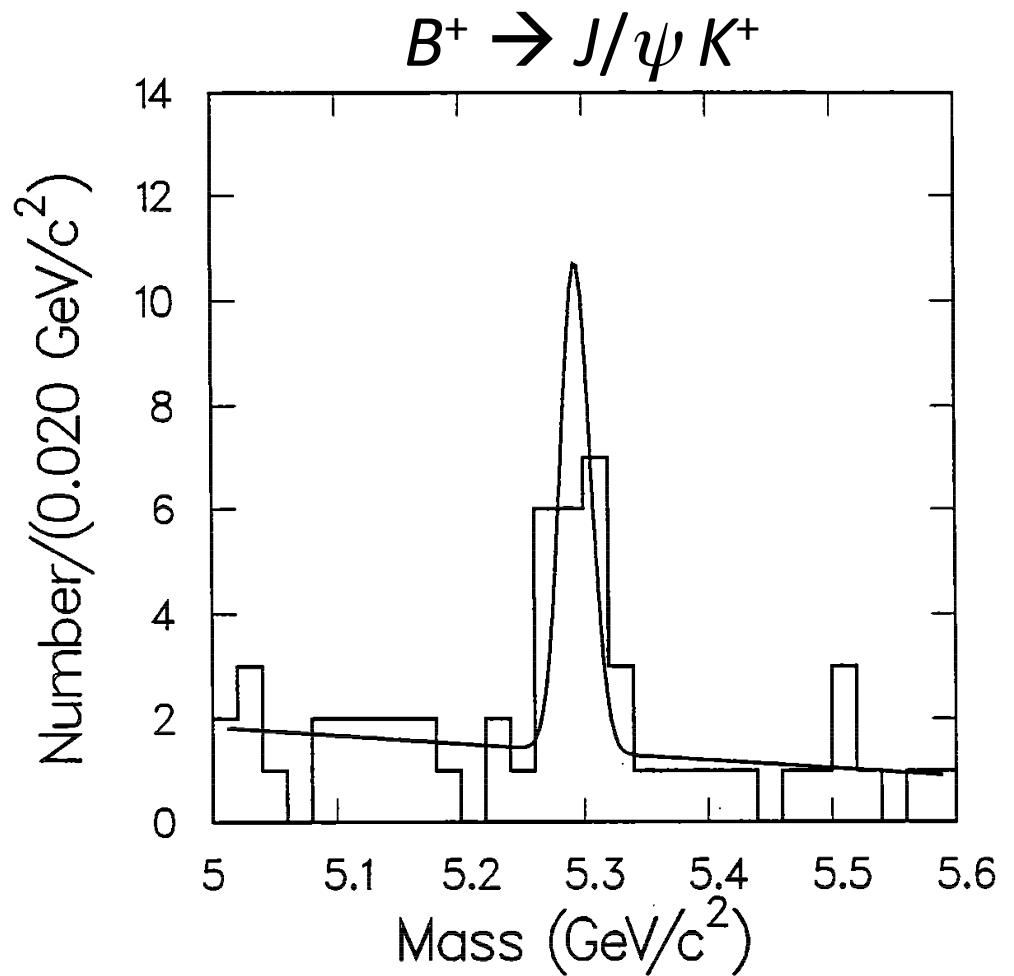


# Let's Play Ball!



# A Little History

- First fully reconstructed  $B$  decay at a hadron collider: PRL 68, 3403 (1992).
- Silicon vertex detector: 1992
- Displaced vertex trigger: 2001



# A Little More History

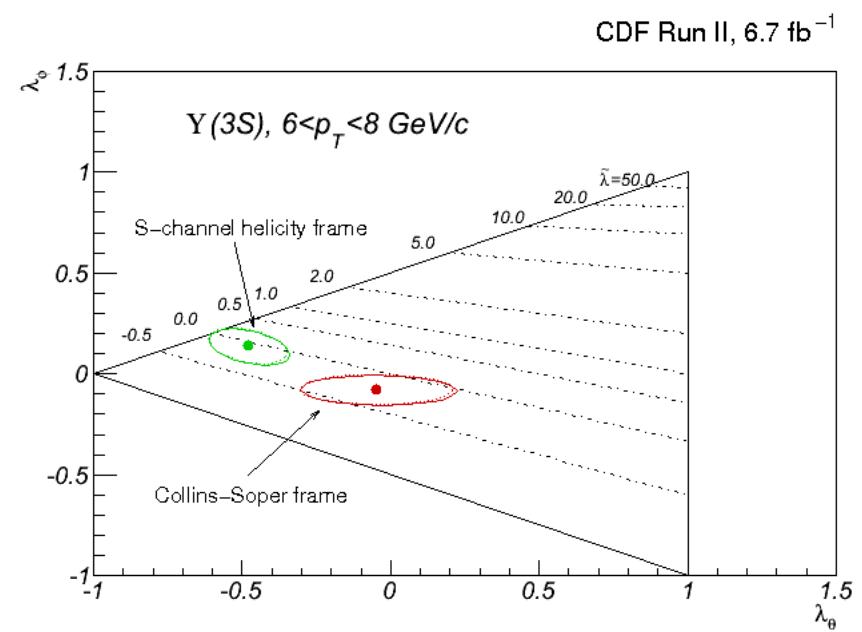
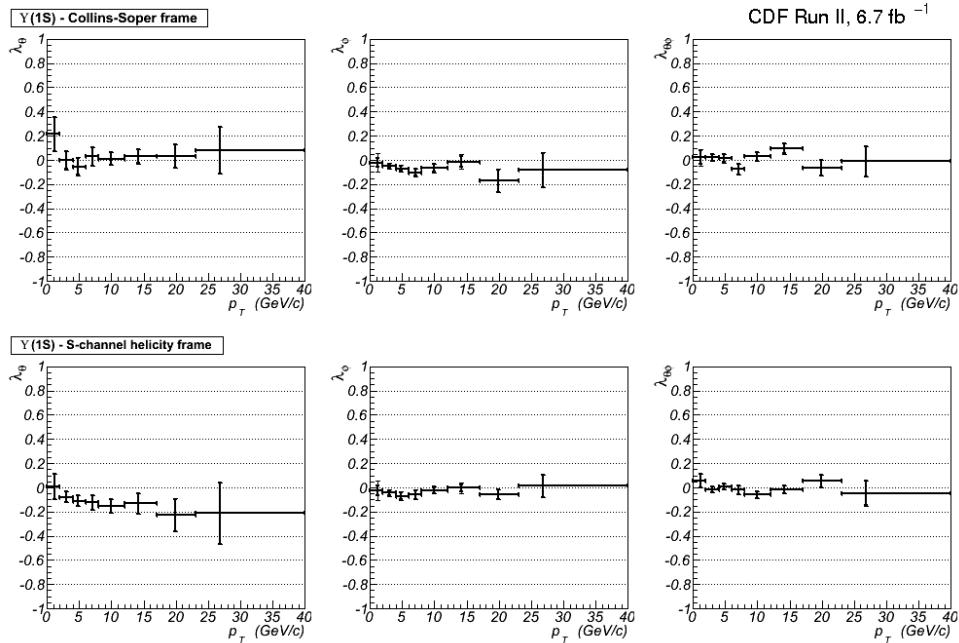
- Quarkonia production cross sections measured
- Observation of  $B_c$  meson
- 2004: Observation of  $X(3872)$
- 2006: Observation of  $B_s$  mixing
- 2008: Evidence for  $D^0$  mixing
- Observation of many b baryons:  $\Xi_b^{0,-}$ ,  $\Sigma_b^{(*)\pm}$ ,  $\Omega_b$
- Evidence for  $B_s \rightarrow \pi^+ \pi^-$

# **RECENT RESULTS**

# $Y$ Polarization



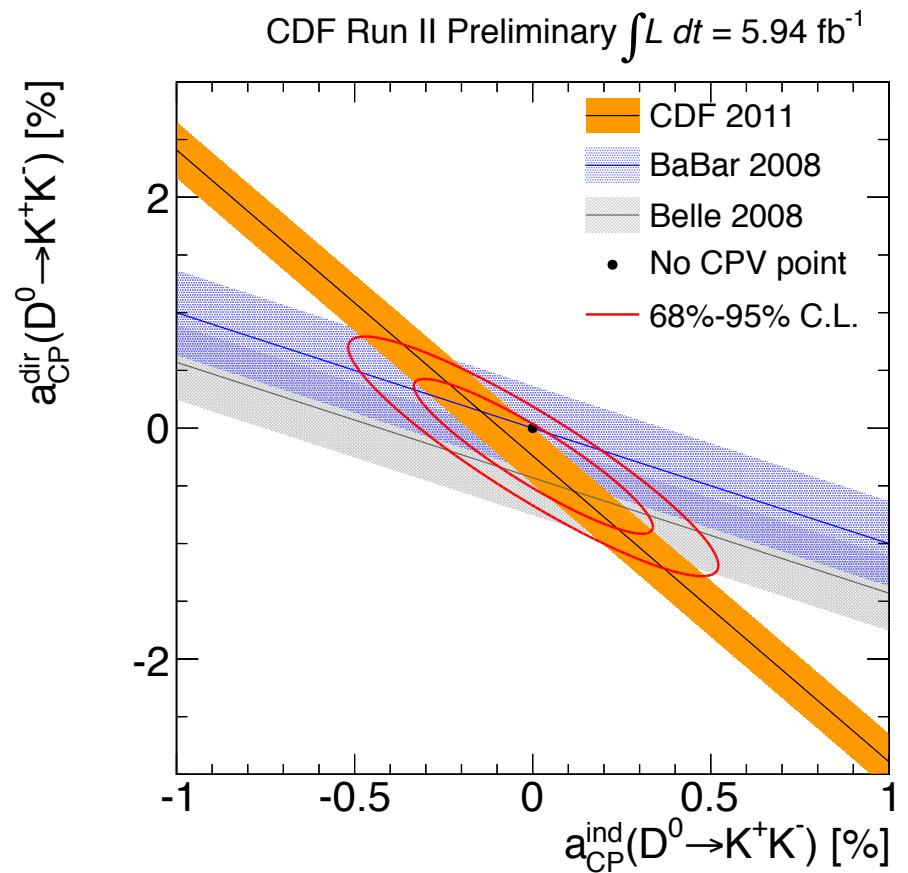
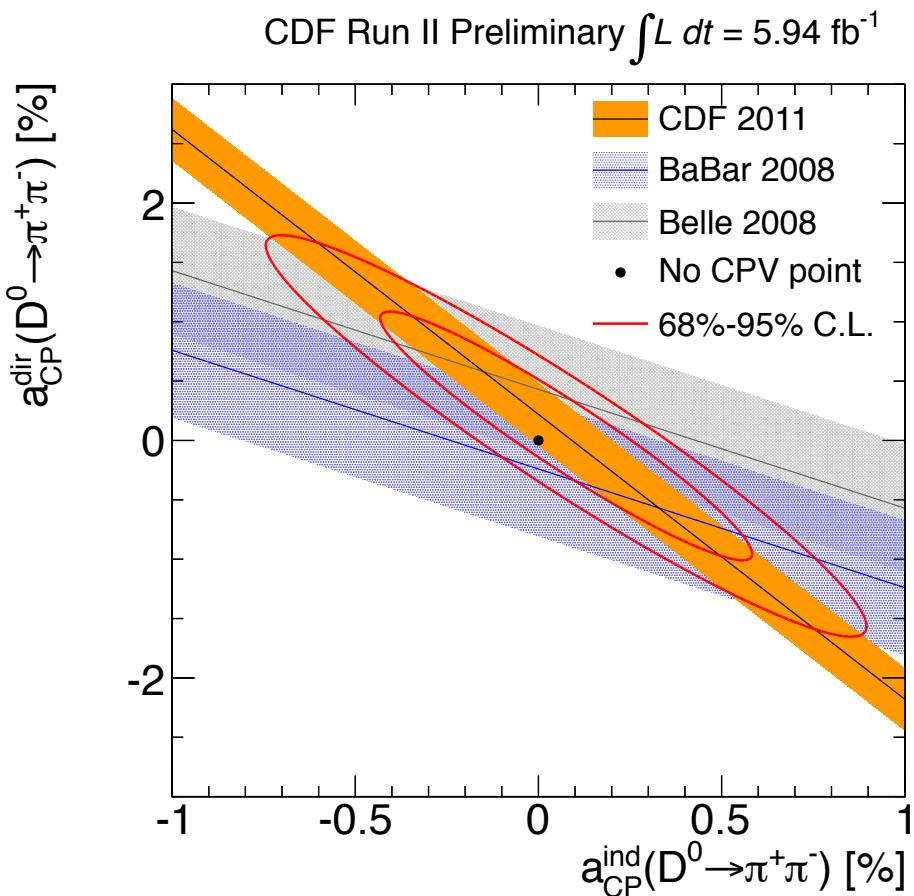
- Full 3-D fit; estimation of bkg. and its polarization; use 2 frames; fits for 1S, 2S, and 3S states
- No evidence for significant polarization.



# Charm Asymmetries:



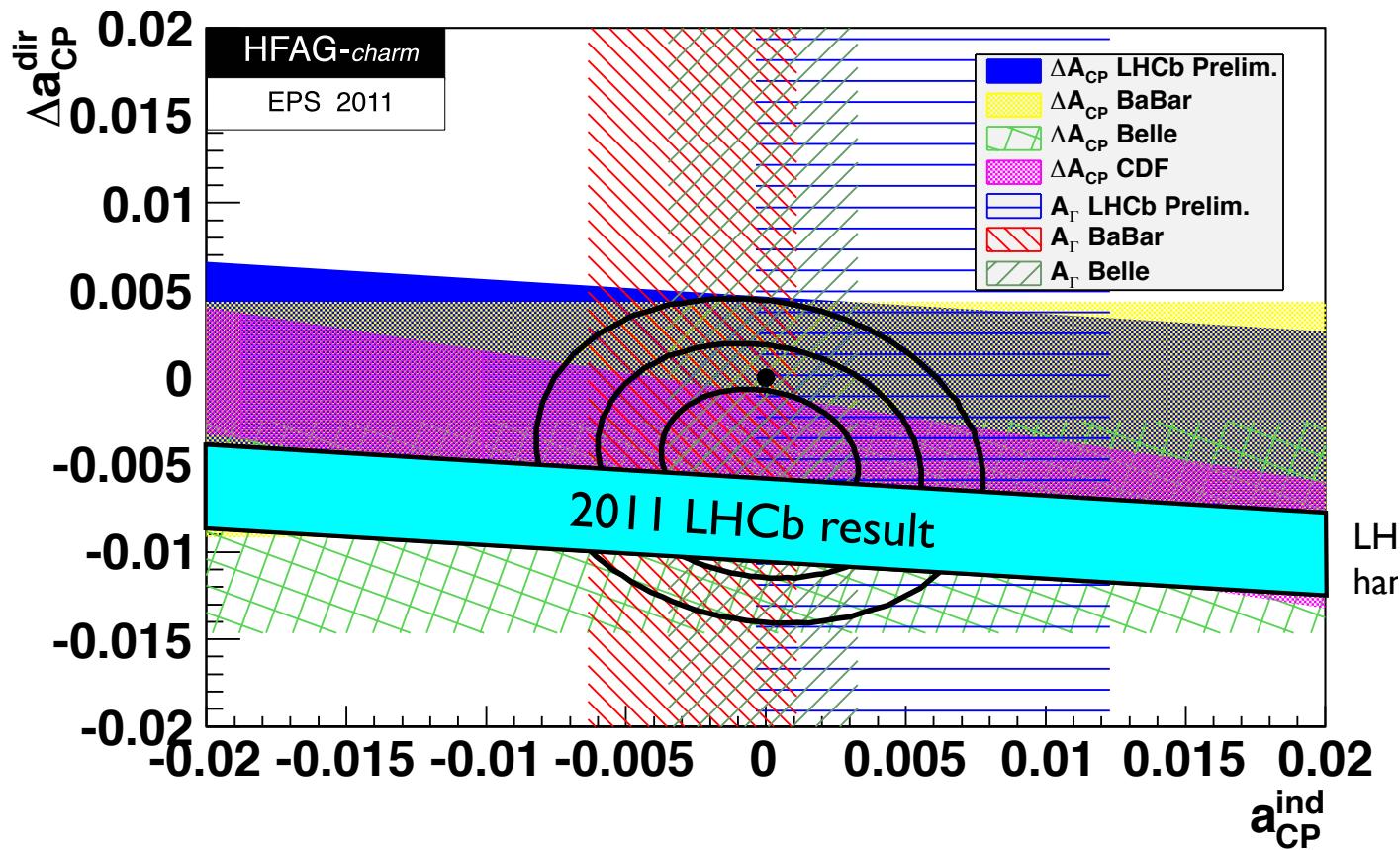
- 2010 – 2011: CDF measures ACP in  $D^0 \rightarrow \pi\pi$  and  $D^0 \rightarrow KK$  separately



# LHCb $\Delta A_{CP}$ Measurement:

- Fall 2011: LHCb measures  $A_{CP}$  difference between  $D^0 \rightarrow KK$  and  $D^0 \rightarrow \pi\pi$ , **3.5 $\sigma$  from SM.**

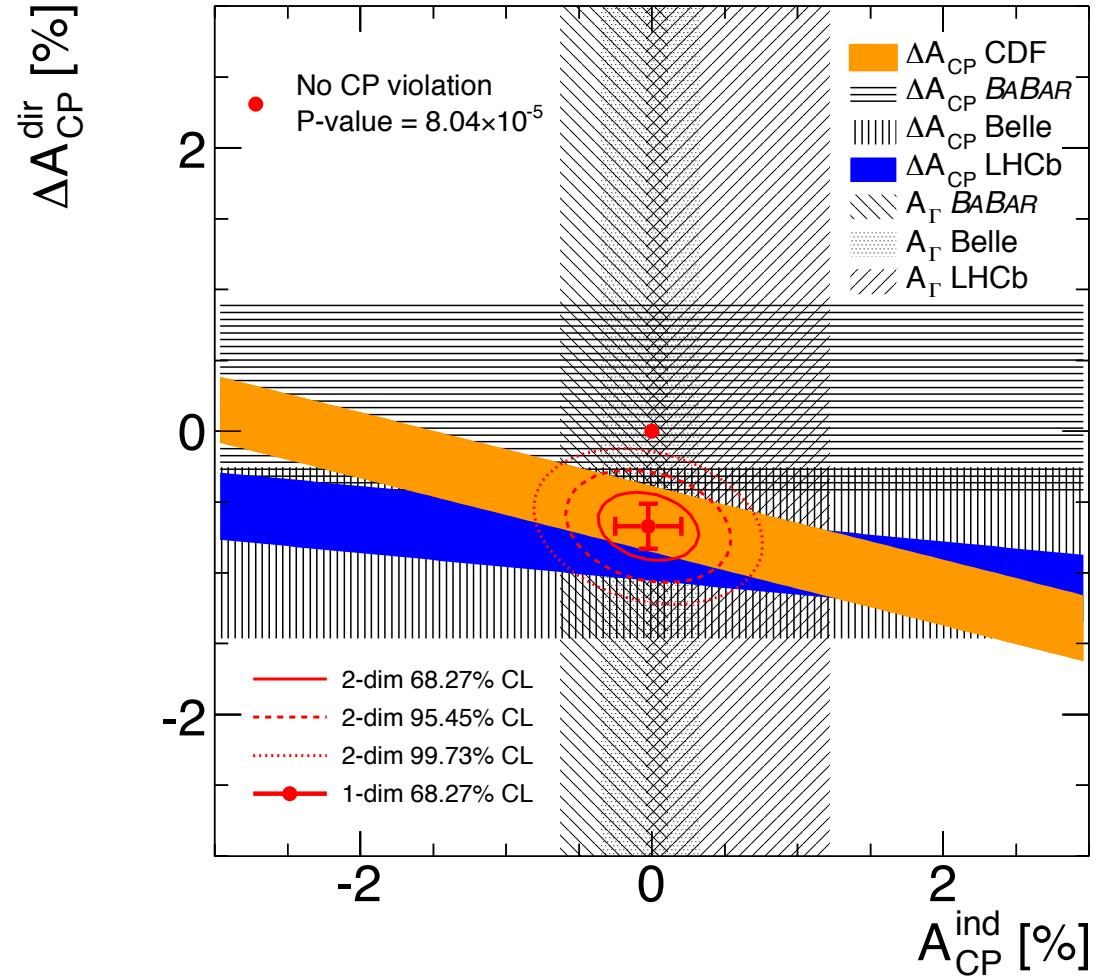
$$\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$$



# CDF $\Delta A_{CP}$ Measurement:



- 2012: Analysis optimized to measure the difference.
- Combination of all measurements **almost  $4\sigma$  from SM.**



$$\Delta A_{CP} = (-0.62 \pm 0.21 \pm 0.10)\%$$

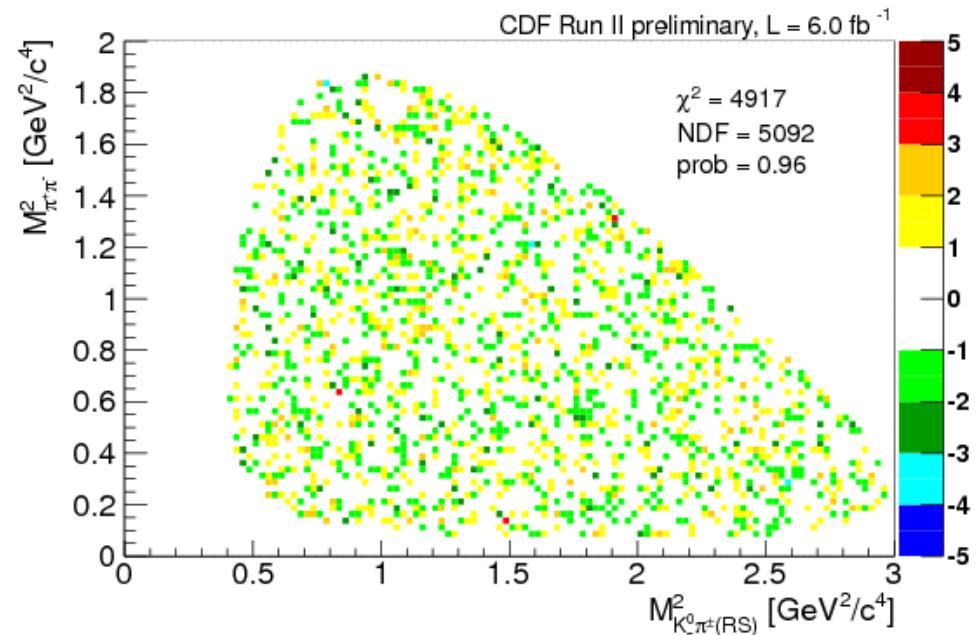
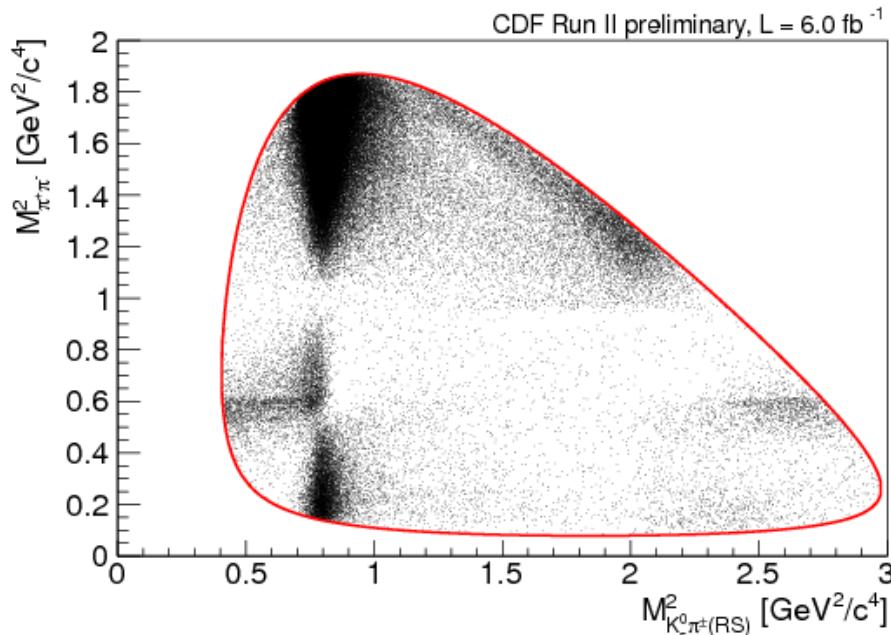
# Raises Questions:

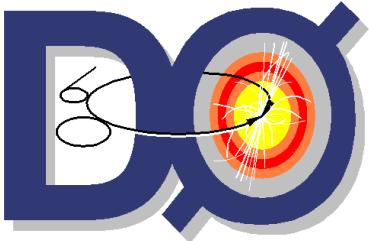
- Is the deviation from SM expectation (zero) real?
  - CDF result increases the significance of the deviation
  - Improve precision, measure other modes
- Is the SM expectation really about  $10^{-3}$ ?
  - Measure other modes
  - Isolate and constrain effects
    - penguin contributions
    - isospin breaking
    - and so on
- Need for guidance from theorists

# CP Asymmetry in $D^0 \rightarrow K_S\pi^+\pi^-$



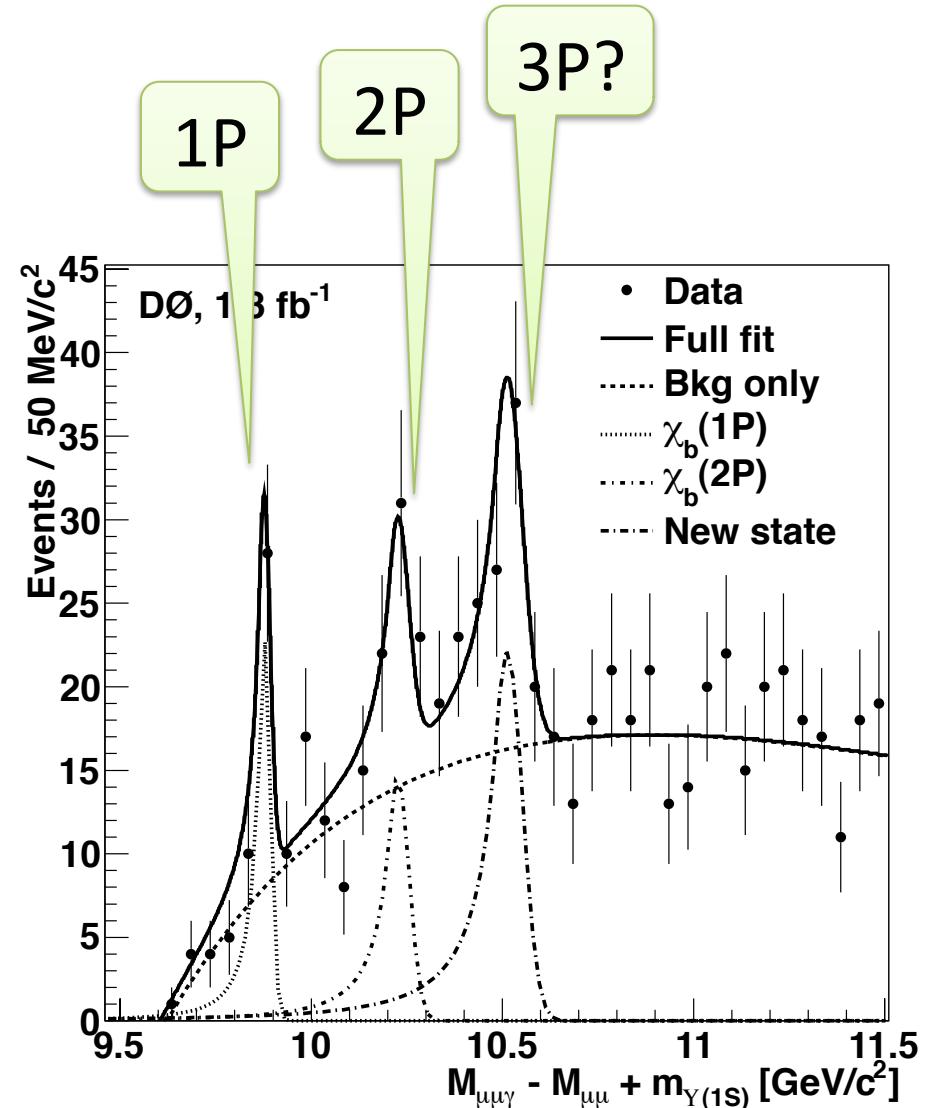
- Dalitz plot: isobar analysis and Miranda procedure
- Overall ACP =  $-0.0005 \pm 0.0057 \pm 0.0054$
- Asymmetries determined for resonance modes
  - all are consistent with zero





# $\chi_b(3P)$ Confirmation

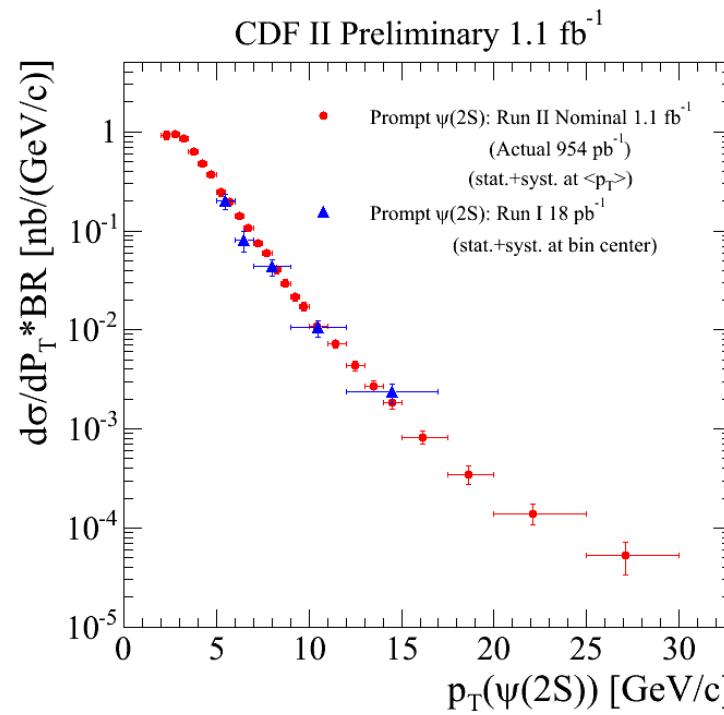
- First new particle observed at LHC by ATLAS confirmed with Tevatron data by D0.
- Observed in  $Y(1S)\gamma$  mode.
- Mass of  $10.55 \pm 0.02$  GeV is consistent with ATLAS state at  $10.53 \pm 0.01$  GeV.



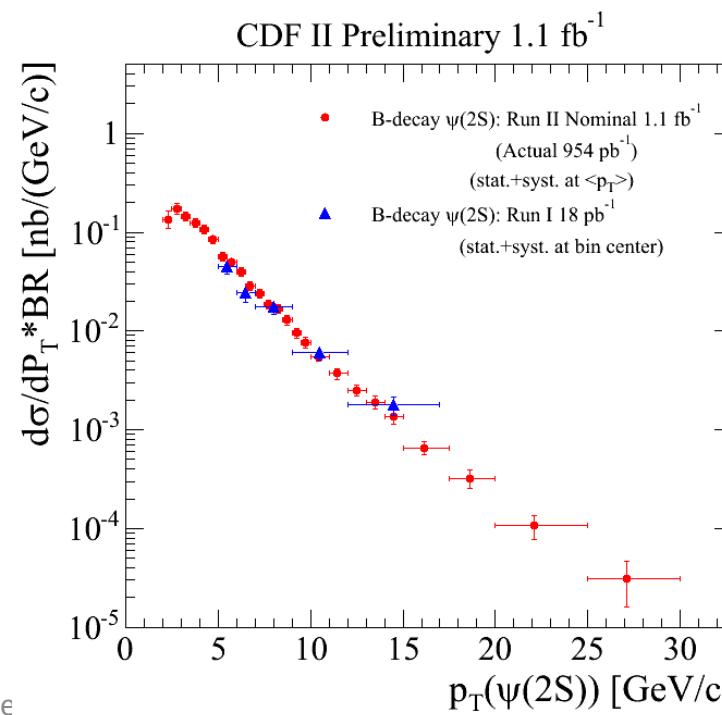
# **POSSIBLE FUTURE DIRECTIONS**

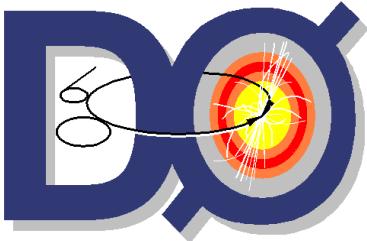
# Production Cross Sections

- Production cross sections at Tevatron energy represent unique information.
  - Most existing measurements are with less than  $1 \text{ fb}^{-1}$



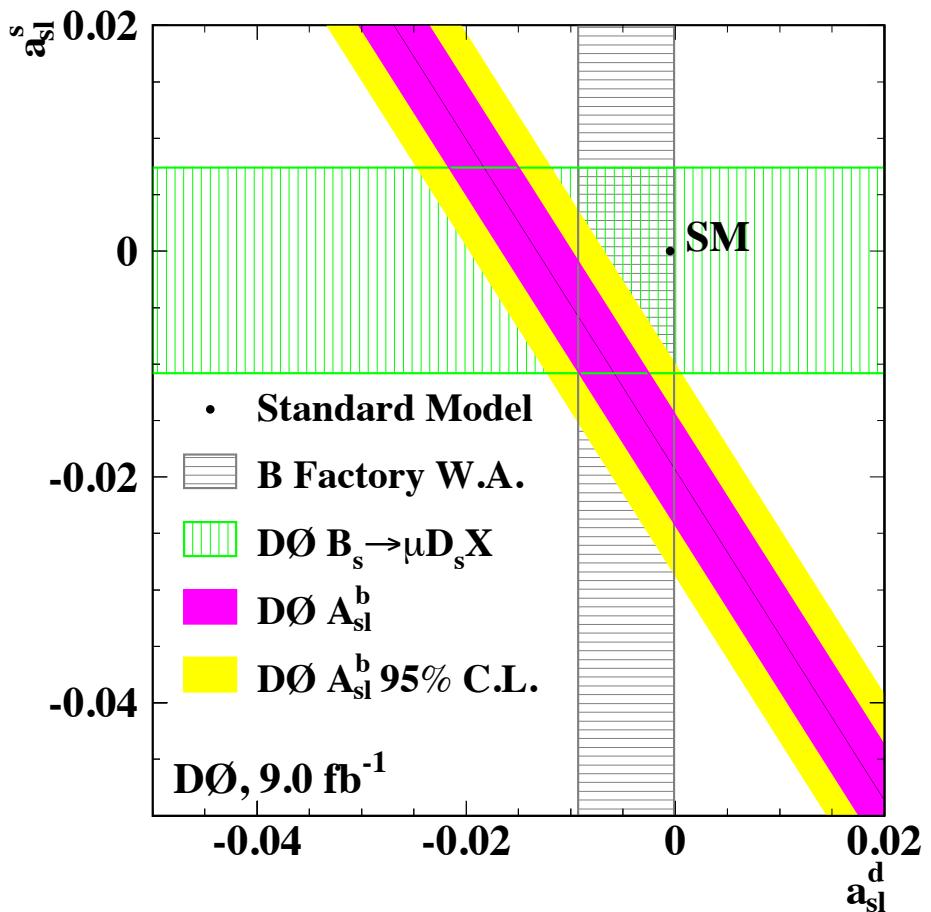
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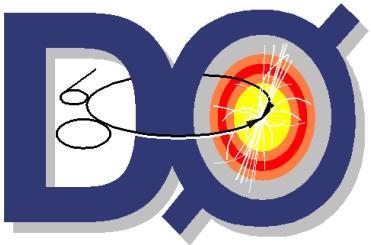




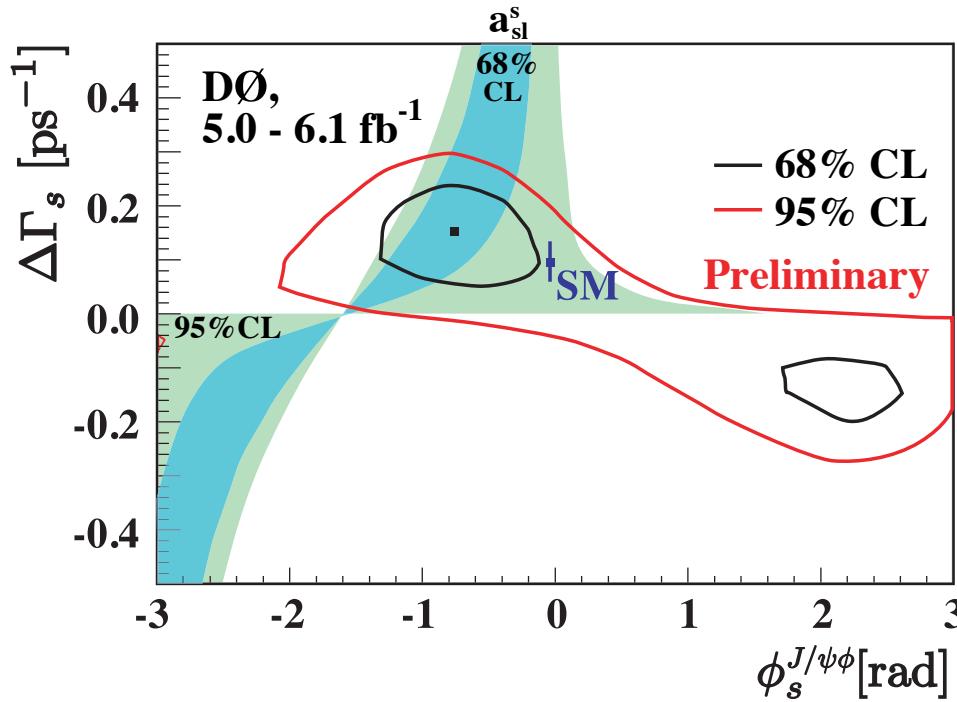
# $a_{sl}$ in $B$ Decays: Status

- 2010: DØ dimuon asymmetry result
  - $3.2\sigma$  from SM
- 2011: Updated result
  - $3.9\sigma$  from SM
- Note green and gray bands





# Relation to $\phi_s$

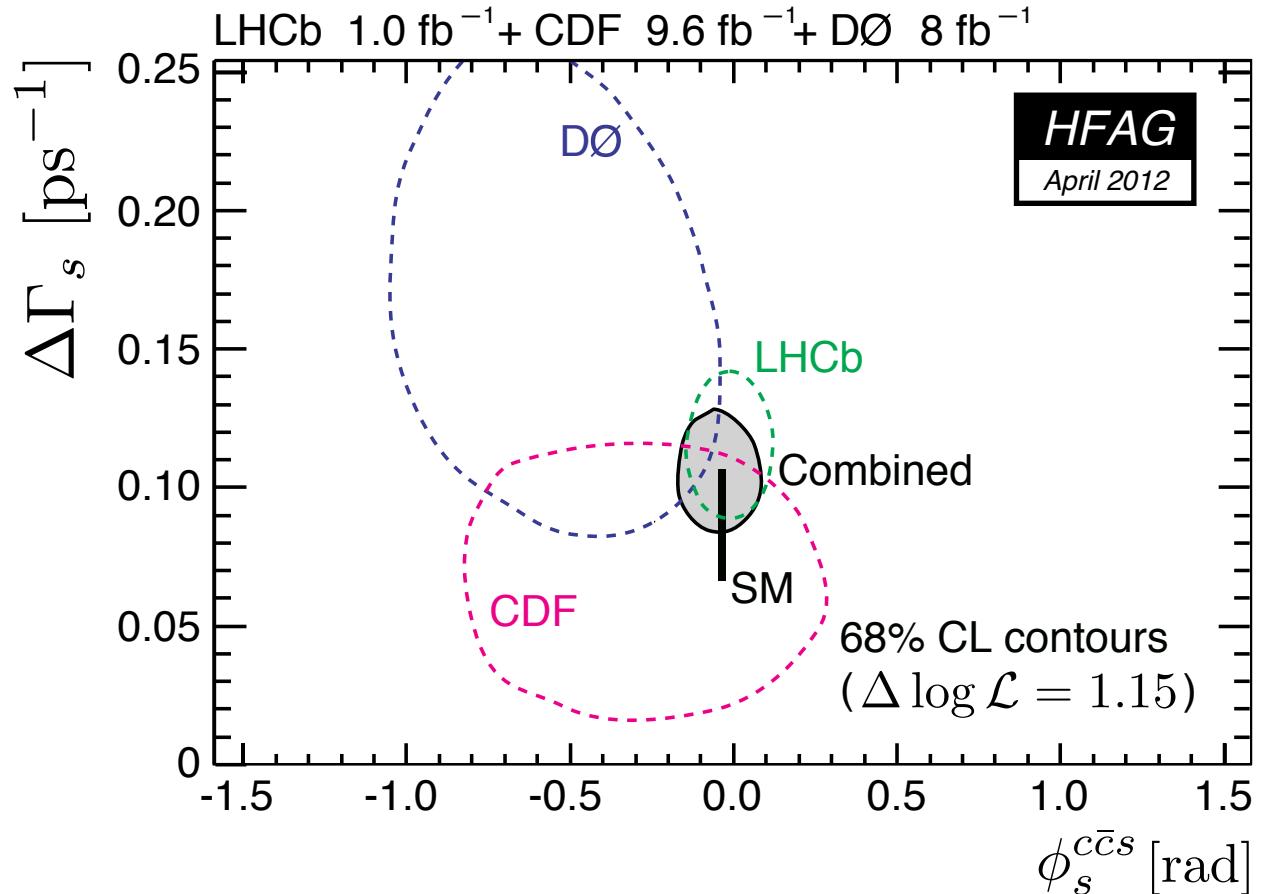


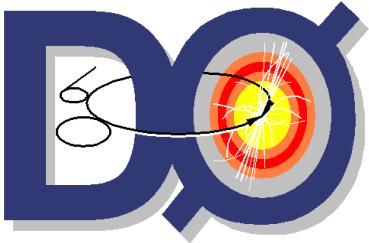
$$a_{fs} = \frac{\Delta\Gamma}{\Delta M} \tan\phi$$

- The D0 result was bolstered by consistency with anomalous  $\phi_s$  from  $B_s$  →  $J/\psi \phi$
- $\phi_s$  results moving to SM point → tension with dimuon asymmetry result

# Recent $\phi_s$ Combination

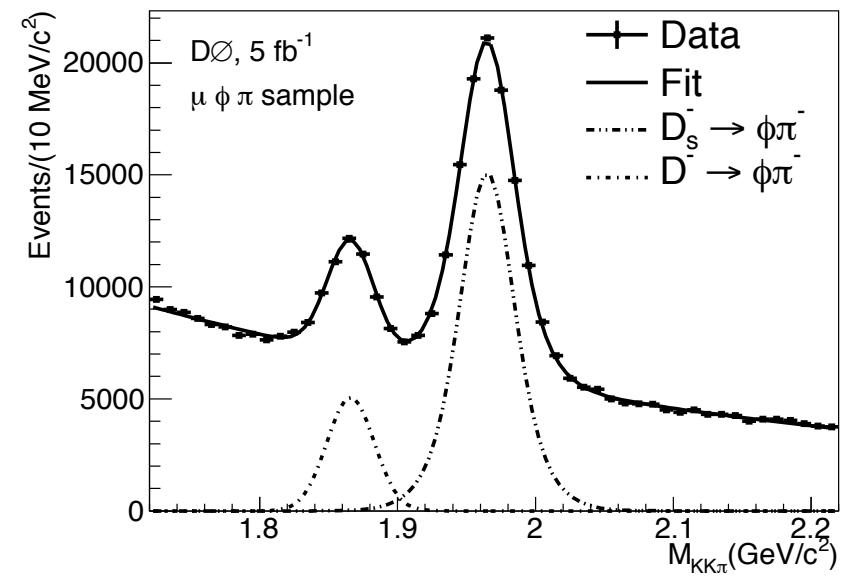
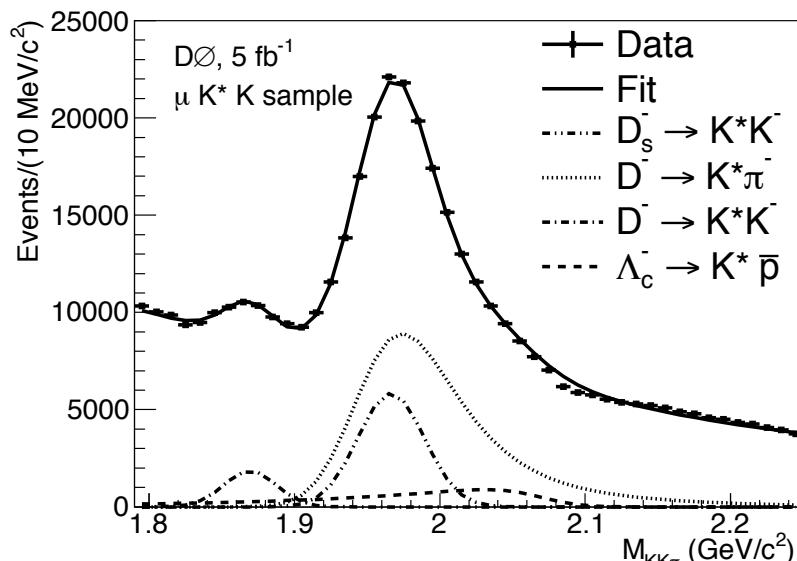
- Has converged to SM expectation, less consistent than early indications.
- From  
 $B_s \rightarrow J/\psi \phi$





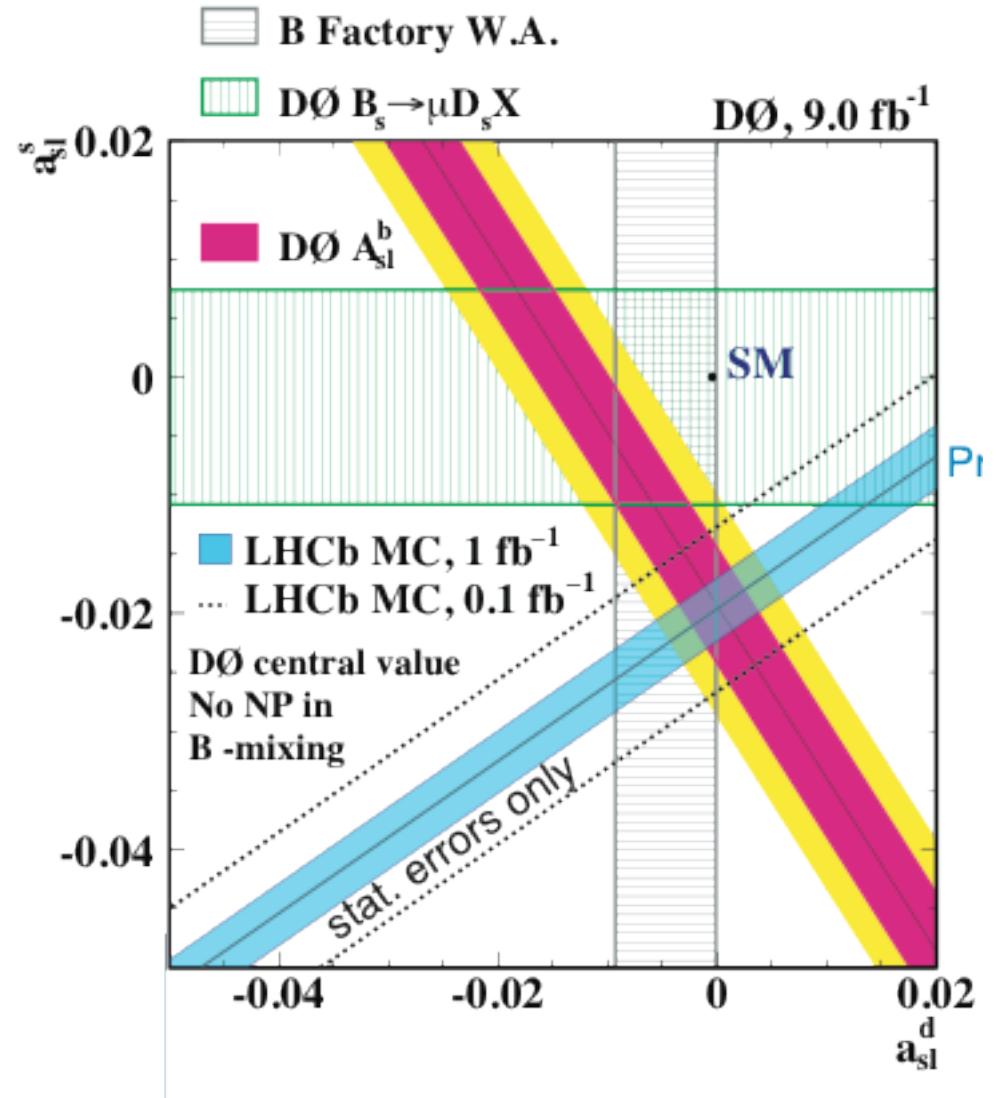
# D0 $a_{SL}$ Result

- D0 has published two  $a_{SL}$  results:
  - most recent is PRD 82, 012003 (2010).
- Analysis uses about 115k  $D_s\mu$  events
  - $a_{SL} = [-1.7 \pm 9.1 \pm 1.5] \times 10^{-3}$



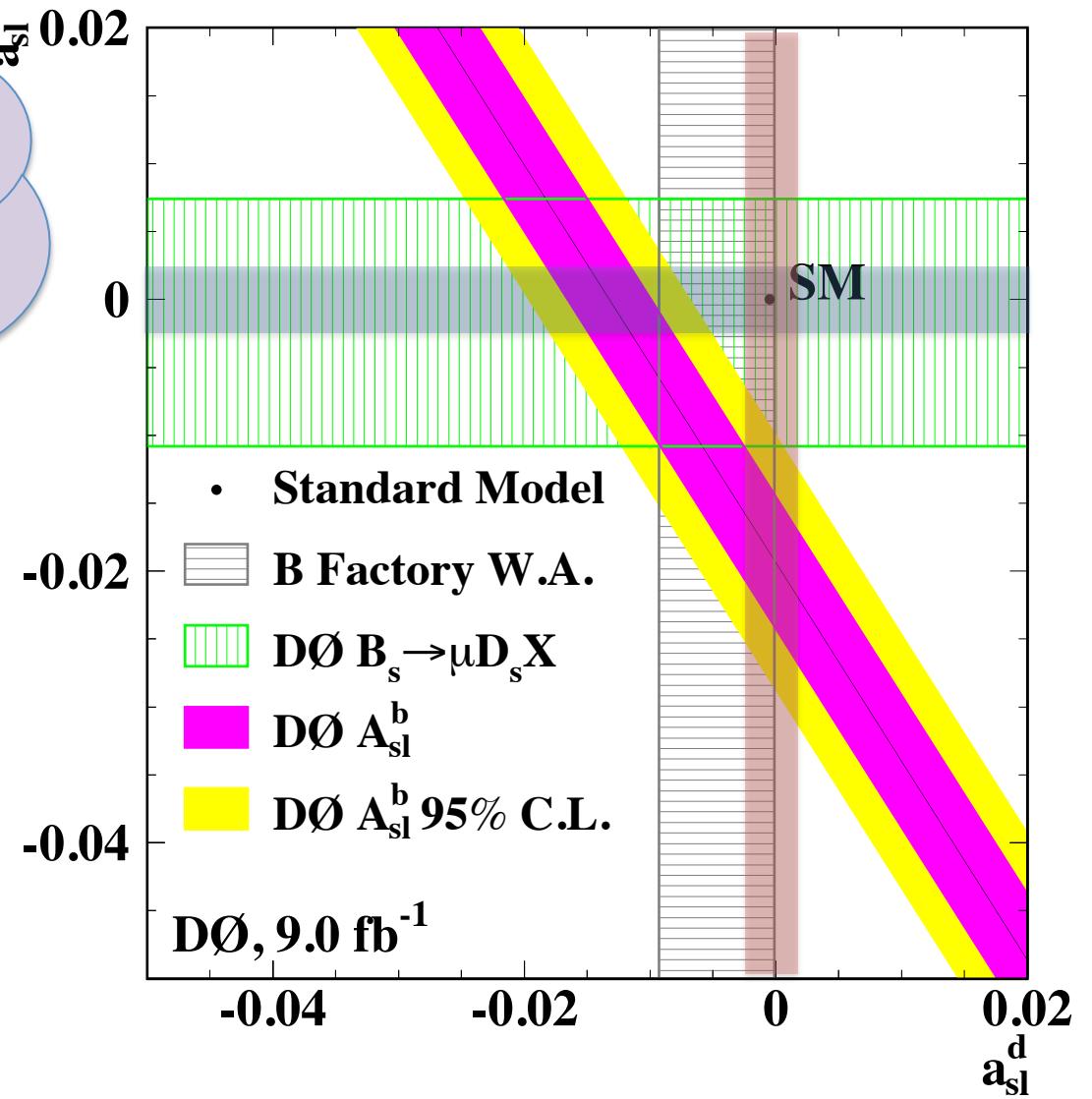
# LHCb Potential (cont'd)

- And  $a^s - a^d$  measurement likely isn't enough to settle the issue!
- Another complementary measurement is needed.



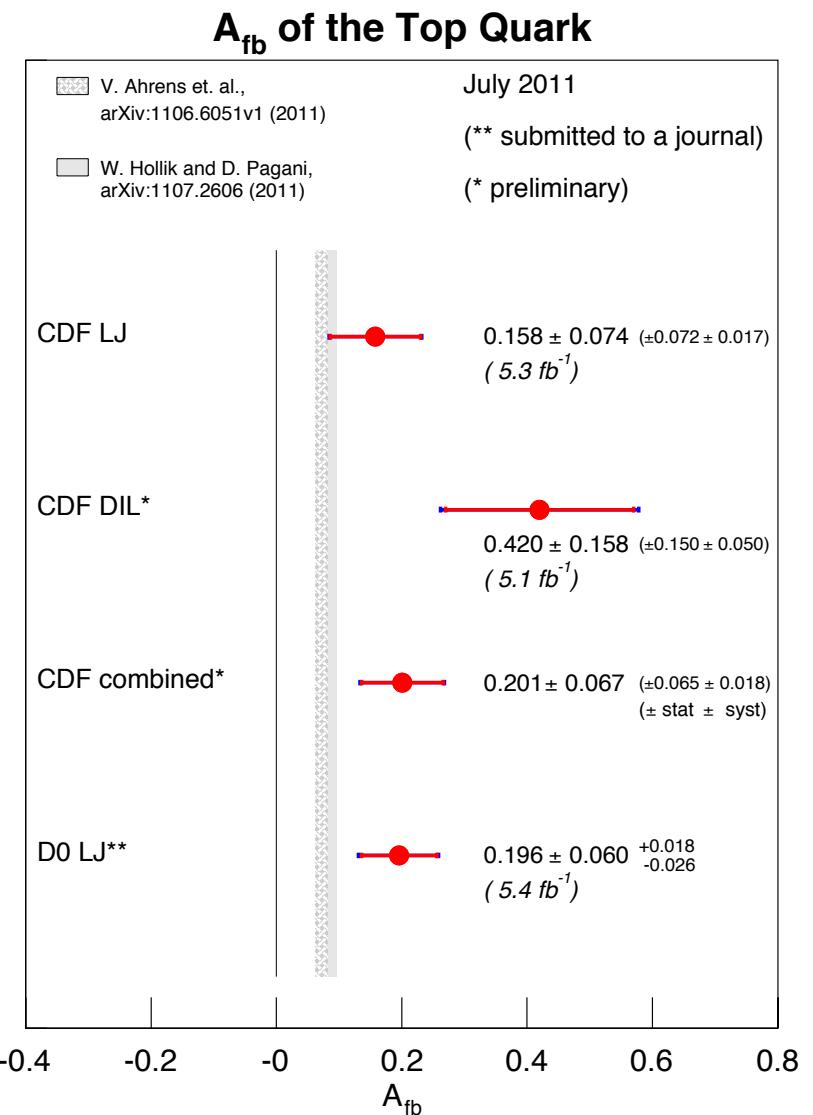
# Potential Impact of Measurement

0.2% uncertainty makes an interesting constraint.



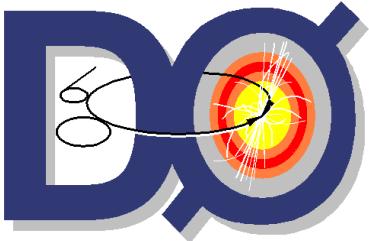
# AFB in Charm and Bottom

- AFB in top is large,  $\approx 20\%$ .
- Original CDF lep+jet result confirmed in dileptons and by D0.
- $M_{tt}$  dependence
- Source unknown
- Could effect exist for next heaviest quark (b) or other up-type quarks (c)?



# Potential Impact

- Less theory to go on.
- Basically, searching for a related anomaly to guide theory.
- Evidence for an AFB in bottom or charm would be exciting.
- Ruling out a sizable AFB would be interesting.
- Gaining more insight would be an accomplishment.



# Summary



- The Tevatron experiments pioneered heavy flavor physics at hadron colliders.
- Interesting results still come from CDF and D0.
  - and a few anomalies to investigate
- Much more information available at
  - <http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm>
  - <http://www-cdf.fnal.gov/physics/new/bottom/bottom.html>



# **BACKUP**