CP Violation and Suppressed B_s Decays at CDF

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XXV Rencontres de Physique de La Vallée d'Aoste

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Outline

- Suppressed B_s Decays
  - $B_s \to J/\psi\ f_0(980)$ (New for LaThuile)
  - $B_s \to J/\psi\ K_S^0$
- Fragmentation Fractions (New)
- CP Violation
  - $B^+ \to D^0 h^+$: ADS Method
  - $D^0 \to K^+K^-, \pi^+\pi^-$ (New)

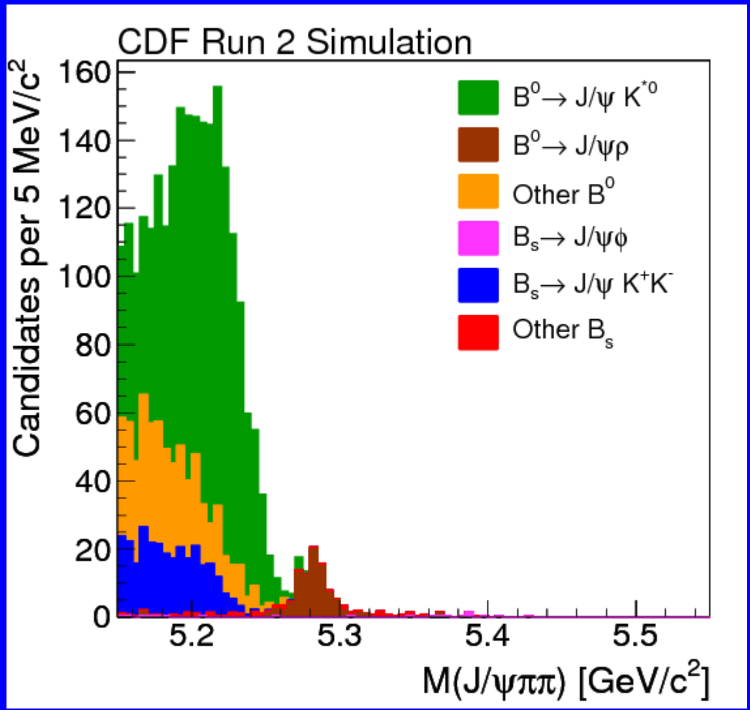
$B_s \to J/\psi\ f_o(980)$

- CP=-1 eigenstate
  - Unambiguous measure of lifetime $1/\Gamma_H$
  - Clean measure of CP violating parameter β_s (weak phase)
    - $B_s \to J/\psi\,\phi$ requires complex angular analysis for vector-vector final state
  - Understand S-wave contributions to β_s measurement in $B_s \to J/\psi\,\phi$
- New result from Belle
  - $Br(B_s \to J/\psi\ f_0,\ f_0 \to ,\ \pi^+\pi^-) = 0.34^{+0.11+0.03+0.08}_{-0.14-0.02-0.05} \times 10^{-4}$
- Observation by LHCb

$$R = \frac{Br(B_s \to J/\psi\, f_0,\, f_0 \to \pi^+\pi^-)}{Br(B_s \to J/\psi\, \varphi,\, \varphi \to K^+K^-)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

CDF Analysis

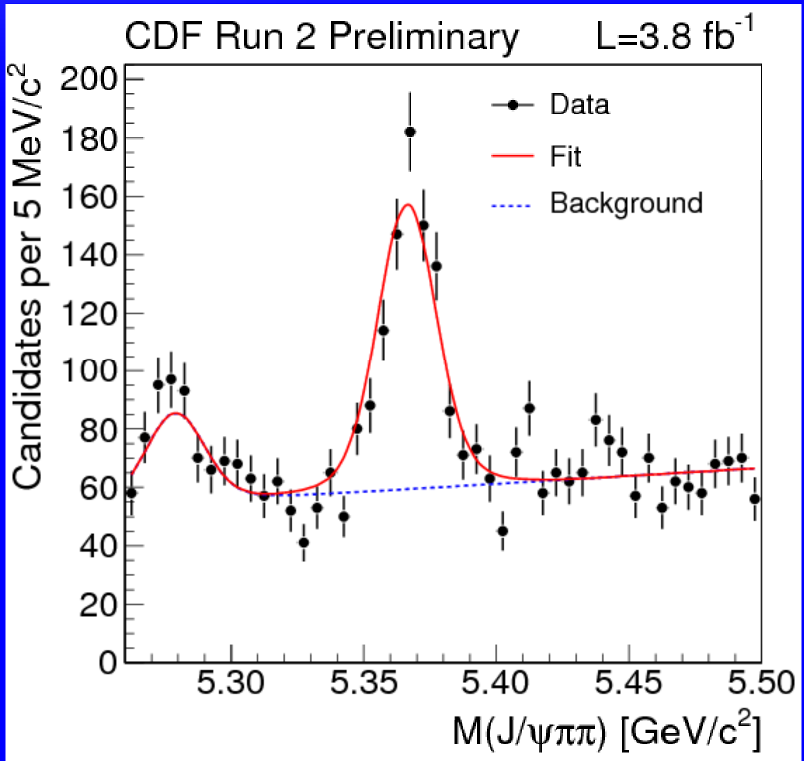
- Start with loose selection of μμππ candidates
  - f_0 is wide, so $0.85<M(\pi\pi)<1.2$ GeV
- Neural Net Selection
  - Kinematic variables, track & vertex displacement, isolation
  - High-mass sideband only for background model
  - Use identical selection for $B_s \rightarrow J/\psi\,\phi$ reference mode
- Physics backgrounds from Monte Carlo



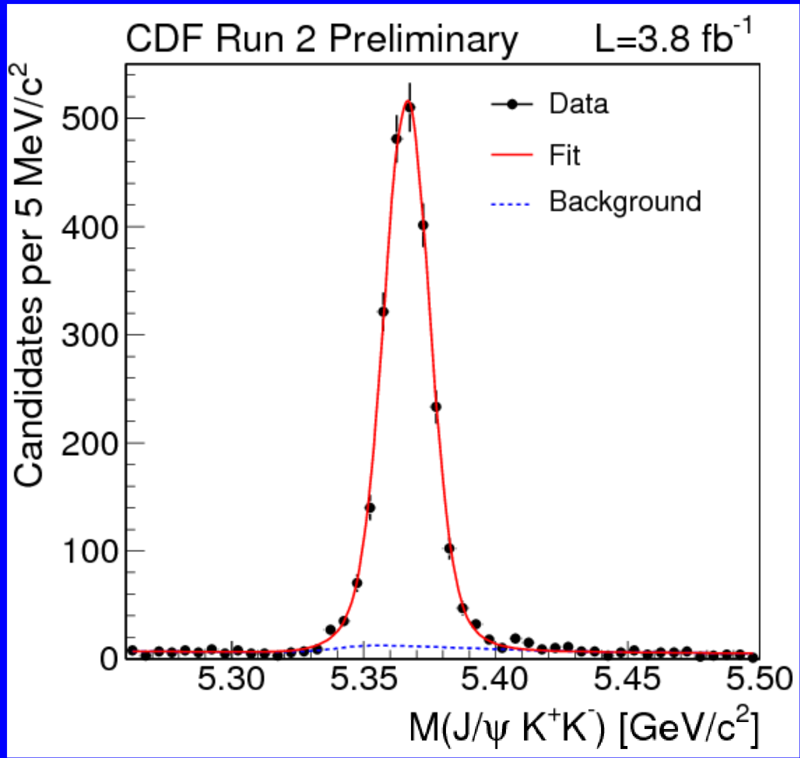
Fit

- Simultaneous log-likelihood fit to signal and normalization channels

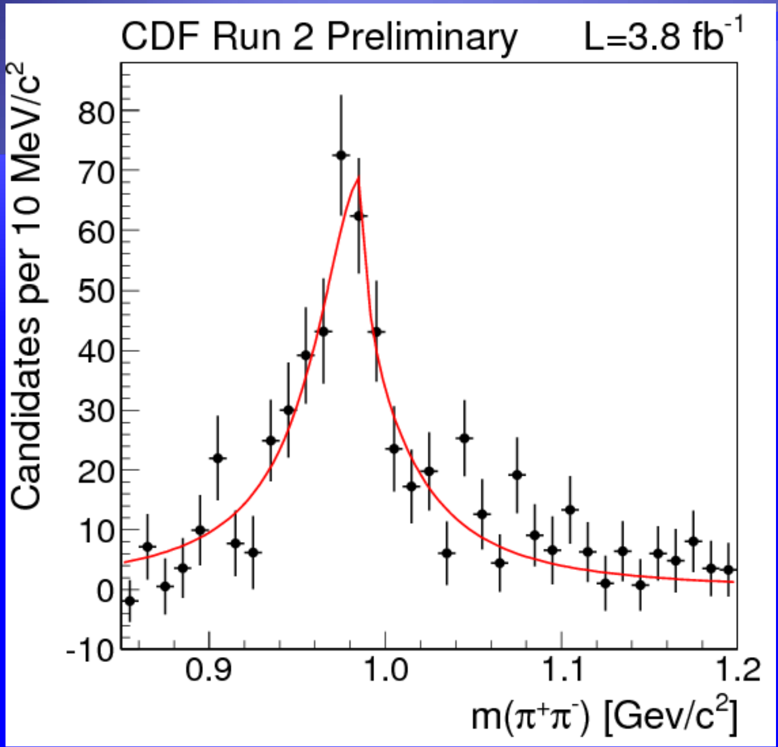
N(J/ψ f_0)=571±37



N(J/ψ ϕ)=2302±49

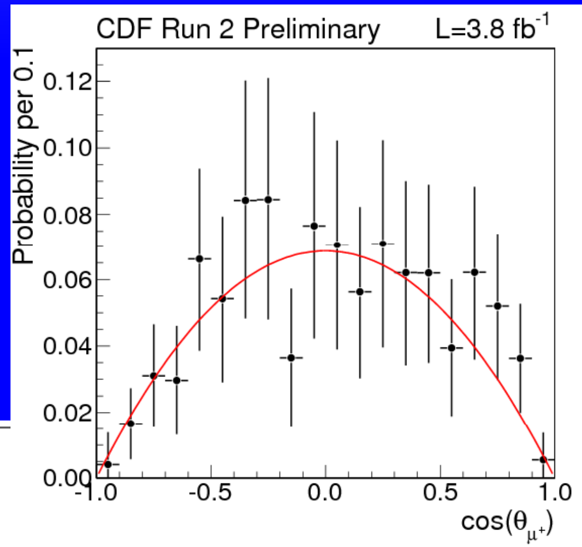


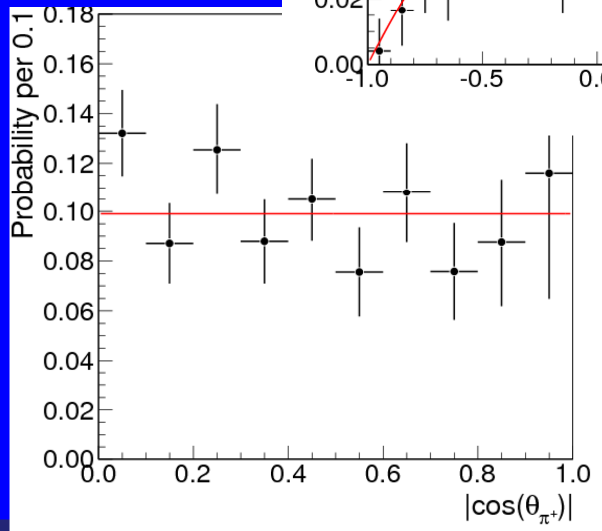
Confirmation of $f_0(980)$



- Dipion mass distribution consistent with f^0
  - Shape parameters consistent with BES, CLEO

- Helicity angles consistent with P→SV decay
  - After efficiency correction





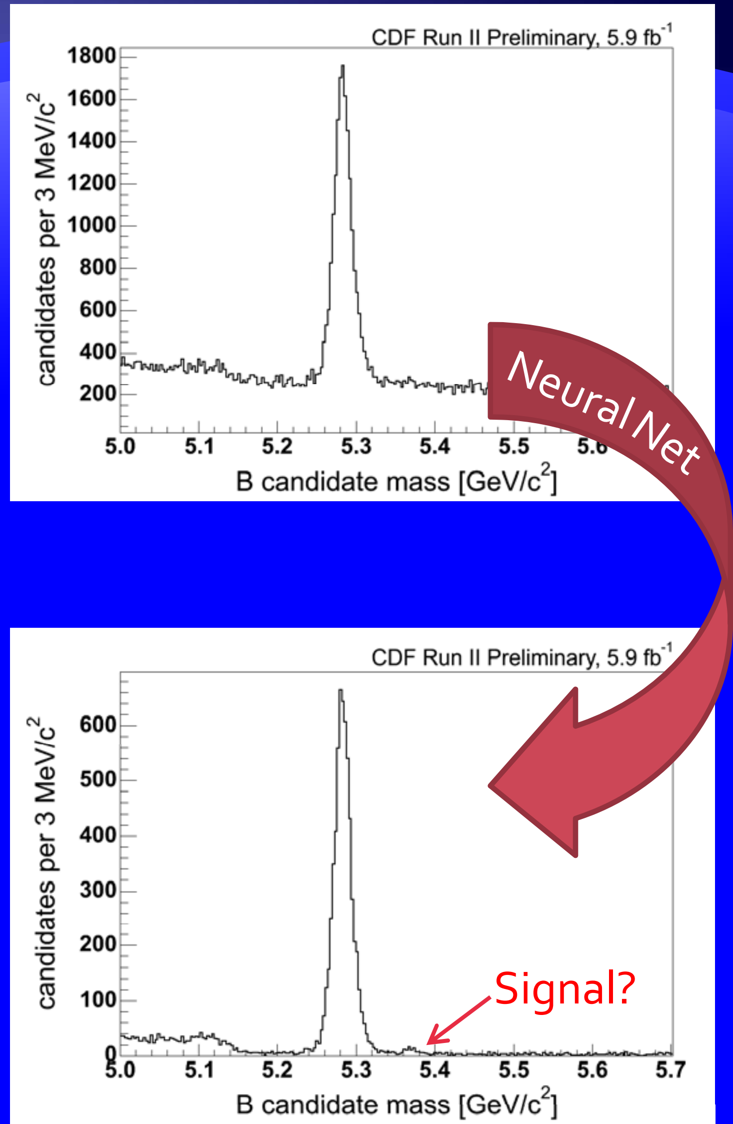
Result:

$$R = \frac{Br(B_s \to J/\psi\, f_0,\, f_0 \to \pi^+\pi^-)}{Br(B_s \to J/\psi\, \varphi,\, \varphi \to K^+K^-)} = 0.290 \pm 0.020(stat) \pm 0.017(sys)$$

- Systematics
  - Fit model
  - Background
  - Relative Efficiency
- For details see public note CDF/10404

$B_s \rightarrow J/\psi\ K_S^0$

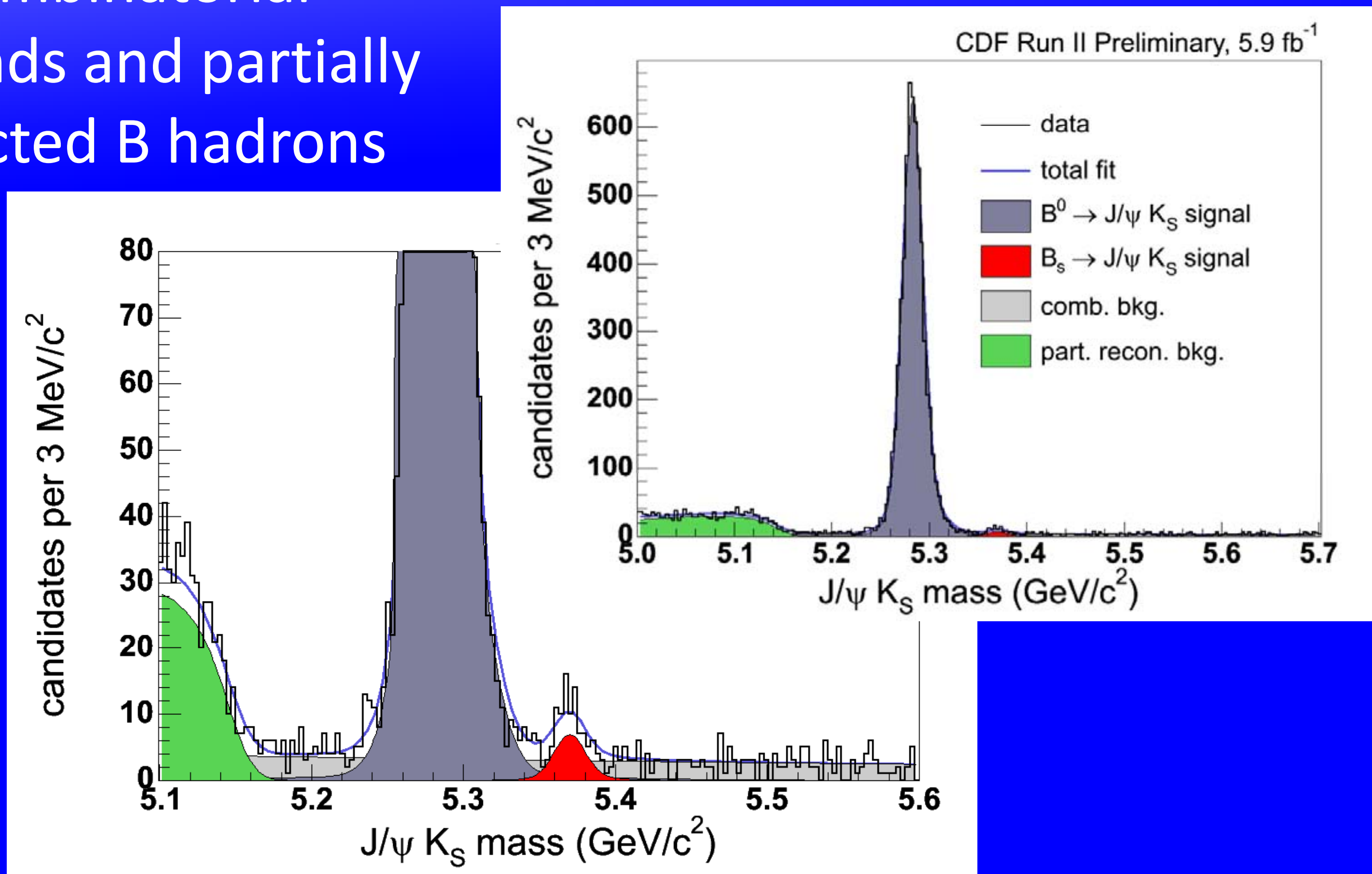
- CKM suppressed decay mode
  - Expect
    $Br(B_s \rightarrow J/\psi\, K_S^0) / Br(B_d \rightarrow J/\psi\, K_S^0) \approx 0.05$
- CP=-1 eigenstate
  - In large samples, measure $1/\Gamma_H$ and β_s
- Reference mode is CKM favored $B_d \rightarrow J/\psi\ K_S^0$
  - Relative efficiency from Monte Carlo
  - Also used to derive signal template
    - Same shape for B_d and B_s, offset by known splitting



Mass Fit

- Binned Log Likelihood
  - Include combinatorial backgrounds and partially reconstructed B hadrons

$N(B_s)=64\pm14$



Results

- Significance
  - Compare to null hypothesis
    - Interpret change in -2log(L) as $\Delta\chi^2$
  - Probability of background fluctuation $4\text{x}10^{-13}$ or 7.2σ
- Branching Ratio:

$$\frac{\mathrm{Br}(B_s^0 \rightarrow J/\psi K_S^0)}{\mathrm{Br}(B_d^0 \rightarrow J/\psi K_S^0)} = 0.041 \pm 0.007(\mathrm{stat.}) \pm 0.004(\mathrm{syst.}) \pm 0.005(\mathrm{frag.})$$

- First observation of CKM suppressed B_s decay
  - Details: http://arxiv.org/abs/1102.1961

Fragmentation Fractions: f_s/f_d

- Two methods
  - Count semileptonic decays and assume SU(3)
    - $\Gamma(B^- \rightarrow D^0 \mu^- \nu) = \Gamma(B^0 \rightarrow D^+ \mu^- \nu) = \Gamma(B_s^0 \rightarrow D_s^+ \mu^- \nu)$
  - Use time-integrated average mixing parameter: $\bar{\chi} = f_d \chi_d + f_s \chi_s$
    - Derived from

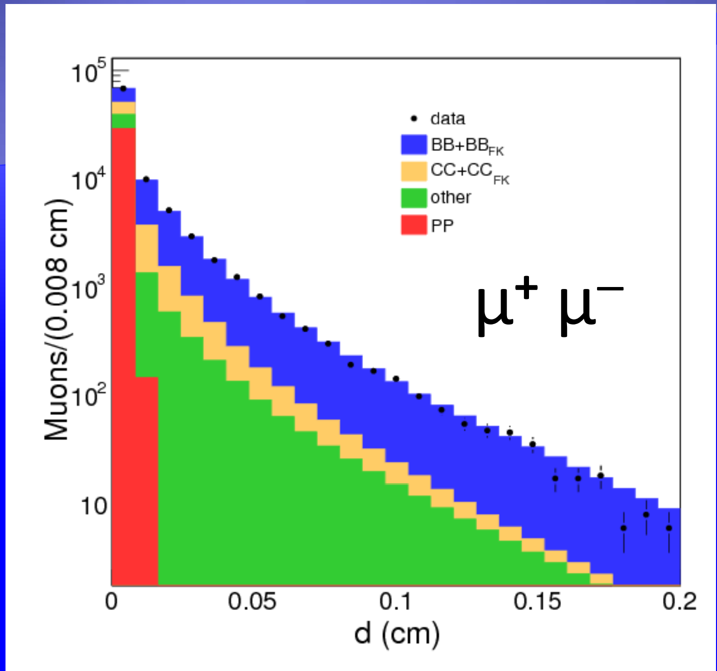
      $$R = [N(l^+ l^+) + N(l^- l^-)] \,/\, N(l^+ l^-)$$

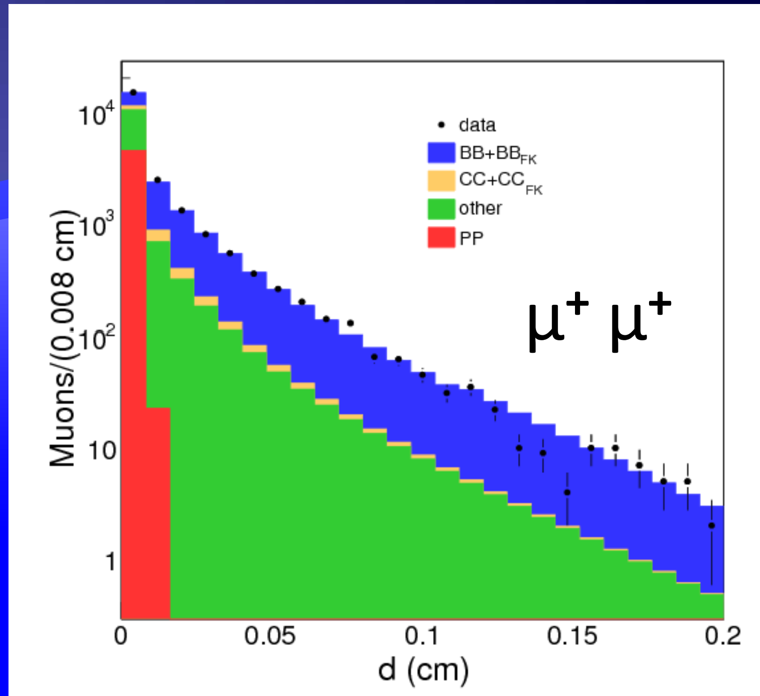
    - Discrepancies in $\bar{\chi}$ from previous measurements
      - CDF Run 1: 0.152±0.013
      - D0: 0.132 ±0.024
      - LEP Average: 0.126 ±0.004
    - Are fractions different in $p\bar{p}$ vs. e^+e^-?

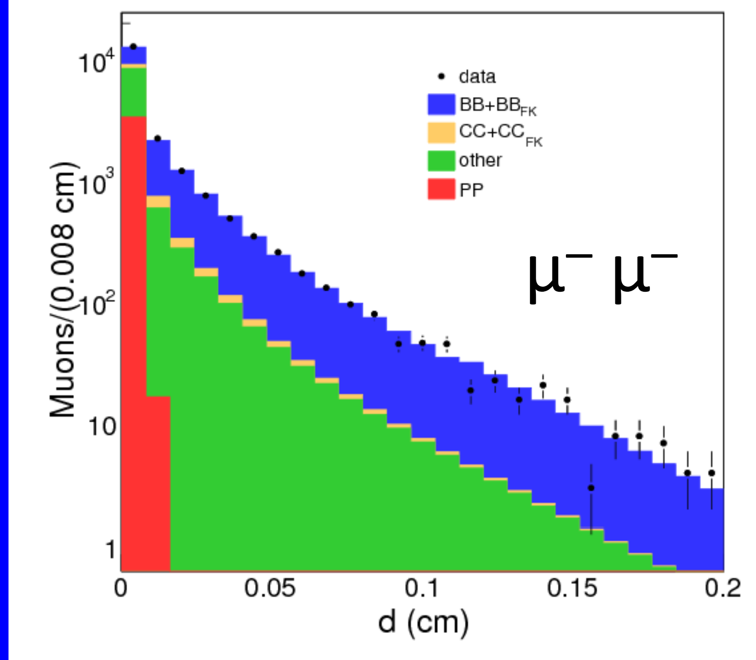
$\bar{\chi}$: New CDF Measurement

- Dimuon data sample
  - 1.4 fb^{-1}
- Use impact parameter to identify source of muons: *b*, *c*, prompt
  - Same technique as $b\bar{b}$ cross-section measurement
  - 2D fit of d_0 using templates from Monte Carlo
  - Constraints on $b,c \rightarrow K,\pi \rightarrow \mu$ also from MC
    - Fake rates from $D^0 \rightarrow K^-\pi^+$ data
  - Much tighter selection than earlier measurements
    - Requires hit in silicon layer 1.7cm from beam

Fit Projections







- $R_{bb,raw} = 0.472 \pm 0.011 \pm 0.007$
  - Systematic from fake muon contributions

Extracting $\bar{\chi}$

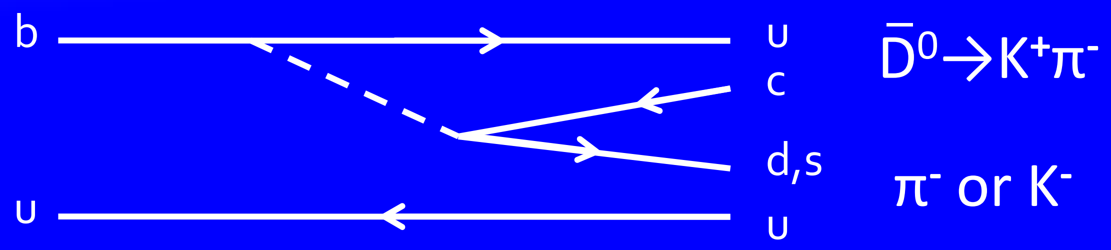
- Many sources of dimuons in $b\bar{b}$ events
  - b semileptonic decay
  - $b \rightarrow c \rightarrow \mu$ sequentials
  - $b \rightarrow \psi \rightarrow \mu\, \mu$
  - Hadron fakes
- Use MC to derive wrong-charge fraction
- Result: $\bar{\chi}=0.126 \pm 0.008$
  - Includes systematic uncertainty on wrong-charge correction
  - Compare to LEP average: 0.1259 ± 0.0042

Further Agreement

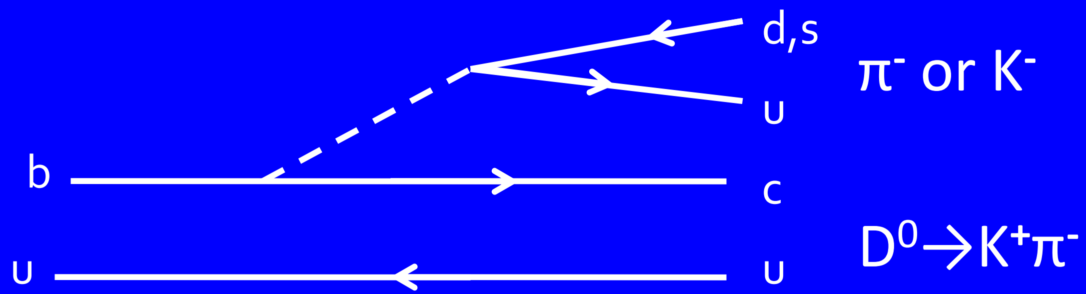
- HFAG average at the Z:
  - $f_s/f_d = 0.256 \pm 0.022$
- CDF result from semileptonics from PRD 77, rescaled for updated $D_s \to \phi\pi$ branching ratio:
  - $f_s/f_d = 0.269 \pm 0.033$
- Maybe fragmentation is universal after all

CPV in $B^- \rightarrow D^0 h^-$

- ADS Method: Interference of two suppressed amplitudes
  - Color-suppressed $b \rightarrow u$ diagram with Cabibbo-allowed $\bar{D}^0$ decay



  - Color-allowed diagram with doubly Cabibbo-suppressed D^0 decay



ADS Observables

- DCS fraction and asymmetry:

$$R_{ADS}(K) = \frac{Br(B^- \to [K^+\pi^-]_D K^-) + Br(B^+ \to [K^-\pi^+]_D K^+)}{Br(B^- \to [K^-\pi^+]_D K^-) + Br(B^+ \to [K^+\pi^-]_D K^+)}$$

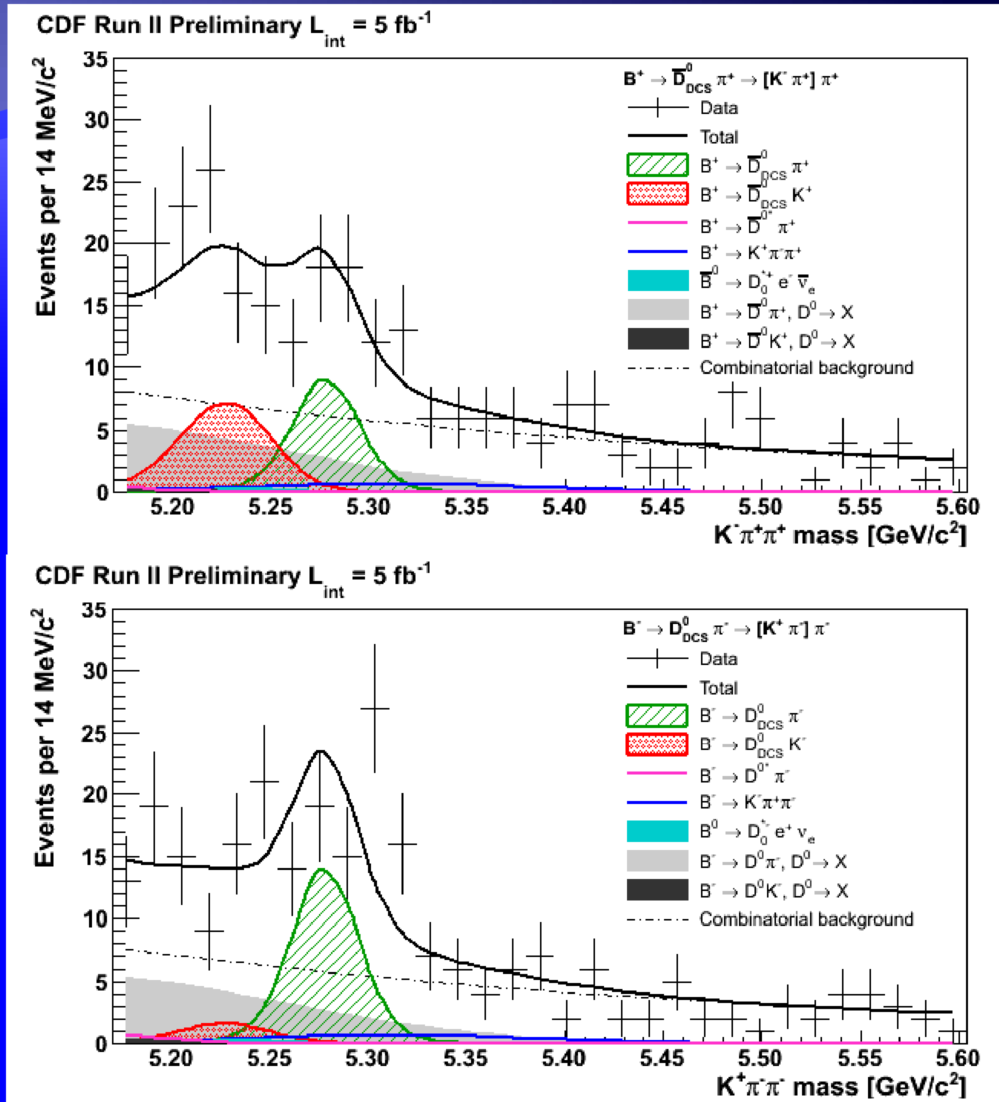
$$A_{ADS}(K) = \frac{Br(B^- \to [K^+\pi^-]_D K^-) - Br(B^+ \to [K^-\pi^+]_D K^+)}{Br(B^- \to [K^+\pi^-]_D K^-) + Br(B^+ \to [K^-\pi^+]_D K^+)}$$

- These are a function of CKM angle γ
  - $R_{ADS} = r_B^2 + r_D^2 + r_B r_D \cos\gamma \cos(\delta_B+\delta_D)$
  - $A_{ADS} = 2 r_B r_D \sin\gamma \sin(\delta_B+\delta_D) / R_{ADS}$
  - Where
    - $r_B = |A(b \to u)/A(b \to c)|$
    - $\delta_B = \mathrm{Arg}[A(b \to u)/A(b \to c)]$
    - And similar for r_D and δ_D

Details in PRL 78, 3257, (1997) & PRD 63, 036005, (2001).

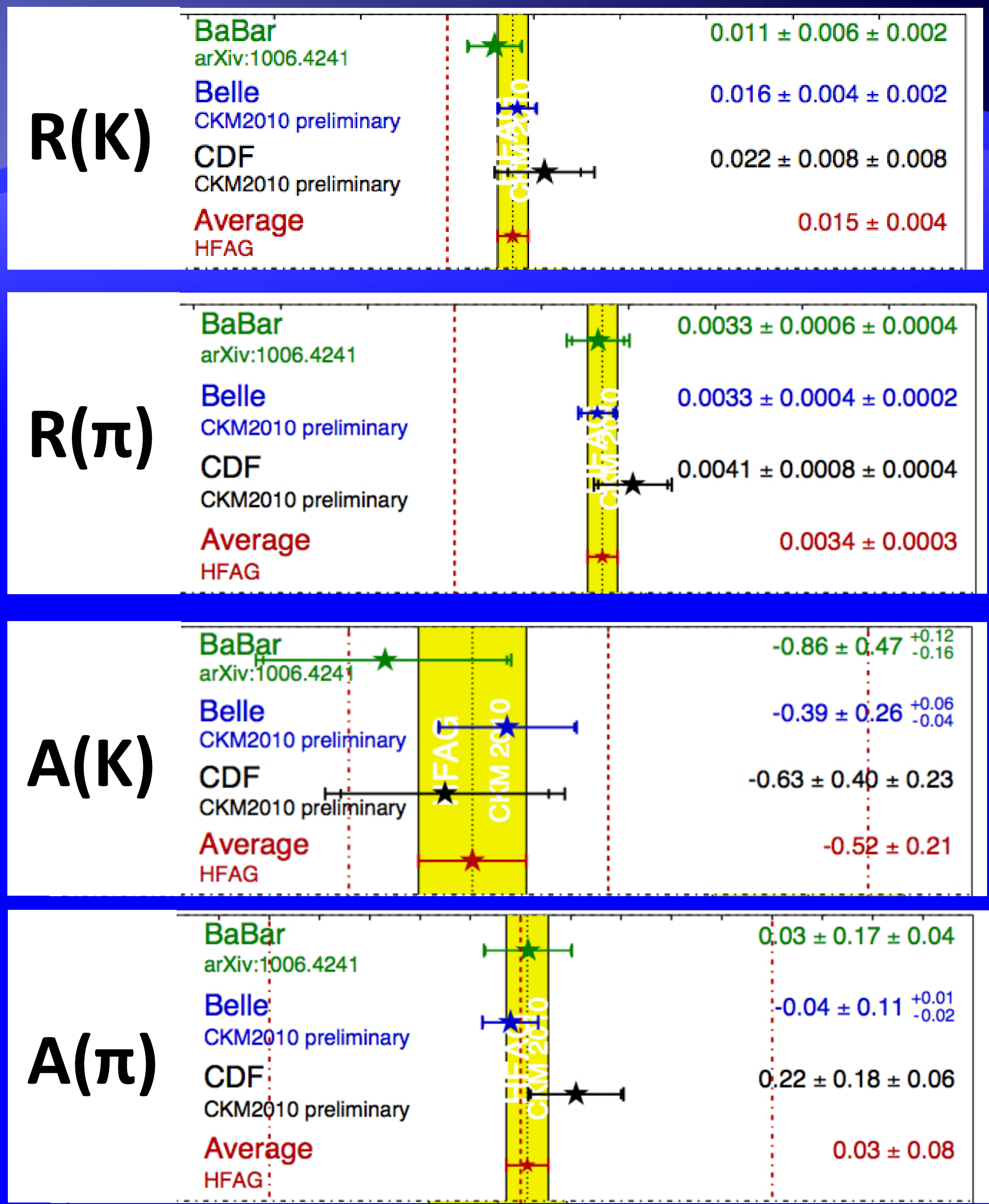
CDF Signals

- Optimize cuts using Cabibbo-favored modes to limit combinatorial background
  - Kinematic variables
  - B candidate isolation
  - Vertexing
- Likelihood fit using mass and dE/dx to separate D^0K^- and $D^0\pi^-$ signals
  - B backgrounds constrained from Cabibbo favored modes



Results

- Correction to raw asymmetry for K^+ vs. K^- efficiency
- Systematic uncertainties from fit model, physics backgrounds and dE/dx
- First application of ADS metond at a hadron collider
  - Details in public note CDF/10309



Search for CP Violation in $D^0 \rightarrow K^+K^-$ & $\pi^+\pi^-$

- Negligible penguin contribution to charm decays in SM
  - CPV in charm would point to new physics
- Asymmetry:

$$A_{CP} = \frac{\Gamma(D^0 \rightarrow h^+h^-) - \Gamma(\overline{D}^0 \rightarrow h^+h^-)}{\Gamma(D^0 \rightarrow h^+h^-) + \Gamma(\overline{D}^0 \rightarrow h^+h^-)}$$

- In the usual mixing formalism:

$$A_{CP}(t) = \frac{\eta_{CP}}{2}\frac{t}{\tau}\left[y\left(\left|\frac{p}{q}\right| - \left|\frac{q}{p}\right|\right)\cos\varphi + x\left(\left|\frac{p}{q}\right| + \left|\frac{q}{p}\right|\right)\sin\varphi \right]$$

- Time-Integrated Asymmetry:

$$A_{CP} = a_{CP}^{Direct} + \frac{\langle t \rangle}{\tau} a_{CP}^{Indirect}$$

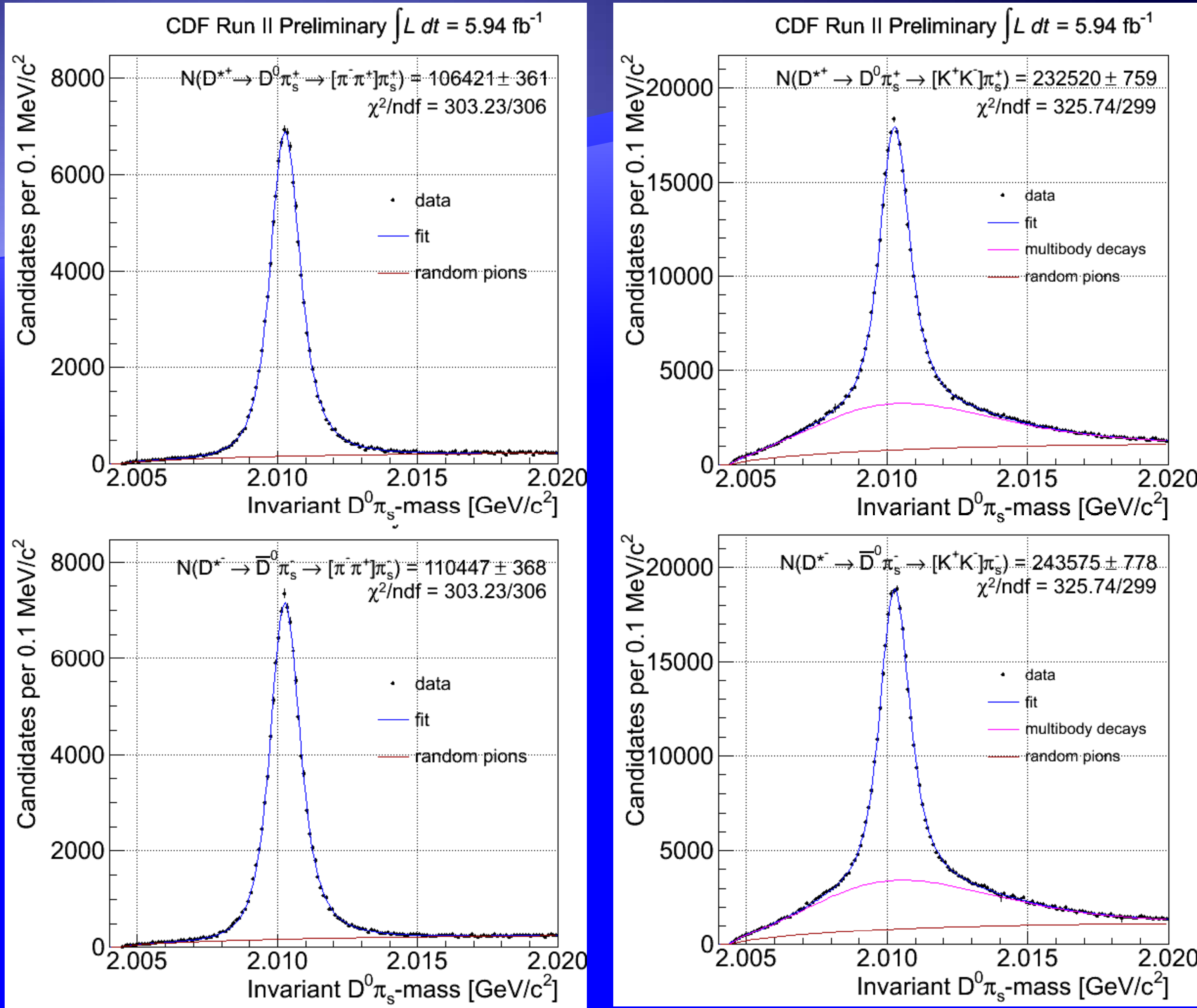
D* Tagged Analysis

- Asymmetry of signal sample:
  - $A(h^+h^-,\pi^*) = A_{CP}(h^+h^-) + \delta(\pi^*)$
- Retrieve asymmetry of D* tag in CKM favored mode:
  - $A(K^-\pi^+,\pi^*) = A_{CP}(K^-\pi^+) + \delta(K^-\pi^+) + \delta(\pi^*)$
- Now need asymmetry from $D^0 \rightarrow K^-\pi^+$
  - $A(K^-\pi^+) = A_{CP}(K^-\pi^+) + \delta(K^-\pi^+)$
- Now we solve:
  - $A_{CP}(h^+h^-) = A(h^+h^-,\pi^*) - A(K^-\pi^+,\pi^*) + A(K^-\pi^+)$
  - Measure these three asymmetries

Data Samples

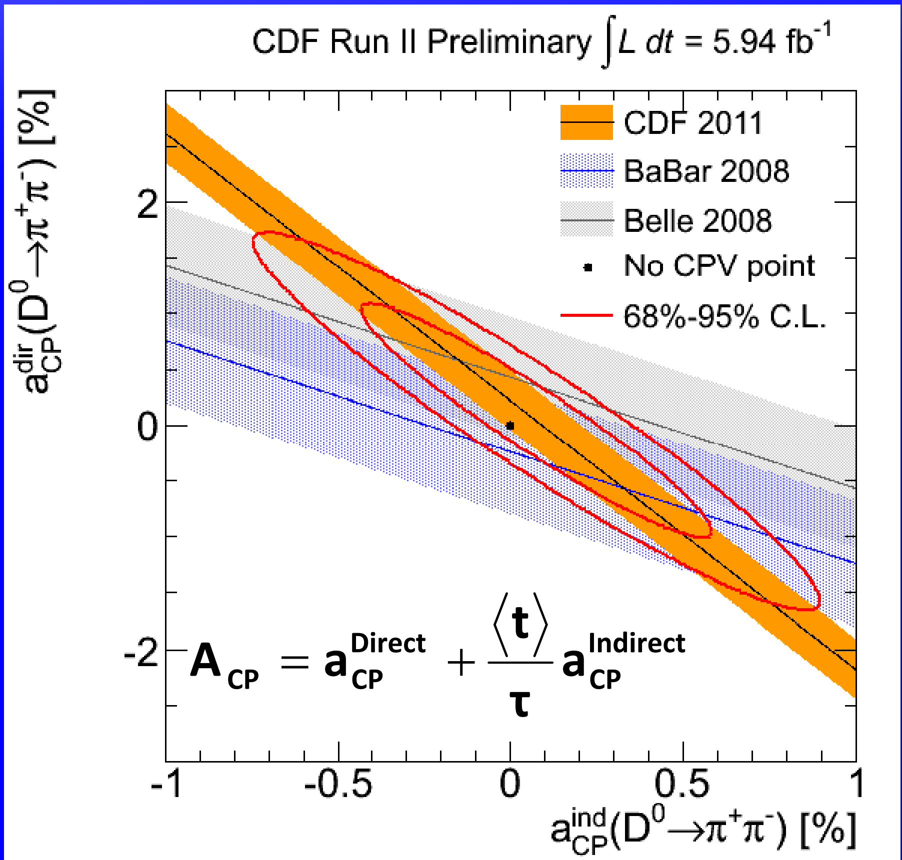
- Key assumptions:
  - Soft pion efficiency independent of D^0 decay mode
    - Confirmed in data
  - No production charge asymmetry for D^0 or D^*
    - QCD
  - No variation of acceptance with rapidity
    - Confirmed in data
- All collected with displaced-vertex trigger
  - Nearly identical kinematics
  - MC checked for small differences

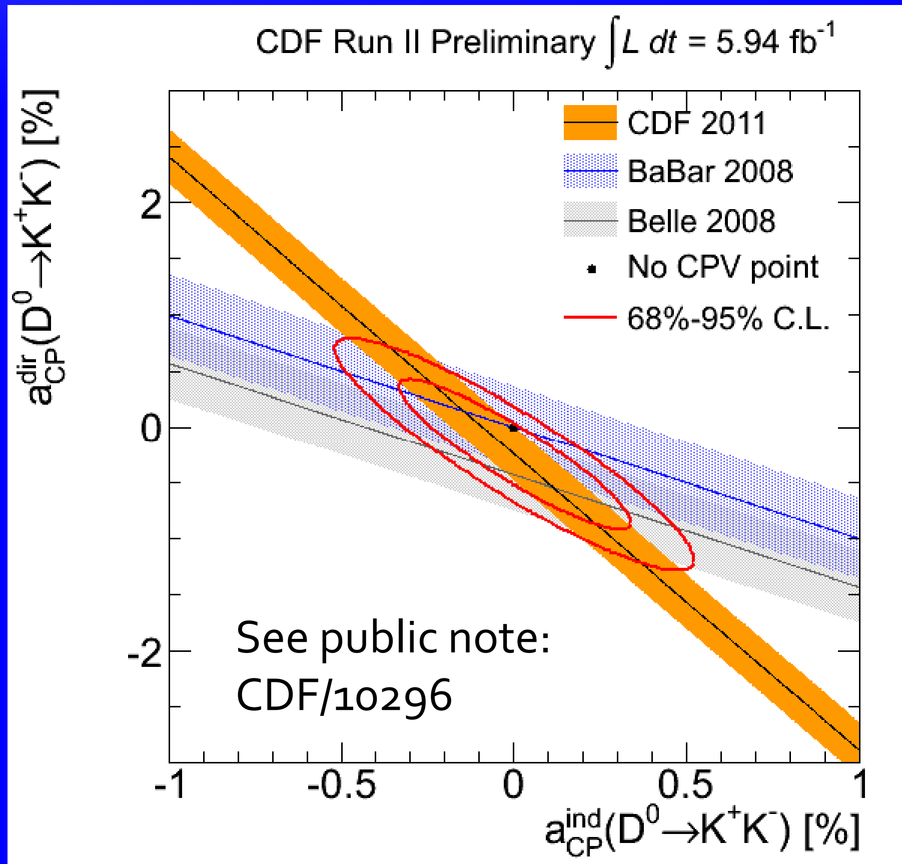
Fits


CDF Run II Preliminary ∫L dt = 5.94 fb^{-1}
N(D^{*+} → D$^0\pi_s^+$ → [π$^-$π$^+$]π_s^+) = 106421 ± 361
χ^2/ndf = 303.23/306
data
fit
random pions
Candidates per 0.1 MeV/c^2
Invariant D$^0\pi_s$-mass [GeV/c^2]
CDF Run II Preliminary ∫L dt = 5.94 fb^{-1}
N(D^{*+} → D$^0\pi_s^+$ → [K$^+$K$^-$]π_s^+) = 232520 ± 759
χ^2/ndf = 325.74/299
data
fit
multibody decays
random pions
Candidates per 0.1 MeV/c^2
Invariant D$^0\pi_s$-mass [GeV/c^2]
N(D^{*-} → $\overline{D}^0\pi_s^-$ → [π$^-$π$^+$]π_s^-) = 110447 ± 368
χ^2/ndf = 303.23/306
data
fit
random pions
Candidates per 0.1 MeV/c^2
Invariant D$^0\pi_s$-mass [GeV/c^2]
N(D^{*-} → $\overline{D}^0\pi_s^-$ → [K$^+$K$^-$]π_s^-) = 243575 ± 778
χ^2/ndf = 325.74/299
data
fit
multibody decays
random pions
Candidates per 0.1 MeV/c^2
Invariant D$^0\pi_s$-mass [GeV/c^2]

World's Best Results

- ACP($D^0 \to \pi^+\pi^-$)=
  +0.22±0.24 ±0.11 %
- ACP($D^0 \to K^+K^-$)=
  -0.24±0.22 ±0.10 %





Conclusions

- $B_s \to J/\psi\ f_0(980)$: $R_{f/\phi} = 0.313 \pm 0.021 \pm 0.020$
- $Br(B_s \to J/\psi\ K_S^0)/Br(B_d \to J/\psi\ K_S^0) = 0.041 \pm 0.009$
- $\bar{\chi} = 0.127 \pm 0.008$
- $B^+ \to D^0 h^+$: ADS Analysis
  - $R(K) = 22.5 \pm 8.4 \pm 7.9 \times 10^{-3}$
  - $A(K) = -0.63 \pm 0.40 \pm 0.23$
  - $R(\pi) = 4.1 \pm 0.8 \pm 0.4 \times 10^{-3}$
  - $A(\pi) = 0.22 \pm 0.18 \pm 0.06$
- $A_{CP}(D^0 \to \pi^+\pi^-) = +0.22 \pm 0.24 \pm 0.11\ \%$
- $A_{CP}(D^0 \to K^+K^-) = -0.24 \pm 0.22 \pm 0.10\ \%$

World's Best

First Suppressed B_s Decay

First at Hadron Collider

World's Best

Final Thought:

"I'm not dead yet"

Many more results expected for summer