Cornell University
Floyd R. Newman Laboratory for
Elementary-Particle Physics

Heavy Flavor Physics at the Tevatron

46th Rencontres de Moriond (Electroweak)

La Thuile, 3/16/2011

Julia Thom-Levy, Cornell University

Outline:

Today showing 6 new results (mostly from this year) that use 1.4 to 6 fb^{-1}. Data to tape: ~9 fb^{-1}

– B_s mixing phase through $B_s \rightarrow J/\psi\phi$ and A_{sl}, *D0 public note 6098, CDF public note 10206, May 2010*

–time-integrated B mixing probability *CDF, new, public note 10335*

–$B_s \rightarrow J/\psi\ f_0$ observation and BR *CDF, new, public note 10404*

– CPV in $D \rightarrow \pi\pi$ and KK *CDF, new, public note 10296*

–First ADS analysis of CPV in $B^+ \rightarrow D^0 h^+$ *CDF, Sept.2010, public note 10309*

B_s mixing phase

- B_s mixing phase is expected to be tiny in SM and unconstrained by the 2006 measurement of the B_s mixing frequency. Large values, as those induced by NP are not experimentally excluded

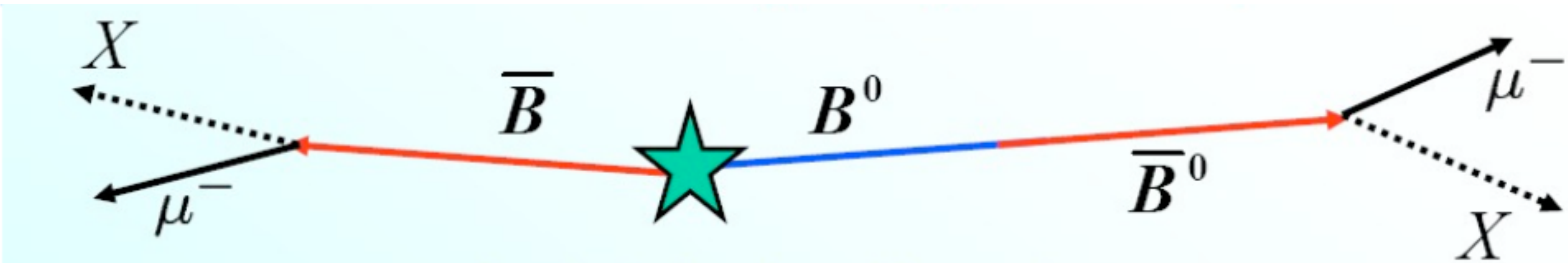
$$\beta_s^{SM} = \arg(-V_{ts}V_{tb}^* / V_{cs}V_{cb}^*) \approx 0.02$$

- access by looking at the time evolution of flavor tagged $B_s \to J/\psi\phi$ decays or, inclusively, by measuring anomalous mixing rate difference between B_s and $\overline{B}_s$ (A_{SL})

- CDF and D0 pursue both paths and first measurements showed interesting indications of departure from SM which call for more scrutiny- check with independent measurements

Di-muon charge asymmetry

V. A. Abazov et al, Phys. Rev. Lett. ***105****, 081801 (2010)*



Decay of B tags its flavor

- Measure:

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

N^{++}: Number of events with 2 b hadrons decaying semileptonically to produce same sign muon pair: one muon from b->μX, 2nd muon from decay after mixing.

- If the rate of B→$\overline{\text{B}}$ is the same as $\overline{\text{B}}$→B, this quantity will be zero. The SM expectation is ~few 10^{-4}.
- A_{sl} is derived from dimuon and inclusive muon asymmetries:

$$A \equiv \frac{N^{++} - N^{--}}{N^{++} + N^{--}} \quad \text{and} \quad a \equiv \frac{n^{+} - n^{-}}{n^{+} + n^{-}}$$

$\mu\mu$ charge asymmetry result

- D0 6.1 fb^{-1}analysis yields:

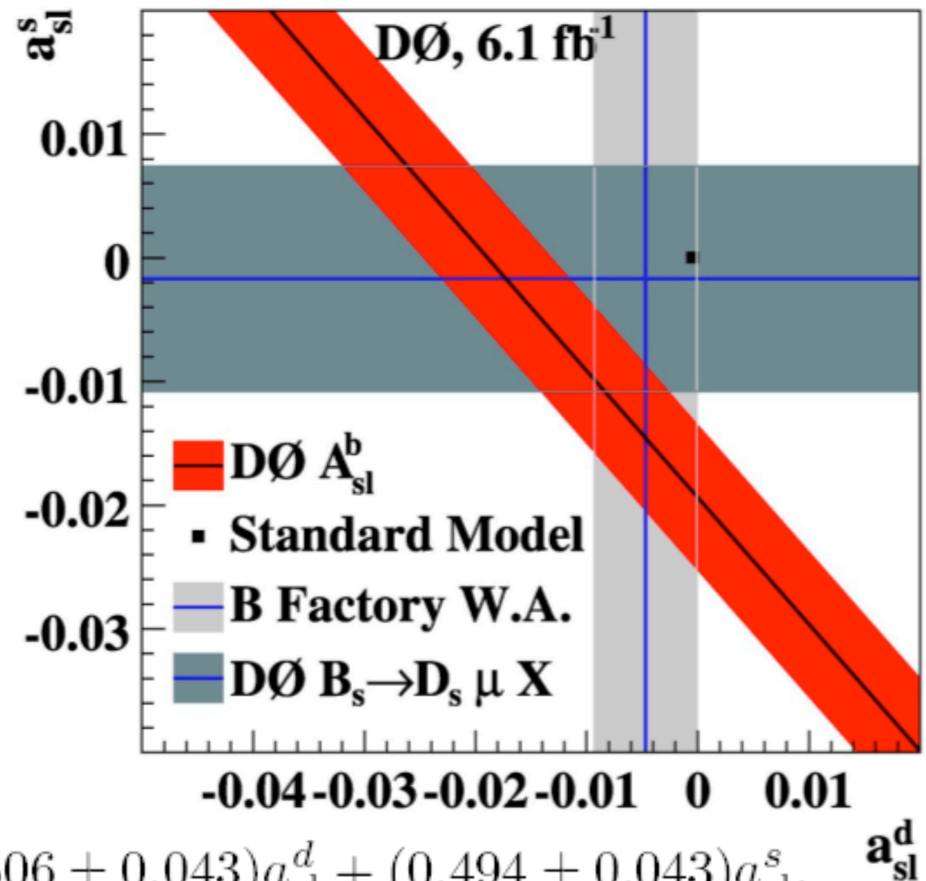
$$A_{sl}^{b} = (-0.957 \pm 0.251(stat) \pm 0.146(syst))\%$$

- SM prediction:

$$A_{sl}^{b}(SM) = (-0.023^{+0.005}_{-0.006})\%$$

using prediction of a_d and a_s from *A. Lenz, U. Nierste, hep-ph/0612167*

- Differs from SM by ~3.2σ
  - Indication of an anomalously large B_s mixing phase?



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

CDF prospects for A_{sl}?

- Very interesting D0 results, need independent verification
- CDF is working it, using a different technique:
  - Use muon impact parameter (IP) information to fit for sample composition, ensuring that same-sign dimuons come from B decays
  - IP fitter is a standard solid technique also used in the published correlated $B\bar{B}$ cross-section *PRD 77, 072004 (2008)*
- Our first step: measure time-integrated mixing probability $\bar{\chi}$
  - Comparison to $\bar{\chi}$ LEP to validate impact parameter fitter

$\overline{\chi}$: Time-integrated mixing probability

Defined as: $\overline{\chi} = \dfrac{\Gamma(B^0_{d,s} \to \overline{B}_{d,s} \to l^+ X)}{\Gamma(B_{all} \to l^{\pm} X)}$

- Average probability: $\overline{\chi} = f_d \chi_d + f_s \chi_s$

- At CDF, measure number of muon pairs ($\mu^+\mu^-$ and $\mu^{\pm}\mu^{\pm}$) from double semileptonic b hadrons, derive $\overline{\chi}$ from

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

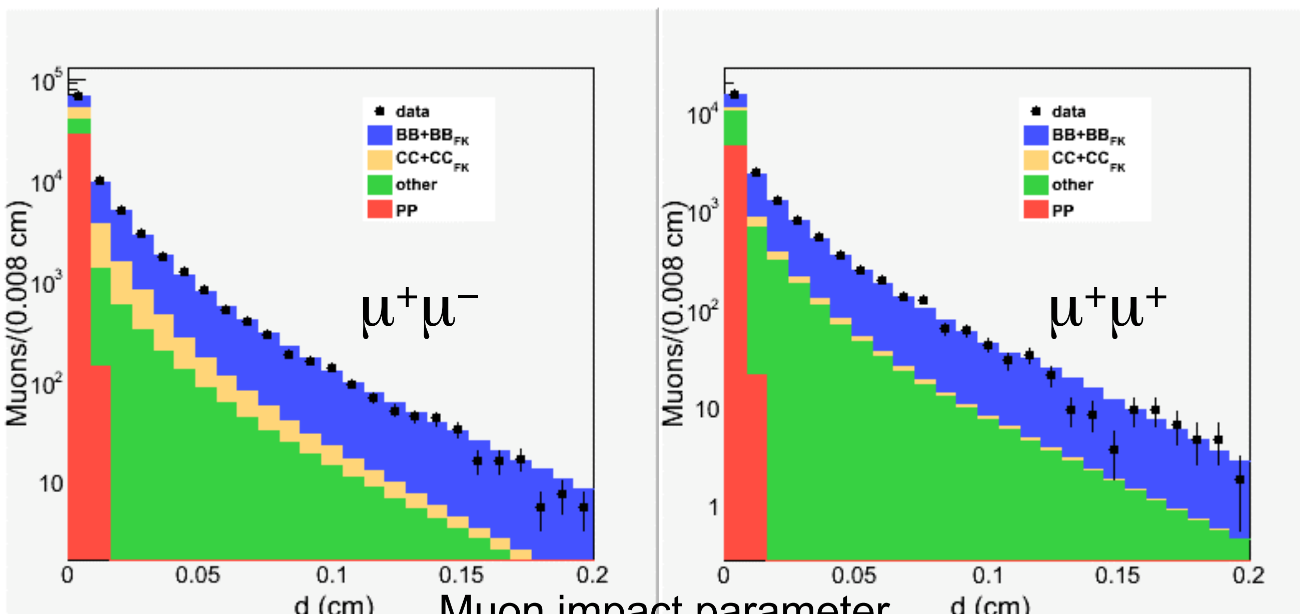
- previous CDF measurement showed discrepancy with LEP *Phys.Rev.D69:012002,2004*

$\overline{\chi}$: New CDF measurement

CDF Public Note 10335

- Using 1.4 fb^{-1} of data
- Muon impact parameter identifies source (b,c or prmt)
- New since last time: much tighter selection
  - Require muon hit in L00
- Result: $\overline{\chi}$= 0.126±0.008 (LEP: 0.126± 0.004)
  - Encouraging first step toward A_{sl} measurement

Fit projections:

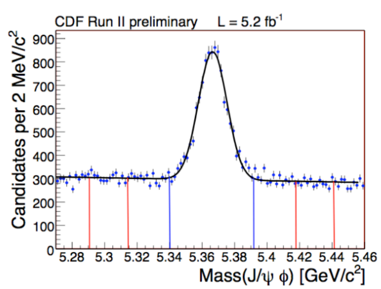


Muon impact parameter

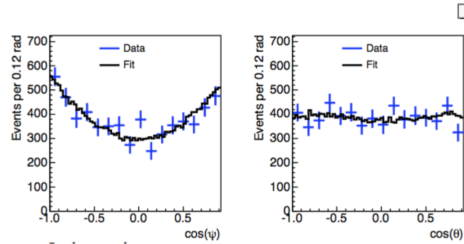
$B_s \to J/\psi\phi$ system

- $B_s \to J/\psi\phi$ decays: best way of probing new CPV in B_s mixing
- Difficult angular analysis: decay of B_s(spin 0) to J/ψ (spin 1) and ϕ(spin 1) leads to
  - L=0 (s-wave), 2 (d-wave) → CP even (=light B_s if no CPV)
  - L=1 (p-wave) → CP odd (= heavy Bs if no CPV)
- Analysis at a glance: di-muon trigger, NN selection
  - Simultaneous fit to mass, decay time, angles and production flavor distributions yields a fit to β_s

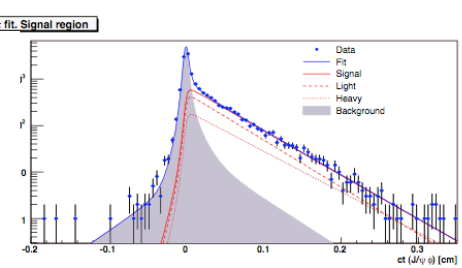
Mass to separate signal from bckg



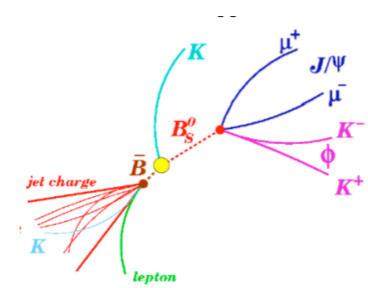
Angles to separate CP-even/odd



Decay time to know time evolution



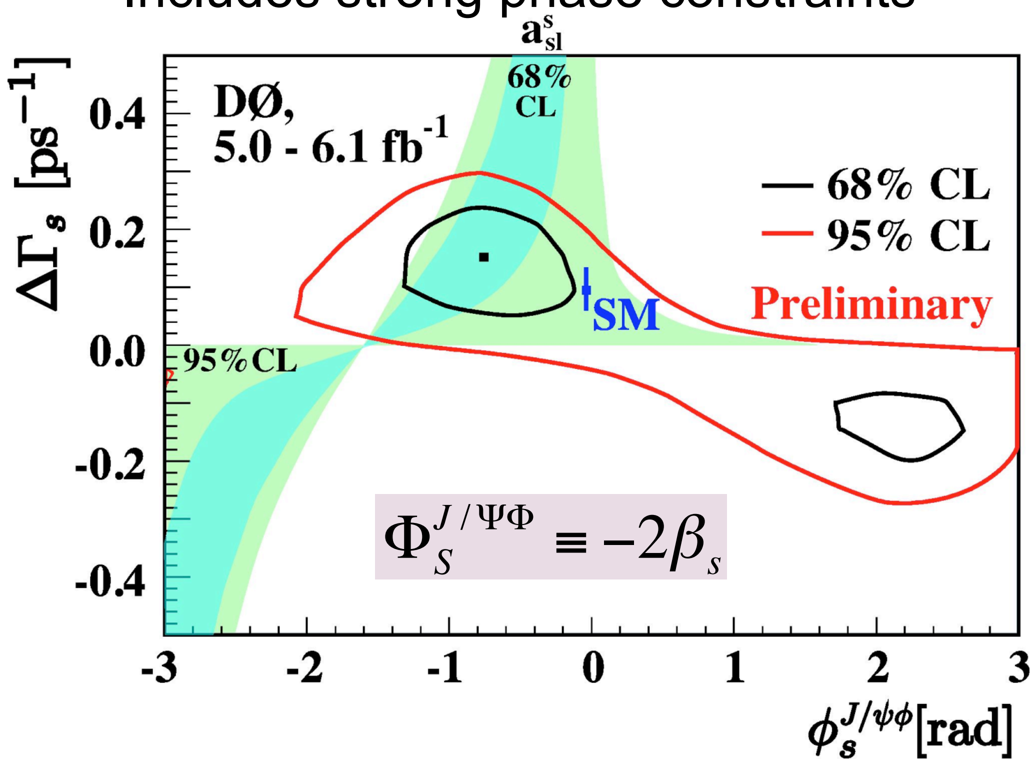
Flavor tagging to separate B from Bbar



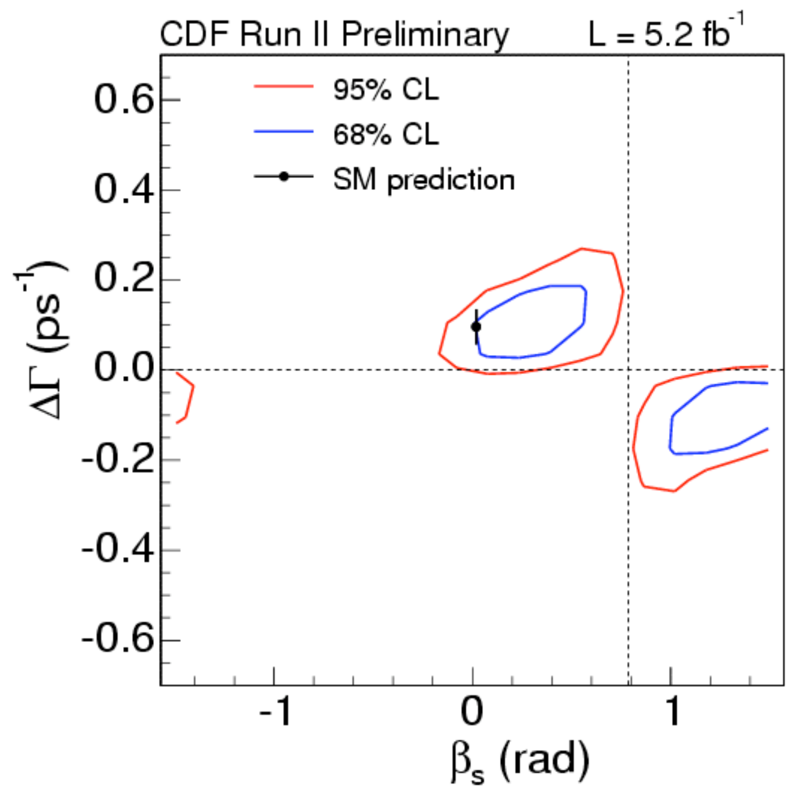
CPV in B_s mixing in $B_s \rightarrow J/\psi\phi$ decays

D0: 6.1 fb^{-1} of data

Includes strong phase constraints



CDF: 5.2 fb^{-1} of data



D0: 1.1σ deviation

CDF: 0.8σ

Situation still fluid- updated measurements needed

Another way to access β_s

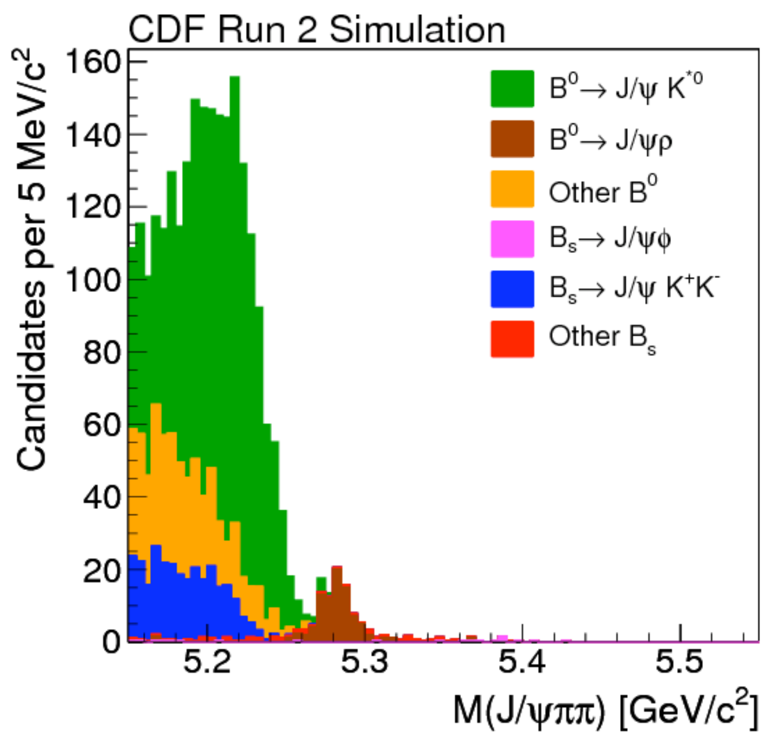
- CDF is working on using a suppressed B_s decay to measure lifetime and CP violating parameter β_s: $B_s \rightarrow J/\psi f0(980)$
- $B_s \rightarrow J/\psi f0(980)$ is a CP=–1 eigenstate
  – Clean measure of CP violating parameter β_s because no complex angular analysis as in $B_s \rightarrow J/\psi\phi$
- Today reporting first step toward this goal: reconstruction of a signal and measurement of Br of $B_s \rightarrow J/\psi f0(980)$, $f0(980) \rightarrow \pi^+\pi^-$ in 3.8 fb^{-1} of CDF data

public note 10404

$B_s \rightarrow J/\psi f0(980)$ analysis

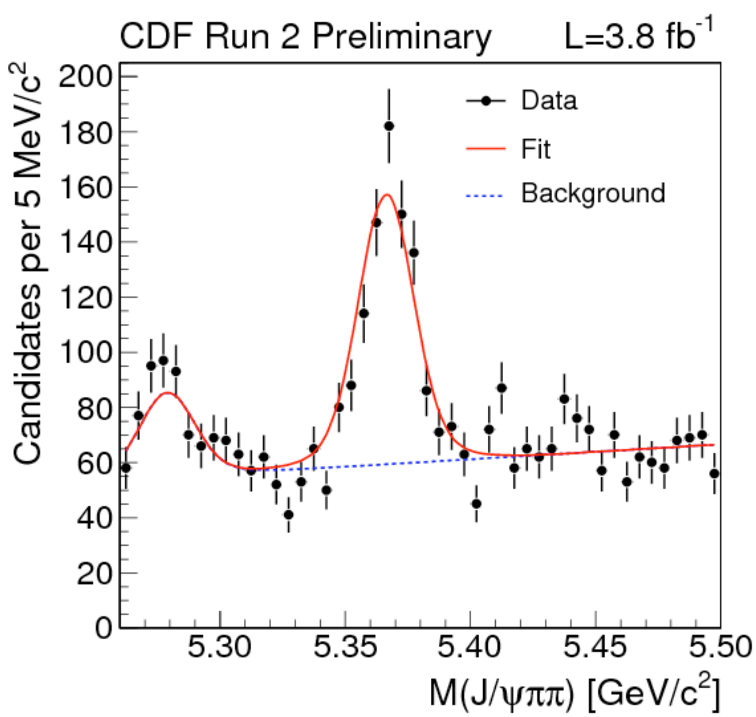
- Start with loose selection of $\mu\mu\pi\pi$ candidates
  - f0 is wide, so $0.85<M(\pi\pi)<1.2$ GeV

- Neural Net Selection
  - Kinematic variables, track & vertex displacement, isolation
  - Use identical selection for $B_s \rightarrow J/\psi\phi$ reference mode
- Physics background derived from MC simulation:



Fit

- Simultaneous log-L fit to signal and normalization channels
- Signal: N(J/ψf0(980))=571±37(stat.)±25(syst.) events
  - N(J/ψϕ)=2302±49



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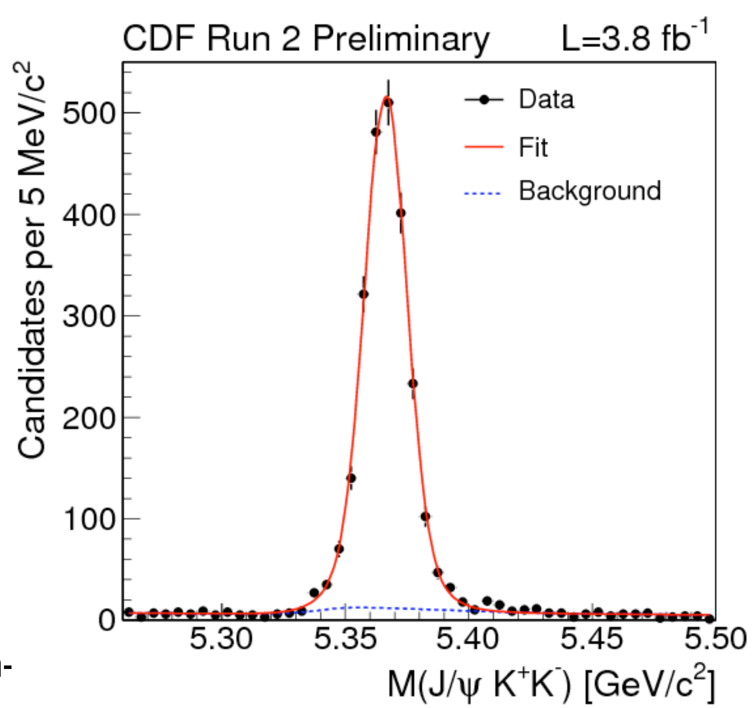


public note 10404

Result

New

$$R_{f0,\varphi} = \frac{BR(B_s \to J/\Psi f_0, f_0 \to \pi\pi)}{BR(B_s \to J/\Psi\Phi, \Phi \to KK)} = 0.292 \pm 0.020(stat) \pm 0.017(syst)$$

from which we derive:

$$BR(B_s \to J/\Psi f_0, f_0 \to \pi\pi) =$$
$$1.85 \pm 0.13(stat) \pm 0.11(syst) \pm 0.57(PDG) \times 10^{-4}$$

Stat.significance of $B_s \to J/\psi f0(980)$, $f0(980) \to \pi^+\pi^-$ observation: 17.9σ

confirms results from Belle and LHCb, and is more precise.

Results so far

- Unique to Tevatron: B_s physics, and therefore complementary to B factories
- But the Tevatron can also be competitive with the B factories in B^+/B_0 and charm physics.

Search for CPV in D→ππ and D→KK

- CPV in charm sector larger than ~0.1% would be a clear indication of NP
- CP violation measurements in charm unique probe into up-quark sector. As in D^0 oscillations, NP particles could play a role enhancing the size of CPV

e.g. D.-S. Du, Eur. Phys. J. C 50 (2007) 579;
Y. Grossman, A. Kagan, and Y. Nir, Phys. Rev. D75, 036008 (2006)

- Asymmetry defined as

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

Analysis of D→ππ and D→KK

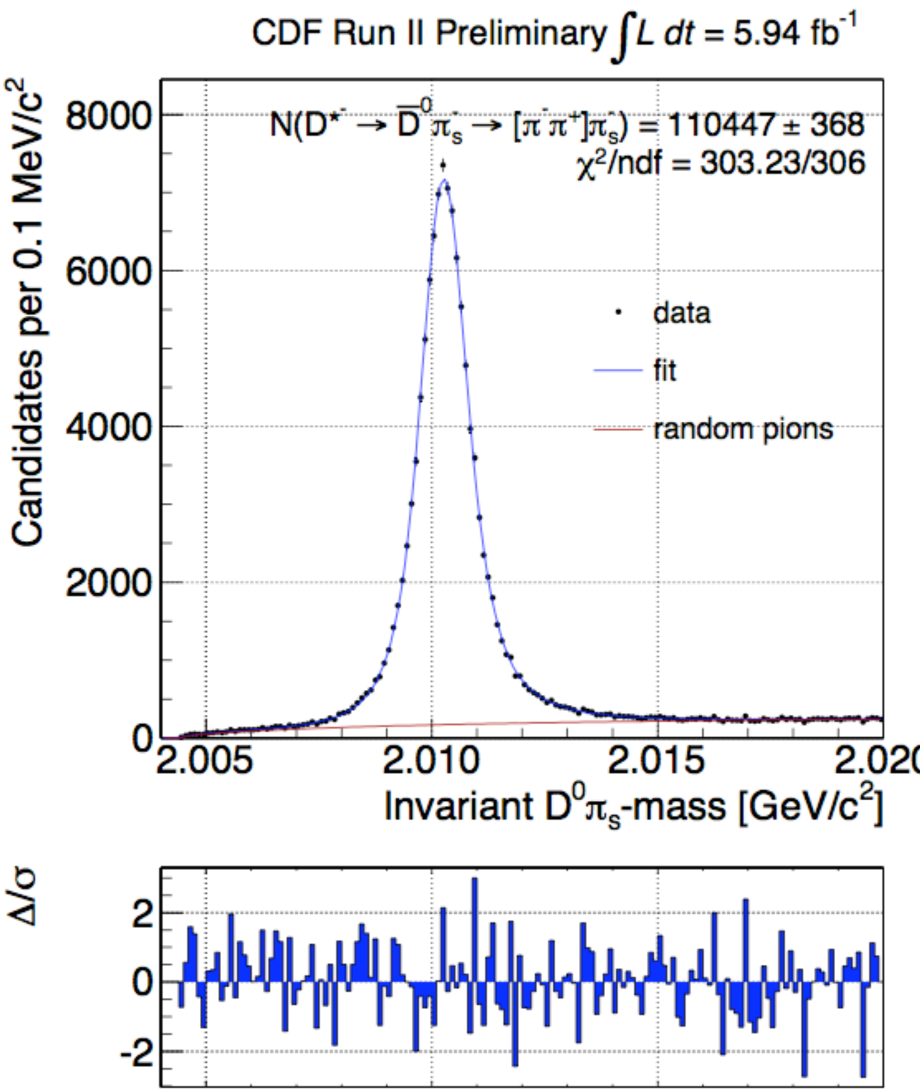
- Using 5.94 fb^{-1} of data, displaced track trigger
- Tag D^0 with a soft pion ($\pi_s^{\pm}$) from D* decay:

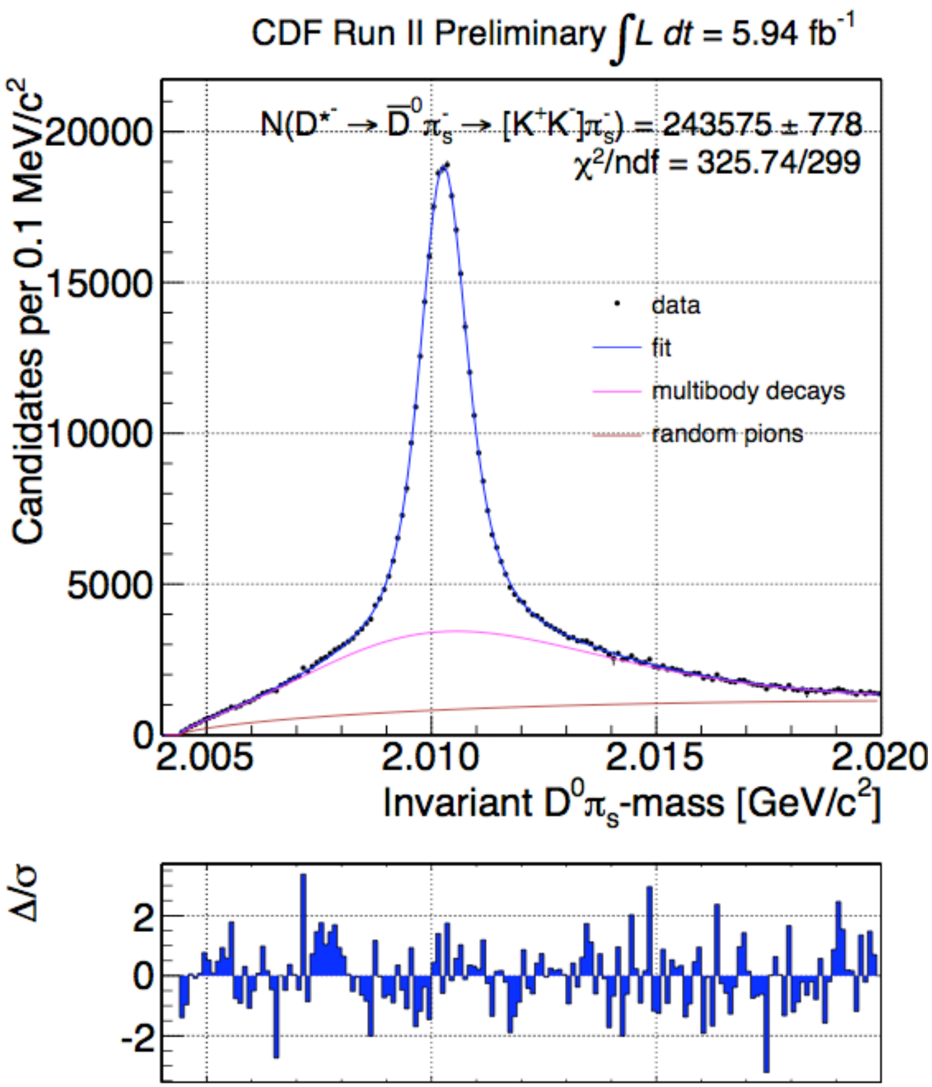
$$D^{*+} \rightarrow D^0\pi_s^+ \text{ and } D^{*-} \rightarrow \overline{D}^0\pi_s^-$$

  – CP symmetric initial state ensures charge symmetric production

- Measure asymmetry in ππ and KK samples and correct for instrumental asymmetry using Kπ samples, with and without D* tag
  – detection efficiencies for π_s^+ and π_s^- are different

Combined fits





Results: World's Best Limit

CDF Public Note 10296

$$A_{CP}(D^0 \rightarrow \pi^+\pi^-) = [+0.22 \pm 0.24(stat.) \pm 0.11(syst.)]\%$$

$$A_{CP}(D^0 \rightarrow K^+K^-) = [-0.24 \pm 0.22(stat.) \pm 0.10(syst.)]\%$$

New

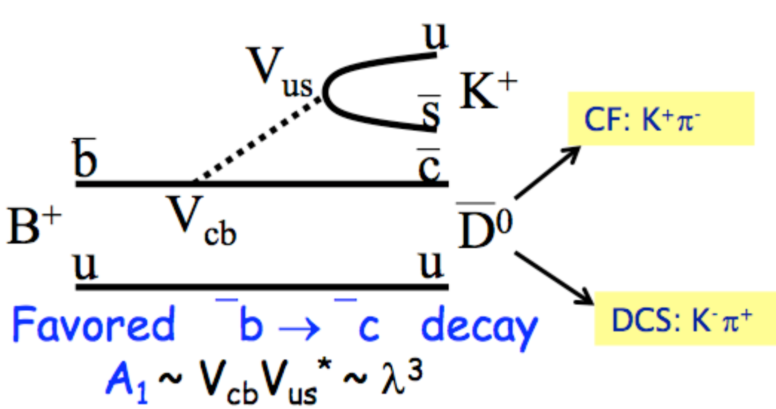
For comparison: Belle 2008 (2nd most precise result):

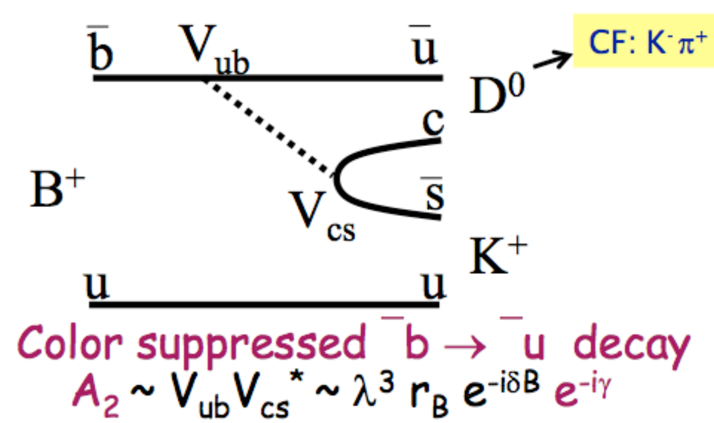
$$A_{CP}(D^0 \rightarrow \pi^+\pi^-) = [+0.43 \pm 0.52(stat.) \pm 0.12(syst.)]\%$$

$$A_{CP}(D^0 \rightarrow K^+K^-) = [-0.43 \pm 0.30(stat.) \pm 0.11(syst.)]\%$$

CPA in $B^{\pm} \to D^0 h^{\pm}$

- Branching fractions and CPA of $B^+ \to D^0 h^+$ allow for a clean measurement of γ
  - least well determined angle of the CKM matrix
- ADS Method: make use of doubly Cabibbo suppressed (DCS) D^0 modes *Atwood-Dunietz-Soni PRL78,3257;PRD63,036005*
  - Look for DCS "wrong sign", e.g. $B^+ \to [K^- \pi^+] K^+$, no tagging, no time-dependent measurement involved.
  - Challenge: rare process with large background
- New CDF measurement of direct CPA for DCS modes
  - Future extraction of CKM angle γ





CPA in $B^- \to D^0 h^-$

Define DCS fraction and asymmetry:

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

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

And similar for $A_{ADS}(\pi)$ (smaller)

These are a function of CKM angle γ:

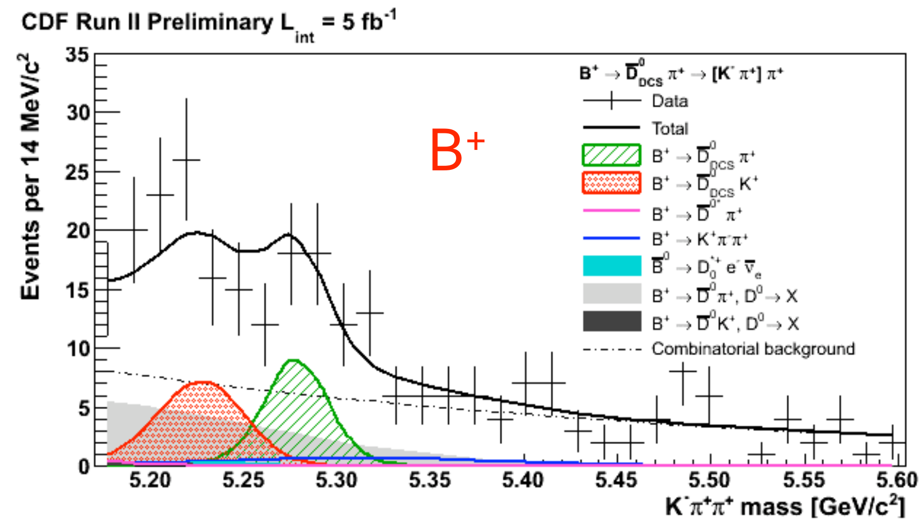
$$R_{ADS} = r_B^2 + r_D^2 + r_B r_D \cos\gamma \cos(\delta_B+\delta_D)$$
$$A_{ADS} = 2 r_B r_D \sin\gamma \sin(\delta_B+\delta_D) / R_{ADS}$$

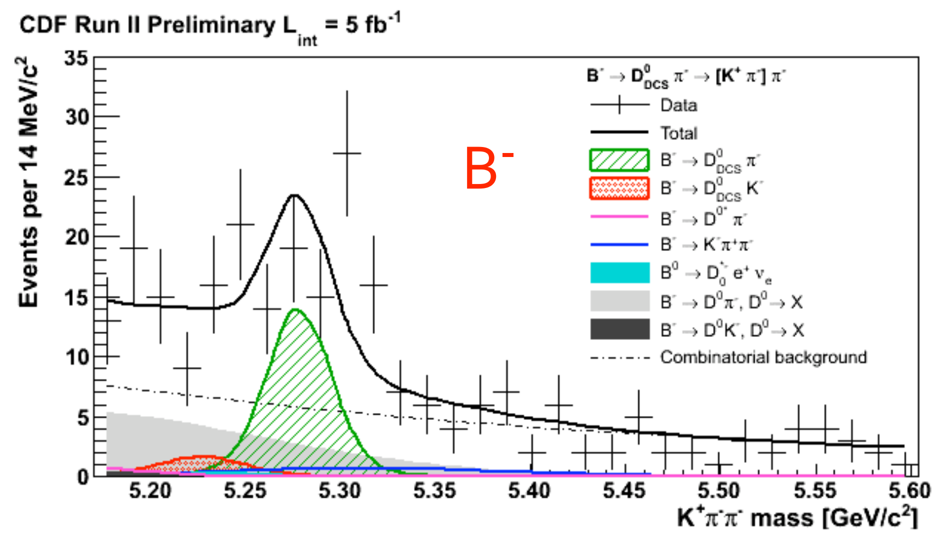
where $r_B = |A(b\to u)/A(b \to c)|$
$\delta_B = Arg[A(b\to u)/A(b\to c)]$ and similar for r_D and δ_D

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

Experimental Challenge

DCS "wrong sign" decays $B^+ \rightarrow [K^- \pi^+]\pi^+$





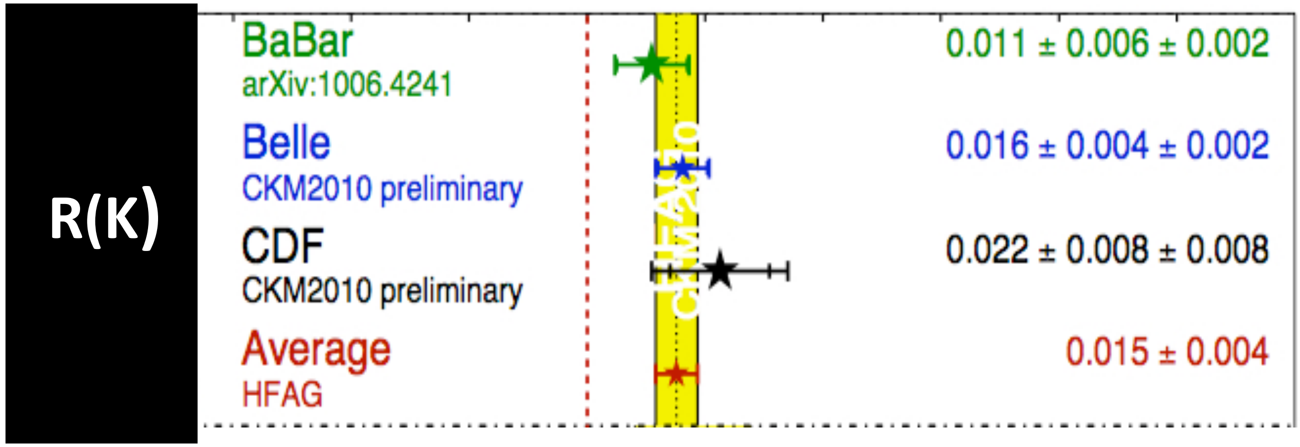
Need to extract the suppressed signals (green/red) buried by combinatorial and physics backgrounds

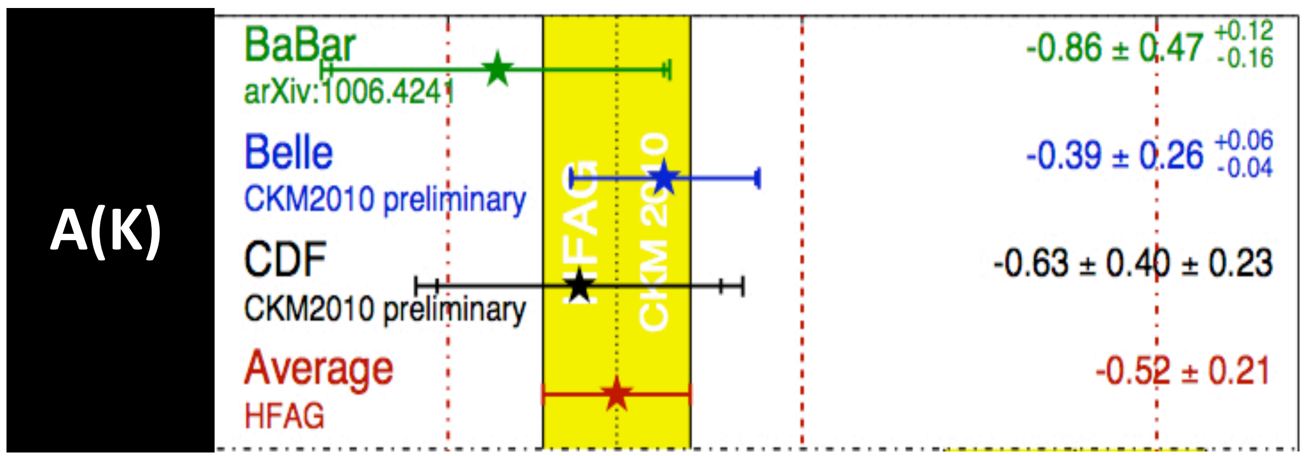
- using 5 fb^{-1} of data, displaced track trigger
- unbiased optimization of the selection on favored mode in data
- combined L-fit that uses kinematic information and PID to distinguish K from π mode, and from backgrounds.

CDF Public Note 10309

Results

First application of ADS method at a hadron machine and uncertainty comparable to e^+e^- machines!





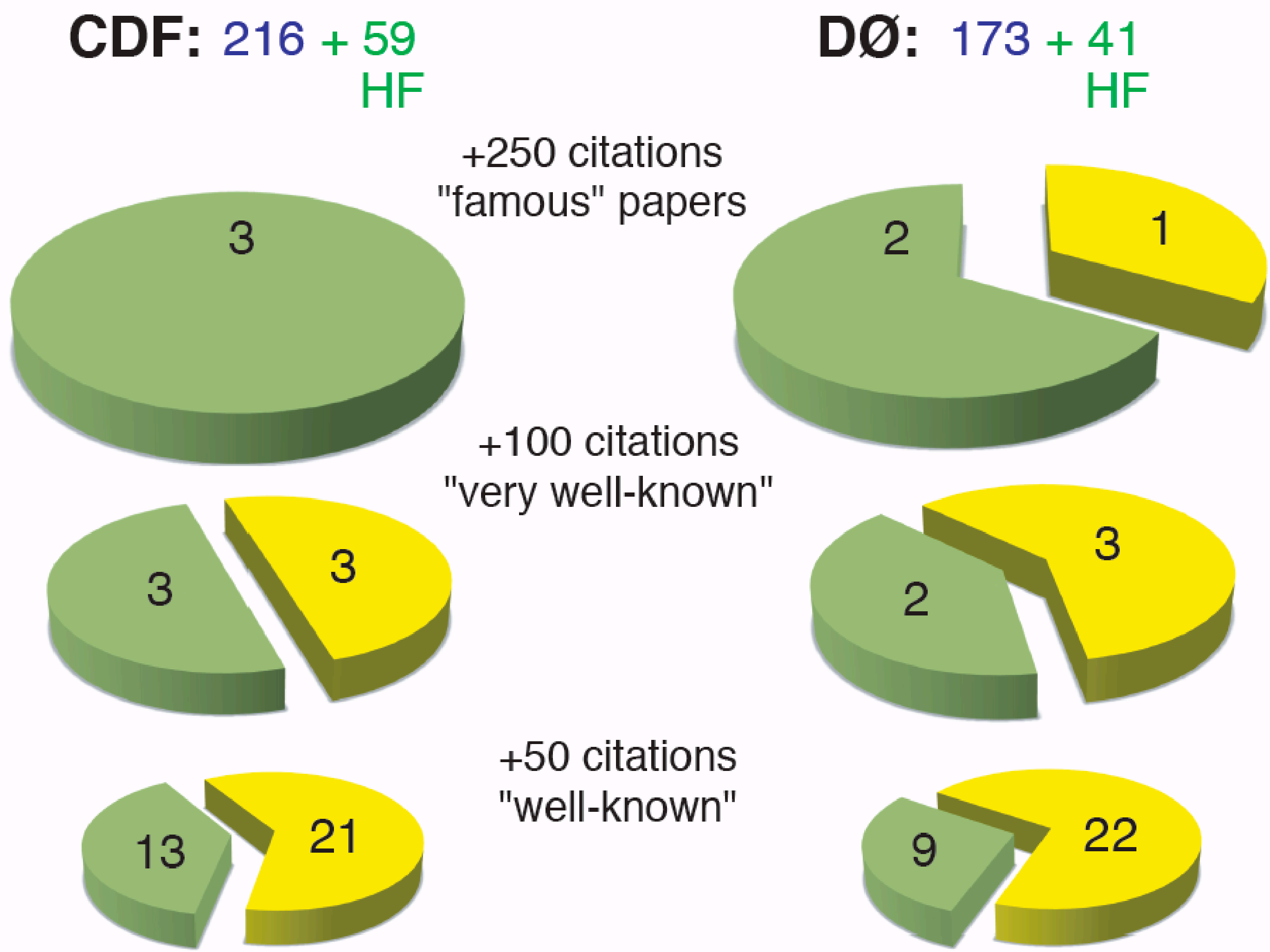
Shown only the K mode (see backup for π mode)

Conclusions

- CDF is producing a steady flow of new, high quality results that keep challenging the standard model predictions and constraining parameters of NP models
- The results shown today use a fraction of the 9 fb^{-1} data sample currently on tape - new results will continue for a while.
- Many other important results are in the pipeline- stay tuned!

Tevatron RunII Heavy Flavor results: Impact

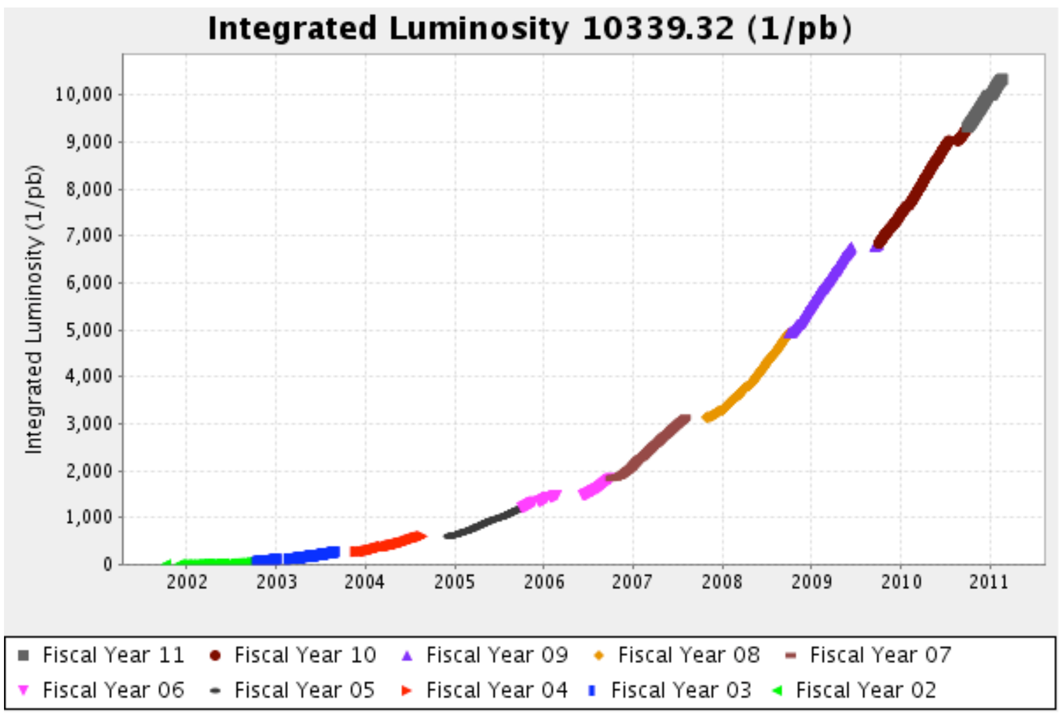
Number of published & submitted Run II publications:



Backup Slides

Datasets

- Tevatron delivering 2.5 fb^{-1}/year
  - Peak L_{inst} 3.5-4 x $10^{32}/cm^2/s$, design was 3 x $10^{32}/cm^2/s$
  - 6-8 interactions per crossing
- Showing results using up to 6.1 fb^{-1} today
- Data to tape ~9 fb-1 each for CDF, D0:



Asl: input from dimuon and incl.muon measurements

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

dimuon semileptonic B_d semileptonic B_s

Measure the raw asymmetries

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

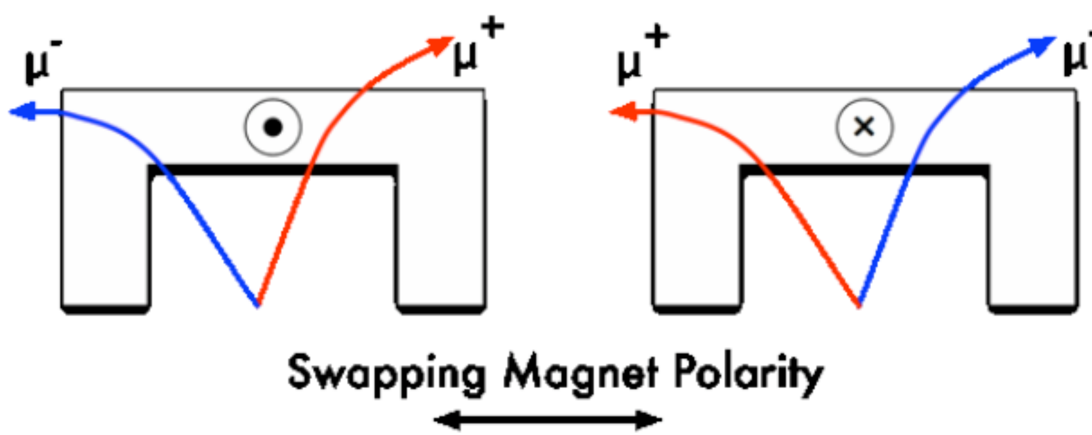
3.7×10^6 events

$$a = \frac{n(\mu^+) - n(\mu^-)}{n(\mu^+) + n(\mu^-)}$$

1.5×10^9 events

A_{sl} experimental issues

- use one muon as the tag and the other as the probe
- at Tevatron, both B^0 and B_s contribute
- two main issues:
  - asymmetric backgrounds from kaon fakes
  - asymmetric $\mu^+$and μ^- acceptance/efficiency
- Deal with acceptance/efficiency issue by periodically reversing polarity on central solenoid and muontoroids.
  - Check residual asymmetry with data.



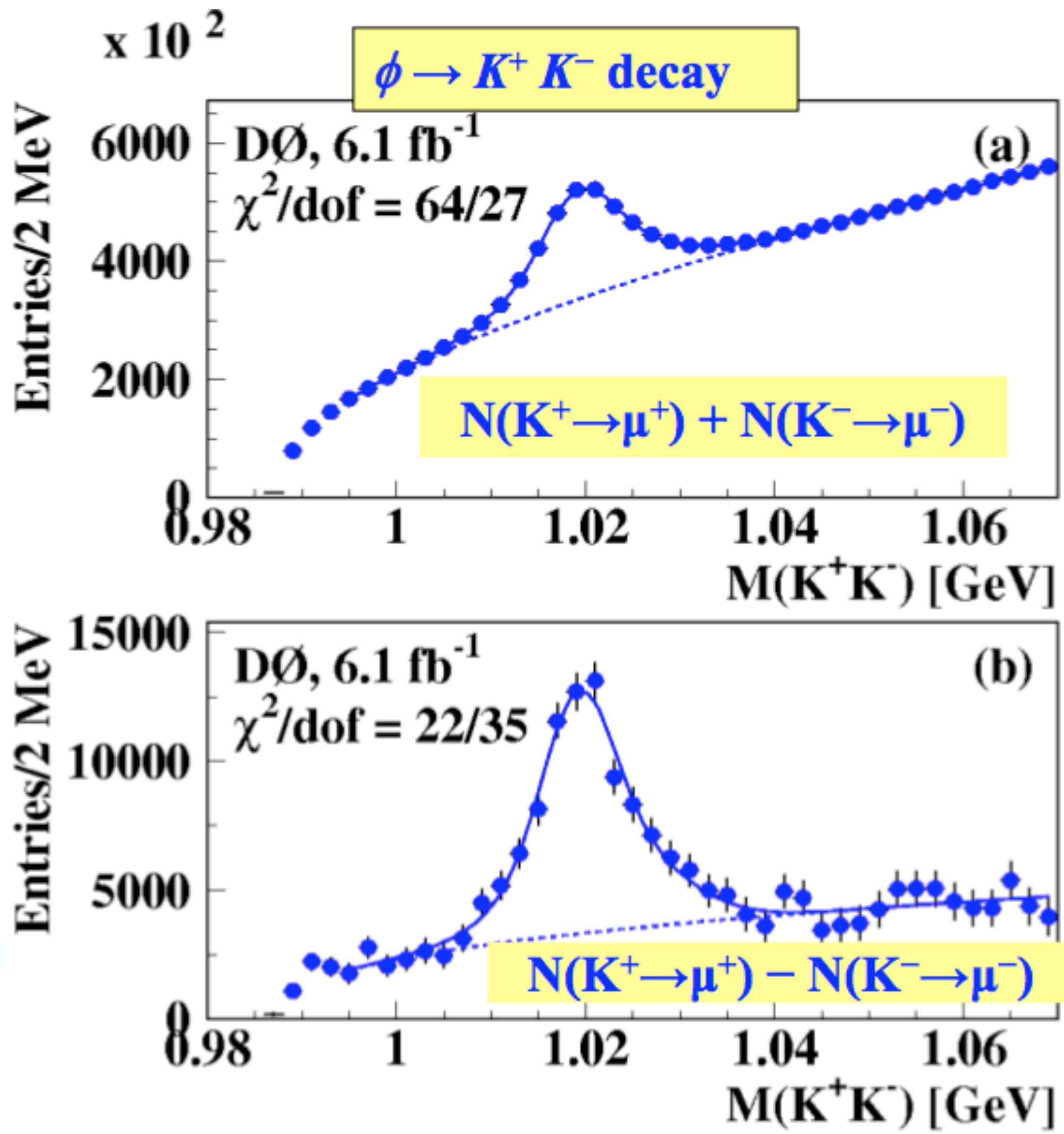
A_{sl} fake muon backgrounds

- $\sigma(K^+N) < \sigma(K^-N)$
- More K^+ get through calorimeter faking muons
- Define sources of Kaons:

$$K^{*0} \to K^+\pi^-$$

$$\varphi(1020) \to K^+K^-$$

- Require that the Kaon is identified as a muon
- Compute asymmetry from observed +/- yields



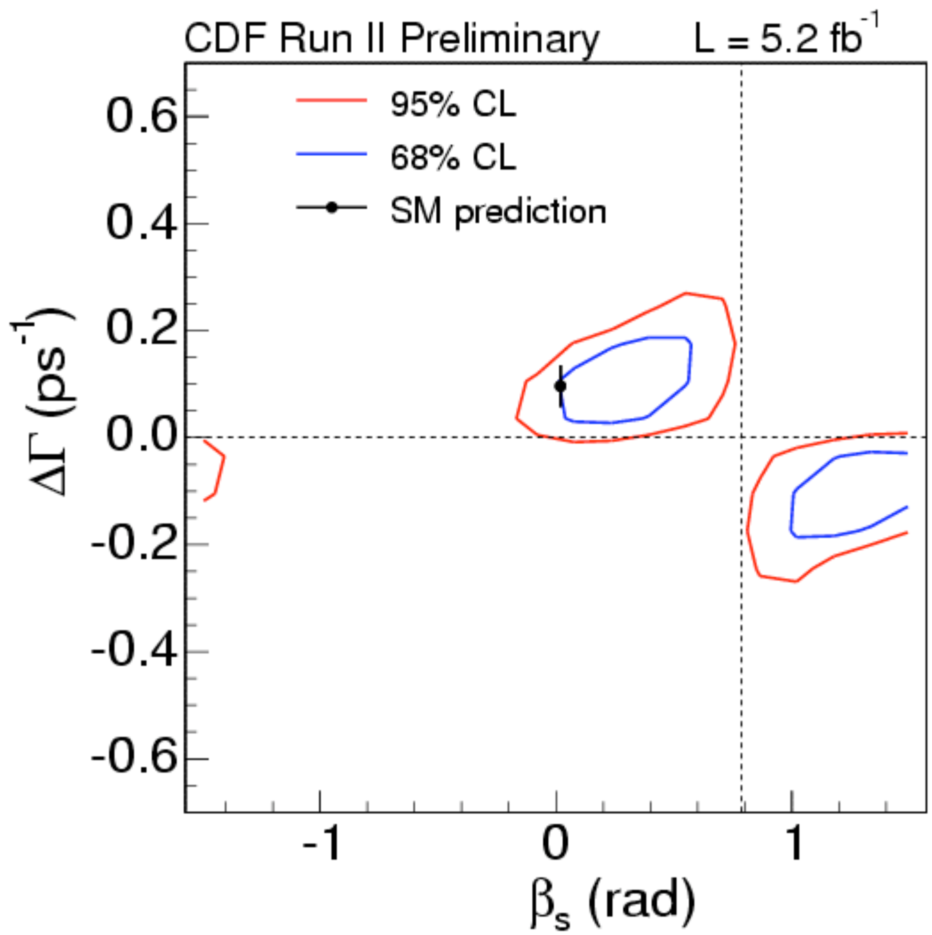
Ju

β_s results CDF

- 5.2 fb^{-1} of CDF data
- Di-muon trigger, NN selection
- Assuming standard model predictions, deviation in the observed data 0.8 σ
- confidence interval of β_s is:

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

[-π/2, -1.44] U [-0.13, 0.68] U [0.89, π/2] at 95% CL.



Results, assuming β_s=0

- World's single most precise measurements of $c\tau$ and $\Delta\Gamma$

$$c\tau_s = 458.6 \pm 7.6\ \text{(stat)} \pm 3.6\ \text{(syst)}\ \mu\text{m}$$

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

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

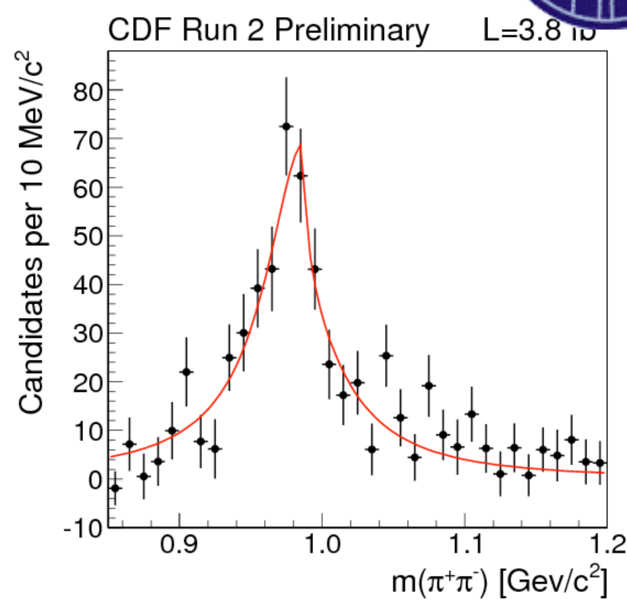
$$|A_0(0)|^2 = 0.524 \pm 0.013\ \text{(stat)} \pm 0.015\ \text{(syst)}.$$

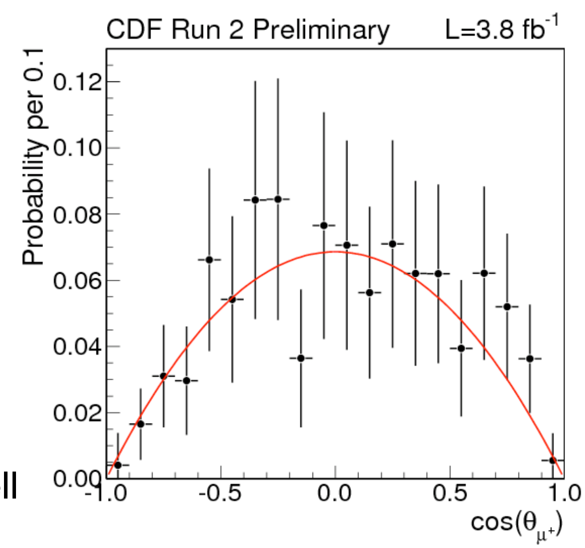
$$\phi_\perp = 2.95 \pm 0.64\ \text{(stat)} \pm 0.07\ \text{(syst)}$$

- S-wave contamination of the signal ϕ meson is < 6.7% at the 95% CL

Confirmation of f0(980)

- Di-pion mass distribution consistent with f0
  - Shape parameters consistent with BES, CLEO
- Helicity angles consistent with expectation
  - after efficiency correction





$B_s \rightarrow J/\psi f0(980)$ observation: comparison to Belle and LHCb results

New result from Belle: *arXiv:1102.2759*

$$BR(B_s \to J/\Psi f_0, f_0 \to \pi^+\pi^-) = 0.34^{+0.11+0.03+0.08}_{-0.14-0.02-0.05} \times 10^{-4}$$

Recent result from LHCb: *Phys.Lett.B698:115,2011*

$$R_{f0,\varphi} = \frac{BR(B_s \to J/\Psi f_0, f_0 \to \pi\pi)}{BR(B_s \to J/\Psi \varphi, \varphi \to KK)} = 0.252^{+0.046+0.027}_{-0.032-0.033}$$

Analysis of $D \rightarrow \pi\pi$ and $D \rightarrow KK$

- Using 5.94 fb^{-1} of data, displaced track trigger
- Tag D^0 with a soft pion ($\pi_s^{\pm}$) from D* decay: $\begin{cases} D^{*+} \rightarrow D^0 \pi_s^+ \\ D^{*-} \rightarrow \overline{D}^0 \pi_s^- \end{cases}$
  - charge symmetric production for D^0 and D*

- The detection efficiencies for π_s^+ and π_s^- are different (instrumental asymmetry)
  - subtract the effect through a combination of uncorrected "raw" asymmetries measured in three samples: $A(h^+h^-, \pi_s)$

$$A(K^-\pi^+, \pi_s)$$

$$A(K^+\pi^-)$$

- Finally, $A_{CP}(h^+h^-) = A(h^+h^-, \pi_s) - A(K^-\pi^+, \pi_s) + A(K^+\pi^-)$

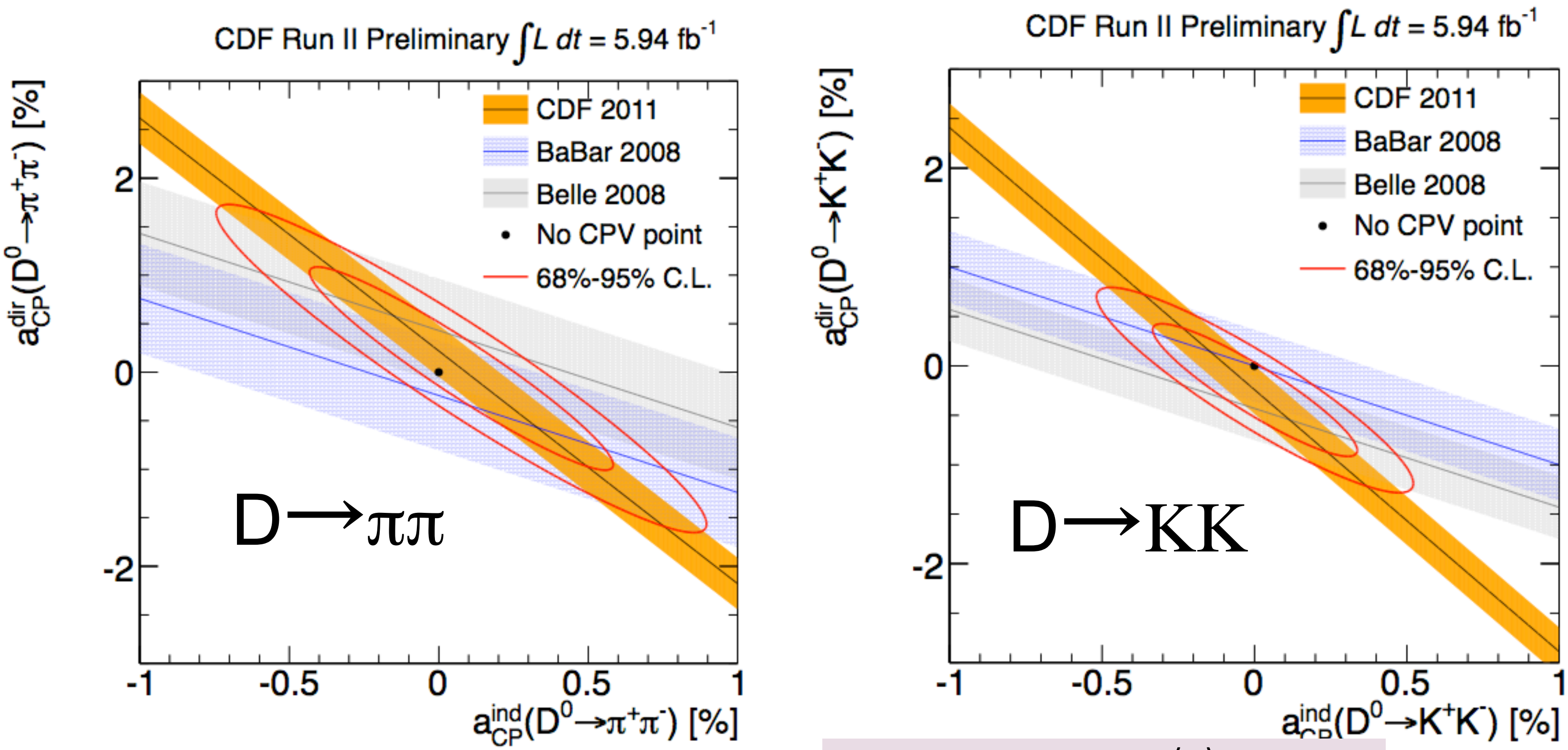
Results: World's Best Limit

CDF Public Note 10296

$$A_{CP}(D^0 \to \pi^+\pi^-) = [+0.22 \pm 0.24(stat.) \pm 0.11(syst.)]\%$$

$$A_{CP}(D^0 \to K^+K^-) = [-0.24 \pm 0.22(stat.) \pm 0.10(syst.)]\%$$

New



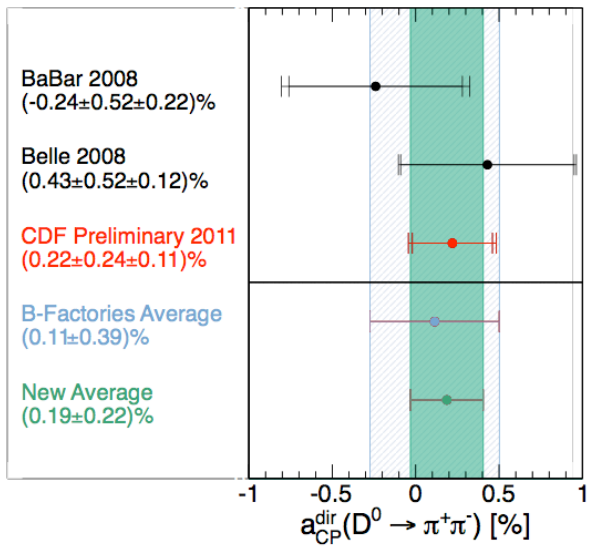
Measured int. asym. is (to 1st order): $$A_{CP} = a_{CP}^{direct} + \frac{\langle t \rangle}{\tau} a_{CP}^{indirect}$$

Result comparisons

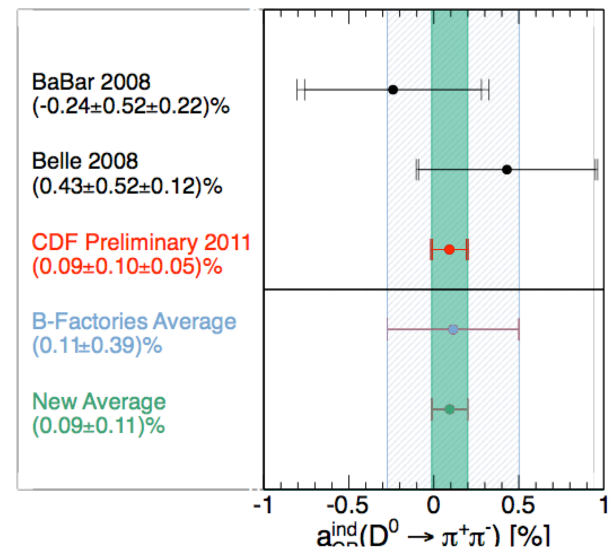
a_{CP}^{dir}, assuming $a_{CP}^{ind}=0$

a_{CP}^{ind}, assuming $a_{CP}^{dir}=0$

$D \to \pi\pi$:



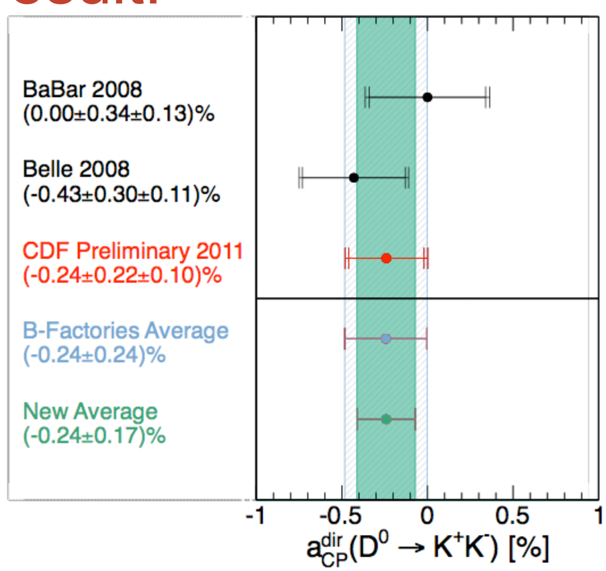
No indirect CPV



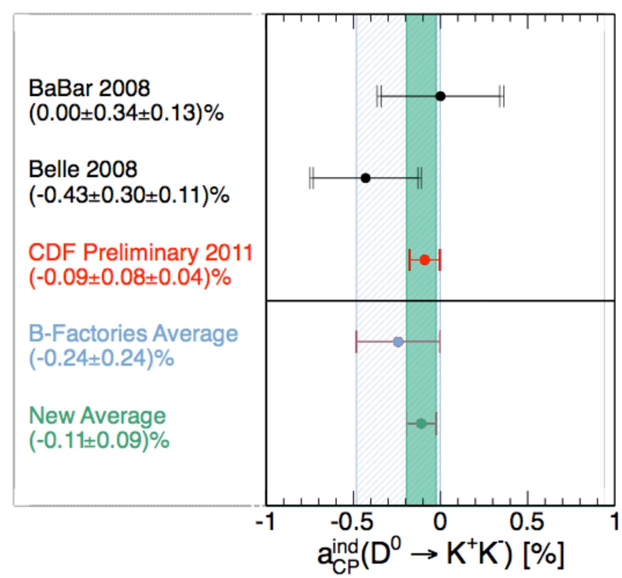
No direct CPV

New CDF result:

$D \to KK$:



vy, Corr



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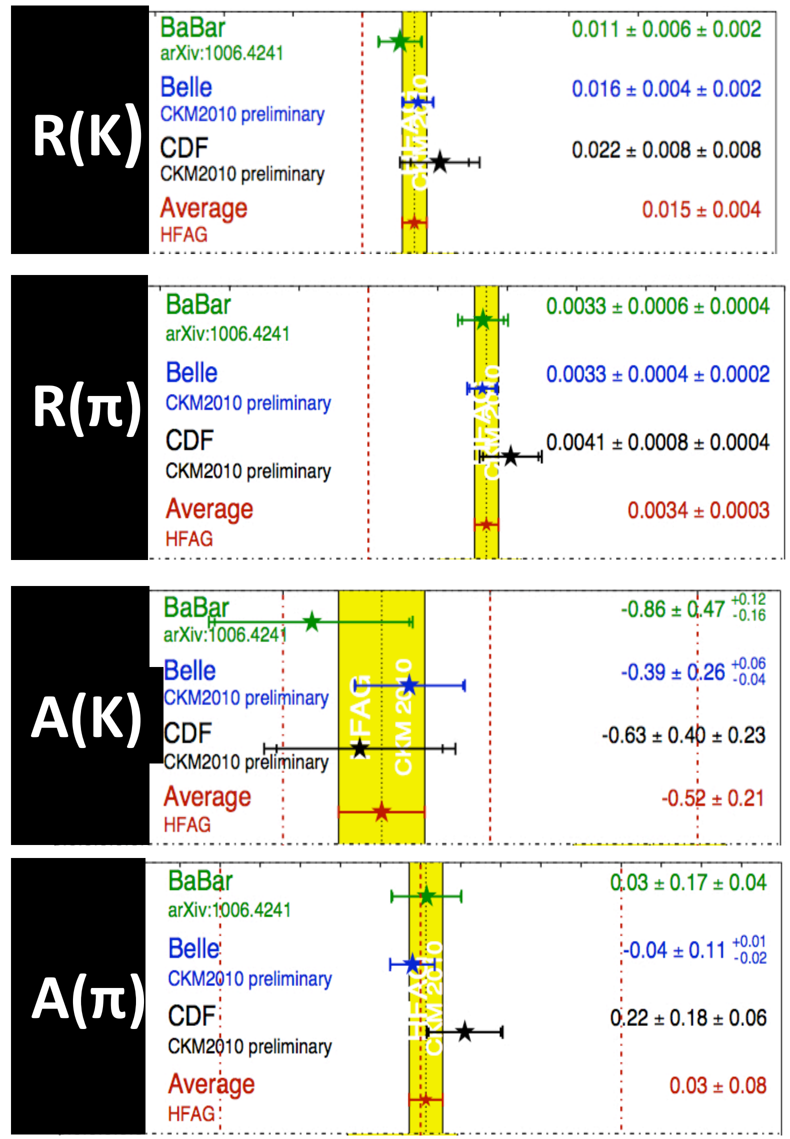
Results

First application of ADS method at a hadron machine and uncertainty comparable to e^+e^- machines!



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