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Searches for BSM physics through CP violation at CDF

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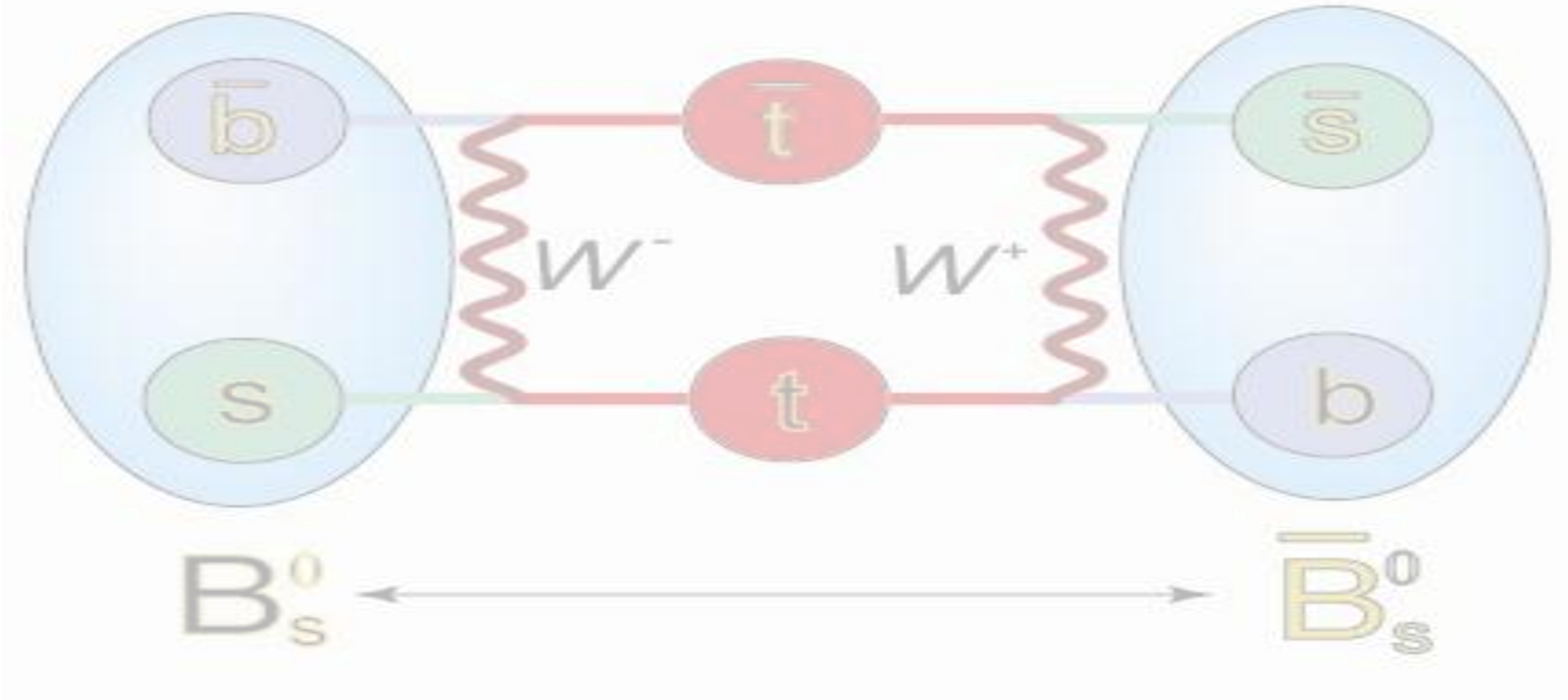
On behalf of CDF Collaboration

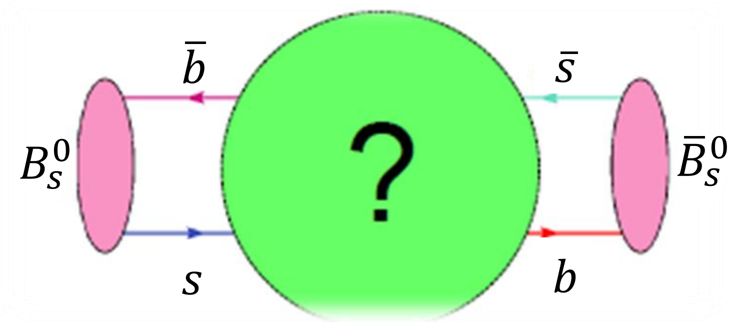
CP Violation Measurements at CDF

- 10^{14} $p\bar{p}$ collisions at 2 TeV in 10 years
  - ✓ CP symmetric, same number of produced meson and anti meson.
  - ✓ 0.1-1% of collisions produce $b\bar{b}$ and $c\bar{c}$ pair, only 0.1-10% recorded
- Final states with charged particles only preferred:
  - ✓ Easier to reconstruct
  - ✓ Mass discriminates against background
- Good decay-time resolution:
  - ✓ 90 fs for $B_s \to J/\psi\varphi$
- Need tagging to know flavor at production
  - ✓ very challenging, ϵD^2 of 5%
- Today: four 2012 results
  - ✓ $B_s \to J/\psi\phi$ (full CDF Run II dataset)
  - ✓ $\mathrm{BR}(B_s^0 \to D_s^{(*)+} D_s^{(*)-})$
  - ✓ Update ΔA_{CP} in $D^0 \to K^+ K^-$ and $D^0 \to \pi^+ \pi^-$ decays (full CDF Run II dataset)
  - ✓ CPV in $D^0 \to K_s \pi^+ \pi^-$ decay



Search for NP in the B_s system

B_S Mixing and NP



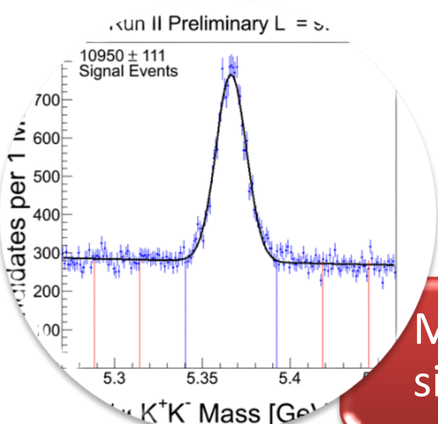
- B_s meson flavor oscillations:
  - Powerful indirect probe for non-SM physics
  - Broad class of SM extension models
- Two physical states (B_{sH} - B_{sL}) with different mass and lifetime
- 3 main observables:
  - Strength (ΔM), very sensitive to NP but consistent with SM (CDF, Phys. Rev. Lett. 97, 242003 (2006))
  - Mixing phase $\beta_s = arg\left(-\frac{V_{tb}^* V_{ts}}{V_{cb}^* V_{cs}}\right)$ very sensitive to NP
    - ✓ Any value significantly larger than a few 10^{-2} indicates NP
    - ✓ Direct and theoretically solid access through time-evolution $B_s \rightarrow J/\psi\varphi$ decays
  - Width difference (ΔΓ), moderately sensitive to NP
    - ✓ Best probed with B_s in J/ψϕ angular analysis

$B_s \rightarrow J/\psi\Phi$ AT A GLANCE

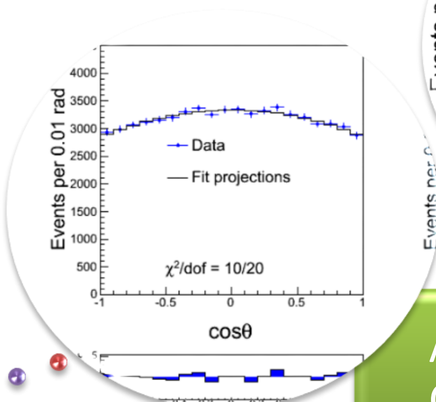
Very complex likelihood fit, 11 physical parameter 21 nuisance:
use mass, angles, decay-time and production flavor distributions

Dimuon trigger

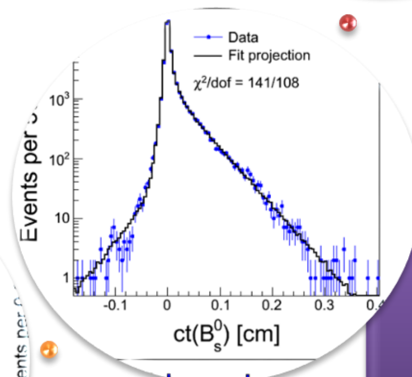
Offline selection



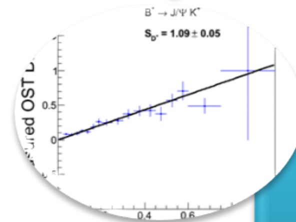
Mass to separate signal from bckg



Angles to separate CP-even/odd



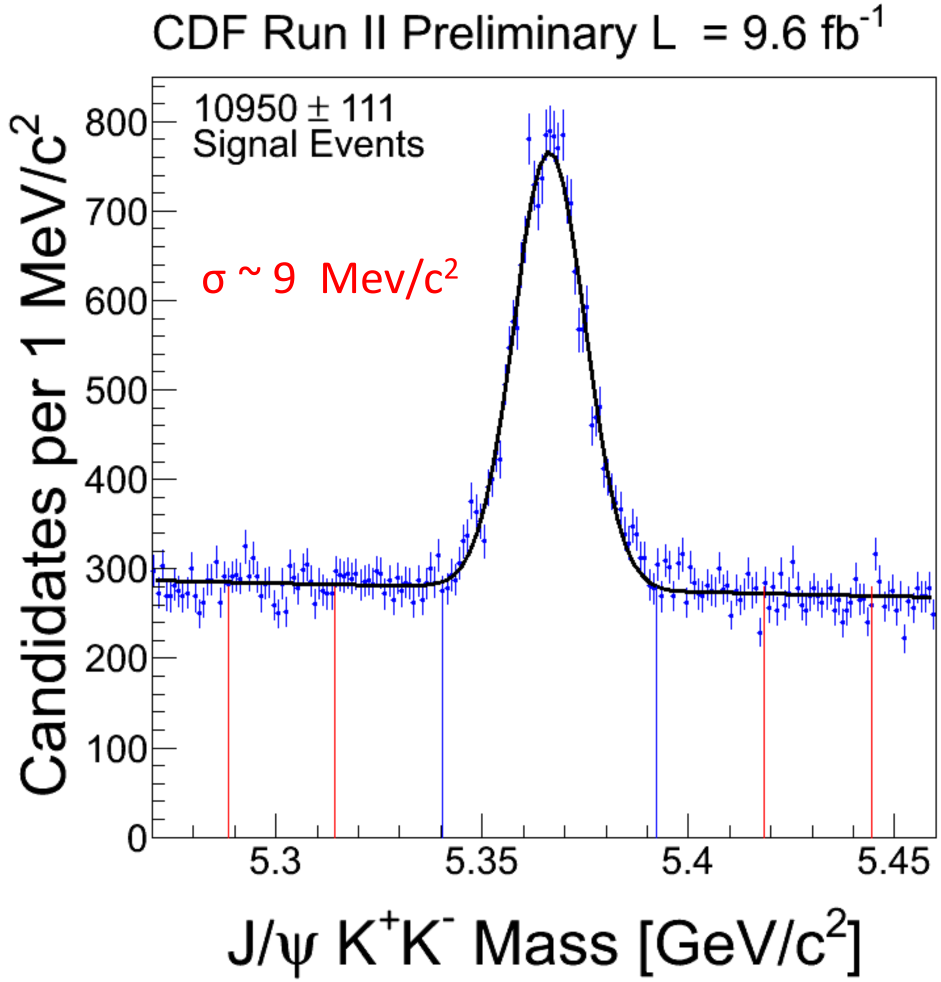
Decay time to know time evolution



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

The Signal

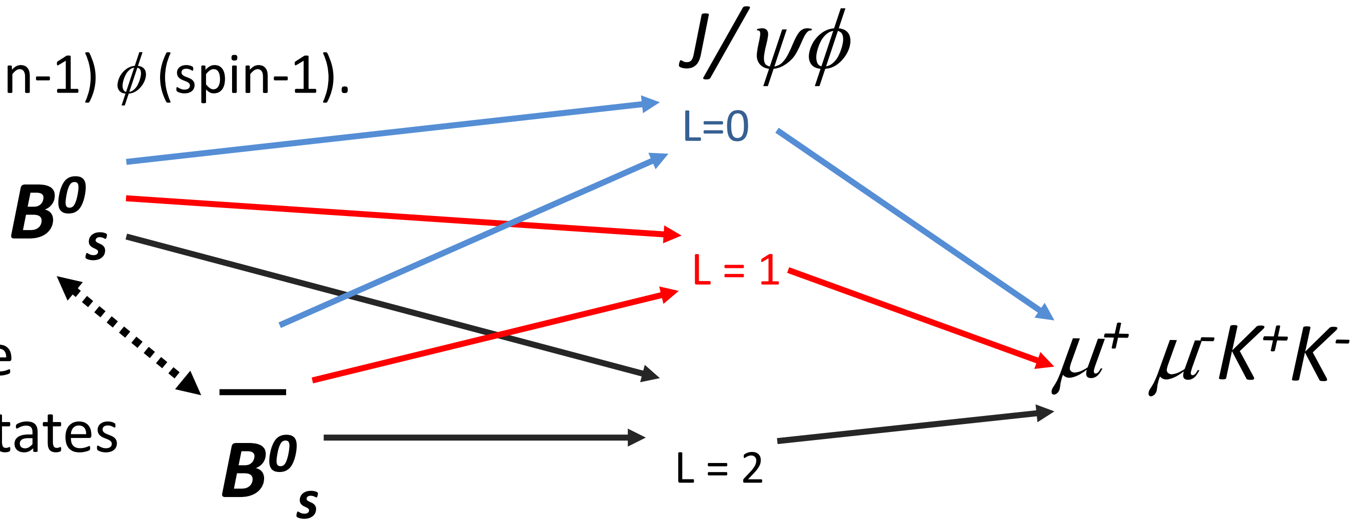
- Full Run II Dataset (10 fb^{-1})
  - ~ 11,000 signal events
  - 95% of bkg is prompt J/psi + random track pair

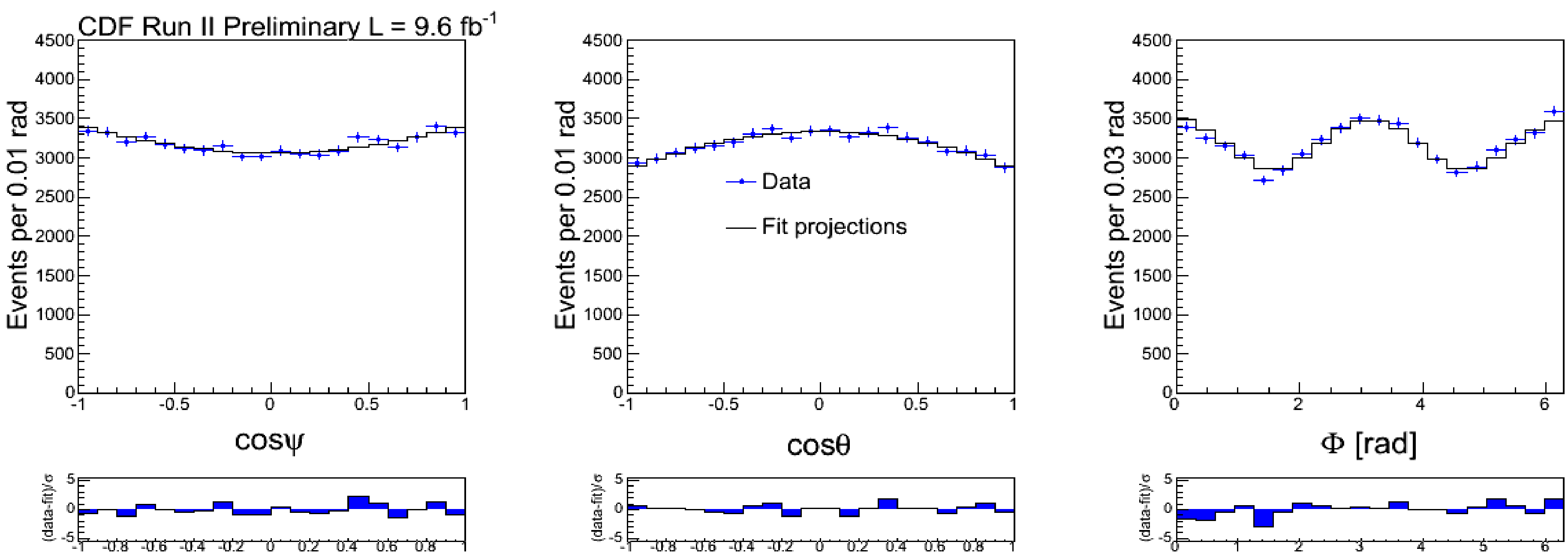


ANGULAR ANALYSIS

B_s^0 (spin-0) $\rightarrow J/\psi$(spin-1) ϕ (spin-1).

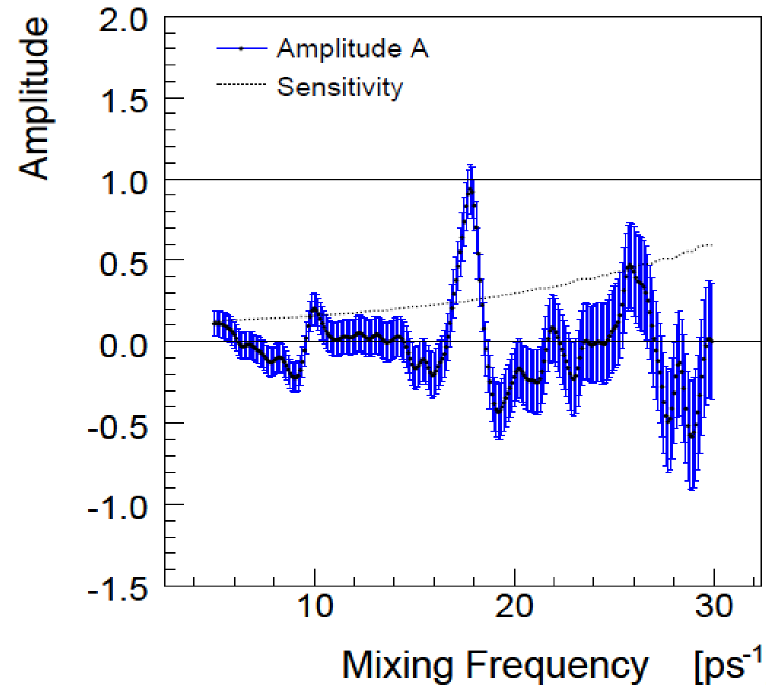
Angular distributions to disentangle different CP states





FLAVOR TAGGING

Greater sensitivity to mixing phase if production flavor is known.

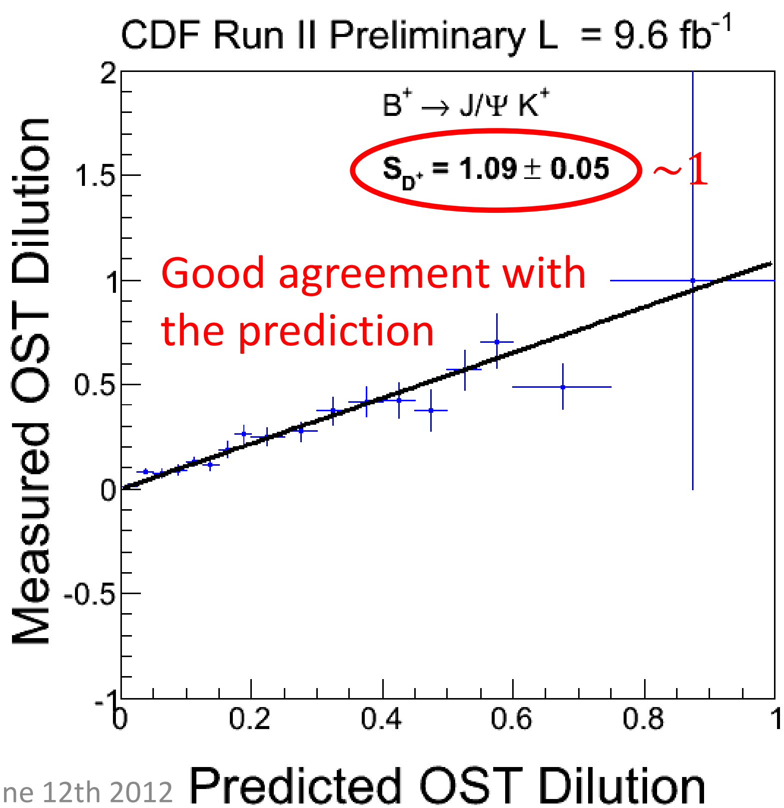


Opposite Side Tagging

- Total tagging power (εD^2) is 1.4%
- Calibrated using 82k B^+ decays

Same Side Kaon Tagging

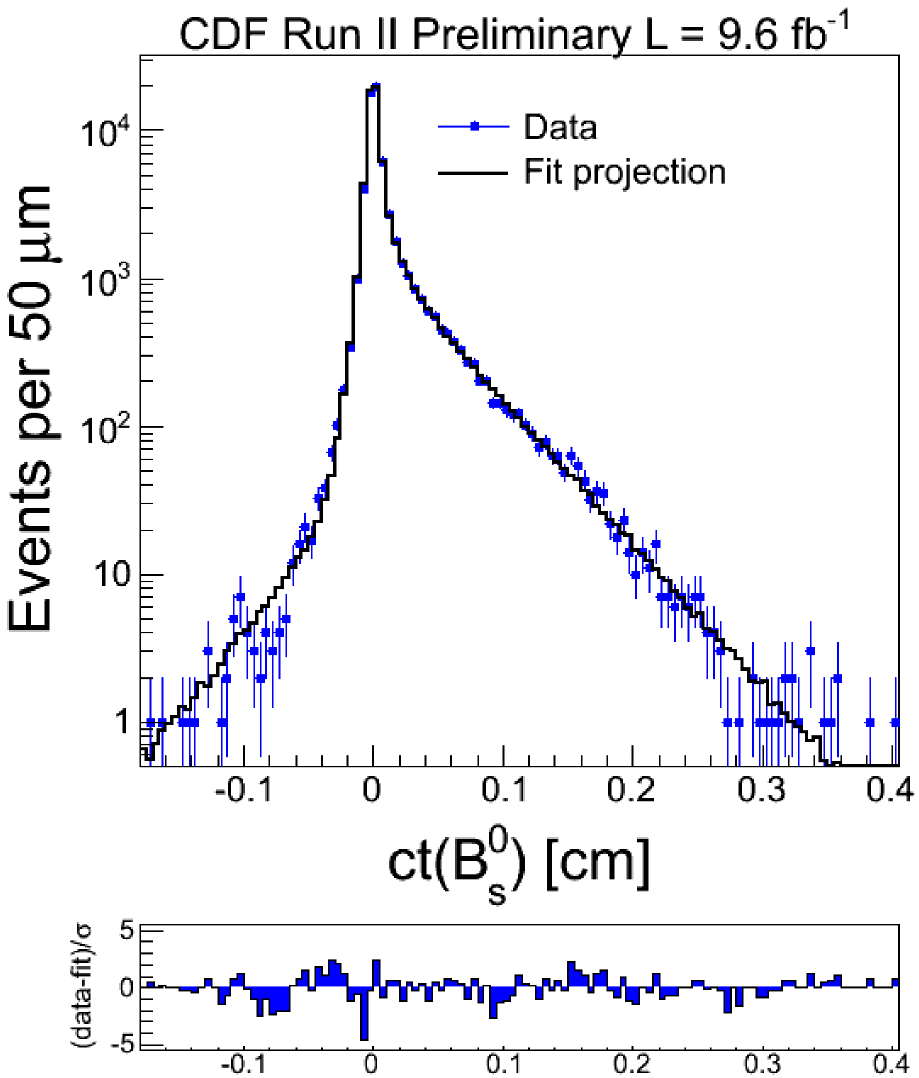
- εD^2 is 3.5%



Same side tagger used only in first half of data. Calibration in latest data not yet completed.

- Modest degradation of the expected mixing phase resolution

Lifetime and Width Difference



$$\Delta\Gamma_s = 0.068 \pm 0.026 \pm 0.007\, ps^{-1}$$
$$\tau_s = 1.528 \pm 0.019 \pm 0.009\, ps$$

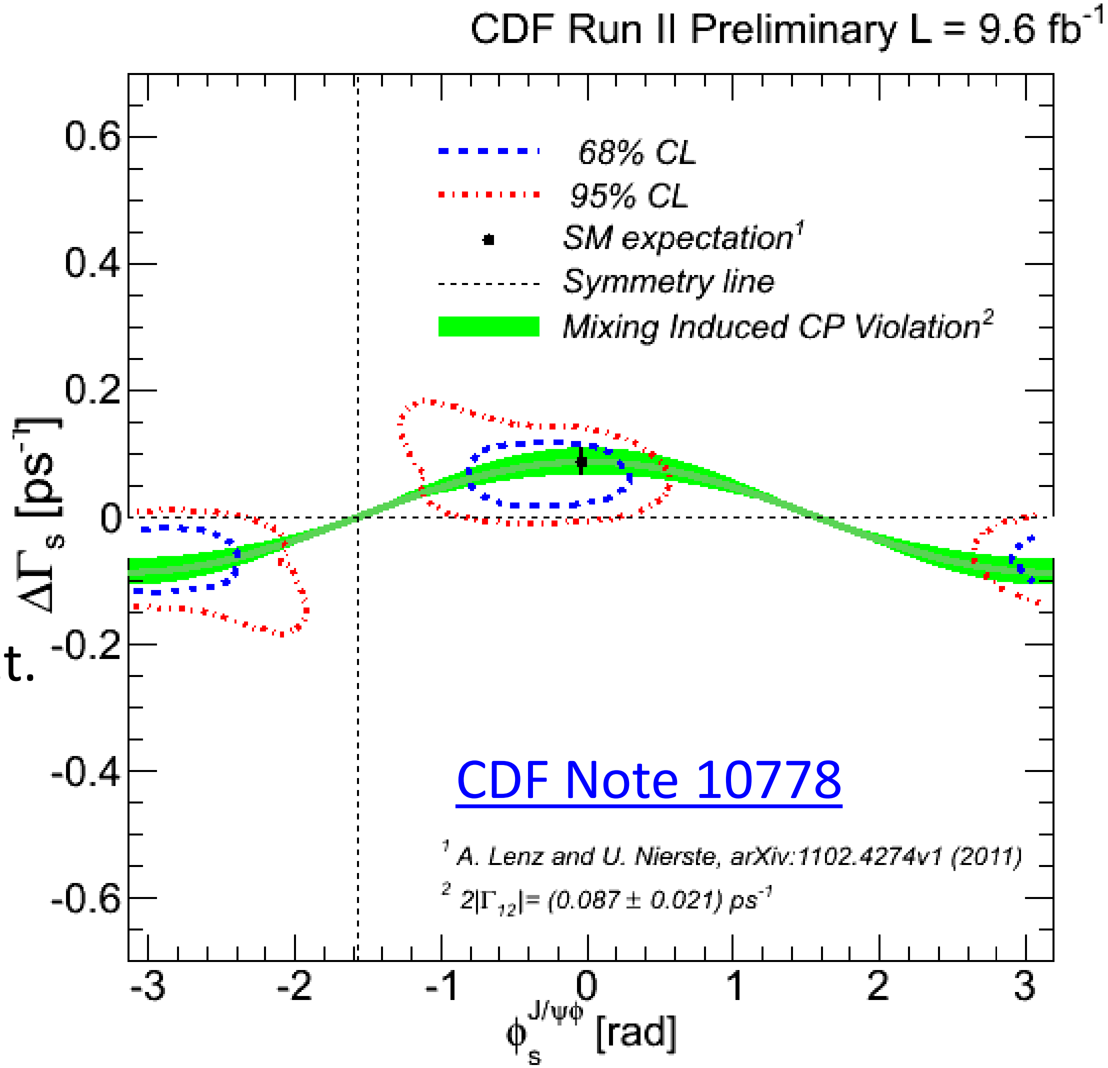
CDF Note 10778

- $\Delta\Gamma_s$ slightly lower than DØ and LHCb determination, but still consistent with them and with SM.
- Important constraint to probe DØ measurement of a_{SL}
- Among the best world's measurements.

Mixing phase results

Mixing phase compatible with SM prediction
$\Phi_s\ in[-0.60, 0.12]$rad @ 68% C.L.

Contours shrink to ~50 % w.r.t. PRD 85, 072002 (2012)

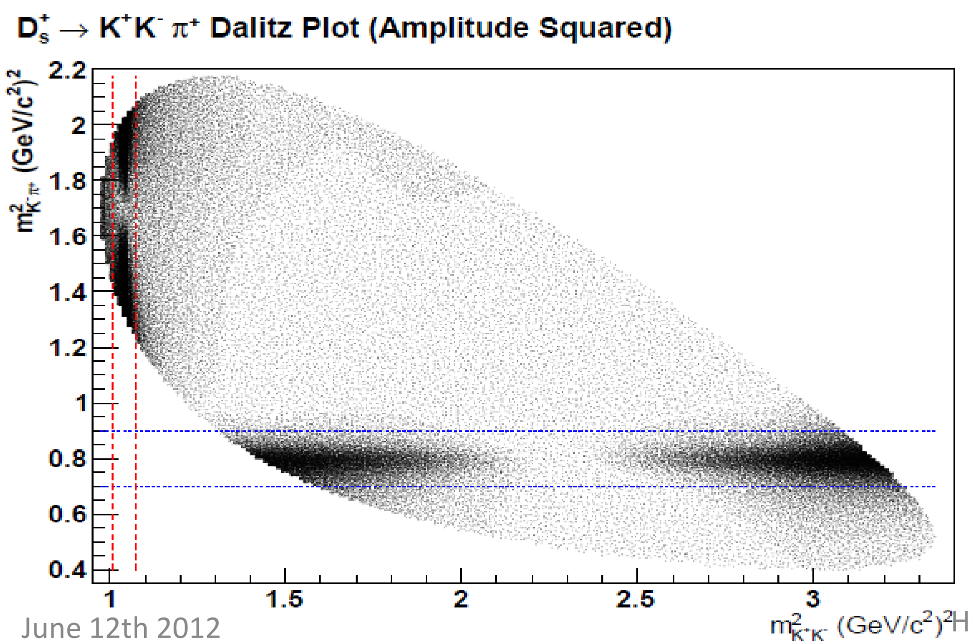


CDF Note 10778

$B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$ Branching Ratios

Update of early Run II analysis (PRL 100, 021803 (2008))

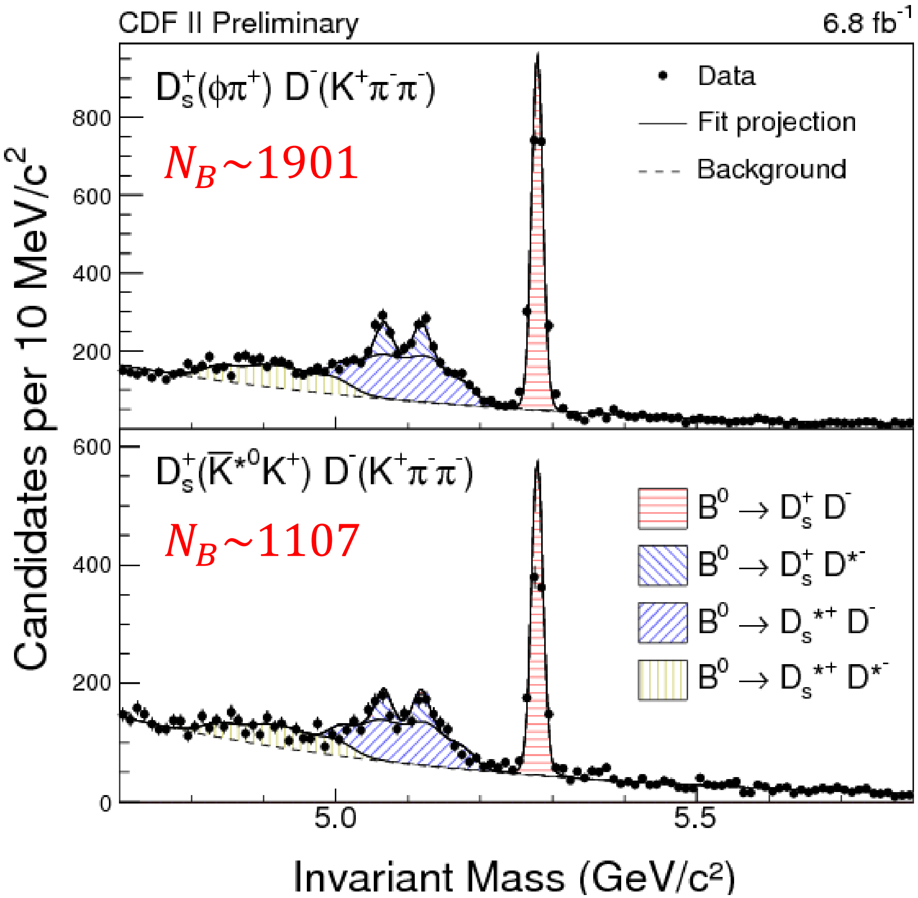
- ~6.8 fb^{-1} of Two Track Trigger data:
- Extract $B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}$ rate relative to $B_d^0 \rightarrow D^- D_s^+$ rate using an unbinned ML fit:
- Simultaneous fit to B_s^0 signal and B_d^0 normalization mode exploits maximum of statistical information and allows using partially reconstructed D_s^* decays as well



- $D_s^+ \rightarrow K^+K^-\pi^+$ and $D^- \rightarrow K^+\pi^-\pi^-$ reconstructed from combination of three tracks.
- First use of Dalitz structure in this analysis to identify better the ϕ and K^* components

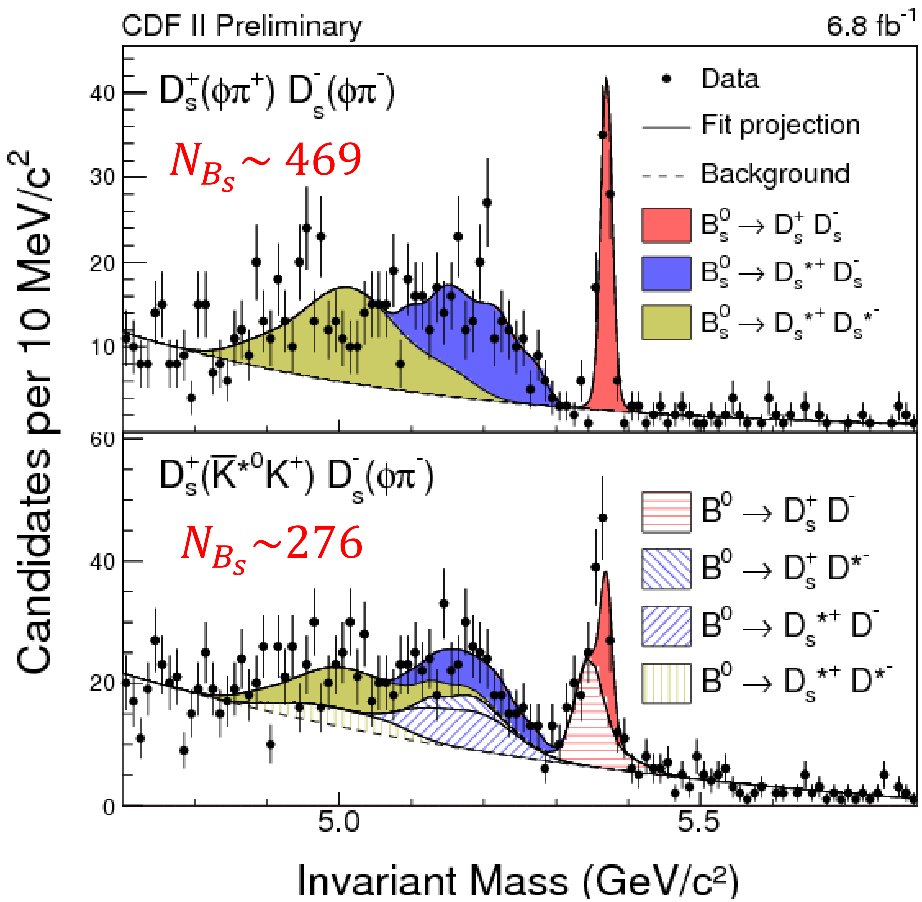
Simultaneous fit

$D_s^+ D^-$



Normalization

$D_s^+ D_s^-$



Signal

RESULTS

- Using known values for B_d branching ratios

$$\boxed{\mathcal{B}\left(B_s^0 \to D_s^{(*)+} D_s^{(*)-}\right) = (3.38 \pm 0.25 \pm 0.30 \pm 0.56)\%}$$

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

World's most precise measurement of this BR

CP Violation in Charm

CP VIOLATION IN CHARM

- Probe the up-quark sector.

  Direct CPV >1% level suggestive of NP.

$$V_{CKM} = \begin{array}{c} \begin{array}{ccc} d & s & b \end{array} \\ \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} \end{array} \begin{array}{c} u \\ c \\ t \end{array}$$

- CDF 2011: world's best measurement of individual asymmetries PRD85, 012009 (2012)

$$A_{CP}(D^0 \to K^+K^-) = (-0.24 \pm 0.22 \pm 0.09)\%$$
$$A_{CP}(D^0 \to \pi^+\pi^-) = (+0.22 \pm 0.24 \pm 0.11)\%$$

$$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$$

Maximally sensitive to NP and experimentally convenient, instrumental asymmetries cancel.

- LHCb 2011: $\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$, 3.5σ from zero.

  First evidence of CPV in charm PRL 108, 111602 (2012)

Independent confirmation crucial to establish it.

$\Delta A_{CP}(D0 \rightarrow h^+h^-)$ with full CDF Run II dataset

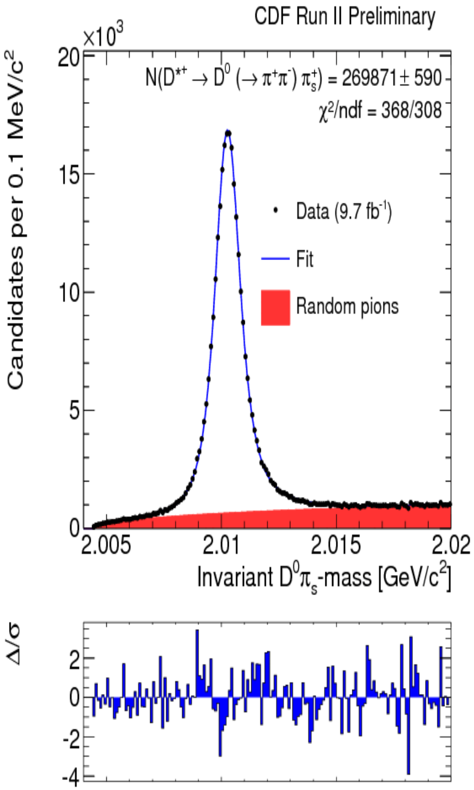
- Measurement updated with full Run II data sample
- Analysis strategy unchanged but new selection has been designed to specifically improve the resolution on ΔA_{CP}
  - About twice more signal events used in the new measurement
  - Expected resolution is competitive with LHCb
- Use $D^* \rightarrow D^0\pi_s$ tag to identify the charm flavor at production
- The instrumental asymmetries induces by soft pion reconstructed in the charge-asymmetric CDF tracker gets canceled in the difference of asymmetries:

$$\Delta A_{CP} = \left(A(K^+K^-) + \cancel{\delta(\pi_s)}\right) - \left(A(\pi^+\pi^-) + \cancel{\delta(\pi_s)}\right)$$

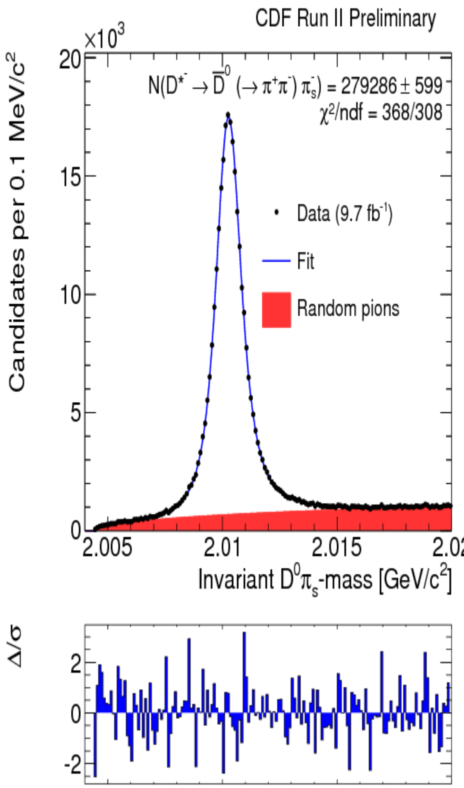
- Reweight kinematic in KK and $\pi\pi$ to be equal for a more accurate cancellation.

FIT RESULTS

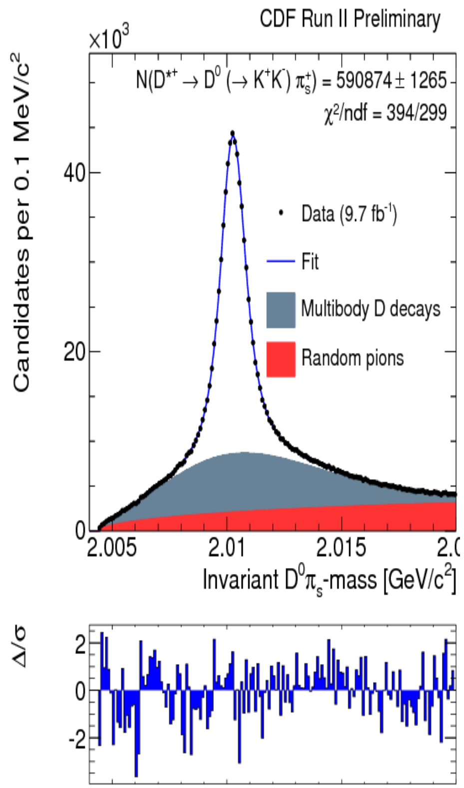
270K $D^0 \rightarrow \pi\pi$



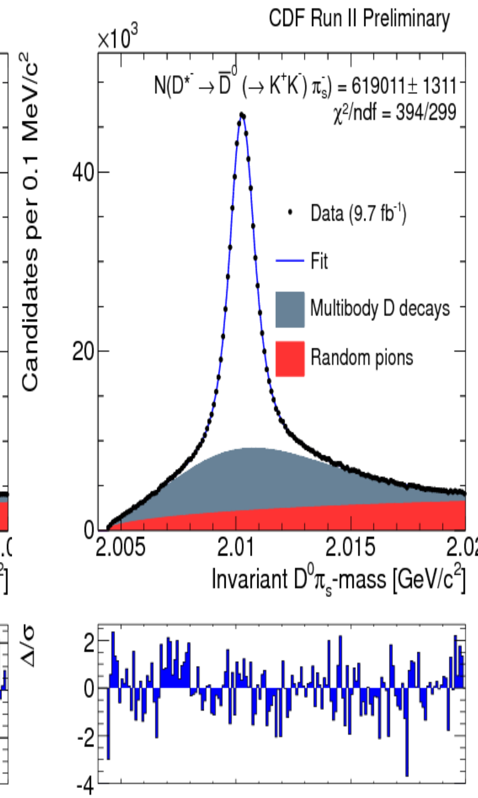
280K $\overline{D}^0 \rightarrow \pi\pi$



591K $D^0 \rightarrow$KK



619K $\overline{D}^0 \rightarrow$KK



$\boldsymbol{Raw\ A}(\pi^+\pi^-) = (-1.71 \pm 0.15)\%$ $\boldsymbol{Raw\ A}(K^+K^-) = (-2.33 \pm 0.14)\%$

CHARM ΔA_{CP} AT CDF

ΔA_{CP} = [-0.62 ± 0.21 (stat) ± 0.10 (syst)]%

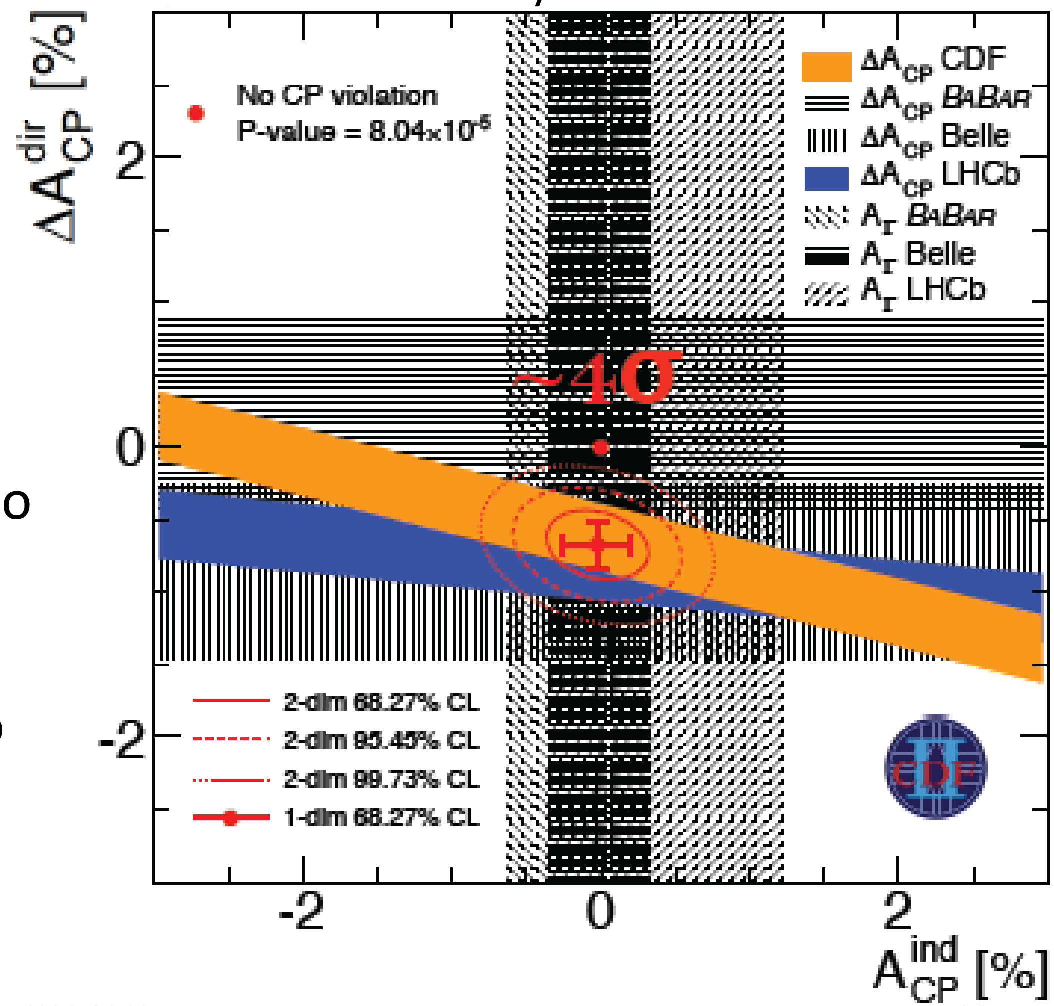
Strong indication of CPV in CDF charm decays

- Confirms LHCb result: same resolution, <1σ difference in central value

  ΔA_{CP}=(-0.82 ± 0.21 ± 0.11)%

- When combining à la HFAG, no CPV point is at ~4σ from zero

$$\Delta A_{CP}{}^{dir} = (-0.67 \ \pm 0.16)\%$$
$$A_{CP}{}^{ind} = (-0.02 \ \pm 0.22)\%$$

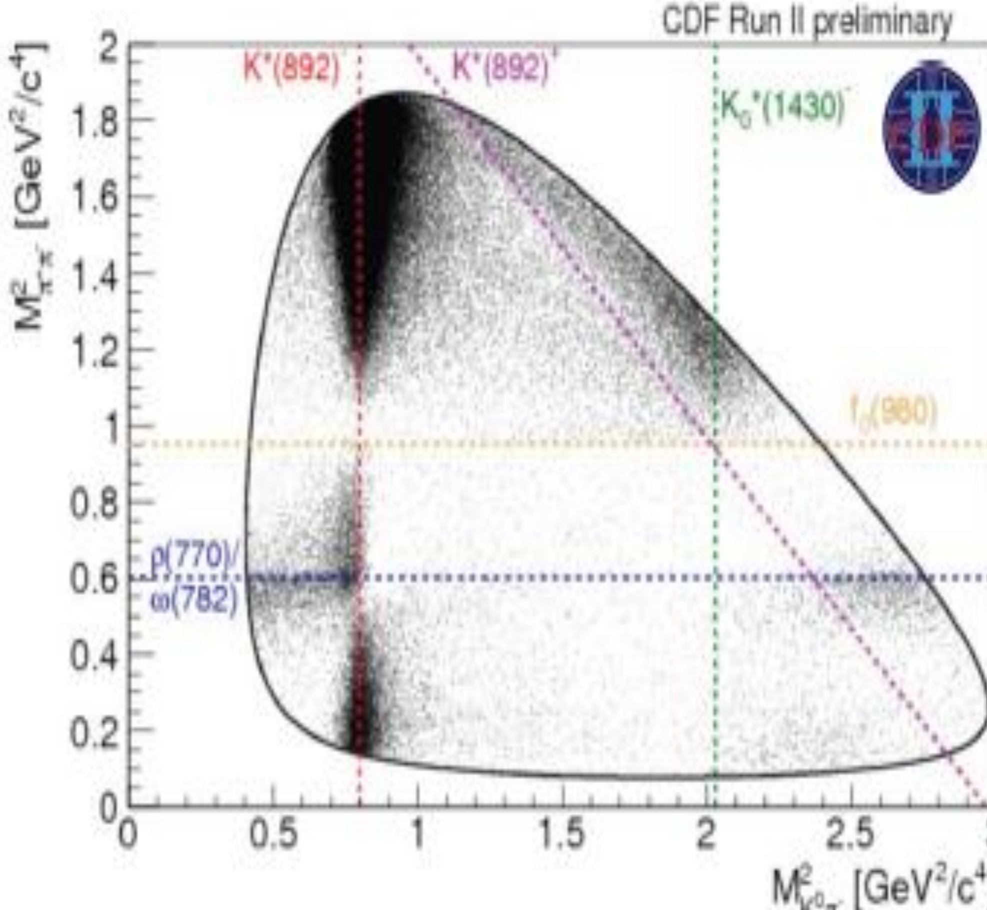


CP Violation in $D^0 \to K_s\pi^+\pi^-$

- In 6 fb^{-1} of two-track trigger data we search for time-integrated CPV in the resonant substructures of the 3-body $D^0 \to K_s\pi^+\pi^-$decay

- First full Dalitz analysis at hadron Collider

- Model-independent bin-by-bin comparison of the D^0 and $\overline{D}^0$ Dalitz plots (Miranda method)



$D^0 \rightarrow K_s\pi^+\pi^-$ RESULTS

- Table lists asymmetries between sub-resonances fit fractions
  - Large improvement w.r.t. CLEO results (PRD70, 091101 (2004))
  - No hints for any CP violating effect
- Overall integrated asymmetry:

CDF Run II preliminary

Resonance	CPV amplitude	CPV Phase
$K^*(892)^-$	$0.004 \pm 0.004 \pm 0.011$	$-0.8 \pm 1.4 \pm 1.3$
$K_0^*(1430)^-$	$0.044 \pm 0.028 \pm 0.041$	$-1.8 \pm 1.7 \pm 2.2$
$K_2^*(1430)^-$	$0.018 \pm 0.024 \pm 0.023$	$-1.1 \pm 1.8 \pm 1.1$
$K^*(1410)^-$	$-0.010 \pm 0.037 \pm 0.021$	$-1.6 \pm 1.9 \pm 2.2$
$\rho(770)$	$-0.003 \pm 0.006 \pm 0.008$	$-0.5 \pm 1.5 \pm 1.4$
$\omega(782)$	$-0.003 \pm 0.002 \pm 0.000$	$-1.8 \pm 2.2 \pm 1.4$
$f_0(980)$	$-0.001 \pm 0.005 \pm 0.004$	$-0.1 \pm 1.3 \pm 1.1$
$f_2(1270)$	$-0.035 \pm 0.037 \pm 0.013$	$-2.0 \pm 1.9 \pm 2.1$
$f_0(1370)$	$-0.002 \pm 0.008 \pm 0.021$	$-0.1 \pm 1.7 \pm 2.8$
$\rho(1450)$	$-0.016 \pm 0.022 \pm 0.135$	$-1.7 \pm 1.7 \pm 3.9$
$f_0(600)$	$-0.012 \pm 0.017 \pm 0.025$	$-0.3 \pm 1.5 \pm 1.4$
σ_2	$-0.011 \pm 0.012 \pm 0.004$	$-0.2 \pm 2.9 \pm 1.1$
$K^*(892)^+$	$0.001 \pm 0.005 \pm 0.002$	$-3.8 \pm 2.3 \pm 1.2$
$K_0^*(1430)^+$	$0.022 \pm 0.024 \pm 0.035$	$-3.3 \pm 4.0 \pm 3.9$
$K_2^*(1430)^+$	$-0.018 \pm 0.029 \pm 0.017$	$4.2 \pm 5.3 \pm 3.0$

$A_{CP}(D^0 \rightarrow K_s\pi^+\pi^-) = (-0.05 \pm 0.57 \pm 0.54)\%$

CDF Public Note 10654

CONCLUSIONS

- Data taking ended in September 30th 2011
  - Big effort in getting the analyses finalized in full dataset:
    All shown results are less than 6 months old
- CDF keeps contributing to HF while passing baton to LHC experiments
  - Finalizing flaship analyses on full Run II dataset …Still more to come!
  - Then refocus on measurements that are unique to Tevatron or systematics-limited
- B_s Mixing Phase
  - Got closer to SM
- CPV in Charm Sector
  - Confirmed LHCb's evidence of CPV in charm with same precision
  - …but No hints of CPV in $\mathrm{D}^0 \rightarrow K_s\pi^+\pi^-$ decay