CPV in the Charm Sector at CDF

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Overview

- Why are charm CPV measurements interesting?
- Time-integrated CP asymmetry with $D^0 \to h^+h^-$
- Measurement of ΔA_{CP} between $D^0 \to KK$ and $D^0 \to \pi\pi$
- Search for CPV in $D^0 \to K_s\pi\pi$

Why is charm CPV interesting?

- Predicted to be small in the SM; can be a probe for new physics
  - Before Nov 2011, many believed it would be << 1%
- Predictions for charm CPV are difficult
  - Dominant terms are non-perturbative / model-dependent
- Precision measurements for charm CPV are difficult
  - Detector effects can mimic the effects of CPV
- See previous talk by Chris Parkes “CPV and Mixing in the Charm Sector at LHCb”, and earlier talks by Ko (Belle), Cenci (BaBar) and Sun (CLEO).

Time-integrated CP violation measurements with $D^0 \to h^+h^-$ ($5.94\ fb^{-1}$)

Phys. Rev. D 85, 012009 (2012)

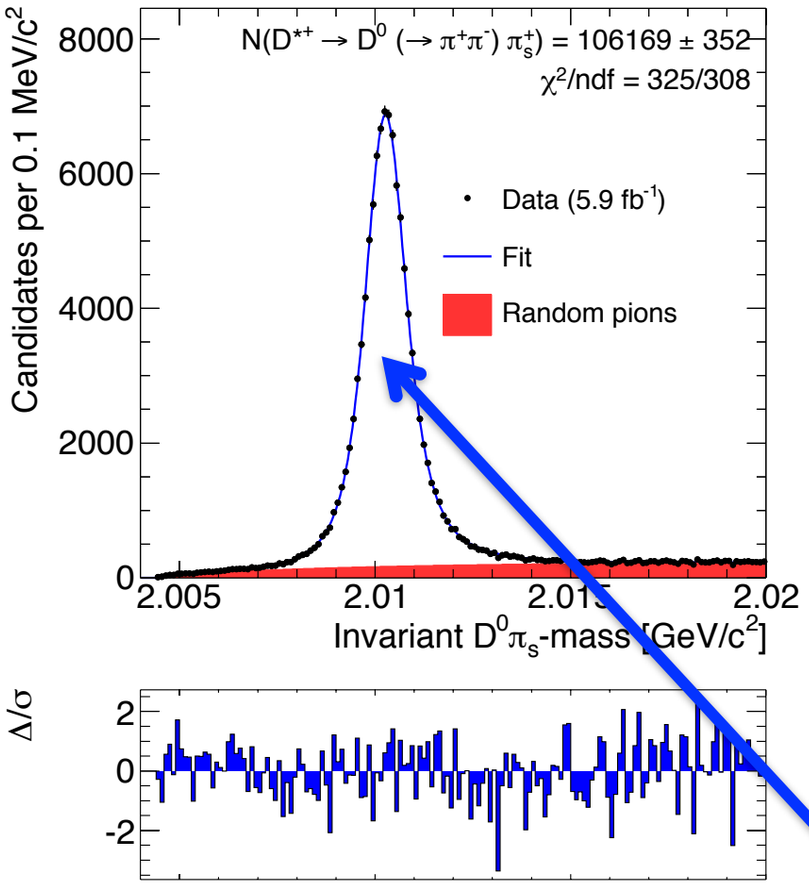
http://www-cdf.fnal.gov/physics/new/bottom/100916.blessed-Dpipi6.0

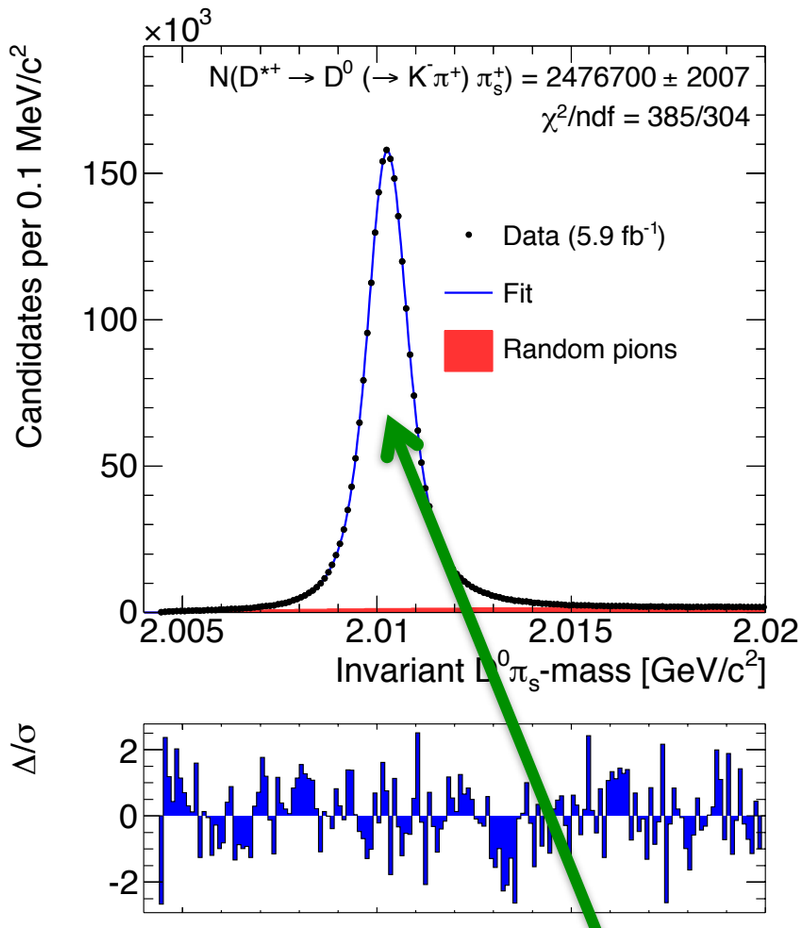
Asymmetry with $D^0 \to h^+h^-$

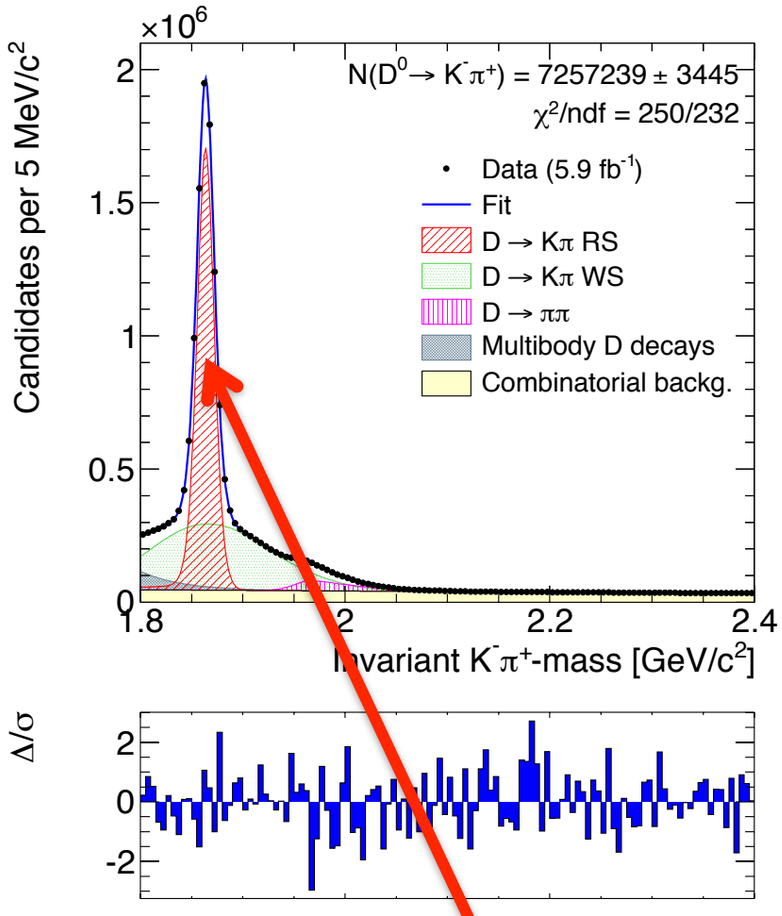
$$A_{CP}^{\pi\pi} = \frac{\Gamma(D^0 \to \pi^-\pi^+) - \Gamma(\overline{D}^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to \pi^-\pi^+) + \Gamma(\overline{D}^0 \to \pi^+\pi^-)}$$

- Use D^{*+} -> D^0 π^+ and c.c. decays, where the charge of the π tags the D^0 production flavor
- To make precision measurement, need to correct for detector effects that can bias the asymmetry
  - Start with the "raw" difference between the number of D^{*+} and D^{*-} (with D^0-> $\pi\pi$), to get the difference between D^0 and D^0-bar
  - The detector can cause an imbalance in the number of charged pions used to form the $D^{*\pm}$. Use the "raw" $D^{*\pm}$ -> $\pi^\pm$ D^0, D^0->K π to correct for that.
  - Lastly, make a correction to the previous correction, to account for detector systematics that affect $K^+\pi^-$ / $K^-\pi^+$
  - Make sure the events are weighted to match p_T and η distributions.

Data Driven Corrections







$$A_{CP}(\pi\pi) = A^*_{raw}(\pi\pi) - A^*_{raw}(K\pi) + A_{raw}(K\pi)$$

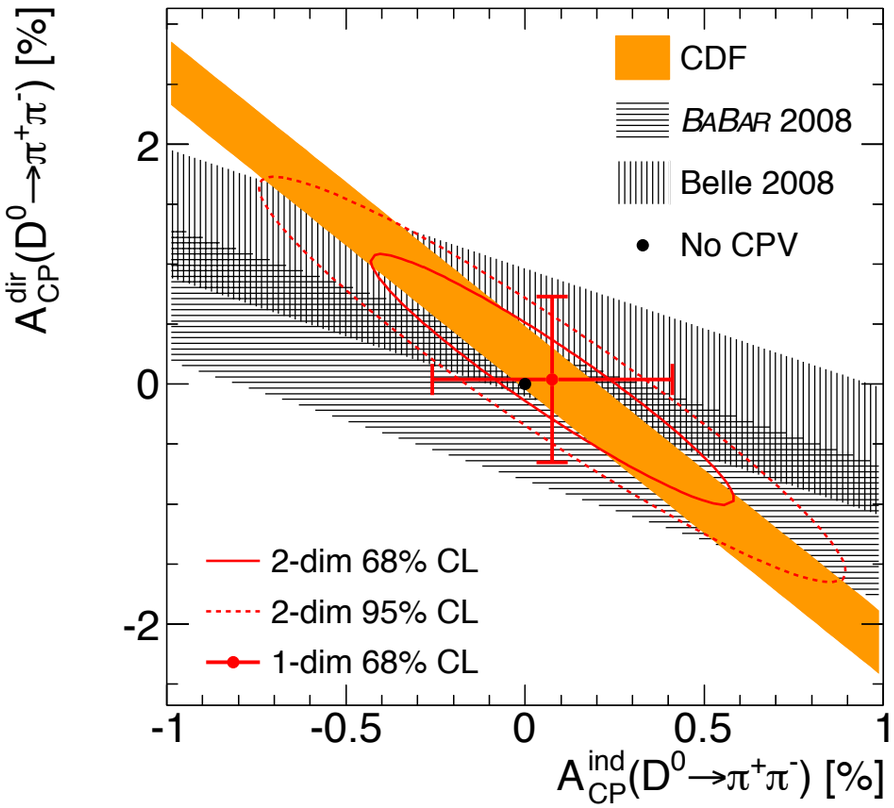
** refers to D* tagged events ; no * means an untagged sample*

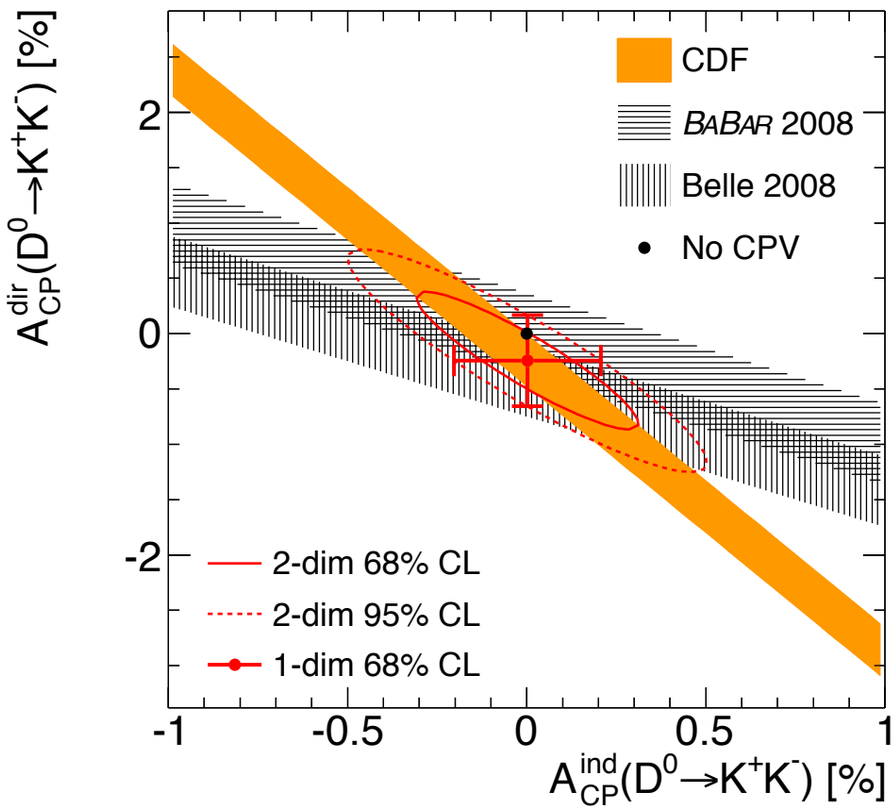
Repeat the procedure for D^0 -> KK

Individual Mode Asymmetries

$$A_{CP}(\pi^+\pi^-) = [0.22 \pm 0.24(\text{stat}) \pm 0.11(\text{sys})]\,\%$$

$$A_{CP}(K^+K^-) = [-0.24 \pm 0.22(\text{stat}) \pm 0.09(\text{sys})]\,\%$$





Note: Measured CP asymmetry is a combination of direct and indirect CP asymmetries

$$A_{CP} = A_{CP}^{dir} + \int_0^\infty A_{CP}(t)D(t)dt \approx A_{CP}^{dir} + \frac{< t >}{\tau} A_{CP}^{ind}$$

Measurement of ΔA_{CP} between $D^0 \to KK$ and $D^0 \to \pi\pi$ ($9.7\ fb^{-1}$)

Phys. Rev. Lett. 109, 111801 (2012)

http://www-cdf.fnal.gov/physics/new/bottom/120216.blessed-CPVcharm10fb

ΔA_{CP} Measurement

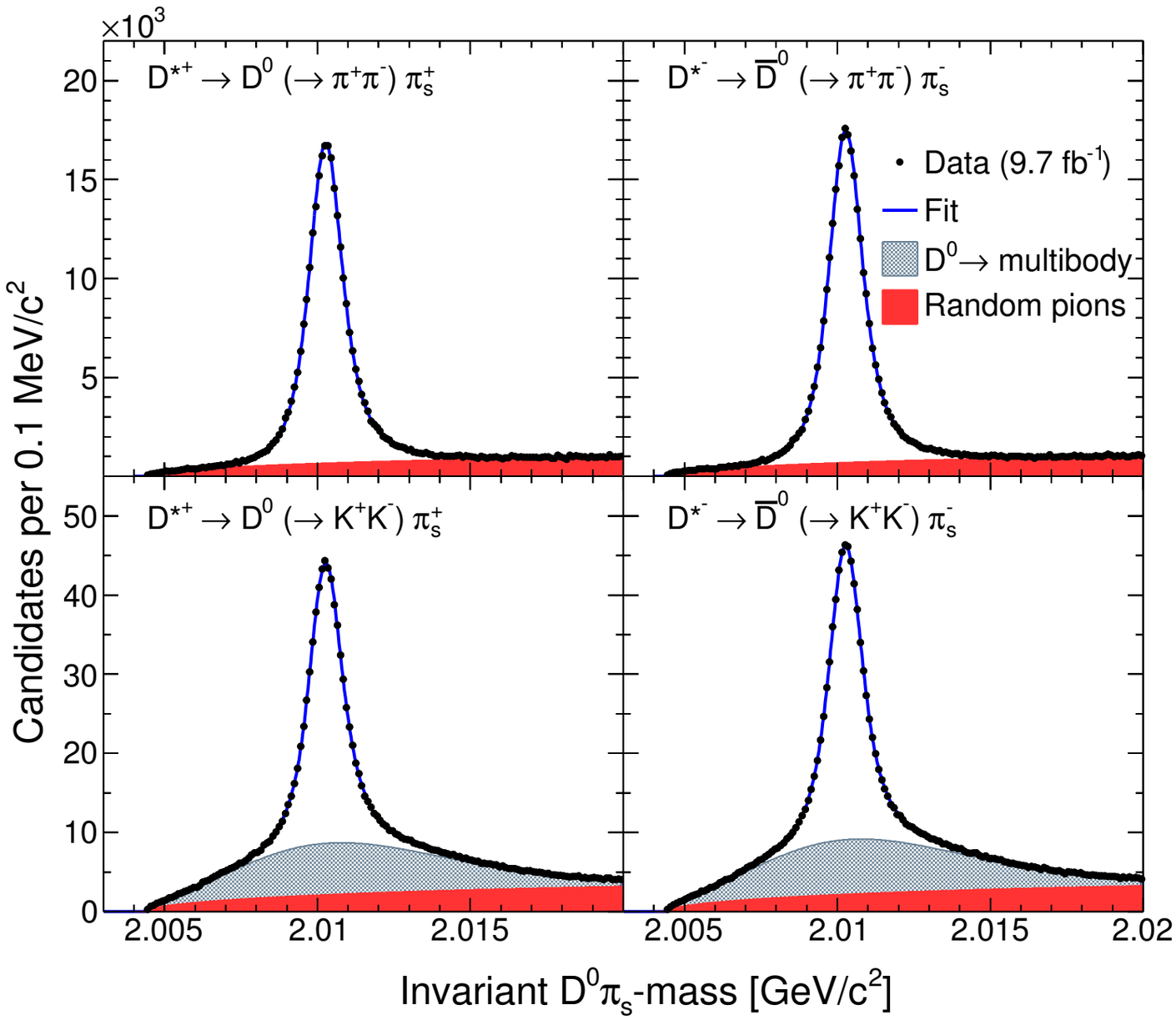
$$\Delta A_{CP} = A^*_{raw}(K^+K^-) - A^*_{raw}(\pi^+\pi^-)$$

- For ΔA_{CP} measurements, event selection can be loosened

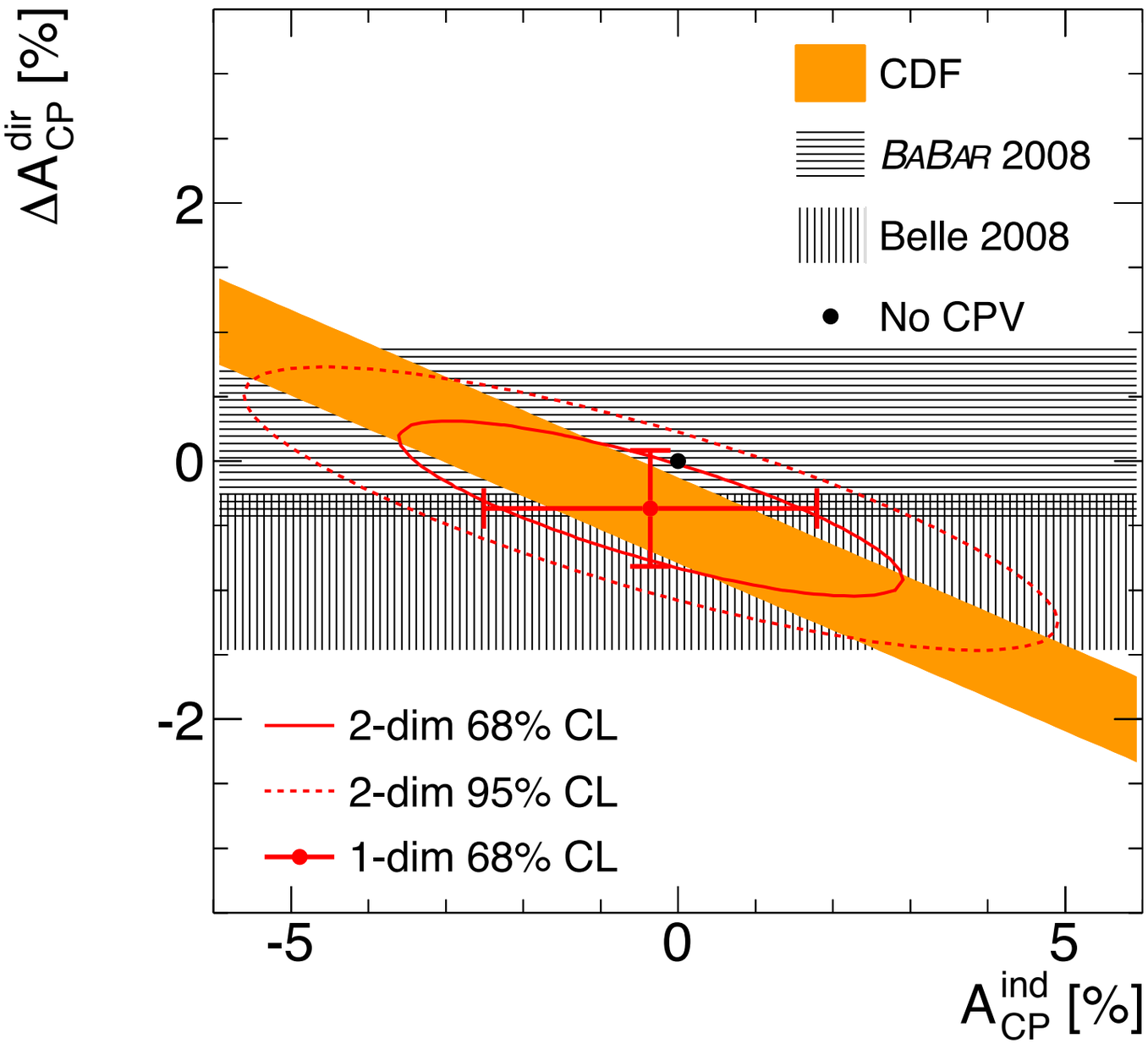
$$A^*_{raw}(\pi\pi) - \cancel{A^*_{raw}(K\pi)} + \cancel{A_{raw}(K\pi)}$$
$$-[A^*_{raw}(KK) - \cancel{A^*_{raw}(K\pi)} + \cancel{A_{raw}(K\pi)}]$$

  - Also, data beyond 6 fb^{-1} was added

- Cross check with data binned in different η, phi regions



ΔA_{CP} Measurement



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

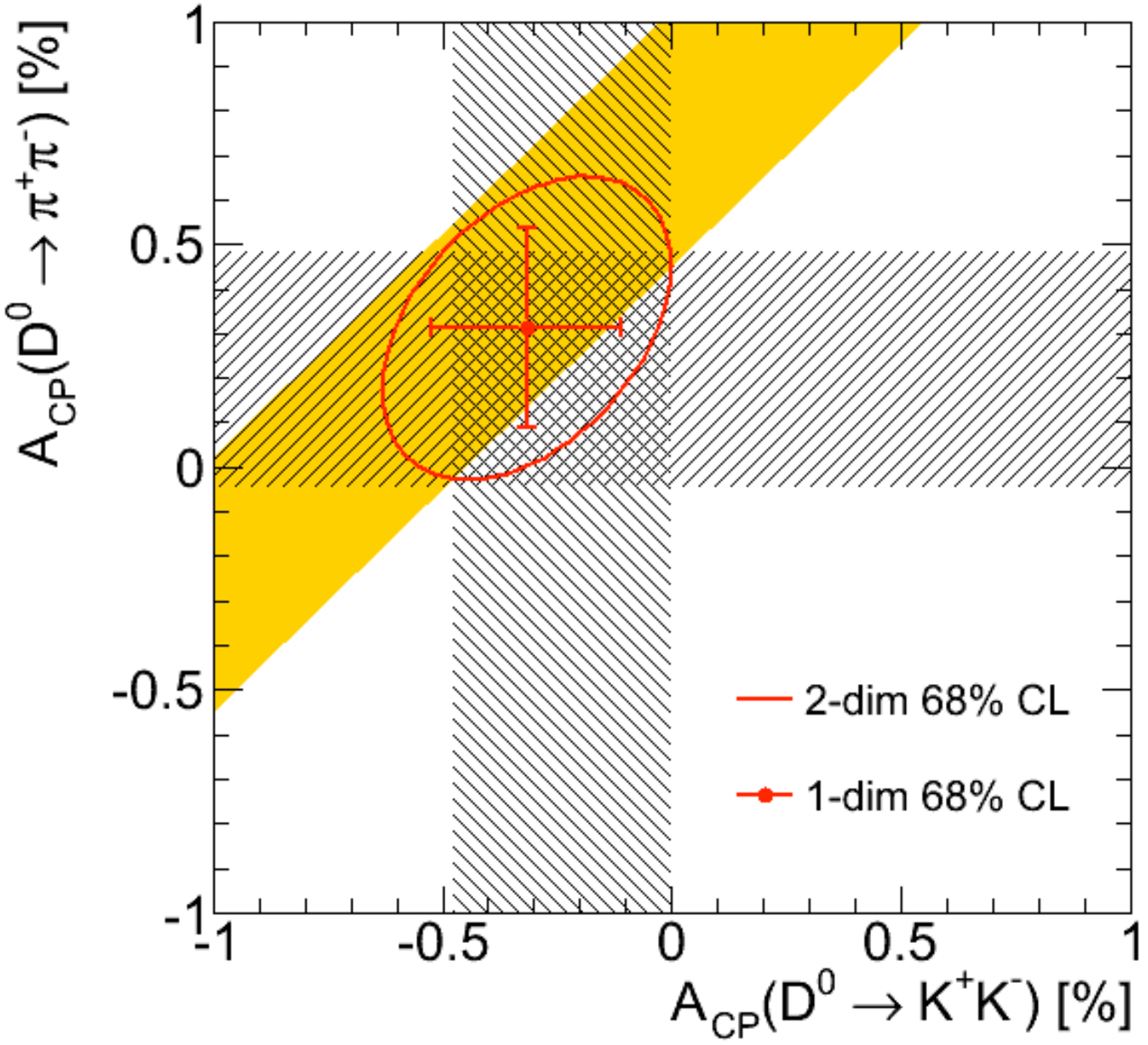
Combined Measurement

$A_{CP}(D^0 \to \pi^+\pi^-) = (+0.31 \pm 0.22)\%$
$A_{CP}(D^0 \to K^+K^-) = (-0.32 \pm 0.21)\%$

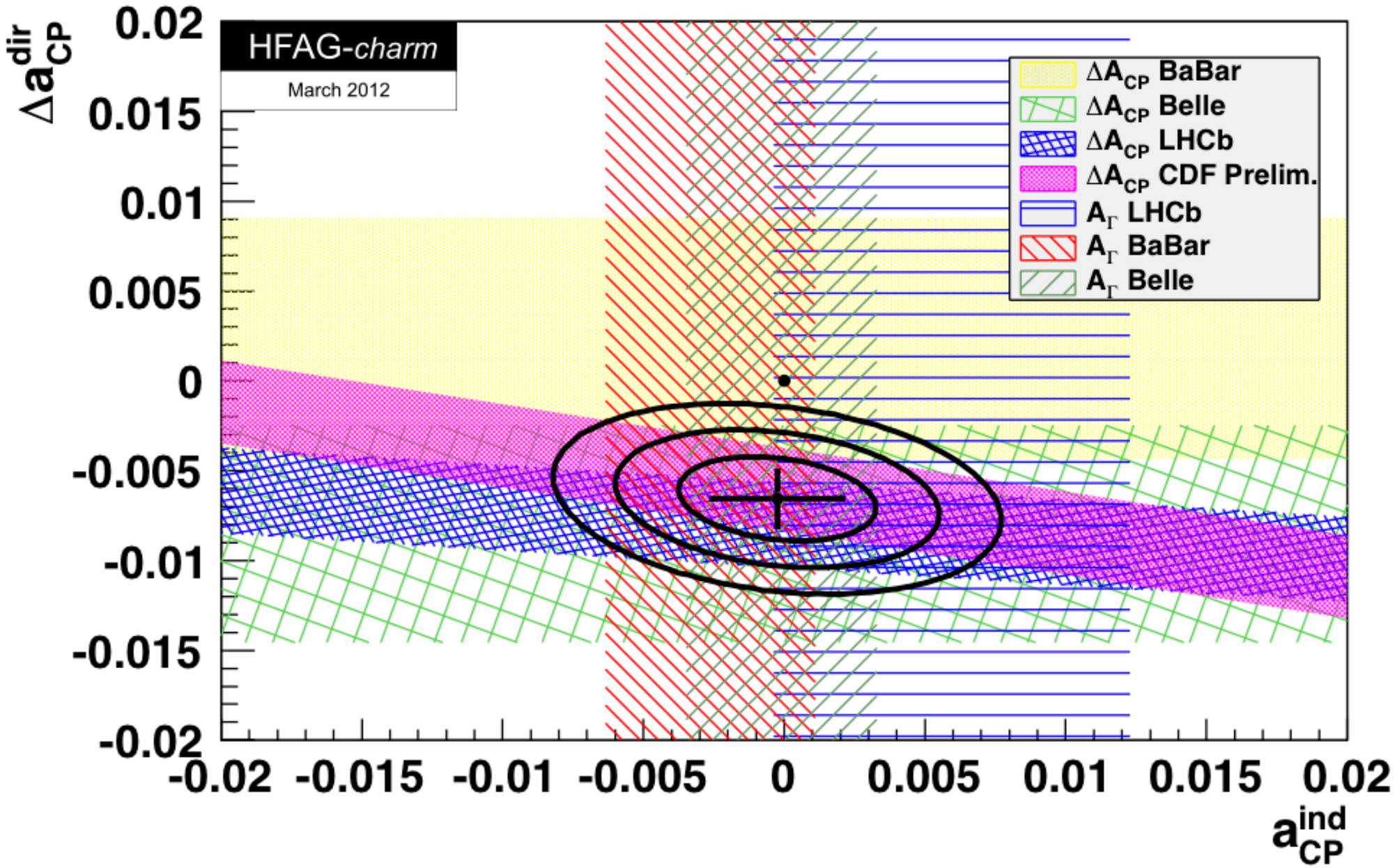
- Can combine the ΔA_{CP} result with the $A_{CP}(\pi\pi)$ and $A_{CP}(KK)$ result

- remove events from the ΔA_{CP} analysis that were used in the other analysis, to create a statistically independent sample

- roughly 15% improvement on uncertainty from the earlier $A_{CP}(\pi\pi)$ and $A_{CP}(KK)$ result



Heavy Flavor Averaging Group
Combination of ΔA_{CP} Results



A_{CP} (indirect) = (-0.025 ± 0.231)% ΔA_{CP} (direct) = (-0.656 ± 0.154)%

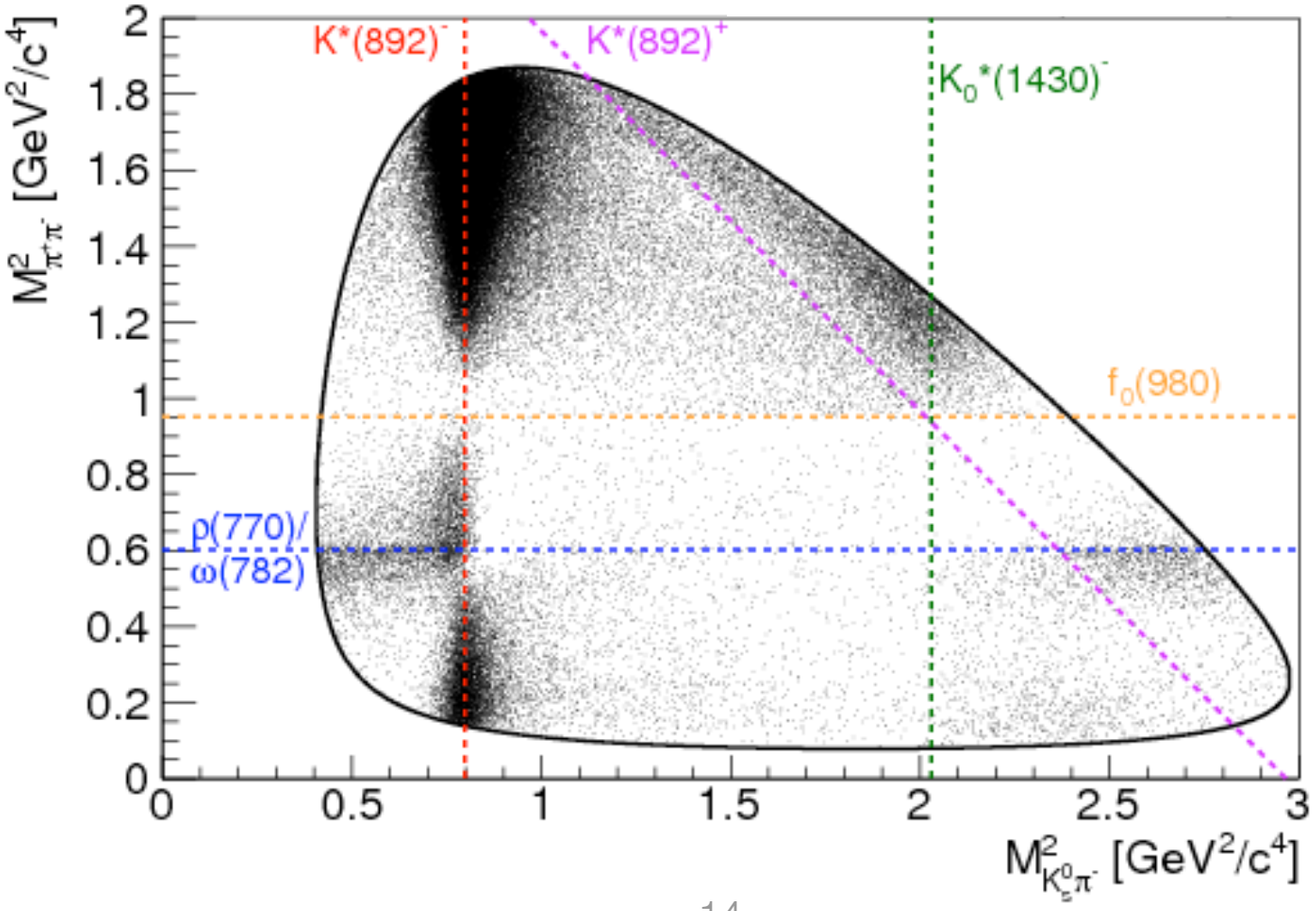
Search for CPV in $D^0 \to K_s\pi^+\pi^-$ ($6.0\ fb^{-1}$)

Phys. Rev. D 86, 032007 (2012)

http://www-cdf.fnal.gov/physics/new/bottom/111013.blessed-D0KSpipi_ACP

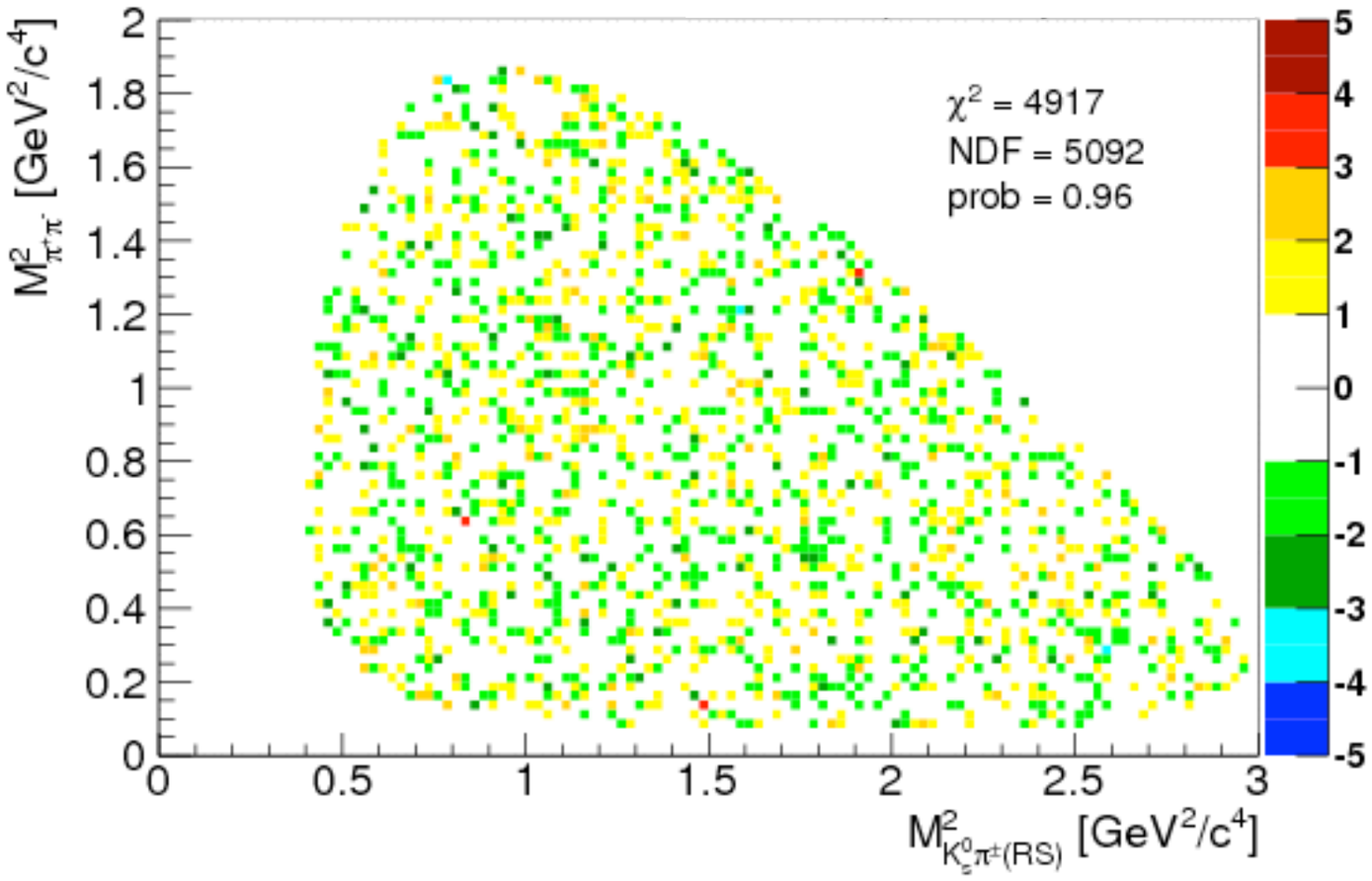
CP Asymmetry in $D^0 \rightarrow K_S\pi^+\pi^-$

- SM expectation of these CP asymmetries is $O(10^{-6})$, well below exp. sensitivity
- Dalitz fit (employing the Isobar model for the involved resonances)
  - First time at a hadron collider using Dalitz plot technique
- Model-independent bin-by-bin comparison of the D^0 and $\overline{D}^0$ Dalitz plots



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

- Overall A_{CP} = -0.0005 ± 0.0057 ± 0.0054
  - Negligible effect from neutral kaon CPV
- Asymmetries determined for resonance modes (next page)



CP Asymmetries for Resonances

Resonance	b amplitude	$\phi\,[^\circ]$ 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	$-0.011 \pm 0.012 \pm 0.004$	$-0.2 \pm 2.9 \pm 1.1$
$K^*(892)^+$	$0.001 \pm 0.005 \pm 0.002$	$-3.8 \pm 2.3 \pm 1.2$
$K_0^*(1430)^+$	$0.022 \pm 0.024 \pm 0.035$	$-3.3 \pm 4.0 \pm 3.9$
$K_2^*(1430)^+$	$-0.018 \pm 0.029 \pm 0.017$	$4.2 \pm 5.3 \pm 3.0$

Conclusion

- Recent CDF results testing charm sector CPV with 3 analyses
  - Time-integrated CP violation measurements with $D^0 \to h^+h^-$
  - Measurement of ΔA_{CP} between $D^0 \to KK$ and $D^0 \to \pi\pi$
  - Search for CPV in $D^0 \to K_s\pi\pi$
- ΔA_{CP} measurement is 2.7 sigma from zero, and consistent with the LHCb result
- No hints of CPV for $K_s\pi\pi$
- Need to continue improving experimental results and predictions to test SM