CDF results on CP violation in charm

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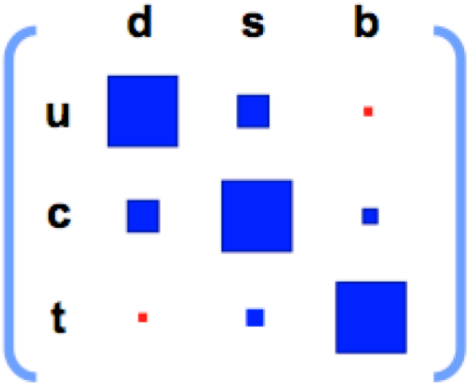
(University of Illinois at Champaign-Urbana)
on behalf of the CDF collaboration

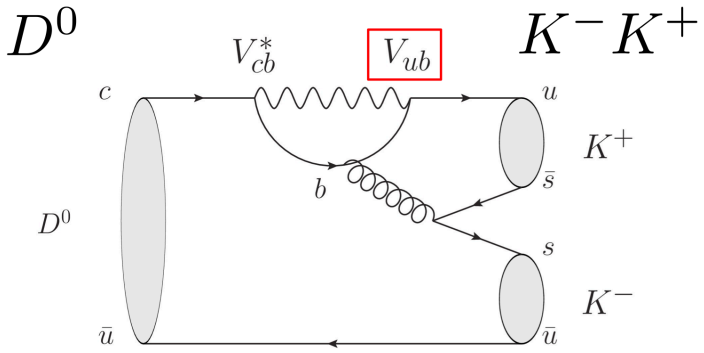
CHARM 2015, Detroit (MI)
05/21/2015

CP Violation in Charm



- Unique probe for physics beyond the SM
  - Probes new physics that couples with up-type quarks

- SM CP violation expected to be small



Suppressed:
- **Small masses of intermediate quarks (GIM)**
- **Small coupling, V_{ub} = O(10^{-3})**

- CPV contributions
  - Decay: $\wp(D^0 \to f) \neq \wp(\bar{D}^0 \to \bar{f})$ Direct CP violation
  - Mixing: $\wp(D^0 \to \bar{D}^0) \neq \wp(\bar{D}^0 \to D^0)$
  - Interference between mixing and decay

} Indirect CP violation

Indirect CPV in $D^0 \to h^+h^-$ decays

- Decays to CP eigenstates can exhibit CPV in mixing or in interference between mixing and decay (indirect CPV)
- Due to the small CPV and charm mixing effects, the rate asymmetry versus decay time can be approximated as

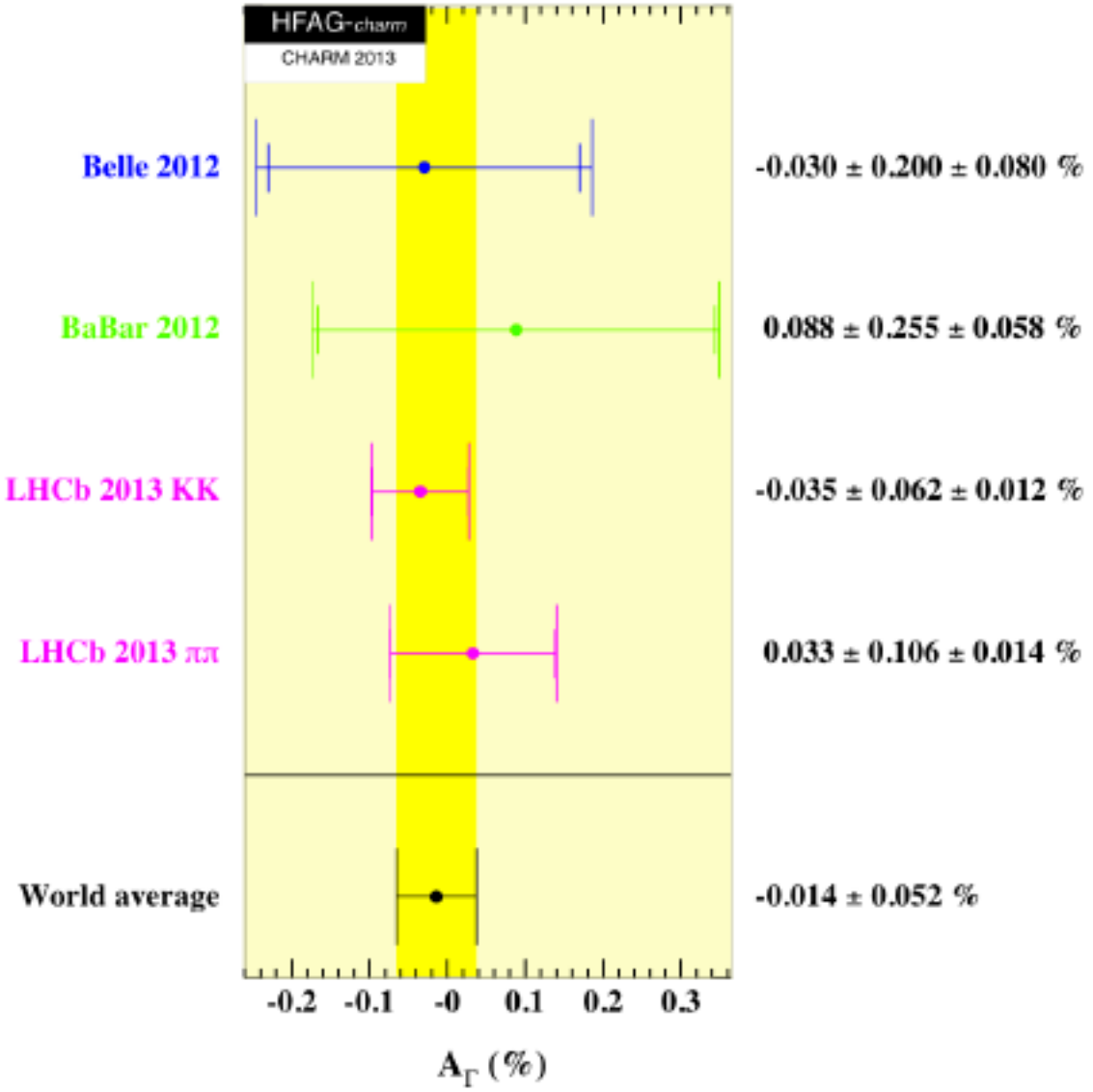
$$A_{CP}(D^0 \to f; t) \approx A_{CP}^{dir}(D^0 \to f) - \frac{t}{\tau} A_\Gamma(D^0 \to f) \quad (x, y \ll \tau/t)$$

$$A_\Gamma = \frac{\hat{\tau}(\bar{D}^0 \to h^+h^-) - \hat{\tau}(D^0 \to h^+h^-)}{\hat{\tau}(\bar{D}^0 \to h^+h^-) + \hat{\tau}(D^0 \to h^+h^-)},$$

Effective-lifetime asymmetry: mostly indirect CPV (J.Phys. G39 (2012) 045005)

An observation of indirect CPV at current experimental sensitivities would indicate contributions from physics beyond the SM

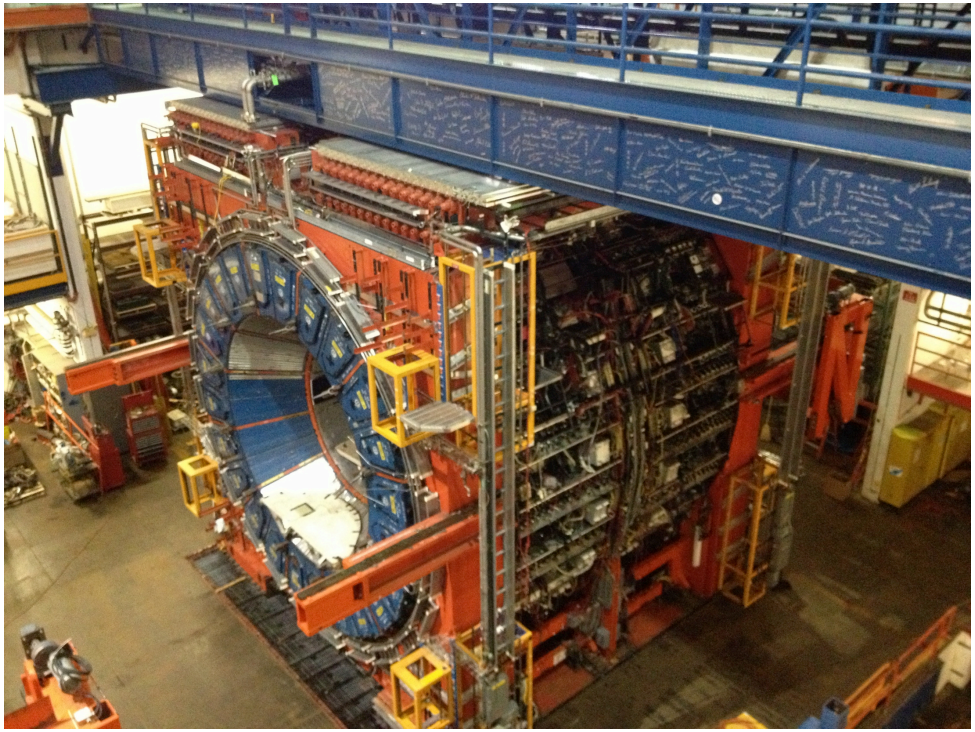
HFAG 2014



No evidence for indirect CPV within 0.05% uncertainty dominated by sample size

CDF in a nutshell

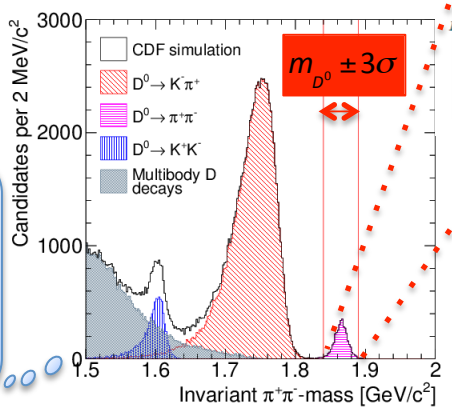
- 10^{14} p-$\bar{p}$ collision at 2 TeV in 10 years
  - Same number of produced mesons and anti-mesons
  - 0.1-1% of collisions produces b-$\bar{b}$ and c-$\bar{c}$ pair, only 0.1-10% on tape
- Final states with charged particles only preferred:
  - Easier to reconstruct
  - Mass discriminates against background
- σ_{IP} ~40 μm, σ_{pT}~0.07%p_T
- Before the beginning of data taking, we did not know we could do charm.
  Charm just did not appear in CDF Run II physics program

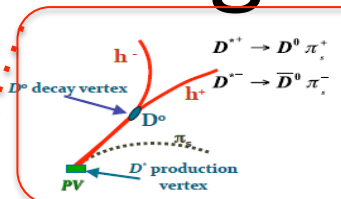


Analysis at a glance

Trigger on displaced tracks

Offline: M(h^+h^-)used to separate $D^0 \rightarrow KK$ and $D^0 \rightarrow \pi\pi$





$D^* \rightarrow D^0 \pi_s$ decays to identify flavor at production time

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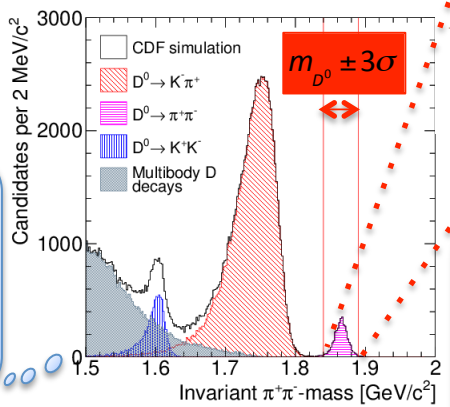

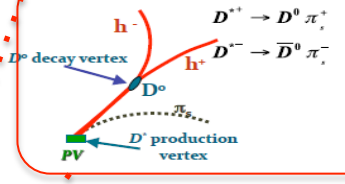

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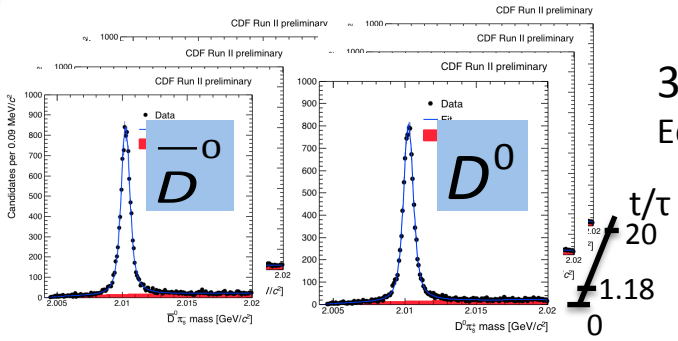

30 t/τ Bins:
Equally populated

$D^0\pi_s$ mass used to separate signal from backgrounds

Analysis at a glance

Trigger on displaced tracks

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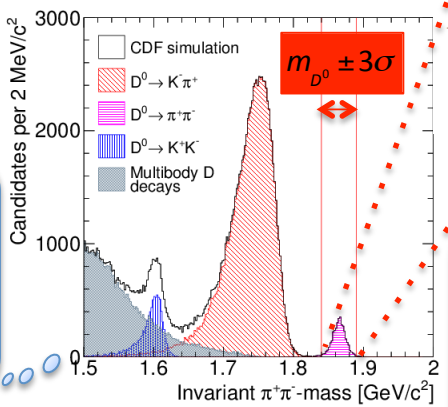

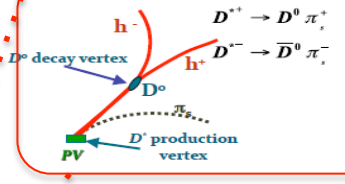

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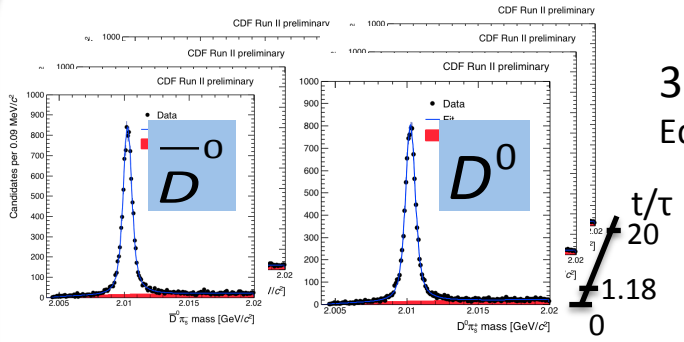

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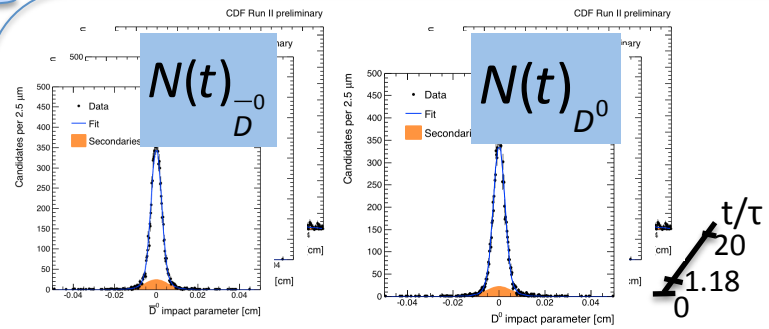

D^0 IP used to separate promptly produced D^* from those originated in B decays

Analysis at a glance

Trigger on displaced tracks

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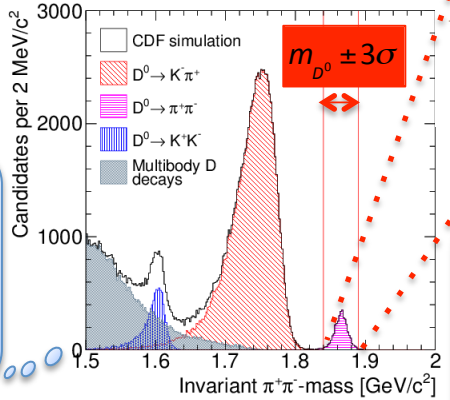
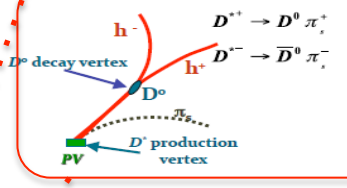
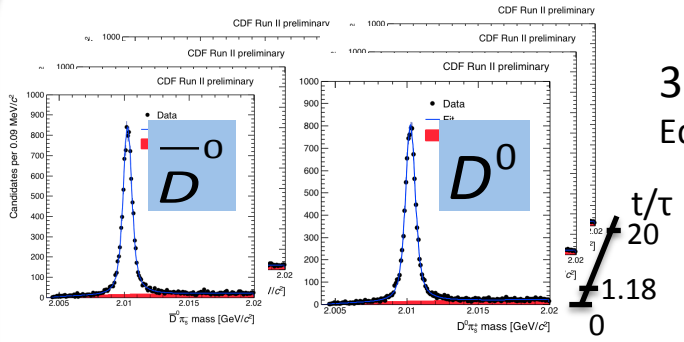




$D^* \to D^0 \pi_s$ decays to identify flavor at production time



30 t/τ Bins:
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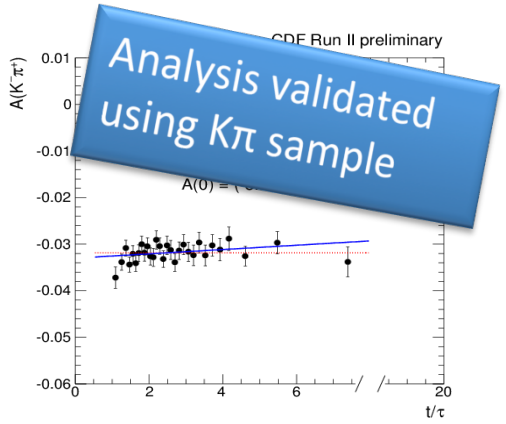
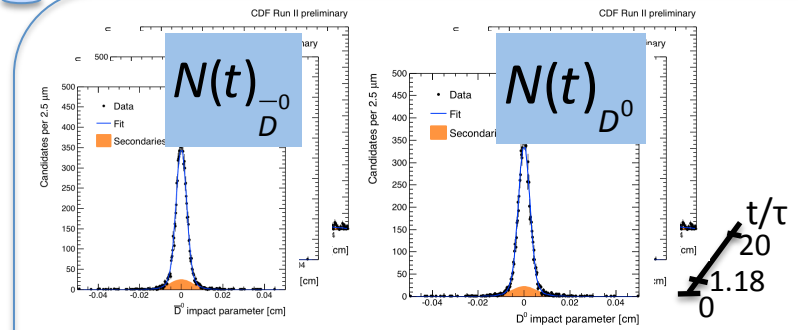
$D^0\pi_s$ mass used to separate signal from backgrounds

Fit asymmetry of prompt signal vs decay time with linear function

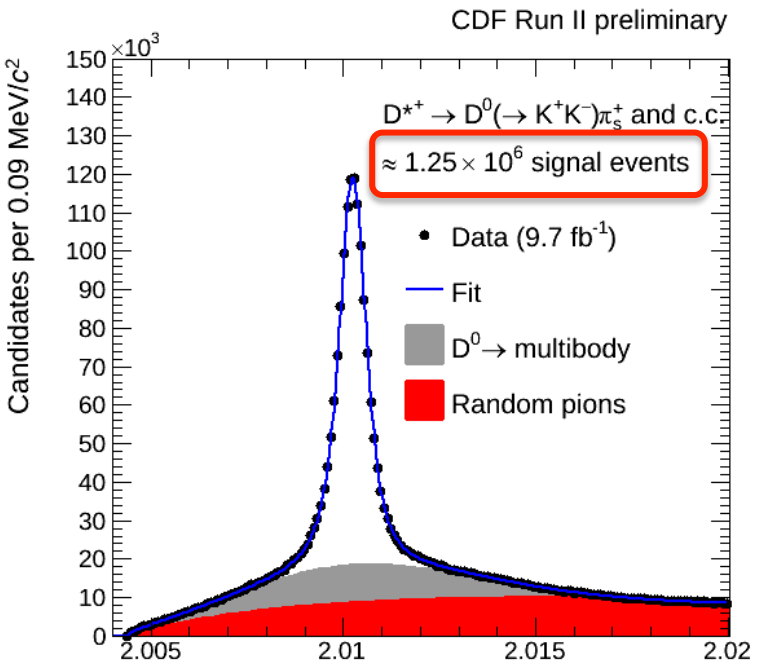


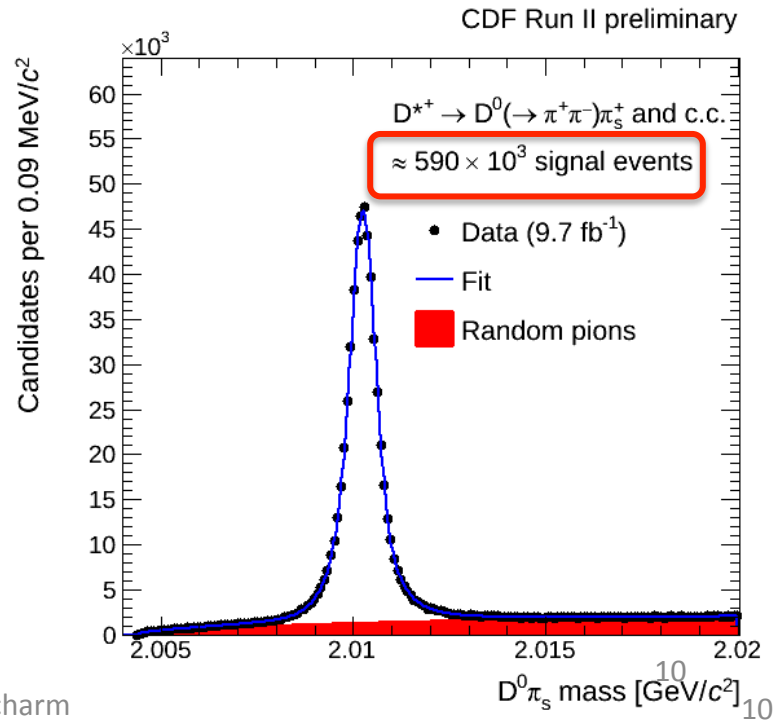


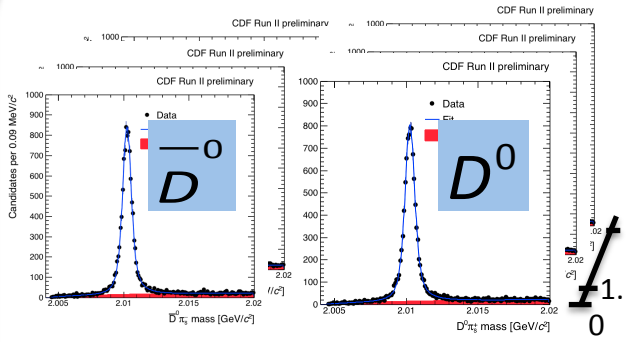
D^0 IP used to separate promptly produced D^* from those originated in B decays

Data Sample

- Full CDF Run II data set: ~9.7 fb^{-1}
- Trigger:
  - Two tracks with IP<100 μm and transverse displacement requirement on h^+h^- candidates
- Offline selection
  - Trigger confirmation + D^* (hence soft pion) beam line constrained
- Backgrounds
  - Random pions (dominates in ππ sample)
  - Multibody mis-reconstructed decays (e.g. $D^0 \to h^-\pi^+\pi^0$) pollutes KK sample.







30 t/τ Bins:
Equally populated

$D^0\pi_s$ mass used to separate signal from backgrounds

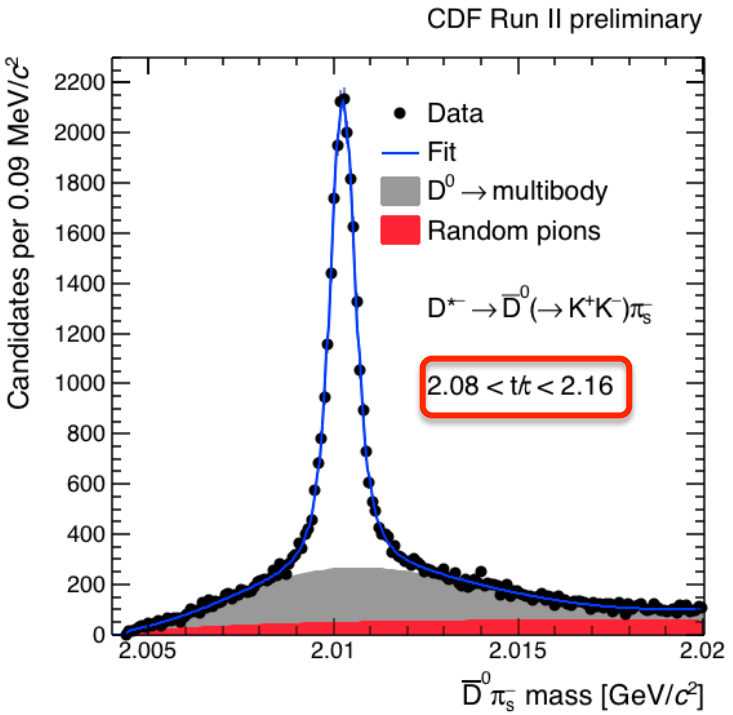
Fit description

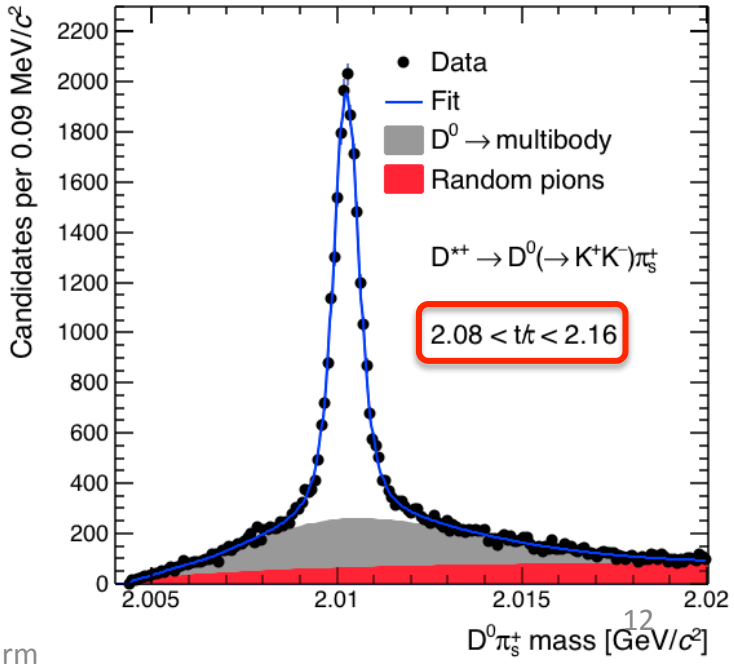
TIME-DEPENDENT MASS FIT

Time-dependent mass Fit

- Total sample split in 30 decay-time bins for D^{*+} and D^{*-} separately

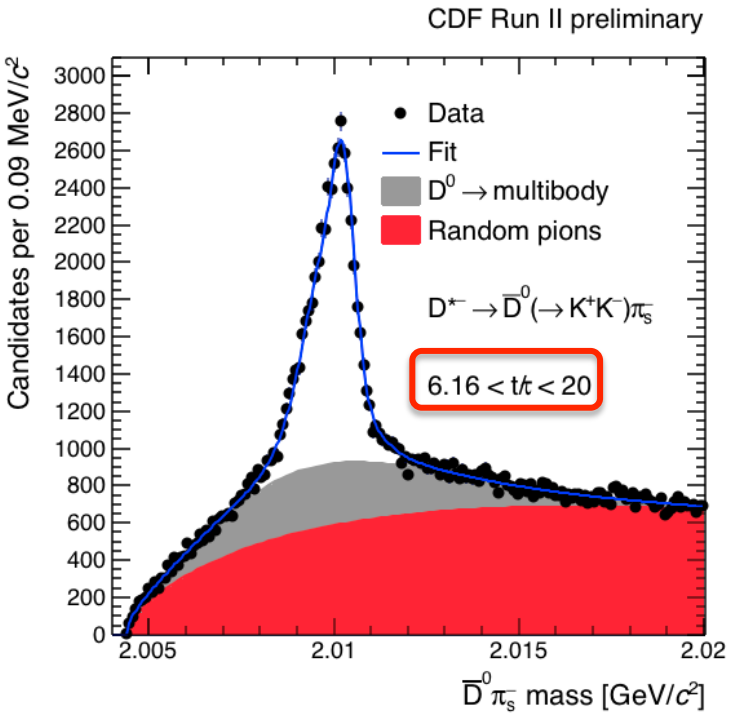
- Independent fits in each time bin
  - Signal shapes fixed to Kπ sample
  - Background free to float

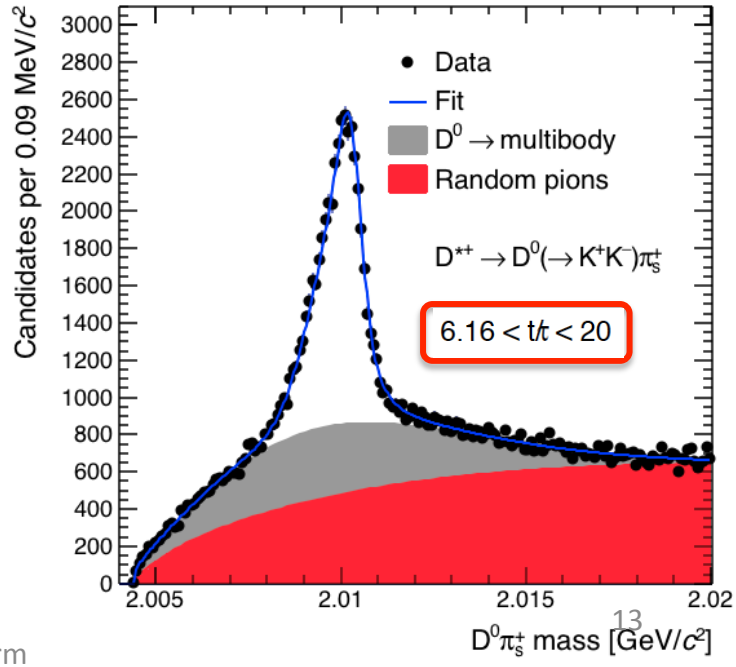


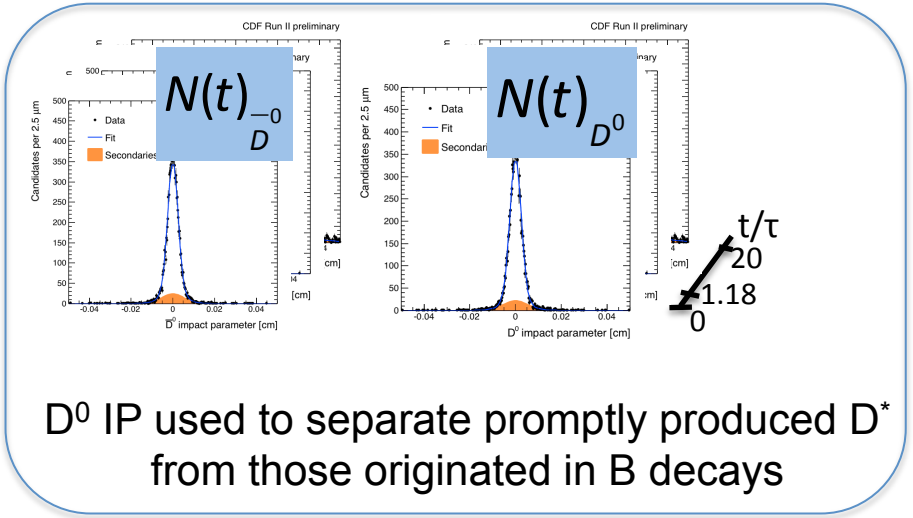


Time-dependent mass Fit

- Total sample split in 30 decay-time bins for D^{*+} and D^{*-} separately
- Independent fits in each time bin
  - Signal shapes fixed to Kπ sample
  - Background free to float
- Time-dependent signal shape due to beam constraint (secondaries contamination)







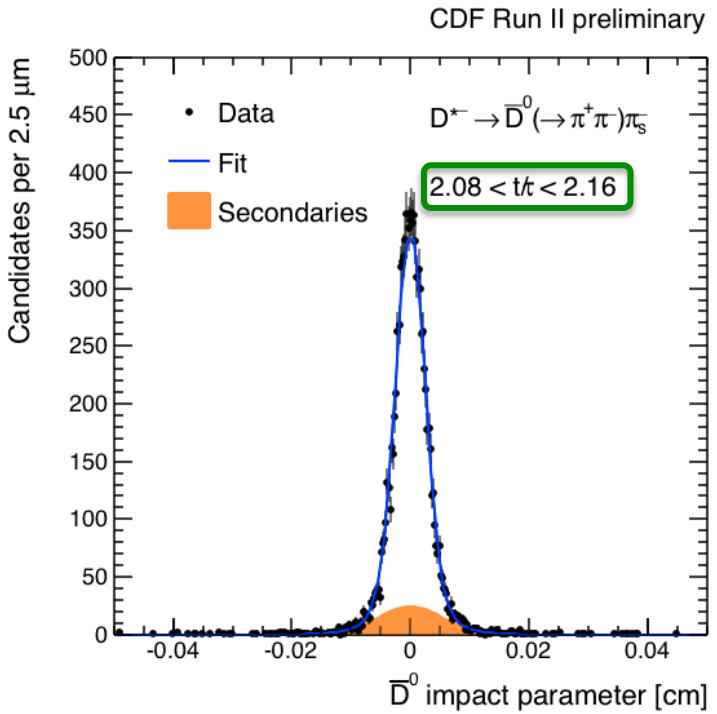
D^0 IP used to separate promptly produced D^* from those originated in B decays

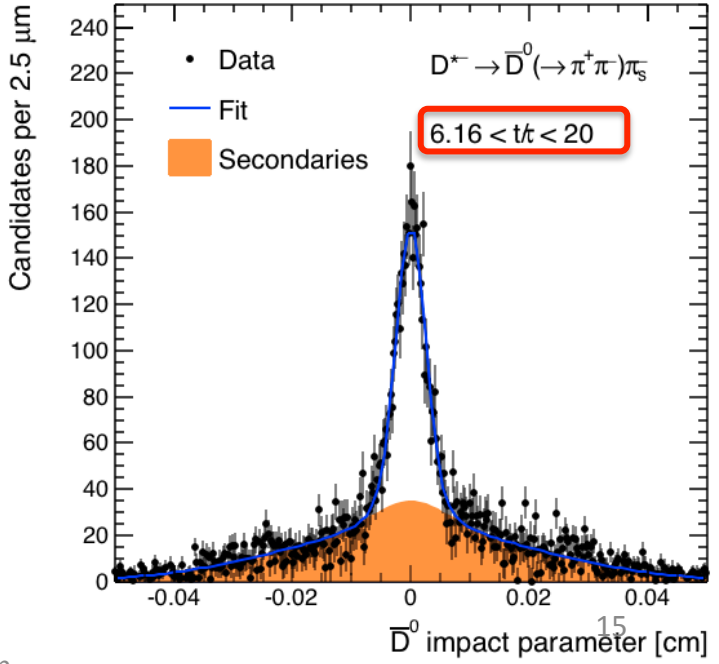
Fit description

TIME-DEPENDENT IP FIT

Time-dependent IP Fit

- Mass fits used to form bkg-subtracted IP distributions in each time-bin
- Prompt shape from first time bin ($t/\tau<1.18$) where bias from B->D is negligible:
  - assumed to be time-independent
- Secondaries shape free to vary in each time bin
- Prompt and secondaries shapes assumed flavor-independent, IP evaluated before reconstructing D^*



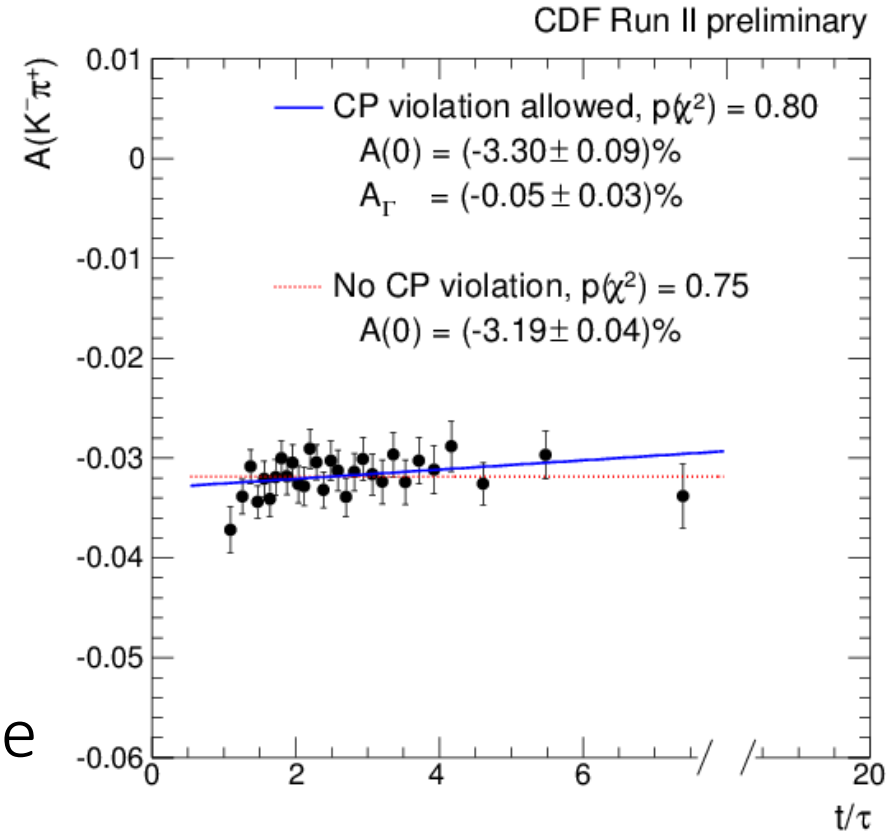


Linear fit to extract A_Γ

- Prompt yields vs t from IP fits used to evaluate the time-dependent asymmetry:

$$A_{CP}(t) = \frac{N(t)_{D^0} - N(t)_{\bar{D}^0}}{N(t)_{D^0} + N(t)_{\bar{D}^0}} \approx A(0) - \frac{t}{\tau} A_\Gamma$$

$A(0) = A_{CP}^{dir} + A_{det}$

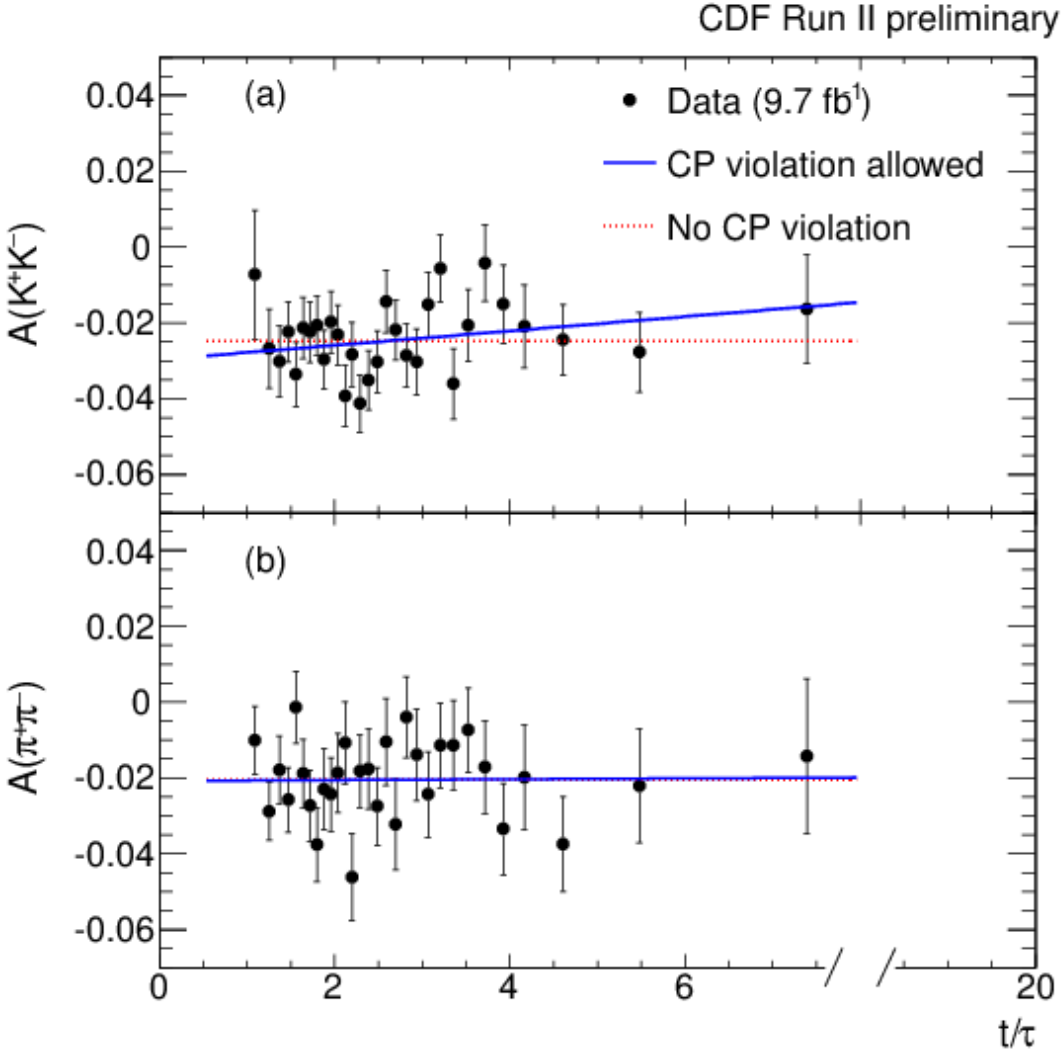


- A_{det} checked to be time-independent using Kπ sample
  - ~-2% offset due to π^+ vs π^- detection asymmetry
  - ~-1% offset due to K^+ vs K^- detection asymmetry

Dominant systematic uncertainties

Source	$\Delta A_\Gamma(\pi^+\pi^-)$	$\Delta A_\Gamma(K^+K^-)$
Background subtraction	0.021%	0.038%
Impact parameter shapes	0.026%	0.010%
Decay-time scale	0.001%	0.003%
Total	0.033%	0.039%

Final results



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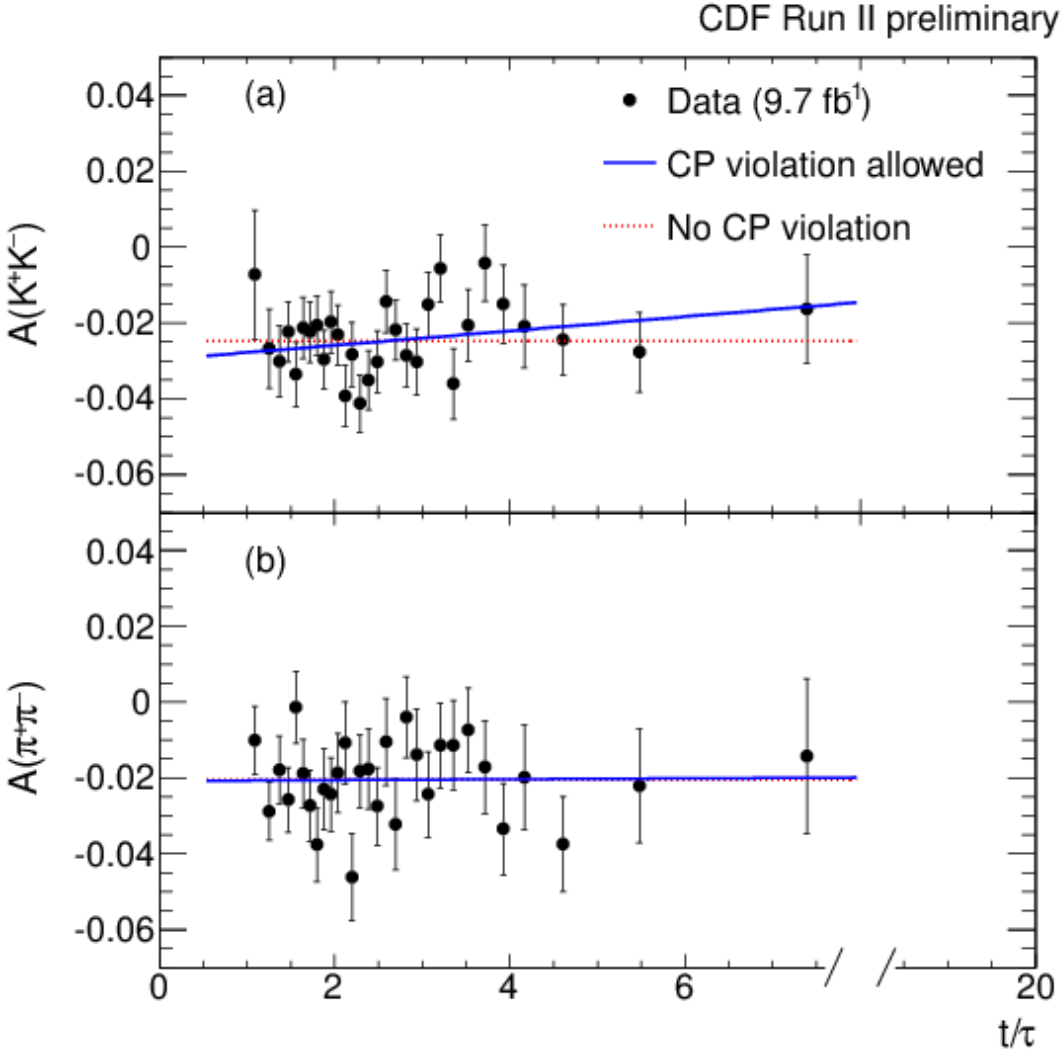


- Compatible with the absence of CP violation
- Consistent with determinations from other experiments
- Among the world's best results

$A_\Gamma(\pi\pi) = (-0.1 \pm 1.8(\text{stat.}) \pm 0.3(\text{syst.})) \times 10^{-3}$

$A_\Gamma(KK) = (-1.9 \pm 1.5(\text{stat.}) \pm 0.4(\text{syst.})) \times 10^{-3}$

$\langle A_\Gamma \rangle = (-1.2 \pm 1.2) \times 10^{-3}$

PRD 90, 111103(R) 2014

A CDF "Charming" history

- The A_Γ measurement is just the latest result of a successful charm program that spans >10 years and established that charm physics is possible in hadron collisions
- Thanks to SVT we find all central tracks with p_T>2GeV/c^2 and determine their displacement
  - Decay-time resolution of 90fs (about 20% of D lifetimes)
- First CDF CP violation measurement in charm 10 years old.

PRL 94, 122001 (2005) PHYSICAL REVIEW LETTERS week ending 1 APRIL 2005

Measurement of Partial Widths and Search for Direct *CP* Violation in D^0 Meson Decays to K^-K^+ and $\pi^-\pi^+$

D. Acosta,[16] T. Affolder,[9] T. Akimoto,[54] M. G. Albrow,[15] D. Ambrose,[43] S. Amerio,[42] D. Amidei,[33] A. Anastassov,[50]

A CDF "Charming" history

- Follow up in 2012 with 5.9 fb^{-1} of CDF data

PHYSICAL REVIEW D 85, 012009 (2012)

Measurement of *CP*-violating asymmetries in $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$ decays at CDF

T. Aaltonen,[21] B. Álvarez González,[9,aa] S. Amerio,[40a] D. Amidei,[32] A. Anastassov,[15,y] A. Annovi,[17] J. Antos,[12]

  - Purely data-based measurement of CP violating asymmetries
  - No input from Monte Carlo, nor assumptions on CP conservation in favored decays

- Results consistent with CP conservation and in agreement with theoretical predictions
  - $A_{CP}(\pi\pi)$= (+0.22±0.24(stat.)±0.11(syst.))%
  - $A_{CP}(KK)$= (-0.24±0.22(stat.)±0.09(syst.))%

Most precise measurement of these quantities at publication time

A CDF "Charming" history

- ΔA_{CP} result at permil level (2012)

PRL 109, 111801 (2012) PHYSICAL REVIEW LETTERS week ending 14 SEPTEMBER 2012

Measurement of the Difference in *CP*-Violating Asymmetries in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ Decays at CDF

T. Aaltonen,[21] B. Álvarez González,[9,aa] S. Amerio,[40a] D. Amidei,[32] A. Anastassov,[15,y] A. Annovi,[17] J. Antos,[12]

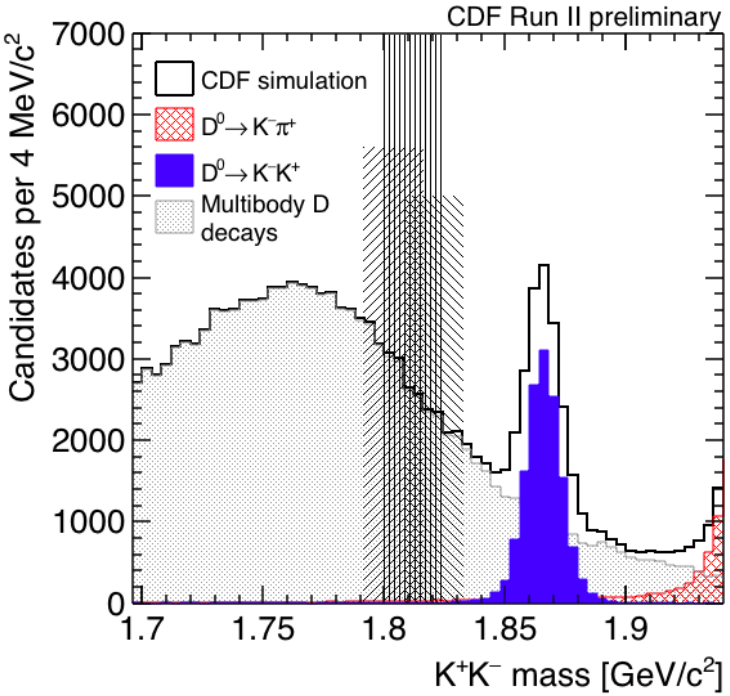
- ΔA_{CP}= (-0.62±0.21(stat.)±0.10(syst.))%
  - Consistent with presence of CP violation
  - Agreement with LHCb determination, PRL 108, 111602 (2012): ΔA_{CP}= (-0.82±0.21(stat.)±0.11(syst.))%

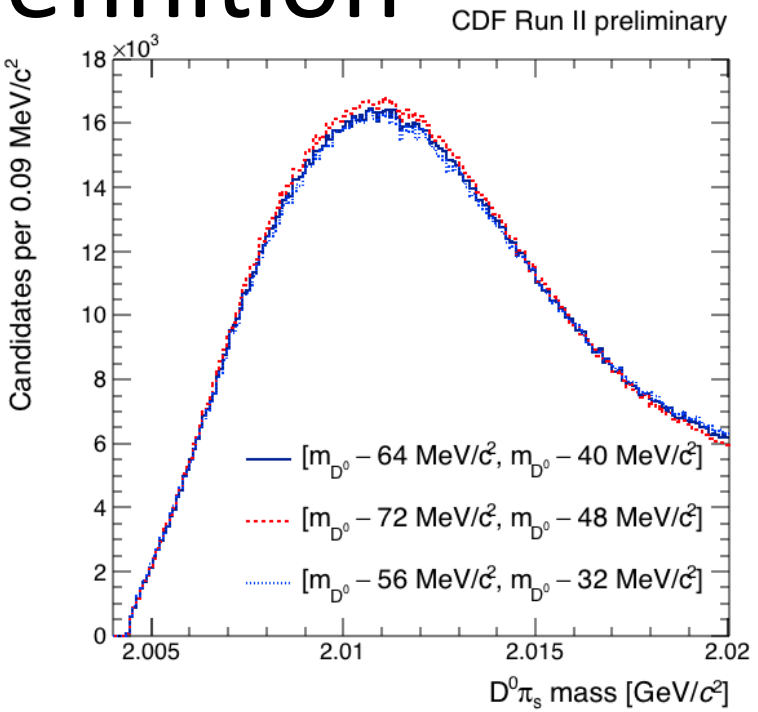
Conclusions

- Today shown a search for indirect CPV in $D^0 \to h^+h^-$ decays
  - No sign of CPV found as expected from SM prediction
  - Results compatible with other experimental determinations
- CDF at the Tevatron established that a successful and competitive charm program can be done in hadron collisions
- Four years after Tevatron shutdown CDF keep contributing with relevant flavor results

Backup

Sideband definition





- $\pi\pi$ sample: sideband at nigh $m(D^0\pi_s)$ to subtract random pion background
  - $2.015 < |M(D^0\pi_s)| < 2.02$ GeV/c^2
- KK sample: sideband at low m(KK) due to the presence of multibody decay bkg
  - $-8\sigma < |M(KK) - m_{D0}| < -5\sigma$ and $|M(D^0\pi_s) - m_{D^*}| < 2.4$ MeV/c^2

Linear fit to extract A_Γ

- Prompt yields vs t from IP fit used to evaluate the time-dependent asymmetry:

$$A_{CP}(t) = \frac{N(t)_{D^0} - N(t)_{\bar{D}^0}}{N(t)_{D^0} + N(t)_{\bar{D}^0}} \approx A(0) - \frac{t}{\tau} A_\Gamma$$

- Random tagged ππ sample (same D^* sample with D^0 flavor randomly assigned) to check against fit bias
  - About 100 randomized samples

No Bias found