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CP-violating triple product asymmetries in Charm decays

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on behalf the LHCb and BaBar Collaborations

Outline

Theoretical Introduction

- *CPV* and *T*-odd correlations

Search at LHCb

- *CPV* search using *T*-odd correlations in $D^0 \rightarrow K^+K^-\pi^+\pi^-$ decays

More observables

- The study of further triple-product correlations has been recently suggested

Search at Babar

- Extraction of TP correlation asymmetries with BaBar data

  $D^0 \rightarrow K^+K^-\pi^+\pi^-$, $D_{(s)}{}^+ \rightarrow K^+K^0{}_S\pi^+\pi^-$

Conclusions

CP Violation in Charm Mesons Decays

Small CKM contribution

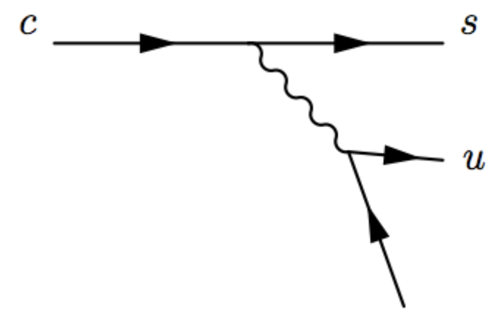
- *CPV* is expected to be small in the charm sector due to small CKM amplitude

New Physics

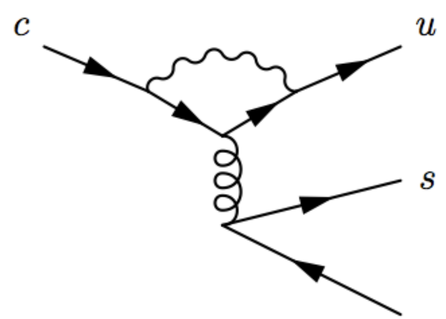
- May enhance this amplitude through the introduction of new processes and particles

Recently

- Mixing in charm is established within SM expectation
- Experiments have recorded enough statistics to probe *CPV* with sensitivities approaching 10^{-3}
- If any NP effect is out there we should start to be able to see it



(a) *Tree diagram.*



(b) *Penguin diagram.*

CP Violation

CPV in decay

$$\mathcal{A}_f \equiv \frac{\Gamma(M^- \to f^-) - \Gamma(M^+ \to f^+)}{\Gamma(M^- \to f^-) + \Gamma(M^+ \to f^+)}$$

- ***CPV*** **is measured as the asymmetry between the decay rate of a meson and charge-conjugate state**

$$\mathcal{A}_{f\pm} = -\frac{2|a_1 a_2|\sin(\delta_2 - \delta_1)\sin(\phi_2 - \phi_1)}{|a_1|^2 + |a_2|^2 + 2|a_1 a_2|\cos(\delta_2 - \delta_1)\cos(\phi_2 - \phi_1)}$$

CPV in mixing

$$\frac{q}{p} \neq 1, \quad \mathcal{A}_{SL}(t) \equiv \frac{d\Gamma/dt(\overline{M}^0_{\rm phys}(t) \to l^+ X) - d\Gamma/dt(M^0_{\rm phys}(t) \to l^- X)}{d\Gamma/dt(\overline{M}^0_{\rm phys}(t) \to l^+ X) + d\Gamma/dt(M^0_{\rm phys}(t) \to l^- X)}$$

- ***CPV*** **measured from the mixing parameters**

$$\mathcal{A}_{SL} = -\left|\frac{\Gamma_{12}}{M_{12}}\right| \sin(\phi_M - \phi_\Gamma)$$

CPV in interference between decay and mixing

$$Im(\lambda_f) \neq 0, \quad \lambda_f \equiv \frac{q}{p}\frac{\overline{A}_f}{A_f}, \quad \mathcal{A}_{f_{CP}}(t) \equiv \frac{d\Gamma/dt(\overline{M}^0_{\rm phys}(t) \to f_{CP}) - d\Gamma/dt(M^0_{\rm phys}(t) \to f_{CP}}{d\Gamma/dt(\overline{M}^0_{\rm phys}(t) \to f_{CP} + d\Gamma/dt(M^0_{\rm phys}(t) \to f_{CP}}$$

- ***CPV*** **asymmetry is modified by mixing effects**

$$\mathcal{A}_{f_{CP}}(t) = \eta_f \sin(\phi_M + 2\phi_f)\sin(\Delta m t)$$

ϕ: weak phases, from CKM
δ: unitarity (strong) phases

T-odd Observables

G. Valencia, Phys. Rev. D39 (1989) 3339

A different point of view

- **Describe invariant matrix element in the most general way (quasi two-body)** $B(p) \to V_1(k,\epsilon_1)V_2(q,\epsilon_2)$

$$M = a\epsilon_1 \cdot \epsilon_2 + \frac{b}{m_1 m_2}(p\cdot\epsilon_1)(p\cdot\epsilon_2) + i\frac{c}{m_1 m_2}\epsilon^{\alpha\beta\mu\nu}\epsilon_{1\alpha}\epsilon_{2\beta}k_\mu p_\nu$$

S+D+P

$$a = \sum_j |a_j|e^{i(\delta_{sj}+\phi_{sj})};\quad b = \sum_j |b_j|e^{i(\delta_{dj}+\phi_{dj})};\quad c = \sum_j |c_j|e^{i(\delta_{pj}+\phi_{pj})}$$

$$\bar{a} = \sum_j |a_j|e^{i(\delta_{sj}-\phi_{sj})};\quad \bar{b} = \sum_j |b_j|e^{i(\delta_{dj}-\phi_{dj})};\quad \bar{c} = \sum_j |c_j|e^{i(\delta_{pj}-\phi_{pj})}$$

- **A triple-product correlation arises in $|M|^2$ from terms involving the *c* amplitude (Im[ac*], Im[bc*]) wrt $\vec{k}\cdot(\vec{\epsilon}_1\times\vec{\epsilon}_2)$**

$$A_B = \frac{\Gamma(k\cdot\epsilon_1\times\epsilon_2>0)-\Gamma(k\cdot\epsilon_1\times\epsilon_2<0)}{N_B}$$
$$\approx \Im(ac^*) = |ac|e^{i(\delta_s-\delta_p)}e^{i(\phi_s-\phi_p)} = |ac|\sin(\Delta\delta+\Delta\phi)$$

- **The same observable on the charge-conjugate decay gives**

$$A_{\bar{B}} \approx |ac|e^{i(\delta_s-\delta_p)}e^{-i(\phi_s-\phi_p)} = |ac|\sin(\Delta\delta-\Delta\phi)$$

- **That allows the definition of the *CPV* observable**

$$a_{CP}^{T-\text{odd}} = A_B + A_{\bar{B}} \approx \cos\Delta\delta\sin\Delta\phi$$

Comparison to Direct CPV

A. Datta and D. London, Int.J.Mod.Phys. A19 (2004) 2505

They are complementary

- The only difference is in the unitarity phases that enter differently in the game

$$a_{CP} \propto \sin\Delta\delta \sin\Delta\phi$$
$$a_{CP}^{T-\mathrm{odd}} \propto \cos\Delta\delta \sin\Delta\phi$$

(*)

- a_{CP} is more sensitive to *CPV* when the difference in the strong phases is large
- $a_{CP}^{T\text{-odd}}$ is more sensitive to *CPV* when the difference in the strong phases between the interfering amplitudes is small
- Datta and London demonstrated that a TP asymmetry can be also built with interference between decay and mixing, but it is proportional to $\sin\Delta\delta$ as well.

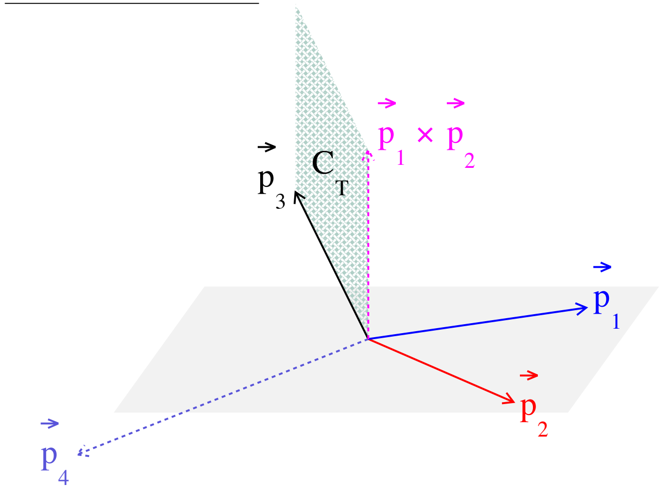
(*) **Caveat**: in a_{CP} the two phases are from different diagrams, in a_{CP}^{Todd} from different spin contributions

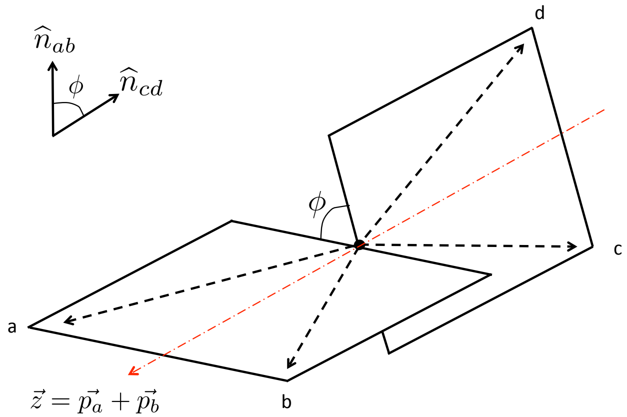
Experimental Technique

Defining a T-odd observable

- One needs at least 3 independent momentum or spin variables

4-body decay





$$C_T = (\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_3$$

$$\sin\phi = (\hat{n}_{ab} \times \hat{n}_{cd}) \cdot \hat{z}$$

- Momenta can be also used to define angles

T-odd Correlation Asymmetry

Asymmetries

- Two asymmetries are measured separately on the particle and charge-conjugate decays

$$A_T = \frac{\Gamma(C_T > 0) - \Gamma(C_T < 0)}{\Gamma}$$

$$\bar{A}_T = \frac{\bar{\Gamma}(-\overline{C}_T > 0) - \bar{\Gamma}(-\overline{C}_T < 0)}{\bar{\Gamma}}$$

- The *CP*-violating asymmetry is

$$a_{CP}^{T-\mathrm{odd}} = \frac{1}{2}(A_T - \bar{A}_T)$$

Charm Mesons Decays

Four-body decays

- So far: $D^0 \to K^+K^-\pi^+\pi^-$, $D^+ \to K^+K^0_S\pi^+\pi^-$, $D_s^+ \to K^+K^0_S\pi^+\pi^-$

T-odd observable

- $C_T = \vec{p}(K^+) \cdot \vec{p}(\pi^+) \times \vec{p}(\pi^-)$

Analysis

- Spilt data sample in 4 depending on D^0 flavour and C_T sign
- Extract the number of signal events for each sample
- Calculate the asymmetry

$$a_{CP}^{T-\mathrm{odd}} = \frac{1}{2}(A_T - \bar{A}_T)$$

Results From Previous Experiments

Used prompt D^0 and $D_{(s)}^+$ decays

- **FOCUS (2005) N_{ev}~1k**

Link et al., Phys. Lett. B662 (2005)239

$$a_{CP}^{T-\mathrm{odd}}(D^0) = (1.0 \pm 5.7(\mathrm{stat}) \pm 3.7(\mathrm{syst}))\%$$

$$a_{CP}^{T-\mathrm{odd}}(D^+) = (2.3 \pm 6.2(\mathrm{stat}) \pm 2.2(\mathrm{syst}))\%$$

$$a_{CP}^{T-\mathrm{odd}}(D_s^+) = (-3.6 \pm 6.7(\mathrm{stat}) \pm 2.3(\mathrm{syst}))\%$$

- **BaBar (2010-2011) N_{ev}~50k**

del Amo Sanchez et al., Phys. Rev. D81 (2010) 111103(R)
Lees et al., Phys. Rev. D84 (2011) 031103(R)

$$a_{CP}^{T-\mathrm{odd}}(D^0) = (1.0 \pm 5.1(\mathrm{stat}) \pm 4.4(\mathrm{syst})) \times 10^{-3}$$

$$a_{CP}^{T-\mathrm{odd}}(D^+) = (-12.0 \pm 10.0(\mathrm{stat}) \pm 4.6(\mathrm{syst})) \times 10^{-3}$$

$$a_{CP}^{T-\mathrm{odd}}(D_s^+) = (-13.6 \pm 7.7(\mathrm{stat}) \pm 3.4(\mathrm{syst})) \times 10^{-3}$$

- **BaBar provided significant statistical improvement (x10)**

Results From LHCb - $D^0 \to K^+K^-\pi^+\pi^-$

hep-ex/1408.1299, submitted to JHEP

Semileptonic B decay

- $D^0 \to K^+K^-\pi^+\pi^-$ from semileptonic B decays, tagged from muon charge
  $B \to D^0\mu^- X$, $D^0 \to K^+K^-\pi^+\pi^-$
- Clean sample

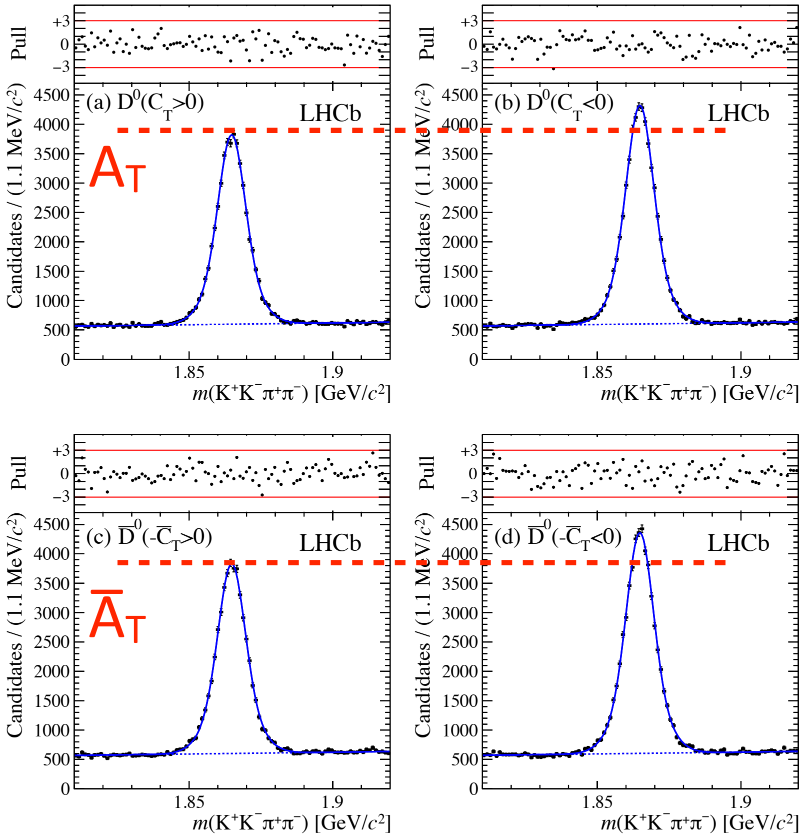
Data Sample

- 2011+2012: $3fb^{-1}$

Fit Model

- Samples simultaneously fit to a model of two Gaussian distributions over an exponential shape
- Asymmetry parameters extracted from the fit

$B \to D^0\mu^- X$, $D^0 \to K^+K^-\pi^+\pi^-$



$3fb^{-1}$: N_{ev}~170k

Results From LHCb

hep-ex/1408.1299, submitted to JHEP

Three Measurements

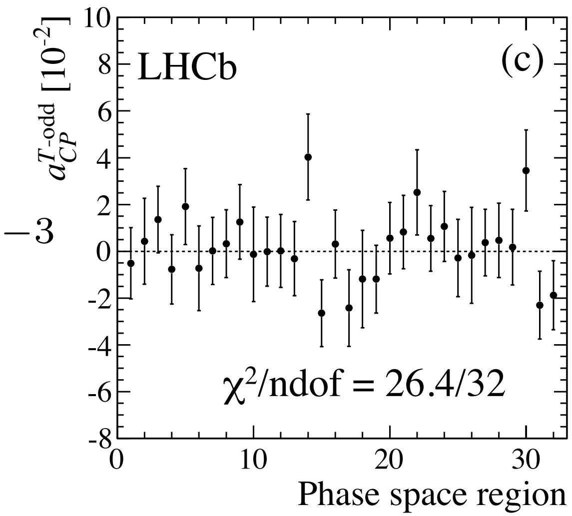
1. **Integrated**

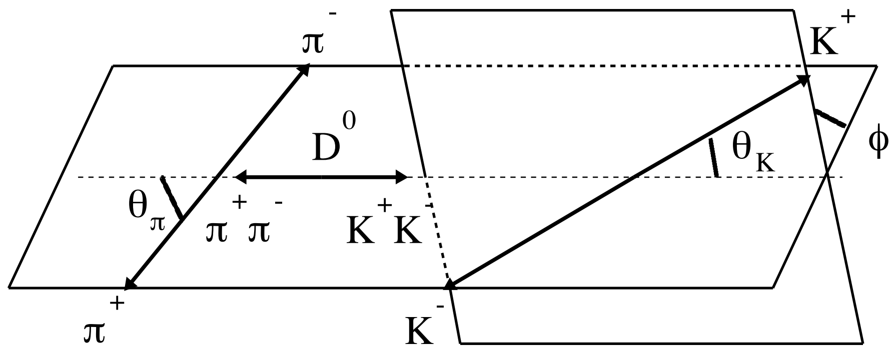
$$a_{CP}^{T-\mathrm{odd}}(D^0) = (1.8 \pm 2.9(\mathrm{stat}) \pm 0.4(\mathrm{syst})) \times 10^{-3}$$

2. **Bins of phase-space**

   No significant deviation from 0 observed

   CP conservation tested with $P(\chi^2)$=74%

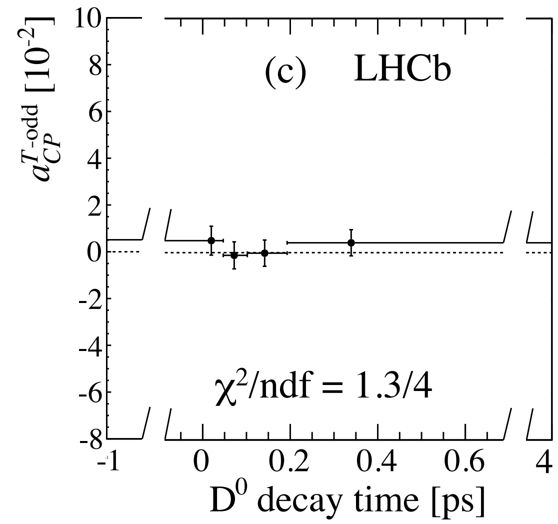




3. **Bins of proper time**

   No significant deviation from 0 observed

   CP conservation tested with $P(\chi^2)$=83%



Results From LHCb - A_T and $\bar{A}_T$

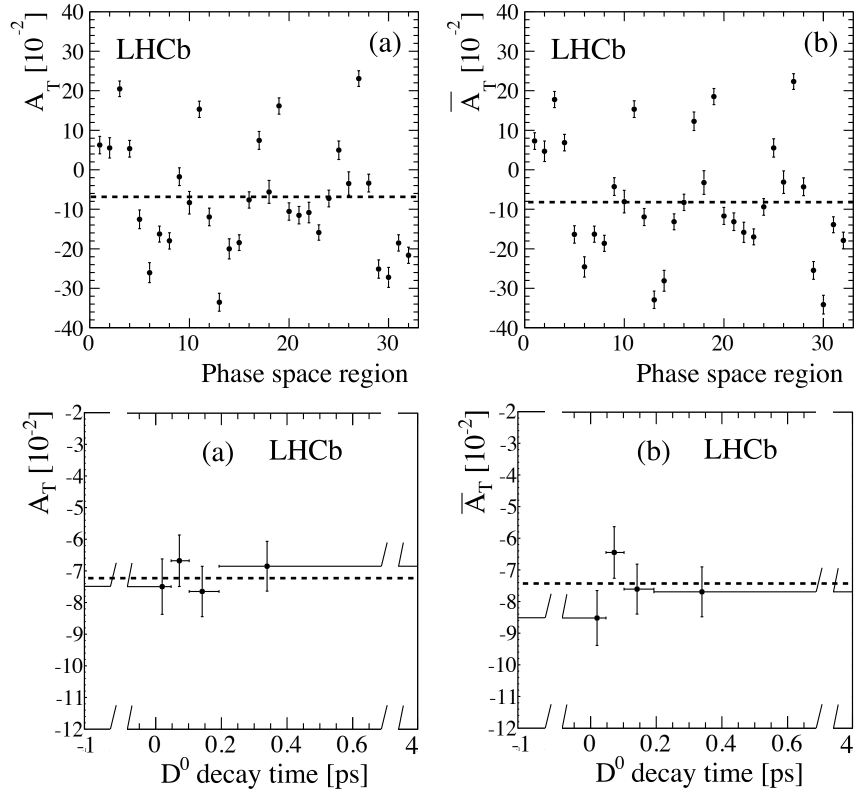
hep-ex/1408.1299, submitted to JHEP

$B \to D^0 \mu^- X,\ D^0 \to K^+ K^- \pi^+ \pi^-$

Local asymmetries up to 30%

FSI Effects?

- It's possible that FSI are producing effects in all the three measurements
- Significant differences in bins of phase space
- Average consistent wrt D^0 decay time
- Wide spectrum of resonances and rescattering among the final state particles



$$A_T(D^0) = (-71.8 \pm 4.1(\text{stat}) \pm 1.3(\text{syst})) \times 10^{-3}$$

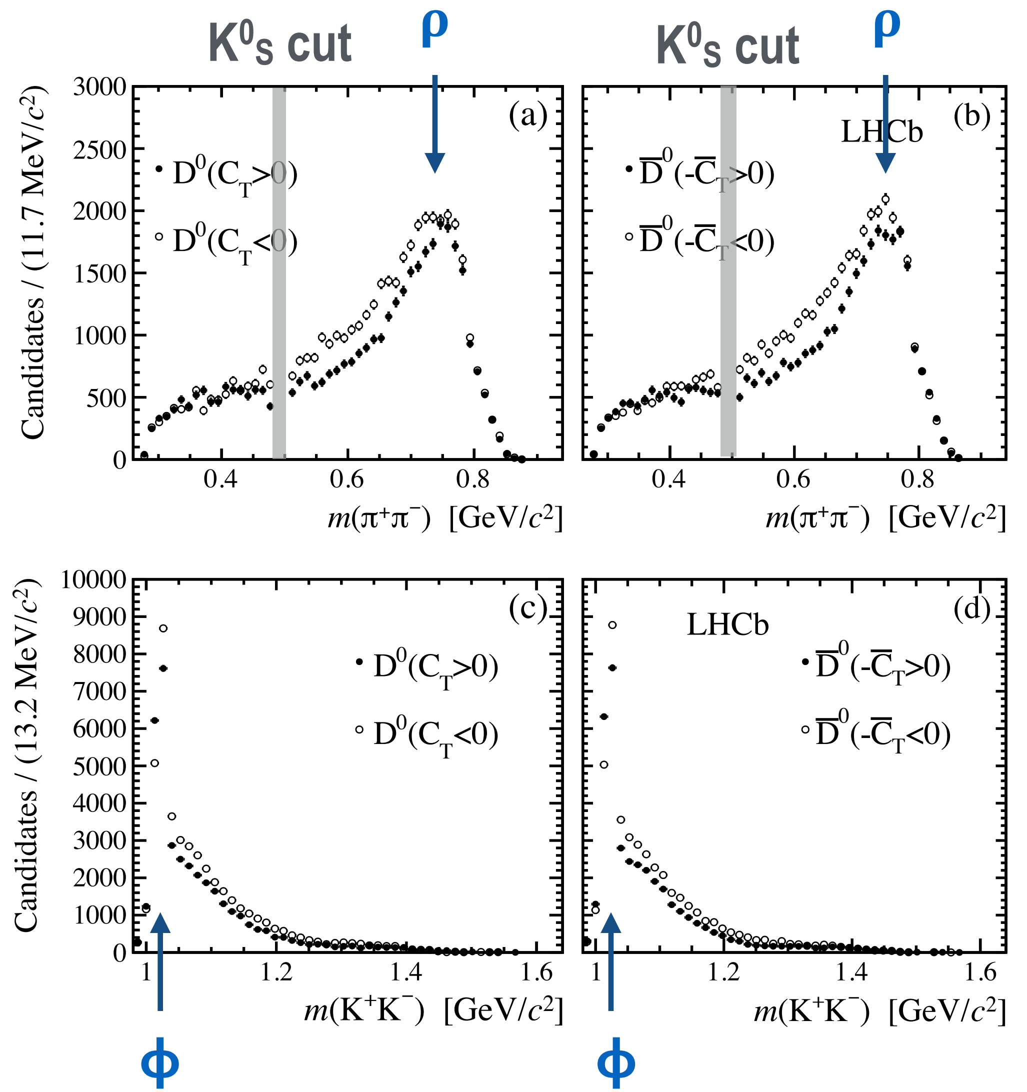
$$\bar{A}_T(D^0) = (-75.5 \pm 4.1(\text{stat}) \pm 1.2(\text{syst})) \times 10^{-3}$$

A Rich Resonant Structure

hep-ex/1408.1299, submitted to JHEP

Resonant structure in $D^0 \to K^+K^-\pi^+\pi^-$

- Clear evidence for φ and ρ resonances
- Significant difference in the distributions vs C_T
- Visible effects in angular variables as well
- $D^0 \to K^0_S K^+K^-$ removed by $\pi^+\pi^-$ invariant mass cut



An Almost Systematic Free Measurement

hep-ex/1408.1299, submitted to JHEP

Reconstruction Efficiency ☺

- Does not affect at all the result: A_T and $\bar{A}_T$ asymmetries are calculated separately on the same final state

Particle Identification ☺

- The same considerations apply to particle identification

Systematic uncertainty estimates

Contribution	$\Delta A_T(\%)$	$\Delta \bar{A}_T(\%)$	$\Delta a_{CP}^{T\text{-odd}}(\%)$
Prompt background	±0.09	±0.08	±0.00
Detector bias	±0.04	±0.04	±0.04
C_T resolution	±0.02	±0.03	±0.01
Fit Model	±0.01	±0.01	±0.01
Flavor misidentification	±0.08	±0.07	±0.00
Total	±0.13	±0.12	±0.04

C_T Resolution ✌

- Estimated accurately from Monte Carlo, almost cancels in a_{CP}^{Todd}

Peaking Backgrounds under $D^0/\bar{D}^0$ signal ✌

- Any contamination affects the asymmetry as $A \to A(1 - f) + f A^d$ ← very small effect
  f - contamination fraction; A^d - asymmetry of the contamination sample

Flavour Mistag ✌

- Considering the events with flavour mistag as a contamination $a_{CP}^{T\text{-odd}} \to a_{CP}^{T\text{-odd}} - \Delta\omega/2(A_T+\bar{A}_T)$
  $\Delta\omega = \omega^+ - \omega^-$ — difference among the mistag probabilities, measured from control samples
  $B \to D^{*+}\mu^- X$, ($D^{*+} \to D^0\pi^+$, $D^0 \to K^+K^-\pi^+\pi^-$); $B \to D^0\mu^- X$ ($D^0 \to K^-\pi^+\pi^+\pi^-$)

Detector bias ✌

- Conservative estimate from control sample of CF $D^0 \to K^-\pi^+\pi^+\pi^-$

LHCb Summary

hep-ex/1408.1299, submitted to JHEP

Three approaches

- ***CPV* is searched for in $D^0 \to K^+K^-\pi^+\pi^-$ using:**
  1. A measurement integrated over the phase space
  2. Measurements in different regions of the phase space
  3. Measurements as a function of the D^0 decay time

Results

- **No *CPV* found**
- **Nevertheless, a lot of interesting information in the phase space of the decay, with local A_T asymmetries up to 30%**
  These results are interpreted as possible effects of FSI produced by the rich resonant structure of the decay
- **a_{CP}^{Todd} measured for the first time in bins of D^0 decay time**

Remarks

- **Systematic uncertainties are found to be very small (as expected) in these observables**
  High statistics control samples, toy studies

More Asymmetries

A. Bevan, hep-ph/1408.3813

Theoretical reinterpretation

- **A recent paper by A. Bevan reinterprets the asymmetries outlined before and suggests describing them as *C*, *P*, and *CP* asymmetries**
- **A_T interpreted as a *P*-odd (A_P) rather than *T*-odd observable since time-reversal test is not possible**

$$P(C_T) = P(\vec{p}_{K^+} \cdot \vec{p}_{\pi^+} \times \vec{p}_{\pi^-}) = -\vec{p}_{K^+} \cdot \vec{p}_{\pi^+} \times \vec{p}_{\pi^-} = -C_T$$

- **Assuming**

$$\Gamma_+ = \Gamma(C_T > 0) \qquad \bar{\Gamma}_+ = \bar{\Gamma}(\overline{C}_T > 0)$$
$$\Gamma_- = \Gamma(C_T < 0) \qquad \bar{\Gamma}_- = \bar{\Gamma}(\overline{C}_T < 0)$$

- **One gets**

$$A_P = \frac{\Gamma_+ - \Gamma_-}{\Gamma_+ + \Gamma_-}; \quad \bar{A}_P = \frac{\bar{\Gamma}_+ - \bar{\Gamma}_-}{\bar{\Gamma}_+ + \bar{\Gamma}_-}$$

- **Considering that $C(A_P) = \bar{A}_P$ and $CP(A_P) = -\bar{A}_P$ the following asymmetries testing *C* and *CP* can be extracted**

$$a_C^P = \frac{1}{2}\left(A_P - \bar{A}_P\right) \qquad a_{CP}^P = \frac{1}{2}\left(A_P + \bar{A}_P\right) = a_{CP}^{T-\mathrm{odd}}$$

More Asymmetries (cont.)

A. Bevan, hep-ph/1408.3813

Same exercise for C operator

- One observes that $C(C_T) = \bar{C}_T$

$$C(C_T) = C(\vec{p}_{K^+} \cdot \vec{p}_{\pi^+} \times \vec{p}_{\pi^-}) = \vec{p}_{K^-} \cdot \vec{p}_{\pi^-} \times \vec{p}_{\pi^+} = \bar{C}_T$$

$$A_C = \frac{\bar{\Gamma}_- - \Gamma_-}{\bar{\Gamma}_- + \Gamma_-}; \quad \bar{A}_C = \frac{\bar{\Gamma}_+ - \Gamma_+}{\bar{\Gamma}_+ + \Gamma_-}$$

$P(A_C)=\bar{A}_C$

$$a_P^C = \frac{1}{2}(A_C - \bar{A}_C) \qquad a_{CP}^C = \frac{1}{2}(A_C + \bar{A}_C)$$

$CP(A_C)=-\bar{A}_C$

…and for *CP*

$$CP(C_T) = CP(\vec{p}_{K^+} \cdot \vec{p}_{\pi^+} \times \vec{p}_{\pi^-}) = -\vec{p}_{K^-} \cdot \vec{p}_{\pi^-} \times \vec{p}_{\pi^+} = -\bar{C}_T$$

$$A_{CP} = \frac{\bar{\Gamma}_+ - \Gamma_-}{\bar{\Gamma}_+ + \Gamma_-}; \quad \bar{A}_{CP} = \frac{\bar{\Gamma}_- - \Gamma_+}{\bar{\Gamma}_- + \Gamma_+}$$

$P(A_{CP})=\bar{A}_{CP}$

$$a_P^{CP} = \frac{1}{2}(A_{CP} - \bar{A}_{CP}) \qquad a_C^{CP} = \frac{1}{2}(A_{CP} + \bar{A}_{CP})$$

$C(A_{CP})=-\bar{A}_{CP}$

Reanalysis of BaBar data

Extraction of the asymmetries

- BaBar data from $D^0 \rightarrow K^+K^-\pi^+\pi^-$, $D_{(s)}^+ \rightarrow K^0_S K^+\pi^+\pi^-$ used to extract all the asymmetries

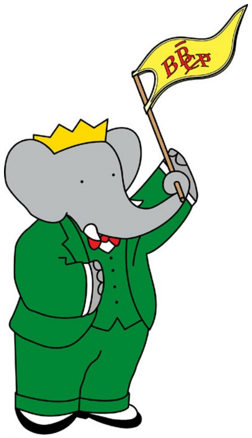
del Amo Sanchez et al., Phys. Rev. D81 (2010) 111103(R)
Lees et al., Phys. Rev. D84 (2011) 031103(R)

- A_T and $\bar{A}_T$ translated to yields

$$\Gamma_+ = N_{D^0}\left(1 + A_P\right) \qquad \bar{\Gamma}_+ = N_{\bar{D}^0}\left(1 - \bar{A}_P\right)$$

$$\Gamma_- = N_{D^0}\left(1 - A_P\right) \qquad \bar{\Gamma}_- = N_{\bar{D}^0}\left(1 + \bar{A}_P\right)$$

- Systematic uncertainties propagated by assuming them to be Gaussian-distributed



Original Analysis of BaBar $D^0 \to K^+K^-\pi^+\pi^-$

The 2010 analysis

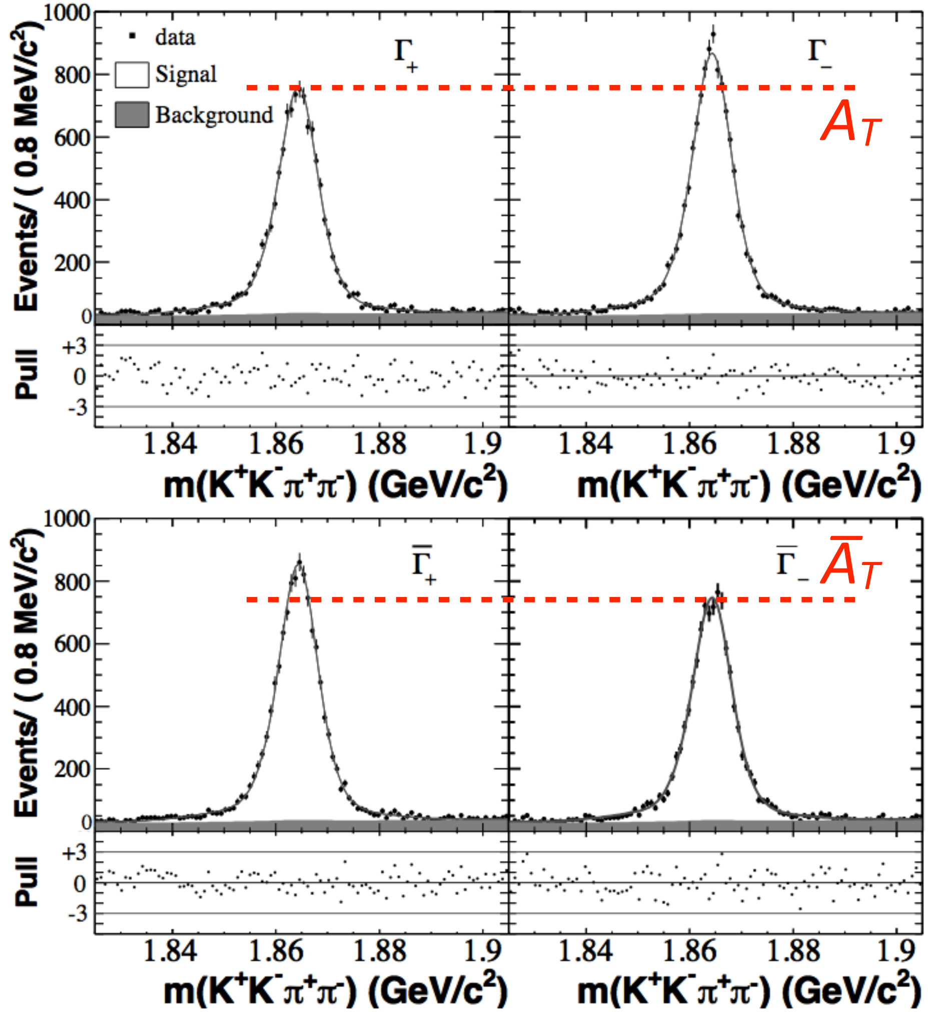
del Amo Sanchez et al., Phys. Rev. D81 (2010) 111103(R)

- Prompt $D^{*+} \to D^0\pi^+$ decays
- 2D fit to $m(K^+K^-\pi^+\pi^-)$ and $\Delta m = m(K^+K^-\pi^+\pi^-\pi_s^+) - m(K^+K^-\pi^+\pi^-)$
- N_{ev} = 47k
- Most important systematic uncertainties from particle identification and selection criteria in general
- Asymmetries:

$$A_T(D^0) = (-68.5 \pm 7.3_{\rm stat} \pm 5.8_{\rm syst}) \times 10^{-3}$$

$$\bar{A}_T(\bar{D}^0) = (-70.5 \pm 7.3_{\rm stat} \pm 3.9_{\rm syst}) \times 10^{-3}$$

$$a_{CP}^{T-{\rm odd}}(D^0) = (1.0 \pm 5.1_{\rm stat} \pm 4.4_{\rm syst}) \times 10^{-3}$$



Analysis of BaBar $D_{(s)}^{+} \rightarrow K^0_S K^+ \pi^+ \pi^-$

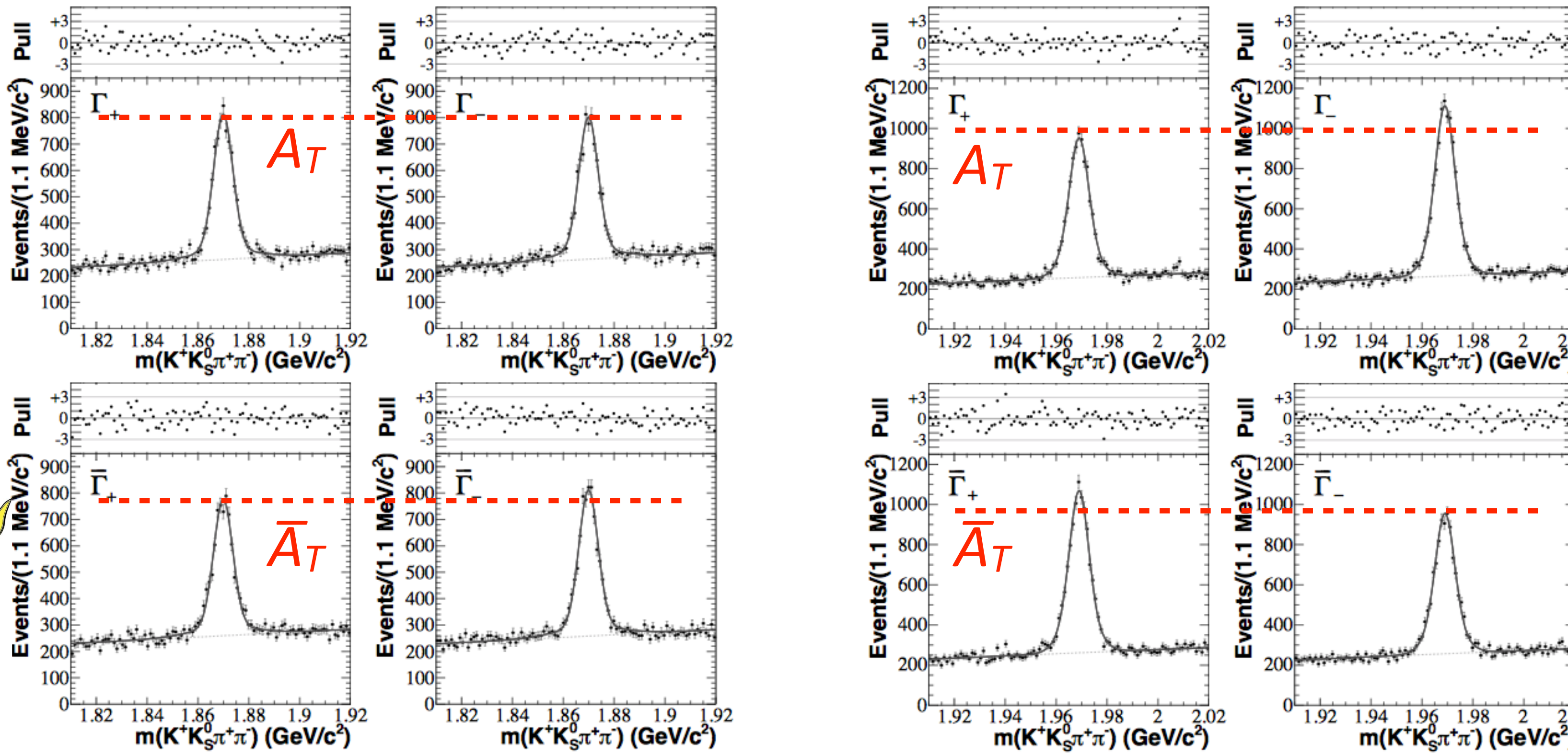
Lees et al., Phys. Rev. D84 (2011) 031103(R)

Original analysis

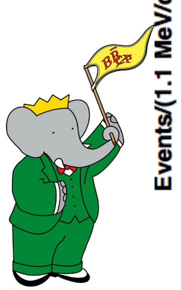
- About 20(30)k $D_{(s)}^{+}$ decays reconstructed
- One-dimensional fit
- Main systematics from PID and selection criteria

$$A_T(D^+) = (+11.2 \pm 14.1_{\rm stat} \pm 5.7_{\rm syst}) \times 10^{-3}$$
$$\bar{A}_T(D^-) = (+35.1 \pm 14.3_{\rm stat} \pm 7.2_{\rm syst}) \times 10^{-3}$$
$$A_T(D_s^+) = (-99.2 \pm 10.7_{\rm stat} \pm 8.3_{\rm syst}) \times 10^{-3}$$
$$\bar{A}_T(D_s^-) = (-72.1 \pm 10.9_{\rm stat} \pm 10.7_{\rm syst}) \times 10^{-3}$$
$$a_{CP}^{T-{\rm odd}}(D^+) = (-12.0 \pm 10.0_{\rm stat} \pm 4.6_{\rm syst}) \times 10^{-3}$$
$$a_{CP}^{T-{\rm odd}}(D_s^+) = (-13.6 \pm 7.7_{\rm stat} \pm 3.4_{\rm syst}) \times 10^{-3}$$

D^+



D_s^+



Event Rates and Systematic Uncertainties

BaBar Preliminary

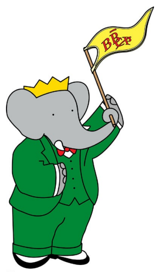
Event Rates

- Event rates exacted from the fit results on the asymmetries

Event rate	D^0	D^+	D_s^+
Γ_+	10974 ± 117	5406 ± 136	6792 ± 135
Γ_-	12587 ± 125	5287 ± 131	8287 ± 153
$\overline{\Gamma}_+$	12380 ± 124	5073 ± 104	7886 ± 121
$\overline{\Gamma}_-$	10749 ± 116	5443 ± 111	6826 ± 107

Extraction of the systematic uncertainties

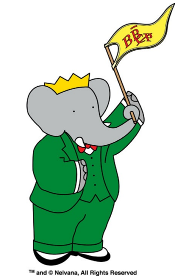
- Systematic uncertainties assumed to be Gaussian
- The uncertainty on the event rates are then extracted from the ones on the asymmetries
- In addition three other sources of uncertainty have been considered:
  - Slow-pion tag asymmetry (for A_C and A_{CP} - negligible) [D^0]
  - Neutral Kaon regeneration and interference (5-6x10^{-4} from $D^+ \rightarrow K^0_S h^+$) [$D_{(s)}^+$]
  - K^+/K^- interaction with detector material (affects A_C and A_{CP}, 5x10^{-3}) [$D_{(s)}^+$]



Results of the Reanalysis

BaBar Preliminary

All the asymmetries



- Possible effects of FSI
- Observation of *P* and *C* violation
- No *CPV*

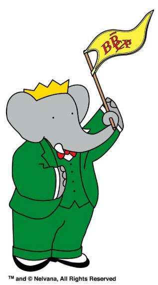
	Asymmetry	$D^0 \to K^+K^-\pi^+\pi^-$	$D^+ \to K^0_S K^+\pi^+\pi^-$	$D^+_s \to K^0_S K^+\pi^+\pi^-$
$\not{P}$,FSI	A_P	$-0.069 \pm 0.007 \pm 0.006\,(7.5)$	$0.011 \pm 0.014 \pm 0.006\,(0.7)$	$-0.099 \pm 0.011 \pm 0.008\,(7.3)$
	$\overline{A}_P$	$0.071 \pm 0.007 \pm 0.004\,(8.8)$	$-0.035 \pm 0.014 \pm 0.007\,(2.2)$	$0.072 \pm 0.011 \pm 0.011\,(4.6)$
$\not{C}$,FSI	a^P_C	$-0.070 \pm 0.005 \pm 0.001\,(13.5)$	$0.023 \pm 0.011 \pm 0.002\,(2.1)$	$-0.086 \pm 0.009 \pm 0.002\,(9.3)$
	a^P_{CP}	$0.001 \pm 0.005 \pm 0.004\,(0.2)$	$-0.012 \pm 0.010 \pm 0.005\,(1.1)$	$-0.014 \pm 0.008 \pm 0.003\,(1.6)$
$\not{C}$	A_C	$0.060 \pm 0.007 \pm 0.001\,(8.3)$	$-0.026 \pm 0.016 \pm 0.005\,(1.6)$	$0.080 \pm 0.013 \pm 0.005\,(5.7)$
$\not{C}$	$\overline{A}_C$	$-0.079 \pm 0.007 \pm 0.001\,(10.8)$	$0.020 \pm 0.016 \pm 0.005\,(1.2)$	$-0.092 \pm 0.012 \pm 0.005\,(7.1)$
$\not{P}$	a^C_P	$0.070 \pm 0.005 \pm 0.001\,(13.5)$	$-0.023 \pm 0.011 \pm 0.002\,(2.1)$	$0.086 \pm 0.009 \pm 0.002\,(9.3)$
	a^C_{CP}	$-0.009 \pm 0.005 \pm 0.000\,(1.8)$	$-0.004 \pm 0.011 \pm 0.010\,(0.3)$	$-0.006 \pm 0.009 \pm 0.010\,(0.4)$
	A_{CP}	$-0.008 \pm 0.007 \pm 0.004\,(1.0)$	$-0.016 \pm 0.016 \pm 0.008\,(0.9)$	$-0.020 \pm 0.012 \pm 0.008\,(1.4)$
	$\overline{A}_{CP}$	$-0.010 \pm 0.008 \pm 0.004\,(1.1)$	$0.008 \pm 0.016 \pm 0.008\,(0.5)$	$0.008 \pm 0.013 \pm 0.009\,(0.5)$
	a^{CP}_P	$0.001 \pm 0.005 \pm 0.004\,(0.2)$	$-0.012 \pm 0.011 \pm 0.006\,(1.0)$	$-0.014 \pm 0.009 \pm 0.006\,(1.3)$
	a^{CP}_C	$-0.009 \pm 0.005 \pm 0.000\,(1.8)$	$-0.004 \pm 0.011 \pm 0.010\,(0.3)$	$-0.006 \pm 0.009 \pm 0.010\,(0.4)$

BaBar Summary

BaBar Preliminary

Tests of C, P and CP violation

- Exploited all the information from T-odd correlations in 4-body $D_{(s)}$ decays
- $D^0 \to K^+K^-\pi^+\pi^-$ (CS), $D^+ \to K^+K^0_S\pi^+\pi^-$ (CS), $D_s^+ \to K^+K^0_S\pi^+\pi^-$ (CF) decays are studied
- No evidence of CP violation from the tests performed
- No evidence of C or P violation from the tests performed on D^+
- Significant deviation from 0 is found for some tests in D^0 and D_s^+
- These results are interpreted as observation of C and P violation in $D^0 \to K^+K^-\pi^+\pi^-$ and $D_s^+ \to K^+K^0_S\pi^+\pi^-$ decays



Conclusions

Alternative and Complementary Tests

- Searches for *CPV* through asymmetries in *T*-odd moments are alternative and complementary to "standard" *CPV* measurements
- *T*-odd moments can be used for studying *P* and *C* symmetries as well
- Applicable to many possible particle decays

Low Systematics

- Previous analysis have demonstrated that the systematic uncertainties are very small

Outlook

- Given the very low systematic uncertainties, such measurements could become extremely competitive at LHCb ($10fb^{-1}$) or future experiments (Belle-II, LHCb Upgrade,…)