Recent Charm Physics results

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INFN - Sezione di Milano

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Outline

- Recent results presented at Charm 2012:
  - search for CP violation
  - D^0-$\overline{D}^0$ mixing
  - Rare decays
- AWG activity
  - analyses ongoing
  - analyses to be studied

Search for CP violation

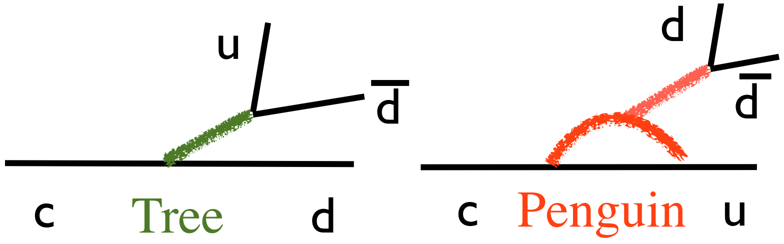
Charm Physics and searches for Physics beyond the Standard Model

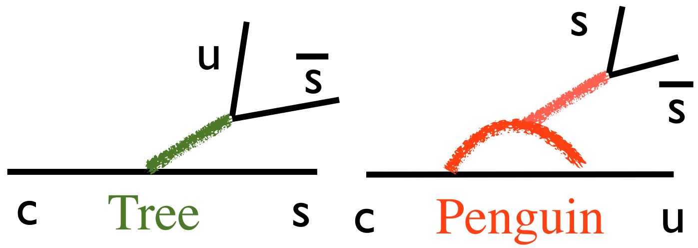
- Recent evidence of CP violation (CPV) in D^0 decays from LHCb and CDF has renewed the interest for searching new physics in the charm sector:
  - observed asymmetries are marginally compatible with the SM but not conclusive for establishing new Physics.
- Some hot topics in Charm Physics:
  - Search for CP violation in Single Cabibbo Suppressed (SCS) decays, uniquely sensitive to new physics through tree-penguin interference:
    - measure CP asymmetries in individual decay modes and keep improving precision;
    - measure additional decay modes with similar quark transitions: $c \rightarrow u\ d\ \bar{d}$bar, $c \rightarrow u\ s$ sbar.
  - Search for Flavor Changing Neutral Current (FCNC) decays, highly suppressed in the standard model:
    - however difficult to calculate SM long distance contributions.

Understanding origin of CPV in SCS decays

- Enrico Franco, Satoshi Mishima and Luca Silvestrini arXiv:1203.3131
- Gino Isidori, Jernej F. Kamenik Zoltan Ligeti and Gilad Perez arXiv:1111.4987

. Another important experimental handle to decide whether the observed signal can or cannot be accommodated in the SM would be observing or constraining CP violation in other decay modes. corresponding to the same quark-level transitions.





Decays that are accessible at the B factories, not a complete list!

- $D^0 \to \pi^+\pi^-, \pi^+\pi^-\pi^0, 2\pi^+2\pi^-, 2\pi^0$
- $D^+ \to \pi^+\pi^0, \pi^+\eta, \pi^+\eta', 2\pi^+\pi^-, 2\pi^+\pi^-\pi^0$
- $D_s^+ \to K_s\pi^+, K^+\pi^+\pi^-, K_s\pi^+\pi^0, K^+\pi^0, K^+\eta, K^+\eta'$
- $\Lambda_c^+ \to p\pi^+\pi^-, p2\pi^+2\pi^-$

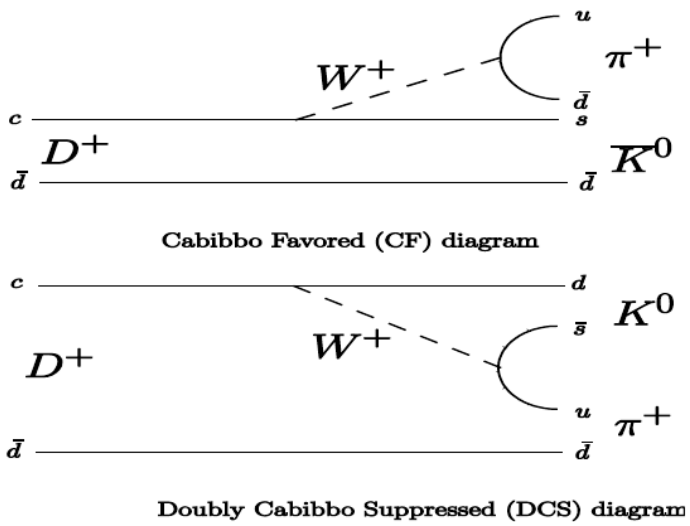
- $D^0 \to K^+K^-, K^+K^-\pi^0, K_sK^-\pi^+, K_sK^+\pi^-$
- $D^+ \to K_sK^+, \pi^+\Phi, K^+K^-\pi^+\pi^0, K_sK^+\pi^+\pi^-$
- $D_s^+ \to 2K^+K^-$
- $\Lambda_c^+ \to pK^+K^-$

CP violation in D decays with a K_S in final state

- CP asymmetry in charm decays with a K_S in the final state is expected to be (-0.332±0.006)% due to CPV in K^0-$\bar{K}^0$ mixing.
- Sizable difference from this value would indicate CP violation in the Δc transition (very small in the SM) indicating possible new physics effects.

Example: $D^+ \rightarrow K_S^0 \pi^+$

$$A_{CP}^{D^+\to K_S^0\pi^+} \equiv \frac{\Gamma(D^+\to K_S^0\pi^+) - \Gamma(D^-\to K_S^0\pi^-)}{\Gamma(D^+\to K_S^0\pi^+) + \Gamma(D^-\to K_S^0\pi^-)} = A_{CP}^{\Delta C} + A_{CP}^{\bar{K}^0}, \quad (1)$$



Measurement of ΔA_{CP} from LHCb

A. Carbone at Charm 2012

$D^0 \rightarrow KK$, $D^0 \rightarrow \pi\pi$

$L = 0.6\ \mathrm{fb}^{-1}$

Phys.Rev.Lett. 108 (2012) 111602

- We are looking for CP asymmetry defined as

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

with f=KK and f=ππ and

$$A_{\mathrm{raw}}(f) = \boxed{A_{CP}(f)} + \boxed{\cancel{A_{\mathrm{D}}(f)}} + \boxed{A_{\mathrm{D}}(\pi_s)} + \boxed{A_{\mathrm{P}}(D^{*+})}$$

Physics CP asymmetry

Detection asymmetry of D^0

Production asymmetry

Detection asymmetry of "slow" pions

- $D/\overline{D}$ (as well as $B/\overline{B}$) production asymmetries need to be taken into account in proton-proton interactions at LHC

$$\boxed{\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)}$$

- the production and the "slow" pion detection asymmetries will cancel

Systematics & Result

A. Carbone at Charm 2012

Kinematic binning	0.02%
Fit procedure	0.08%
Peaking background	0.04%
Multiple candidates	0.06%
Fiducial cuts	0.01%
Sum in quadrature	0.11%

Several of the systematic uncertainties have a statistical component -- should come down as data sample grows.

$$\Delta A_{CP} = [-0.82 \pm 0.21(\text{stat.}) \pm 0.11(\text{sys.})]\,\%$$

Significance: 3.5σ

- Total samples in $10 fb^{-1}$ (after D^* tag):
  - 1.21M KK
  - 0.55M $\pi\pi$

Result

from CDF

$$A_{obs}(KK) - A_{obs}(\pi\pi) = (-2.33 \pm 0.14)\% - (-1.71 \pm 0.15)\% =$$

G. Punzi at Charm 2012

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

CDF Public note 10784

This is 2.7σ away from zero, indicating presence of CP violation in CDF charm data.

The uncertainty of 0.2 % dominated by the sample size.

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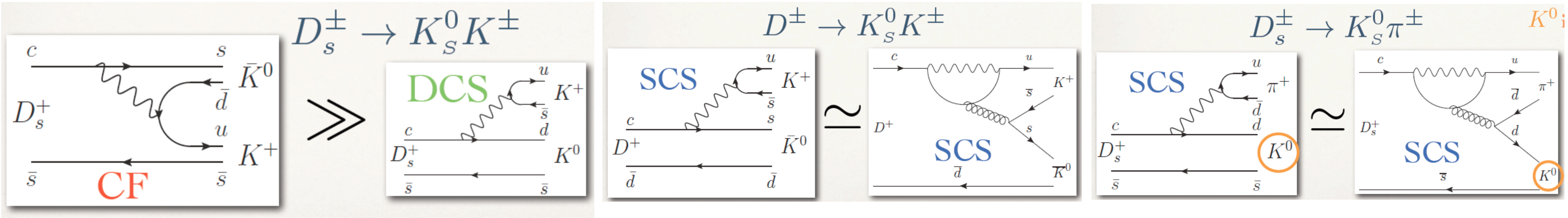
Search for CPV in $D_{(s)}^{\mp} \rightarrow K_S^0 h^{\mp}$ at BaBar



- Contribution from $K^0 - \overline{K}^0$ mixing [PDG 2010]: **+(-)0.332±0.006%** when a K^0 ($\overline{K}^0$) is in the final state
- Any deviation would be evidence of CP violation in the charm system
- Already published by BaBar: $D^{\pm} \rightarrow K_S^0 \pi^{\pm}$ [Phys. Rev. D 83, 071103(R) (2011)]
  ACP=(-0.11±0.13(stat)±0.10(syst))% (after removing $K^0 - \overline{K}^0$ mixing contrib.)

Reconstructed asymmetry

- Measured asymmetry is the sum of three contributions:

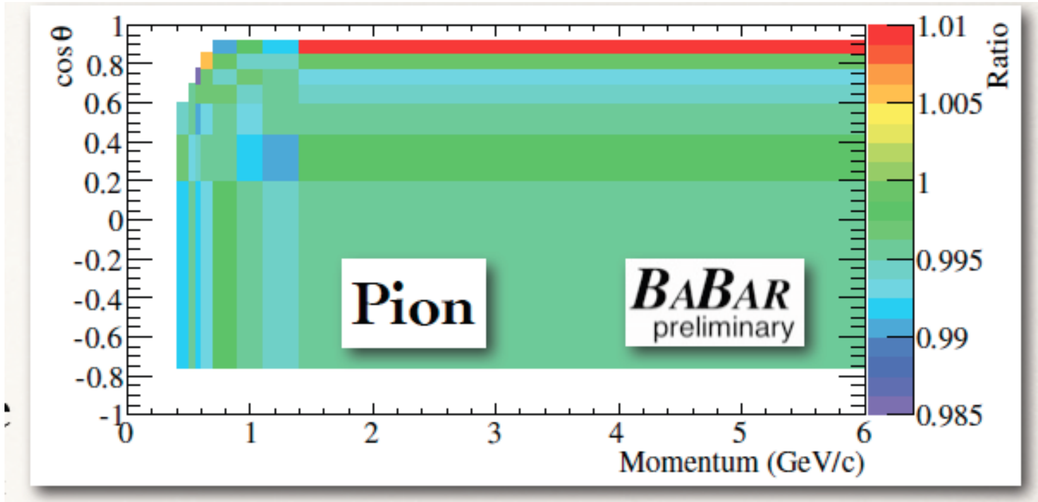
$$A_{\text{rec}}^{D_{(s)}} = A_{CP}^{D_{(s)}} + A_{FB}^{D_{(s)}}(\cos\theta^*_{D_{(s)}}) + A_{\varepsilon}^{(\pi,K)}(p^{\text{lab}}_{(\pi,K)}, \cos\theta^{\text{lab}}_{(\pi,K)})$$

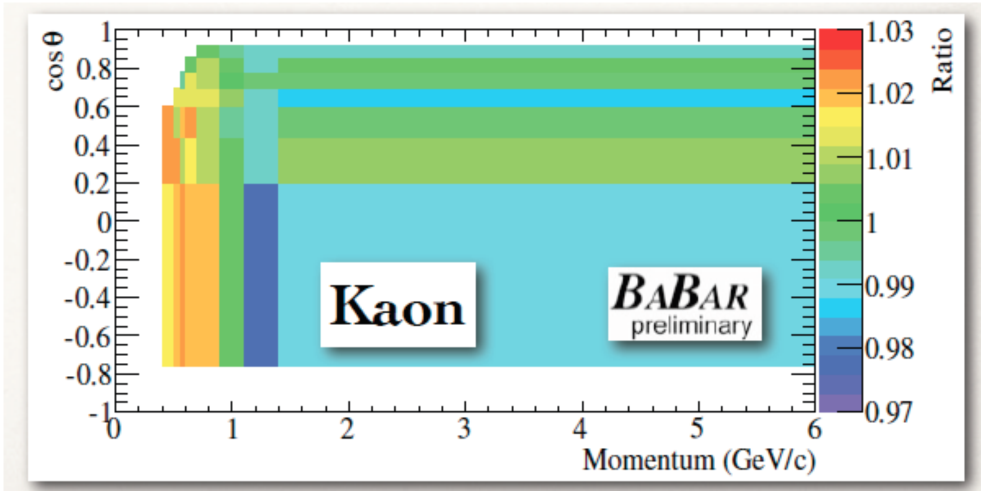
  - **CP asymmetry, A_{CP}**
  - **Fwd/Bwd asymmetry in $c\bar{c}$ production, A_{FB}**
    - virtual photon interference with virtual Z^0
  - **Detector-induced charge reconstruction asymmetry, A_ε**
    - reconstruction asymmetries and material interactions
    - affecting only the track not coming from the K_S
- Corrections will be applied to remove A_ε , while A_{CP} and A_{FB} are measured

- Data-driven method to remove detector-induced asymmetry A_ε
- **100M generic tracks with no asymmetry from physics:**
  Y(4S) events, after continuum subtraction

$$N_{\text{rec}}(\vec{p}) = N_{\text{recOnPeak}}(\vec{p}) - N_{\text{recOffPeak}}(\vec{p}) \cdot \frac{\mathcal{L}_{\text{OnPeak}}}{\mathcal{L}_{\text{OffPeak}}}$$

$$R = \frac{\epsilon^+(\vec{p})}{\epsilon^-(\vec{p})} = \frac{N^+_{\text{rec}}(\vec{p})}{N^-_{\text{rec}}(\vec{p})}$$





CP asymmetry extraction

- After removing the charge asymmetry induced by detector effect, the measured asymmetry can be written as:

$$A = \frac{N_{D+} - N_{D-}}{N_{D+} + N_{D-}} = \frac{A_{FB} + A_{CP}}{1 + A_{FB}A_{CP}} \approx A_{FB} + A_{CP}$$

- A_{FB} asymmetry is an odd function of the D polar angle Θ in CMS (only first order term below):

$$A_{FB}(\cos\Theta) = \frac{8}{3} a_{FB} \frac{\cos\Theta}{1 + \cos^2\Theta} \rightarrow$$

$$A_{FB} = \frac{A^{\cos\Theta>0} + A^{\cos\Theta<0}}{2}$$

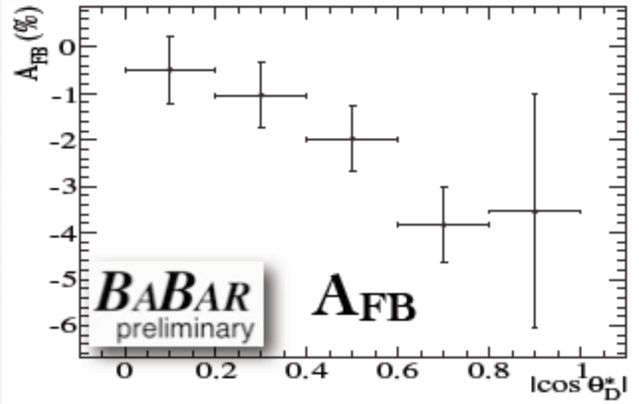
$$A_{CP} = \frac{A^{\cos\Theta>0} - A^{\cos\Theta<0}}{2}$$

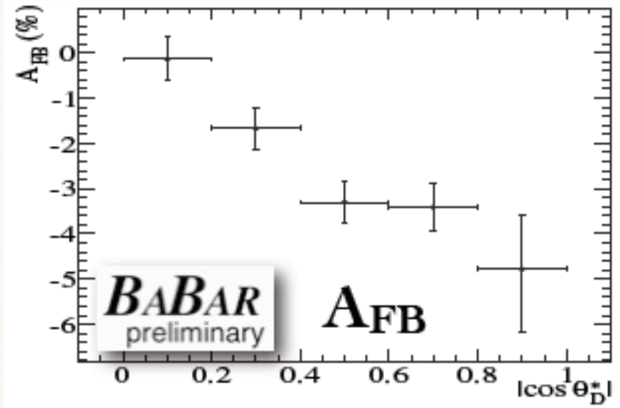
- Each pairs of symmetric $\cos\Theta$ bins produces one asymmetry value
- Values are combined using a χ^2 minimization

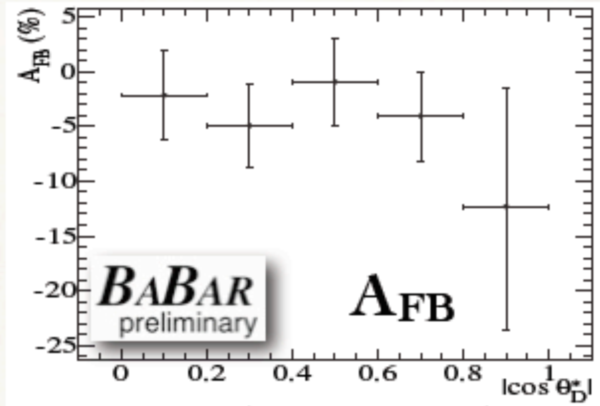
A_{CP}, A_{FB} extraction

$$A_{FB}(|\cos\theta^*_D|) = \frac{A(+|\cos\theta^*_D|) - A(-|\cos\theta^*_D|)}{2}$$

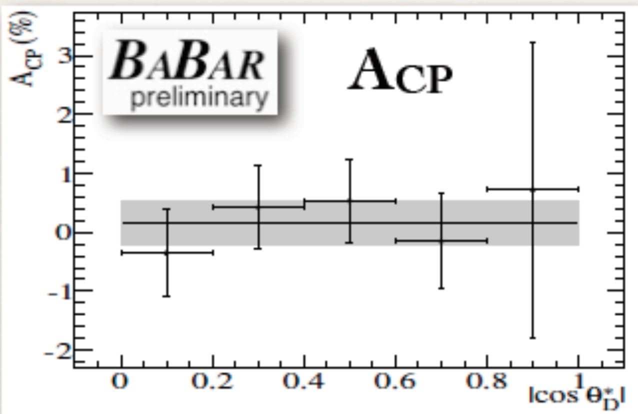
$$A_{CP}(|\cos\theta^*_D|) = \frac{A(+|\cos\theta^*_D|) + A(-|\cos\theta^*_D|)}{2}$$

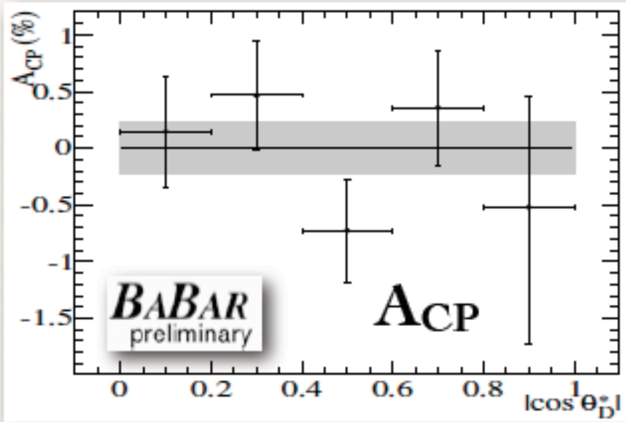


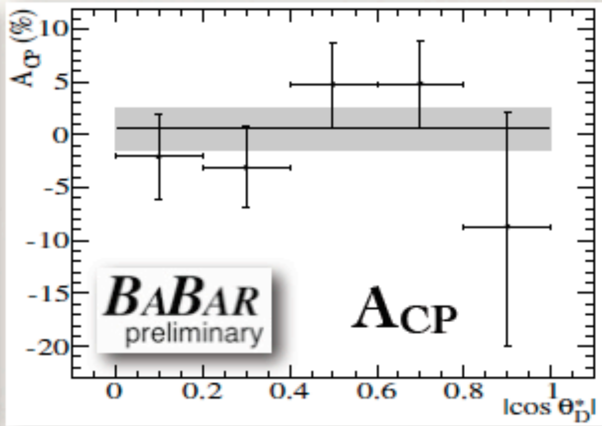




$D^{\pm} \to K^0_S K^{\pm}$ $\qquad$ $D_s^{\pm} \to K^0_S K^{\pm}$ $\qquad$ $D_s^{\pm} \to K^0_S \pi^{\pm}$







A_{CP} 0.155±0.36% $\qquad$ **A_{CP} 0.00±0.23%** $\qquad$ **A_{CP} 0.6±2.0%**

Systematics

- Dominant contributions:
  - correction of detector-induced asymmetry
  - choice of binning (only for $D_s^\pm \to K_S^0 \pi^\pm$)

Syst. uncertainty (absolute)	$D^\pm \to K_S^0 K^\pm$	$D_s^\pm \to K_S^0 K^\pm$	$D_s^\pm \to K_S^0 \pi^\pm$
Efficiency of PID selectors	0.05%		0.05%
Statistics of control sample	0.23%		0.06%
Selection of control sample	0.01%		0.01%
$\cos\Theta^*$ binning	0.04%	0.02%	0.27%
K^0-$\overline{K}^0$ regeneration [1]	0.05%	0.05%	0.06%
K_S^0-K_L^0 interference [2]	0.015%	0.014%	0.008%
Total	0.25%	0.24%	0.29%

[1] arxiv:1006.1938
[2] arXiv:1110.3790v1

Final values

- Corrections to the final values for biases and interference effect

	$D^{\pm} \to K_S^0 K^{\pm}$	$D_s^{\pm} \to K_S^0 K^{\pm}$	$D_s^{\pm} \to K_S^0 \pi^{\pm}$
A_{CP} value from the fit	$(+0.16 \pm 0.36)\%$	$(0.00 \pm 0.23)\%$	$(+0.6 \pm 2.0)\%$
Correction for the bias from toy MC experiments	$+0.013\%$	-0.01%	–
Correction for the bias in the PID selectors	-0.05%	-0.05%	-0.05%
Correction for the K_S^0-K_L^0 interference (ΔA_{CP})	$+0.015\%$	$+0.014\%$	-0.008%
A_{CP} final value	$(+0.13 \pm 0.36 \pm 0.25)\%$	$(-0.05 \pm 0.23 \pm 0.24)\%$	$(+0.6 \pm 2.0 \pm 0.3)\%$
A_{CP} contribution from K^0-$\overline{K}^0$ mixing	$(-0.332 \pm 0.006)\%$	$(-0.332 \pm 0.006)\%$	$(+0.332 \pm 0.006)\%$
A_{CP} final value (charm only)	$(+0.46 \pm 0.36 \pm 0.25)\%$	$(+0.28 \pm 0.23 \pm 0.24)\%$	$(+0.3 \pm 2.0 \pm 0.3)\%$

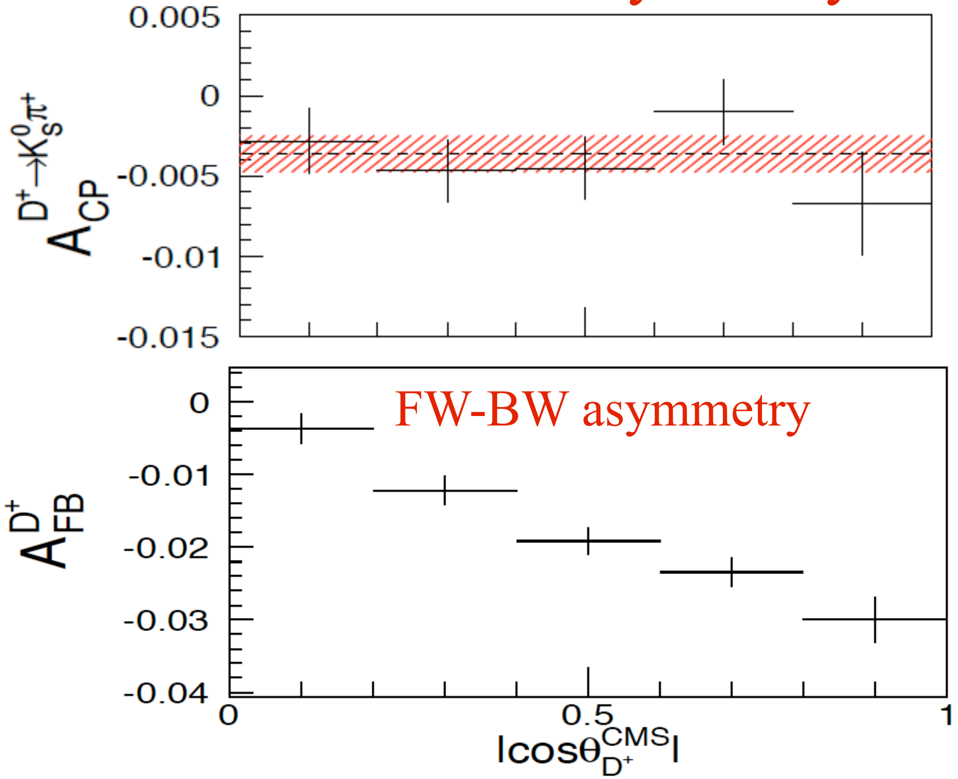
469 fb^{-1} **(value)±(stat)±(syst)**

- No sign of physics beyond the SM

	BABAR(469 fb^{-1})	Belle(673 fb^{-1}) [1]
$D^+ \to K_S^0 K^+$	$(+0.13 \pm 0.36 \pm 0.25)\%$	$(-0.16 \pm 0.58 \pm 0.25)\%$
$D_s^+ \to K_S^0 K^+$	$(-0.05 \pm 0.23 \pm 0.25)\%$	$(+0.12 \pm 0.36 \pm 0.22)\%$
$D_s^+ \to K_S^0 \pi^+$	$(+0.6 \pm 2.0 \pm 0.3)\%$	$(5.45 \pm 2.50 \pm 0.33)\%$

[1] Phys. Rev. Lett. 104, 181602 (2010)

Search for CP violation in $D^+ \to K^0_S \pi^+$



Systematic errors

Source	$\sigma_{A_{CP}}$ (%)
$A_\epsilon^{\pi^+}$ determination	0.064
Fitting	0.003
$\cos\theta_{D^+}^{CMS}$ binning	0.008
$A_{\mathcal{D}}$ correction	0.016
Total	0.067

- *A_D is due to different K^0-$\overline{K^0}$ interaction with material*
- *Asymmetry due to neutral kaons to be corrected with acceptance effects as a function of K_S decay time by (1.040±0.005)* Y. Grossman and Y. Nir, arXiv:1110.3790

$$A_{CP}^{D^+\to K_S^0\pi^+} = -0.363 \pm 0.094 \pm 0.067\ (\%)$$

977 fb^{-1}

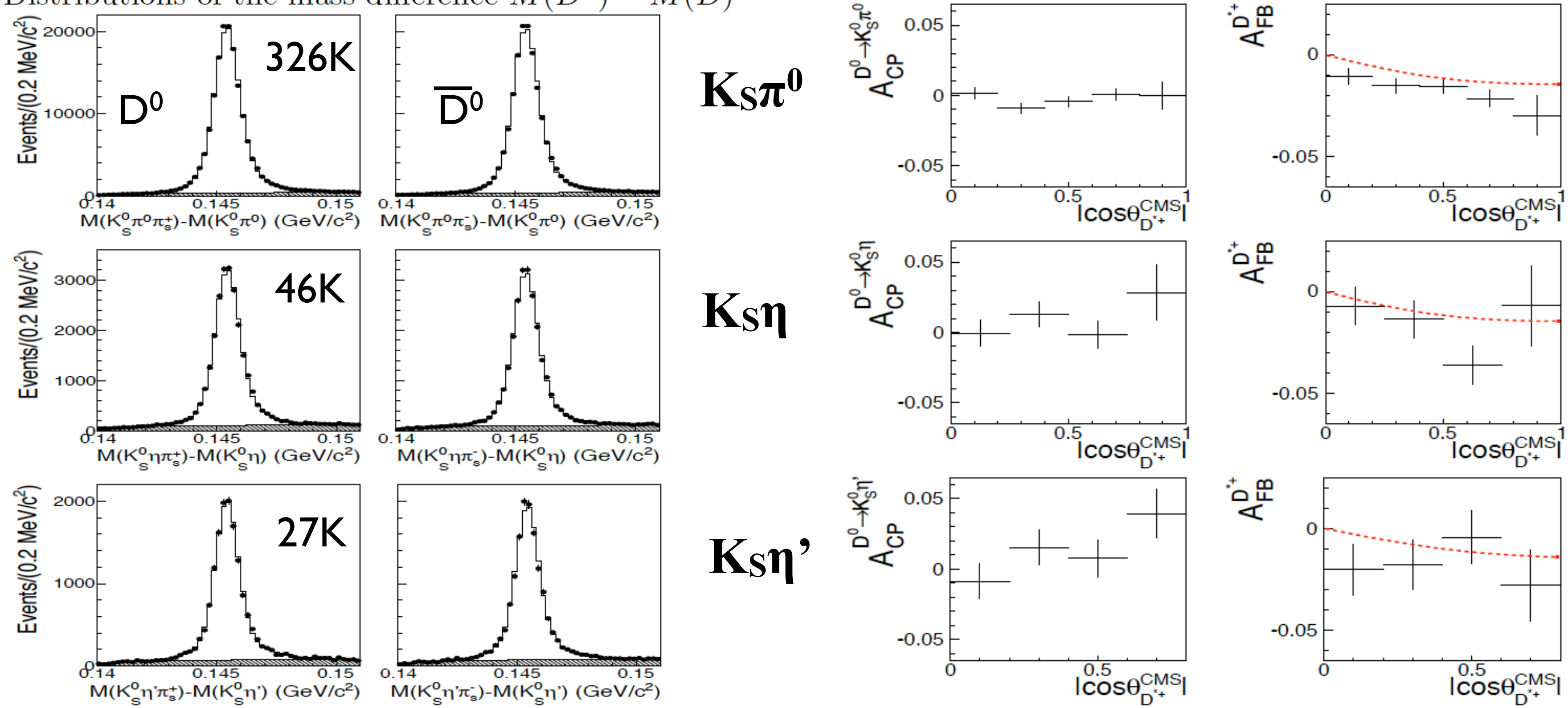
arXiv:1203.6409v1

3.2 standard deviations away from zero

Phys. Rev. Lett. 106, 211801 (2011) 791 fb^{-1}

Search for CPV in $D^0 \to K^0_S P^0$ decays

Distributions of the mass difference $M(D^*) - M(D)$

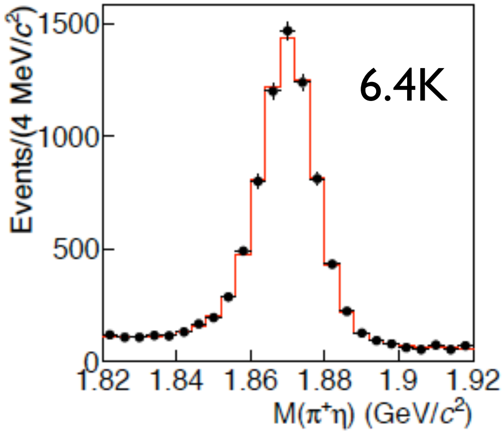


	Belle (%)
$A_{CP}^{D^0\to K^0_S\pi^0}$	$-0.28\pm0.19\pm0.10$
$A_{CP}^{D^0\to K^0_S\eta}$	$+0.54\pm0.51\pm0.16$
$A_{CP}^{D^0\to K^0_S\eta'}$	$+0.98\pm0.67\pm0.14$

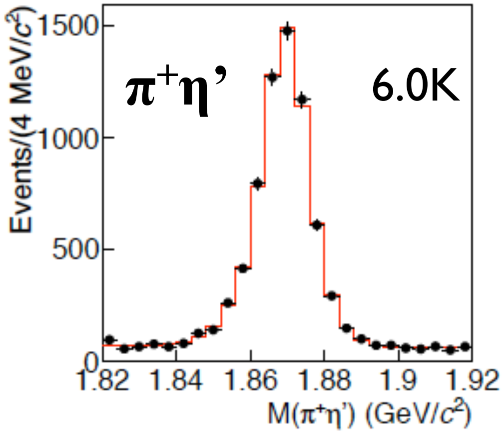
Source	$K^0_S\pi^0$ (%)	$K^0_S\eta$ (%)	$K^0_S\eta'$ (%)
$A_\epsilon^{\pi_s^+}$ determination	0.08	0.08	0.08
Fitting	0.02	0.12	0.10
$\cos\theta^{CMS}_{D^{*+}}$ binning	<0.01	0.01	0.03
$K^0/\bar{K}^0$-material effects	0.06	0.06	0.06
Total	0.10	0.16	0.14

Search for CP violation in SCS $D^+ \to \pi^+\eta^{(\prime)}$ and $D^+ \to \pi^+\phi$ decays

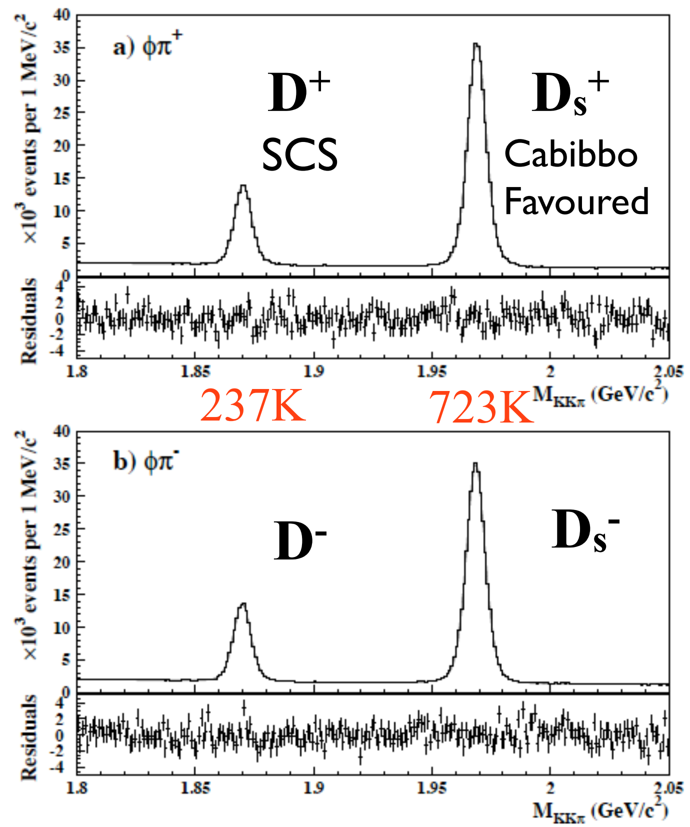
$D^+ \to \pi^+\eta$, $\eta \to \pi^+\pi^-\pi^0$



$D^+ \to \pi^+\eta'$, $\eta' \to \pi^+\pi^-\eta_{\gamma\gamma}$



$D^+ \to \pi^+\phi$, $\phi \to K^+K^-$



791 fb^{-1} **Phys. Rev. Lett. 107, 221801 (2011)**

$$A_{CP}^{D^+\to\pi^+\eta} = (+1.74 \pm 1.13 \pm 0.19)\%$$

$$A_{CP}^{D^+\to\pi^+\eta'} = (-0.12 \pm 1.12 \pm 0.17)\%.$$

955 fb^{-1} arXiv:1110.0694v2

$$A_{CP}^{D^+\to\phi\pi^+} = (+0.51 \pm 0.28 \pm 0.05)\%$$

assuming no CPV in CF $D_s^+ \to \pi^+\phi$

Recent BaBar $D^{\pm} \rightarrow K^{+}K^{-}\pi^{\pm}$ (vs $\cos\theta_{CM}$)

$$A \equiv \frac{N_{D^+}/\epsilon_{D^+} - N_{D^-}/\epsilon_{D^-}}{N_{D^+}/\epsilon_{D^+} + N_{D^-}/\epsilon_{D^-}}$$

[BaBar Preliminary]

Integrated Asymmetry:

$(0.35 \pm 0.30 \pm 0.15)\%$

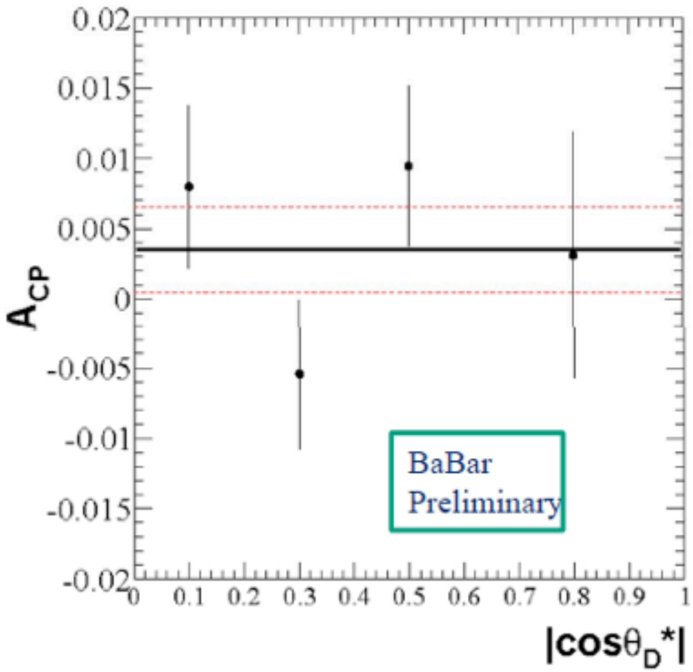
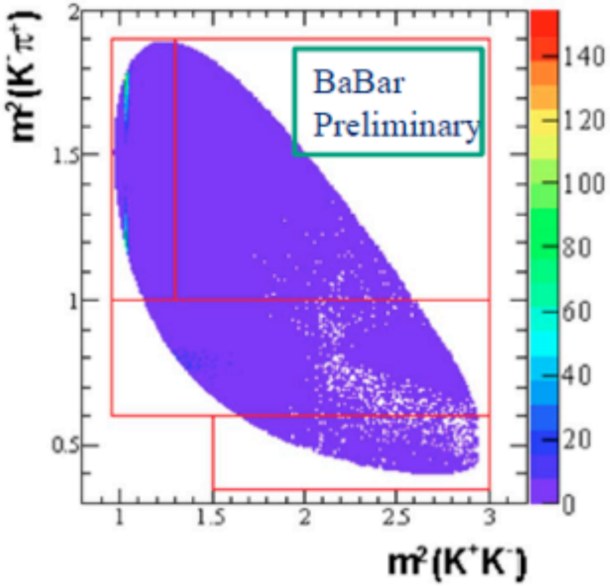


FIG. 3: CP asymmetry as a function of $|\cos\theta_{CM}|$ in the data sample. The solid line represents the central value of A_{CP} and the dashed lines represent the $\pm 1\sigma$ interval, determined from a χ^2 minimization assuming no dependence on $|\cos\theta_{CM}|$.

Recent BaBar $D^{\pm} \rightarrow K^{+}K^{-}\pi^{\pm}$ (CPV By Regions)

[BaBar Preliminary]



Dalitz plot region	$N(D^+)$	$\epsilon(D^+)[\%]$	$N(D^-)$	$\epsilon(D^-)[\%]$	$A_{CP}[\%]$
Below $\bar{K}^*(892)^0$	1882 ± 70	7.00	1859 ± 90	6.97	$-0.65 \pm 1.64 \pm 1.73$
$\bar{K}^*(892)^0$	36770 ± 251	7.53	36262 ± 257	7.53	$-0.28 \pm 0.37 \pm 0.21$
$\phi(1020)$	48856 ± 289	8.57	48009 ± 289	8.54	$-0.26 \pm 0.32 \pm 0.45$
Above $\bar{K}^*(892)^0$ and $\phi(1020)$	25616 ± 244	8.01	24560 ± 242	8.00	$1.05 \pm 0.45 \pm 0.31$

TABLE I: Yields, efficiencies, and *CP* asymmetry in regions of the Dalitz plot shown in Fig. 5. For the *CP* asymmetry the first error is statistical and the second is systematic.

Recent BaBar $D^{\pm} \to K^{+}K^{-}\pi^{\pm}$ (LHCb Style)

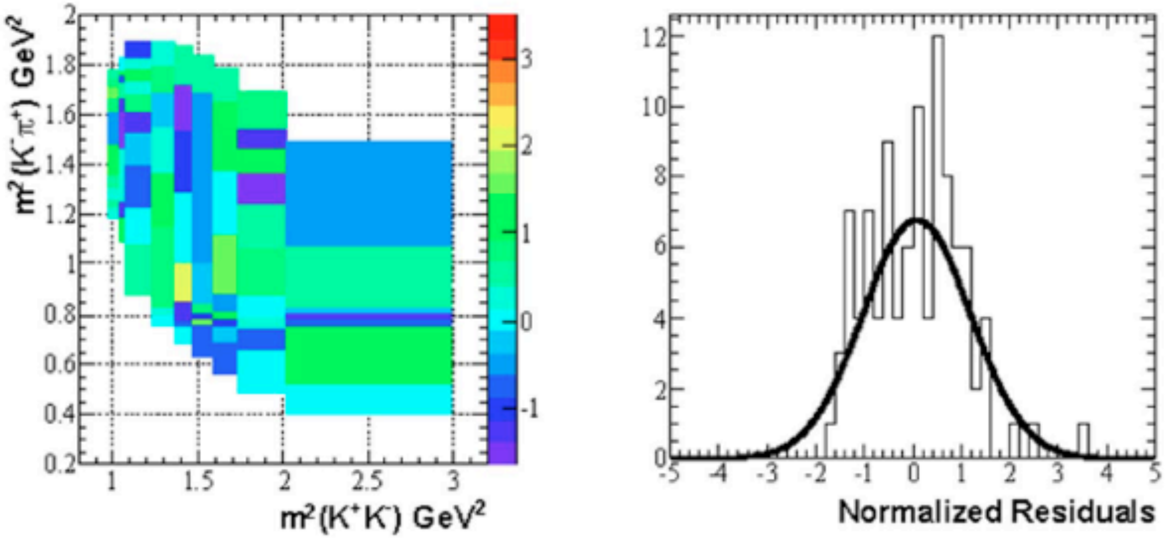


FIG. 4: Normalized residuals of the D^{+} and D^{-} Dalitz plots in equally populated bins (left) and their distribution fitted with a Gaussian. We find the distribution to have a mean of 0.08 ± 0.15 and a width of 1.11 ± 0.15 and a probability of 72% that the two Dalitz plots are consistent with no CP asymmetry.

Recent BaBar $D^{\pm} \to K^+K^-\pi^{\pm}$ (Simultaneous Fit to D^+, D^-)

[BaBar Preliminary]

Resonance	r (%)	$\Delta\phi$ (°)
$\bar{K}^*(892)^0$	0. (FIXED)	0. (FIXED)
$\bar{K}_0^*(1430)^0$	$-9.40^{+5.65}_{-5.36} \pm 4.42$	$-6.11^{+3.29}_{-3.24} \pm 1.39$
$\phi(1020)$	$0.35^{+0.82}_{-0.82} \pm 0.60$	$7.43^{+3.55}_{-3.50} \pm 2.35$
NR	$-14.30^{+11.67}_{-12.57} \pm 5.98$	$-2.56^{+7.01}_{-6.17} \pm 8.91$
$\kappa(800)$	$2.00^{+5.09}_{-4.96} \pm 1.85$	$2.10^{+2.42}_{-2.45} \pm 1.01$
$a_0(1450)^0$	$5.07^{+6.86}_{-6.54} \pm 9.39$	$4.00^{+4.04}_{-3.96} \pm 3.83$
	Δx	Δy
$f_0(980)$	$-0.199^{+0.106}_{-0.110} \pm 0.084$	$-0.231^{+0.100}_{-0.105} \pm 0.079$
$f_0(1370)$	$0.019^{+0.049}_{-0.048} \pm 0.022$	$-0.0045^{+0.037}_{-0.039} \pm 0.016$

$$r = \frac{|\mathcal{M}_r|^2 - |\bar{\mathcal{M}}_r|^2}{|\mathcal{M}_r|^2 + |\bar{\mathcal{M}}_r|^2}$$

$$\Delta\phi = \phi_r - \bar{\phi}_r$$

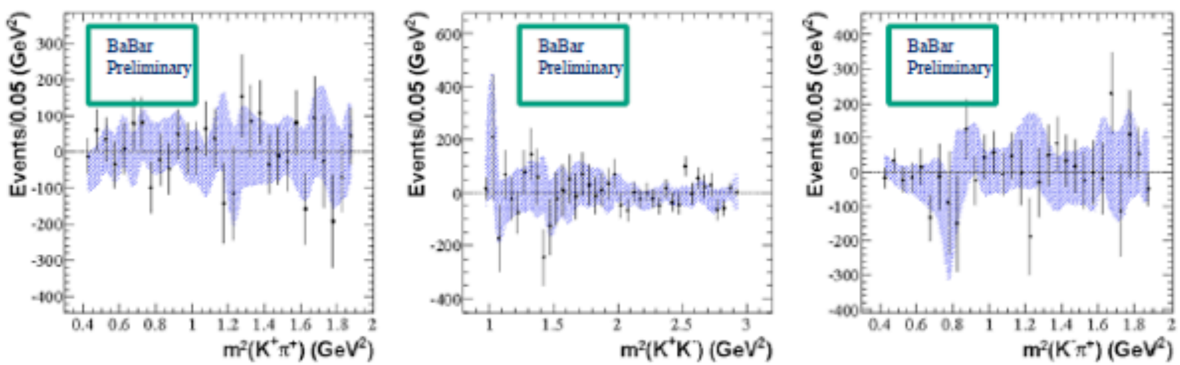
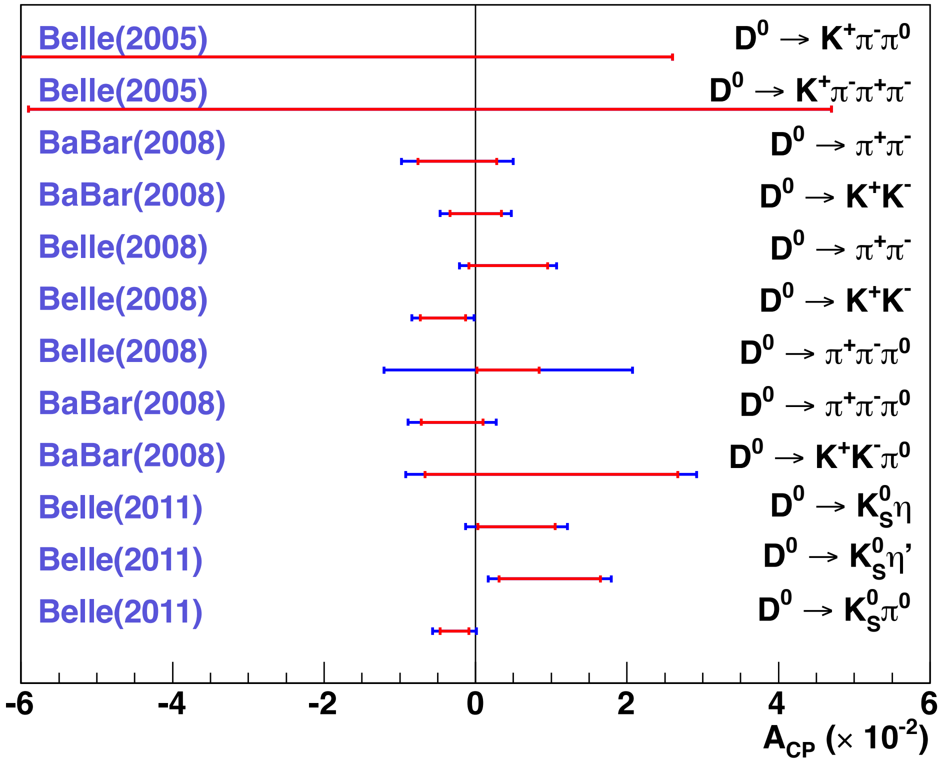


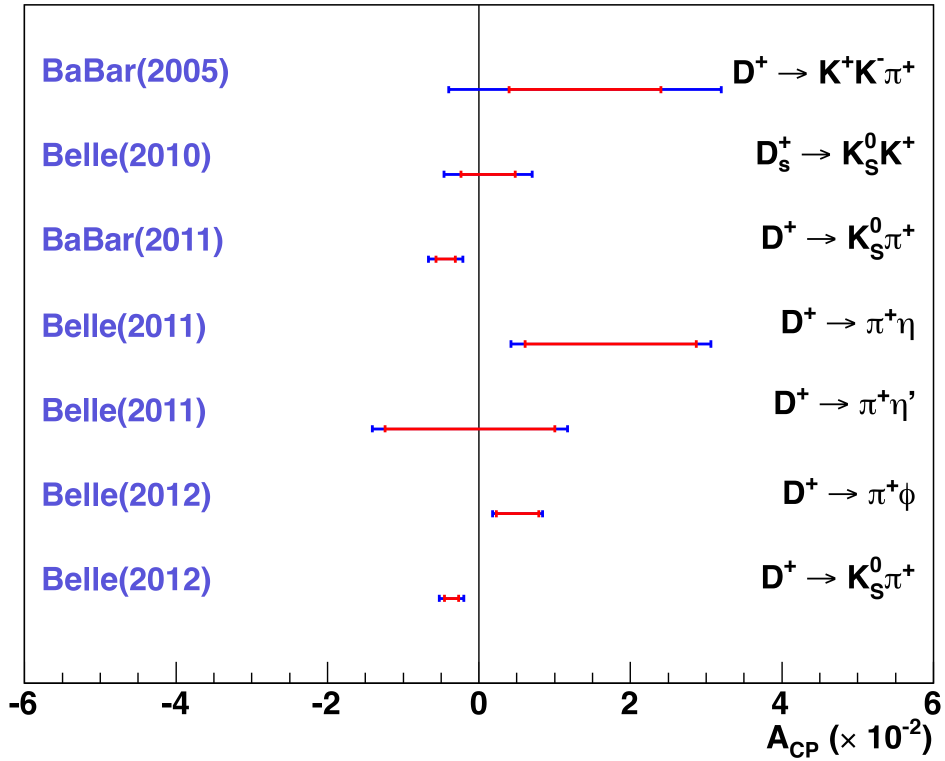
FIG. 6: The difference of the Dalitz plot projections of data (points) and the fit (blue curve) between the D^+ and D^- decays. The width of the curve represents the $\pm 1\sigma$ error of the fit.

Time-integrated CPV measurements at the B factories

D^0 modes: direct + indirect CPV



$D_{(s)}^+$ modes: direct CPV



At the B factories was found evidence of CP violation in $D^+ \to K_S^0\pi^+$ decays. Systematic errors kept under control below the 10^{-3} level.

Search for direct CPV at SuperB

- No ongoing studies for determining sensitivity to direct CP violation (AFAIK) in charm decays at SuperB. Several modes are better reconstructed at B factories than at hadron colliders (and some at charm threshold):
  - $D^0 \to \pi^+\pi^-\pi^0$, $2\pi^0$, $K_S K_S$, $D^0 \to V\gamma$, ...
  - $D^+ \to \pi^+\pi^0$,....
- Feasibility of the analysis at $\Upsilon(4S)$ and at charm threshold:
  - establish optimal experimental technique;
  - bkg studies;
  - evaluation of systematic errors (?);
  - sensitivity.
- Good place where to contribute. List of golden channel to study from theorists.

D^0-$\bar{D}^0$ mixing

Mixing and CPV with Lifetime Ratio Analysis

➔ Other experimental observables sensitive to mixing and to *CP* Violation:

Mixing & CPV observables

$$y_{CP} = \frac{\Gamma(CP+)}{\Gamma_D} - 1 \quad \& \quad \Delta Y = \frac{\Gamma(CP+)}{\Gamma_D} A_\Gamma$$

$\Gamma(CP+) = [\ \Gamma(D^0 \to CP+) + \Gamma(\overline{D}^0 \to CP+)\ ]/2$

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

$\Gamma(CP+)$ = effective D^0 width for decays to CP+ eigenstates

➔ In terms of the mixing & CPV parameters:

$$y_{CP}^{hh} = y\cos\phi_{\cancel{hh}} + \frac{1}{2}\left[A_M + A_D^{hh}\right] x\sin\phi_{\cancel{hh}} - \frac{1}{4}A_M A_D^{hh}\ y\cos\phi_{\cancel{hh}}$$

$$\Delta Y^{hh} = -x\sin\phi_{\cancel{hh}} + \frac{1}{2}\left[A_M + A_D^{hh}\right] y\cos\phi_{\cancel{hh}} + \frac{1}{4}A_M A_D^{hh}\ x\sin\phi_{\cancel{hh}}$$

direct CPV:

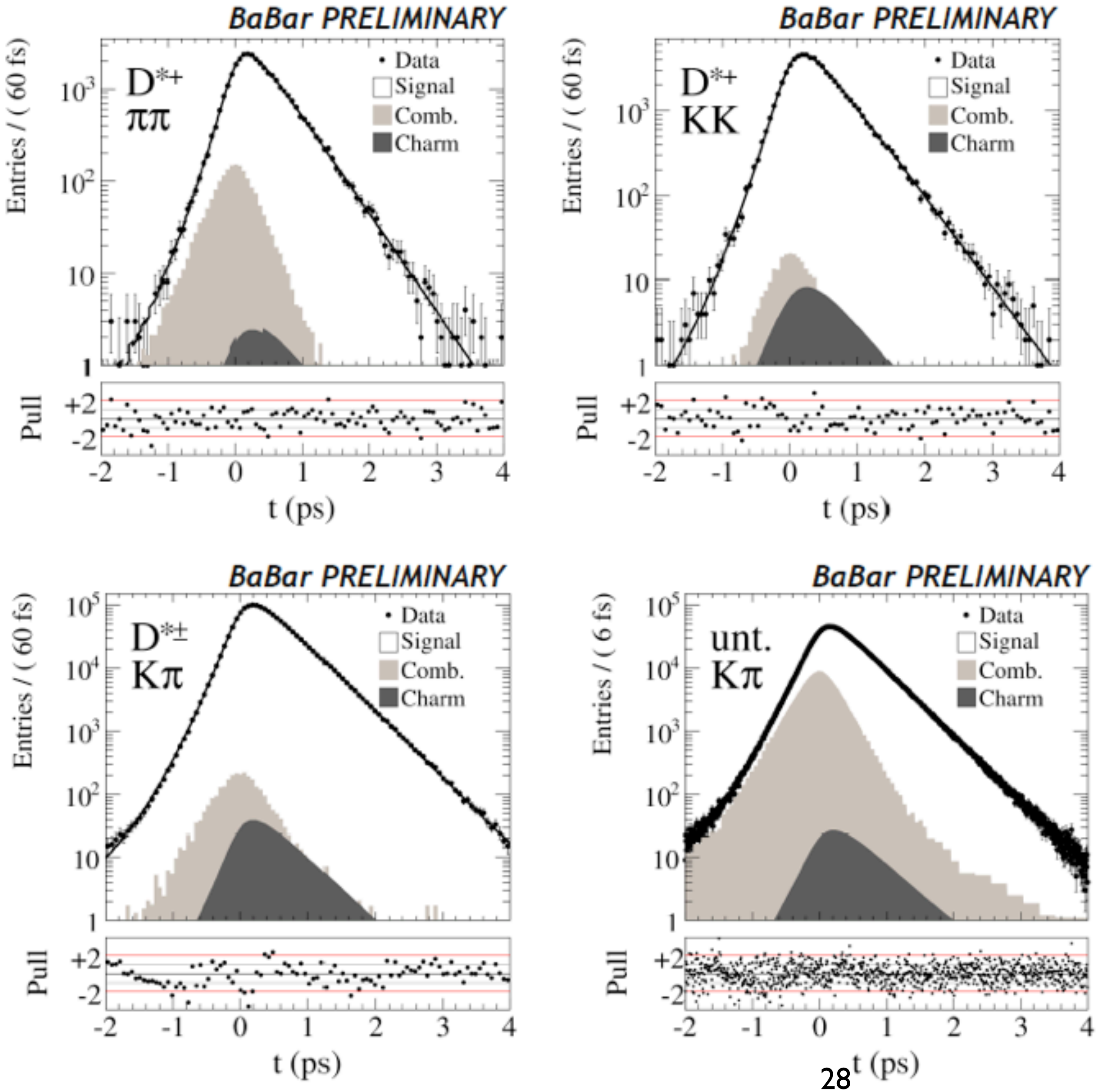
$$A_D^{hh} = \frac{|A_{hh}/\bar{A}_{hh}|^2 - |\bar{A}_{hh}/A_{hh}|^2}{|A_{hh}/\bar{A}_{hh}|^2 + |\bar{A}_{hh}/A_{hh}|^2}$$

CPV in mixing:

$$A_M = \frac{r_m^2 - r_m^{-2}}{r_m^2 + r_m^{-2}}$$

- in general, both observables depend on the final state
- sensitivity to direct CPV ~ 10^{-4}, below our current experimental precision [J.Phys.G G39. 045005 (2012)]
- in the SM, φ is the same for all the final states to a very good approximation [PRD 80. 076008 (2009)]
- in case of no *CP* violation: $y_{CP} = y$ and $\Delta Y = 0$.

Proper Time Fit Projections



CP+ lifetimes

$$\tau^+ = (405.69 \pm 1.25)\ \text{fs}$$
$$\bar{\tau}^+ = (406.40 \pm 1.25)\ \text{fs}$$

[stat error only]

D^0 lifetime

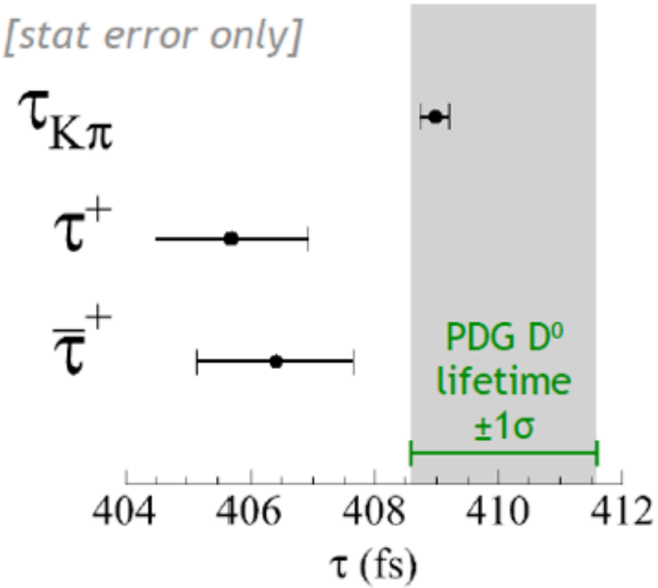
$$\tau_{K\pi} = (408.97 \pm 0.24)\ \text{fs}$$

[stat error only]

Lifetime Fit Results & Interpretation

BaBar PRELIMINARY

[stat error only]



BaBar PRELIMINARY

$$y_{CP} = [0.720 \pm 0.180(\mathrm{stat}) \pm 0.124(\mathrm{syst})]\%$$

$$\Delta Y = [0.088 \pm 0.255(\mathrm{stat}) \pm 0.058(\mathrm{syst})]\%$$

➔ exclude no-mixing hypothesis @ 3.3σ

➔ no CPV observed

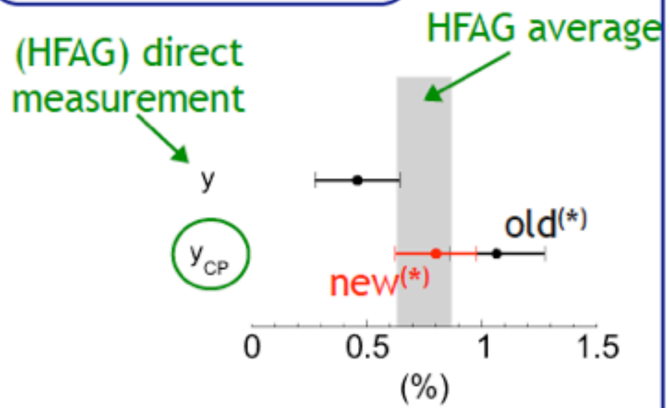
➔ most precise single measurement of y_{CP};

➔ this result is compatible at least 2% (5%) with previous *BaBar* result [PRD 80, 071103 (2009)], considering:

- systematic errors *fully* (63%) correlated,
- 40% of the events in the current dataset are also present in the previous datasets (63% correlation);

➔ this result supersedes the previous *BaBar* results.

HFAG y averages



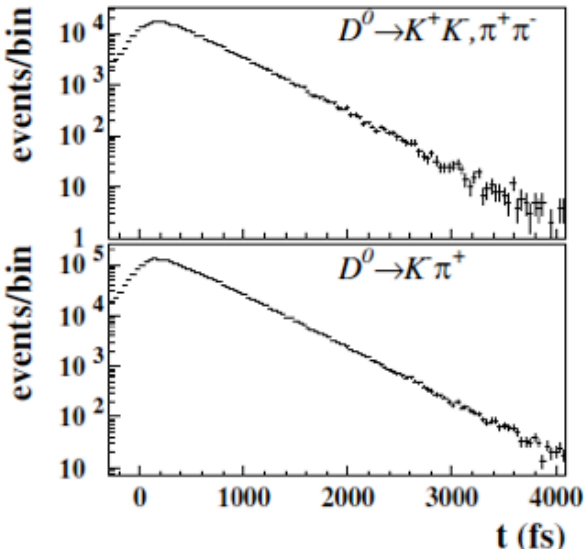
compatibility y vs y_{CP}: from 3% to 18%

(*) "old" → (April 2012 HFAG average) excluding the measurement presented here
"new" → including this measurement and excluding the previous BaBar one

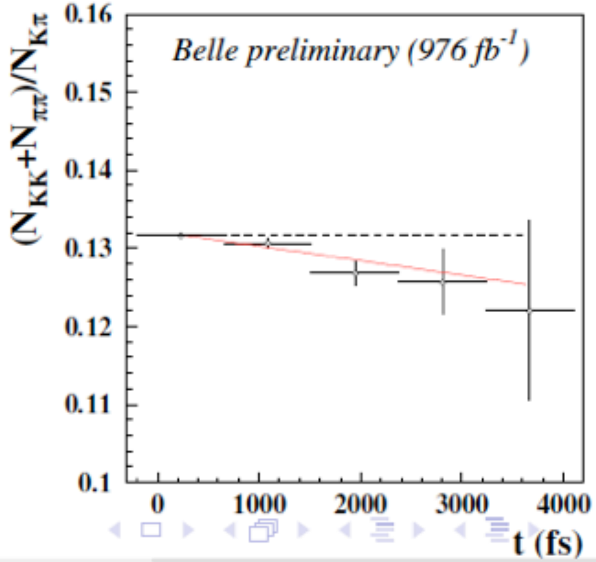
Results (preliminary)

$$y_{CP} = (+1.11 \pm 0.22 \pm 0.11)\%$$
$$A_\Gamma = (-0.03 \pm 0.20 \pm 0.08)\%$$

- y_{CP} is at 4.5σ when both errors are combined in quadrature and at 5.1σ if only statistical error is considered
- A_Γ is consistent with no indirect CP violation.

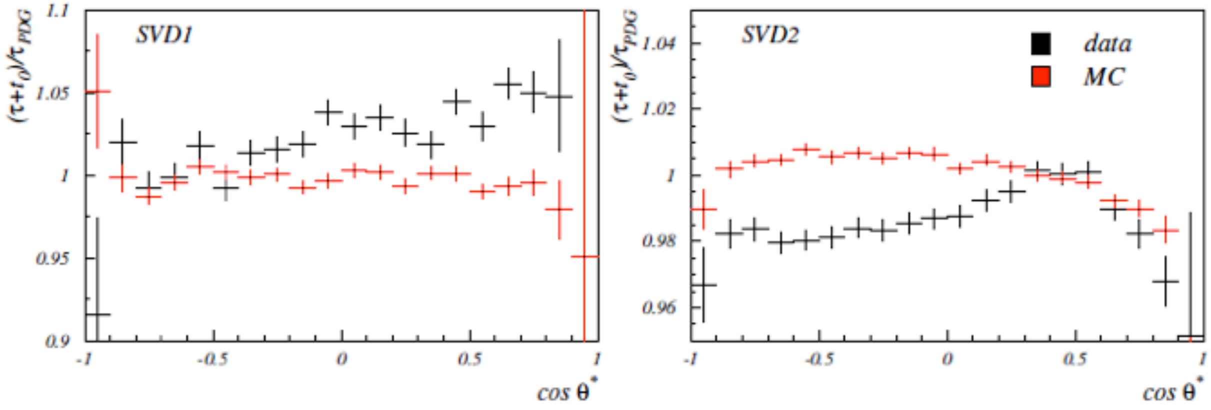


divide distributions $\longrightarrow$



$D^0 \to K^+K^-, \pi^+\pi^-$ (update with 976 fb^{-1})

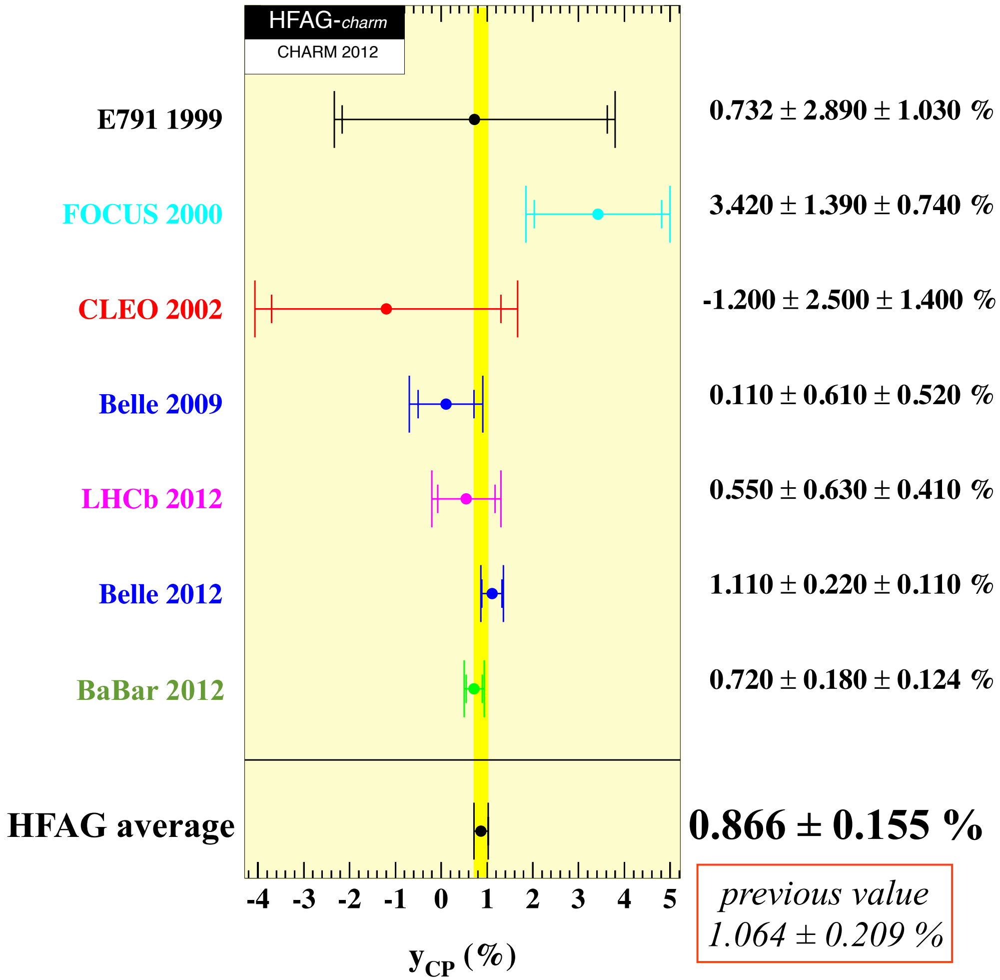
Mean proper decay time as a function of $\cos\theta^*$ for $D^0 \to K^-\pi^+$



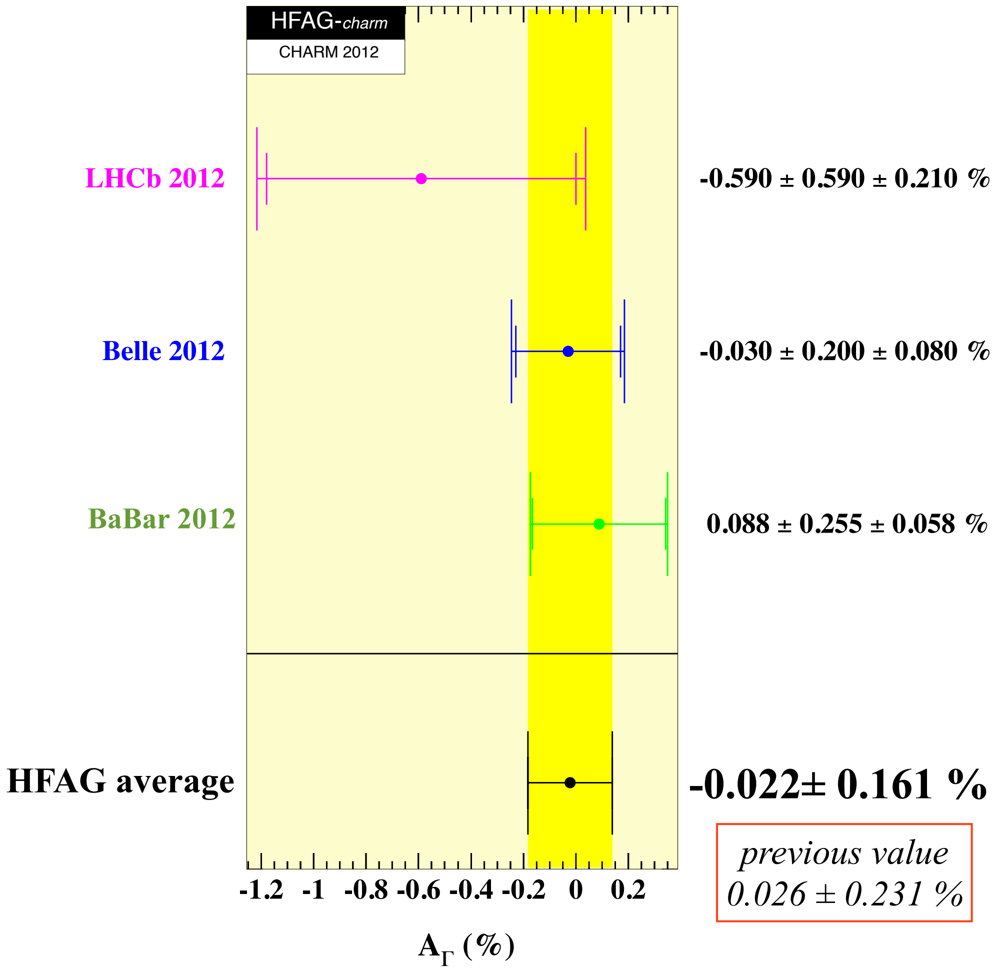
- Disagreement between data and MC of up to 5% of lifetime
  - due to different resolution function offsets
  - attributed to SVD misalignments
- Measurement therefore performed in bins of $\cos\theta^*$
  - 20 bins
  - additional cut: $|\cos\theta^*| < 0.9$ (1% events lost)

New HFAG averages for y_{CP} and A_Γ

NEW



previous value
1.064 ± 0.209 %



previous value
0.026 ± 0.231 %

Including new BaBar and Belle results: significant improvement in the uncertainty and lower value for y_{CP}.

Sensitivity studies at SuperB for charm mixing and CPV

Decay Mode	*BABAR*	Super$B$	LHCB
K^+K^- (D^*-tag):			
N (Events)	88×10^3	13.7×10^6	8×10^6
Δy_{CP} (stat)	$\pm 3.9 \times 10^{-3}$	0.28×10^{-3}	0.5×10^{-3}
K^+K^- (no tag):			
N (Events)	330×10^3	51.4×10^6	–
Δy_{CP} (stat)	$\pm 2.3 \times 10^{-3}$	0.19×10^{-3}	–
$K^+\pi^-$ (WS):			
N (Events)	5.1×10^3	0.79×10^6	0.23×10^6
$\Delta y'$ (stat)	$\pm 4.4 \times 10^{-3}$	0.31×10^{-3}	0.87×10^{-3}
$\Delta x'^2$ (stat)	$\pm 3.0 \times 10^{-4}$	0.21×10^{-4}	0.64×10^{-4}

- Several sensitivity studies for charm mixing and search for CP violation. Relatively good shape.
- Model independent Dalitz plot 3-body analyses not studied yet. Approach suggested by Bondar et. al. Requires charm threshold coherent data.

Strategy	Decay	$\sigma(\lvert q_D/p_D \rvert) \times 10^2$	$\sigma(\phi_M)^\circ$
HFAG (direct *CPV* allowed):			
Global χ^2 fit	<All modes>	± 18	± 9
Asymmetries a_z:			
x_D	<All modes>	± 1.8	
y_D	<All modes>	± 1.1	
y_{CP}	K^+K^-	± 3.8	$a_z = \frac{z^+ - z^-}{z^+ + z^-} \approx \frac{1 - \left\lvert \frac{q}{p} \right\rvert^2}{1 + \left\lvert \frac{q}{p} \right\rvert^2}$
y'	$K^+\pi^-$	± 4.9	
x'^2	$K^+\pi^-$	± 4.9	–
x''	$K^+\pi^-\pi^0$	± 5.4	–
y''	$K^+\pi^-\pi^0$	± 5.0	–
TDDP (*CPV* allowed):			
Model-dependent	$K_S^0 h^+h^-$	± 8.4	± 3.3
BES III DP model	$K_S^0 h^+h^-$	± 3.7	± 1.9
Super$B$ DP model	$K_S^0 h^+h^-$	± 2.7	± 1.4
SL Asymmetries a_{SL}:			
75 ab^{-1} at $\Upsilon(4S)$	$X\ell\nu_\ell$	± 10	
500 fb^{-1} at $\psi(3770)$	$K\pi$	± 10	
500 fb^{-1} at $\psi(3770)$	$X\ell\nu_\ell$	TBD	

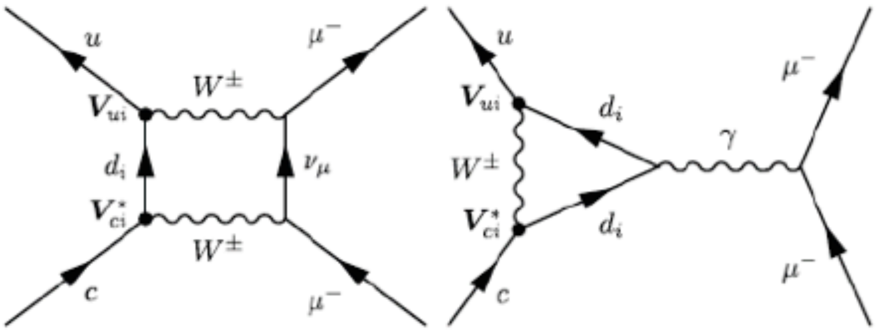
Rare decays

D. Pedrini at Charm 2012

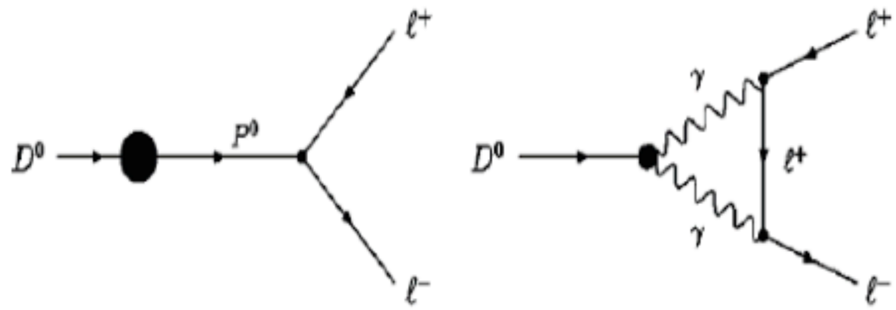
Motivation

- FCNC decay $D^0 \rightarrow \mu^+\mu^-$ is highly suppressed in SM

(~$\mathbf{10^{-18}}$ from short-distance, increasing to ~$\mathbf{10^{-13}}$ when long-distance processes are included, [Burdnam et al.,Phys.Rev.D66:014009,2002])



short-distance



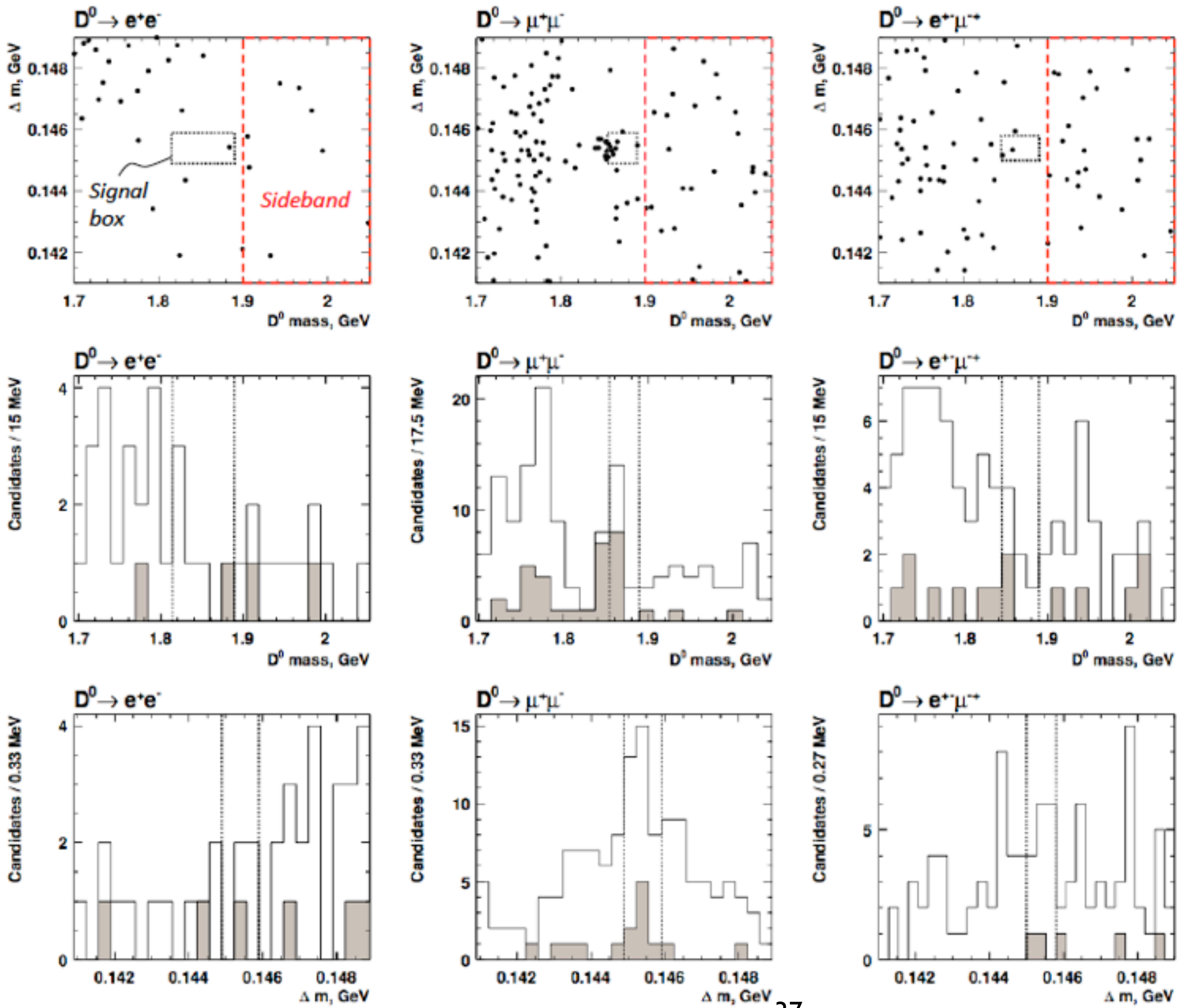
long-distance

New Physics contributions can enhance the branching ratio by several order of magnitudes.

Search for D^0 to ll' – Overview

- Preliminary results based on 468 fb^{-1} of BaBar data.
  - Full dataset at or near the Upsilon(4S).
- Combinatoric backgrounds also dominated by semileptonic *B* and charm decays
  - Suppressed with kinematic and vertex requirements
- Signal yield estimated in a "Cut-and-count" approach.
- Signal normalized relative to D^0 to $\pi^+\pi^-$
  - Several sources of systematic uncertainties eliminated.
- Combinatoric background estimated from upper D^0 mass sideband
- Peaking background from D^0 to $\pi^+\pi^-$ estimated from mis-ID probabilities measured in data.

Search for D^0 to ll' – selected events



$\Delta m \equiv m(D^{*+}) - m(D^0)$

Scatter plot of Δm vs m(D^0)

m(D^0) projections
open – wide Δm
shaded – signal Δm

Δm projections
open – wide m(D^0)
shaded – signal m(D^0)

BaBar preliminary

Search for D^0 to ll' – Results

	$D^0 \to e^+e^-$	$D^0 \to \mu^+\mu^-$	$D^0 \to e^\pm\mu^\mp$
$N_{BG}^{\rm comb}$ (combinatoric background)	$0.97 \pm 0.39 \pm 0.35$	$1.24 \pm 0.27 \pm 0.25$	$1.00 \pm 0.25 \pm 0.20$
$N_{BG}^{\pi\pi}$ (peaking $\pi^+\pi^-$ background)	$0.037 \pm 0.012 \pm 0.004$	$2.64 \pm 0.22 \pm 0.43$	$0.42 \pm 0.08 \pm 0.02$
N_{BG} (total background)	$1.01 \pm 0.39 \pm 0.35$	$3.88 \pm 0.35 \pm 0.50$	$1.42 \pm 0.26 \pm 0.20$
$N_{\rm obs}$ (events in signal box)	1	8	2
$\epsilon_{\ell\ell}$ (signal efficiency)	9.48%	6.29%	6.97%
$\mathcal{B}_{\ell\ell}$ (signal branching fraction)	$(0.1\ ^{+0.7}_{-0.4}) \times 10^{-7}$	$(3.3\ ^{+2.6}_{-2.0}) \times 10^{-7}$	$(0.5\ ^{+1.3}_{-0.9}) \times 10^{-7}$
$\mathcal{B}_{\ell\ell}$ 90% confidence interval	$< 1.7 \times 10^{-7}$	$[0.6, 8.1] \times 10^{-7}$	$< 3.3 \times 10^{-7}$

All results are preliminary

- Systematic uncertainties
  - Multiplicative: about 5%, mostly from $\pi\pi/ll$ PID efficiency uncertainty.
  - Additive, comb BG: sig/SB ratio from varying fit of background MC.
  - Additive, $\pi\pi$ BG: data vs MC difference in mis-ID prob. and double-fake correlation factor.
- Branching fraction results
  - Used Feldman-Cousins to determine 90% confidence interval. Systematics included.
  - No statistically significant excess over expected background.
  - Upward background fluctuation in $\mu\mu$ mode (~5% probability or 1.6 "sigma").
  - BF limits similar in sensitivity to Belle results°, though not better (lower).
  - LHCb sensitivity★ in $\mu\mu$ mode now at 10^{-8} level. No sign of signal.

°Belle publication: M. Petric *et al.*, PRD **81**, 091102(R) (2010).
★LHCb preliminary: W. Bonivento and F. Dettori *et al.*, LHCb-CONF-2012-005.

$D^0 \to \mu^+\mu^-$ at LHCb

Normalization: $D^{*+} \to D^0(\to \pi^+\pi^-)\pi^+$ yield extracted with an unbinned extended two-dimensional fit in mass and Δm

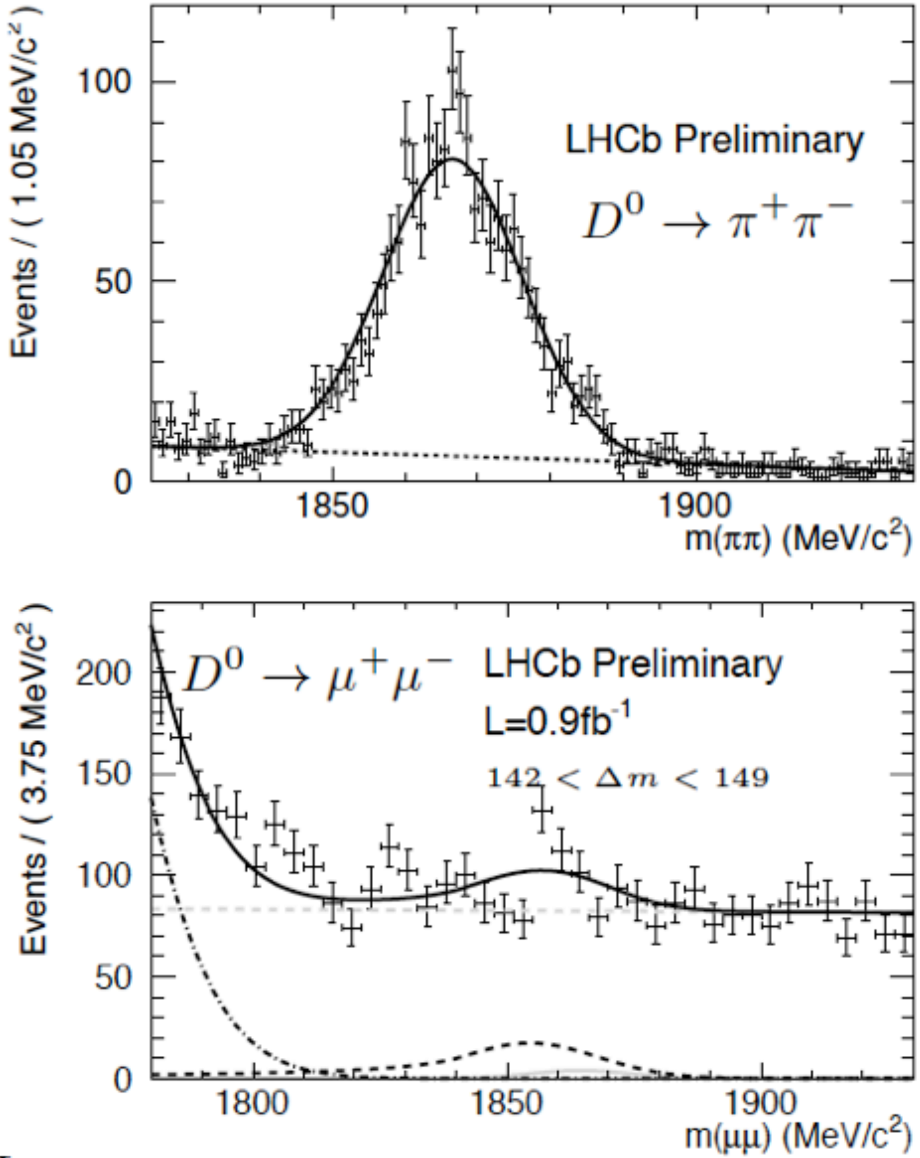
Single event sensitivity :

$$\alpha = (1.96 \pm 0.23) \cdot 10^{-10}$$

- Two-dimensional fit in $M(\mu\mu)$ and Δm
- Signal: gaussian(M) $\times$ double gauss (Δm)
- $D^0 \to \pi^+\pi^-$ mis-ID: Crystal Ball(M) $\times$ double gauss (Δm)
- $D^0 \to K^-\pi^+$ tail mis-ID: gaussian(M) $\times$ gaussian (Δm)
- Combinatorial background: expo(M) $\times$ f(Δm)

$$f(\Delta m) = \left(\frac{\Delta m}{a}\right)^2 (1 - e^{\frac{\Delta m - \Delta m_0}{c}}) + b \cdot (\frac{\Delta m}{d} - 1)$$

[LHCb-CONF-2012-005]



$\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3\ (1.1) \cdot 10^{-8}$ at 95 (90)%CL

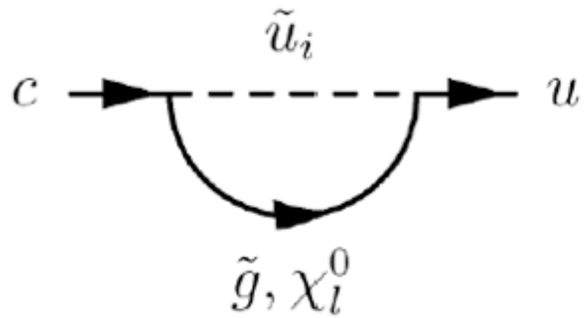
NIKHEF

$D^0 \to \gamma\gamma$

- SM short distance contribution at 3×10^{-11}
- Long distance contribution mainly due to Vector Meson Dominance, predicted to be [Phys.Rev. D66 (2002) 014009]

$$\mathcal{B}^{VMD}_{D^0 \to \gamma\gamma} \simeq 3.5^{4.0}_{-2.6} \cdot 10^{-8}$$

- However $c \to u\gamma$ process can be enhanced up to $6 \cdot 10^{-6}$ (200 times the SM) level in MSSM [Phys.Lett. B500 (2001) 304-312]



$D^0 \to \gamma\gamma$ at BaBar

Fit procedure:

- Unbinned maximum likelihood fit to invariant mass
- $D^0 \to \gamma\gamma$ signal: crystal ball and bifurcated gaussian
- Combinatorial background: 2^{nd} order Chebychev polynomial
- $D^0 \to \pi^0\pi^0$ background Crystal Ball function

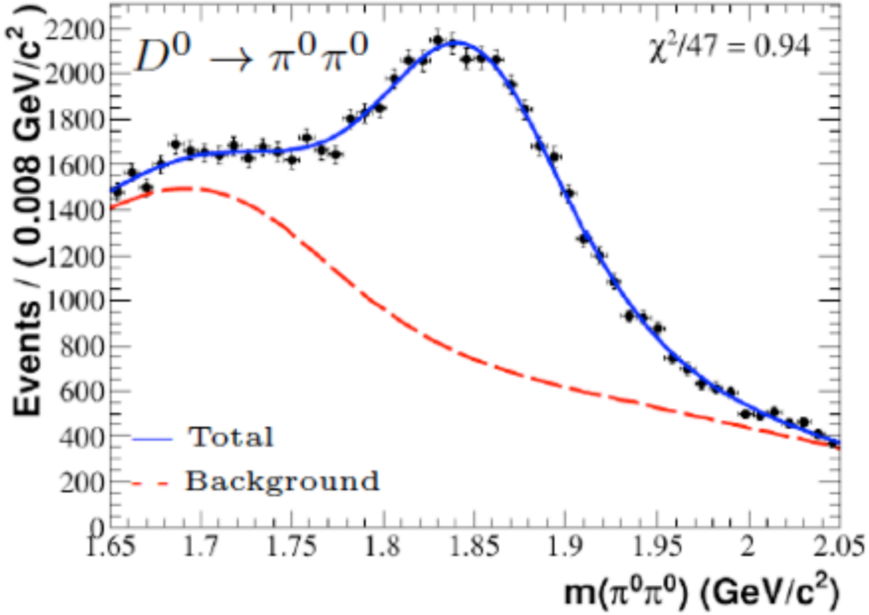
Results:[BaBar submitted to Physical Revew D]
Measured a $D^0 \to \pi^0\pi^0$ branching fraction:

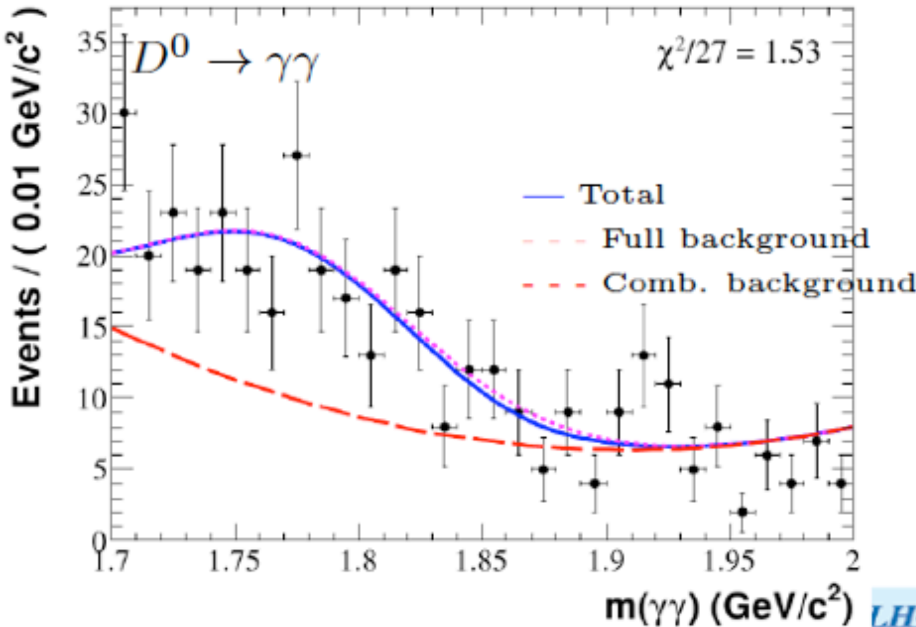
$$\mathcal{B}_{D^0\to\pi^0\pi^0} = (8.4 \pm 0.1 \pm 0.3) \cdot 10^{-4}$$

For $D^0 \to \gamma\gamma$ found negative signal yield $N = -6 \pm 15$ events leading to an upper limit:

$$\mathcal{B}_{D^0\to\gamma\gamma} < 2.2 \cdot 10^{-6} \quad \text{at90\%CL}$$

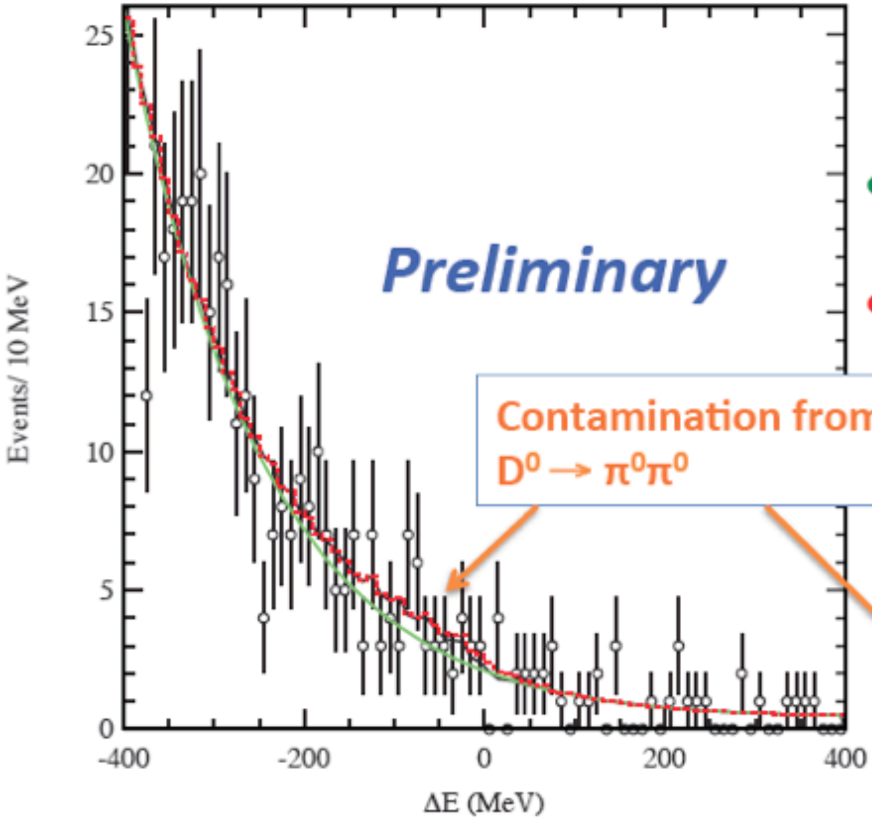
which is constraints NP to at most 70 times the SM.





From BES III

Hajime Muramatsu 15



Contamination from $D^0 \rightarrow \pi^0\pi^0$

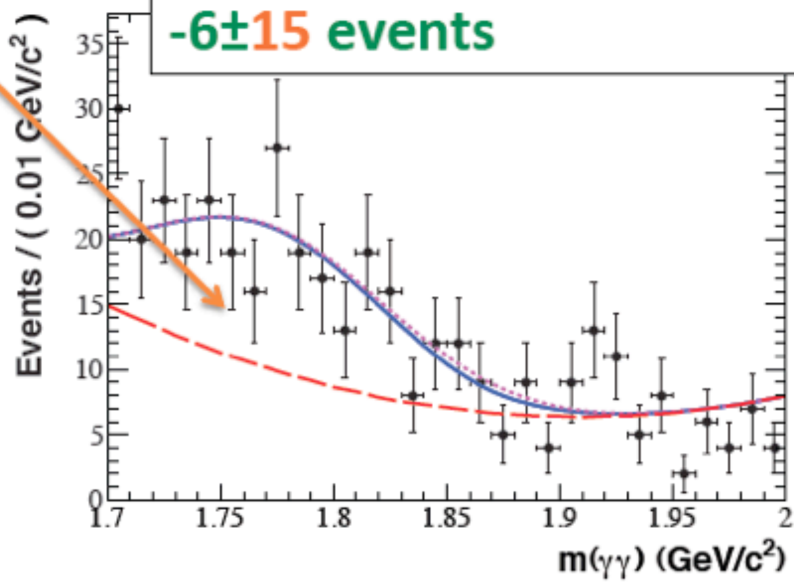
Fit to DATA

2.9 fb^{-1} at $\sqrt{s}$ = 3.773 GeV [~ 21 M D^0 produced]

- Gives: -2.9±7.1 events
- No significant signals.

$B(D^0 \rightarrow \gamma\gamma) < 4.6\times10^{-6}$ UL @ 90% CL.

BaBar:hep-ex:1110.6480
-6±15 events



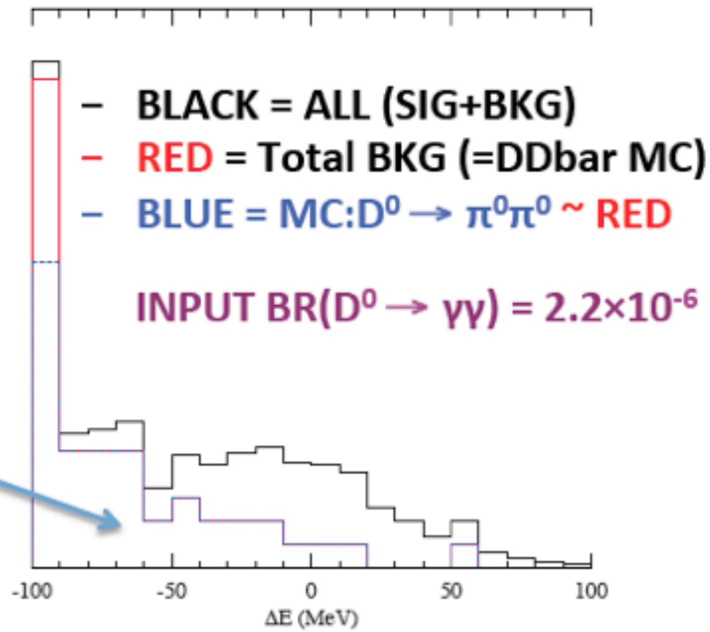
W.r.t. the BaBar's result:

- BKG_{BESIII}/BKG_{BaBar} ~ 0.5
- $\varepsilon_{BESIII}/\varepsilon_{BaBar}$ ~ 2
- BUT, $N_{BESIII}(D^0)/N_{BaBar}(D^0)$ ~ 0.1

Prospects

- Should have improved results (i.e., systmatics) on $B(D^0 \to \gamma\gamma)$ soon along with a measurement on $B(D^0 \to \pi^0\pi^0)$.

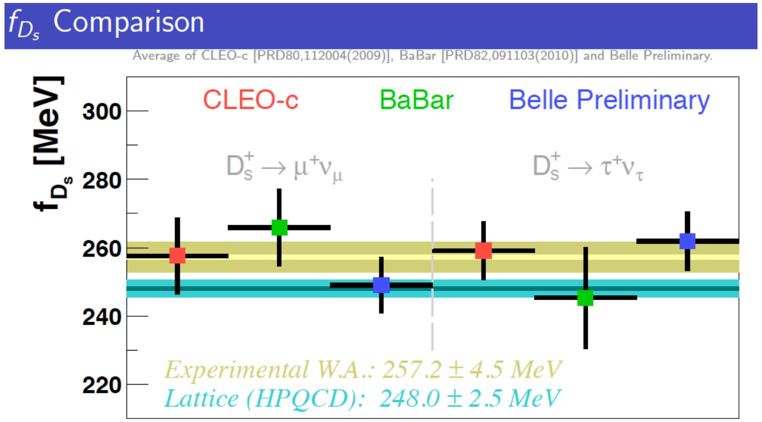
- Another possible method which takes real advantage of our unique data set:
  - Our D^0s from $\psi(3770)$ are always produced in pairs.
  - Reconstruct one D^0 with known channels while looking for $D^0 \to \gamma\gamma$ on the other.
  - This double-tag method might leave us only the irreducible background from $D^0 \to \pi^0\pi^0$ (i.e., no Bhabha, qqbar contaminations) which we measure.



- Intend to look for other radiative decays of D^+, D^0, and D_s^+ as well.

Sensitivity studies at SuperB for rare decays

- Studies are ongoing using Fast Simulation for sensitivity studies of:
  - $D^0 \to \mu^+\mu^-$, $D^0 \to \mu^+\mu^-\gamma$(which is the rate for this in the SM?), $D^0 \to \gamma\gamma$,...
- It would be interesting to study also sensitivities for:
  - $D^+ \to \mu^+\nu$, $D_s^+ \to \mu^+\nu$, $\tau^+\nu$ at $\psi(3770)$ and $\psi(4170)$ respectively.



CLEO-c similar achieved similar precision on $f(D_s)$ to B factories with about x500 less integrated luminosity.

- Study sensitivities for FCNC modes:
  - $c \to u\, l^+l^-$