Recent results on mixing and CPV in charm decays at B factories

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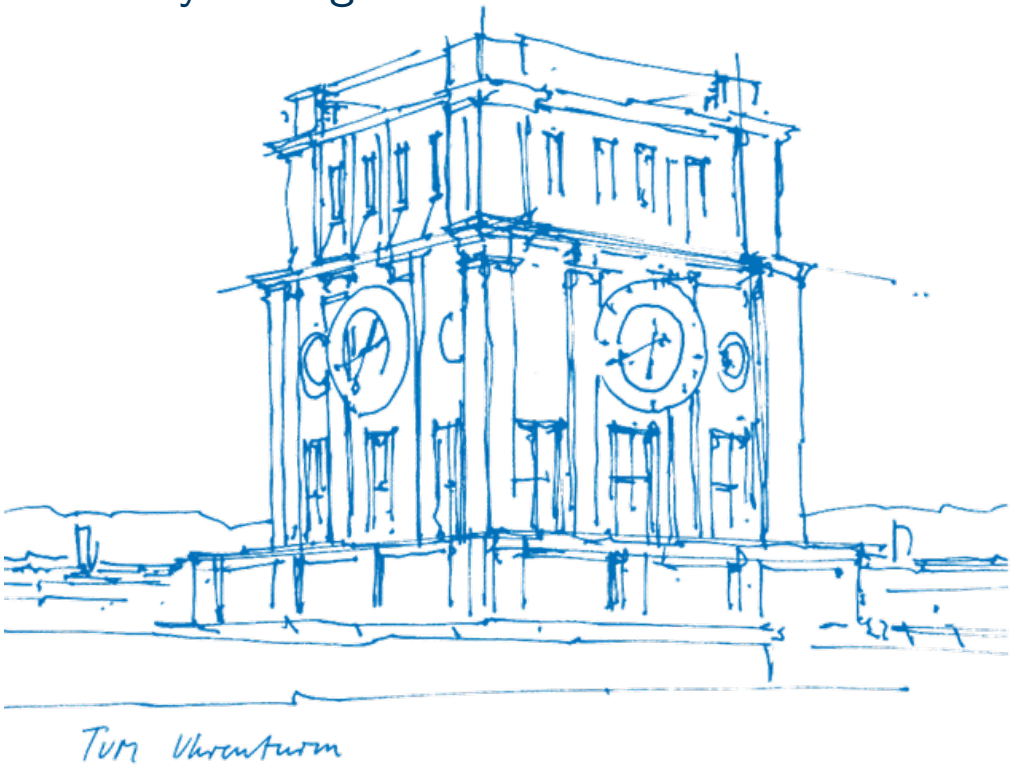
10th International Workshop on the CKM Unitarity Triangle
Heidelberg, September 18, 2018



Outline

- B Factories
- Analysis Methods
- Recent Mixing Measurements
  - $D^0 \to \pi^+\pi^-\pi^0$
  - $D^0 \to K^+K^-$ and $\pi^+\pi^-$
- Recent CP-Violation Measurements
  - $D^+ \to \pi^+\pi^0$
  - $D^0 \to K^0_S K^0_S$
  - $D^0 \to \rho^0\gamma, \phi\gamma,$ and $\bar{K}^{*0}\gamma$

The B Factories: BaBar & Belle

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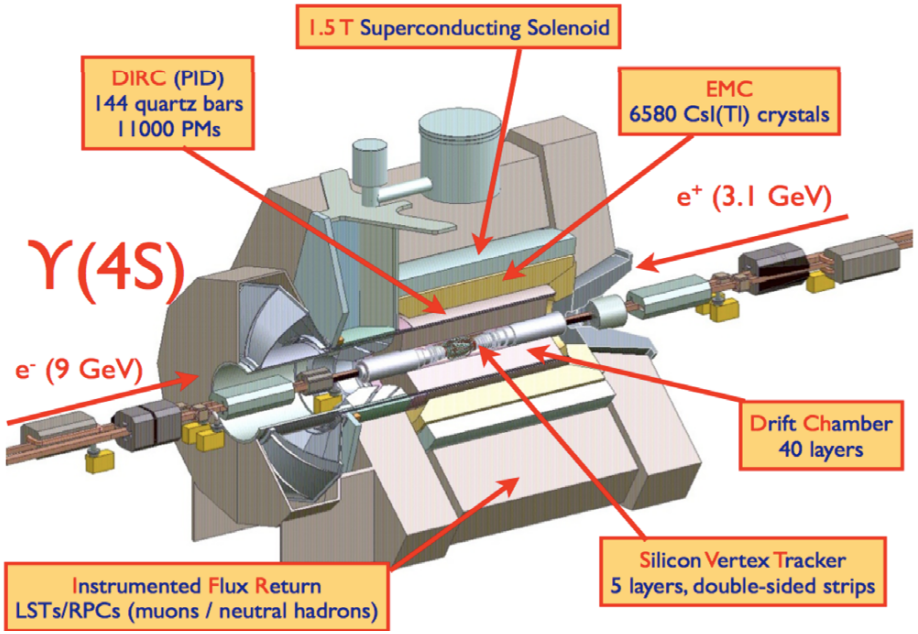
Experiments at asymmetric-energy e^+e^- colliders

$$\text{BaBar} \quad @ \quad \text{PEP-II} \quad \longrightarrow \quad \sim 550\,\text{fb}^{-1}$$
$$\text{Belle} \quad @ \quad \text{KEKB} \quad \longrightarrow \quad \sim 1\,\text{ab}^{-1}$$

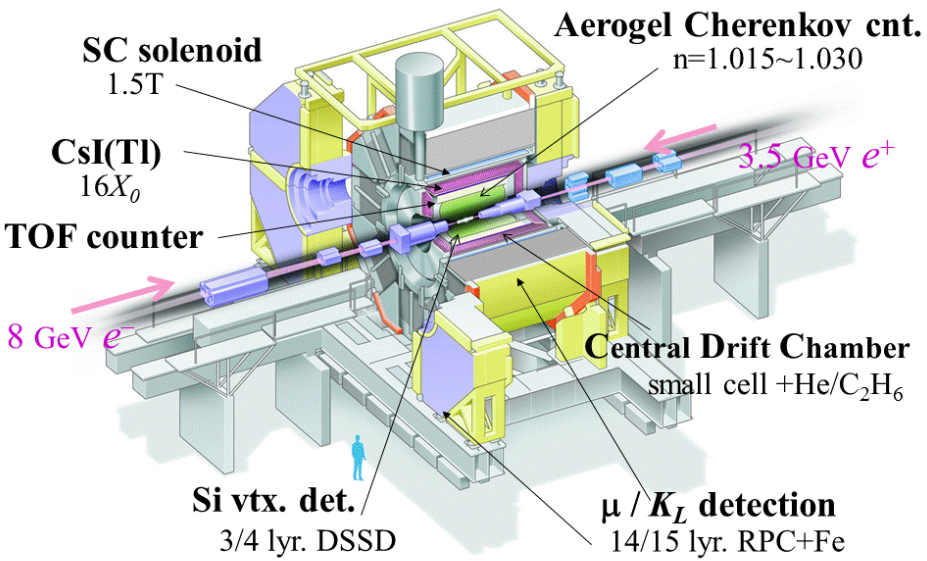
running mostly at $\sqrt{s} \approx \Upsilon(4S)$ mass $\longrightarrow$ for B physics

Cross section for $c\bar{c}$ (1.3 nb) larger than for $b\bar{b}$ (1.1 nb)

BaBar



Belle



Methods: Final-State Particles

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I will present some recent analyses of decays

$$D^{\pm} \text{ or } D^0 \to K^{\pm},\ \pi^{\pm},\ K^0_S,\ \pi^0,\ \gamma$$

How do we reconstruct such events?

- $K^{\pm}$, $\pi^{\pm}$:
  - tracks in the detector $\to$ selected by track quality $\to$ "good" tracks
  - identified by PID information from detectors $\to$ "good" pions and kaons
- K^0_S
  - via decay to $\pi^+\pi^-$
  - identified by displacement, vertexing, ... $\to$ "good" K^0_S's
- π^0
  - via decay to $\gamma\gamma$
  - identified by diphoton invariant mass $\to$ "good" π^0's
- γ
  - seen as cluster in electromagnetic calorimeter
  - selected by quality and disociation with tracks & π^0's $\to$ "good" photons

Methods: D mesons from $c\bar{c}$ events

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Now we have our final-state particles

- Reconstruct D
  - by invariant mass, by vertexing
  - veto uds and non-D B decays
- Require minimum momentum of D (or D^*)
  - veto $b\bar{b}$ events with decay to charm
  - veto combinatorically constructed D

Methods: Flavor Tagging

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Now we have our D meson, we tag flavor (and veto background)

- From D^* decay:

$$\begin{aligned} D^{*+} &\to \pi^+ D^0 \\ D^{*-} &\to \pi^- \overline{D}^0 \end{aligned}$$

  (rest of the event ignored)

- Full charm event reconstruction

$$e^+e^- \to c\bar{c} \to X_{\mathrm{frag}} + X_{\bar{c}} + D^{(*)}$$

  (see A. Schwartz's talk on Belle II)

Both help reduce backgrounds, too.

Methods: Lifetime

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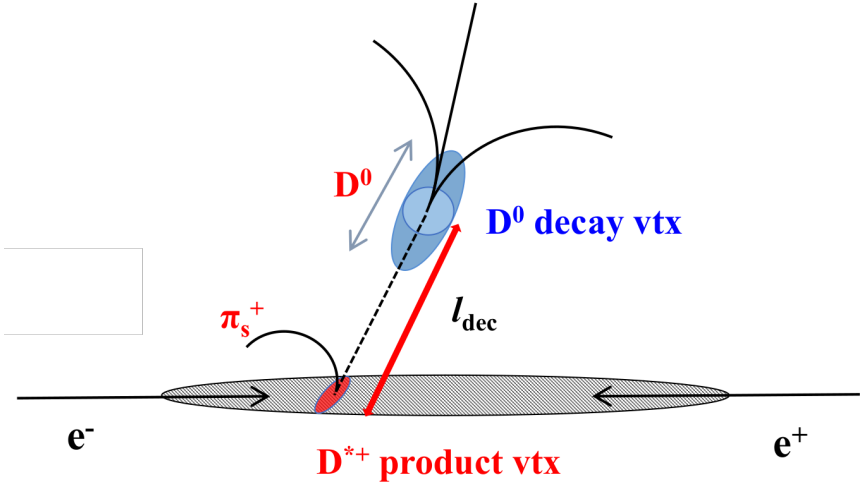
Mixing measurements require lifetime:



$$t_{\mathrm{meas}} = l_{\mathrm{dec}}/c\beta\gamma \quad \text{with} \quad \beta\gamma = \left|\vec{p}_{\mathrm{D}^0}\right|/m_{\mathrm{D}^0}$$

(with a projection of $\vec{l}_{\mathrm{dec}}$ onto $\hat{p}_{\mathrm{D}^0}$ often used)

uncertainty on t from uncertainties on production vertex, decay vertex, and momentum used to create resolution function:

$$\mathcal{R}(t_{\mathrm{true}}|t_{\mathrm{meas}}, \sigma_t^2)$$

$D^0 \to \pi^+\pi^-\pi^0$: BaBar; PRD93, 112014 (2016)

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Measurement of $D^0/\overline{D}^0$ mixing parameters from time-dependent Dalitz analysis

$$x = \frac{m_1 - m_2}{\frac{1}{2}(\Gamma_1 + \Gamma_2)} \quad \text{and} \quad y = \frac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$$

the normalized mass-eigenstate mass & width differences, where

$$\left|D^0(t)\right\rangle = \frac{1}{2p}\left(\left|D_1^0(t)\right\rangle + \left|D_2^0(t)\right\rangle\right) \quad \text{and} \quad \left|\overline{D}^0(t)\right\rangle = \frac{1}{2q}\left(\left|D_1^0(t)\right\rangle - \left|D_2^0(t)\right\rangle\right)$$

with flavor eigenstates D^0 and $\overline{D}^0$; and mass eiegenstates D_1^0 and D_2^0

$D^0 \to \pi^+\pi^-\pi^0$: BaBar; PRD93, 112014 (2016)

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From a data sample of 468 fb^{-1} at and below $\sqrt{s} \approx \Upsilon(4S)$ mass

$$\boxed{D^{*+} \to \pi_s^+ D^0, \quad D^{*-} \to \pi_s^- \overline{D}^0 \quad \text{and} \quad D^0/\overline{D}^0 \to \pi^+\pi^-\pi^0}$$

Extra care is taken to veto spurious "soft" pions (π_s^+)

A fit is performed to the whole decay chain to contrain

- the D decay vertex
- the D production vertex (D^* decay vertex)
- the D mass
- the π^0 mass

Require:

- D momentum above minimum $\to$ remove BG and B decay
- $\Delta m \equiv m(D^*) - m(D)$ within narrow band of nominal value
- $t \in [-2, 3]$ps and $\sigma_t < 0.8$ ps
- veto against $D^0 \to K_S^0\pi^0,\ K^-\pi^+\pi^0,\ K_S^0\pi^+\pi^-$ events

$D^0 \to \pi^+\pi^-\pi^0$: BaBar; PRD93, 112014 (2016)

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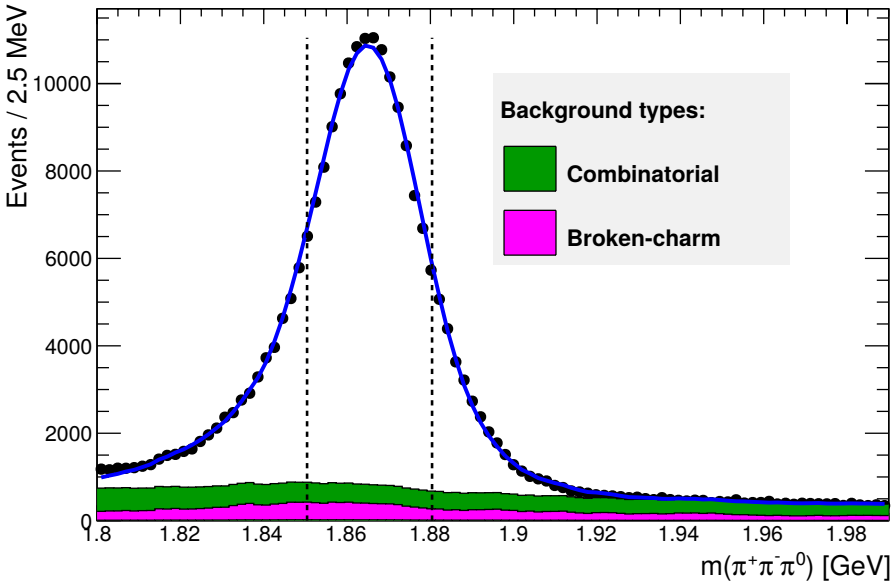
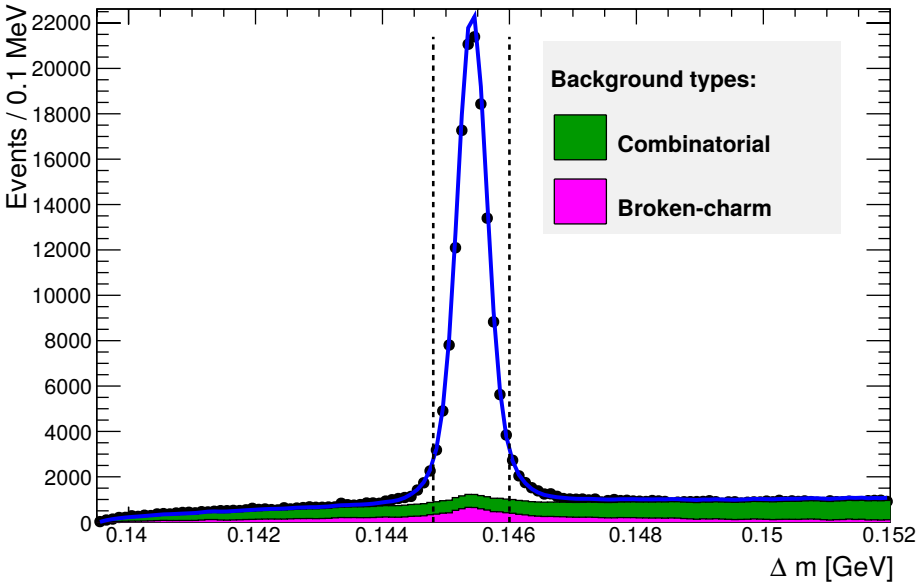
$\Rightarrow 138 \times 10^3$ decays with 91 % purity





("Broken charm" = misreconstructed D^0)

includes small fraction ($< 1\,\%$) of wrongly-reconstructed D^*
$\to$ flavor tagging assumed random

$D^0 \to \pi^+\pi^-\pi^0$: BaBar; PRD93, 112014 (2016)

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D^* decays to flavor eigenstate, which decays to $\pi^+\pi^-\pi^0$ according to

$$|\mathcal{A}|^2 \propto \overbrace{e^{-\frac{t}{\tau_D}}|A|^2\left[\cosh\left(y\frac{t}{\tau_D}\right)+\cos\left(x\frac{t}{\tau_D}\right)\right]}^{\text{direct}} + \overbrace{e^{-\frac{t}{\tau_D}}\left|\frac{q}{p}\bar{A}\right|^2\left[\cosh\left(y\frac{t}{\tau_D}\right)-\cos\left(x\frac{t}{\tau_D}\right)\right]}^{\text{mixing}}$$
$$\underbrace{-\,2e^{-\frac{t}{\tau_D}}\left[\mathrm{Re}\left(\frac{q}{p}A^*\bar{A}\right)\sinh\left(y\frac{t}{\tau_D}\right)-\mathrm{Im}\left(\frac{q}{p}A^*\bar{A}\right)\sin\left(x\frac{t}{\tau_D}\right)\right]}_{\text{interference}}$$

holding at all points in the Dalitz space:

$$A \equiv A(s_+, s_-), \quad \bar{A} \equiv \bar{A}(s_+, s_-) \quad \text{with} \quad s_+ \equiv m^2(\pi^+\pi^0), \quad s_- \equiv m^2(\pi^-\pi^0)$$

time-dependent unbinned Dalitz-plot analysis to fit

- amplitudes for decay to intermediate states
- x, y, and τ_D

including convolution with time resolution function

analysis assumes CP: $q/p = 1$ and $\bar{A}(s_+, s_-) = A(s_-, s_+)$

$D^0 \to \pi^+\pi^-\pi^0$: BaBar; PRD93, 112014 (2016)

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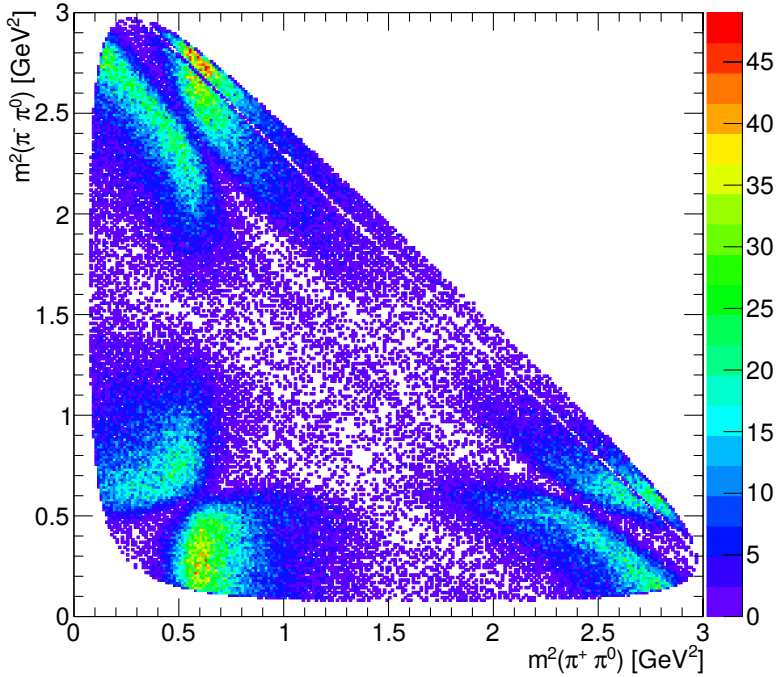
The Dalitz model contains

- $\rho(770)$, $\rho(1450)$, $\rho(1700)$ in positive, negative, and neutral charges
- $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, $f_2(1270)$, and $f_0(500)$
- and a flat nonresonant component



$D^0 \to \pi^+\pi^-\pi^0$: BaBar; PRD93, 112014 (2016)

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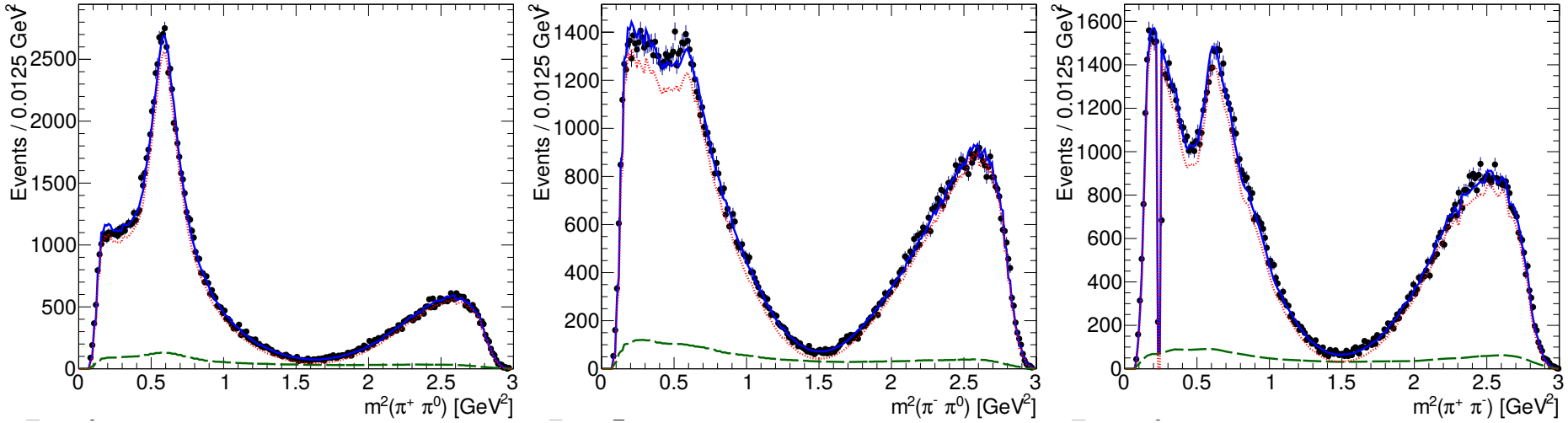
- and a flat nonresonant component

s_+ s_- s_0



data, fit, signal function, background function (from sidebands)

$D^0 \to \pi^+\pi^-\pi^0$: BaBar; PRD93, 112014 (2016)

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The fit results in

$$\boxed{x = (15 \pm 12 \pm 6)‰ \qquad y = (2 \pm 9 \pm 5)‰} \qquad \tau_D = (410.2 \pm 3.8)\,\text{fs}$$

From $D^0 \to K^0_S\pi^+\pi^-$

		x	y	
2016	LHCb	$(-8.6 \pm 5.3 \pm 1.7)$ ‰	$(-0.3 \pm 4.6 \pm 1.3)$ ‰	
2016	Belle	$(5.6 \pm 1.9^{+0.7}_{-1.3})$ ‰	$(3.0 \pm 1.5^{+0.5}_{-0.8})$ ‰	
2014	BaBar	$(1.6 \pm 2.3 \pm 1.4)$ ‰	$(5.7 \pm 2.0 \pm 1.5)$ ‰	(incl. $K^0_S K^+K^-$)
2005	CLEO	$(19^{+32}_{-33} \pm 6)$ ‰	$(-14 \pm 24 \pm 9)$ ‰	

$D^0 \to K^+K^-, \pi^+\pi^-$: Belle; PLB753 412 (2016)

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updated measurement of $y_{\rm CP}$ and A_Γ using the full Belle data set in decays

$$D^0 \to K^+K^- \quad \text{and} \quad D^0 \to \pi^+\pi^-$$

$$\boxed{y_{\rm CP} \equiv \frac{\tau(D^0 \to K^-\pi^+)}{\tau(D^0 \to h^+h^-)} - 1}$$

and

$$\boxed{A_\Gamma \equiv \frac{\tau(\overline{D}^0 \to h^+h^-) - \tau(D^0 \to h^+h^-)}{\tau(\overline{D}^0 \to h^+h^-) + \tau(D^0 \to h^+h^-)}}$$

These relate to x and y: $(\phi \equiv \arg(q/p))$

$$y_{\rm CP} = \frac{1}{2}\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) y\cos\phi - \frac{1}{2}\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) x\sin\phi \xrightarrow{\text{CP}} y$$

$$A_\Gamma = \frac{1}{2}\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) y\cos\phi - \frac{1}{2}\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) x\sin\phi \xrightarrow{\text{CP}} 0$$

So $y_{\rm CP} \neq y \to$ CP violation.

$D^0 \to K^+K^-, \pi^+\pi^-$: Belle; PLB753 412 (2016)

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From a data sample of 976 fb^{-1}

$$\boxed{D^{*+} \to \pi_s^+ D^0, \quad D^{*-} \to \pi_s^- \overline{D}^0 \quad \text{and} \quad D^0/\overline{D}^0 \to K^+K^-, \pi^+\pi^-, K^-\pi^+}$$

requiring "good" pions and kaons

- fit for D decay vertex
- fit for D production vertex (D^* decay vertex)

Require

- D^* momentum above minimum $\to$ remove BG and B decay
- D mass within 2.25σ window around nominal mass
- Δm within narrow window of nominal value
- $\sigma_t < 370\,\mathrm{fs}$

$D^0 \to K^+K^-, \pi^+\pi^-$: Belle; PLB753 412 (2016)

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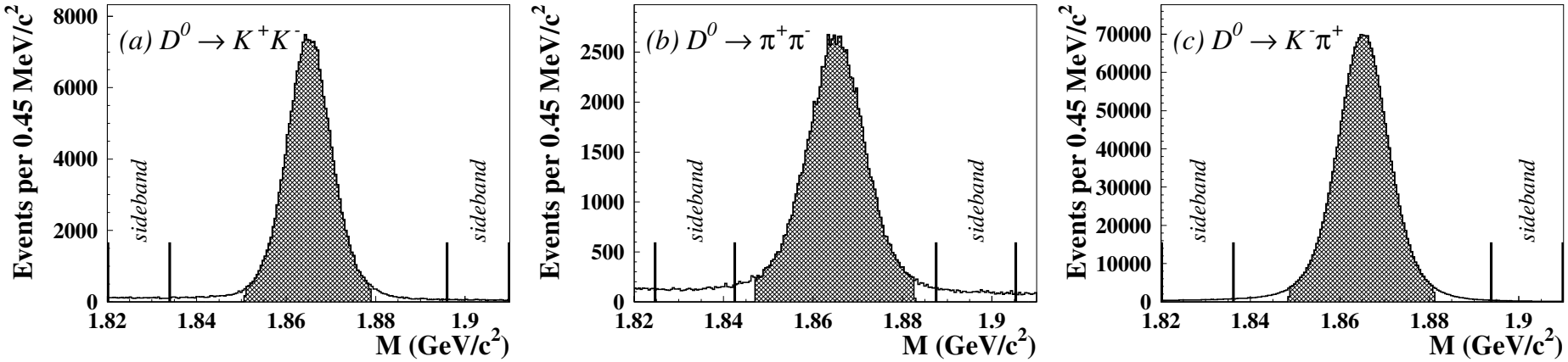
$\Rightarrow$

- 242×10^3 K^+K^- events; 98 % pure
- 114×10^3 $\pi^+\pi^-$ events; 93 % pure
- 2.61×10^6 $K^-\pi^+$ events; 99.7 % pure



$D^0 \to K^+K^-, \pi^+\pi^-$: Belle; PLB753 412 (2016)

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measured lifetimes fit to with distributions

$$F(t) \propto \frac{1}{\tau}\int_0^\infty e^{-t/\tau}\mathcal{R}(t|t_{\rm meas},\sigma_t^2)\,{\rm d}t + \text{Background}(t)$$

resolution function accounts for dependence on polar angle of D^0 in CM frame.
It is determined from MC.

The background contains a prompt component and an exponentially decaying component.
It is fixed from fits to the sidebands and MC.

simultaneous fit for $y_{\rm CP}$ and A_Γ (and $\tau_{\rm D}$) to

- $D^0 \to K^+K^-$
- $\overline{D}^0 \to K^+K^-$
- $D^0 \to \pi^+\pi^-$
- $\overline{D}^0 \to \pi^+\pi^-$
- $D^0 \to K^-\pi^+ \quad + \quad \overline{D}^0 \to K^+\pi^-$

$D^0 \to K^+K^-, \pi^+\pi^-$: Belle; PLB753 412 (2016)

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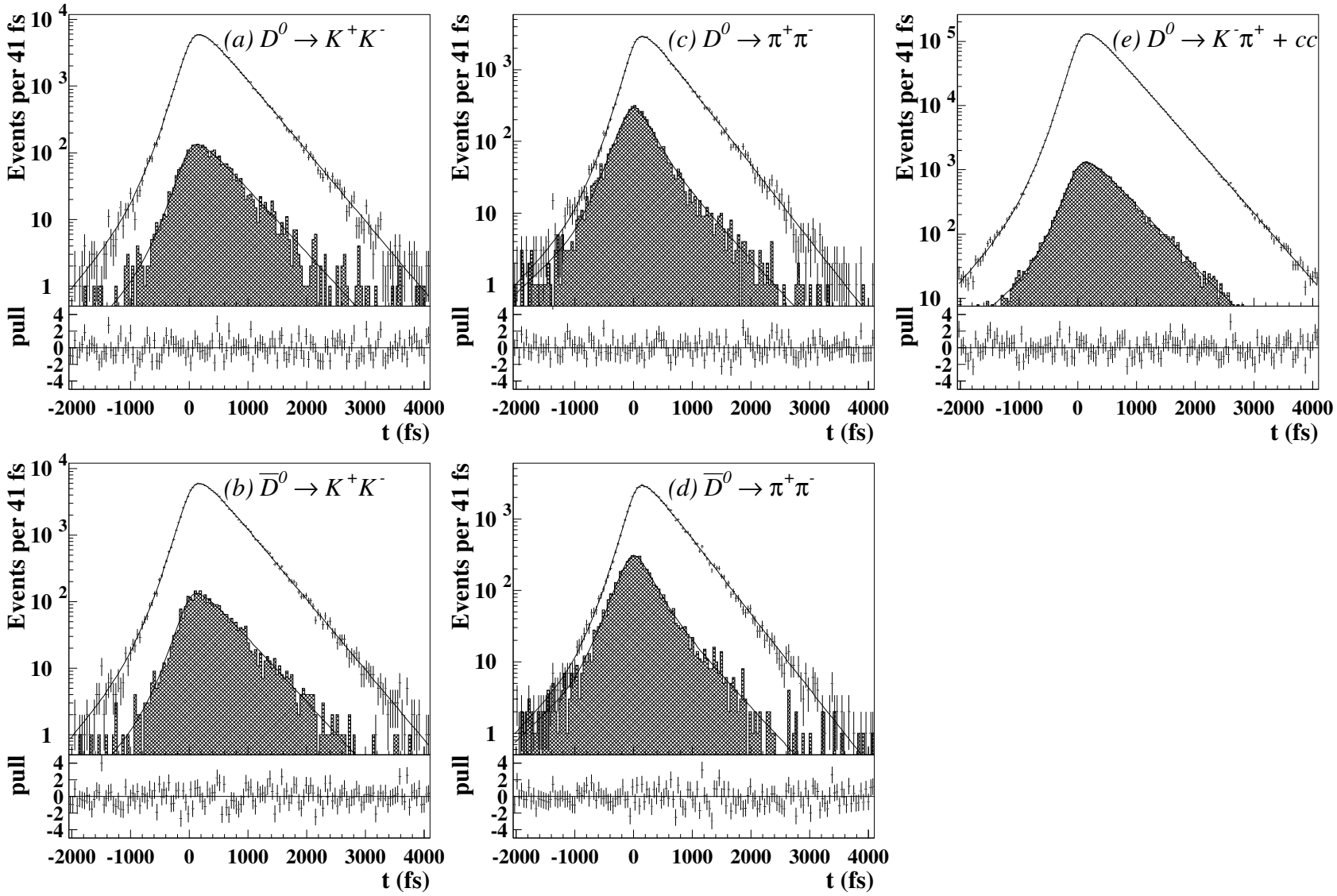

$D^0 \to K^+K^-, \pi^+\pi^-$: Belle; PLB753 412 (2016)

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The fit results in

$$\boxed{y_{\rm CP} = (11.1 \pm 2.2 \pm 0.9)‰ \qquad A_\Gamma = (-0.3 \pm 2.0 \pm 0.7)‰} \quad \tau_{\rm D} = (408.46 \pm 0.54)\,\text{fs}$$

Also from K^+K^-, $\pi^+\pi^-$

		$y_{\rm CP}$	A_Γ
2016	LHCb (D^*)		$(-0.12 \pm 0.28 \pm 0.10)‰$
2016	LHCb (leptonic)		$(-0.30 \pm 0.32 \pm 0.10)‰$
2012	BaBar	$(7.2 \pm 1.8 \pm 1.2)‰$	$(0.9 \pm 2.6 \pm 0.6)‰$
2007	Belle	$(13.1 \pm 3.2 \pm 2.5)‰$	$(0.1 \pm 3.0 \pm 1.5)‰$

Previous systematic uncertainty reduced;
in large part from robust resolution function:

- 1.4 ‰ → 0.3 ‰ in $y_{\rm CP}$;
- 0.8 ‰ → 0.02 ‰ in A_Γ

$D^+ \to \pi^+\pi^0$: Belle; PRD97, 011101 (2018)

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For D $\to \pi\pi$, the standard model expectation is

$$A^{\mathrm{CP}}(\Delta I = 3/2) \approx 0 = \boxed{A^{\mathrm{CP}}(\mathrm{D}^+ \to \pi^+\pi^0) < \mathcal{O}\left(10^{-3}\right)}$$

[Buccella *et al.* PLB302.319 (1993); Grossman, Kagan, Zupan PRD85.114036 (2012); Atwood, Soni PTEP2013.9.093B05 (2013)]

So measuring a sizeable CP asymmetry is a sign of new physics.

$D^+ \to \pi^+\pi^0$: Belle; PRD97, 011101 (2018)

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We can also use the measurement to inform $A^{\rm CP}(\Delta I = 1/2)$:

$$\left|\mathcal{A}(D^0 \to \pi^+\pi^-)\right|^2 + \left|\mathcal{A}(D^0 \to \pi^0\pi^0)\right|^2 - \frac{2}{3}\left|\mathcal{A}(D^+ \to \pi^+\pi^0)\right|^2 = 3\left|\mathcal{A}_{\Delta I=1/2}\right|^2$$

$$\boxed{A^{\rm CP}(\Delta I = 1/2) \approx \frac{\mathcal{B}_{+-}A^{\rm CP}_{+-} + \mathcal{B}_{00}A^{\rm CP}_{00} - \frac{2}{3}\frac{\tau_0}{\tau_+}\mathcal{B}_{+0}A^{\rm CP}_{+0}}{\mathcal{B}_{+-} + \mathcal{B}_{00} + \frac{2}{3}\frac{\tau_0}{\tau_+}\mathcal{B}_{+0}}}$$

Current measurements:

$$A^{\rm CP}_{+-} = (+0.13 \pm 0.14)\,\% \qquad \text{(world average)}$$

$$A^{\rm CP}_{00} = (-0.03 \pm 0.65)\,\% \qquad \text{(Belle)}$$

$$A^{\rm CP}_{+0} = \boxed{(+2.9 \pm 2.9)\,\%} \qquad \text{(CLEO)}$$

$D^+ \to \pi^+\pi^0$: Belle; PRD97, 011101 (2018)

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We measure

$$\frac{N(D^+ \to \pi^+\pi^0) - N(D^- \to \pi^-\pi^0)}{N(D^+ \to \pi^+\pi^0) + N(D^- \to \pi^-\pi^0)} \equiv A^{\rm raw}_{\pi\pi} \approx A^{\rm CP}_{+0} + A^{\rm FB}_{D} + A^{\rm det}_{\pi}$$

$$\frac{N(D^+ \to \pi^+K^0_S) - N(D^- \to \pi^-K^0_S)}{N(D^+ \to \pi^+K^0_S) + N(D^- \to \pi^-K^0_S)} \equiv A^{\rm raw}_{\pi K} \approx A^{\rm CP}_{\pi K} + A^{\rm FB}_{D} + A^{\rm det}_{\pi}$$

So

$$A^{\rm CP}(D^+ \to \pi^+\pi^0) = \underbrace{A^{\rm CP}(D^+ \to \pi^+K^0_S)}_{(-0.363 \pm 0.115)\,\%\ \text{(Belle)}} + A^{\rm raw}_{\pi\pi} - A^{\rm raw}_{\pi K}$$

$D^+ \to \pi^+\pi^0$: Belle; PRD97, 011101 (2018)

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From a data sample of 921 fb^{-1} reconstruct

$$D^\pm \to \pi^\pm\pi^0 \quad \text{and} \quad D^\pm \to \pi^\pm K_S^0$$

requiring "good" pions, π^0's, and K_S^0's
both via $D^{*\pm} \to \pi_s^0 D^\pm$ ("tagged") and without ("untagged")

Require

- $D^{(*)}$ momentum above minimum $\to$ veto BG and B decays

Categorize:

- If π_s^0 found such that Δm is within 1.5σ of nominal value $\to$ "tagged" sample
- Else $\to$ "untagged" sample

Fit for A^{raw} separately in the "tagged" and "untagged" samples $\to$ combine

$D^+ \to \pi^+\pi^0$: Belle; PRD97, 011101 (2018)

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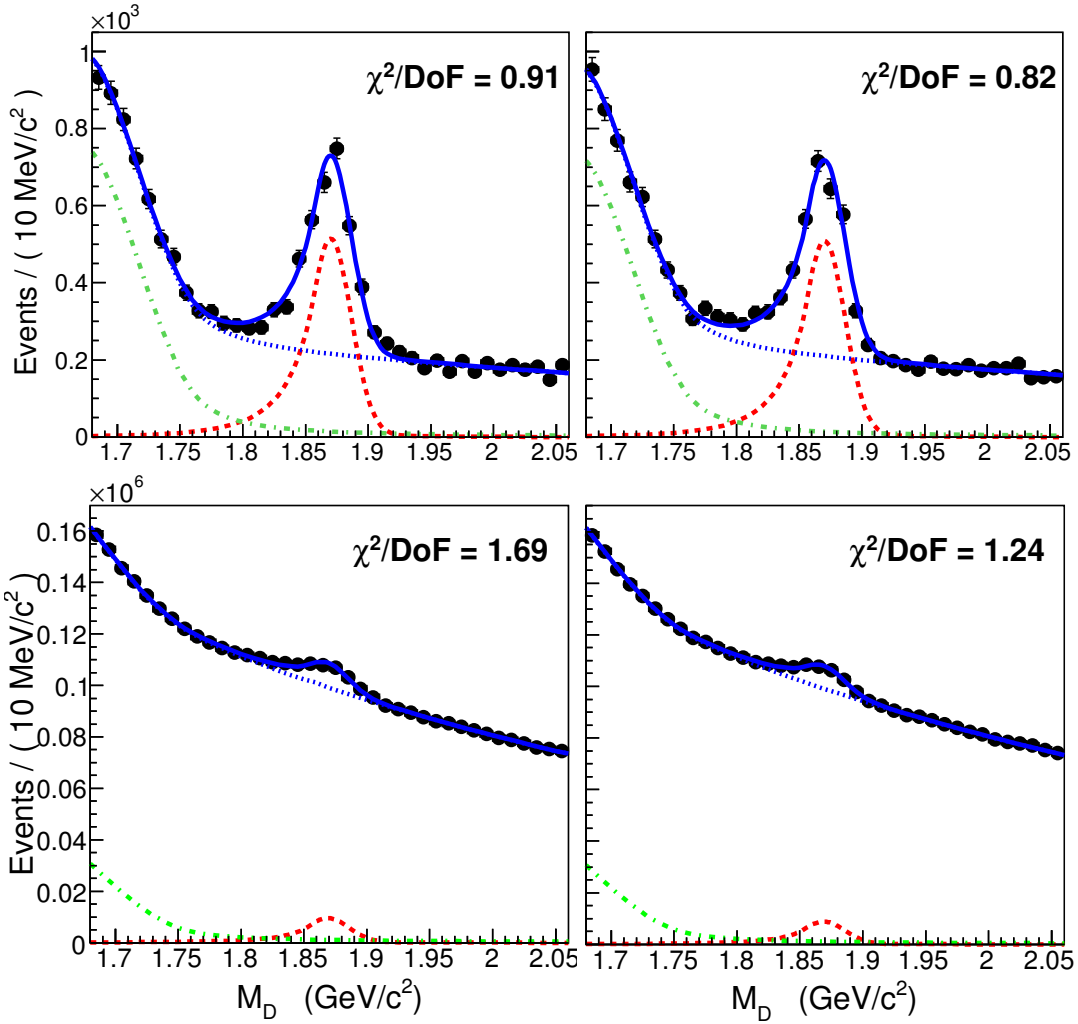
tagged

D^+



D^-

untagged

$D^+ \to \pi^+\pi^0$: Belle; PRD97, 011101 (2018)

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Yields from fit results:

- Tagged: $\approx 7 \times 10^3$ $\pi^\pm\pi^0$ events; $\approx 70 \times 10^3$ $\pi^\pm K_S^0$ events.
- Untagged: $\approx 100 \times 10^3$ $\pi^\pm\pi^0$ events; $\approx 1 \times 10^6$ $\pi^\pm K_S^0$ events.

And the combined result from all fits:

$$A^{\mathrm{CP}}(D^+ \to \pi^+\pi^0) = (+2.31 \pm 1.24 \pm 0.23)\ \%$$

previously $(2.9 \pm 2.9)\,\%$ (CLEO) @ Belle II $\to$ ($\pm 0.18 \pm 0.20)\%$

And an update to

$$A^{\mathrm{CP}}(\Delta I = 1/2) = (-2.2 \pm 2.7)\,\%$$

previously $(-2.7 \pm 4.2)\,\%$ @ Belle II : uncertainty $\lesssim 0.05\,\%$

$D^0 \to K_S^0 K_S^0$: Belle; PRL119, 171801 (2017)

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possible decay to find CP violation in D decay, as we heard yesterday:

$$\left| A^{\mathrm{CP}}(D^0 \to K_S^0 K_S^0) \right| \leq \mathcal{O}(1\,\%)$$

[Hiller, Jung, Schacht PRD87.014024 (2013); Nierste, Schacht PRD92.054036 (2015)]

From a data sample of 921 fb^{-1}

$$\boxed{D^{*+} \to \pi_s^+ D^0, \quad D^{*-} \to \pi_s^- \overline{D}^0 \quad \text{and} \quad D^0 \to K_S^0 K_S^0}$$

from "good" K_S^0's identified by a neural network.

Again, we measure A^{CP} relative to another channel:

$$A^{\mathrm{CP}}(D^0 \to K_S^0 K_S^0) = A^{\mathrm{raw}}_{K_S^0 K_S^0} - A^{\mathrm{raw}}_{K_S^0 \pi^0} + \underbrace{A^{\mathrm{CP}}(D^0 \to K_S^0 \pi^0)}_{(-0.20 \pm 0.17)\,\%\ \text{(PDG)}} + \underbrace{A_K^{\epsilon}}_{-0.11\,\%}$$

Require

- D^* momentum above minimum $\to$ veto BG and B decays
- $\pi_s^{\pm}$ originates from e^+e^- interaction point
- $m(K_S^0)$ and $m(\pi^0)$ within 4σ of nominal value
- $m(D)$ within 3σ of nominal value

$D^0 \to K_S^0 K_S^0$: Belle; PRL119, 171801 (2017)

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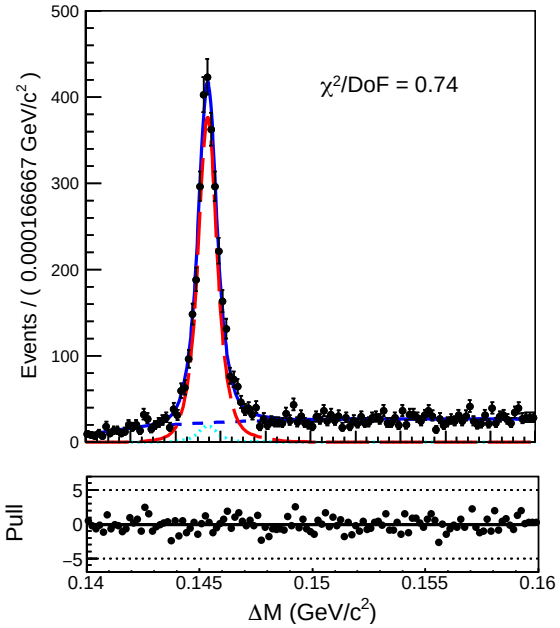
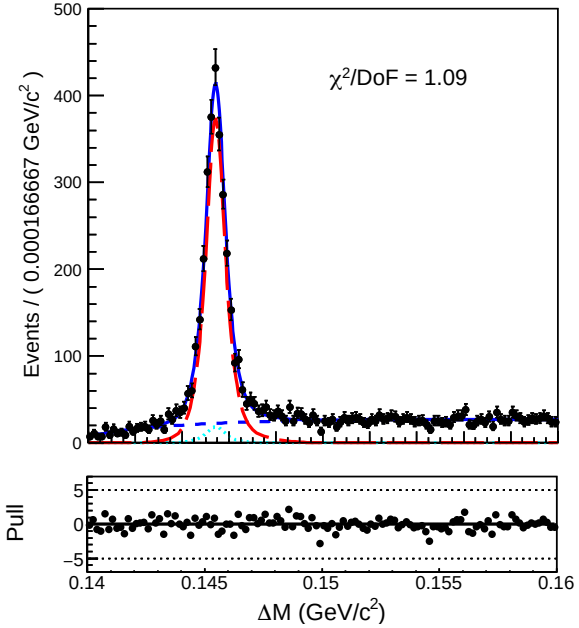
unbinned fit to Δm distributions to get raw asymmetries

$D^0 \to K_S^0 K_S^0$



$\overline{D}^0 \to K_S^0 K_S^0$



$D^0 \to K^0_S K^0_S$: Belle; PRL119, 171801 (2017)

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The fit results in

$$\boxed{A^{\mathrm{CP}}(D^0 \to K^0_S K^0_S) = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\ \%}$$

$$\mathcal{B}(D^0 \to K^0_S K^0_S) = (1.321 \pm 0.023 \pm 0.036 \pm 0.044) \times 10^{-4}$$

Previous measurements

2015	LHCb	$(-2.9 \pm 5.2 \pm 2.2)\%$
2000	CLEO	$(-23 \pm 19)\%$

@ Belle-II: $\to (\quad \pm 0.21 \pm 0.04)\%$

$D^0 \to V\gamma$: Belle; PRL118 051801 (2017)

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$$\left| A^{\mathrm{CP}}(D^0 \to V\gamma) \right| \geq \mathcal{O}(\%) \to \text{new physics}$$

[Isidori, Kamenik PRL109.171801]

From a data sample of 943 fb^{-1}

$$D^{*+} \to \pi_s^+ D^0 \quad \text{and} \quad D^0 \to \underbrace{\pi^+\pi^-}_{\rho^0}\gamma,\ \underbrace{K^+K^-}_{\phi}\gamma,\ \underbrace{\pi^+K^-}_{\bar{K}^{*0}}\gamma$$

using "good" pions, kaons, and photons; and veto agaist γ from π^0

require

- "good" D and D^* vertices
- $m(h^+h^-)$ within wide window around V mass
- Δm within narrow window of nominal value

$A^{\mathrm{CP}}(D^0 \to [h^+h'^-]_V\gamma)$ measured relative $A^{\mathrm{CP}}(D^0 \to h^+h'^-)$

$$A^{\mathrm{CP}}_{V\gamma} = A^{\mathrm{raw}}_{V\gamma} - A^{\mathrm{raw}}_{h^+h'^-} + A^{\mathrm{CP}}_{h^+h'^-} \quad \text{with} \quad V \to h^+h'^-$$

$\Rightarrow$ cancels forward-backward and detection asymmetries

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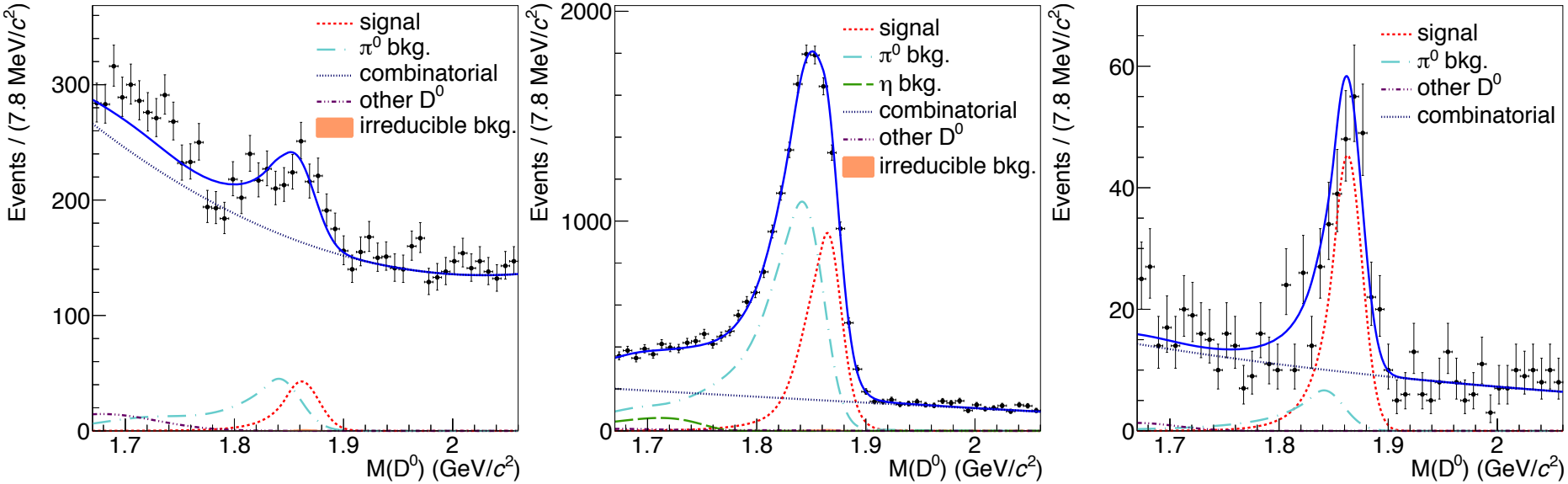
2D unbinned fits to $m(D^0)$ and $V \to h^+h'^-$ helicity angle for $A_V^{\rm raw}$

$D^0 \to \rho^0\gamma$ $\quad$ $D^0 \to \phi\gamma$ $\quad$ $D^0 \to \bar{K}^{*0}\gamma$



$$A_{\rho\gamma}^{\rm CP} = (5.6 \pm 15.2 \pm 0.6)\% \quad A_{\phi\gamma}^{\rm CP} = (-9.4 \pm 6.6 \pm 0.1)\% \quad A_{K^*\gamma}^{\rm CP} = (-0.3 \pm 2.0 \pm 0.04)\%$$

statistical uncertainty @ Belle-II $\to$

2.1 % $\quad$ 0.9 % $\quad$ 0.3 %

Summary

- BaBar & Belle have an impressive record of measurements

- Analyses are still published nearly a decade after the end of running
  - (2016) x and y in $D^0 \to \pi^+\pi^-\pi^0$
  - (2016) y_{CP} and A_Γ in $D^0 \to K^+K^-$ and $\pi^+\pi^-$
  - (2017) A_{CP} in $D^0 \to K^0_S K^0_S$
  - (2017) A_{CP} in $D^0 \to \rho^0\gamma,\ \phi\gamma,$ and $\bar{K}^{*0}\gamma$
  - (2018) A_{CP} in $D^+ \to \pi^+\pi^0$

  - See also S. Bahinipati's talk on Thursday on triple-product asymmetries in
    - $D^+ \to K^0_S K^+\pi^-\pi^-$,
    - $D^0 \to K^0_S\pi^+\pi^-\pi^0$,
    - $D^0 \to K^+K^-\pi^+\pi^-$

- Many results dominated by statistical uncertainties
  $\to$ Belle II will greatly reduce these (see talks today by J. Kumar; G. Casarosa)