CHARM Mixing, CP-Violation, and non leptonic decays at B-factories

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VIII CHARM, Bo

BELLE

Outlook

- Brief theory reminder
- Charm @ the B-factories
- Recent results
  - Mixing with time-dependent Dalitz analysis of $D^\circ \to \pi^+ \pi^- \pi^0$ @BABAR
  - CPV and BR with $D^\circ \to \Phi/K^*/\rho\, \gamma$ @ Belle
  - CPV with $D^\circ \to K_s K_s$ @ Belle
- Conclusions

Theory reminder : mixing

- Production : flavor eigenstates $D^0/\overline{D}^0$
- Time evolution : mass eigenstates D_1/D_2

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$$

- Flavor oscillation :

$$|\langle D^0|D^0(t)\rangle|^2 \propto [\cosh(y\,t/\tau)+\cos(xt/\tau)]$$ "UNMIXED"

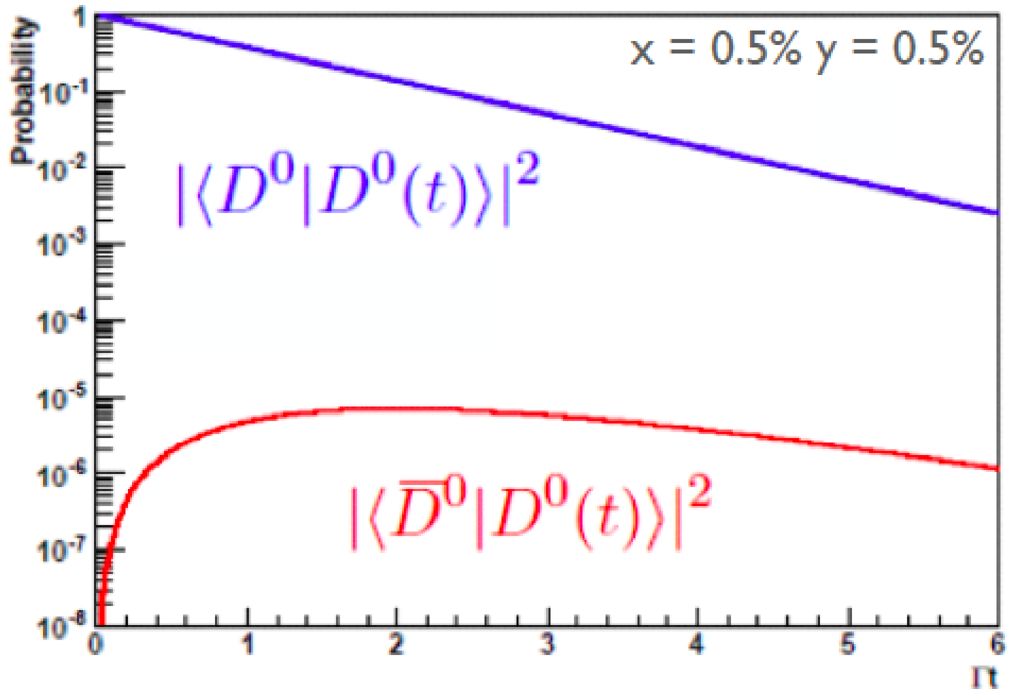
$$|\langle \overline{D}^0|D^0(t)\rangle|^2 \propto [\cosh(y\,t/\tau)-\cos(xt/\tau)]$$ "MIXED"

- Mixing parameters :

$$\Gamma = (\Gamma_1+\Gamma_2)/2 = 1/\tau$$

$$x = (m_1-m_2)/\Gamma$$

$$y = (\Gamma_1-\Gamma_2)/(\Gamma_1+\Gamma_2)$$



Theory reminder : CPV

- Direct :

$$|\mathcal{A}_f| = |\mathcal{A}(D \to f)| \neq |\mathcal{A}(\overline{D} \to \bar{f})| = |\overline{\mathcal{A}}_{\bar{f}}|$$

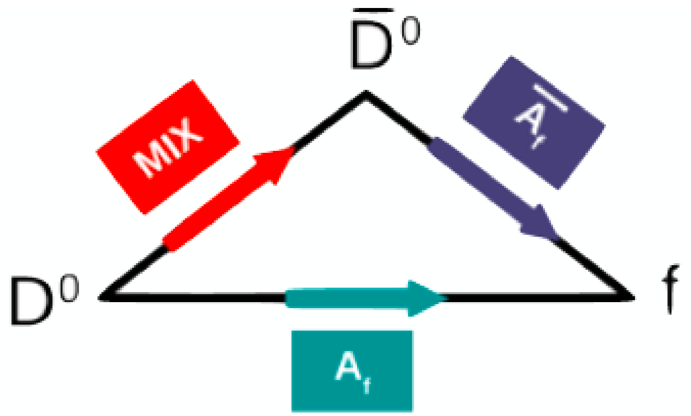
$$\mathcal{A}_{CP} = \frac{|\mathcal{A}_f|^2 - |\overline{\mathcal{A}}_{\bar{f}}|^2}{|\mathcal{A}_f|^2 + |\overline{\mathcal{A}}_{\bar{f}}|^2}$$

- Mixing induced :

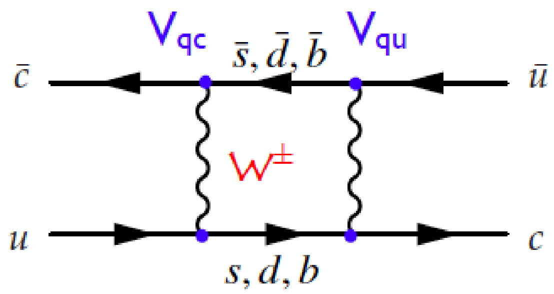
$$\mathrm{Prob}(D^\circ \to \overline{D^\circ}) \neq \mathrm{Prob}(\overline{D^\circ} \to D^\circ) \quad \Leftrightarrow \quad |q/p| \neq 1$$

- Interference of the two in CP eigenstates $(f \equiv \bar{f})$:

$$\lambda_f = \frac{q}{p}\frac{\overline{\mathcal{A}}_f}{\mathcal{A}_f} = \left|\frac{q}{p}\frac{\overline{\mathcal{A}}_f}{\mathcal{A}_f}\right| e^{i(\delta_f + \phi_f)}$$



Standard Model



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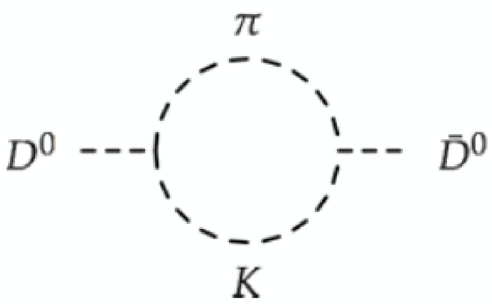


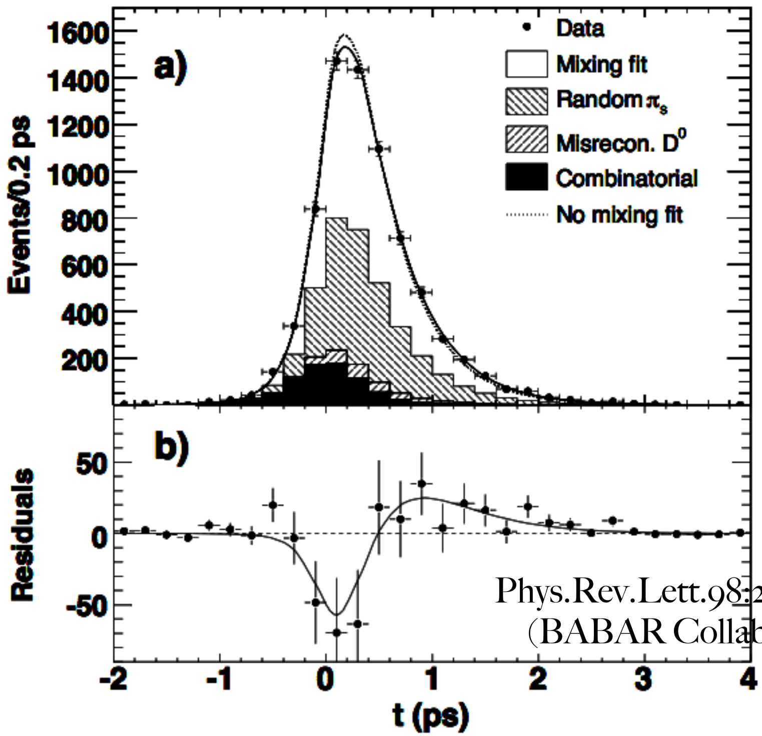
- Short distance:
  - light quarks in the loop
  - GIM & CKM supressed
- Long distance:
  - real particles in the loop
  - dominant contribution
- Large uncertainties in the calculation, expect
  - $x, y \sim 0.5\%$, $\mathcal{A}_{CP} \sim 10^{-3}$
- Values in excess of ~ 1% :
  - may be sign of NEW PHYSICS

Status : mixing

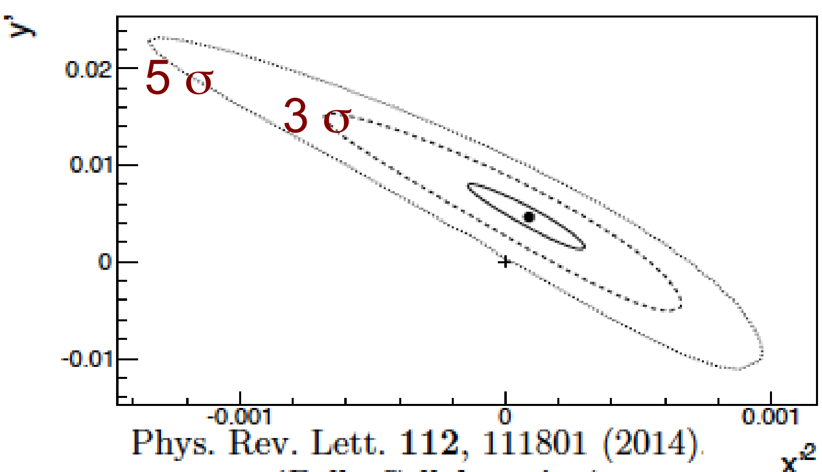
- Mixing assessed at the B-factories in D° ->Kπ transitions
- Strong phases : measure effective parameters

$$x' = x\cos\delta_{K\pi} + y\sin\delta_{K\pi}$$
$$y' = y\cos\delta_{K\pi} - x\sin\delta_{K\pi}$$

- Then :
  - focus on phase-free approches
  - determine x and y



Phys.Rev.Lett.98:211802,2007 (BABAR Collaboration)



Phys. Rev. Lett. **112**, 111801 (2014). (Belle Collaboration).

Status : CPV ?

- No positive observation – yet
- Where to look ?
- Nierste :
  - SCS decays in two pseudoscalar mesons ($D^0 \to K_s K_s$)
- Bigi :
  - "3 & 4-body final states not backup for information from two-body – landscapes are very different"

"Charm and Strange, recent results and future perspectives"
(Gagan Mohanty, summary talk at ICHEP 2016)

Measurements at B-factories

- Extensive study of mixing and CPV in several final states

BABAR Contributions

(Giulia Casarosa,XIII Int. Conf. on Heavy Quarks and Leptons)

mixing

- $D^0 \to \pi^+\pi^-, K^+K^-$ y_{CP}
- $D^0 \to K^+\pi^-$ x'^2, y'
- $D^0 \to K_S\pi^+\pi^-, K_SK^+K^-$ x, y
- $D^0 \to K^+\pi^-\pi^0$ y'', x''^2
- $\boxed{D^0 \to \pi^+\pi^-\pi^0 \quad x, y}$

NEW PRELIMINARY RESULT

direct CPV

- $D^0 \to \pi^+\pi^-, K^+K^-$ $A_{CP}, \Delta A_{CP}$
- $D^0 \to K^+K^-\pi^0$
- $D^0 \to \pi^+\pi^-\pi^0$
- $D_s^+ \to K_S\pi^+$
- $D_s^+ \to K_SK^+$
- $D^+ \to K_S\pi^+$
- $D^+ \to K^+K^-\pi^+$
- ☆ $D^+ \to \pi^+\pi^0$ ALMOST READY…

$$A_{CP} = \frac{(\Gamma_D - \Gamma_{\bar{D}})}{(\Gamma_D + \Gamma_{\bar{D}})}$$

direct vs indirect CPV

$A_{CP}, \Delta Y$ (aka A_Γ)

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

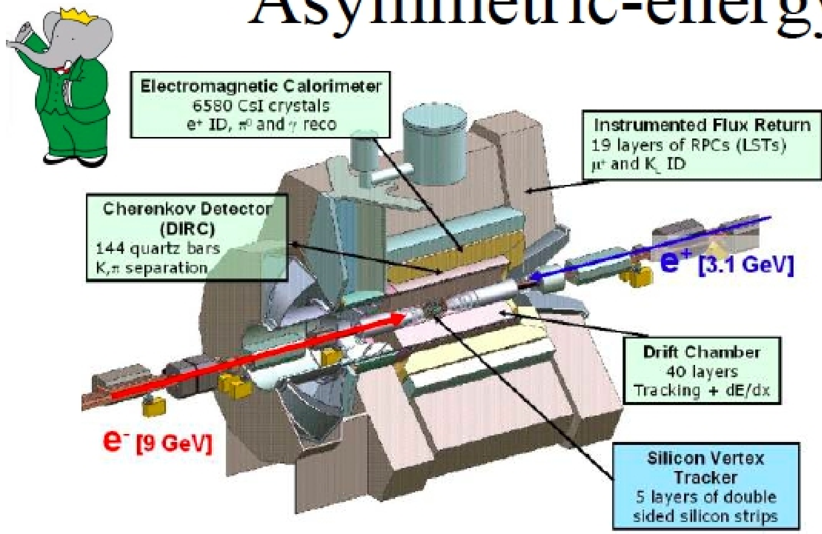
CP violation with triple-product asymmetries

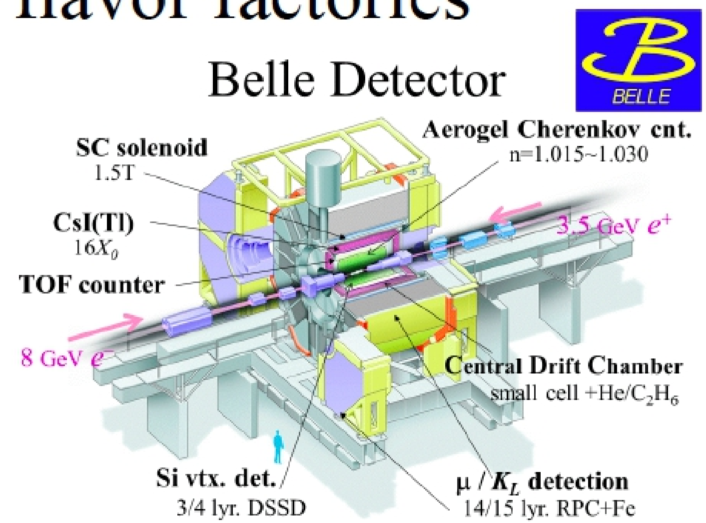
$$C_T = (\vec{p}_1 \times \vec{p}_2) \cdot \vec{p}_3$$

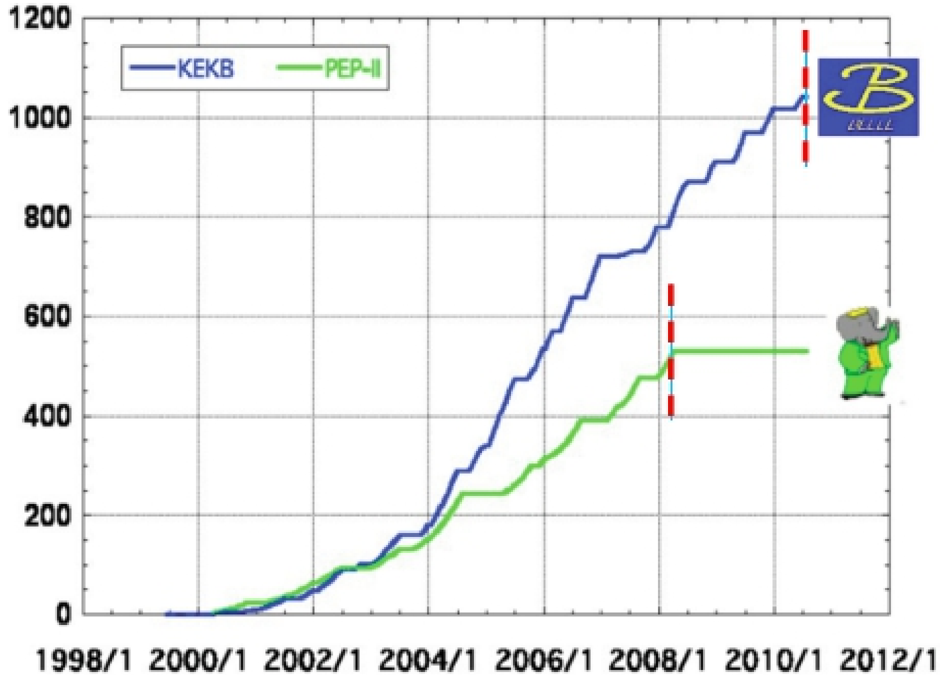
- $D^0 \to K^+K^-\pi^+\pi^-$
- $D^+ \to K_SK^+\pi^+\pi^-$
- $D_s^+ \to K_SK^+\pi^+\pi^-$

- Similar list for Belle

Asymmetric-energy flavor factories







Belle : $\sim 1.2\cdot 10^9$ $(e^+e^- \rightarrow c\bar{c})$ events

Babar : $\sim 0.7\cdot 10^9$ $(e^+e^- \rightarrow c\bar{c})$ events

Results from B-factories

- This talk, focus on new results :

$D^\circ - \overline{D^\circ}$ mixing with $D^\circ \to \pi^+ \pi^- \pi^\circ$ decays at BaBar

arXiv :1604.00857

$\mathcal{A}_{CP}$ with $D^\circ \to K_s K_s$ decays at Belle

arXiv:1603.03257

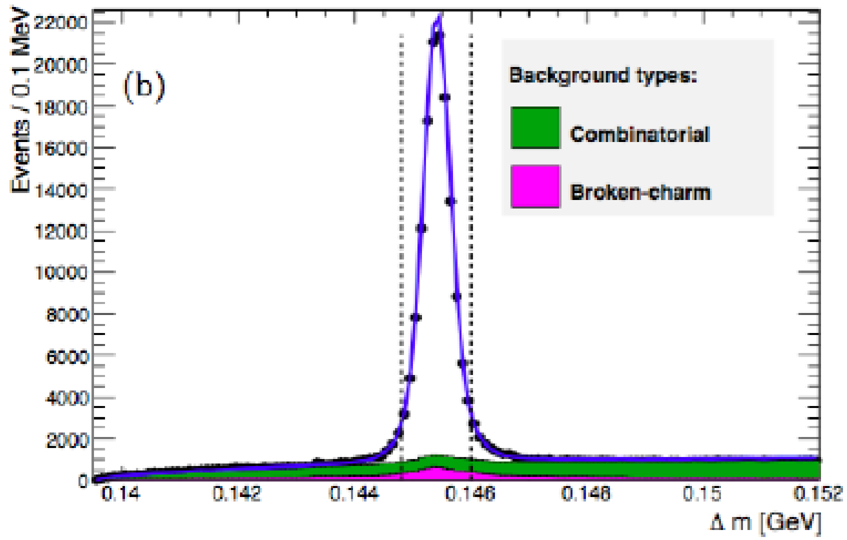
$\mathcal{A}_{CP}$ with $D^\circ \to \phi/\rho/K^* \gamma$ at Belle

Belle Conf 1609

Common Features

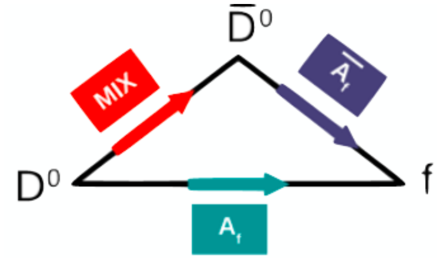
- Use $D^{*+} \to \pi^+ D^0$ decays (and cc)
  - very good signal / noise
  - soft pion charge tags D^0 flavor at production time (~ 99% efficient)
- Focus on prompt charm
  - cut on $p_D > p_{threshold}$ (~ 2.5 GeV)
- apply beam spot constraint in kinematic fits
  - improve S/N
  - improve proper time resolution

$$\sigma_t \simeq \tau_{D^0}$$



BABAR : Mixing with $D^0 \to \pi\pi\pi$

- Common final state to D^0 and $\overline{D^0}$
- CP :
  - exchange D^0 and $\overline{D^0}$
  - exchange π^+ and π^-
  - invert all momenta



$$CP\,|\,\pi^+(\vec{p}_1)\;\pi^-(\vec{p}_2)\;\pi^0(\vec{p}_3)\rangle =$$
$$= |\,\pi^-(-\vec{p}_1)\;\pi^+(-\vec{p}_2)\;\pi^0(-\vec{p}_3)\rangle$$

- Assuming CP conservation, $\overline{D^0}$ and D^0 belong to the same Dalitz plot with:

$$\overline{\mathcal{A}}_f(s_-,s_+) = \mathcal{A}_f(s_+,s_-)$$

$$s_+ = m^2(\pi^+,\pi^0)$$
$$s_- = m^2(\pi^-,\pi^0)$$

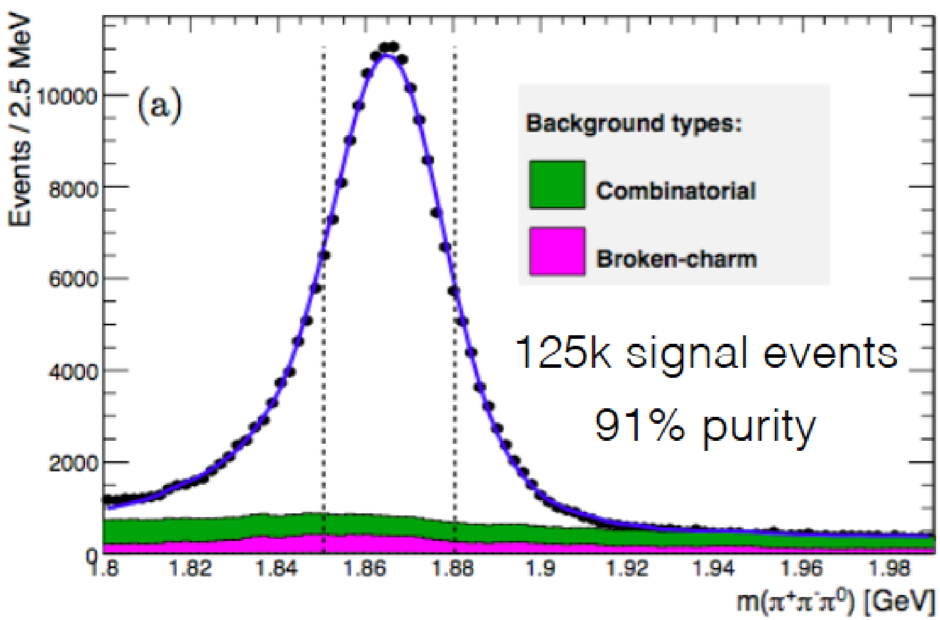
- Strong phases not an issue anymore

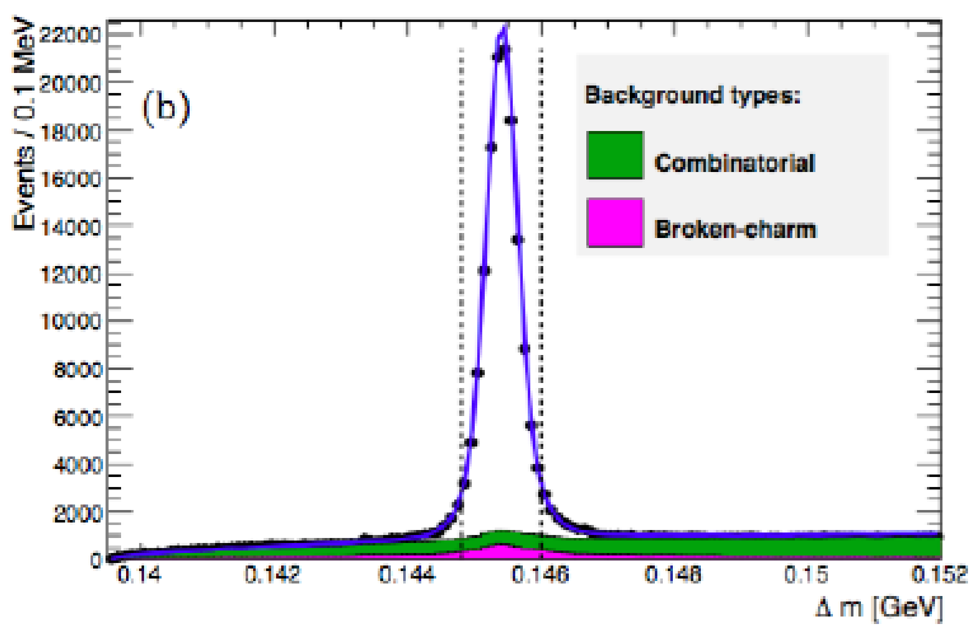
$$\overline{\mathcal{A}}_f = \mathcal{A}(\overline{D^0} \to \pi^+\pi^-\pi^0)$$
$$\mathcal{A}_f = \mathcal{A}(D^0 \to \pi^+\pi^-\pi^0)$$

Mixing with D° –> πππ

Vetoes on $D^0 \to K^-\pi^+$, $D^0 \to K^-\pi^+\pi^0$,
$D^0 \to K_S\,\pi^+\pi^0$, $D^0 \to K_S\,\pi^0$
$E_{\text{lab}}(\pi^0) > 350$ MeV
$p_{\text{cms}}(D^0) > 2.8$ GeV to remove $B \to D$ events
$-2 < t(D^0) < 3$ ps, $\sigma_t < 0.8$ ps
$P(\chi^2) > 0.1\%$ for the D^* candidates

- Tight cuts on m(D°), Δm
  - 125 k evts
  - 91% purity
- Time-dependent analysis across the Dalitz plot
- Unbinned maximum likelihood fit to (t, s_+, s_-)
- Blind analysis





Time function

$$|\mathcal{M}(D^0)|^2 \propto \frac{1}{2} e^{-\Gamma_D t} \Big\{ |A_f|^2 \left[\cosh(y\Gamma_D t) + \cos(x\Gamma_D t)\right]$$ Direct decay

$$+ \left|\frac{q}{p}\overline{A}_f\right|^2 \left[\cosh(y\Gamma_D t) - \cos(x\Gamma_D t)\right]$$ Through mixing

$$- 2\left[\mathrm{Re}\left(\frac{q}{p}A_f^*\overline{A}_f\right)\sinh(y\Gamma_D t) \; -\mathrm{Im}\left(\frac{q}{p}A_f^*\overline{A}_f\right)\sin(x\Gamma_D t)\right]\Big\}$$ Interference

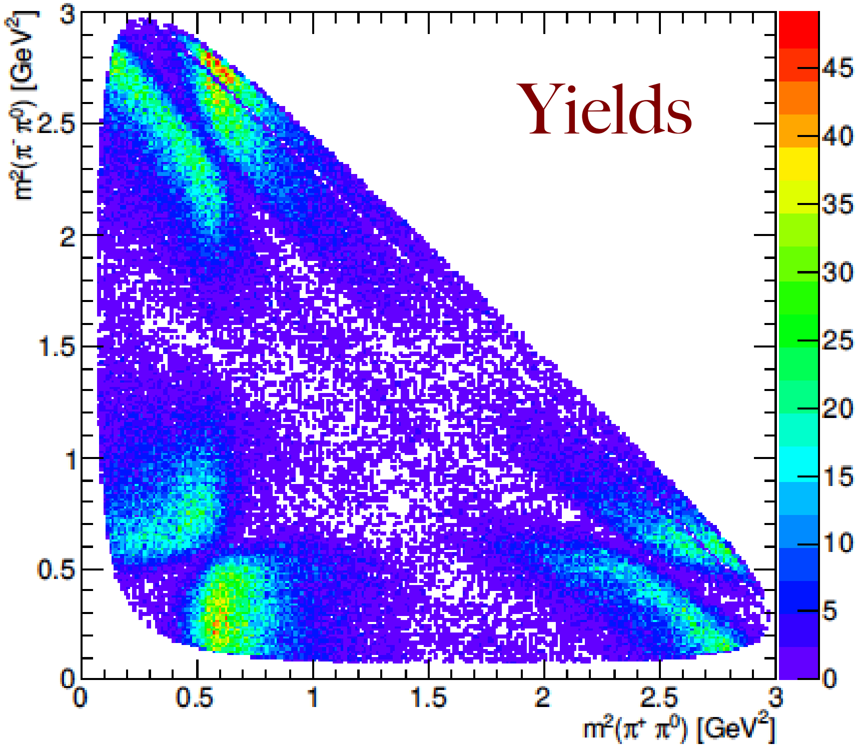
Resolution function : sum of three Gaussian

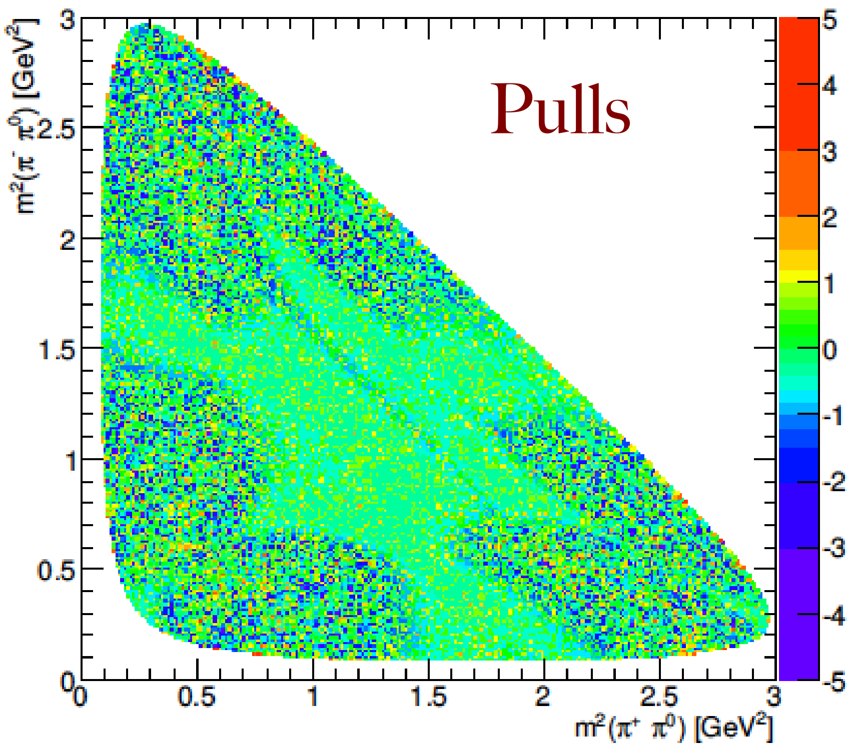
Account for correlations between $\sigma(t)$ and $s_{+,}$ s_{-}

Dalitz Analysis

- Isobar model $\overline{A}_f(s_-, s_+) = A_f(s_+, s_-) = \sum_k c_k \mathcal{W}_k(s_+, s_-)$

$\mathcal{W}_k$: relativistic Breit Wigner
$\times$ spin dependent angular factor
$\times$ Blatt Weisskopf form factors

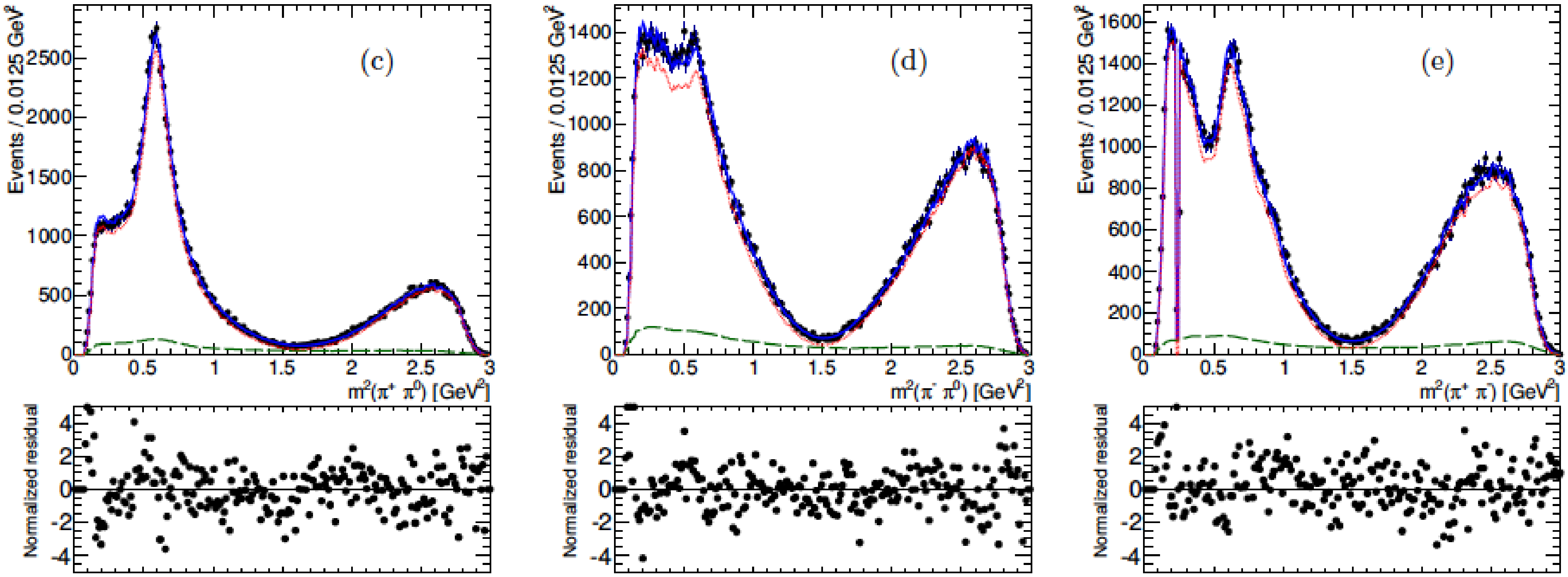




Dalitz Analysis

- Large pull values nead phase space boundaries
  - observed in MC as well
  - finite resolution effect causing migration from the edges of the Dalitz plot
- Bias from test on MC samples :

$$\Delta x = +0.58\,\%$$
$$\Delta y = -0.05\,\%$$



Results : BABAR Collaboration arXiv 1604.00857

$$x = (1.5 \pm 1.2 \pm 0.6)\%$$

$$y = (0.2 \pm 0.9 \pm 0.5)\%$$

$$\tau(D^\circ) = 410.2 \pm 3.8 \text{ fs}$$

Output of amplitude analysis

State	Fit to data results: Magnitude	Phase (°)	Fraction f_r (%)
$\rho(770)^+$	1	0	66.4±0.5
$\rho(770)^0$	0.55±0.00	16.1±0.4	23.9±0.3
$\rho(770)^-$	0.73±0.01	−1.6±0.5	35.6±0.4
$\rho(1450)^+$	0.55±0.07	−7.7±8.2	1.1±0.3
$\rho(1450)^0$	0.19±0.07	−70.4±15.9	0.1±0.1
$\rho(1450)^-$	0.53±0.06	8.2±6.7	1.0±0.2
$\rho(1700)^+$	0.91±0.15	−23.3±10.3	1.5±0.5
$\rho(1700)^0$	0.60±0.13	−56.3±16.0	0.7±0.3
$\rho(1700)^-$	0.98±0.17	78.9±8.5	1.7±0.6
$f_0(980)$	0.06±0.00	−58.8±2.9	0.3±0.0
$f_0(1370)$	0.20±0.03	−19.6±9.5	0.3±0.1
$f_0(1500)$	0.18±0.02	7.4±7.4	0.3±0.1
$f_0(1710)$	0.40±0.08	42.9±8.8	0.3±0.1
$f_2(1270)$	0.25±0.01	8.8±2.6	0.9±0.0
$f_0(500)$	0.26±0.01	−4.1±3.7	0.9±0.1
NR	0.43±0.07	−22.1±11.7	0.4±0.1

Systematic uncertainties

Source	x [%]	y [%]
"Lucky" false slow pion fraction	0.01	0.01
Time resolution dependence on reconstructed D^0 mass	0.03	0.02
Amplitude-model variations	0.31	0.12
Resonance radius	0.02	0.10
DP efficiency parametrization	0.03	0.03
DP normalization granularity	0.03	0.04
Background DP distribution	0.21	0.11
Decay time window	0.18	0.19
σ_t cutoff	0.01	0.01
Number of σ_t ranges	0.11	0.26
σ_t parametrization	0.05	0.03
Background-model MC time distribution parameters	0.06	0.11
Fit bias correction	0.29	0.02
SVT misalignment	0.20	0.23
Total	0.56	0.46

CPV

Belle : CPV in D° -> V γ (V=φ/K*/ρ)

- SM extensions may enhance $\mathcal{A}_{CP}$ to few % G. Isidori and J. F. Kamenik, PRL **109** (2012) 171801
- Decay $D^0 \to \rho^0\gamma$ not observed before
- BR and $\mathcal{A}_{CP}$ measured w.r.t. normalization samples

$$\mathcal{B}_{\text{sig}} = \mathcal{B}_{\text{norm}} \times \frac{\mathcal{N}_{\text{sig}}}{\mathcal{N}_{\text{norm}}} \times \frac{\epsilon_{\text{sig}}}{\epsilon_{\text{norm}}}$$

$$\mathcal{A}^{\text{sig}}_{CP} = \mathcal{A}^{\text{sig}}_{\text{raw}} - \mathcal{A}^{\text{norm}}_{\text{raw}} + \mathcal{A}^{\text{norm}}_{CP}$$

PDG

$$\mathcal{A}_{\text{raw}} = \frac{\mathcal{N}(\pi^+ V\gamma) - \mathcal{N}(\pi^- V\gamma)}{\mathcal{N}(\pi^+ V\gamma) + \mathcal{N}(\pi^- V\gamma)}$$

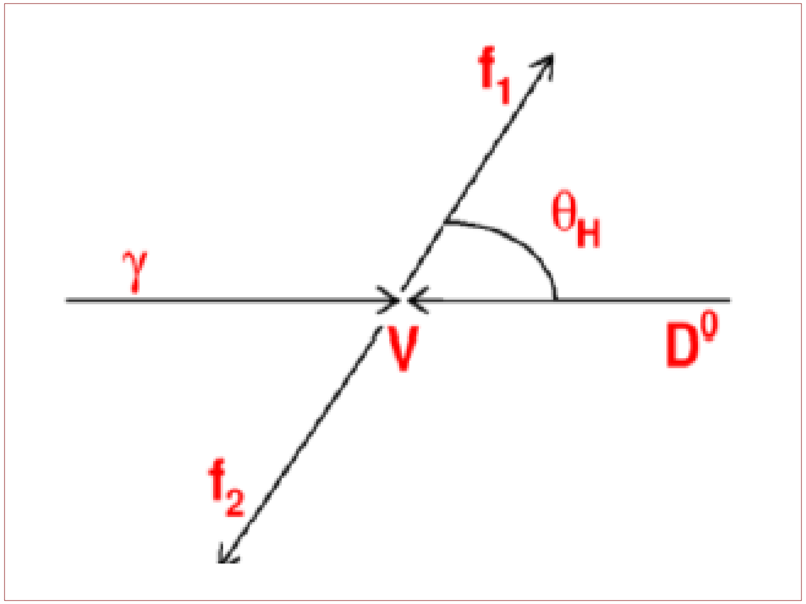
Signal	Norm.	Signal Yield
$D^0 \to \phi\gamma \to K^+K^-\gamma$	$D^0 \to K^+K^-$	524 ± 35
$D^0 \to \bar{K}^{*0}\gamma \to K^-\pi^+\gamma$	$D^0 \to K^-\pi^-$	9104 ± 396
$D^0 \to \rho^0\gamma \to \pi^+\pi^-\gamma$	$D^0 \to \pi^+\pi^-$	500 ± 85

Belle : CPV in D° –> V γ

- Main background : D° –> V π°, with a missed γ
  - Neural Network to optimize π^0 rejection by removing γγ pairs
- Tags :
  - m(Vγ)
  - helicity angle θ_H

$$\text{signal} \propto (1-\cos\theta_H)^2$$

$$\pi^{\circ}\,\text{backg} \simeq (\cos\theta_H)^2$$



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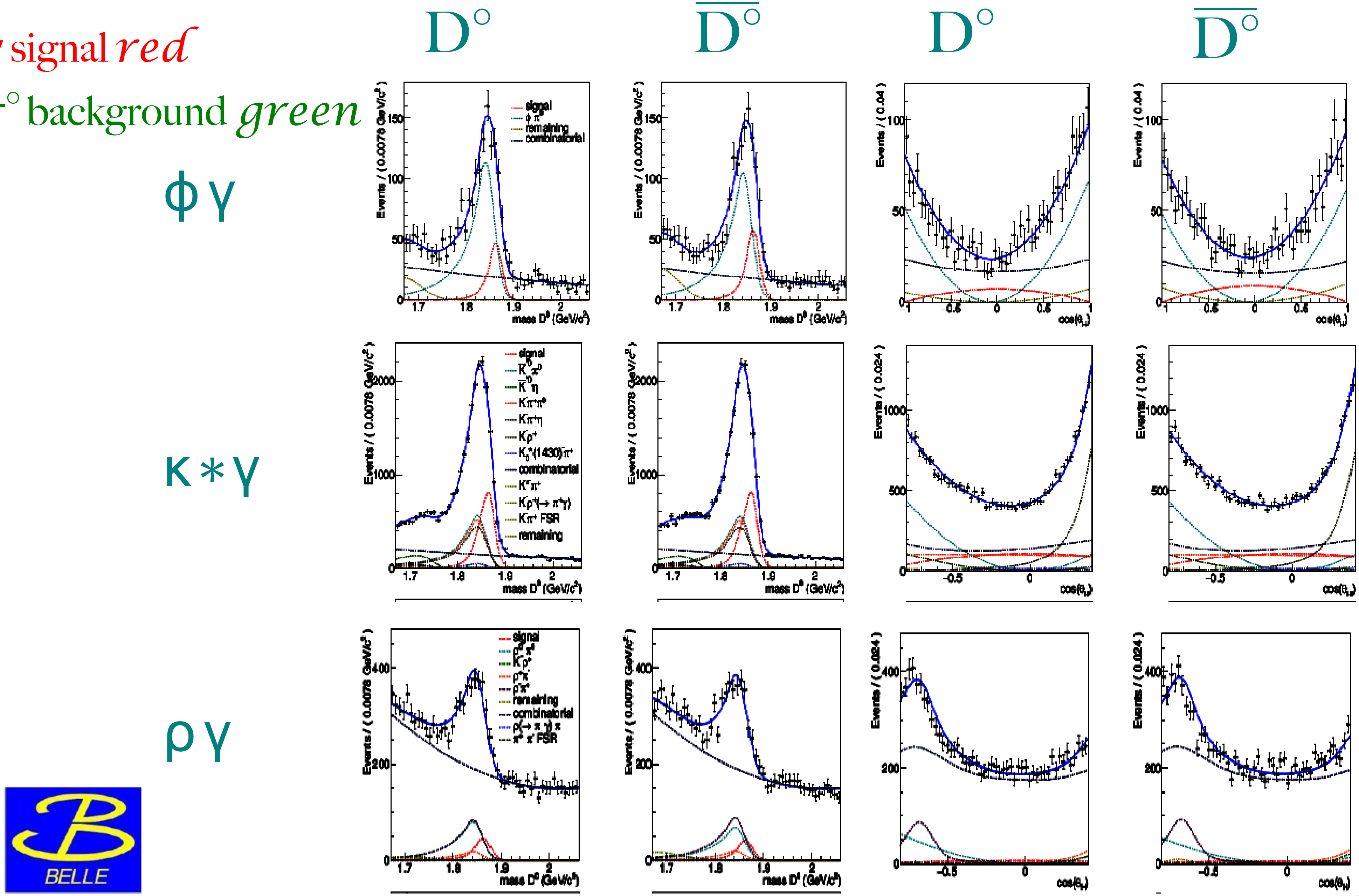
Belle : CPV in D° –> V γ

γ signal *red*

π° background *green*



CPV in D° –> V γ : results

$$\mathcal{B}\left(D^0 \to \phi\gamma\right) = (2.76 \pm 0.20 \pm 0.08) \times 10^{-5}$$ consistent with BABAR

$$\mathcal{B}\left(D^0 \to \overline{K}^{*0}\gamma\right) = (4.66 \pm 0.21 \pm 0.18) \times 10^{-4}$$ 3.3 σ wrt BABAR

$$\mathcal{B}\left(D^0 \to \rho^0\gamma\right) = (1.77 \pm 0.30 \pm 0.08) \times 10^{-5}$$ First observation

$$\mathcal{A}_{CP}\left(D^0 \to \phi\gamma\right) = -(0.094 \pm 0.066 \pm 0.001)$$
$$\mathcal{A}_{CP}\left(D^0 \to \overline{K}^{*0}\gamma\right) = -(0.003 \pm 0.020 \pm 0.000)$$
$$\mathcal{A}_{CP}\left(D^0 \to \rho^0\gamma\right) = 0.056 \pm 0.151 \pm 0.006$$

- Results consistent with no CPV
- Statistical errors dominate

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Belle : CPV in $D^\circ \to K_s K_s$

- S.M. 95% Upper Limit. for direct CPV : 1.1 % PRD 92, 054036 (2015)
- (Possible) interference with NP : sizable enhancement PRD 87, 014024 (2013)
- Normalization : $D^\circ \to K_s \pi^\circ$

$$\mathcal{A}_{CP}^{D^\circ \to K_s K_s} = \mathcal{A}_{RAW}^{D^\circ \to K_s K_s} - \mathcal{A}_{RAW}^{D^\circ \to K_s \pi^\circ} + \mathcal{A}_{CP}^{D^\circ \to K_s \pi^\circ} + \mathcal{A}_{\epsilon}^{K^\circ/\overline{K^\circ}}$$

$$A_\epsilon^{K^0/K^0} = (-0.11 \pm 0.01)\%$$

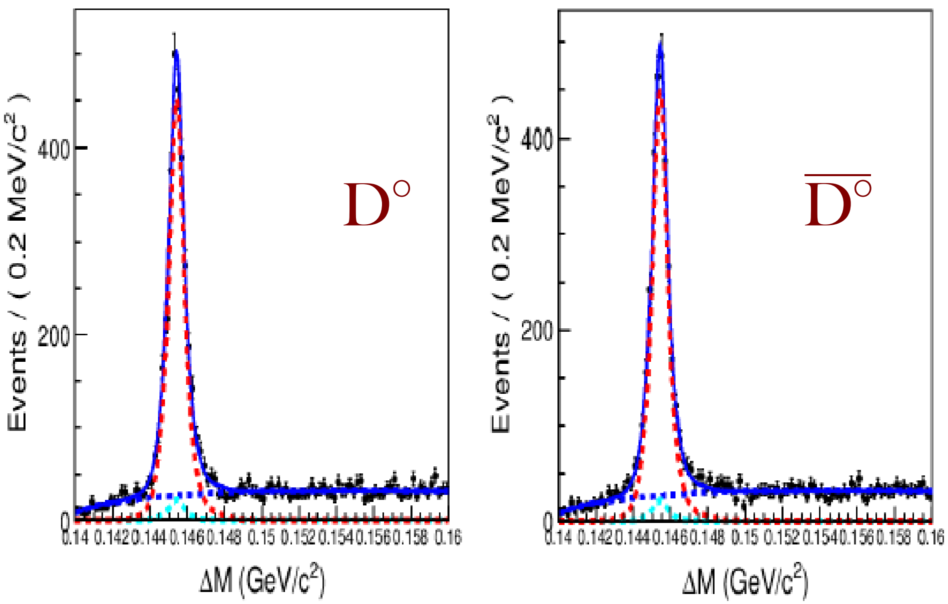
$K^\circ/\overline{K^\circ}$ interaction with the detector material PRD 84, 111501 (2011)

$$A_{CP}^{D^0 \to K_S^0 \pi^0} = (-0.20 \pm 0.17)\%$$

PDG

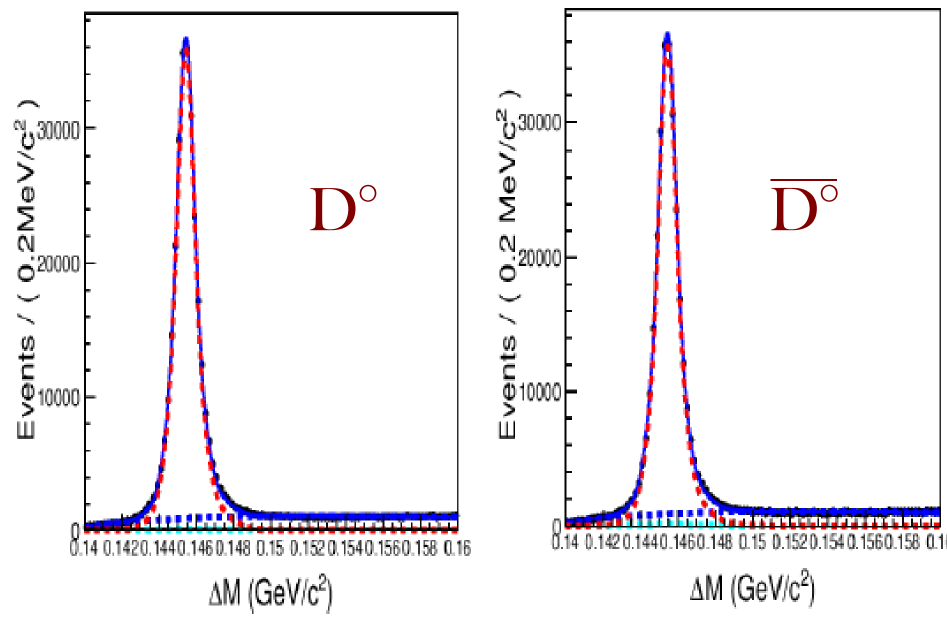
Belle : CPV in D° -> $K_S K_S$

$D \to K^0_S K^0_S$: Signal mode



- Efficiency = $(11.04 \pm 0.02)\%$
- Signal Yield = 5399 ± 87
- $A^{raw} = (0.45 \pm 1.53)\%$

$D \to K^0_S \pi^0$: Normalization mode



- Efficiency = $(12.60 \pm 0.02)\%$
- Signal Yield = 531807 ± 796
- $A^{raw} = (0.16 \pm 0.14)\%$

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Belle : CPV in D° -> $K_s K_s$

$$\mathcal{A}_{CP}(D^\circ \to K_s K_s) = (-0.002 \pm 1.53 \pm 0.17)\%$$

[Belle CONF-1609]

CLEO $(-23 \pm 19)\%$ 13.7 fb^{-1} PRD **63** (2001) 071101

LHCb $(-2.9 \pm 5.2 \pm 2.2)\%$ 3 fb^{-1} JHEP 10 (2015) 055

Source	Systematic uncertainty, in %
Signal shape	$\pm$ 0.01
Peaking background	$\pm$ 0.01
$K^0/\bar{K}^0$ material effects	$\pm$ 0.01
A_{CP} measurement of $K_S^0\pi^0$	$\pm$ 0.17
Total	$\pm$ 0.17

Summary (I)

- Years after shutdown, B-factories still provide competitive results on charm-Physics.
- I have discussed few brand new results on
  - Mixing in $D^0 \to \pi\pi\pi$ (BABAR)

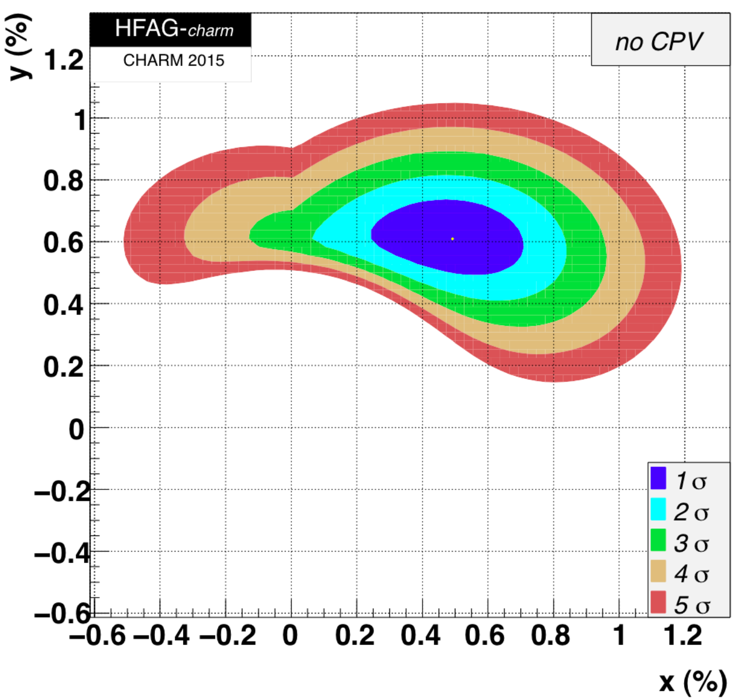
$$x = (1.5 \pm 1.2 \pm 0.6)\,\%$$
$$y = (0.2 \pm 0.9 \pm 0.5)\,\%$$

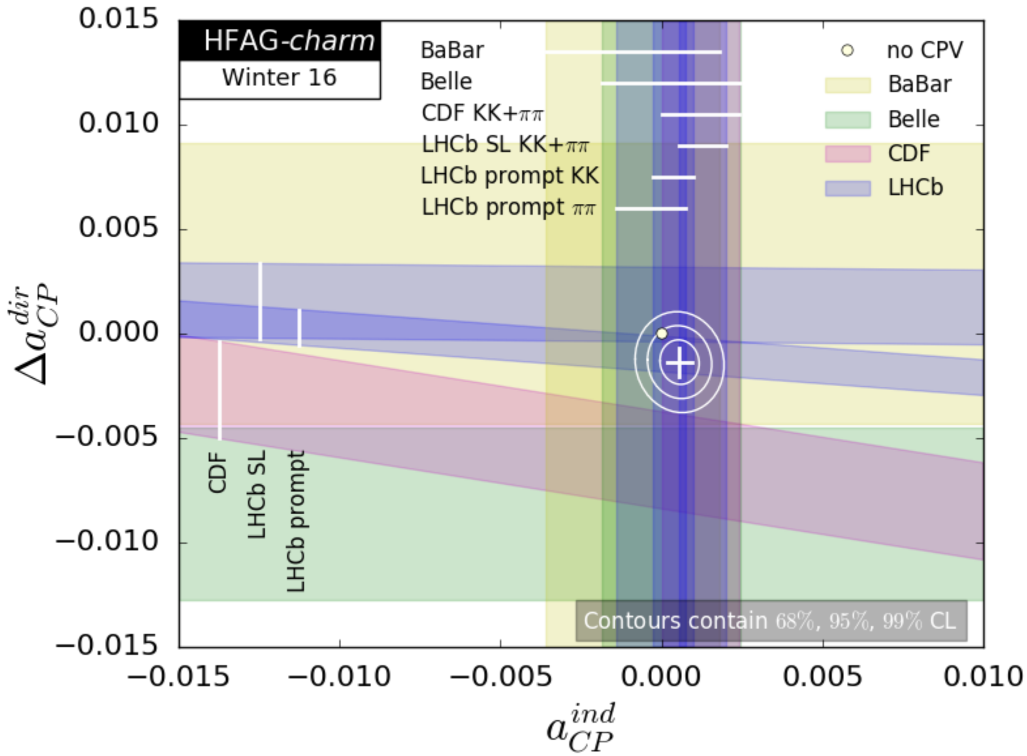
  - CPV (Belle)

$$\mathcal{A}_{CP}(D^0 \to K_s K_s) = (-0.002 \pm 1.53 \pm 0.17)\,\%$$
$$\mathcal{A}_{CP}(D^0 \to \phi\gamma) = -(0.094 \pm 0.066 \pm 0.001)$$
$$\mathcal{A}_{CP}(D^0 \to \overline{K}^{*0}\gamma) = -(0.003 \pm 0.020 \pm 0.000)$$
$$\mathcal{A}_{CP}(D^0 \to \rho^0\gamma) = 0.056 \pm 0.151 \pm 0.006$$

Summary (II)

- Mixing is well established, and being studied in several new channels
- ... whereas CPV has not yet been observed
- However all results are limited by σ(STAT)
- ... paving the way for the super–B factory at BelleTwo





Backup

RARE non leptonic DECAY:

D -> γγ at Belle

[PRD 93 (2016) 051102]

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$D^\circ \to \gamma\gamma$

- Standard Model : $\mathcal{B}(D^\circ \to \gamma\gamma) \sim 10^{-8}$ G. Burdman *et al.*, PRD **66** (2002) 014009
- MSSM with gluino exchange : $\mathcal{B}(D^\circ \to \gamma\gamma) \sim 10^{-6}$ S. Prelovsek and D. Wyler, PLB **500** (2001) 304
- Peaking backgrounds :
  - $D^\circ \to hh'$ ($h,h' = \pi^0, \eta, K_{S,L}$) with unresolved $\gamma\gamma$
  - Use π^0 veto and e.m. cluster shape in calorimeter (E_9/E_{25})
- Signal extraction :
  - 2D fit to $m(\gamma\gamma)$, Δm

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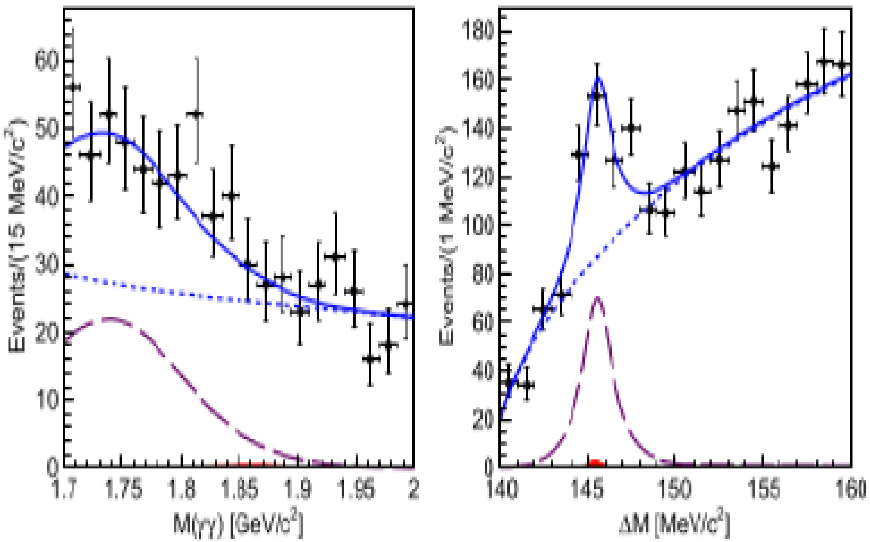
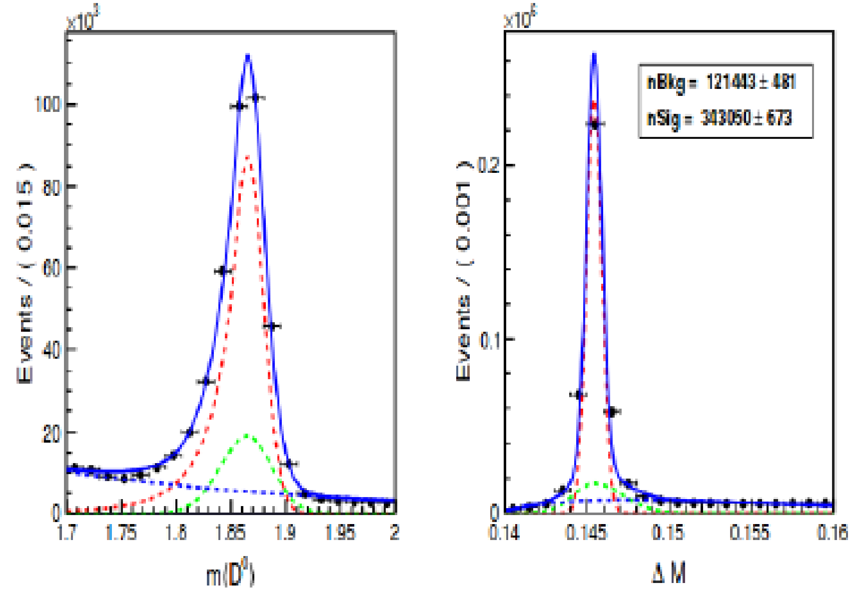
D° -> γγ

$D \to \gamma\gamma$: Signal mode



$D \to K_S^0\pi^0$:Normalization mode



- Efficiency = 7.3%
- Signal Yield = 4 ± 15

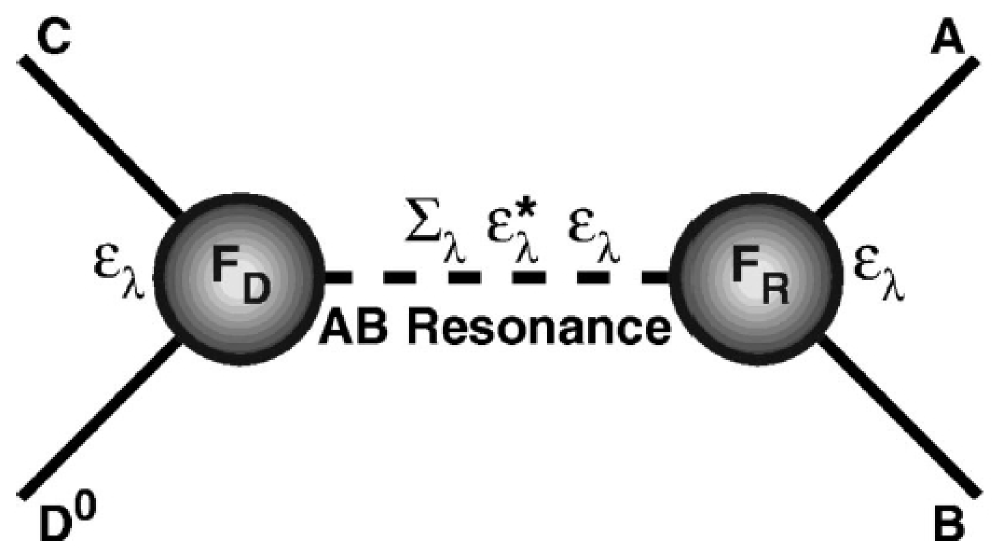
- Efficiency = 7.2%
- Signal Yield = 343050 ± 673

$$\mathcal{B}(D^\circ \to \gamma\gamma) < 8.5\times10^{-7} \quad @90\%\,CL$$

Experiment	Luminosity	$\mathcal{B}$ UL at 90% C.L	References
CLEO	13.8 fb^{-1}	2.9×10^{-5}	PRL **90** (2003) 101801
BaBar	470.5 fb^{-1}	2.2×10^{-6}	PRD **85** (2012) 091107
BESIII	2.92 fb^{-1}	3.8×10^{-6}	PRD **91** (2015) 112015

BELLE

The Dalitz Model



$$d\Gamma = \frac{|\mathcal{M}|^2}{256\pi^3 M_D^3} dM_{12}^2 dM_{23}^2$$

$$\mathcal{M} = F_D (P_{D^0} + P_C)_\mu \frac{\sum_\lambda \varepsilon_\lambda^{\mu *} \varepsilon_\lambda^\nu}{M_r^2 - M_{AB}^2 - iM_r \Gamma_{AB}} (P_A - P_B)_\nu F_r$$

$$\sum_\lambda \varepsilon_\lambda^{\mu *} \varepsilon_\lambda^\nu = -g^{\mu\nu} + \frac{P_{AB}^\mu P_{AB}^\nu}{M_{AB}^2}$$

$$\Gamma_{AB} = \Gamma_r \left(\frac{p_{AB}}{p_r}\right)^{2J+1} \left(\frac{M_r}{M_{AB}}\right) F_r^2 .$$

F_r, F_D : form factors, use Blatt-Weisskopf penetration factors

J. Blatt and V. Weisskopf, *Theoretical Nuclear Physics* (Wiley, New York, 1952).

Babar : systematic uncertainties

Time-Integrated Dalitz plot/3

$$A(s_+, s_-) = \sum_i c_i \frac{T(s)}{M_r - s - i\, M_r\, \Gamma(s)} F(s)$$

T is a tensor structure depending on spin

$$\Gamma(s) = \Gamma \left(\frac{q(s)}{q(M_r)}\right)^{2l+1} \left(\frac{M_r}{\sqrt{s}}\right) F^2$$

F is the Blatt-Weisskopf barrier factor

$$F_0 = 1, F_1 = \sqrt{\frac{1+R^2 q^2(M_r)}{1+R^2 q^2(s)}}, F_2 = \cdots$$

Masses and widths fixed to the PDG value

State	J^{PC}	Resonance parameters Mass (MeV)	Width (MeV)	Fit to data results Magnitude	Phase (°)	Fraction f_r (%)
$\rho(770)^+$	1^{--}	775.8	150.3	1	0	66.4±0.5
$\rho(770)^0$	1^{--}	775.8	150.3	0.55±0.01	16.1±0.4	23.9±0.3
$\rho(770)^-$	1^{--}	775.8	150.3	0.73±0.01	−1.6±0.5	35.6±0.4
$\rho(1450)^+$	1^{--}	1465	400	0.55±0.07	−7.7±8.2	1.1±0.3
$\rho(1450)^0$	1^{--}	1465	400	0.19±0.07	−70.4±15.9	0.1±0.1
$\rho(1450)^-$	1^{--}	1465	400	0.53±0.06	8.2±6.7	1.0±0.2
$\rho(1700)^+$	1^{--}	1720	250	0.91±0.15	−23.3±10.3	1.5±0.5
$\rho(1700)^0$	1^{--}	1720	250	0.60±0.13	−56.3±16.0	0.7±0.3
$\rho(1700)^-$	1^{--}	1720	250	0.98±0.17	78.9±8.5	1.7±0.6
$f_0(980)$	0^{++}	980	44	0.06±0.01	−58.8±2.9	0.3±0.1
$f_0(1370)$	0^{++}	1434	173	0.20±0.03	−19.6±9.5	0.3±0.1
$f_0(1500)$	0^{++}	1507	109	0.18±0.02	7.4±7.4	0.3±0.1
$f_0(1710)$	0^{++}	1714	140	0.40±0.08	42.9±8.8	0.3±0.1
$f_2(1270)$	2^{++}	1275.4	185.1	0.25±0.01	8.8±2.6	0.9±0.1
$f_0(500)$	0^{++}	500	400	0.26±0.01	−4.1±3.7	0.9±0.1
NR				0.43±0.07	−22.1±11.7	0.4±0.1

To estimate systematics:

- We vary the radii R from 1.5 to 5 GeV^{-1}
- We remove a resonance from the fit, and if $\Delta\chi^2 < 100$, we estimate the variation in x, y
- We also allow the mass and width of $f_0(500)$ to float

To estimate any possible bias, the same fit is performed to MC samples with given $x = \pm 1\%, y = \pm 1\%$

The mean bias is $\Delta x = 0.58\%, \Delta y = -0.05\%$

Dominant sources of systematics are:

- Amplitude-model variations, estimated removing the least relevant resonances
- Combinatorial DP distribution, when the MC is used instead of data
- Different decay time windows, and number of σ_t ranges
- Fit bias correction, taken as half of the bias measured from MC
- Effect of SVT misalignment, estimated creating MC signal samples with deliberately-wrong alignment files

Source	x [%]	y [%]
"Lucky" false slow pion fraction	0.01	0.01
Time resolution dependence on reconstructed D^0 mass	0.03	0.02
Amplitude-model variations	0.31	0.12
Resonance radius	0.02	0.10
DP efficiency parametrization	0.03	0.03
DP normalization granularity	0.03	0.04
Background DP distribution	0.21	0.11
Decay time window	0.18	0.19
σ_t cutoff	0.01	0.01
Number of σ_t ranges	0.11	0.26
σ_t parametrization	0.05	0.03
Background-model MC time distribution parameters	0.06	0.11
Fit bias correction	0.29	0.02
SVT misalignment	0.20	0.23
Total	0.56	0.46

Results :

$$x = (1.5 \pm 1.2 \pm 0.6)\,\%$$

$$y = (0.2 \pm 0.9 \pm 0.5)\,\%$$

$$\tau(D^{\circ}) = 410.2 \pm 3.8\,\text{fs}$$

BABAR Collaboration arXiv 1604.00857

State	Fit to data results		
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WORLD AVERAGE