Summary on WG7

Mixing and CP violation in charm system

$x_D, y_D, |q/p|_D, \phi_D$, and direct CPV

Fu-Sheng Yu (Lanzhou Univ)

Vishal Bhardwaj (IISER Mohali), Mirco Dorigo (CERN)

10th CKM workshop @ Heidelberg

Sep, 21, 2018

Monday, 17 September

10:35 **Overview of Charm Physics (theory and experiment)**

Speaker: Stefan Schacht

abstract_schacht.txt

heidelberg-schacht...

charming start

13:15 **WG7 summary charm**

Speakers: Fu-Sheng Yu, Mirco Dorigo (CERN), Vishal Bhardwaj

Hope for a charming end

Thank the organisers 🙂

Why Charm?

- **Unique properties:**
- **CPV and mixing in the up-type quark**
- **Extremely GIM suppression : Null test of SM or NP**
- **And more important : Large data**

$$\boxed{\Delta A_{CP}^{\rm dir} = A_{CP}(D^0 \to K^- K^+) - A_{CP}(D^0 \to \pi^- \pi^+)}$$

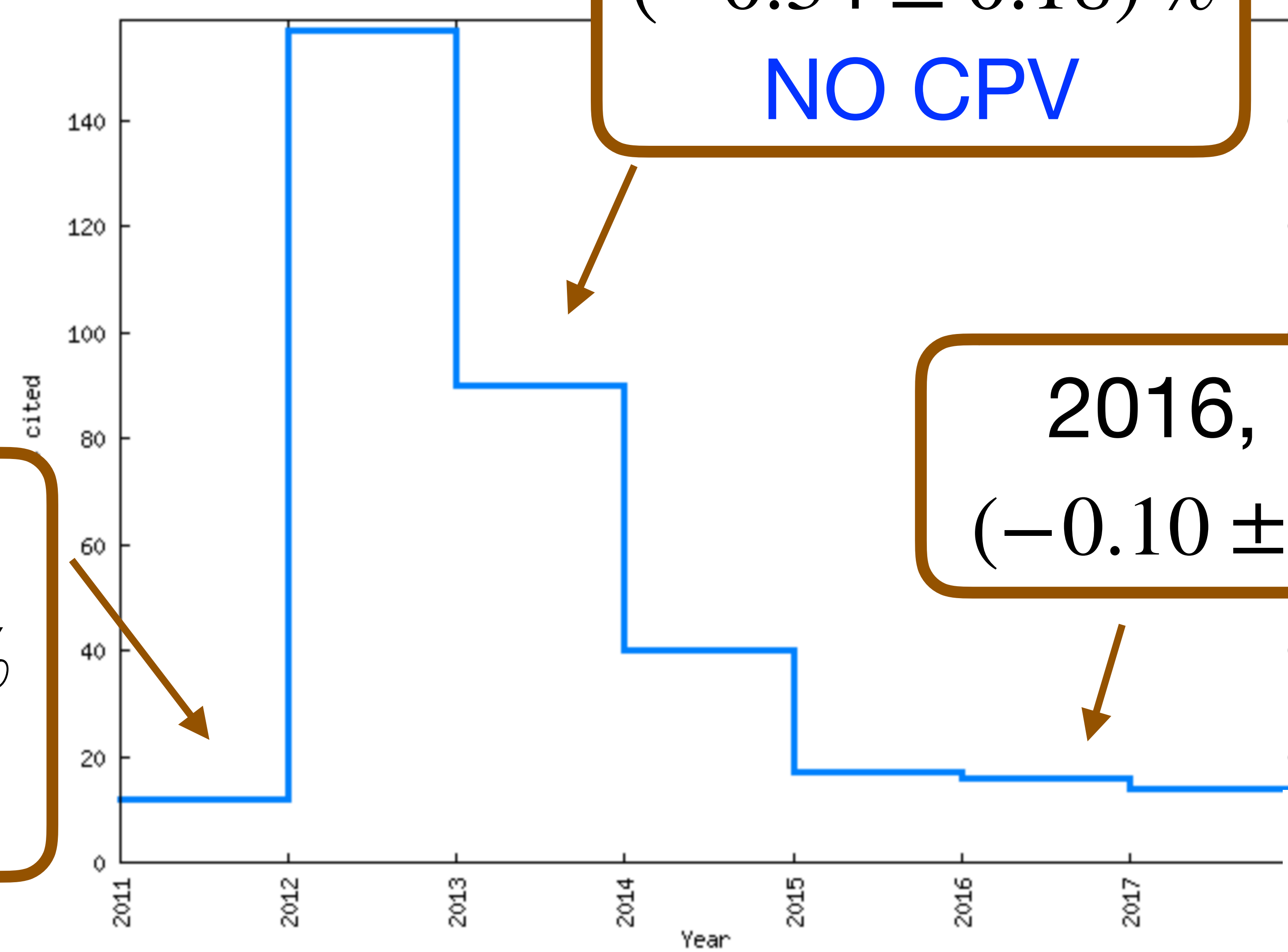
Evidence for CP violation in time-integrated $D^0 \to h^- h^+$ decay rates
LHCb Collaboration (R. Aaij (NIKHEF, Amsterdam) *et al.*). Dec 2011. 8 pp.
Published in **Phys.Rev.Lett. 108 (2012) 111602**

e-Print: **arXiv:1112.0938 [hep-ex]**

Cited by 348 records 250+

Short-lived excitement

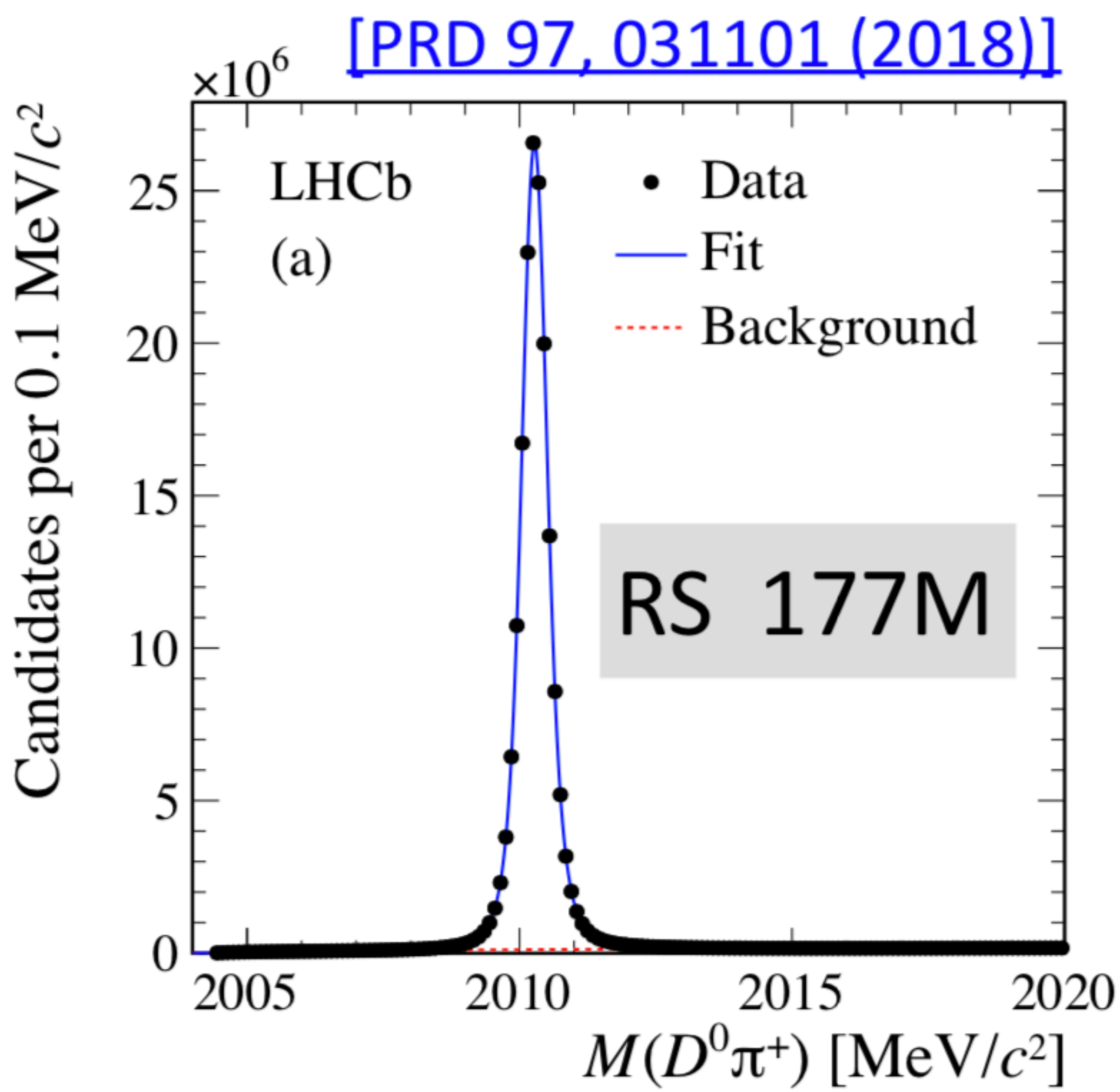
2013, LHCb
$(-0.34 \pm 0.18)\ \%$
NO CPV



2011, LHCb
$(-0.82 \pm 0.24)\ \%$
3.5σ evidence

2016, LHCb
$(-0.10 \pm 0.09)\ \%$

Good News : Large data



Pajero

$D^0 \longrightarrow K^{\pm}\pi^{\mp}$

LHCb 5 fb^{-1} (2011–2016)

10^8 events

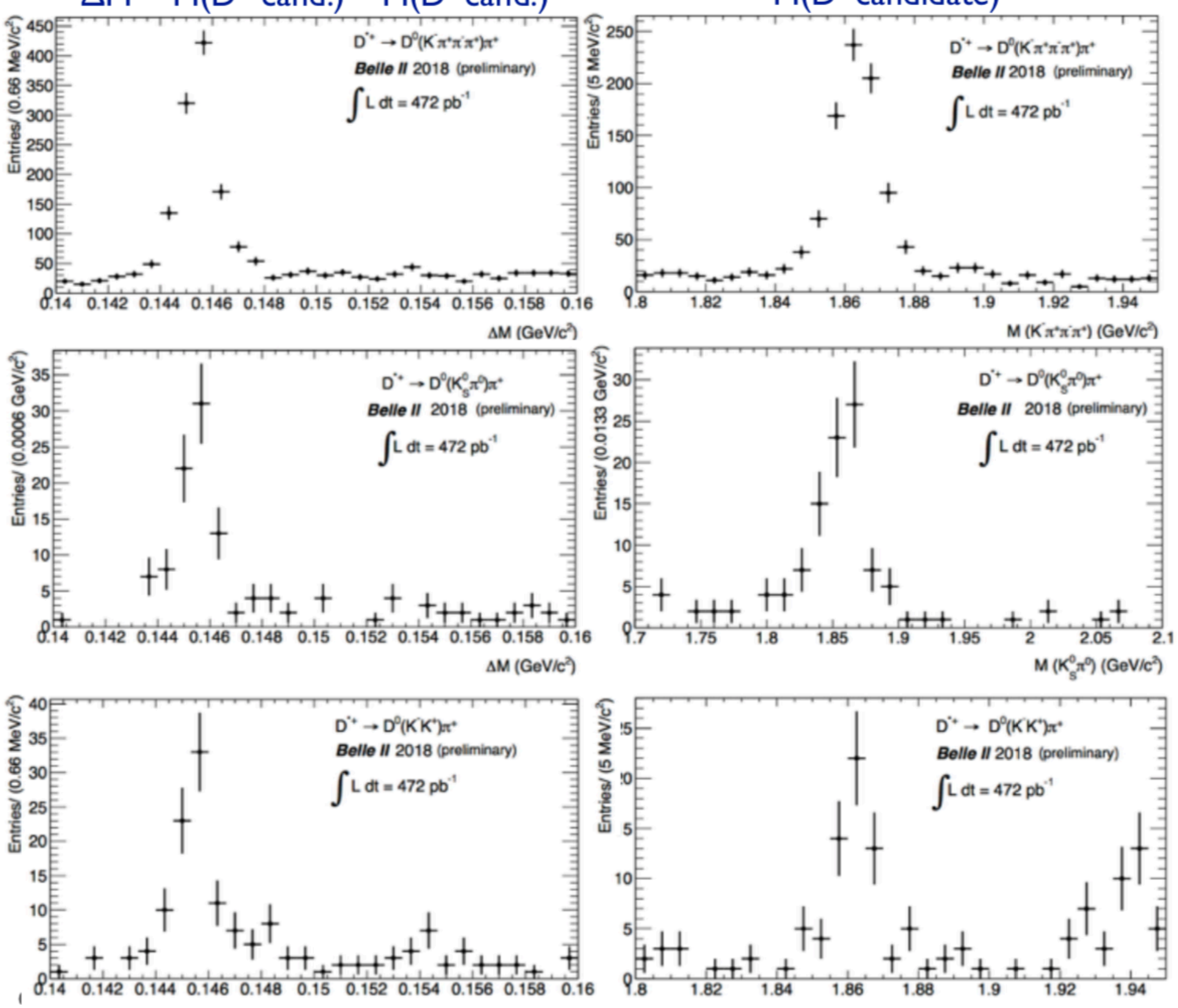
in an individual process!

Almost twice
at the end of this year
+ 4 fb^{-1}

Belle II is ready for charm physics

ΔM = M(D^* cand.) – M(D^0 cand.)

M(D^0 candidate)



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

$D^{*+} \to D^0\pi^+$
$D^0 \to K_S\pi^0$

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

SCS decay

Casarosa,

Kumar

Are you ready?

1. **Mixing and indirect CPV**
2. **Direct CPV**
3. **Charmed baryon prospects**

Mixing in theory

Exclusive approach to mixing: use data!

★ What if we insist on using experimental data anyway?

★ Ex., one can employ Factorizaton-Assisted Topological Amplitudes

in units of 10^{-3}

Modes	$\mathcal{B}$(exp)	$\mathcal{B}$(FAT)	Modes	$\mathcal{B}$(exp)	$\mathcal{B}$(FAT)	Modes	$\mathcal{B}$(exp)	$\mathcal{B}$(FAT)
$\pi^0\overline{K}^0$	24.0 ± 0.8	24.2 ± 0.8	$\pi^0\overline{K}^{*0}$	37.5 ± 2.9	35.9 ± 2.2	$\overline{K}^0\rho^0$	$12.8^{+1.4}_{-1.6}$	13.5 ± 1.4
π^+K^-	39.3 ± 0.4	39.2 ± 0.4	π^+K^{*-}	54.3 ± 4.4	62.5 ± 2.7	$K^-\rho^+$	111.0 ± 9.0	105.0 ± 5.2
$\eta\overline{K}^0$	9.70 ± 0.6	9.6 ± 0.6	$\eta\overline{K}^{*0}$	9.6 ± 3.0	6.1 ± 1.0	$\overline{K}^0\omega$	22.2 ± 1.2	22.3 ± 1.1
$\eta'\overline{K}^0$	19.0 ± 1.0	19.5 ± 1.0	$\eta'\overline{K}^{*0}$	<1.10	0.19 ± 0.01	$\overline{K}^0\phi$	$8.47^{+0.66}_{-0.34}$	8.2 ± 0.6
$\pi^+\pi^-$	1.421 ± 0.025	1.44 ± 0.02	$\pi^+\rho^-$	5.09 ± 0.34	4.5 ± 0.2	$\pi^-\rho^+$	10.0 ± 0.6	9.2 ± 0.3
K^+K^-	4.01 ± 0.07	4.05 ± 0.07	K^+K^{*-}	1.62 ± 0.15	1.8 ± 0.1	K^-K^{*+}	4.50 ± 0.30	4.3 ± 0.2
$K^0\overline{K}^0$	0.36 ± 0.08	0.29 ± 0.07	$K^0\overline{K}^{*0}$	0.18 ± 0.04	0.19 ± 0.03	$\overline{K}^0K^{*0}$	0.21 ± 0.04	0.19 ± 0.03
$\pi^0\eta$	0.69 ± 0.07	0.74 ± 0.03	$\eta\rho^0$		1.4 ± 0.2	$\pi^0\omega$	0.117 ± 0.035	0.10 ± 0.03
$\pi^0\eta'$	0.91 ± 0.14	1.08 ± 0.05	$\eta'\rho^0$		0.25 ± 0.01	$\pi^0\phi$	1.35 ± 0.10	1.4 ± 0.1
$\eta\eta$	1.70 ± 0.20	1.86 ± 0.06	$\eta\omega$	2.21 ± 0.23	2.0 ± 0.1	$\eta\phi$	0.14 ± 0.05	0.18 ± 0.04
$\eta\eta'$	1.07 ± 0.26	1.05 ± 0.08	$\eta'\omega$		0.044 ± 0.004			
$\pi^0\pi^0$	0.826 ± 0.035	0.78 ± 0.03	$\pi^0\rho^0$	3.82 ± 0.29	4.1 ± 0.2			
π^0K^0		0.069 ± 0.002	π^0K^{*0}		0.103 ± 0.006	$K^0\rho^0$		0.039 ± 0.004
π^-K^+	0.133 ± 0.009	0.133 ± 0.001	π^-K^{*+}	$0.345^{+0.180}_{-0.102}$	0.40 ± 0.02	$K^+\rho^-$		0.144 ± 0.009
ηK^0		0.027 ± 0.002	ηK^{*0}		0.017 ± 0.003	$K^0\omega$		0.064 ± 0.003
$\eta'K^0$		0.056 ± 0.003	$\eta'K^{*0}$		0.00055 ± 0.00004	$K^0\phi$		0.024 ± 0.002

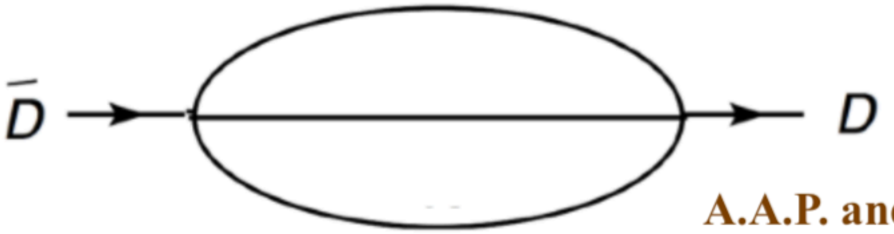
Jiang, Yu, Qin, Li, and Lu, 2017

★ ... but it appears to yield a smaller result, $y_{PP+PV} = (0.21\pm0.07)\%$.

Petrov

Mixing in theory

Since we are to use experimental data,
use Dalitz plot analyses to get at these contributions



A.A.P. and R. Briere
arXiv:1810.xxxx

1. To counteract the effects of finite widths and avoid double counting, one should work directly with Dalitz plot decays of D-mesons.
   - BESIII data on CP-fractions and DP would prove important

T. Gershon, J. Libby, G. Wilkinson
PLB 750 (2015) 338

2. There is no need to perform isobar parameterization of those Dalitz plots, use model-independent parameterizations are advantageous.

A.A.P. and R. Briere
arXiv:1804.xxxx

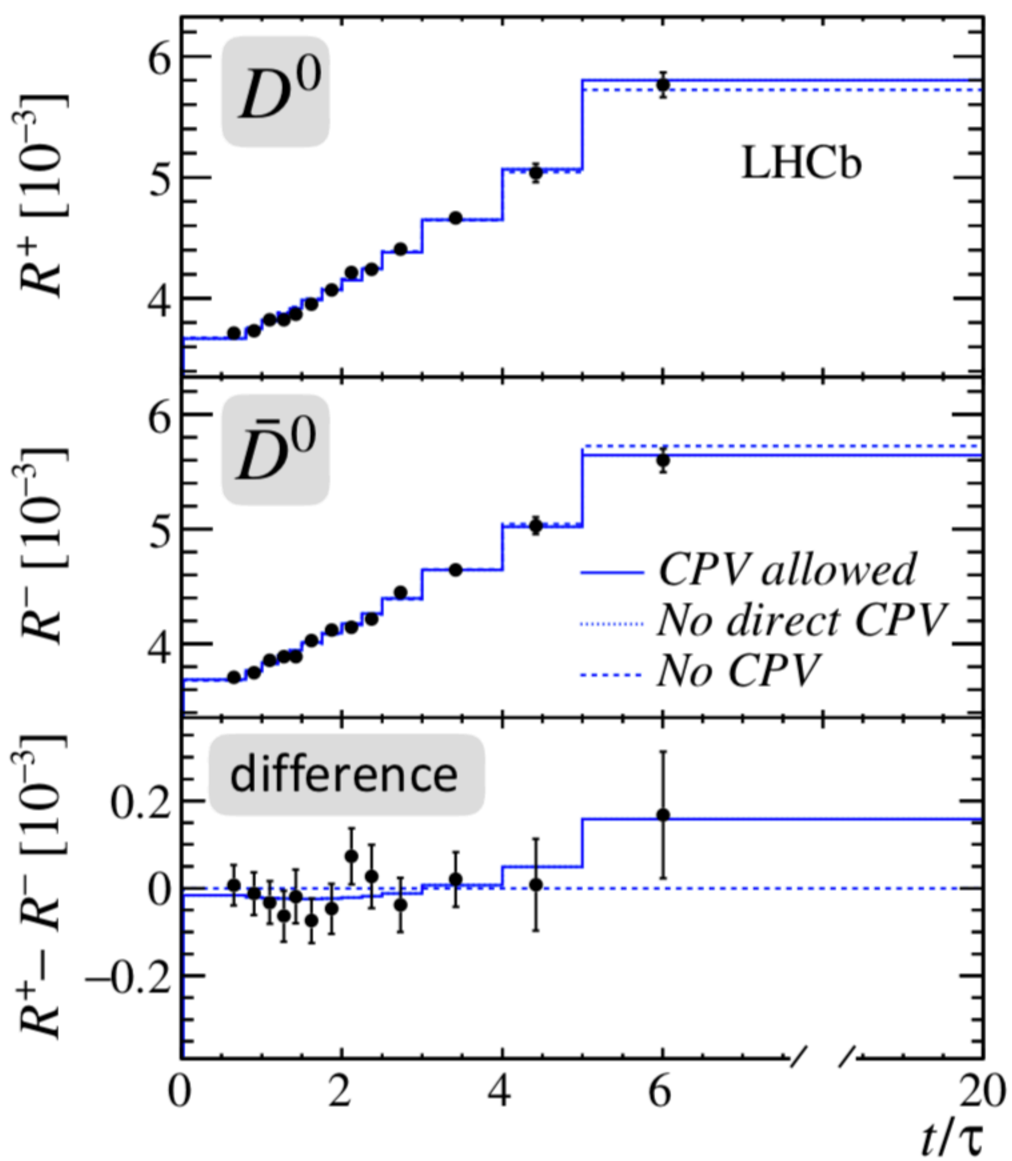
Petrov

Mixing @ LHCb : $D^0 \to K^\pm \pi^\mp$

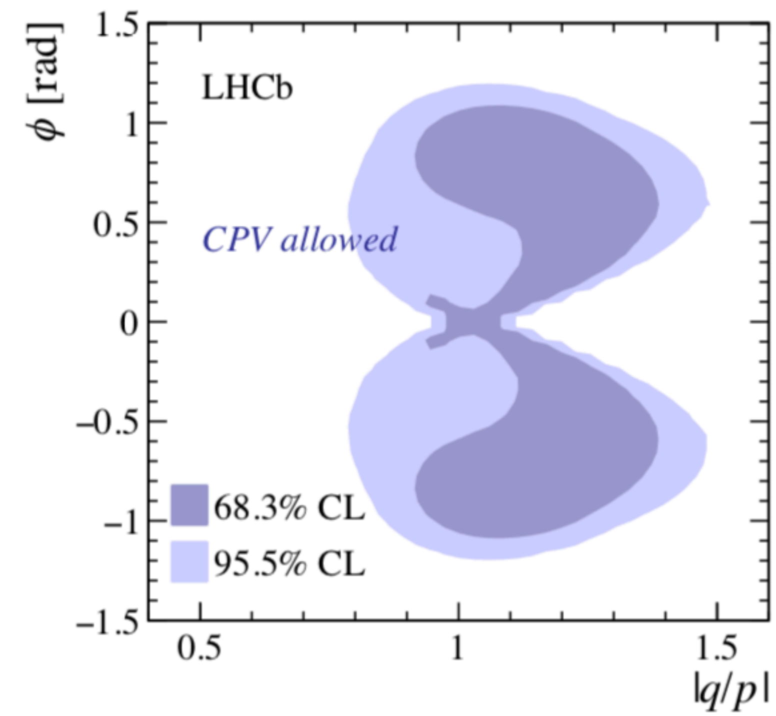
Pajero

[PRD 97, 031101 (2018)]

Results



- No evidence for CPV



- If no CPV is assumed:

$$\boxed{\begin{aligned} x'^2 &= (0.039 \pm 0.023 \pm 0.014) \cdot 10^{-3} \\ y' &= (5.28 \pm 0.45 \pm 0.27) \cdot 10^{-3} \end{aligned}}$$

- Twice as precise as previous superseded LHCb measurement [PRL 111 251801 (2013)]

Mixing @ LHCb : $D^0 \to K_S^0 \pi^+ \pi^-$

x = (-0.86 ± 0.53 ± 0.17)%
y = (0.03 ± 0.46 ± 0.13)%

Gersabeck

First model-independent measurement of x and y with LHCb

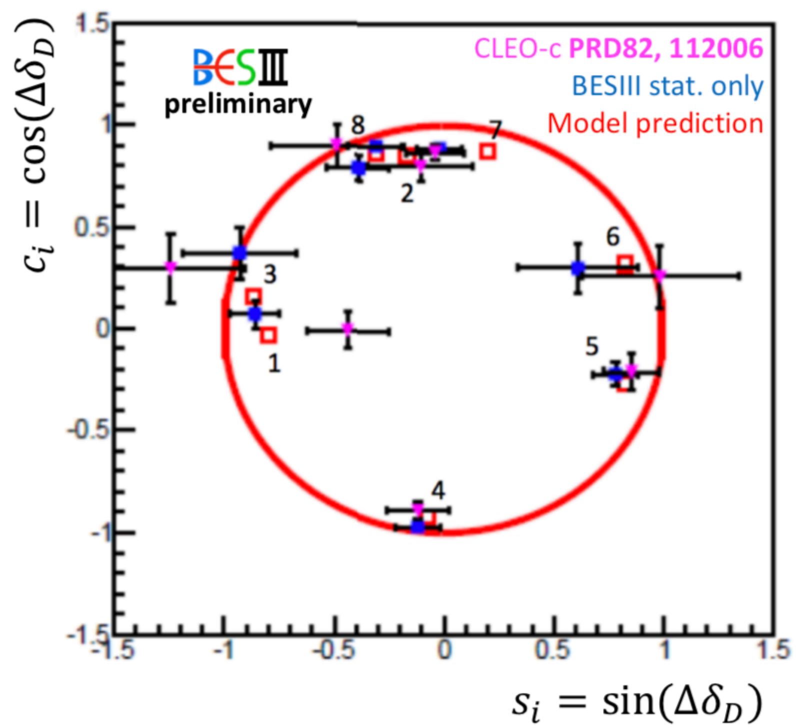
- Time-dependent decay rates expressed as

$$\mathcal{P}(D^0) \approx e^{\Gamma t}\left(T_{-i} - \Gamma t\sqrt{T_i T_{-i}}\{y c_i + x s_i\}\right)$$
$$\mathcal{P}(\overline{D}^0) \approx e^{\Gamma t}\left(T_{-i} - \Gamma t\sqrt{T_i T_{-i}}\{y c_i - x s_i\}\right)$$

assuming CP symmetry

- T_i, c_i and s_i provided by CLEO

→ allows model-independent measurement of mixing parameters x and y



strong phase @ BESIII

Weidenkaff

Need for BESIII to finalize the preliminary measurement of strong phases, as they are crucial input !

Mixing @ B factories

Babar : $D^0 \to \pi^+\pi^-\pi^0$

$$\boxed{x = (15 \pm 12 \pm 6)‰ \qquad y = (2 \pm 9 \pm 5)‰}$$

Greenwald

Belle has more data. Similar results in neutral modes can be expected

Belle II help in complimenting LHCb with neutral modes

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

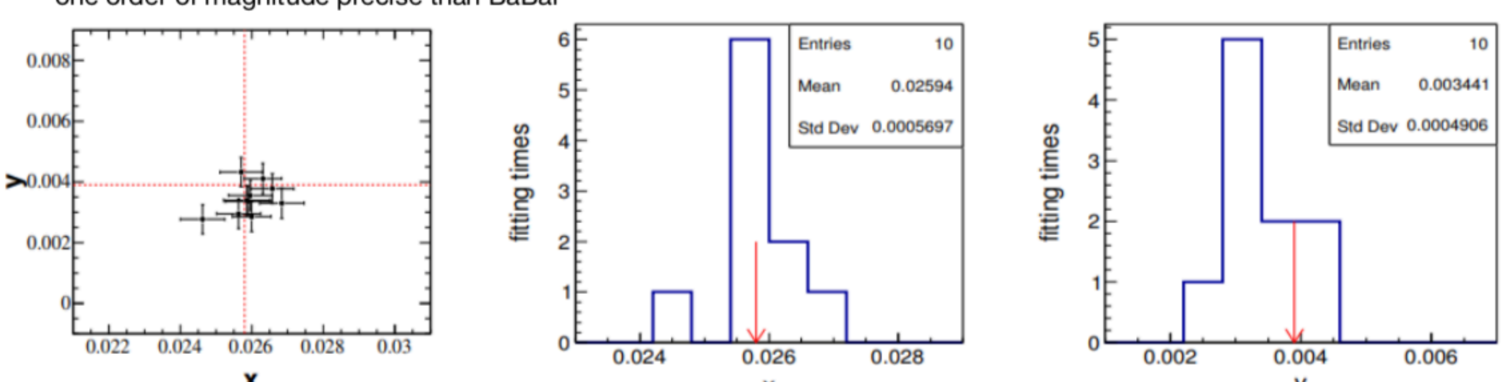
$$x'' = x\cos\delta_{K^+\pi^-\pi^0} + y\sin\delta_{K^+\pi^-\pi^0}$$
$$y'' = y\cos\delta_{K^+\pi^-\pi^0} - x\sin\delta_{K^+\pi^-\pi^0}$$

Belle II predictions

$$\sigma_{x''} = 0.057\%$$
$$\sigma_{y''} = 0.049\%$$

*assuming Belle II reconstruction efficiency is same as Belle

* one order of magnitude precise than BaBar



assuming no CP violation

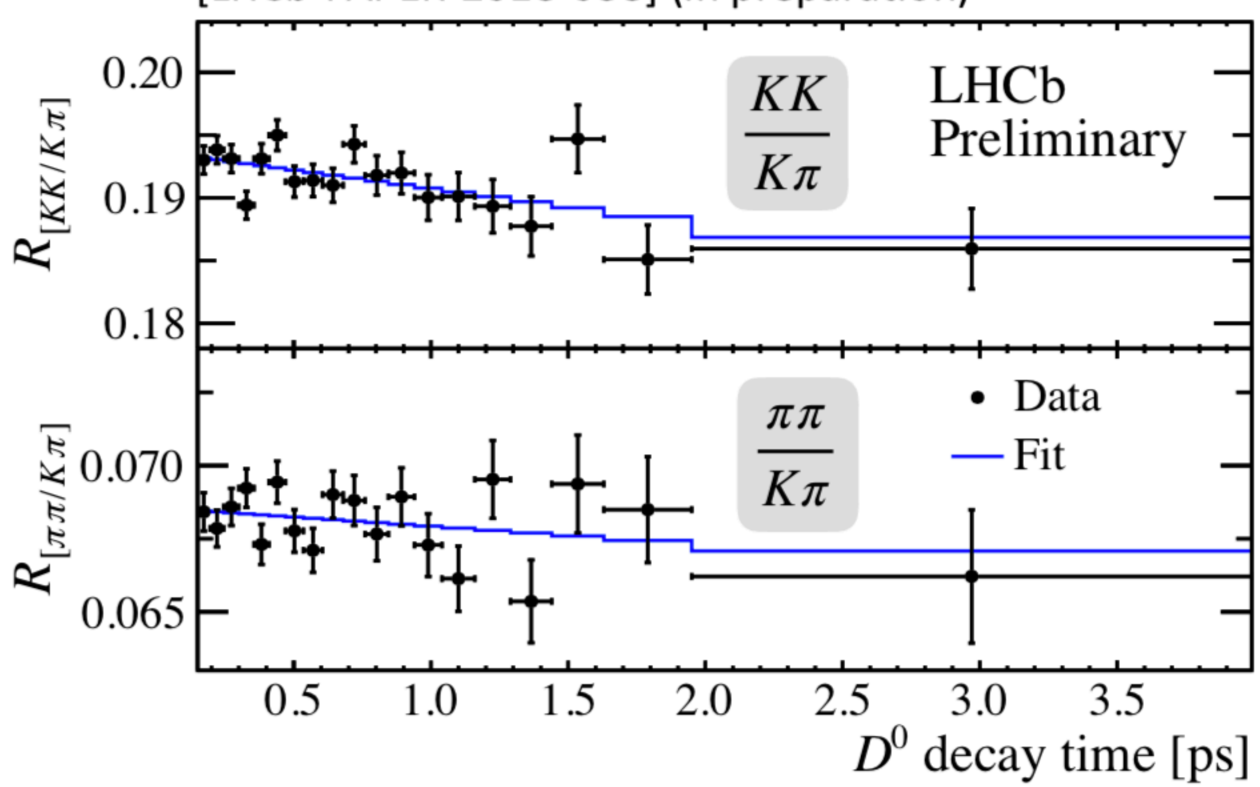
Kumar

Mixing and indirect CPV

$y_{CP} \neq y$ **would indicate CPV**

New!

[LHCb-PAPER-2018-038] (in preparation)



Pajero

$$y_{CP}^{KK} = (0.63 \pm 0.15 \pm 0.11)\,\%$$

$$y_{CP}^{\pi\pi} = (0.38 \pm 0.28 \pm 0.15)\,\%$$

LHCb $\boxed{y_{CP} = (0.57 \pm 0.13 \pm 0.09)\,\%}$

- compatible with $y = \left(0.67^{+0.06}_{-0.13}\right)\,\%$ within 1σ.

Compared to Belle:

$$y_{CP} = (1.11 \pm 0.24)\,\%$$

Greenwald

Mixing and indirect CPV

$$A_\Gamma^{KK} = (-3.0 \pm 3.2 \pm 1.0) \cdot 10^{-4}$$

$$A_\Gamma^{\pi\pi} = (\ \ 4.6 \pm 5.8 \pm 1.2) \cdot 10^{-4}$$

LHCb $\boxed{A_\Gamma = (-2.9 \pm 2.8) \cdot 10^{-4}}$ **Pajero**

Most precise measurement on CPV of charm $\mathcal{O}(10^{-4})$

Compared to Belle:

$$A_\Gamma = (-3 \pm 20 \pm 7) \cdot 10^{-4}$$

Greenwald

2. Direct CPV

DCPV: $\boxed{\Delta A_{CP}^{\mathrm{dir}} = A_{CP}(D^0 \to K^- K^+) - A_{CP}(D^0 \to \pi^- \pi^+)}$

$\mathcal{O}(10^{-4})$

Experiment	ΔA_{CP}	
CDF	$(+62 \pm 21 \pm 10) \times 10^{-4}$	PRL 109 (2012) 111801
BaBar	$(+24 \pm 62 \pm 26) \times 10^{-4}$	PRL 100 (2008) 061803
Belle	$(-87 \pm 41 \pm 6) \times 10^{-4}$	PLB 670 (2008) 190
LHCb (3.0 fb^{-1}, muon-tagged)	$(+14 \pm 16 \pm 8) \times 10^{-4}$	JHEP 07 (2014) 041
LHCb (3.0 fb^{-1}, pion-tagged)	$(-10 \pm 8 \pm 3) \times 10^{-4}$	PRL 116 (2016) 191601

- Most **precise** measurements performed by LHCb
- **Run 2** analysis ongoing
- With the full Run 2 the statistical uncertainty is expected to decrease by a factor 2.4 ($\sim \mathbf{3.5 \times 10^{-4}}$)
    - Expected stat uncertainty of ΔA_{CP} LHCB-PUB-2018-009
        - ~0.03% with Run 1 + Run 2
        - ~0.01% including also Upgrade

Betti

DCPV: $D^0 \rightarrow K_S^0 K_S^0$

- $A_{CP}(K_S^0 K_S^0) < \mathbf{1.1}\%$ $(95\%\mathrm{C.L.})$ → any higher measured value would point to **New Physics** PRD 92 (2015) 054036

Belle $\boxed{A^{\mathrm{CP}}(\mathrm{D}^0 \rightarrow \mathrm{K_S^0 K_S^0}) = (-0.02 \pm 1.53 \pm 0.02 \pm 0.17)\ \%}$

Greenwald

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

LHCb $A_{CP}(K_S^0 K_S^0) = (2.0 \pm 2.9 \pm 1.0)\%$ arXiv:1806.01642

Betti

- ~1% with Run 1 + Run 2

DCPV: $D^+ \to \pi^+\pi^0$

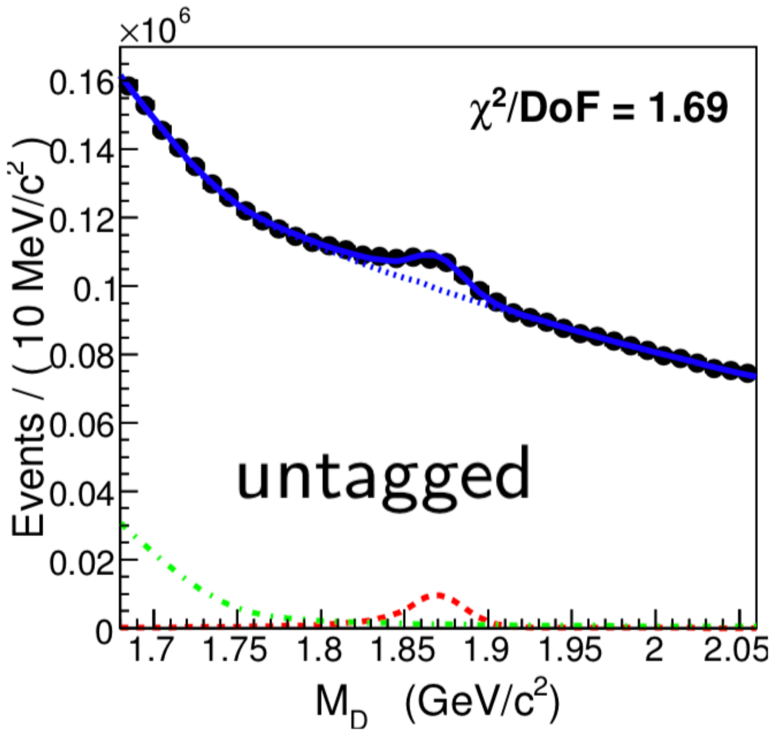
Isospin limit : $A_{CP}(D^0 \to \pi^+\pi^0) = 0$

Observation would signal new physics

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

Greenwald

@ Belle II $\to$ ($\pm 0.18 \pm 0.20$)%



Clean environment at Belle helps to even use untagged samples

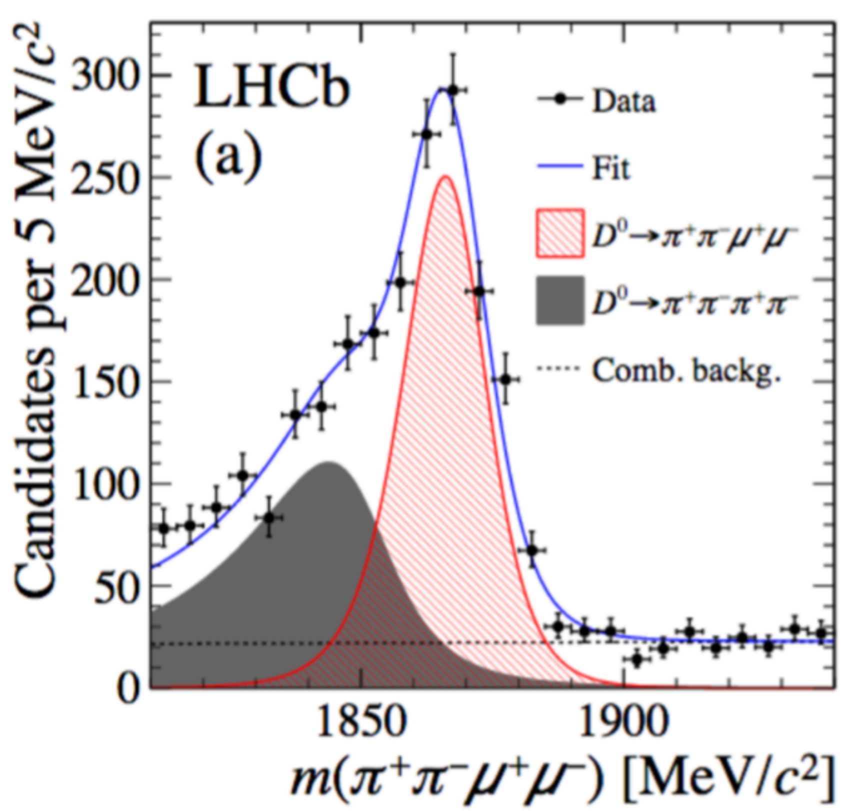
DCPV: $D^0 \to h^+h^-\mu^+\mu^-$

LHCb

$$\boxed{\begin{array}{c} A_{CP}(\pi^+\pi^-\mu^+\mu^-) = (4.9 \pm 3.8 \pm 0.7)\% \\ A_{CP}(K^+K^-\mu^+\mu^-) = (0 \pm 11 \pm 2)\% \end{array}}$$

Betti

See also from Burr, WG3



Rare D decays don't look so rare anymore

~1000 signal $D^0 \to \pi^+\pi^-\mu^+\mu^-$

~100 signal $D^0 \to K^+K^-\mu^+\mu^-$

DCPV: $D \to V\gamma$

Theory : search for new physics

de Boer

CP asymmetry	LQ	SUSY	SM	Belle
$D^0 \to \rho^0\gamma$	$\lesssim 10\%$	$\lesssim 0.2$	$\lesssim \mathcal{O}(10^{-3})$	0.056 ± 0.152

Belle :

Greenwald

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

Belle II

A_{CP} estimated error on	*Belle*	*Belle II statistical error*		
	1/ab	5/ab	15/ab	50/ab
$D^0 \to \rho^0 \gamma$	± 0.152 ± 0.006	± 0.07	± 0.04	± 0.02
$D^0 \to \phi \gamma$	± 0.066 ± 0.001	± 0.03	± 0.02	± 0.01
$D^0 \to \overline{K^{*0}} \gamma$	± 0.020 ± 0.000	± 0.01	± 0.005	± 0.003

Casarosa

Photon Polarization

To search for new physics with radiative D decays

not only CPV, but also photon polarization

de Boer

decay chain	color	CKM	type
$D^0 \to \bar{K}_1^0\gamma \to \bar{K}\pi\pi\gamma$	$1/N_C$	CF	SM
$D^0 \to K_1^0\gamma \to K\pi\pi\gamma$	$1/N_C$	DCS	SM
$D^+ \to K_1^+\gamma \to K\pi\pi\gamma$	1	DCS	SM
$D_s \to K_1^+\gamma \to K\pi\pi\gamma$	1	SCS	FCNC

up-down asymmetries

$$A_{up-down} = \left(\int_0^1 \frac{d\Gamma}{d\cos\tilde{\theta}} d\cos\tilde{\theta} - \int_{-1}^0 \frac{d\Gamma}{d\cos\tilde{\theta}} d\cos\tilde{\theta}\right) \Big/ \int_{-1}^1 \frac{d\Gamma}{d\cos\tilde{\theta}} d\cos\tilde{\theta}$$
$$\propto \lambda_\gamma$$

DCPV : Triple product asymmetry

T-odd asymmetry is a clean and alternative way to search for CPV in charm sector.

Search at Belle: $D^0 \rightarrow K^0_S \pi^+ \pi^- \pi^0$

$$a_{CP}^{T\text{-odd}} = \boxed{\left[-0.28 \pm 1.38\ (\text{stat.})^{+0.23}_{-0.76}\ (\text{syst.})\right] \times 10^{-3}}$$

Search at Belle: $D^0 \rightarrow K^+ K^- \pi^+ \pi^-$

Asymmetries

NEW RESULT

PRELIMINARY

$$a^{CP}_{\cos\Phi} = (3.4 \pm 3.6 \pm 1.7) \times 10^{-3},$$

$$a^{CP}_{\sin\Phi} = (5.2 \pm 3.7 \pm 1.7) \times 10^{-3},$$

$$a^{CP}_{\sin 2\Phi} = (3.9 \pm 3.6 \pm 1.7) \times 10^{-3},$$

$$a^{CP}_{\cos\theta_1 \cos\theta_2 \cos\Phi} = (-0.2 \pm 3.6 \pm 1.6) \times 10^{-3},$$

$$a^{CP}_{\cos\theta_1 \cos\theta_2 \sin\Phi} = (0.2 \pm 3.7 \pm 1.6) \times 10^{-3},$$

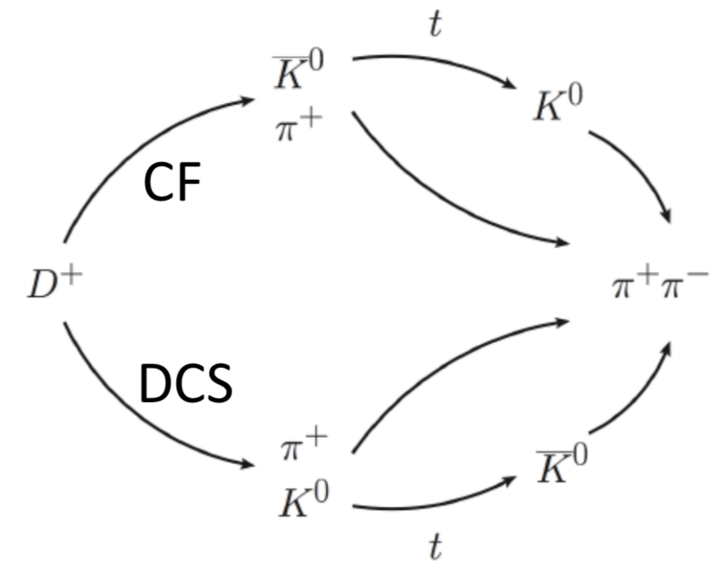
First Measurement
With kinematic asymmetries

Bahinipati

Theory finds new effect in

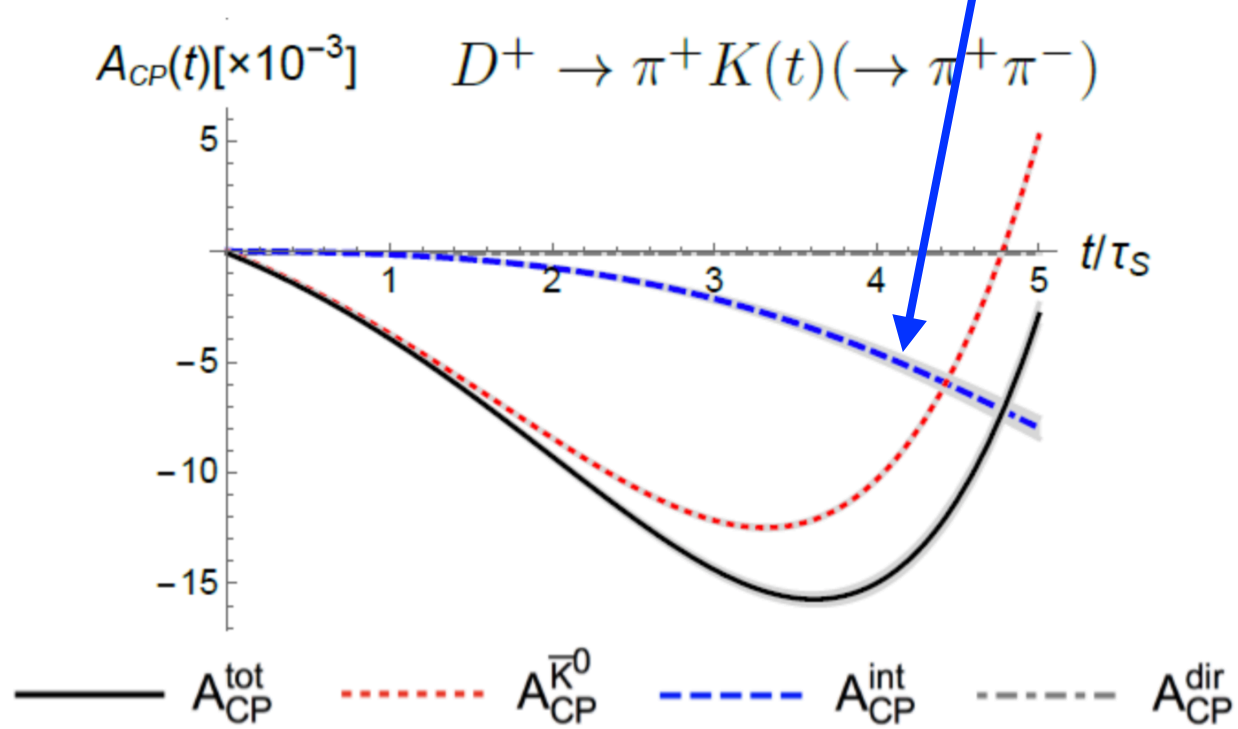
CPV in charm decays into neutral kaons

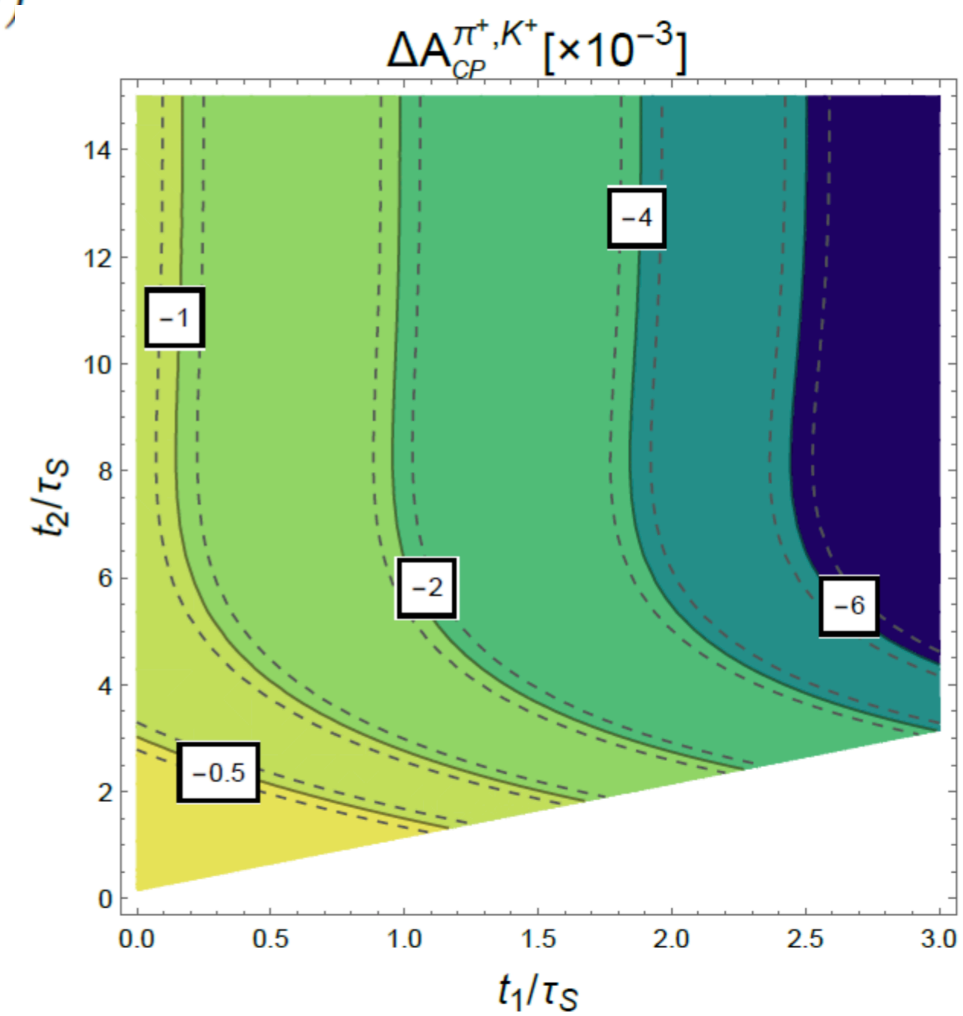
H.n.Li



$$A_{CP}(t) \simeq \left[A_{CP}^{\overline{K}^0}(t) + A_{CP}^{\rm dir}(t) + A_{CP}^{\rm int}(t)\right] / D(t)$$

New effect





Measurement suggestion

$$A_{CP}^{D^+\to\pi^+K_S^0}(t_1,t_2) - A_{CP}^{D_s^+\to K^+K_S^0}(t_1,t_2)$$

Theoretical suggestions on CPV measurements

$$\boxed{D^0 \to K_S^0 K^*}$$

Special Features on top of $D^0 \to K_S K_S$

- Prompt decay $K^{0*} \to K^+ \pi^-$ with charged tracks.
- Hunt for favorable strong phases in Dalitz plot.
- No flavor tagging needed, essentially undiluted untagged CP asymmetry.

SM prediction

[Nierste Schacht PRL119 251801 (2017)]

$$a_{CP}^{\mathrm{dir}}(\overset{(-)}{D} \to K_S K^{*0}) \approx a_{CP}^{\mathrm{dir}}(D^0 \to K_S K^{0*}) \lesssim 0.3\% \,.$$

Theoretical suggestions on CPV measurements

Strategy to enhance charm-CP $\left[\alpha_{PRA} \sim \frac{\mathrm{Im}\,P}{T}\right]$

- Enhance penguin as much as you can
- **For charm-CP extremely important to suppress tree as much as possible:**
- A) avoid W-> ud or us making charge vector state…. e.g. rho^{+-} or K$^{*(+-)}$ …..field-current ….Sakurai VMD ideas B) go for CLS ….color suppressed FS…from tree
- C) go for CBS….cabibbo suppressed FS =>Singly Cabibbo Suppressed [SCS]….**atomatically forced by T-P interference a la Bander, Silverman and A.S PRL 1979**

enhance penguin

suppress tree

Soni

$\pi^0\pi^0(\rho^0)$

$\rho^0\rho^0$

CKM-2018, soni-BNL 26

Theoretical suggestions on CPV measurements

- D^+ (B^+)=> pi+ pi0 is good way to go after, but precise SM predictions are absent and isospin breakings may be sizeable
- Its also important to go after c => u l l, c =u gamma but expected rates are rather small.
- Very good chance that in the next ~5 years, via IF machines, LHCb, Belle-II, STCF along with precise computations …major advances in our understandings of Particle Physics will be made

Soni

DCPV : Belle II prospect

Mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II 50 ab^{-1}(%)
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K^0_S\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.02
$D^0 \to K^0_S K^0_S$	921	$-0.02 \pm 1.53 \pm 0.02 \pm 0.17$	± 0.23
$D^0 \to K^0_S\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K^0_S\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \pi^+\pi^0$	921	$+2.31 \pm 1.24 \pm 0.23$	± 0.17
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K^0_S\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.02
$D^+ \to K^0_S K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.04
$D_s^+ \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

important for A_{CP} sum rules

SM $A_{CP} \simeq 1\%$

important for A_{CP} sum rules

SM $A_{CP} = 0$

New CPV effect

$\mathcal{O}(10^{-4})$

Casarosa

3. Charmed baryon prospects

Partly personal opinions

- data driven
- challenge and opportunity

$\Lambda_c^+ \to pK^-K^+$ and $\Lambda_c^+ \to p\pi^-\pi^+$

LHCb $\boxed{\Delta A_{CP}^{\text{wgt}} = (0.30 \pm 0.91 \pm 0.61)\%}$ Gobel

Measurements on CPV in charmed baryons are coming…

Doubly charmed baryon

first observed via

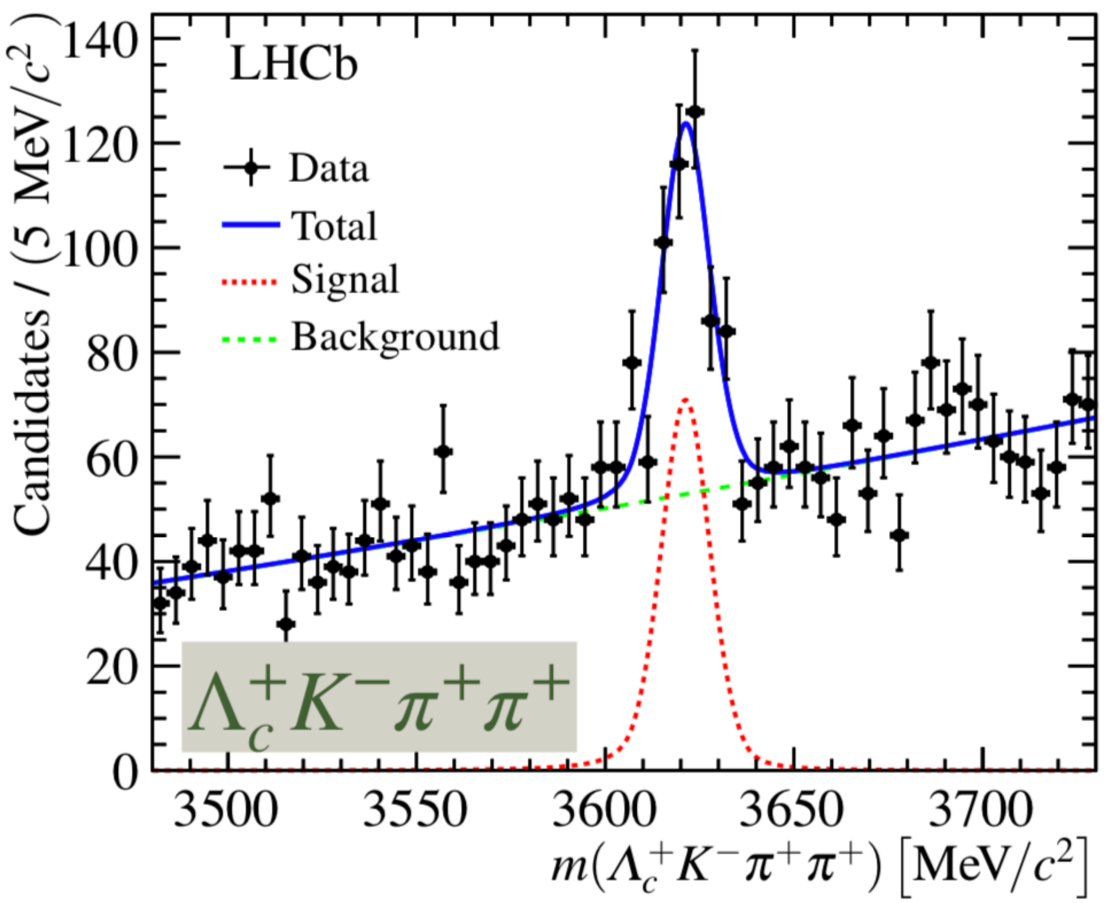
$\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$

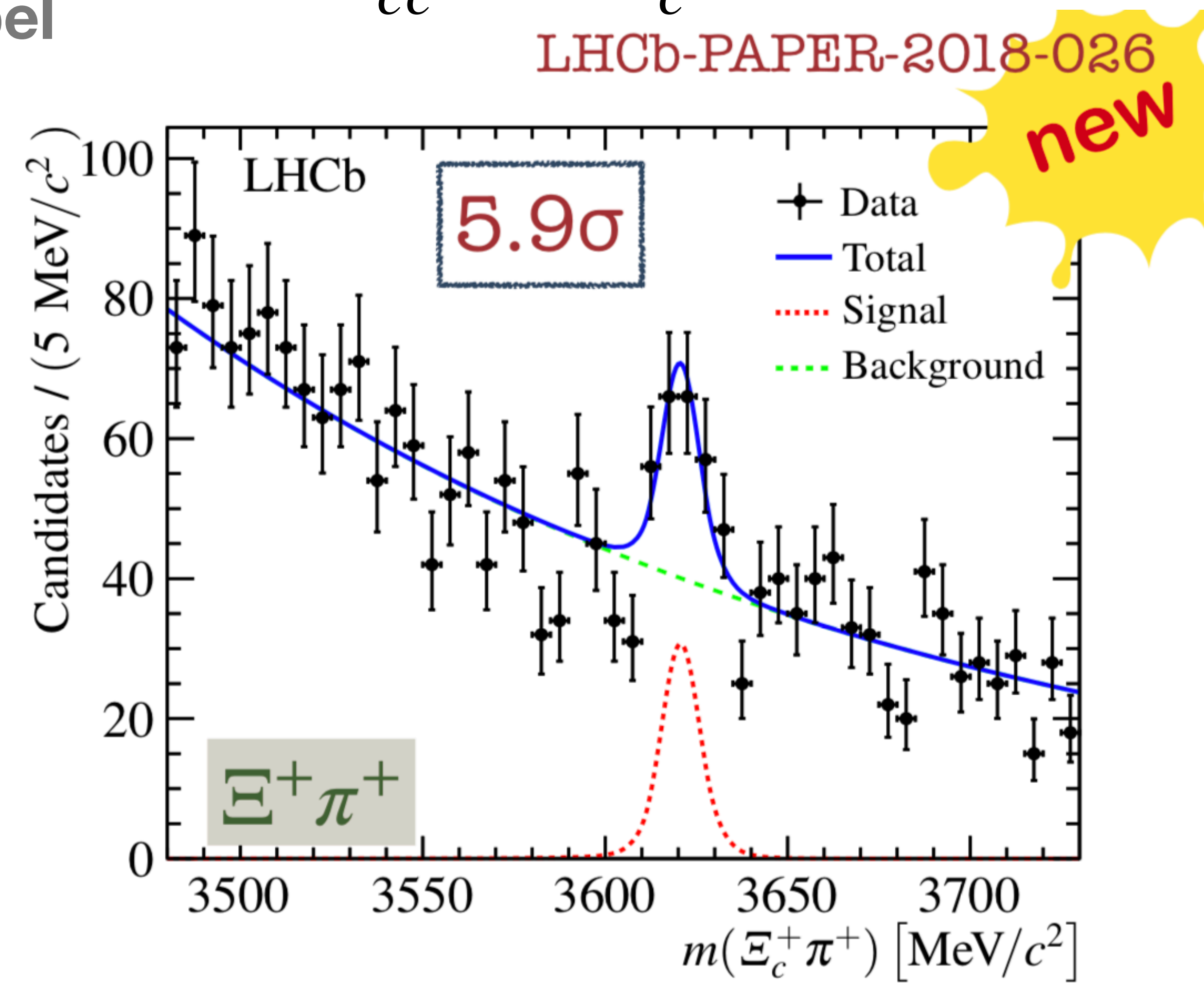
Gobel

and confirmed by

$\Xi_{cc}^{++} \to \Xi_c^+ \pi^+$

LHCb-PAPER-2018-026

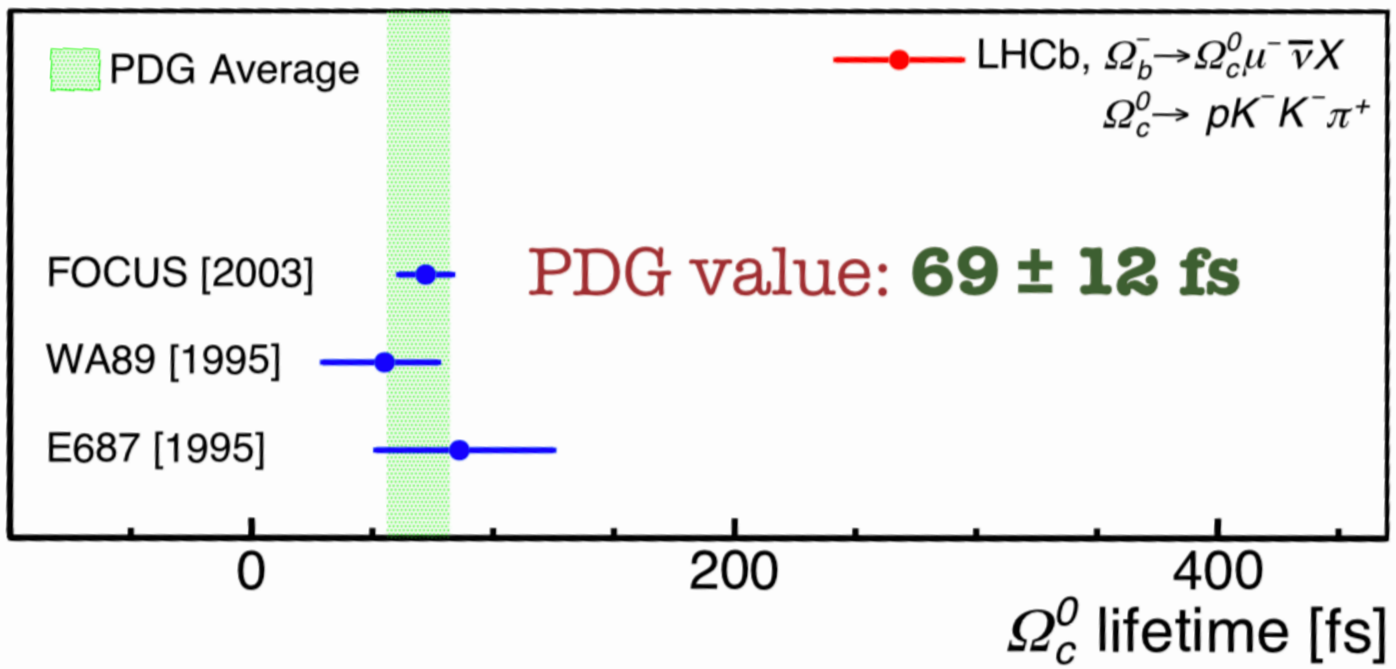




$\tau(\Xi_{cc}^{++}) = 256^{+22}_{-20} \pm 14\,\text{fs}$

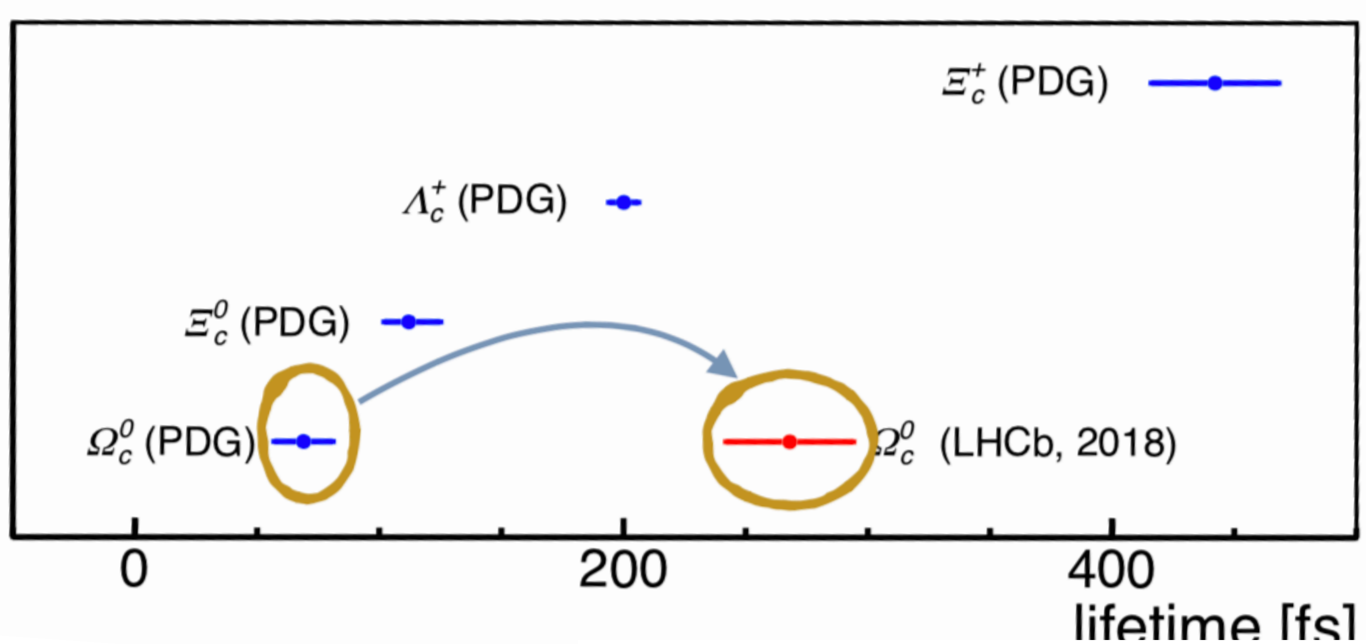
Discovery channels were predicted by FSY, et ac,1703.09086

Lifetime of charmed baryon



$$\tau(\Omega_c^0) = 268 \pm 24_{\rm stat} \pm 10_{\rm syst} \pm 2_{\tau_{D+}}\ {\rm fs}$$

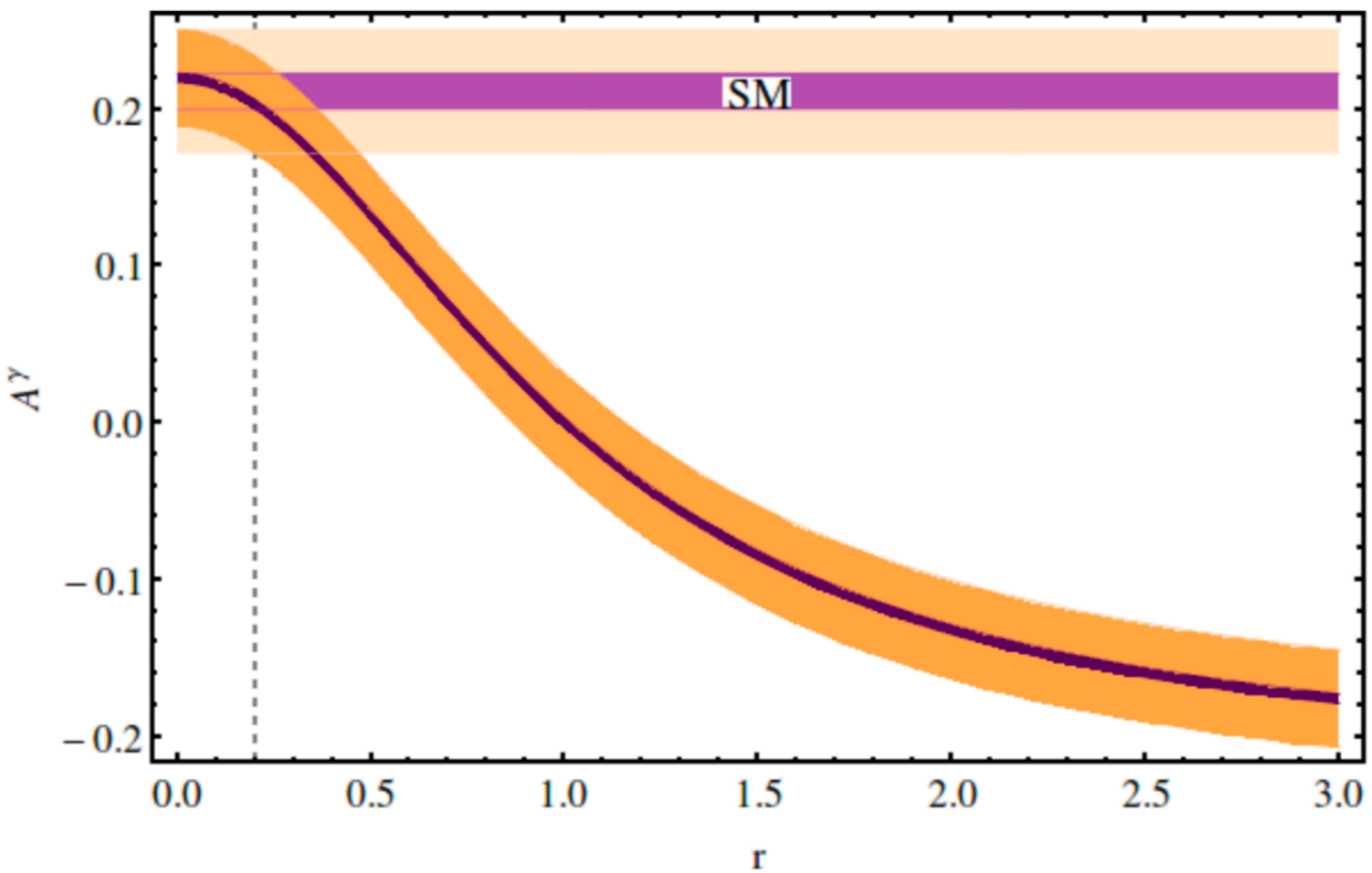
$$\tau(\Xi_c^+) > \tau(\Omega_c^0) > \tau(\Lambda_c^+) > \tau(\Xi_c^0)$$



Gobel

$\Lambda_c \to p\gamma$ Photon polarization

suggested



de Boer

$$A^\gamma = -\frac{P_{\Lambda_c}}{2}\frac{1-|r|^2}{1+|r|^2}, \quad r = \frac{A_7'}{A_7}$$

Suggest to probe CPV in $\Xi_c^+ \to pK^-\pi^+$

$$Br(\Lambda_c^+ \to pK^+K^-) \sim 0.15\,\%$$

- Larger BR by one order

$$\updownarrow$$

U-spin symmetry: $Br(\Xi_c^+ \to pK^-\pi^+) = (2.2 \pm 0.8)\%$

FSY, et ac, 1703.09086; Jiang, **FSY**, 1802.02948

- Longer lifetime would benefit measurement at LHCb

$$\tau(\Lambda_c^+) = (200 \pm 6) \times 10^{-15} s, \qquad \tau(\Xi_c^+) = (442 \pm 26) \times 10^{-15} s,$$

Probably more data, even if suppressed by production.

Jia, **FSY**, in preparation

Summary of the summary

- **Data of charm is huge => also bring huge challenges but also opportunities to TH and EXP.**
- **Precision of measurements becomes higher**
- **Interplay between theory and experiment is more effective**
- **Charmed baryons are interesting and deserve to be paid out more attention**

Welcome to play the charming games

Thanks !

Backup

y_{CP} in correlated $D^0\overline{D}^0$ decays

Branching fraction

Tag mode	$\mathcal{B}_{D_{CP-}\to Ke\nu}$ (%)	$\mathcal{B}_{D_{CP-}\to K\mu\nu}$ (%)	$\mathcal{B}_{D_{CP-}\to l}$ (%)
K^+K^-	3.44 ± 0.12	3.33 ± 0.12	6.77 ± 0.17
$\pi^+\pi^-$	3.29 ± 0.18	3.35 ± 0.20	6.64 ± 0.27
$K_S^0\pi^0\pi^0$	3.40 ± 0.18	3.48 ± 0.18	6.89 ± 0.26
$\tilde{\mathcal{B}}_{D_{CP-}\to l}$	3.40 ± 0.09	3.37 ± 0.09	6.77 ± 0.12
Tag mode	$\mathcal{B}_{D_{CP+}\to Ke\nu}$ (%)	$\mathcal{B}_{D_{CP+}\to K\mu\nu}$ (%)	$\mathcal{B}_{D_{CP+}\to l}$ (%)
$K_S^0\pi^0$	3.62 ± 0.10	3.33 ± 0.10	6.96 ± 0.15
$K_S^0\omega$	3.32 ± 0.21	3.81 ± 0.21	7.14 ± 0.30
$K_S^0\eta$	3.68 ± 0.26	3.84 ± 0.29	7.52 ± 0.40
$\tilde{\mathcal{B}}_{D_{CP+}\to l}$	3.58 ± 0.09	3.46 ± 0.09	7.04 ± 0.13

combined $\mathcal{CP}$-

combined $\mathcal{CP}$+

$$\boxed{y_{CP} = (-2.0 \pm 1.3 \pm 0.7)\%}$$

(stat.) (sys.)

- Stat. limitation **PLB744, 339 (2015)**
- Sys. uncertainties (ordered)
  - Double tag yield: U_{miss} fit model
  - Fake tag
  - Fit model m_{BC} / Background / $\mathcal{CP}$ purity (K_S^0)

Comparison

PDG 2016

Year	Exper.	final state(s)	y_{CP}(%)	$A_\Gamma(\times10^{-3})$
2015	BES III [43]	$K_S^0\pi^0, K_S^0\eta, K_S^0\omega$ $K^+K^-, \pi^+\pi^-, K_S^0\pi^0\pi^0$	$-2.0\pm1.3\pm0.7$	—
2012	Belle [46]	$K^+K^-, \pi^+\pi^-$	$1.11\pm0.22\pm0.09$	$-0.3\pm2.0\pm0.7$
2012	BaBar [47]	$K^+K^-, \pi^+\pi^-$	$0.72\pm0.18\pm0.12$	$0.9\pm2.6\pm0.6$
2011	LHCb [48]	K^+K^-	$0.55\pm0.63\pm0.41$	$-5.9\pm5.9\pm2.1$
2009*	BaBar [49]	K^+K^-	$1.16\pm0.22\pm0.18$	—
2009	Belle [50]	$K_S^0K^+K^-$	$0.11\pm0.61\pm0.52$	—
2008*	BaBar [51]	$K^+K^-, \pi^+\pi^-$	$1.03\pm0.33\pm0.19$	$2.6\pm3.6\pm0.8$
2007*	Belle [52]	$K^+K^-, \pi^+\pi^-$	$1.31\pm0.32\pm0.25$	$0.1\pm3.0\pm1.5$
2003*	BaBar [53]	$K^+K^-, \pi^+\pi^-$	$0.8\pm0.4^{+0.5}_{-0.4}$	—
2001	CLEO [54]	$K^+K^-, \pi^+\pi^-$	$-1.2\pm2.5\pm1.4$	—
2001	Belle† [55]	K^+K^-	$-0.5\pm1.0^{+0.7}_{-0.8}$	—
2000	FOCUS [56]	K^+K^-	$3.42\pm1.39\pm0.74$	—
1999	E791 [57]	K^+K^-	$0.8\pm2.9\pm1.0$	—
	HFLAV [9]		0.835 ± 0.155	-0.32 ± 0.26

- Less precise then previous measurements
- Compatible within previous measurements

$$\boxed{\text{Follow-up analysis including } K_L\pi^0(\pi^0)}$$

Weidenkaff, Tue

A_{CP} of $D^+ \to K_{S,L}K^+(\pi^0)$ decays

- CPV can arise in SCS decays via interference between tree and penguin processes
- Measure branching fractions using a double tag technique
- Tag side from 6 tag modes $N_{ST} \sim 1.5 \cdot 10^6$
- K_L difficult to reconstruct
- CP asymmetries

$$\boxed{\mathcal{A}_{CP} = \frac{\mathcal{B}(D^+) - \mathcal{B}(D^-)}{\mathcal{B}(D^+) + \mathcal{B}(D^-)}}$$

BESIII preliminary

Mode	$\mathcal{B}(D^+)$ $(\times 10^{-3})$	$\mathcal{B}(D^-)$ $(\times 10^{-3})$	$\overline{\mathcal{B}}$ $(\times 10^{-3})$	$\mathcal{A}_{CP}$ (%)
$K_S^0 K^\pm$	$3.01 \pm 0.12 \pm 0.10$	$3.10 \pm 0.12 \pm 0.10$	$3.06 \pm 0.09 \pm 0.10$	$-1.5 \pm 2.8 \pm 1.6$
$K_S^0 K^\pm \pi^0$	$5.23 \pm 0.28 \pm 0.24$	$5.09 \pm 0.29 \pm 0.22$	$5.16 \pm 0.21 \pm 0.23$	$1.4 \pm 4.0 \pm 2.4$
$K_L^0 K^\pm$	$3.13 \pm 0.14 \pm 0.13$	$3.32 \pm 0.15 \pm 0.13$	$3.23 \pm 0.11 \pm 0.13$	$-3.0 \pm 3.2 \pm 1.2$
$K_L^0 K^\pm \pi^0$	$5.17 \pm 0.30 \pm 0.21$	$5.26 \pm 0.30 \pm 0.20$	$5.22 \pm 0.22 \pm 0.21$	$-0.9 \pm 4.1 \pm 1.6$

- $K_S K^+$ consistent with CLEO-c result
  Phys. Rev. D77, 091106(R) (2008)
- First measurements
- No evidence for CPV with current statistics

Weidenkaff, Tue