WG7: Mixing and CPV in charm

Experiment: Jolanta Brodzicka, Univ. of Manchester
Theory: Jernej Kamenik, JSI Ljubljana

CKM2014, Vienna
September 2014

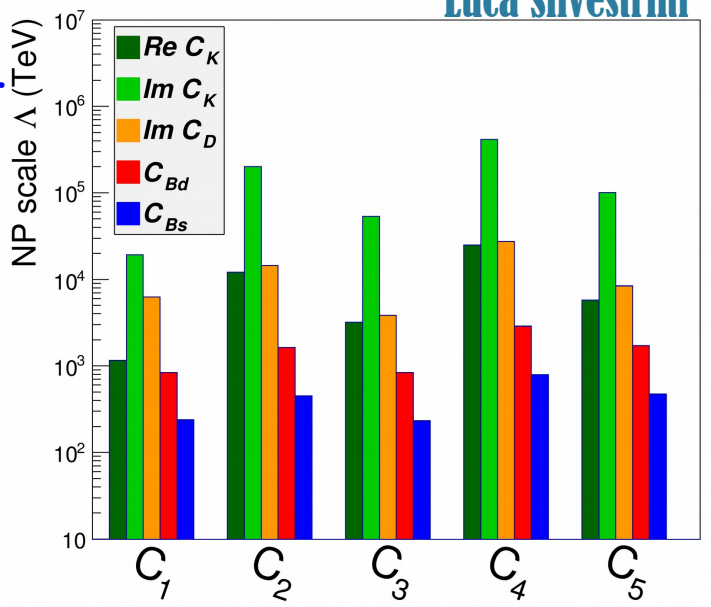
"Everything is smaller in charm"

Mat Charles on Monday

- Does not apply to the effort
- At times less is more (Again, does not apply to the effort)

- CP violation in $\Delta F=2$ processes is the most sensitive probe of NP, reaching scales of $O(10^5)$ TeV
- CPV in D mixing gives best bound after ε_K

Luca Silvestrini



WG7 Sessions

107 - D-Dbar mixing in SM	*Luca SILVESTRINI*	
EI 10 lecture hall, Vienna University of Technology	14:15 - 14:40	
108 - D-mixing and indirect CPV measurements at LHCb	*Silvia BORGHI*	
EI 10 lecture hall, Vienna University of Technology	14:40 - 15:00	
109 - D-mixing and indirect CPV at Belle and prospects for Belle II	*Alan SCHWARTZ*	
EI 10 lecture hall, Vienna University of Technology	15:00 - 15:20	
157 - Search for CPV in D0->hh at CDF	*Leo SABATO*	
110 - Charm mixing and CPV at BaBar	*Chen CHUNHUI*	
EI 10 lecture hall, Vienna University of Technology	15:35 - 15:55	
111 - Recent results and prospects for charm mixing and CPV at Threshold	*Xiao-Rui LYU*	
EI 10 lecture hall, Vienna University of Technology	15:55 - 16:15	
6 - D-Dbar mixing, Charm CPV and NP	*Dr. Wolfgang ALTMANNSHOFER*	
EI 10 lecture hall, Vienna University of Technology	16:45 - 17:10	
112 - CPV in hadronic D decays within SM	*Amarjit SONI*	
EI 10 lecture hall, Vienna University of Technology	17:10 - 17:35	
113 - Direct CPV in two-body and multibody charm decays at LHCb	*Evelina Mihova GERSABECK*	
EI 10 lecture hall, Vienna University of Technology	17:35 - 18:00	
114 - Direct CPV in charm decays at Belle and prospects for Belle II	*Marko STARIC*	
EI 10 lecture hall, Vienna University of Technology	18:00 - 18:20	
8 - SU(3) methods and CPV in D decays	*Stefan SCHACHT*	
EI 10 lecture hall, Vienna University of Technology	18:20 - 18:40	
115 - Dalitz plot studies in hadronic charm decays	*Leonard LESNIAK*	
EI 9 lecture hall, Vienna University of Technology	16:45 - 17:10	
116 - CP violating triple product asymmetry measurements in charm decays	*Maurizio MARTINELLI*	
EI 9 lecture hall, Vienna University of Technology	17:10 - 17:40	
5 - Interplay between flavor violating and flavor diagonal CPV in charm	*Filippo SALA*	
EI 9 lecture hall, Vienna University of Technology	17:40 - 18:00	
7 - CPV in radiative and rare D decays	*Nejc KOŠNIK*	
EI 9 lecture hall, Vienna University of Technology	18:00 - 18:20	
117 - HFAG averages and prospects for mixing and CPV in charm decays	*Dr. Marco GERSABECK*	
EI 9 lecture hall, Vienna University of Technology	18:20 - 18:45	

- Talks:
  8 Experiment
  7 Theory
  1 HFAG
- Most with prospects

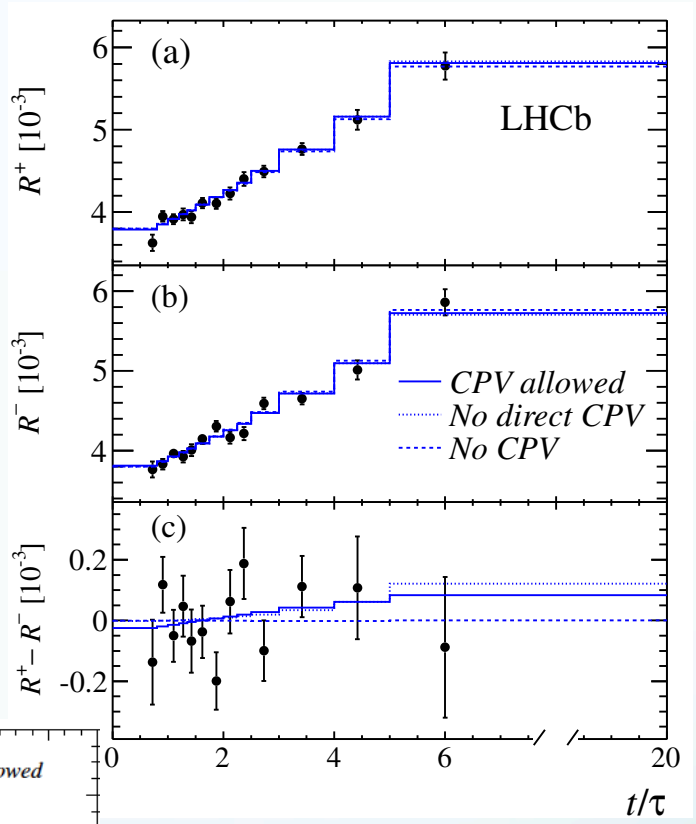
⇨ 6h of charm

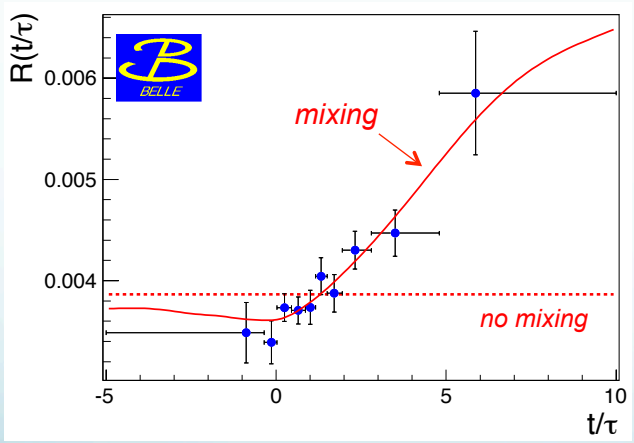
Many thanks to all the speakers!

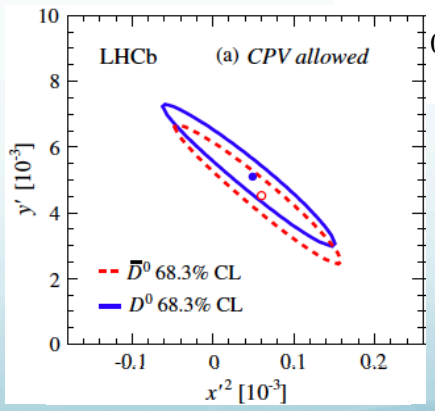
A big leap in D-Mixing

Silvia Borghi
Alan Schwartz

- D-mixing finally discovered
  2013: LHCb CDF 2014: Belle
- Time-dependent ratio of WS/RS $D^0 \rightarrow K\pi$
  ⇨ 'Rotated' mixing parameters y', x'^2
- Far away from seeing a full oscillation…

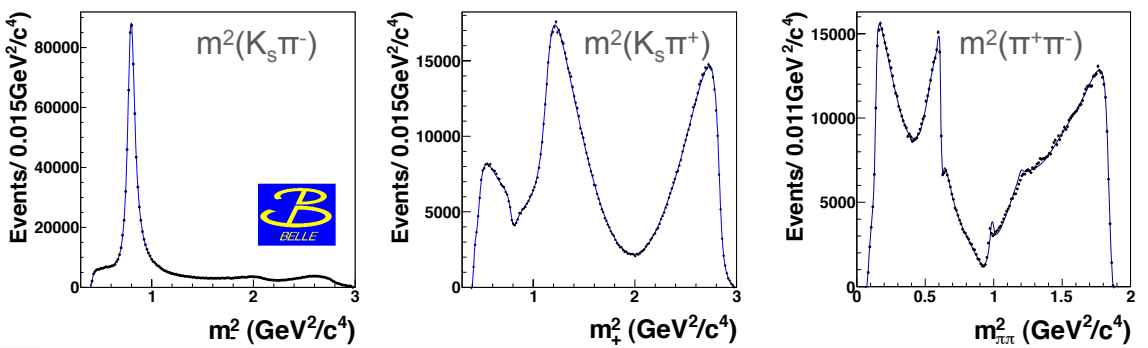


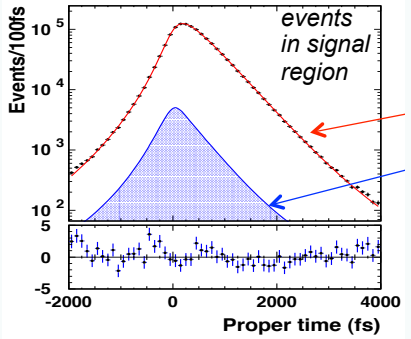




Toward precision x,y…

- x, y only from t-dependent Dalitz plot analysis
- Final Belle result for the golden mode $D^0 \rightarrow K_S\pi^+\pi^-$





- 2.5σ evidence for mixing, no indirect CPV
- Results from LHCb expected soonish

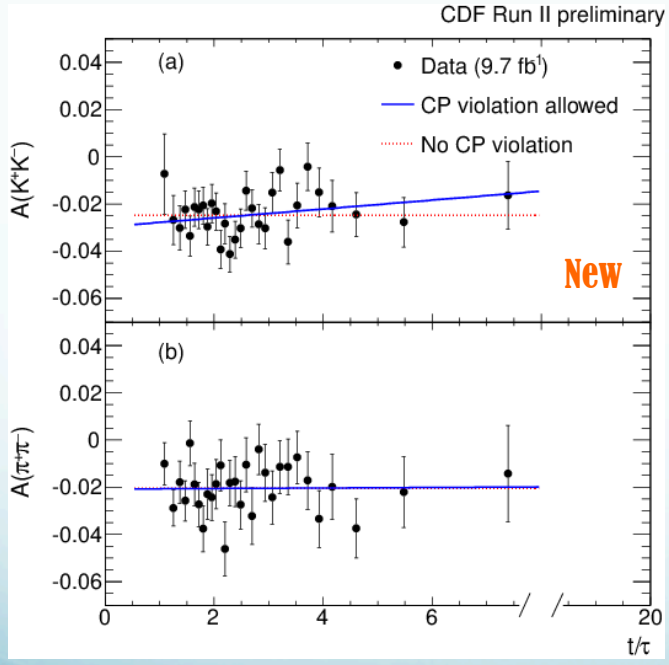
Fit type	Parameter	Fit result
No CPV	x (%)	$0.56 \pm 0.19^{+0.03+0.06}_{-0.09-0.09}$
	y (%)	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.06}$
CPV	x (%)	$0.56 \pm 0.19^{+0.04+0.06}_{-0.08-0.08}$
	y (%)	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.07}$
	$\lvert q/p \rvert$	$0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$
	$\arg(q/p)$ (°)	$-6 \pm 11 \pm 3^{+3}_{-4}$
τ = (410.3 ± 0.6) fs		

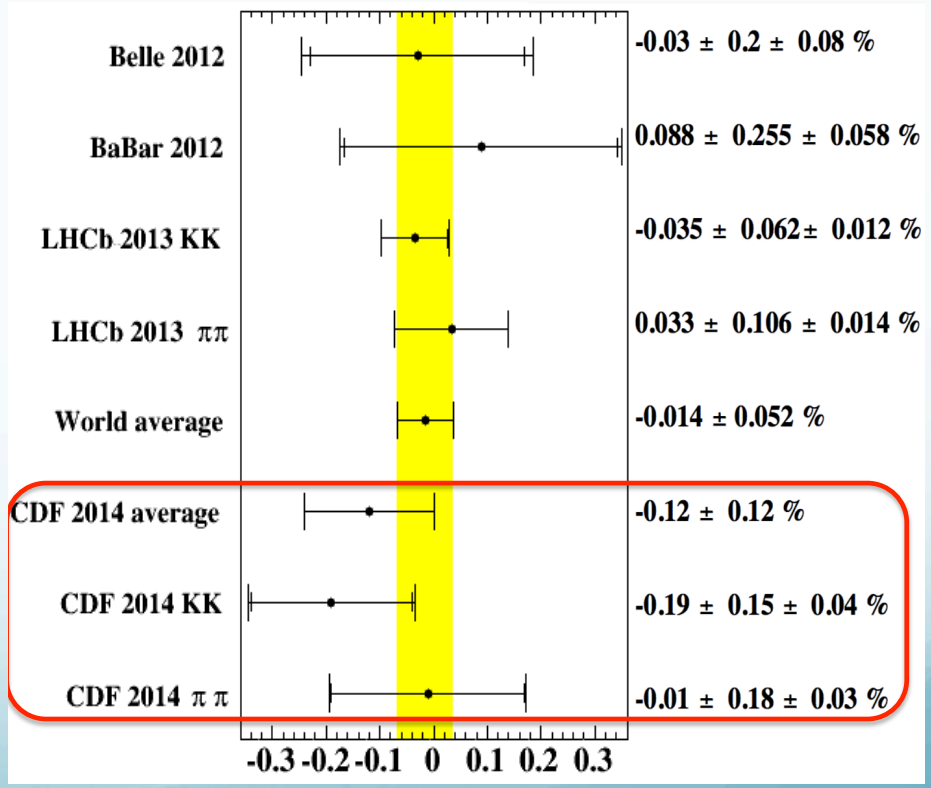
A_Γ : quest for indirect CPV

Silvia Borghi
Alan Schwartz
Leo Sabato

- Related to D-mixing, universal for all CP eigenstates
- Easiest approach: via A_Γ in $D^0 \to \pi\pi$, KK
- SM: $A_\Gamma < 10^{-4}$

$$A_\Gamma \equiv \frac{\tau\left(\overline{D}^0\right) - \tau\left(D^0\right)}{\tau\left(\overline{D}^0\right) + \tau\left(D^0\right)} \approx -a_{CP}^{ind}$$

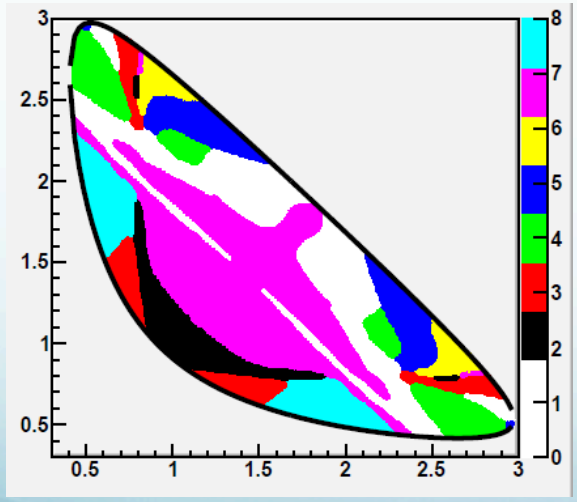


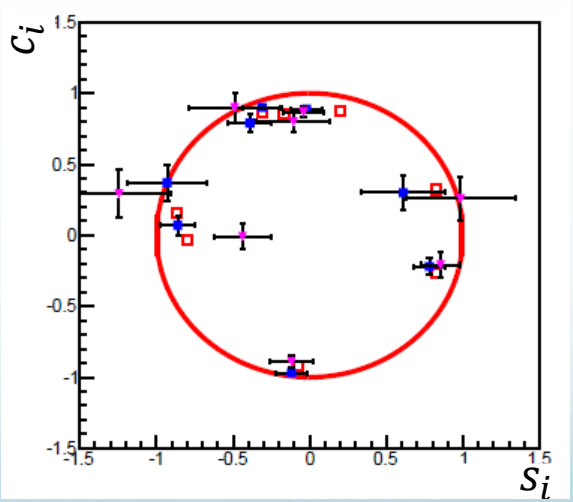


- Still no evidence

Charm made in China

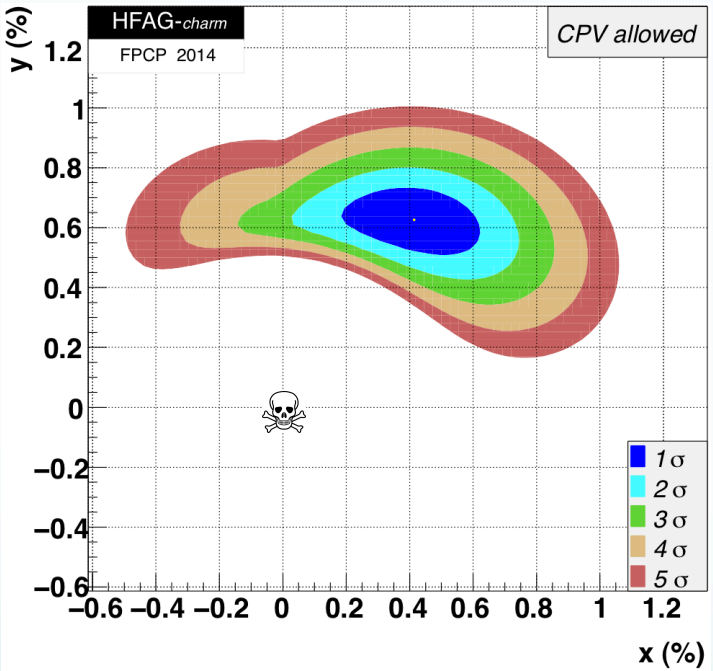
- $e^+e^- \rightarrow \psi(3770) \rightarrow D\underline{D}$ data: BESIII = 3.5×Cleo-c, will increase by factor 7
- Quantum correlation of $D\underline{D}$ ⇨unique way to measure strong phases
- Phase between WS and RS $D^0 \rightarrow K\pi$ $\cos\delta_{K\pi}=1.02\pm0.11\pm0.06\pm0.01$
- Strong phases on $D^0 \rightarrow K_S\pi^+\pi^-$ Dalitz
  ⇨ used to measure D-mixing (instead of Dalitz analysis)

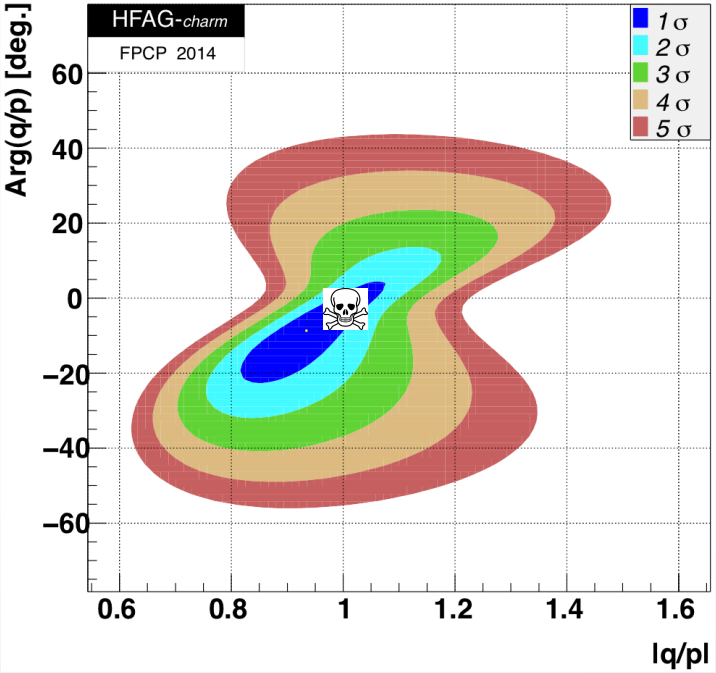




Fitting all together

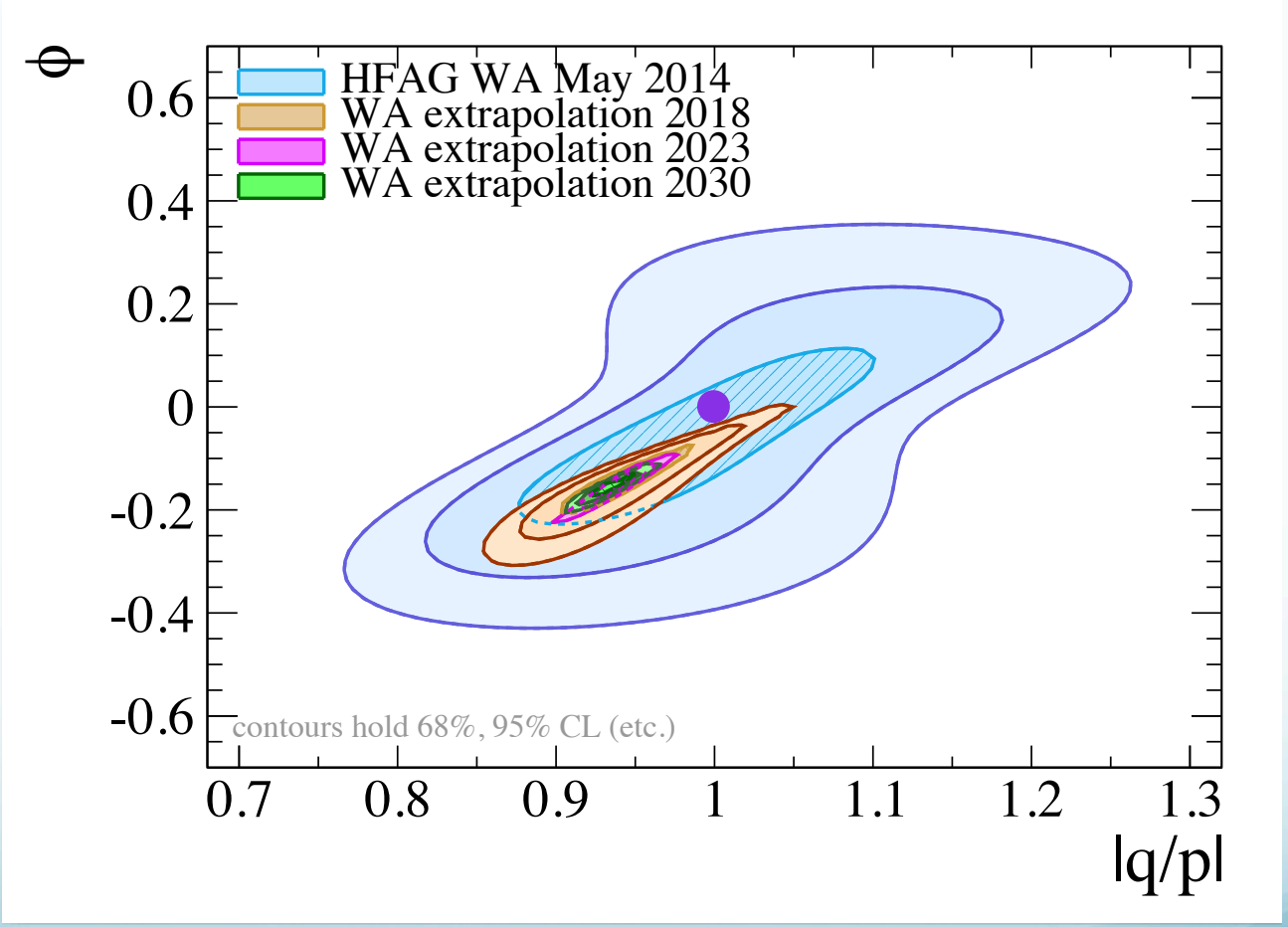
- The contours speak by themselves…





Future

- By Marco Gersabeck



Direct CPV: is there anything out there?

- Arises in decays, specific to decay modes
  ⇨ Time-indep. searches, mode-by-mode, SCS modes are best

- 2-body $D_{(s)}$ decays: difference in total widths between D and $\underline{D}$
  ⇨ Precision up to $10^{-3} \div 10^{-2}$

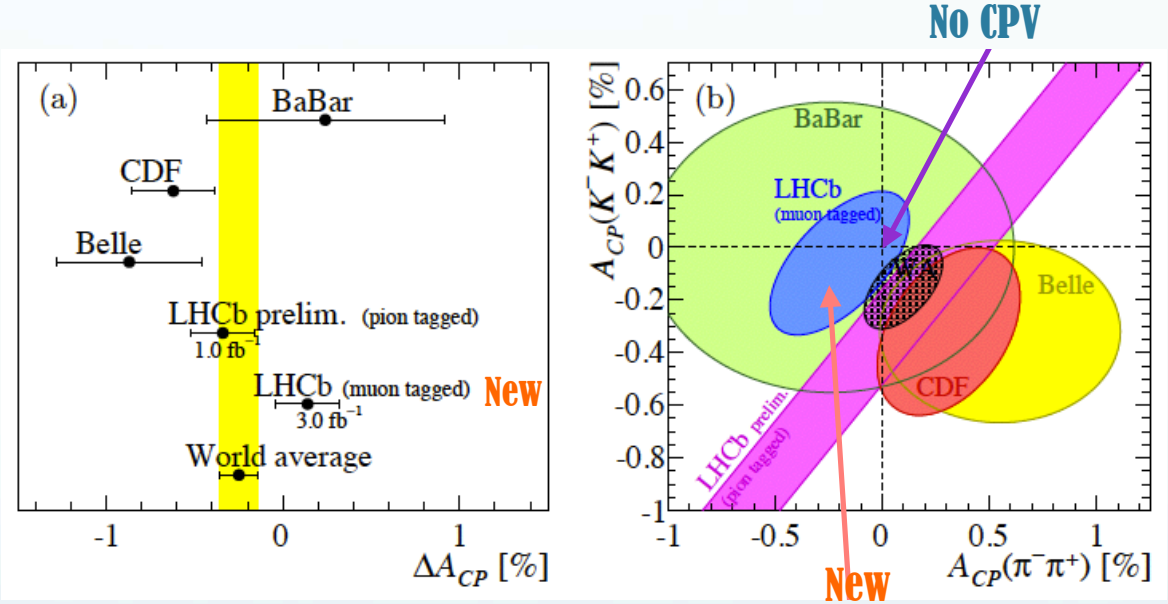
- Multibody final states: many methods
  - model dependent on Dalitz ⇨measure CPV
  - model independent ⇨"discovery" tools
    binned (Miranda method), unbinned (energy test, kNN)
  - based on triple-products

  ⇨ Sensitivity: few % in amplitude changes, few degrees in phase changes

End of ΔA_{CP} saga?

Evelina Gersabeck
Marco Staric

- 2012 LHCb: 3.5σ evidence of CPV in charm
  $\Delta A_{CP}=A_{CP}(D^0\to K^-K^+)-A_{CP}(D^0\to \pi^-\pi^+)=(-0.82\pm0.21\pm0.11)\%$
- Vanished with new results

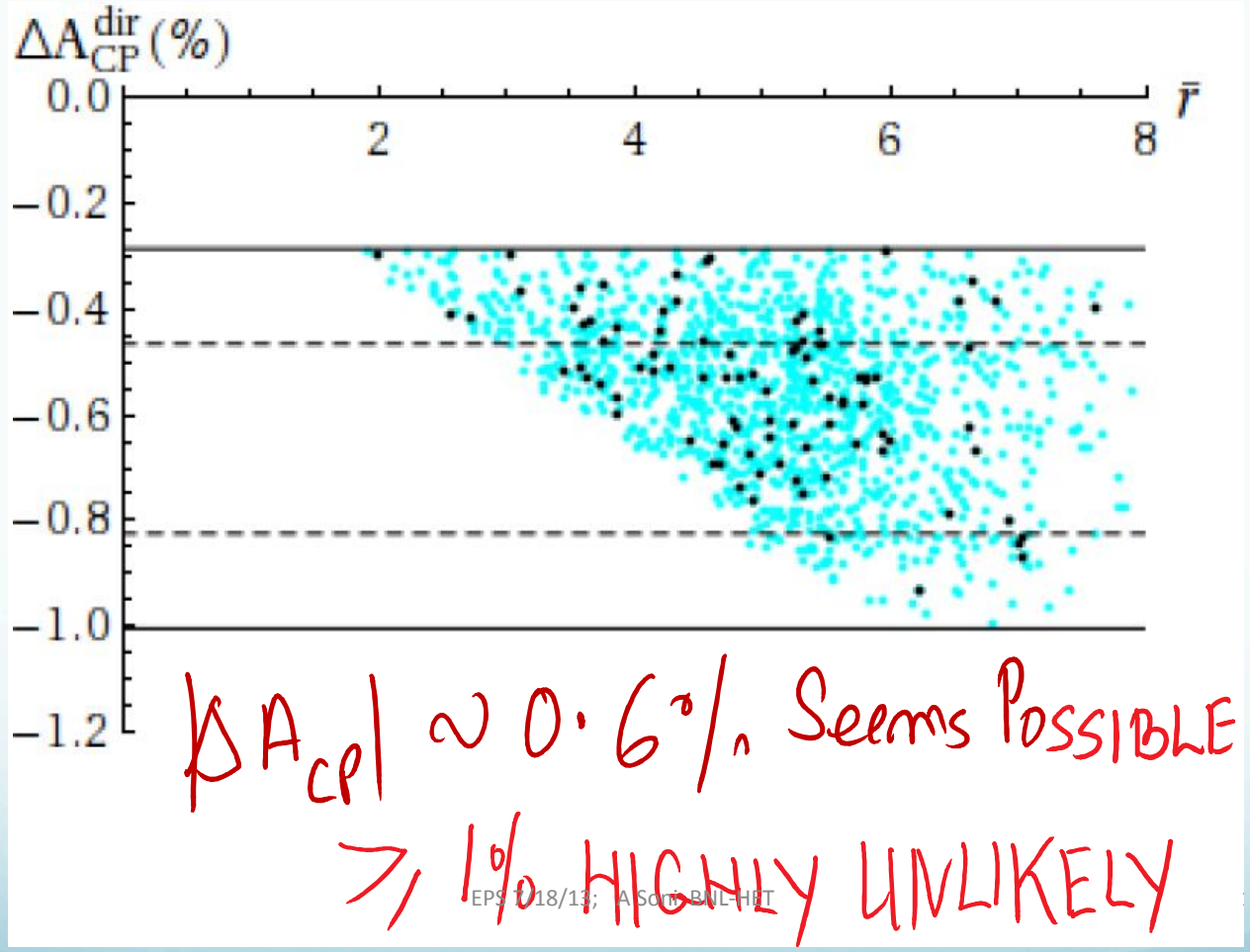


- More to come from LHCb: ΔA_{CP} for pion-tagged D^0 with 3/fb

How large is ΔA_{CP} in SM?

Amarjit Soni
Wolfgang Altmannhofer

- Depends on U-Spin symmetry breaking ($m_s \neq m_d$) in $D^0 \rightarrow P^+P^-$



Where ΔA_{CP} can lead you…

- Largish ΔA_{CP} can be explained with charm chromomagnetic dipole
- It affects neutron-EDM, has to respect d_n exclusion region

- New bound on the charm chromo-EDM (via w)

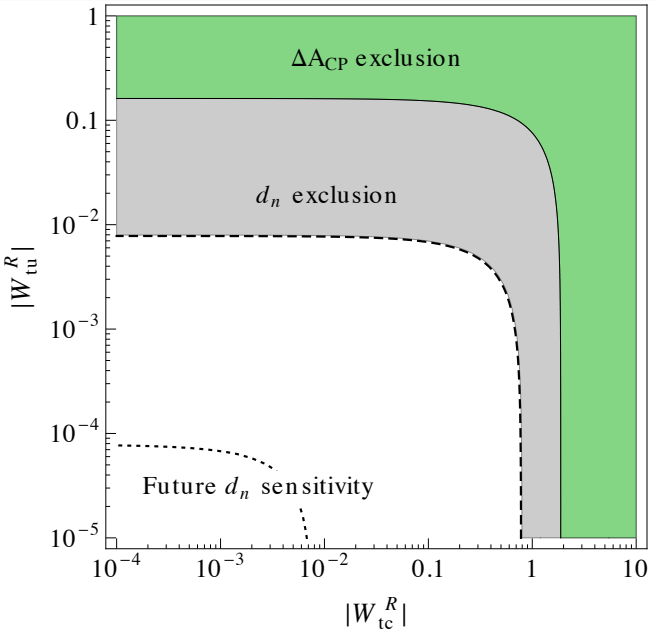
$$\tilde{d}_c < 1.0 \times 10^{-22} e \text{ cm}$$

- General class of models with

  i) largish flavour violation in up quark sector

  ii) $\Lambda_{1,2} \gg \Lambda_3$

  $\Rightarrow$ d_n constrains ΔA_{CP}



Direct CPV: from Belle to BelleII

- 2-body + Dalitz-integrated multibody decays

New and important!

New

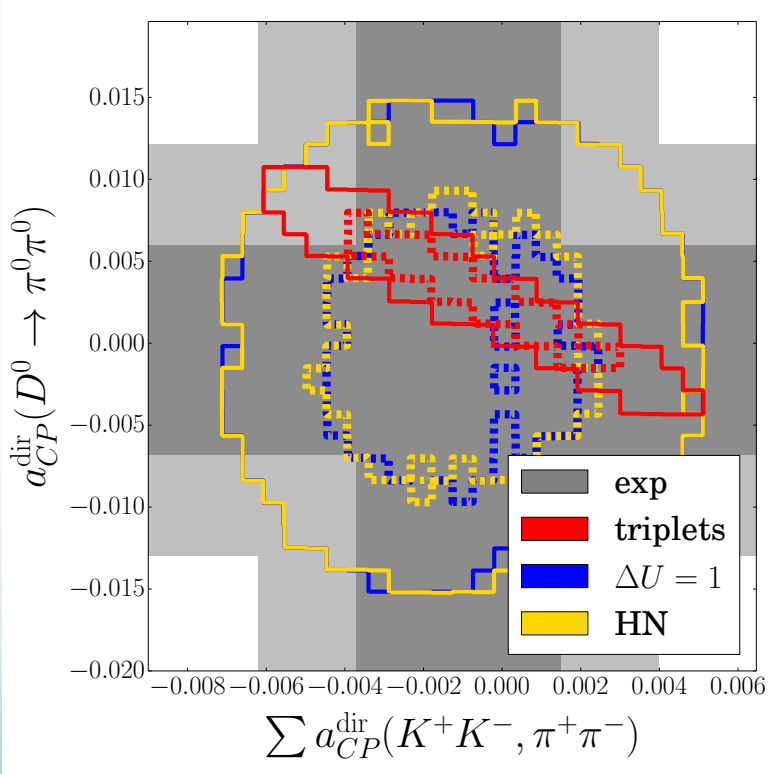
mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K^0_S\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.03
$D^0 \to K^0_S\eta$	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
$D^+ \to \eta\pi^+$	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	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K^0_SK^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D^+_s \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D^+_s \to K^0_SK^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

- ~2024: BelleII precision will reach 10^{-4}

$$\sigma_{BelleII} = \sqrt{(\sigma^2_{stat} + \sigma^2_{sys})\frac{\mathcal{L}_{Belle}}{50\ \mathrm{ab}^{-1}} + \sigma^2_{\mathrm{ired}}}$$

With a little help from $SU(3)_F$

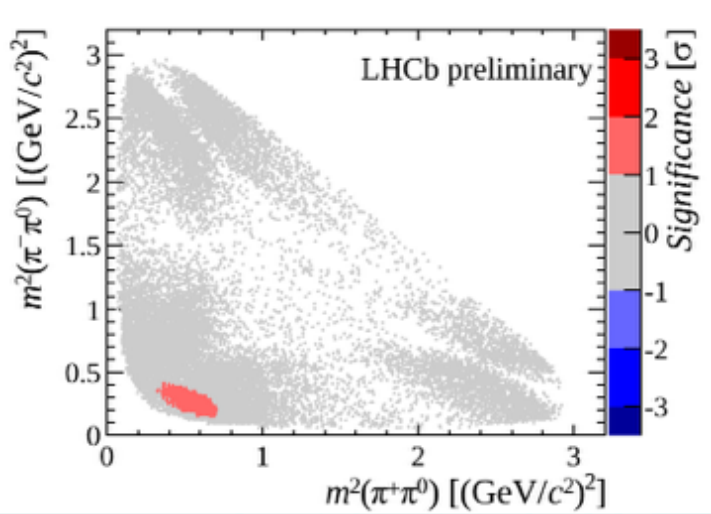
- $SU(3)_F$ breaking ⇨ 'saves' penguins with s,d quarks in the loops
  Exp: $SU(3)_F$ breaking ≤50%
- "With a little theoretical input" SU(3) breaking helps to disentangle SM and NP
  ⇨A_{CP} correlations for $D_{(s)}$➔PP
- Key observables: A_{CP} in D^0➔K_SK_S, D_s➔$K^+\pi^0$, D^+➔$\pi^+\pi^0$, D^0➔$\pi^0\pi^0$, D^0➔K^+K^-, D^0➔$\pi^+\pi^-$



News from LHCb

- Finally decays with π^0: $D^0 \rightarrow \pi^+\pi^-\pi^0$

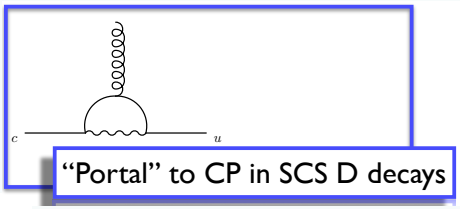
⇨World's best sensitivity to CPV in this channel
⇨Energy test: data consistent with no-CPV at p-value~2%



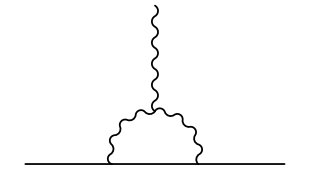
Significance of local asymmetry

Nejc Kosnik

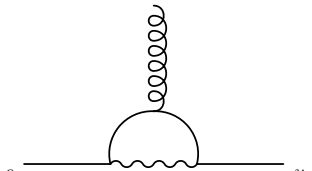
Something promissing



- **Follow-up of charm chromomagnetic dipoles**
  - Chromo- and electromagnetic-dipoles have common origin



$\mathcal{O}_7$



$\mathcal{O}_8$

  - Working assumption: CPV phase in $\mathcal{O}_8$

    How well can we test it in CPV processes dominated by $\mathcal{O}_7$?

$$D \to V\gamma \qquad D \to P\ell^+\ell^-$$

$$D \to PP\gamma$$

- **Direct CPV in D→(ρ/ω)γ ≈ few%**
  Interesting features in leptonic decays

Conclusion

- There is a progress: mixing, A_Γ sensitivity
- Many decays tested. Still no CPV in charm…
- Still a lot to study with current data

  $D_{(s)} \rightarrow PP$, $D \rightarrow V\gamma$, $D \rightarrow Pl^+l^-$
- We will keep digging