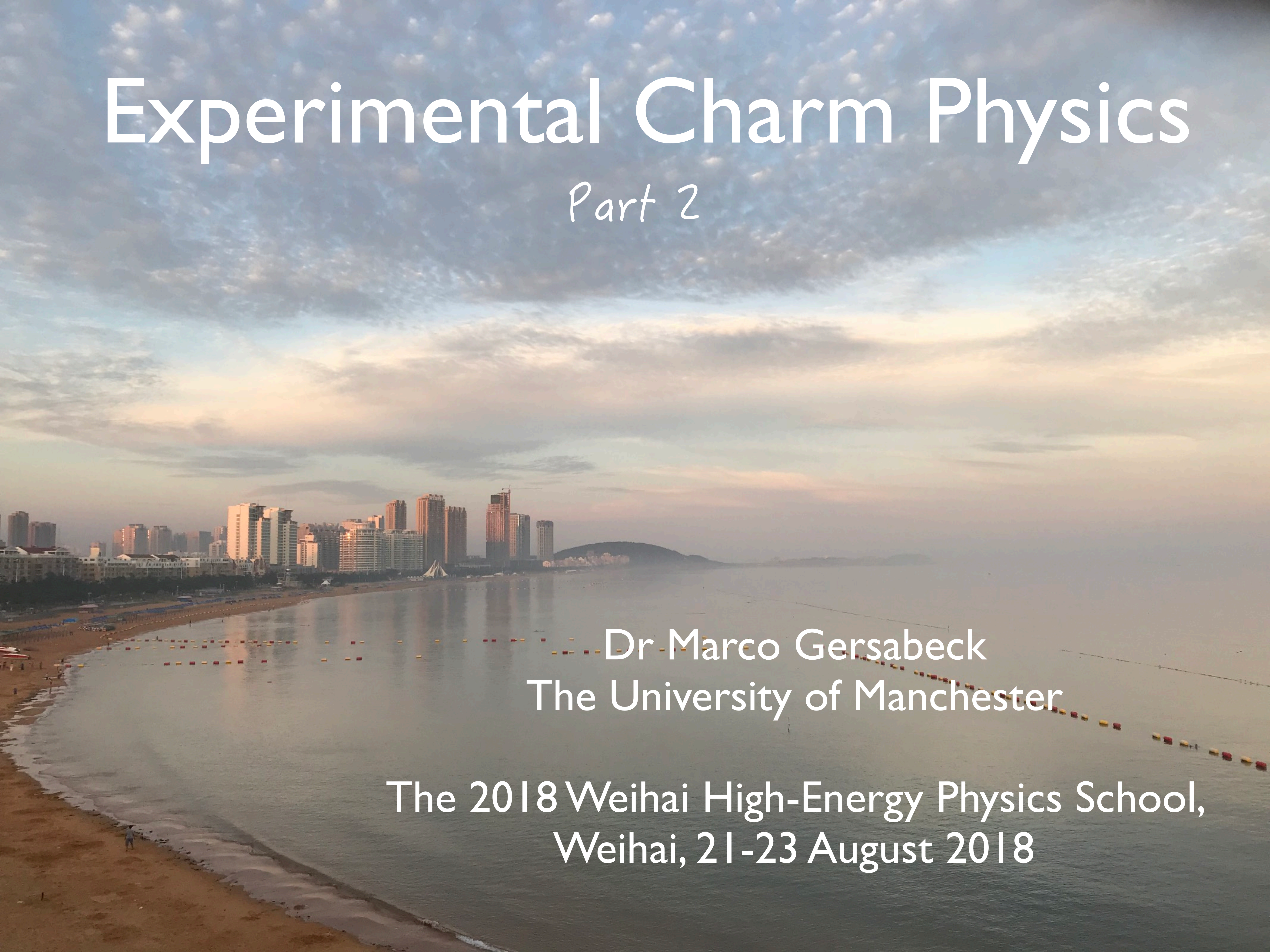

Experimental Charm Physics

Part 2

Dr Marco Gersabeck
The University of Manchester

The 2018 Weihai High-Energy Physics School,
Weihai, 21-23 August 2018

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Measuring mixing

With semi-leptinic decays
With Kπ decays
With KK/ππ decays

Measuring mixing

$$P(M^0 \to \overline{M}^0, t) = \frac{1}{2}\left|\frac{q}{p}\right|^2 e^{-\Gamma t}(\cosh(y\Gamma t) - \cos(x\Gamma t))$$

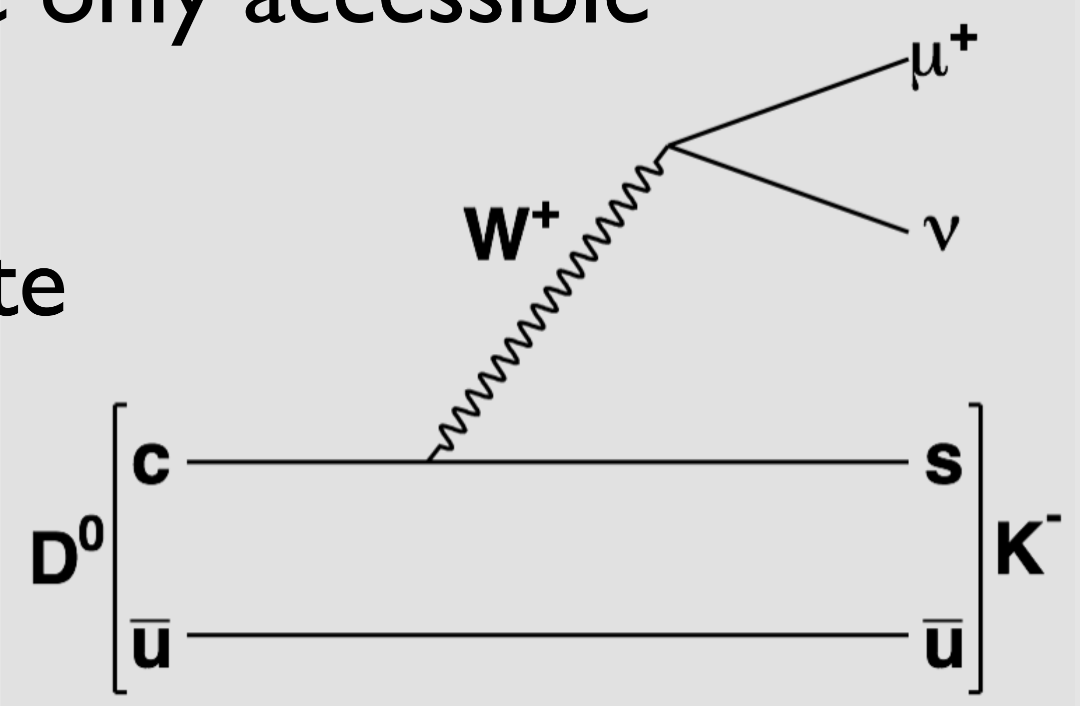
$$\approx \frac{1}{2}(x^2 + y^2)(\Gamma t)^2 - \frac{1}{24}(x^4 - y^4)(\Gamma t)^4$$

current world averages → 3×10^{-5} -7×10^{-11}

need $t > 200\tau$ for a 10% contribution of this term

$D^0 \rightarrow K^+ \mu^- \nu$

- Semileptonic decay is flavour tagging
- Charge-conjugate final state only accessible through mixing
- Measure time-integrated rate
  - ➡ Proportional to mixing probability
    $$\frac{1}{2}(x^2 + y^2)(\Gamma t)^2 \quad \approx 3\times10^{-5}$$
  - ➡ Multiplied by $D^0 \rightarrow K^- \mu^+ \nu$ BF of 3.3% gives unmeasurably small rate for partially reconstructed decay



Wrong-sign Kπ

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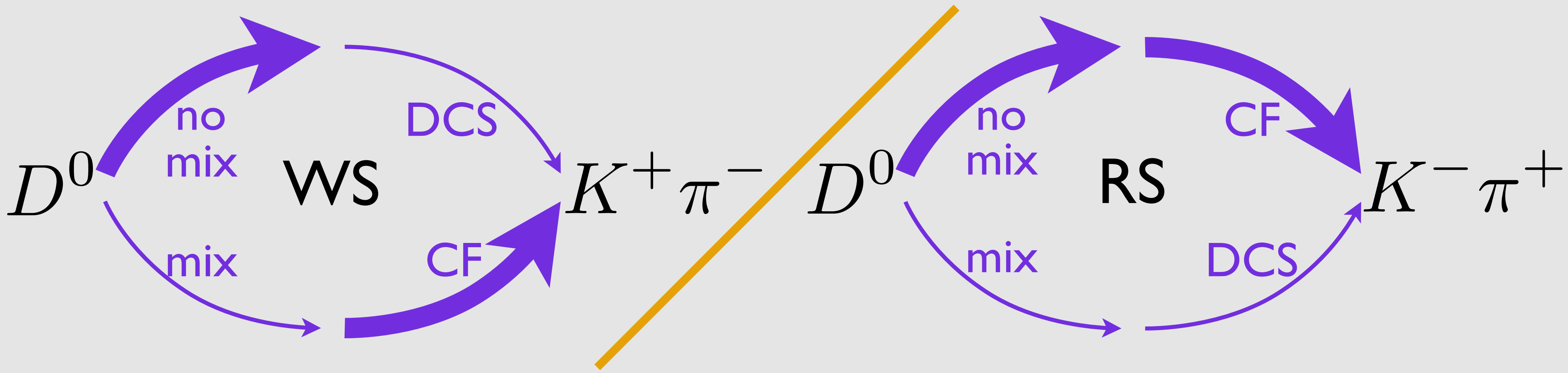


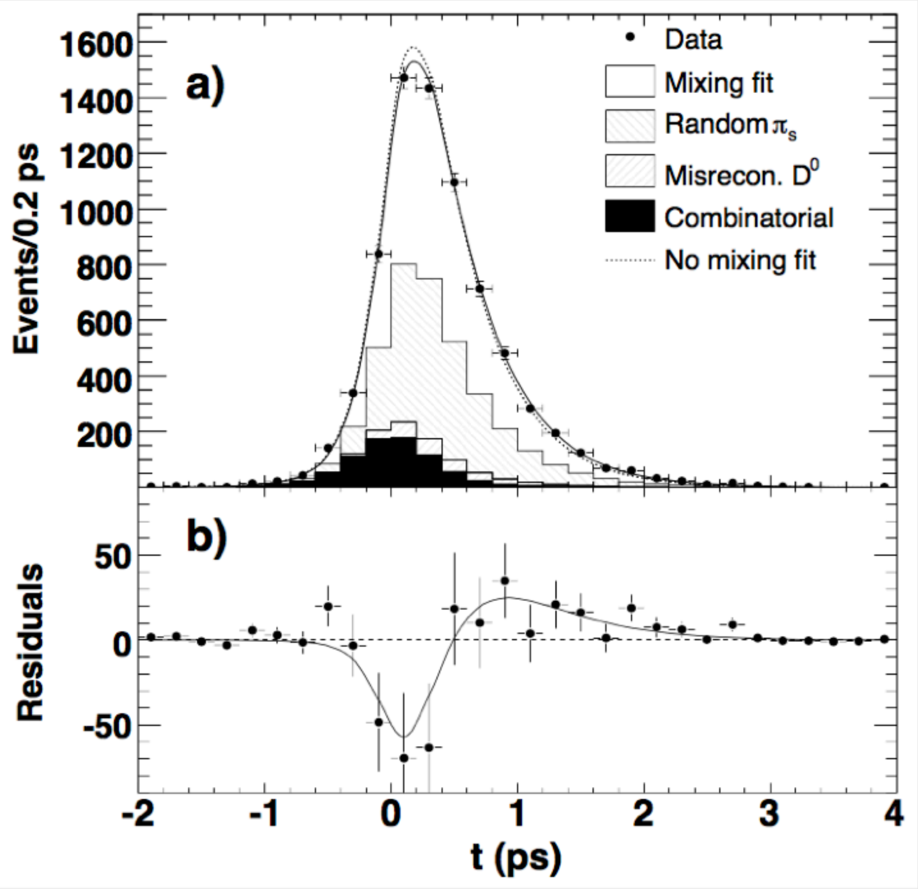
$$N_{WS}(t) = \left| \frac{q}{p} f_-(t)\bar{A}_{\bar{f}} + f_+(t)A_{\bar{f}} \right|^2$$

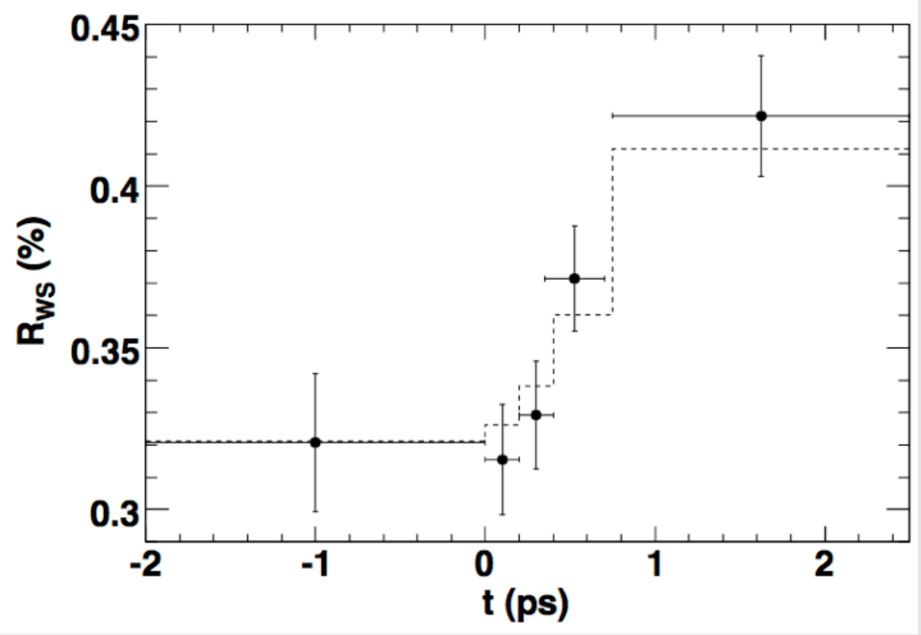
$$R(t) \equiv \frac{N_{WS}(t)}{N_{RS}(t)} \approx R_d + \sqrt{R_D}y'\frac{t}{\tau} + \frac{x'^2 + y'^2}{4}(\frac{t}{\tau})^2$$

- Rotation of mixing parameters by strong phase difference between CF and DCS amplitudes: x,y → x',y'
- Term linear in time only sensitive to y'

Two methods

- Measure effective lifetime of RS and WS samples
  - ➡ Use full statistical power
  - ➡ More complicated as need to model time distribution
  - ➡ Need to account for decay-time resolution (mostly B-factories) and acceptance (mostly hadron colliders)
- Measure ratio of RS and WS yields in bins of decay time
  - ➡ Only need yield extraction
  - ➡ Price in statistical precision limited for very large samples
  - ➡ Harder to exploit correlation of fit parameters across time bins
  - ➡ Assume cancellation of acceptance effects





BaBar, PRL 98 (2007) 211802

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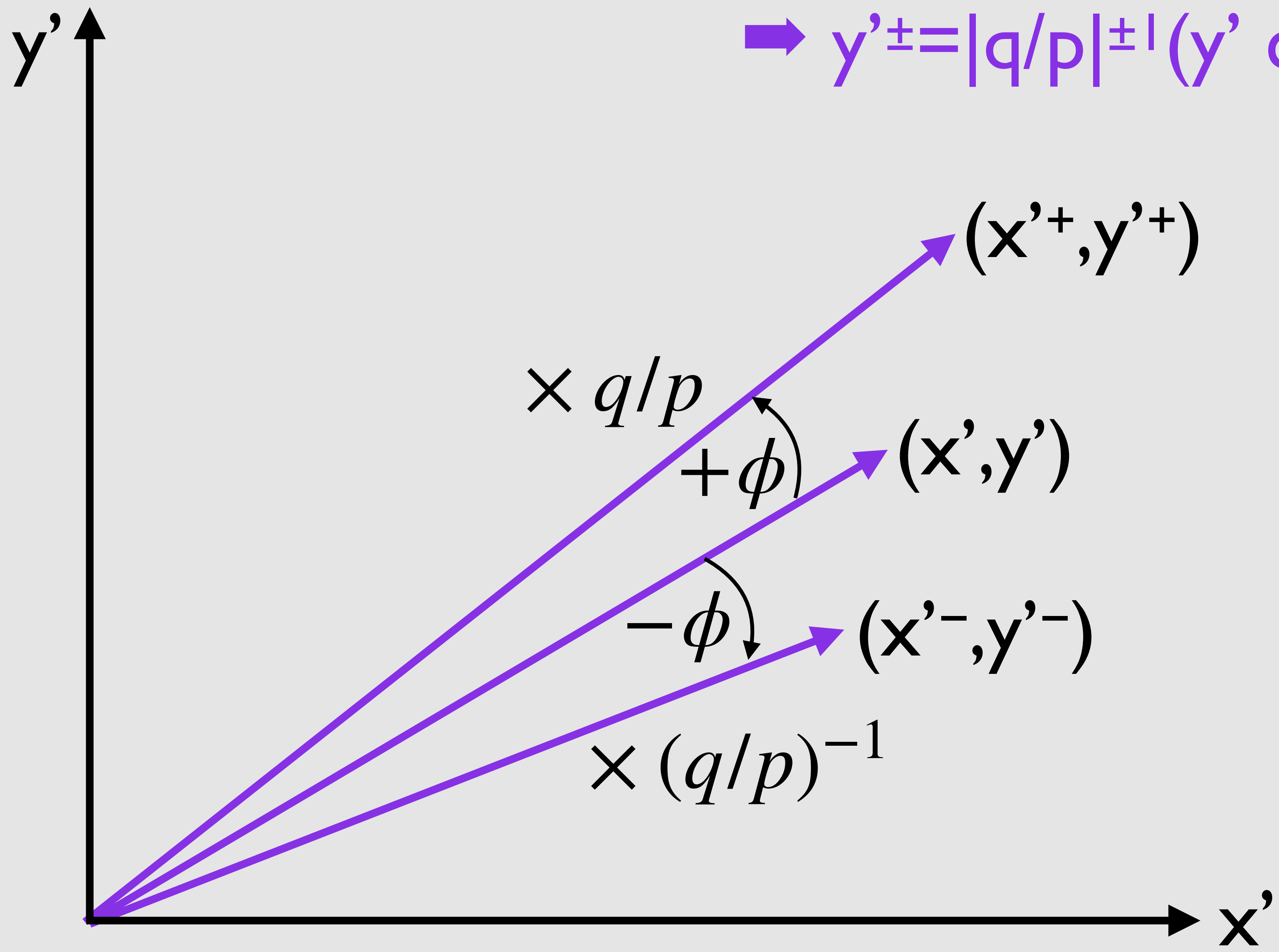
CP violation with WS Kπ

PRL 111 (2013) 251801

- Split by flavour to search for CP violation
- Measure time-dependence for D^0 and $\overline{D}^0$
  - ➡ Give the observables ± superscripts according to D^0 flavour
  - ➡ $x'^{\pm}=|q/p|^{\pm 1}(x' \cos\Phi \pm y' \sin\Phi)$
  - ➡ $y'^{\pm}=|q/p|^{\pm 1}(y' \cos\Phi \mp x' \sin\Phi)$
- Four observables to measure four parameters
  - ➡ Recall that we still have sensitivity to $(x'^{\pm})^2$ only
  - ➡ But no need to constrain strong phase difference
- Very good sensitivity to $|q/p|$ for small ϕ

CPV from WS Kπ

- ➡ $x'^{\pm} = |q/p|^{\pm 1}(x' \cos\Phi \pm y' \sin\Phi)$
- ➡ $y'^{\pm} = |q/p|^{\pm 1}(y' \cos\Phi \mp x' \sin\Phi)$



CPV from WS Kπ

- ➡ $x'^{\pm} = |q/p|^{\pm 1}(x' \cos\Phi \pm y' \sin\Phi)$
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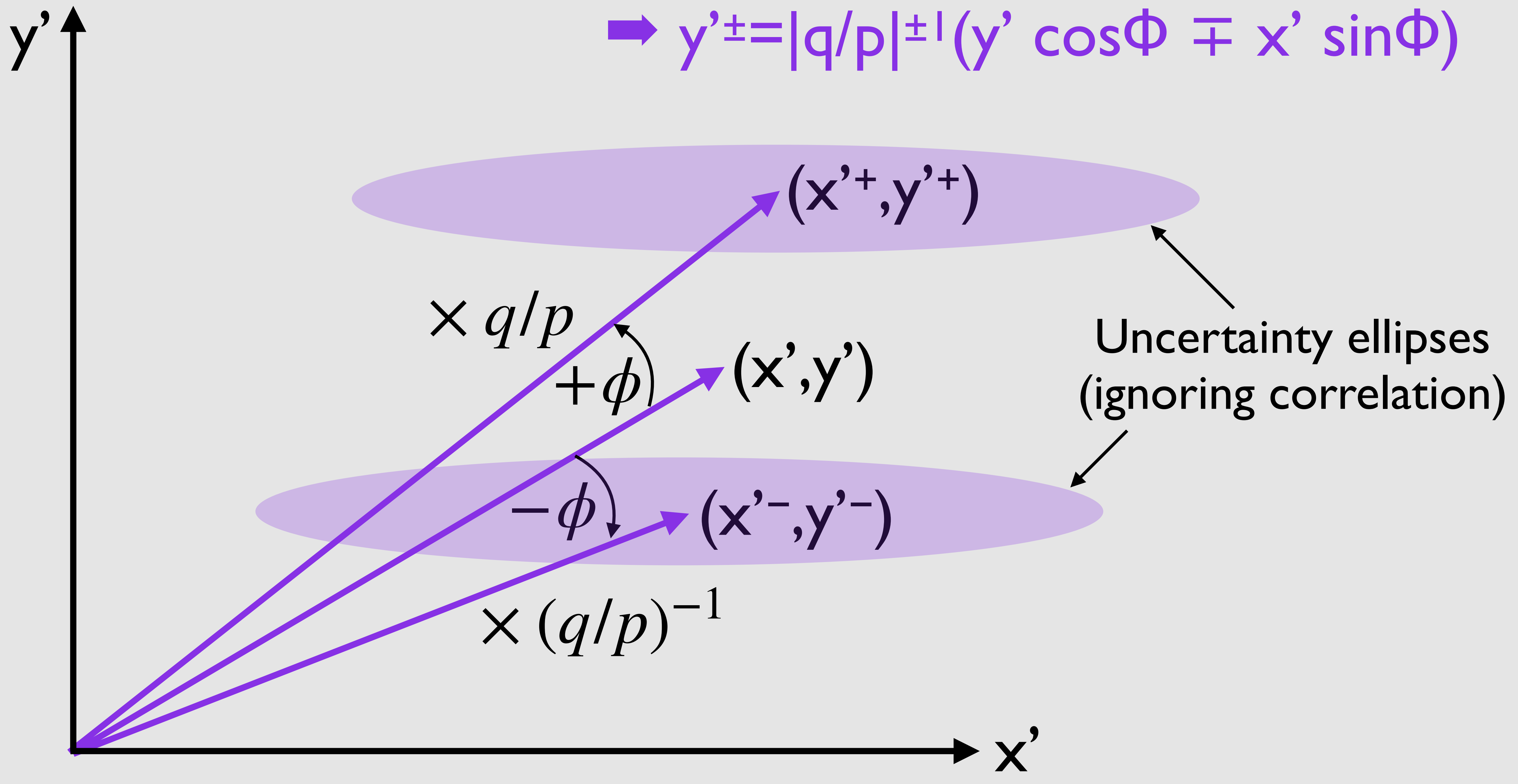
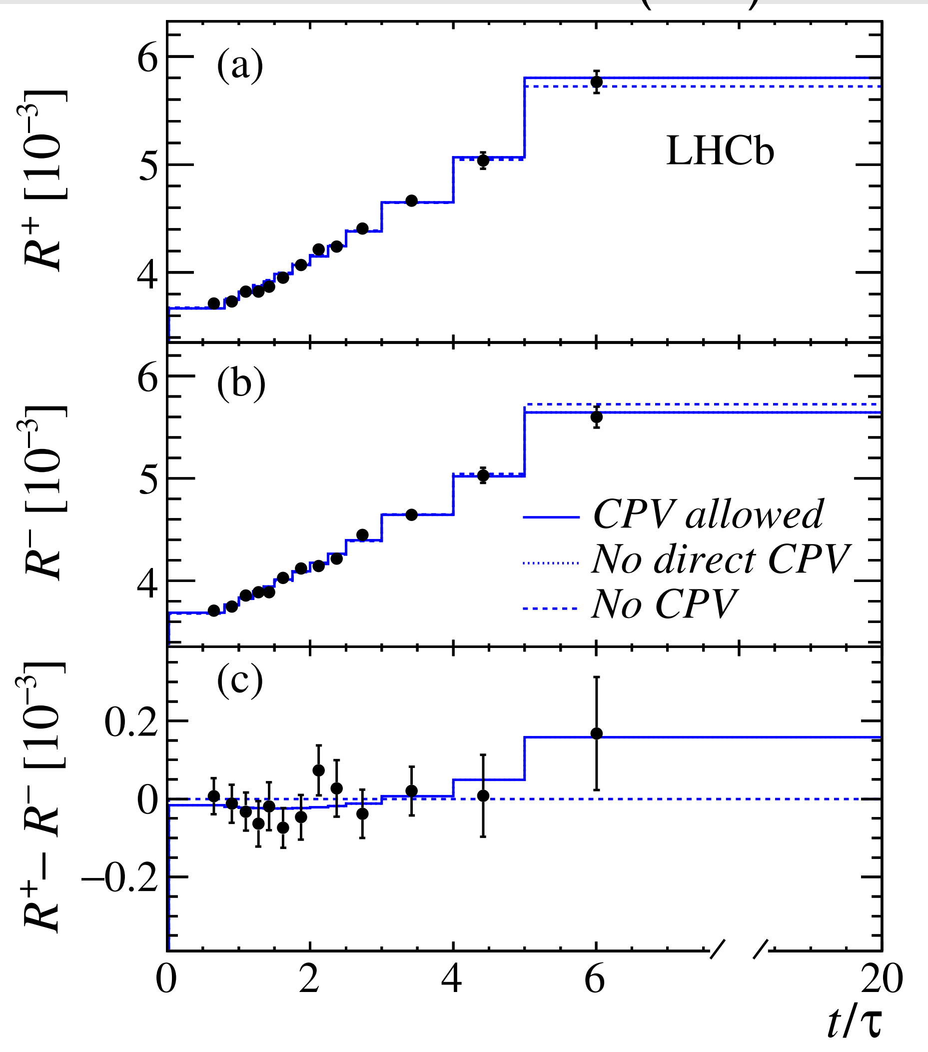
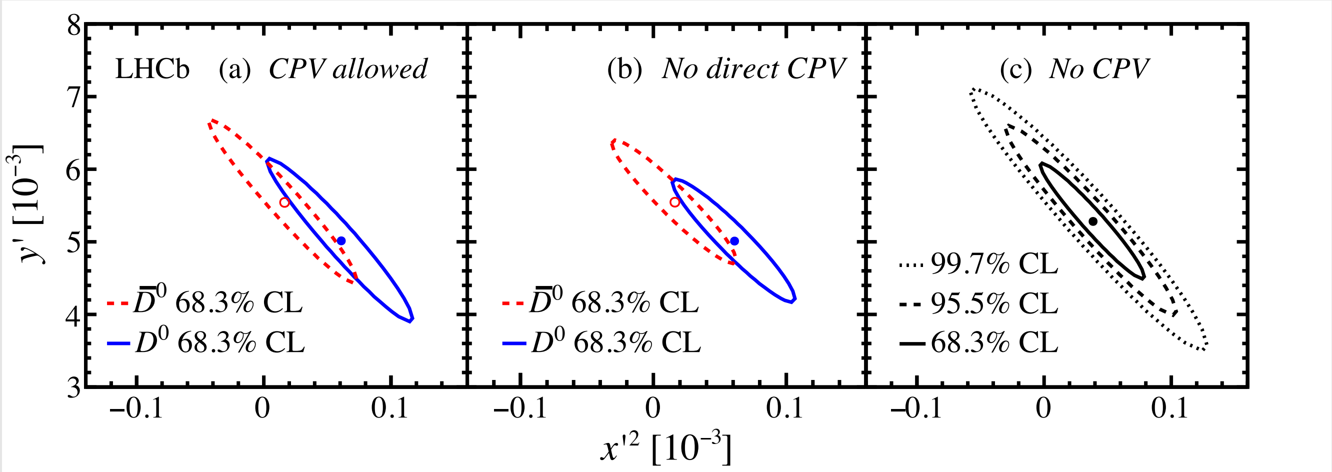


Latest WS Kπ results

PRD 97 (2018) 031101



- Latest measurement based on 2011-2016 data
  - ➡ 180M favoured and 0.7M suppressed decays
- Twice as precise as previous results
- Still no sign for CPV



Measuring lifetimes

- Many measurements based on measurements of lifetime ratios/asymmetries
  - ➡ But no D^0 lifetime measurement published
- Demonstrates the challenge in controlling systematics
  - ➡ LHCb has statistical power to reduce WA uncertainty by orders of magnitude

2014 Review of Particle Physics.
Please use this CITATION: K.A. Olive *et al.* (Particle Data Group), Chin. Phys. C, **38**, 090001 (2014).

D^0 MEAN LIFE

Measurements with an error $> 10E-15$ s have been omitted from the average.

Value (10^{-15} s)	EVTS	Document ID		TECN	Comment
$\mathbf{(41.01 \pm 0.15) \times 10^1}$	OUR AVERAGE				
$409.6 \pm 1.1 \pm 1.5$	210k	LINK	2002F	FOCS	γ nucleus, $\approx$ 180 GeV
$407.9 \pm 6.0 \pm 4.3$	10k	KUSHNIRENKO	2001	SELX	$K^- \pi^+$, $K^- \pi^+ \pi^+ \pi^-$
$413 \pm 3 \pm 4$	35k	AITALA	1999E	E791	$K^- \pi^+$
$408.5 \pm 4.1 {}^{+3.5}_{-3.4}$	25k	BONVICINI	1999	CLE2	$e^+ e^- \approx \Upsilon(4S)$
$413 \pm 4 \pm 3$	16k	FRABETTI	1994D	E687	$K^- \pi^+$, $K^- \pi^+ \pi^+ \pi^-$

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Measuring lifetimes

- Many measurements based on measurements of lifetime ratios/asymmetries

Theoretically challenging as well...

- D

by

PHYSIK-DEPARTMENT

Charm lifetimes within the Heavy Quark Expansion

Lenz, Rauh, Phys.Rev. D88 (2013) 034004

Measurements with an error $> 10E - 15$s have been

Value (10^{-15} s)	EVTS	Document ID		TECN	Comment
$(41.01 \pm 0.15) \times 10^{1}$	**OUR AVERAGE**				
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CP eigenstate lifetimes

- CP eigenstates decay with a decay rate of $\Gamma_{CP\pm}$
- This differs from the mean decay rate Γ by $\Delta\Gamma/2$
- Let's define

$$y_{CP} \equiv \frac{\Gamma_{CP\pm}}{\Gamma} - 1$$

- and for CP symmetry

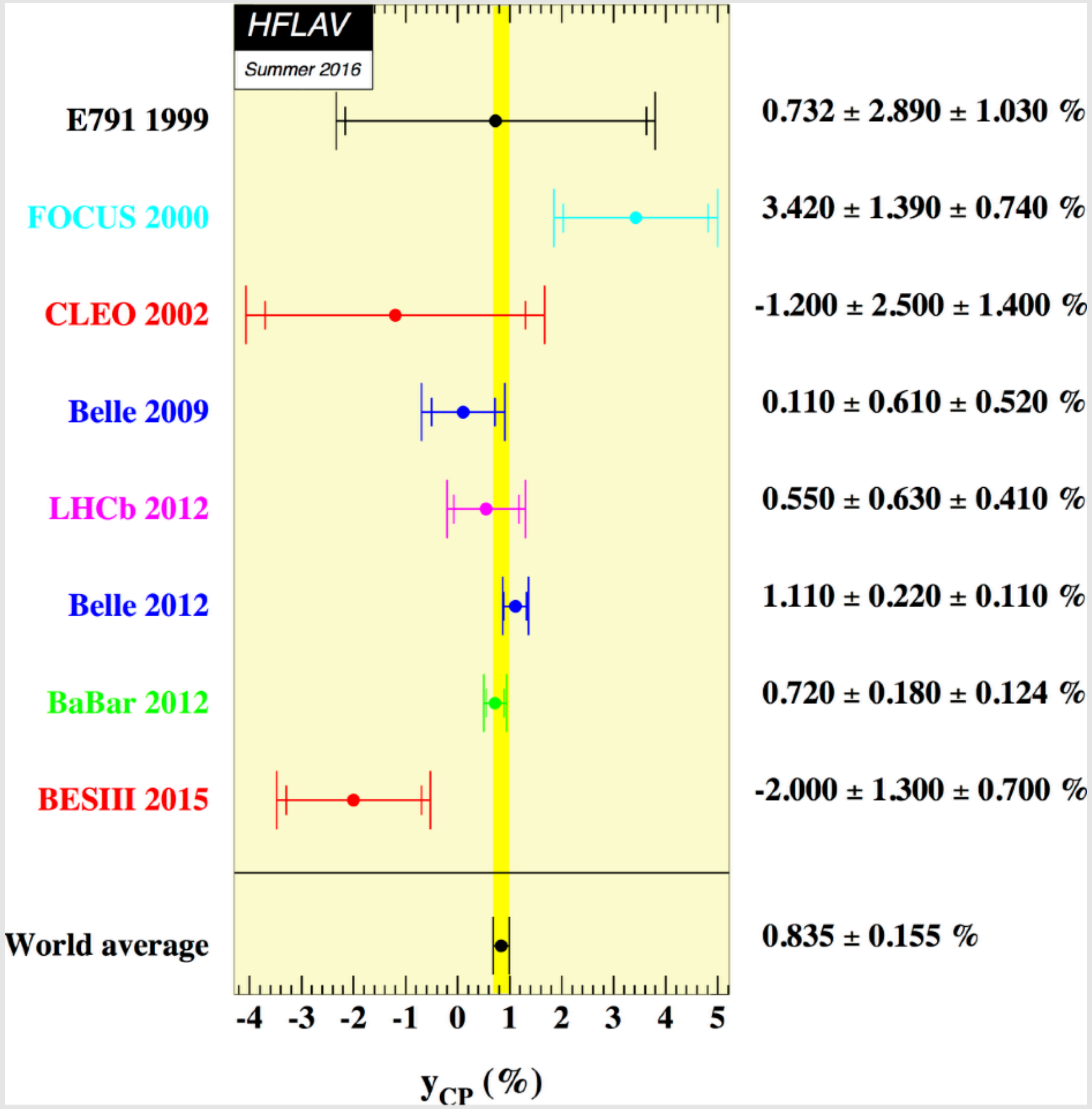
$$y_{CP} \equiv \frac{\Gamma_{CP\pm}}{\Gamma} - 1 = \frac{\Delta\Gamma}{2\Gamma} \equiv y$$

- while allowing for CP violation yields

$$y_{CP} \approx y\cos\phi + a_m x \sin\phi \qquad \text{with } a_m \equiv \frac{|q/p| - |p/q|}{|q/p| + |p/q|}$$

Measuring y_{CP}

- Comparison of decay-time dependence of decays to CP eigenstates (e.g. KK, ππ) to Cabibbo-favoured decays (RS Kπ)
  - ➡ $y_{CP} \equiv \tau_{K\pi}/\tau_{hh} - 1$
- Need to control lifetime measurements of different final states
  - ➡ Limited cancellation of systematic uncertainties e.g. due to acceptance effects



CP violation from eigenstates

- More sensitivity to CP violation is obtained by measuring $y_{(CP)}$ separately in D^0 and $\overline{D}^0$ decays
- This leads to the observable

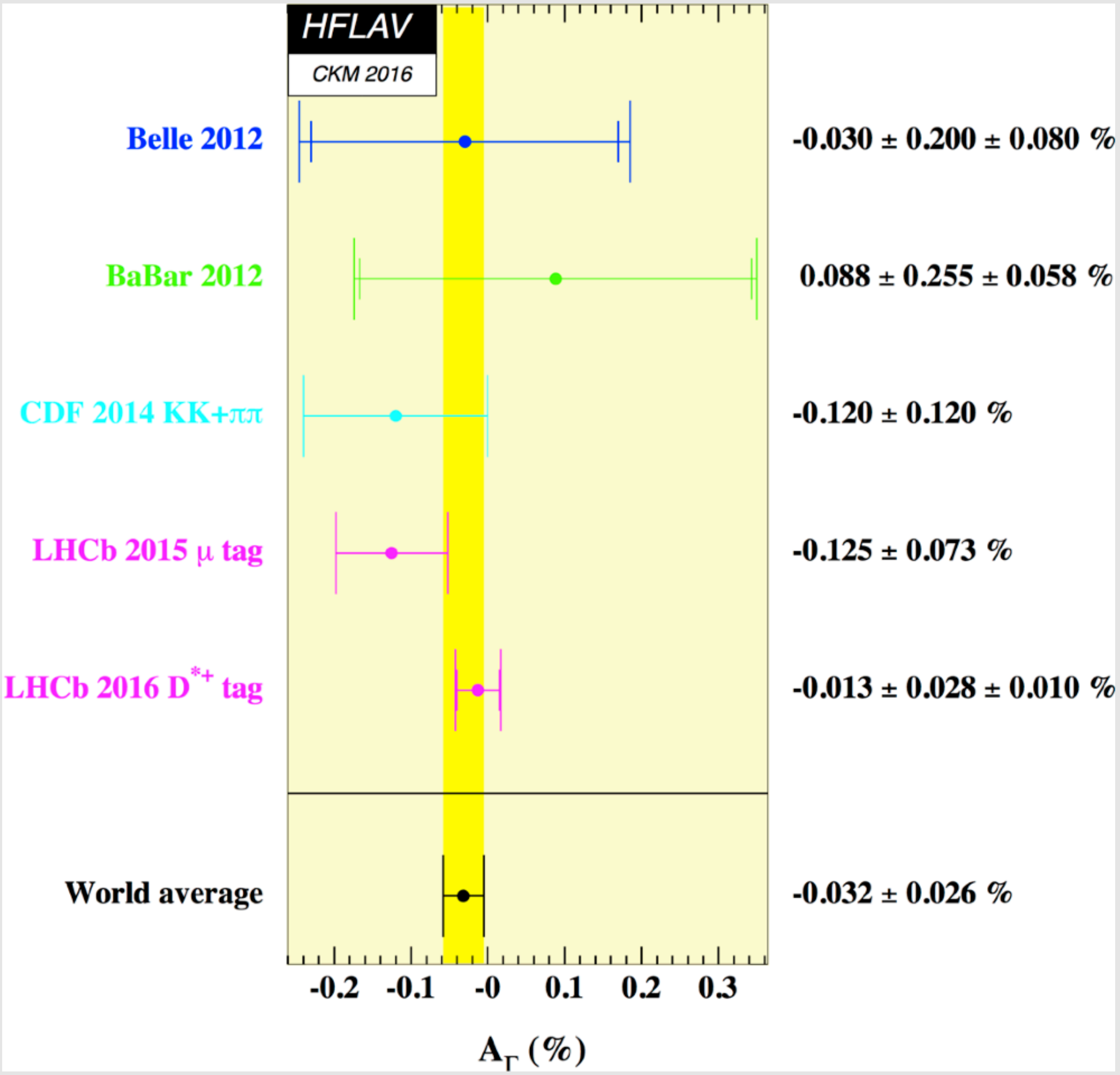
$$A_\Gamma \equiv \frac{\hat{\overline{\tau}} - \hat{\tau}}{\hat{\overline{\tau}} + \hat{\tau}} \approx \eta_{CP}\left[\frac{1}{2}(a_m + a_d) y \cos\phi - x \sin\phi\right]$$

$$\approx - a_{CP}^{ind} + \frac{1}{2} a_d y_{CP}$$

- Here $\hat{\tau}(\hat{\overline{\tau}})$ are the effective decay times of $D^0(\overline{D}^0)$ decays to a CP eigenstate with eigenvalue η_{CP}

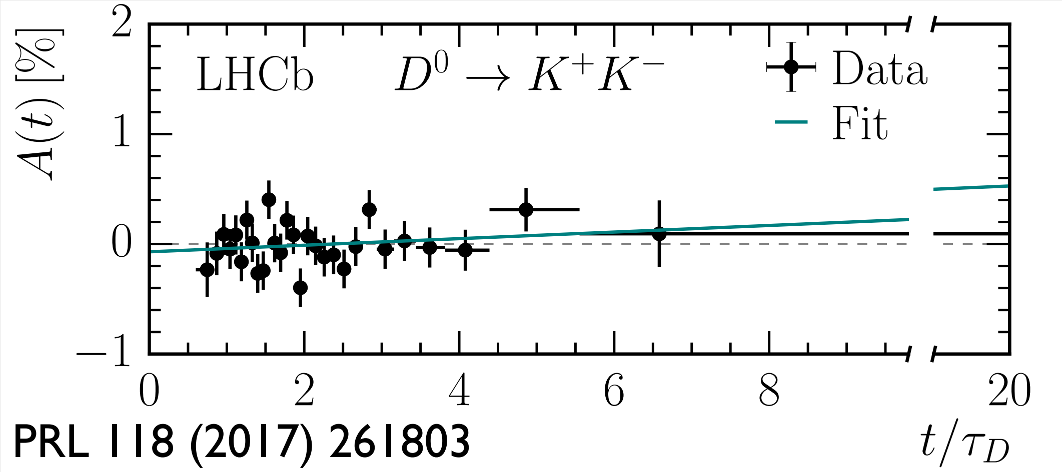
Measuring A_Γ

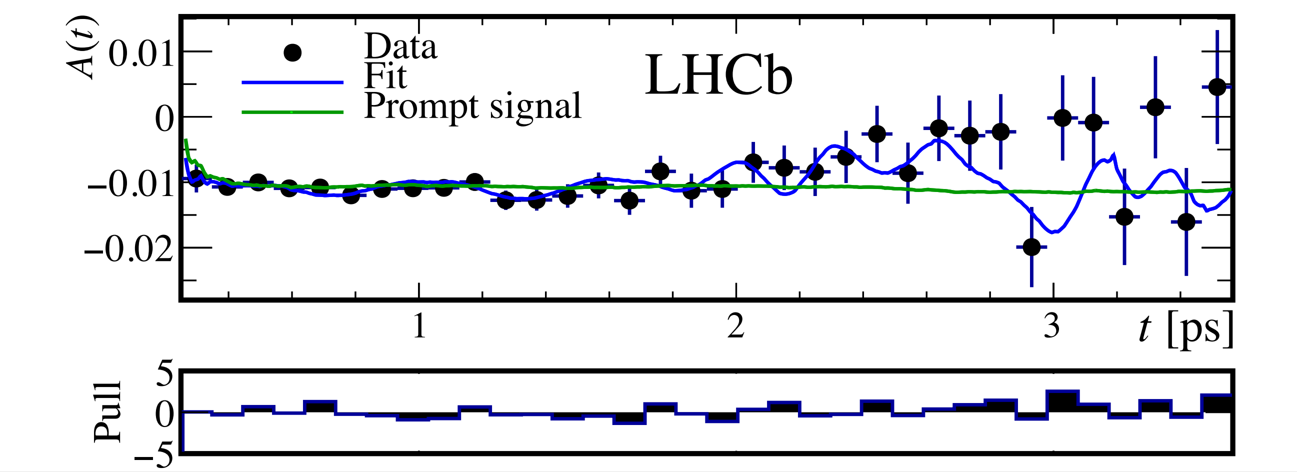
- Acceptance effects are driven by final states
  - ➡ Identical for A_Γ
  - ➡ Systematics largely cancel
- Precision reached 3×10^{-4}
  - ➡ Need to consider second-order systematics



Latest A_Γ results

- Measured as binned ratios and ratios of un-binned lifetimes
  - ➡ Complementary systematics each ~10^{-4}
- Two methods, two final states, one result
  - ➡ $A_\Gamma(K^+K^-) = (-0.30 \pm 0.32 \pm 0.10) \times 10^{-3}$
  - ➡ $A_\Gamma(\pi^+\pi^-) = (+0.46 \pm 0.58 \pm 0.12) \times 10^{-3}$





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Recap

- Two tagging methods for D^0 mesons
  - ➡ Differ in purity, yield, decay-time acceptance
- Charm mixing is small (use Taylor expansion)
- Semi-leptonic decays not sensitive enough
- WS $K\pi$ decays affected by strong-phase differences and only sensitive to x'^2
- CP eigenstates lead to single observables y_{CP} and A_Γ
  - ➡ Excellent sensitivity to observables but not directly to theory parameters

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Lecture 3

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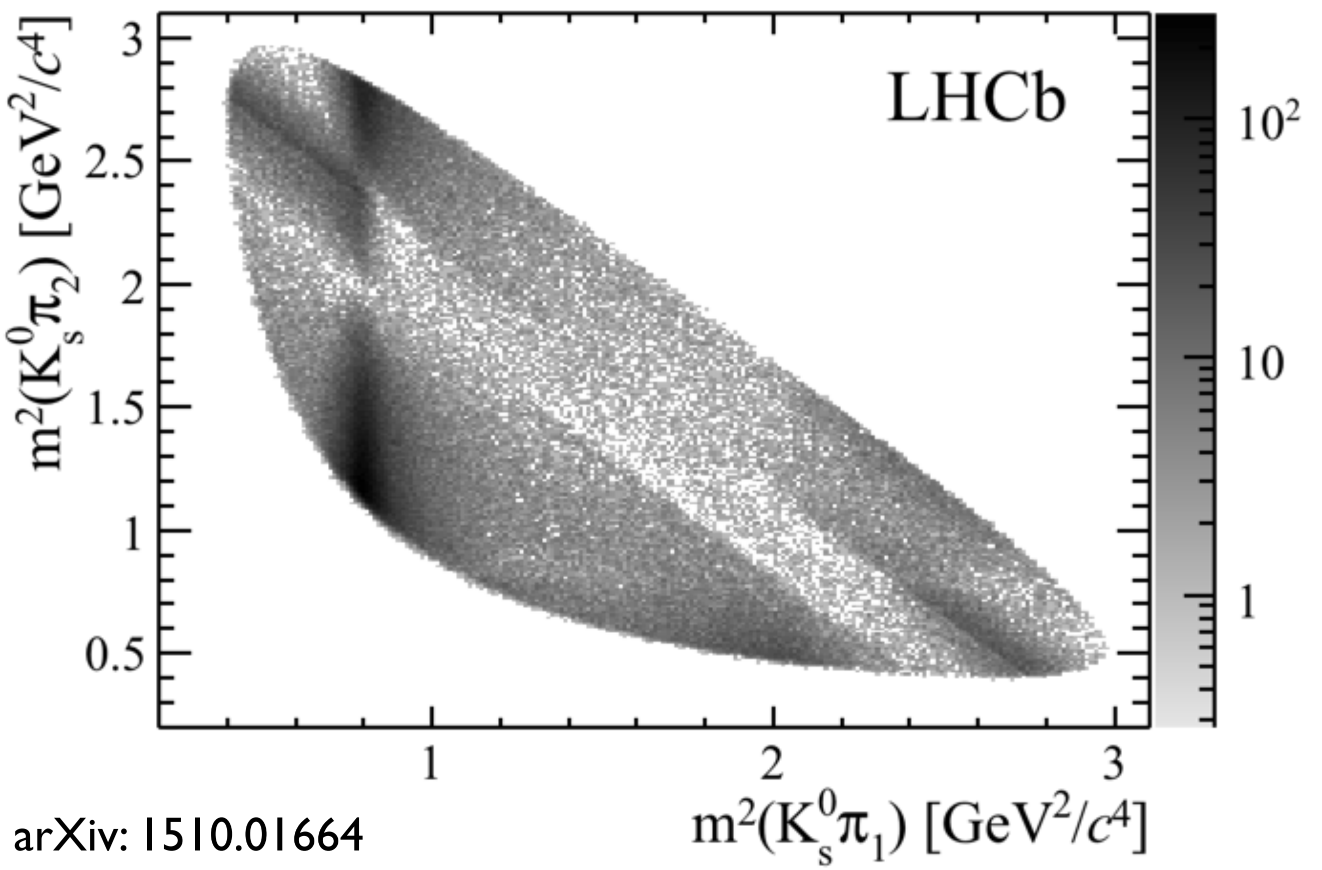
Lecture 3

- Multi-body decays and mixing
- Global averages
- Super-weak constraint

Dalitz plots

see also Hadron Spectroscopy lectures and Dalitz Special by SL Olsen

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

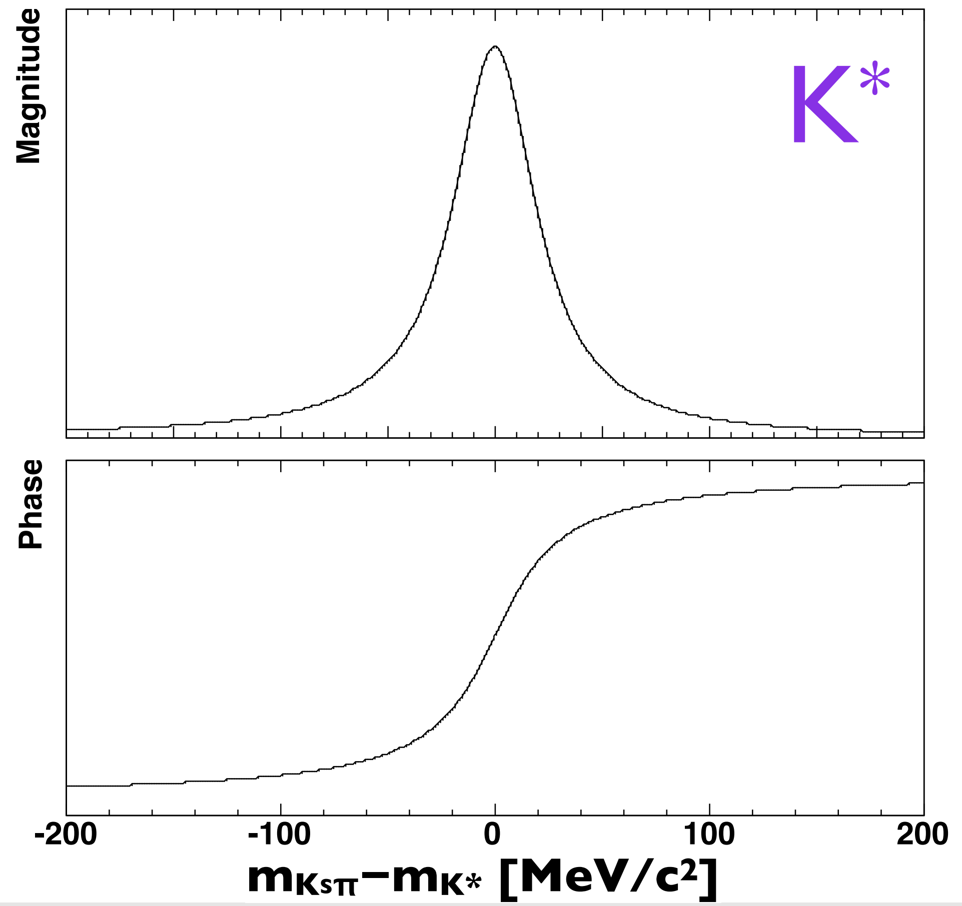


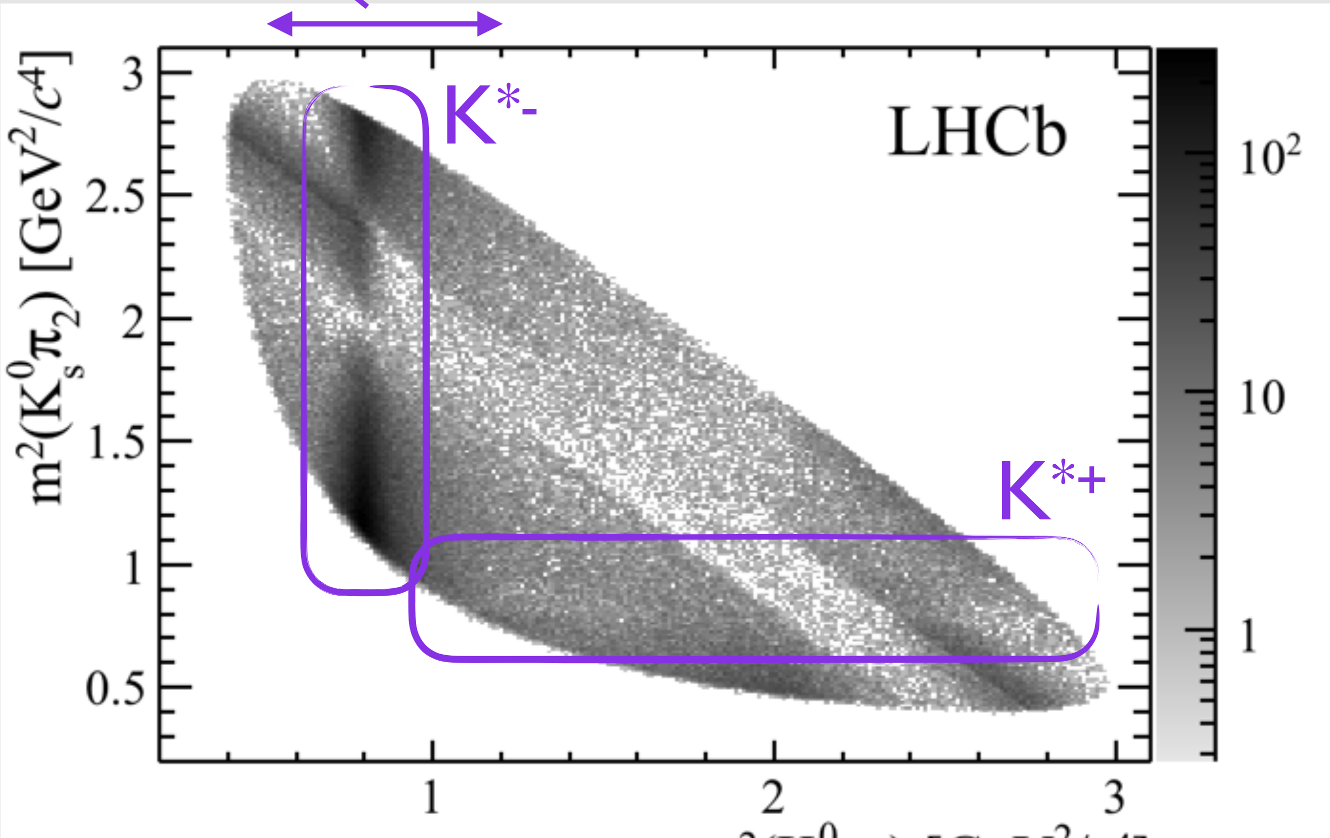
arXiv: 1510.01664

Dalitz plots

see also Hadron Spectroscopy lectures and Dalitz Special by SL Olsen

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





arXiv: 1510.01664

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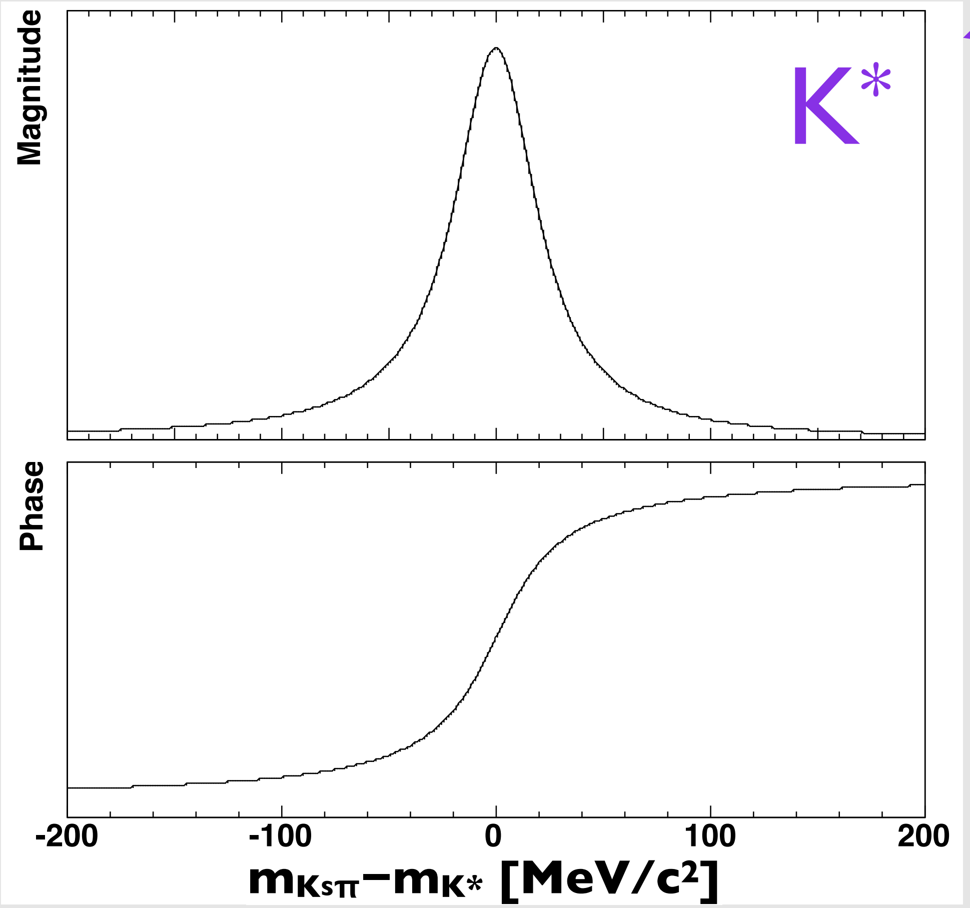
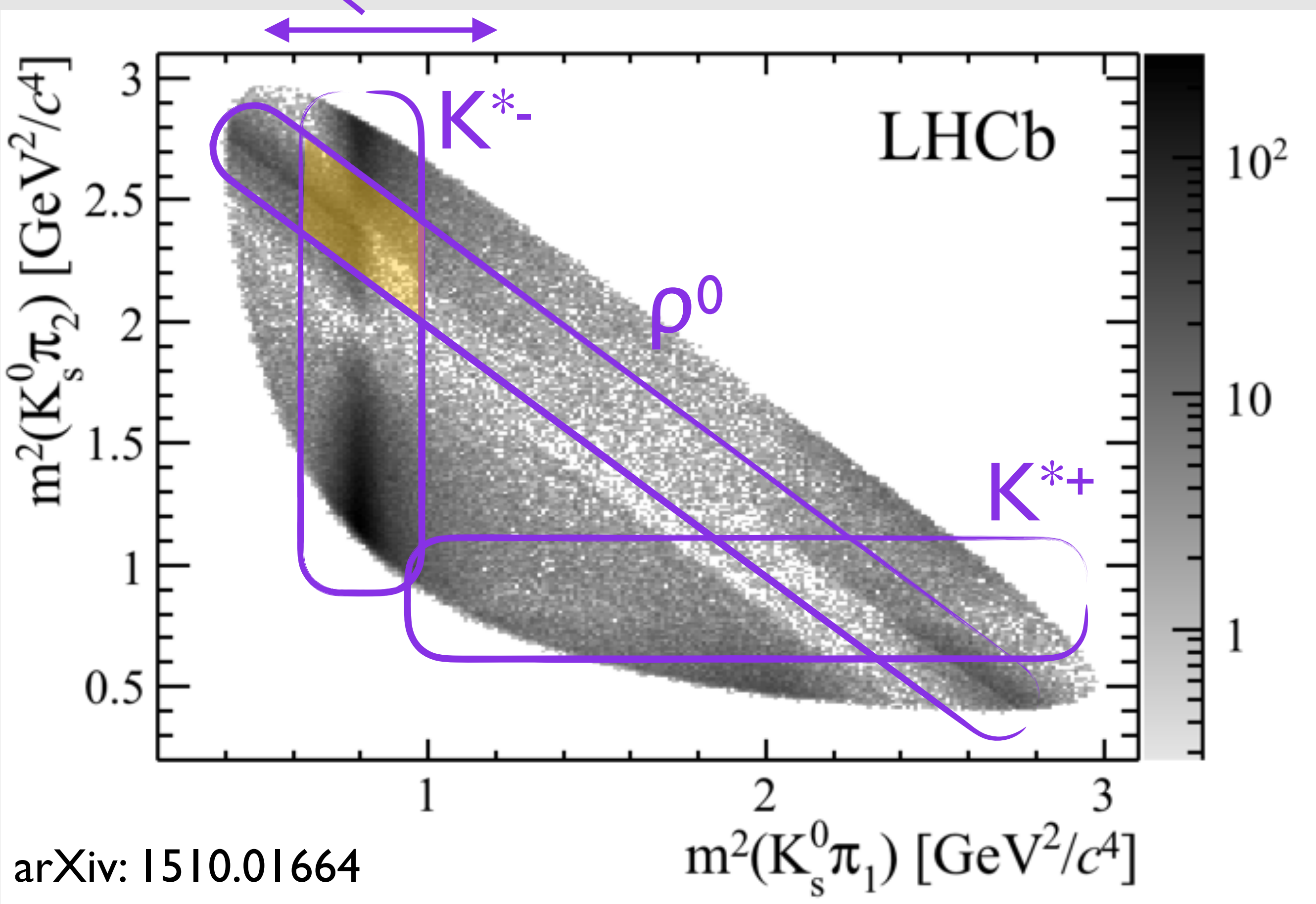


$D^0 \to K_S \pi^- \pi^+$



- Dalitz plot is a sum of complex amplitudes $A_{tot} = \sum A_r$, with r summing over resonances
  - ➡ Full formalism too complex for these lectures
- Interference regions contain rapid phase variation
- Mixing sensitivity e.g. through $K^{*+}\pi^-$ and $K^{*-}\pi^+$ resonances
- Also have CP eigenstates contributing, e.g. $\rho^0 K_S$

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Time-dependent Dalitz

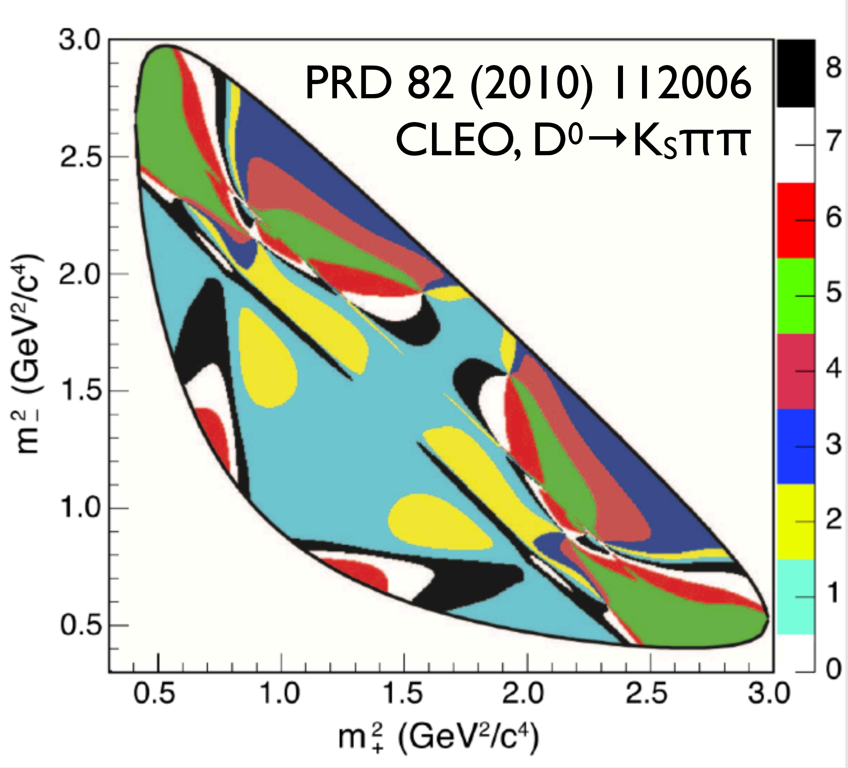
- Have decays to flavour and CP eigenstates
  - ➡ Can study their time dependence
- Amplitude analysis gives access to strong phase variation if CF and DCS decays both present
  - ➡ No rotation of mixing parameters
    - Direct access to x and y

more in a moment

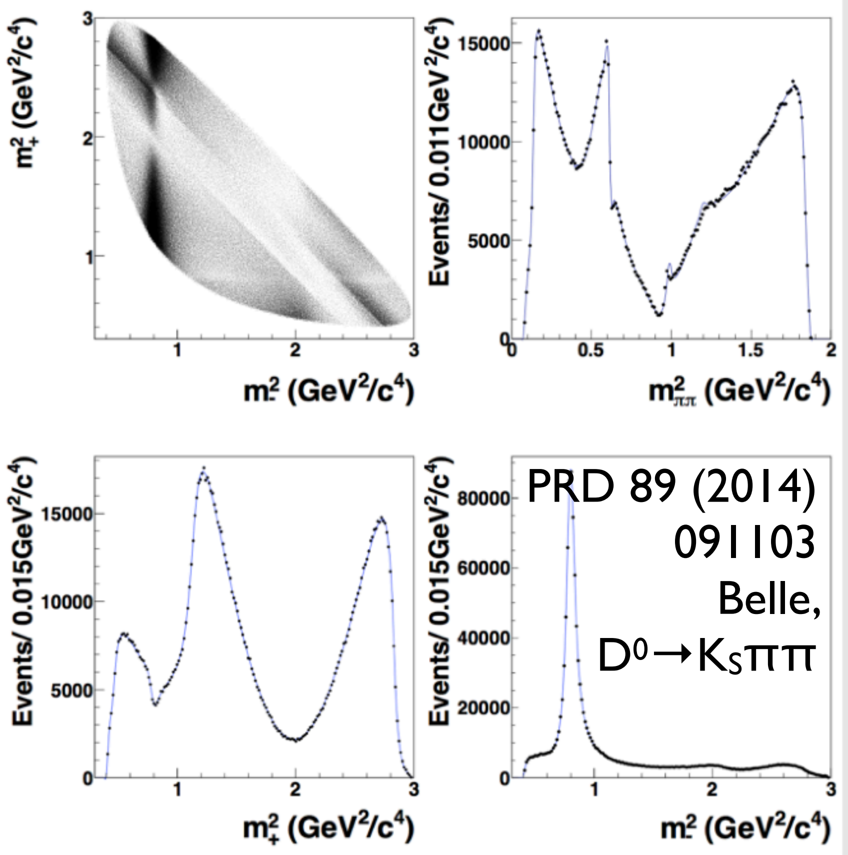
- Splitting by D^0 flavour gives access to CP violation parameters too

Techniques

- Model-independent
  - ➡ Study decay-time evolution in bins of similar strong phase difference



- Model-dependent
  - ➡ Measure underlying parameters directly through model of time-dependence of amplitude structure



Model-dependent

$$|\mathscr{A}_f(t)|^2 = |\frac{1}{2}e^{-\Gamma t}\left[\left(|A|^2 - \left|\frac{q}{p}B\right|^2\right)\cos(x\Gamma t) - 2\Im\left(A\left(\frac{q}{p}B\right)^*\right)\sin(x\Gamma t)\right.$$

$$\left. + \left(|A|^2 + \left|\frac{q}{p}B\right|^2\right)\cosh(y\Gamma t) - 2\Re\left(A\left(\frac{q}{p}B\right)^*\right)\sinh(y\Gamma t)\right]$$

- Need to combine time evolution with phase space distribution

$$A(m^2(K^0_S\pi^-), m^2(K^0_S\pi^+)) = \sum_r c_r A_r(m^2(K^0_S\pi^-), m^2(K^0_S\pi^+)),$$

$$B(m^2(K^0_S\pi^-), m^2(K^0_S\pi^+)) = \sum_r \bar{c}_r A_r(m^2(K^0_S\pi^+), m^2(K^0_S\pi^-)).$$

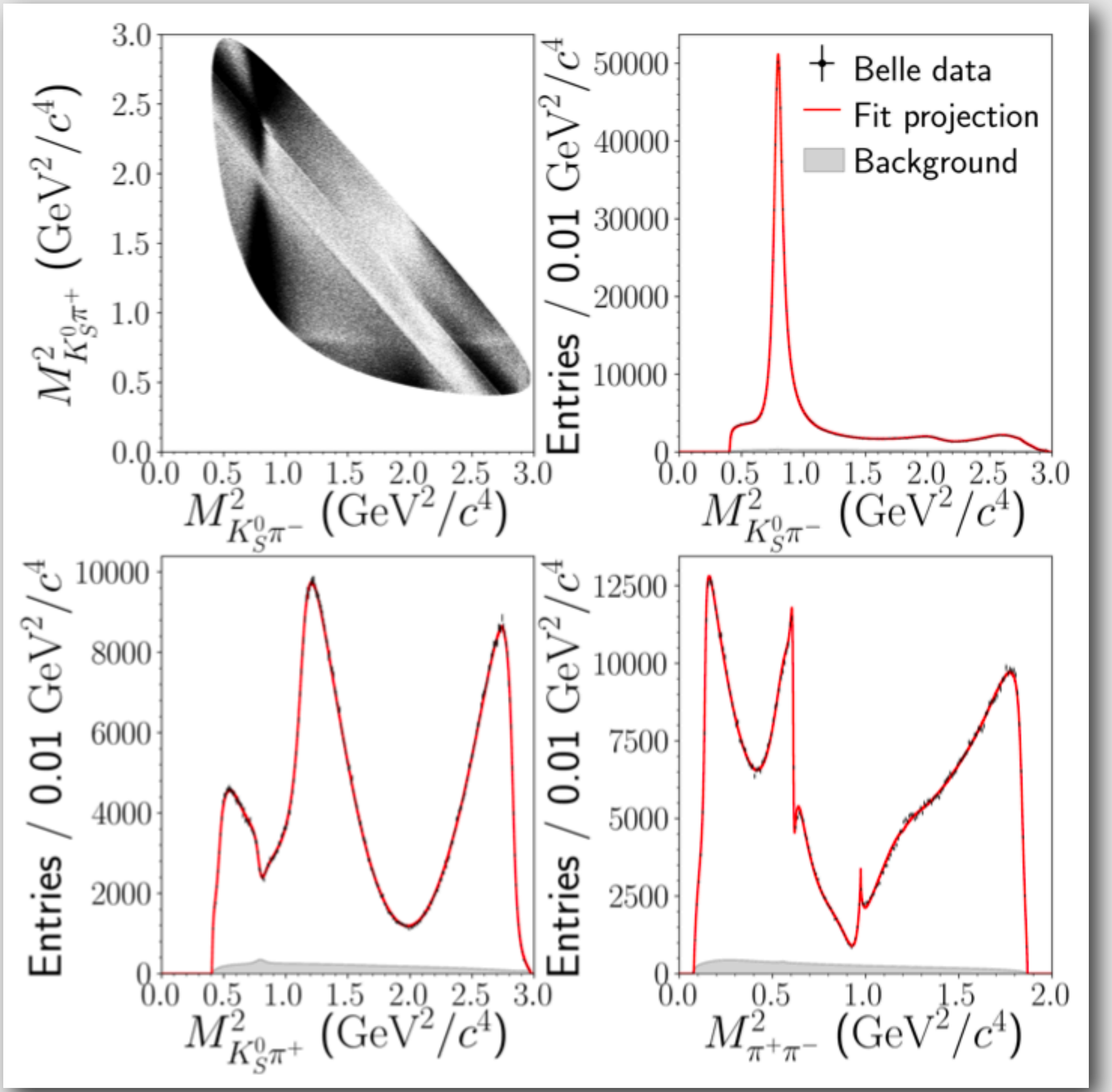
- Assuming no CP violation in decays

$$A_r(m^2(K^0_S\pi^-), m^2(K^0_S\pi^+)) = \bar{A}_r(m^2(K^0_S\pi^+), m^2(K^0_S\pi^-)).$$

Latest model

arXiv:1804.06152
arXiv:1804.06153

- Joint BaBar and Belle amplitude analysis of $D^0 \to K_S \pi\pi$
- 1.2M candidates
- Prime candidate to perform time-dependent analysis to measure x
  - ➡ Feasible both for Belle II and LHCb



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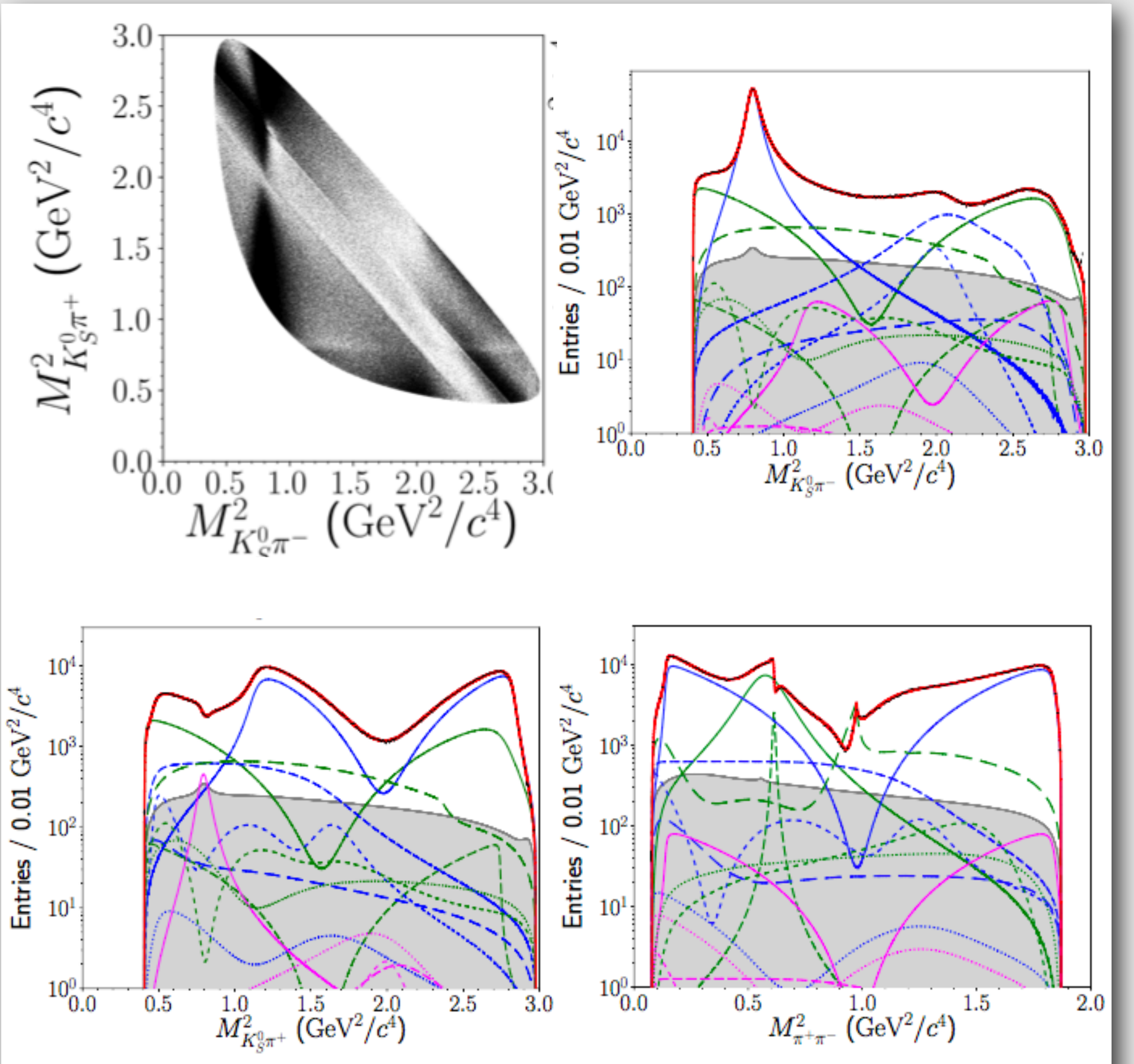

Individual fit contributions

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Experimental issues

- Knowledge of amplitude model
  - ➡ Assigning a systematic uncertainty on accuracy of model is not well defined
- Resolution effects
  - ➡ Both decay time and in phase space
- Acceptance effects
  - ➡ Possible correlation of time and space
- Complex numerical integration
  - ➡ Requires exploitation of every justifiable simplification and optimisation

Model independent

- Based on measurement integrated in bins of phase space:

$$\mathcal{P}_{D^0}(t)_i = e^{-\Gamma t}[T_i + r_{CP}\Gamma t\sqrt{T_i T_{-i}} \times \{y_D(c_i \cos\alpha_{CP} + s_i \sin\alpha_{CP}) + x_D(s_i \cos\alpha_{CP} - c_i \sin\alpha_{CP})\}]$$

- with

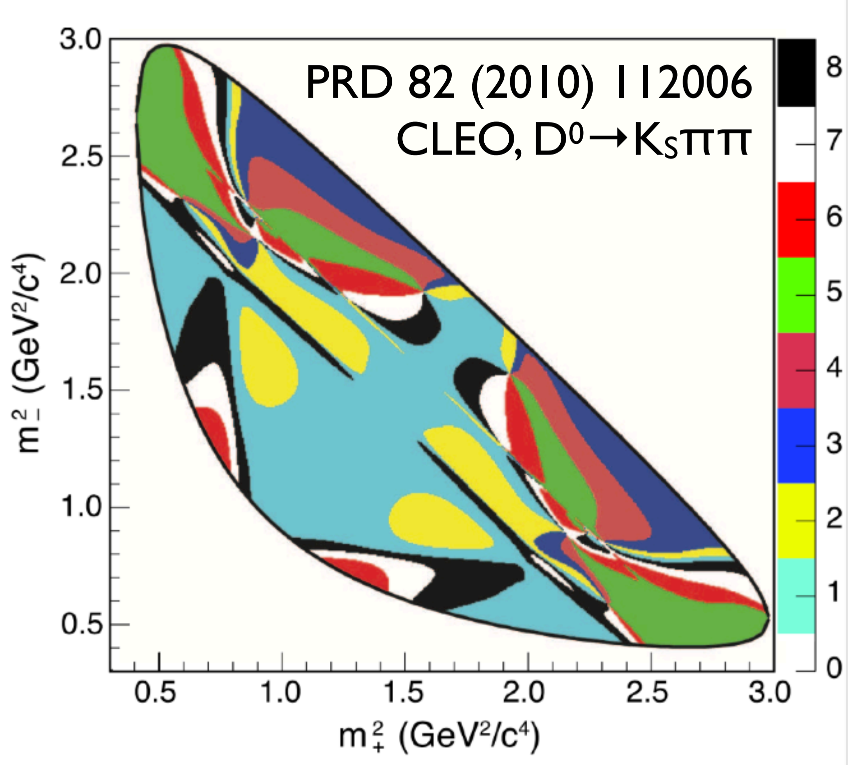
$$T_i = \int_i a^2_{12,13}\mathrm{d}m^2_{12}\mathrm{d}m^2_{13}$$

$$c_i = \frac{1}{\sqrt{T_i T_{-i}}}\int_i a_{12,13}a_{13,12}\cos(\delta_{12,13} - \delta_{13,12})\mathrm{d}m^2_{12}\mathrm{d}m^2_{13}$$

$$s_i = \frac{1}{\sqrt{T_i T_{-i}}}\int_i a_{12,13}a_{13,12}\sin(\delta_{12,13} - \delta_{13,12})\mathrm{d}m^2_{12}\mathrm{d}m^2_{13}.$$

Choice of bins

- Bins chosen to minimise strong phase variation
  - ➡ Informed by model but does not constitute model dependence
- Require external input for c_i and s_i
  - ➡ Measurements using quantum-correlated states: BESIII



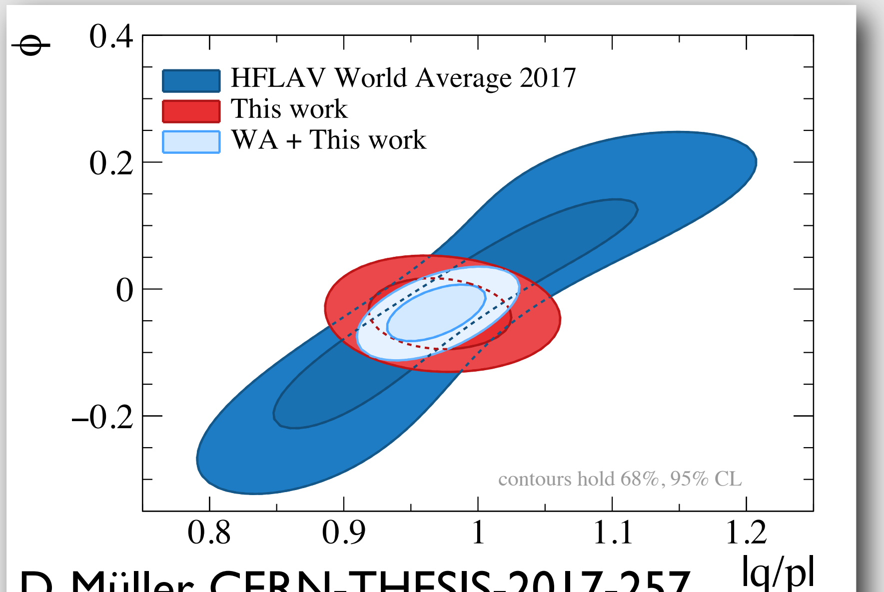
$$c_i = \frac{1}{\sqrt{T_i T_{-i}}} \int_i a_{12,13} a_{13,12} \cos(\delta_{12,13} - \delta_{13,12}) \mathrm{d}m_{12}^2 \mathrm{d}m_{13}^2$$

$$s_i = \frac{1}{\sqrt{T_i T_{-i}}} \int_i a_{12,13} a_{13,12} \sin(\delta_{12,13} - \delta_{13,12}) \mathrm{d}m_{12}^2 \mathrm{d}m_{13}^2.$$

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

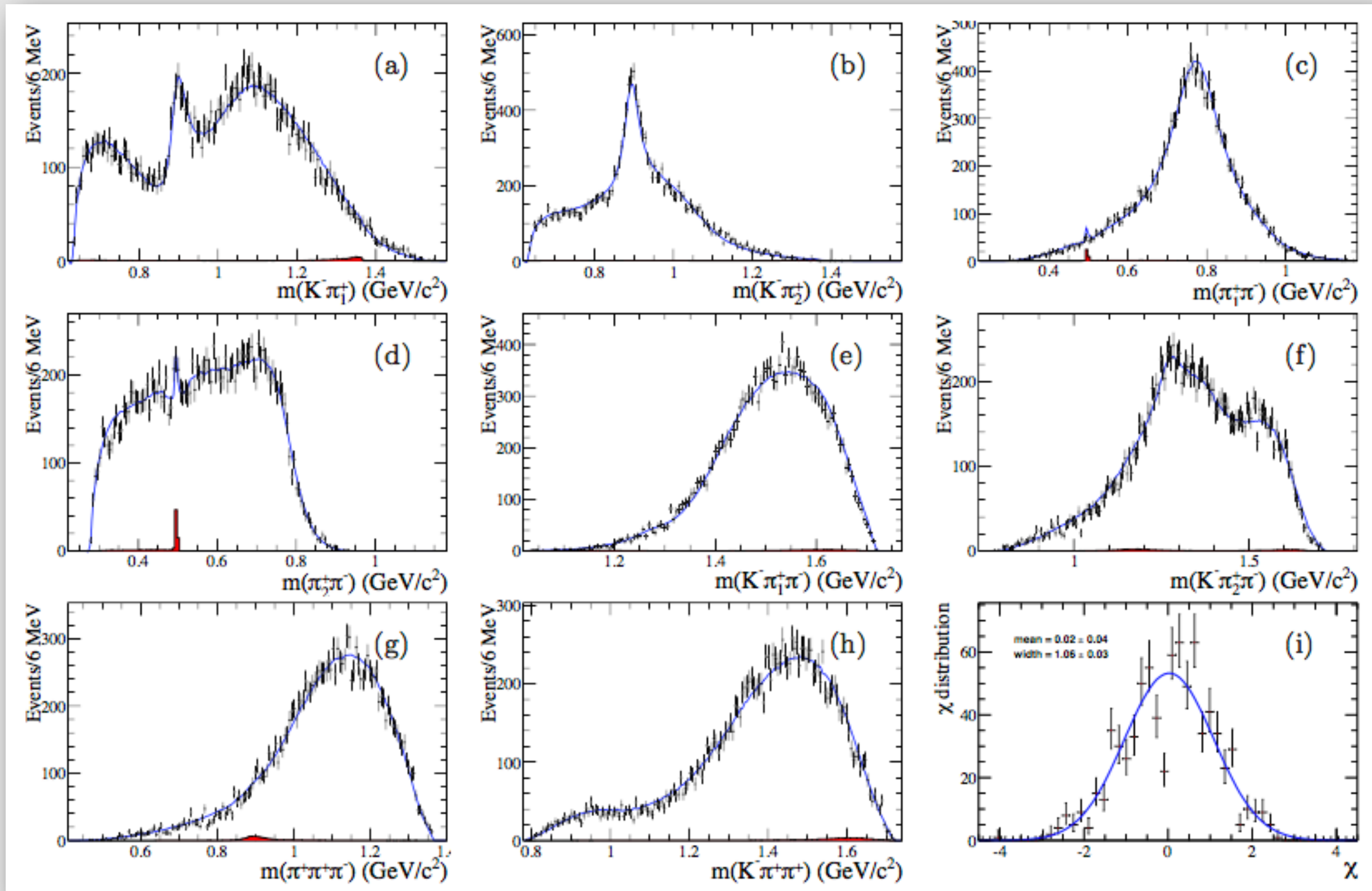
- Doubly Cabibbo-suppressed decay
  - ➡ Equivalent to WS $K\pi$ but with phase space (4-body = 5-dimensional)
- No simultaneous access to CF decay
  - ➡ Mixing parameters are rotated by strong phase difference
  - ➡ But retain linear access to x' through phase variations
- Great potential for CP violating parameters

Potential of $D^0 \to K^\pm\pi^\mp\pi^+\pi^-$ at LHCb



D. Müller, CERN-THESIS-2017-257

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



PRD 95 (2017) 072010

Amplitude	ϕ_i	Fit fraction (%)
$D^0[S] \to \bar{K}^*\rho^0$	$2.35 \pm 0.06 \pm 0.18$	$6.5 \pm 0.5 \pm 0.8$
$D^0[P] \to \bar{K}^*\rho^0$	$-2.25 \pm 0.08 \pm 0.15$	$2.3 \pm 0.2 \pm 0.1$
$D^0[D] \to \bar{K}^*\rho^0$	$2.49 \pm 0.06 \pm 0.11$	$7.9 \pm 0.4 \pm 0.7$
$D^0 \to K^- a_1^+(1260),\ a_1^+(1260)[S] \to \rho^0\pi^+$	0(fixed)	$53.2 \pm 2.8 \pm 4.0$
$D^0 \to K^- a_1^+(1260),\ a_1^+(1260)[D] \to \rho^0\pi^+$	$-2.11 \pm 0.15 \pm 0.21$	$0.3 \pm 0.1 \pm 0.1$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270)[S] \to \bar{K}^{*0}\pi^-$	$1.48 \pm 0.21 \pm 0.24$	$0.1 \pm 0.1 \pm 0.1$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270)[D] \to \bar{K}^{*0}\pi^-$	$3.00 \pm 0.09 \pm 0.15$	$0.7 \pm 0.2 \pm 0.2$
$D^0 \to K_1^-(1270)\pi^+,\ K_1^-(1270) \to K^-\rho^0$	$-2.46 \pm 0.06 \pm 0.21$	$3.4 \pm 0.3 \pm 0.5$
$D^0 \to (\rho^0 K^-)_A\pi^+,\ (\rho^0 K^-)_A[D] \to K^-\rho^0$	$-0.43 \pm 0.09 \pm 0.12$	$1.1 \pm 0.2 \pm 0.3$
$D^0 \to (K^-\rho^0)_P\pi^+$	$-0.14 \pm 0.11 \pm 0.10$	$7.4 \pm 1.6 \pm 5.7$
$D^0 \to (K^-\pi^+)_{S-wave}\rho^0$	$-2.45 \pm 0.19 \pm 0.47$	$2.0 \pm 0.7 \pm 1.9$
$D^0 \to (K^-\rho^0)_V\pi^+$	$-1.34 \pm 0.12 \pm 0.09$	$0.4 \pm 0.1 \pm 0.1$
$D^0 \to (\bar{K}^{*0}\pi^-)_P\pi^+$	$-2.09 \pm 0.12 \pm 0.22$	$2.4 \pm 0.5 \pm 0.5$
$D^0 \to \bar{K}^{*0}(\pi^+\pi^-)_S$	$-0.17 \pm 0.11 \pm 0.12$	$2.6 \pm 0.6 \pm 0.6$
$D^0 \to (\bar{K}^{*0}\pi^-)_V\pi^+$	$-2.13 \pm 0.10 \pm 0.11$	$0.8 \pm 0.1 \pm 0.1$
$D^0 \to ((K^-\pi^+)_{S-wave}\pi^-)_A\pi^+$	$-1.36 \pm 0.08 \pm 0.37$	$5.6 \pm 0.9 \pm 2.7$
$D^0 \to K^-((\pi^+\pi^-)_S\pi^+)_A$	$-2.23 \pm 0.08 \pm 0.22$	$13.1 \pm 1.9 \pm 2.2$
$D^0 \to (K^-\pi^+)_{S-wave}(\pi^+\pi^-)_S$	$-1.40 \pm 0.04 \pm 0.22$	$16.3 \pm 0.5 \pm 0.6$
$D^0[S] \to (K^-\pi^+)_V(\pi^+\pi^-)_V$	$1.59 \pm 0.13 \pm 0.41$	$5.4 \pm 1.2 \pm 1.9$
$D^0 \to (K^-\pi^+)_{S-wave}(\pi^+\pi^-)_V$	$-0.16 \pm 0.17 \pm 0.43$	$1.9 \pm 0.6 \pm 1.2$
$D^0 \to (K^-\pi^+)_V(\pi^+\pi^-)_S$	$2.58 \pm 0.08 \pm 0.25$	$2.9 \pm 0.5 \pm 1.7$
$D^0 \to (K^-\pi^+)_T(\pi^+\pi^-)_S$	$-2.92 \pm 0.14 \pm 0.12$	$0.3 \pm 0.1 \pm 0.1$
$D^0 \to (K^-\pi^+)_{S-wave}(\pi^+\pi^-)_T$	$2.45 \pm 0.12 \pm 0.37$	$0.5 \pm 0.1 \pm 0.1$

- Based on 16000 RS candidates (99.4% purity)
  - ➡ Double-tagged sample via $\bar{D}^0 \to K\pi$ decays
- First study of this decay in this millennium
- Paving the way for time-dependent amplitude analysis

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

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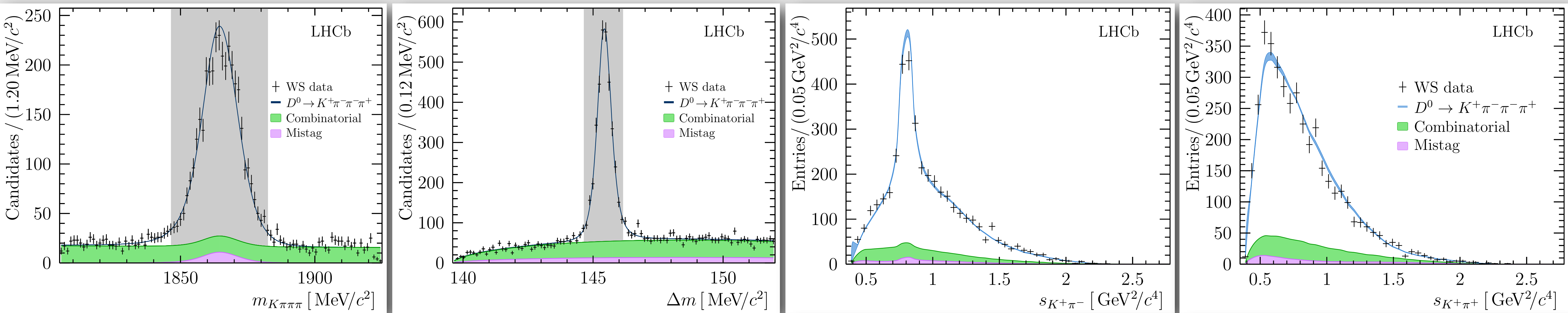
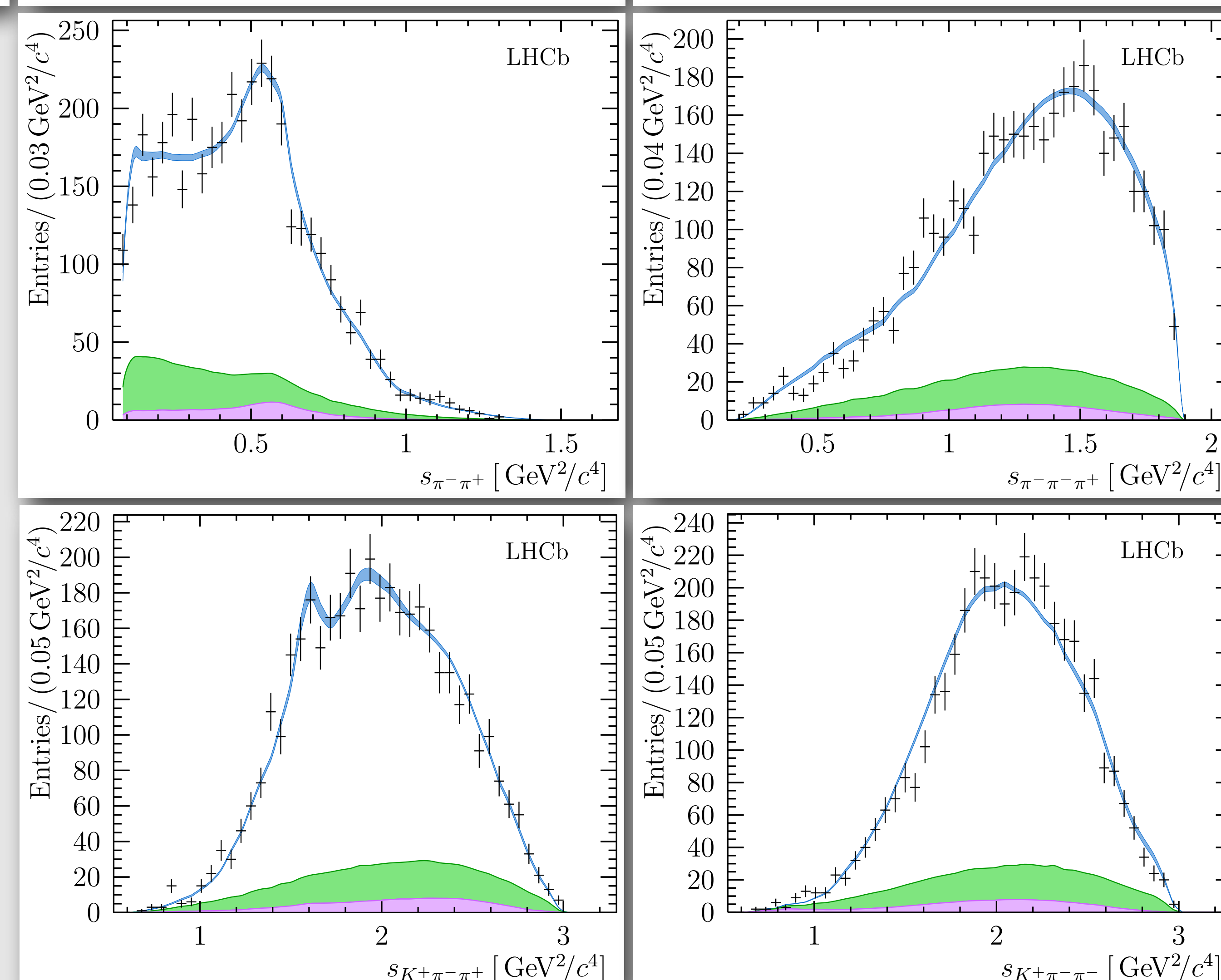
EPJ C78 (2018) 443



- 2011+12 data (3 fb^{-1})
- Based on 2500 WS events (82.4% purity)
  - ➡ Suppressed by factor of ~300
  - ➡ Input to time-dependent analysis
- Also measured RS model with ~900k events (99.6% purity)
  - ➡ Broadly similar but some disagreement on NR contribution



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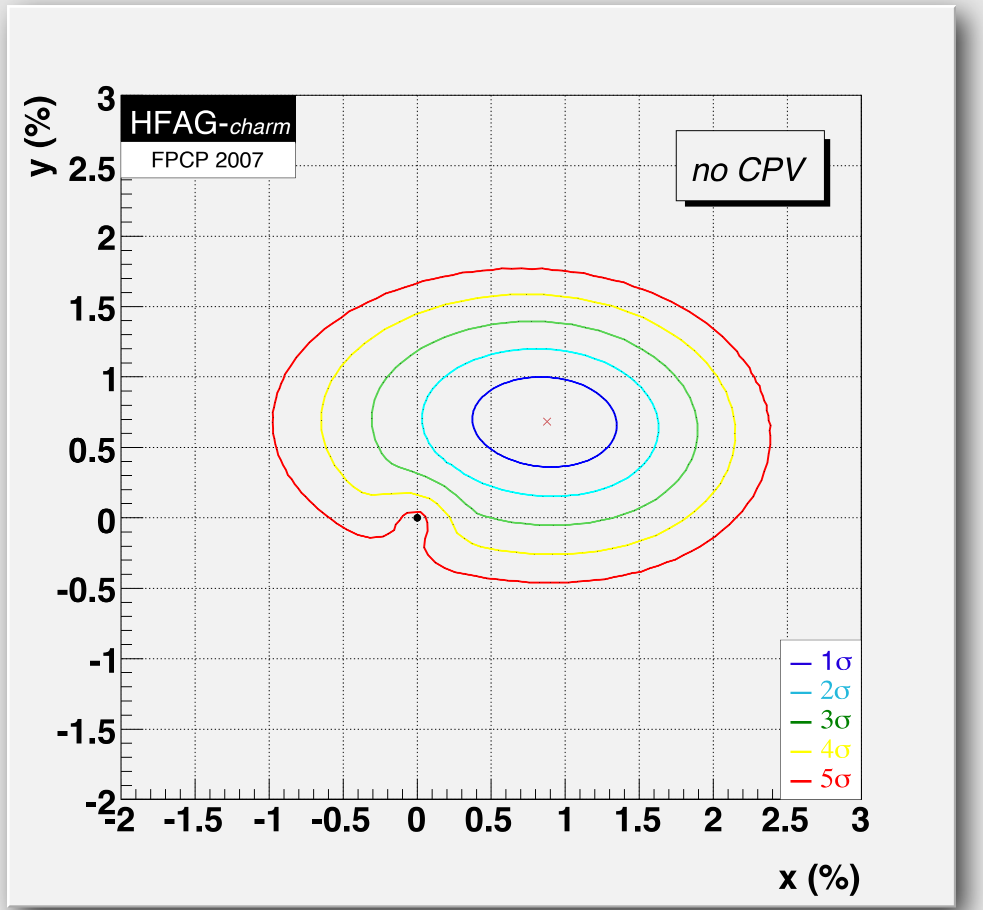
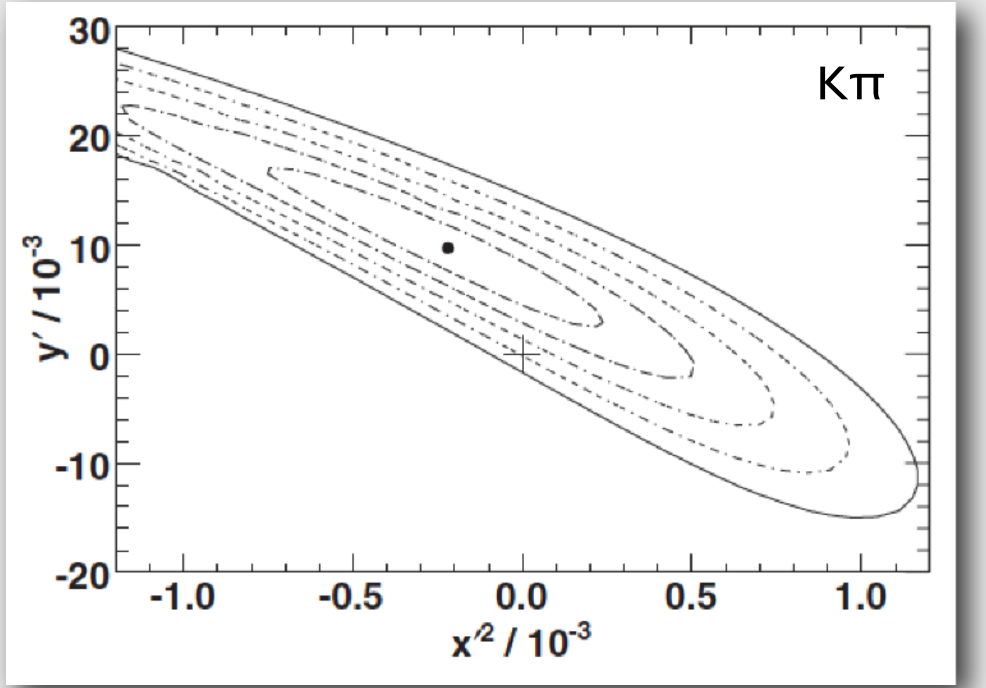
Bringing it all together

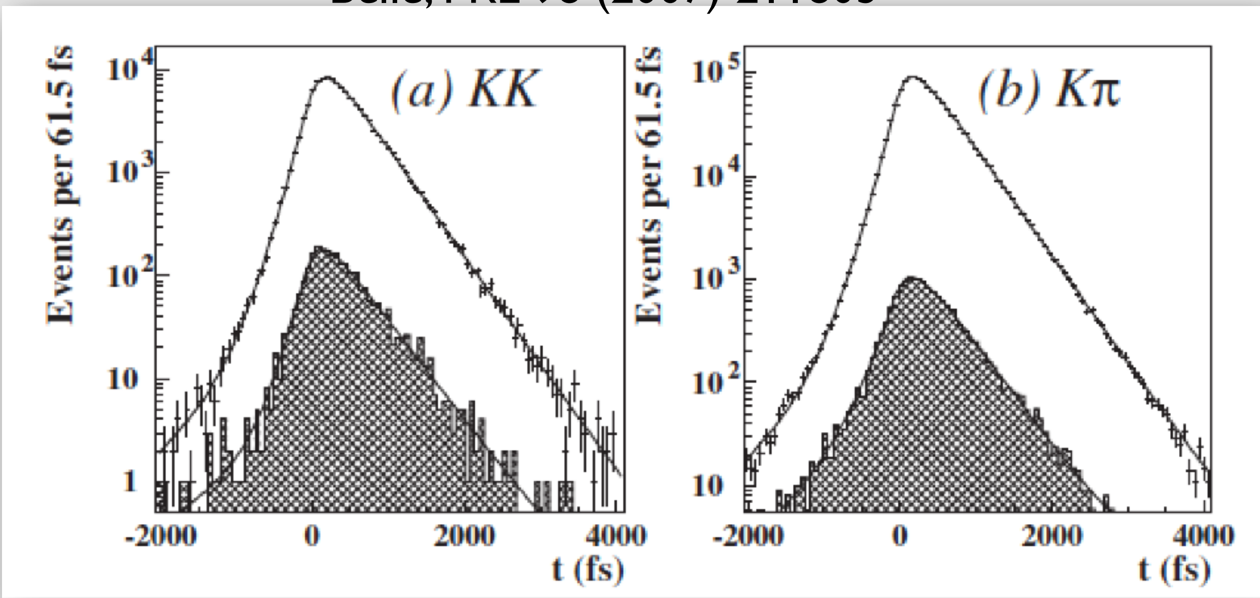
Mixing discovery



BABAR, PRL 98 (2007) 211802



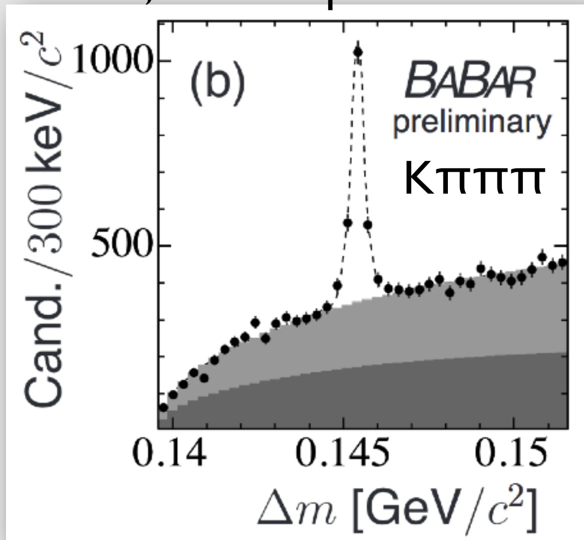
Belle, PRL 98 (2007) 211803



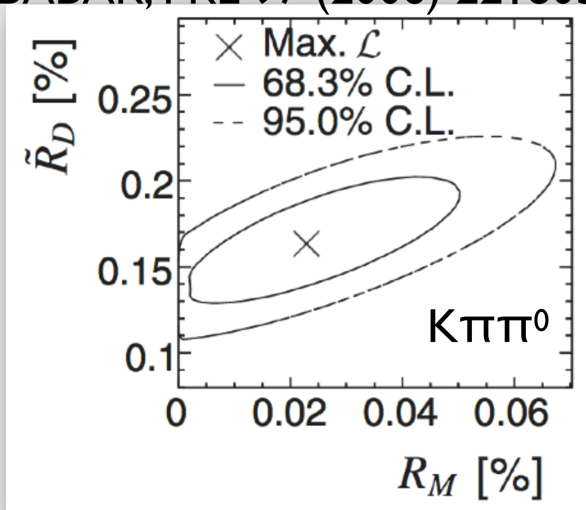
- Discovery through combination of measurements

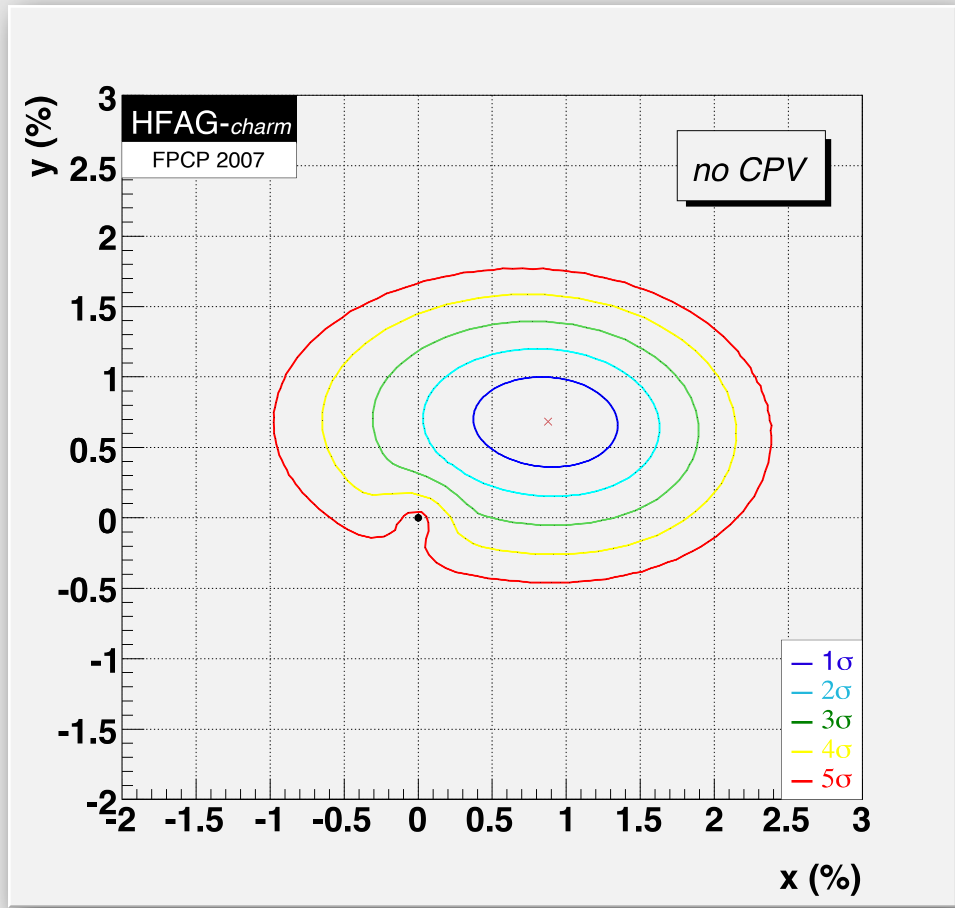
Mixing discovery

BABAR, arXiv:hep-ex/0607090



BABAR, PRL 97 (2006) 221803





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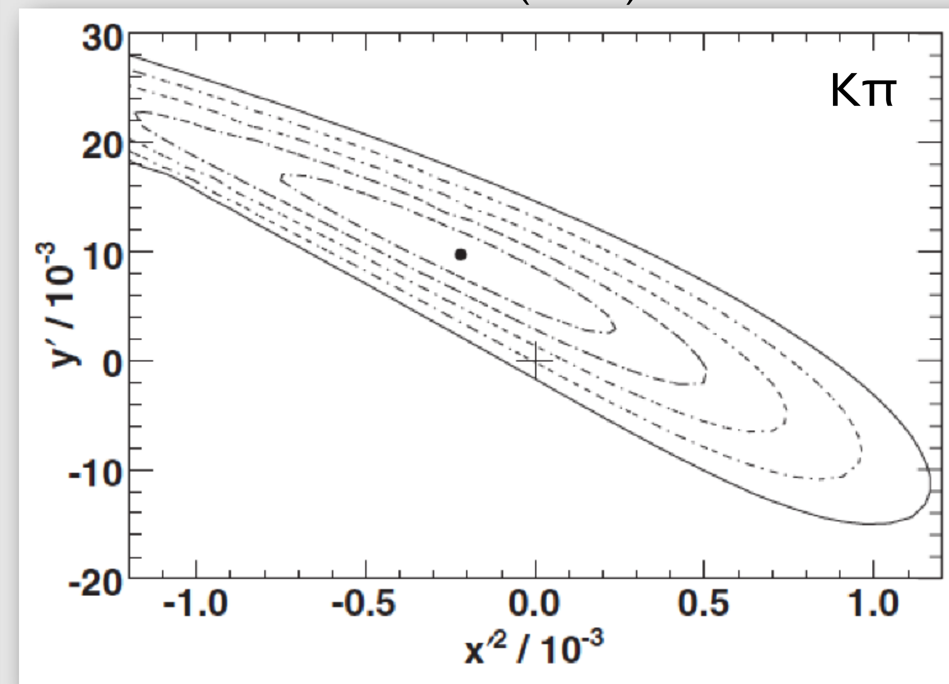
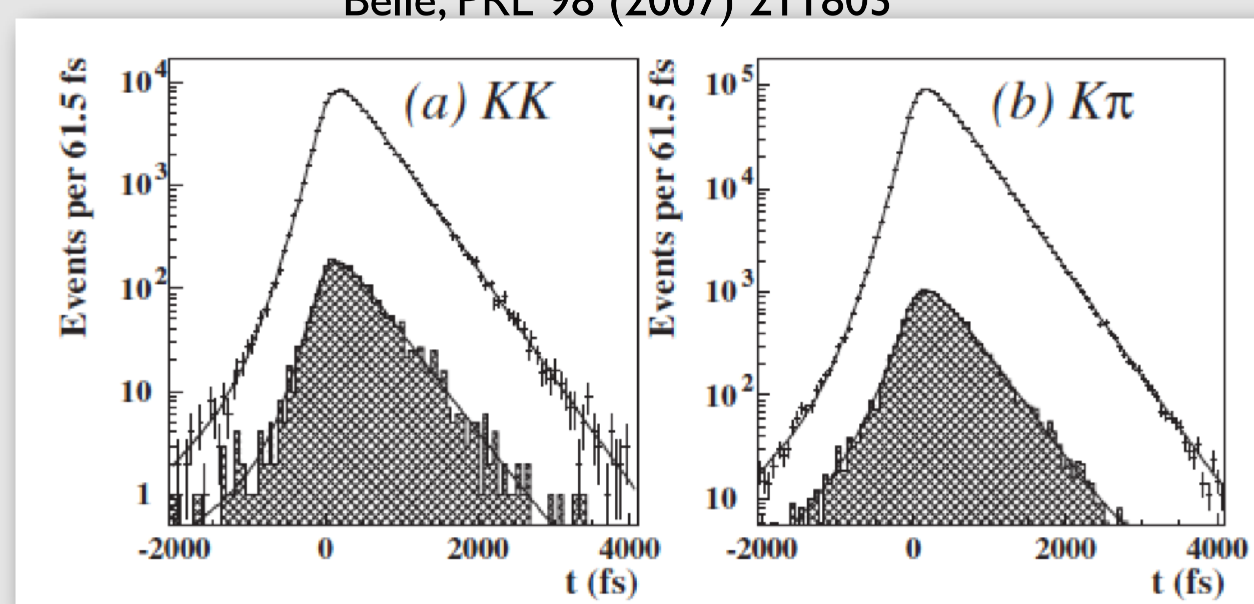
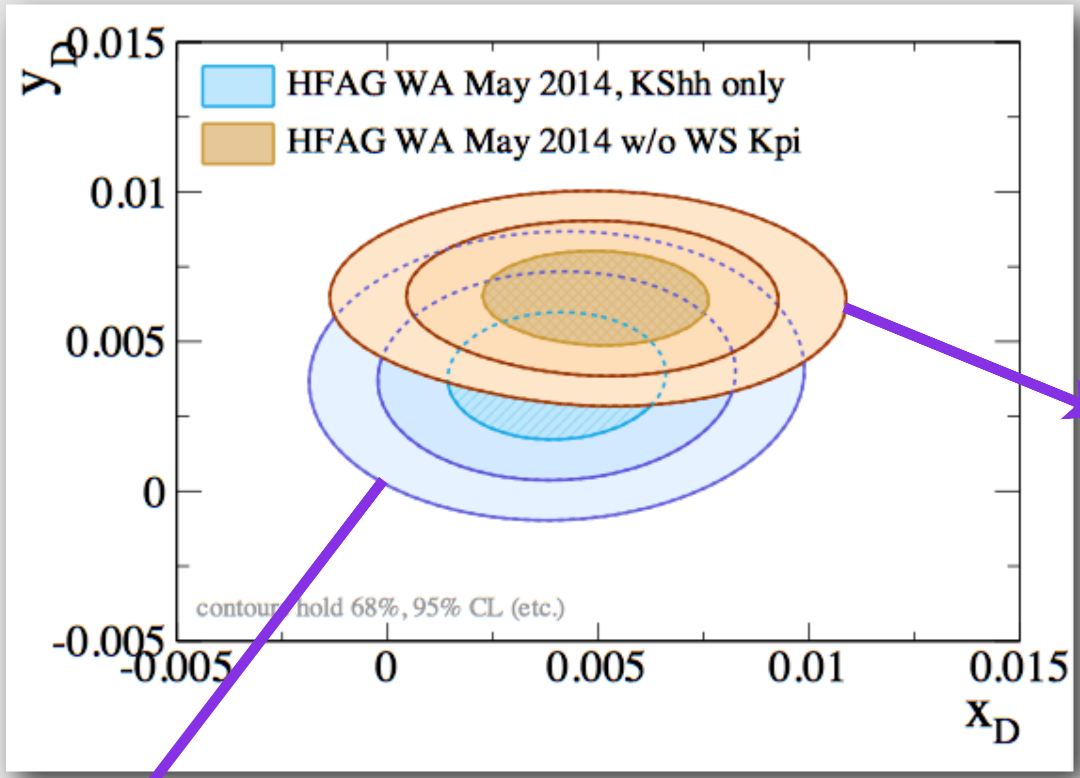


Belle, PRL 98 (2007) 211803



- Discovery through combination of measurements

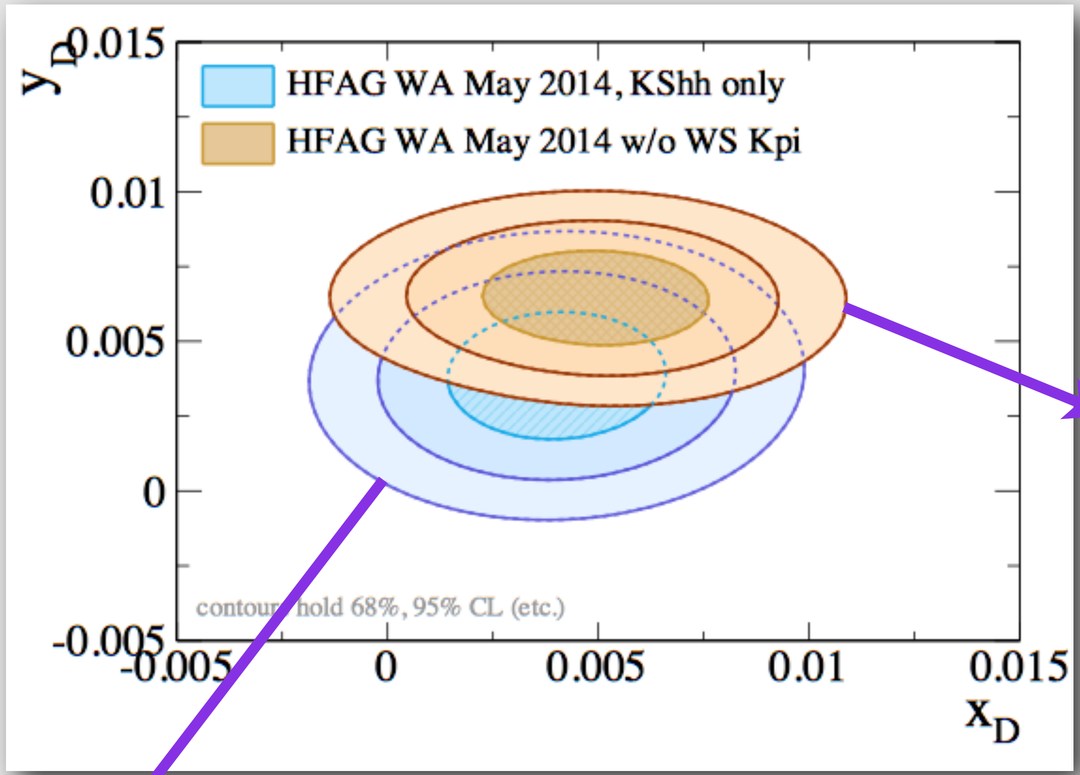
World average decoded

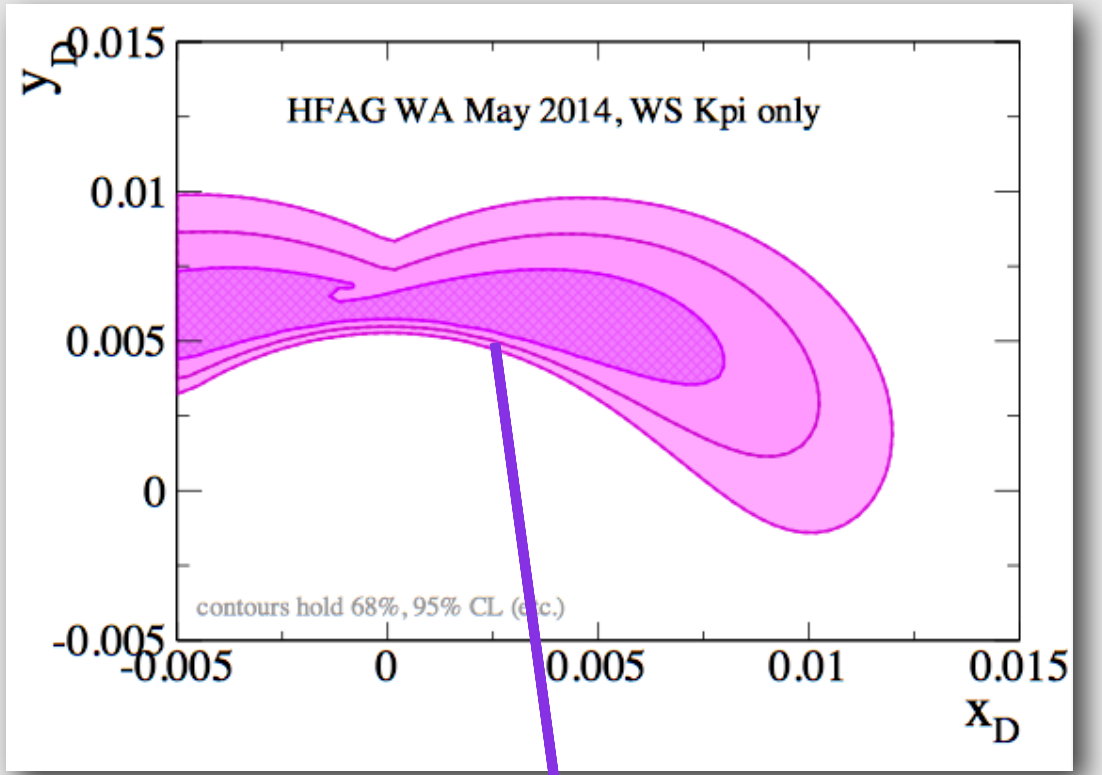


Adding y_{CP} mostly constrains y

x & y measured directly

World average decoded



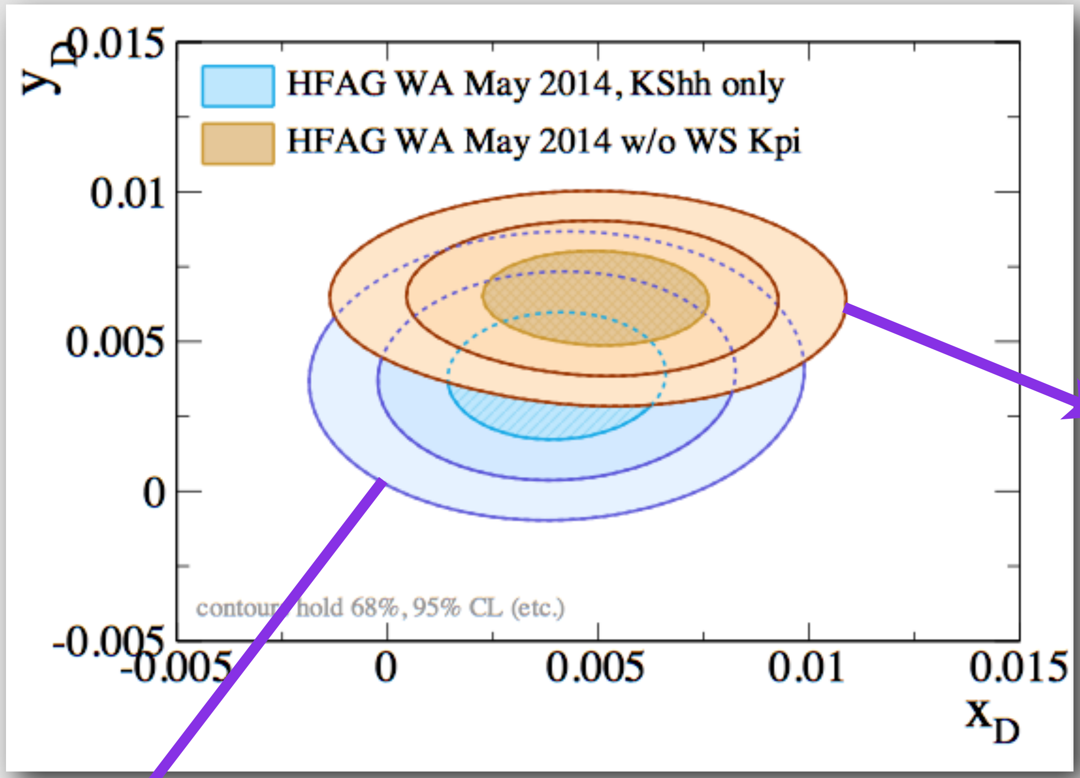


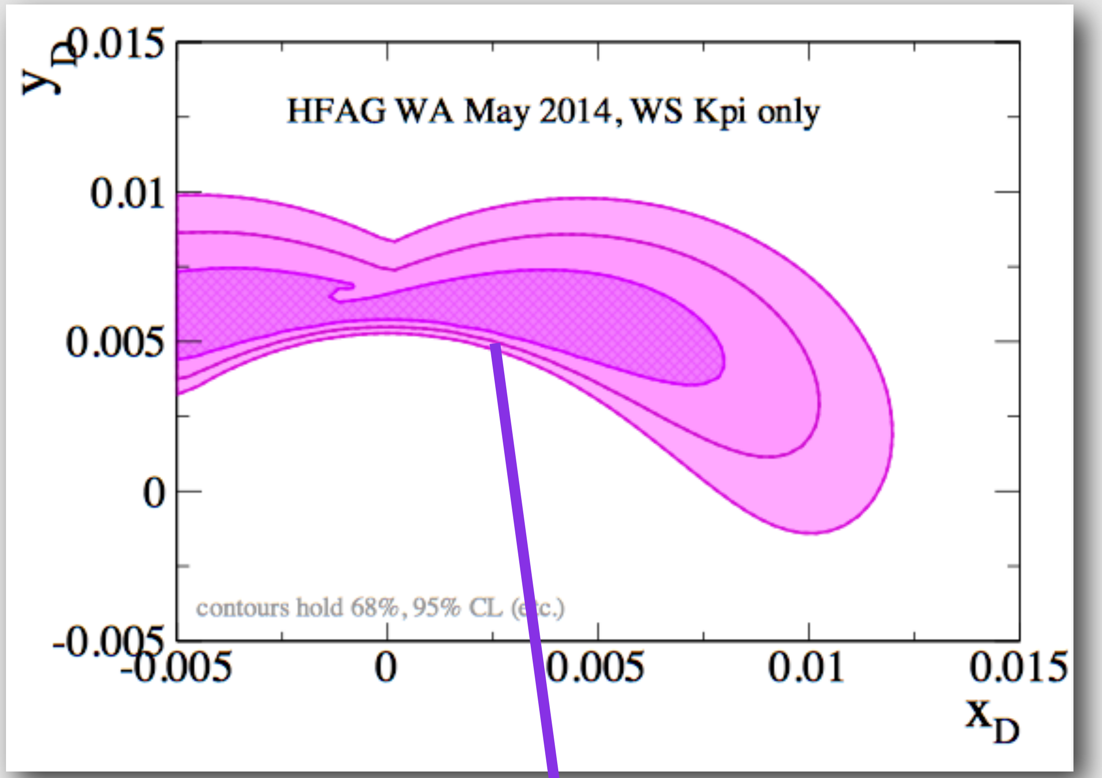
Adding y_{CP} mostly constrains y

x & y measured directly

x^2+y^2 measures a ring
y′ mostly adds information on y ($\delta_{K\pi}$ near 0)

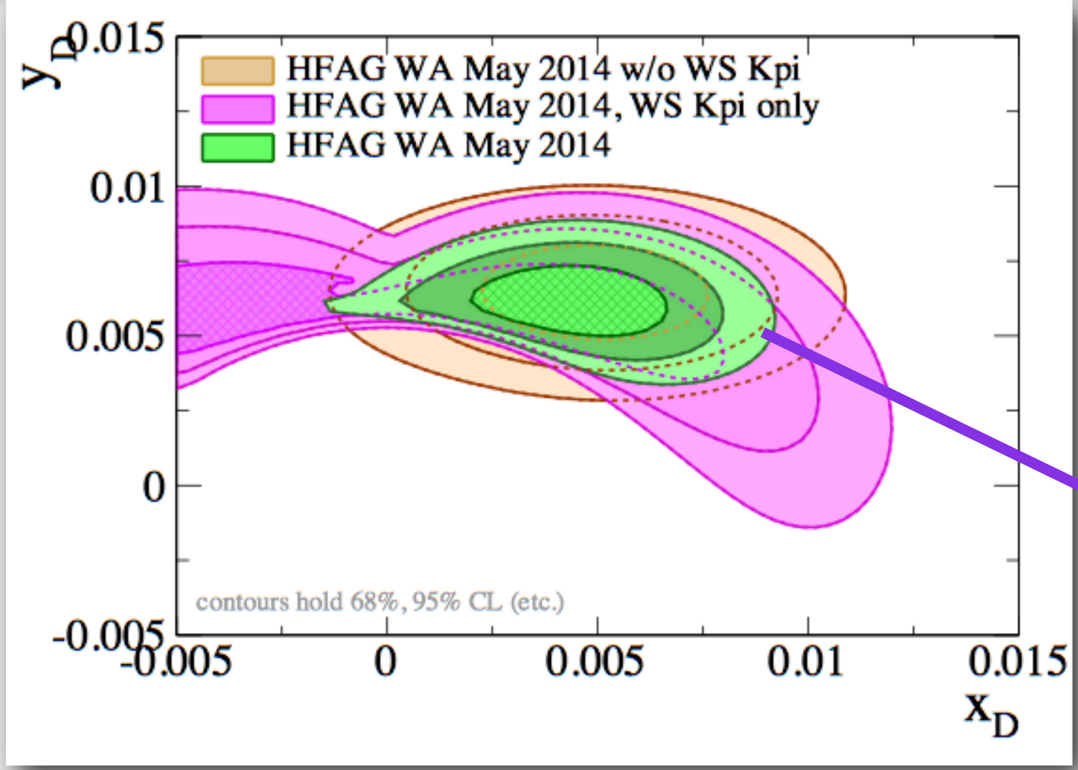
World average decoded





Adding y_{CP} mostly constrains y

x & y measured directly



x^2+y^2 measures a ring

y' mostly adds information on y ($\delta_{K\pi}$ near 0)

Full average following intersection of contours

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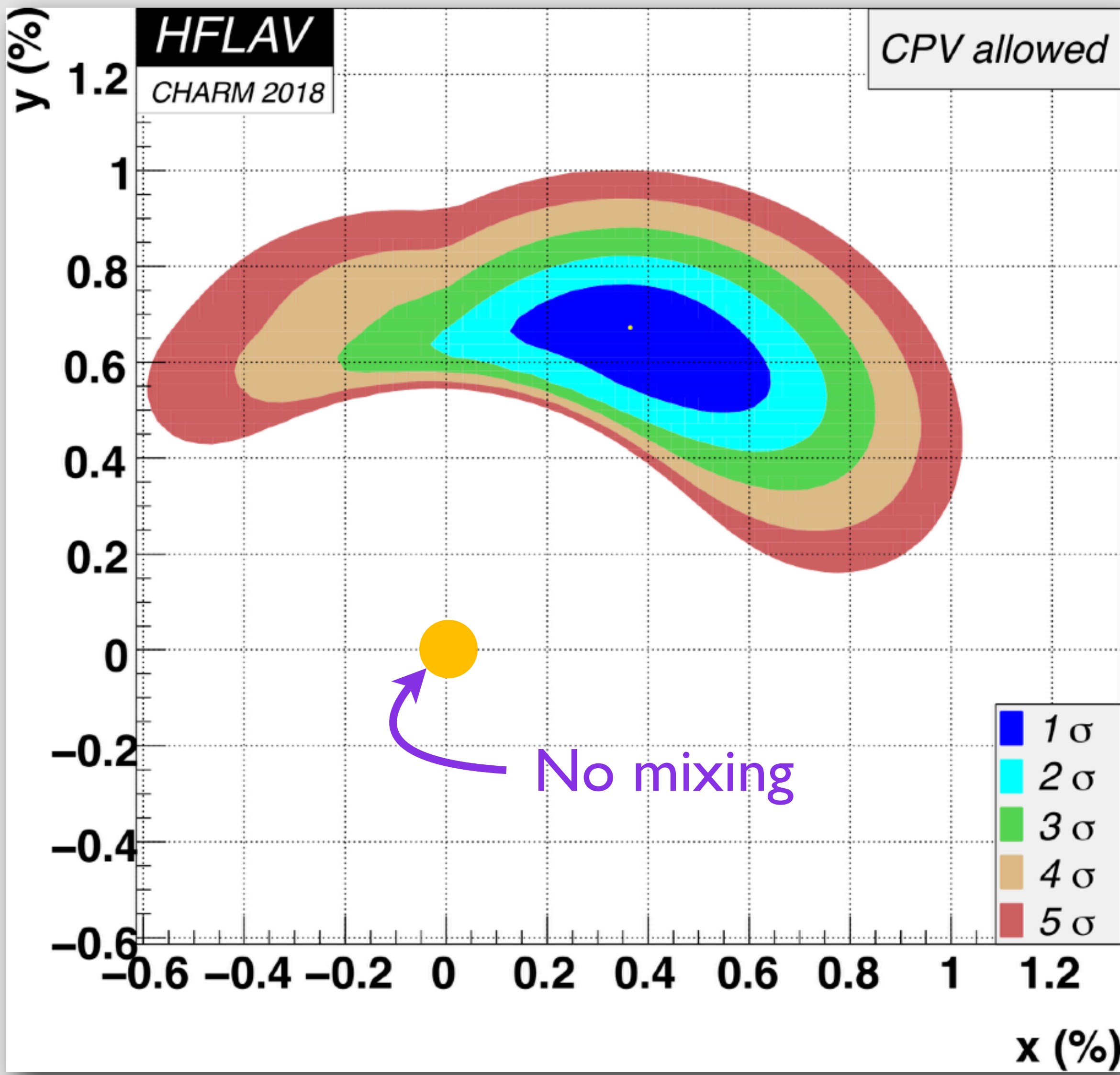
Mixing nowadays



- Mixing established
  - ➡ x≠0 still open question

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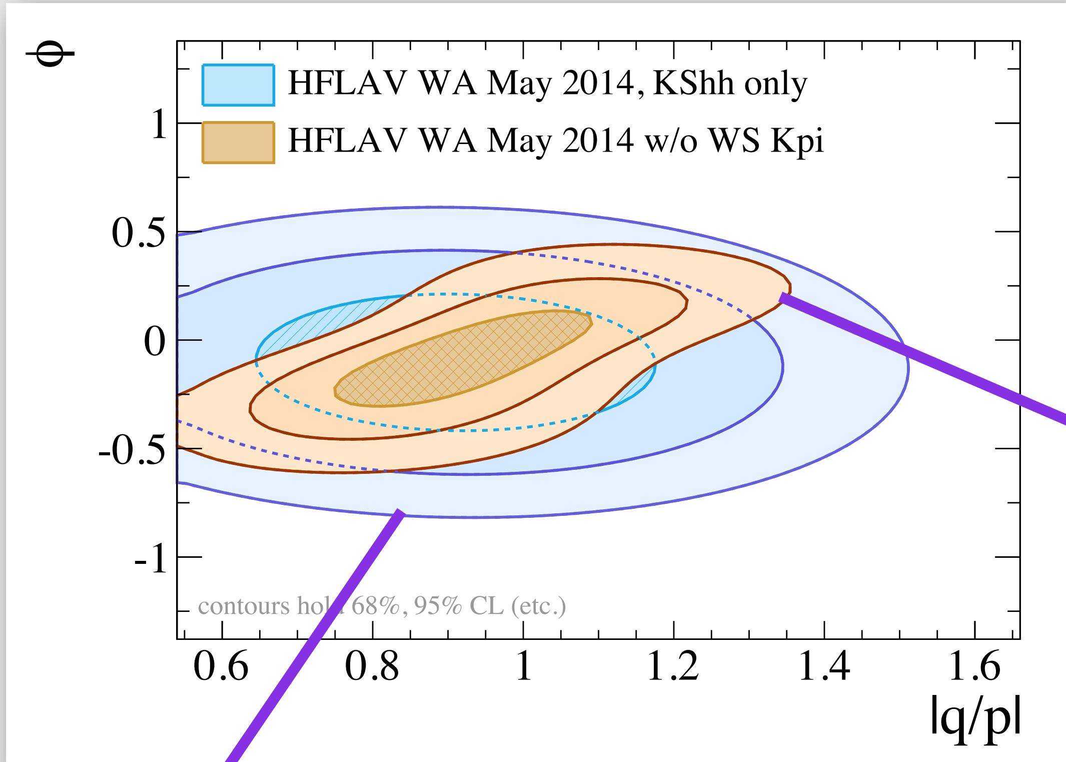
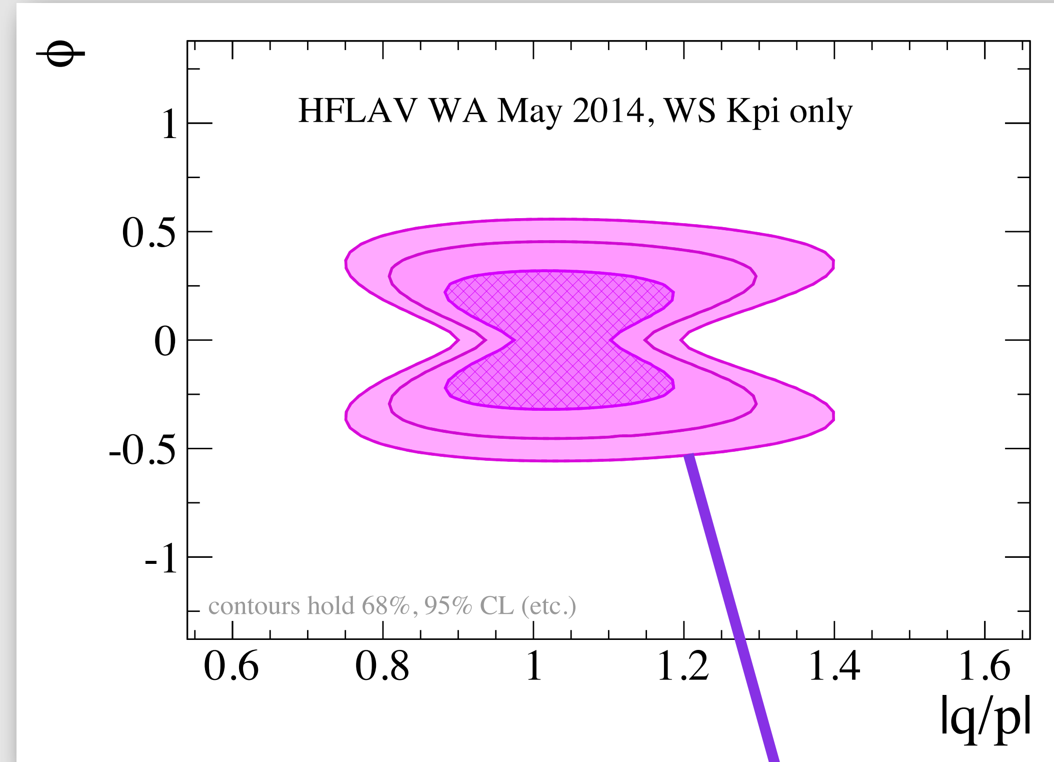
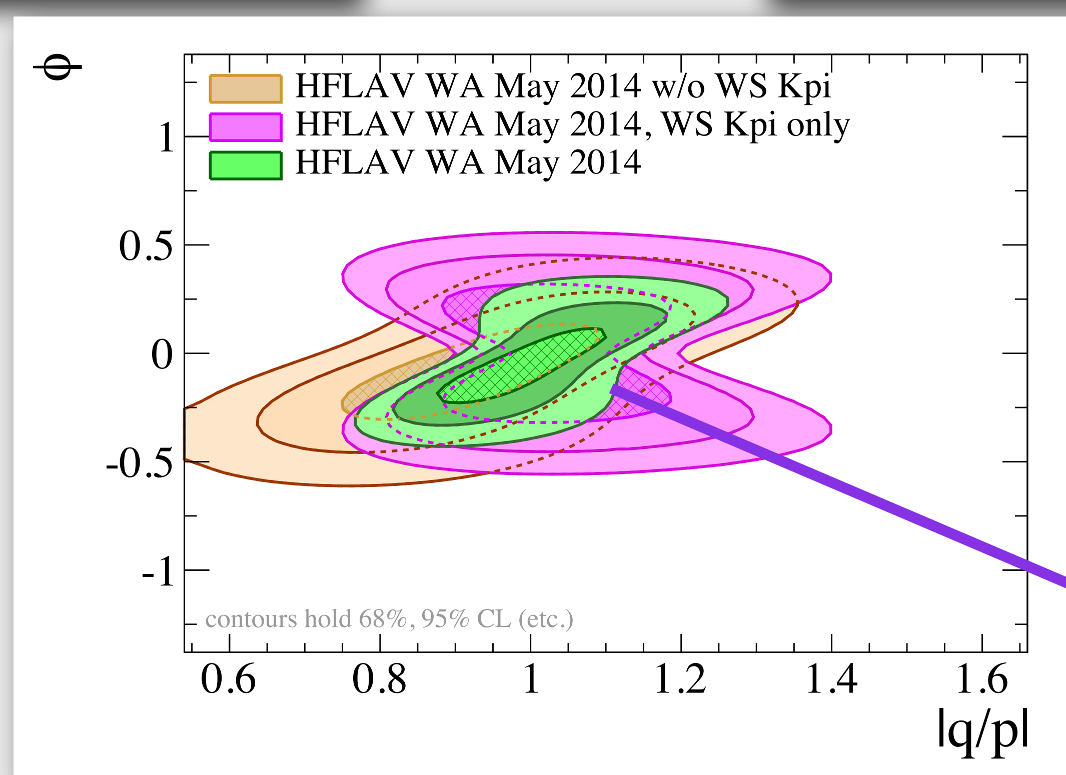
Contributions to CPV





Precise constraints if x and y provided, mostly from A_Γ

Direct access to |q/p| and φ from $K_S hh$



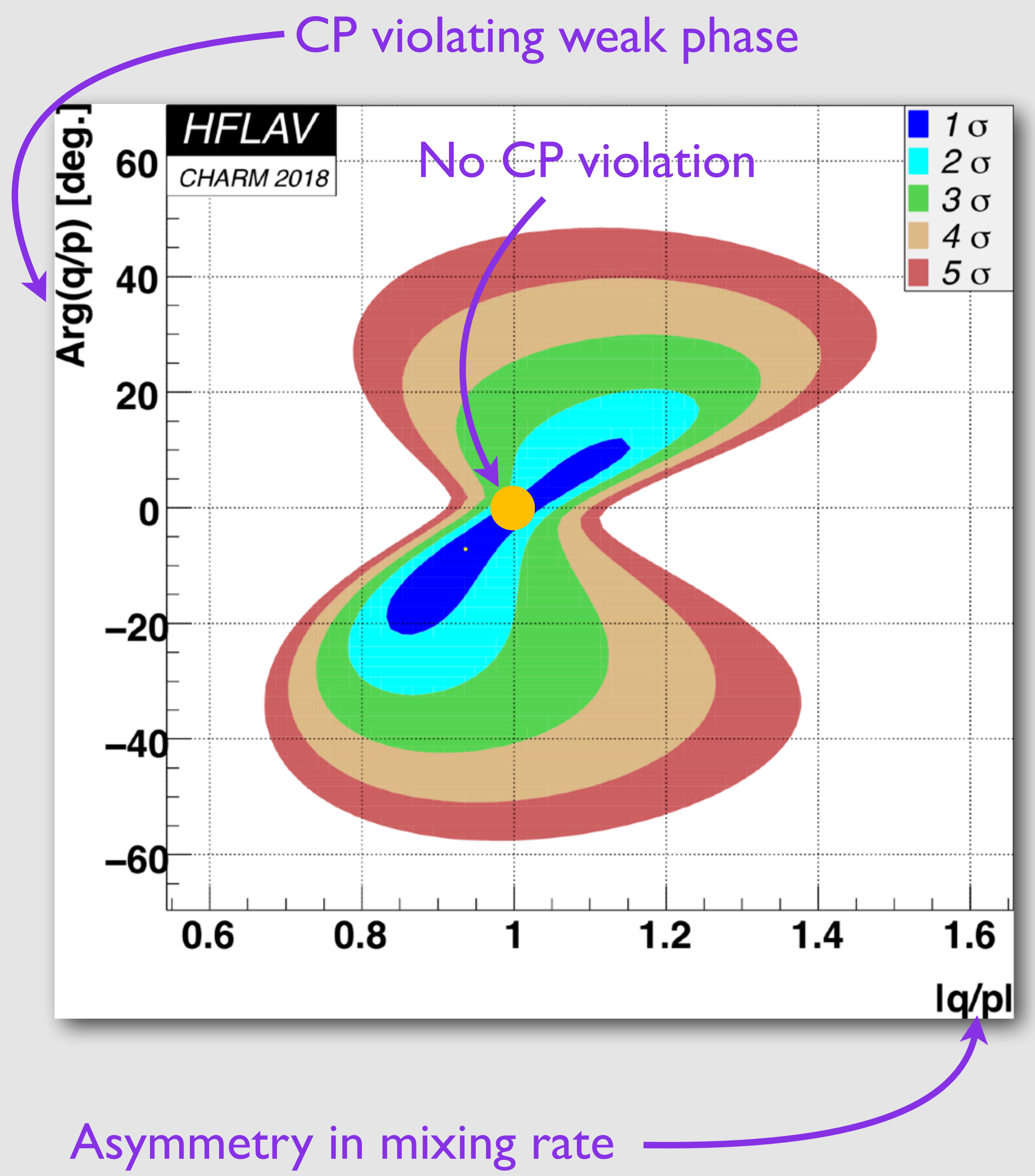
WS $K\pi$: symmetric in φ,

good sensitivity to |q/p| for small φ

Full average following intersection of contours

CP violation overview

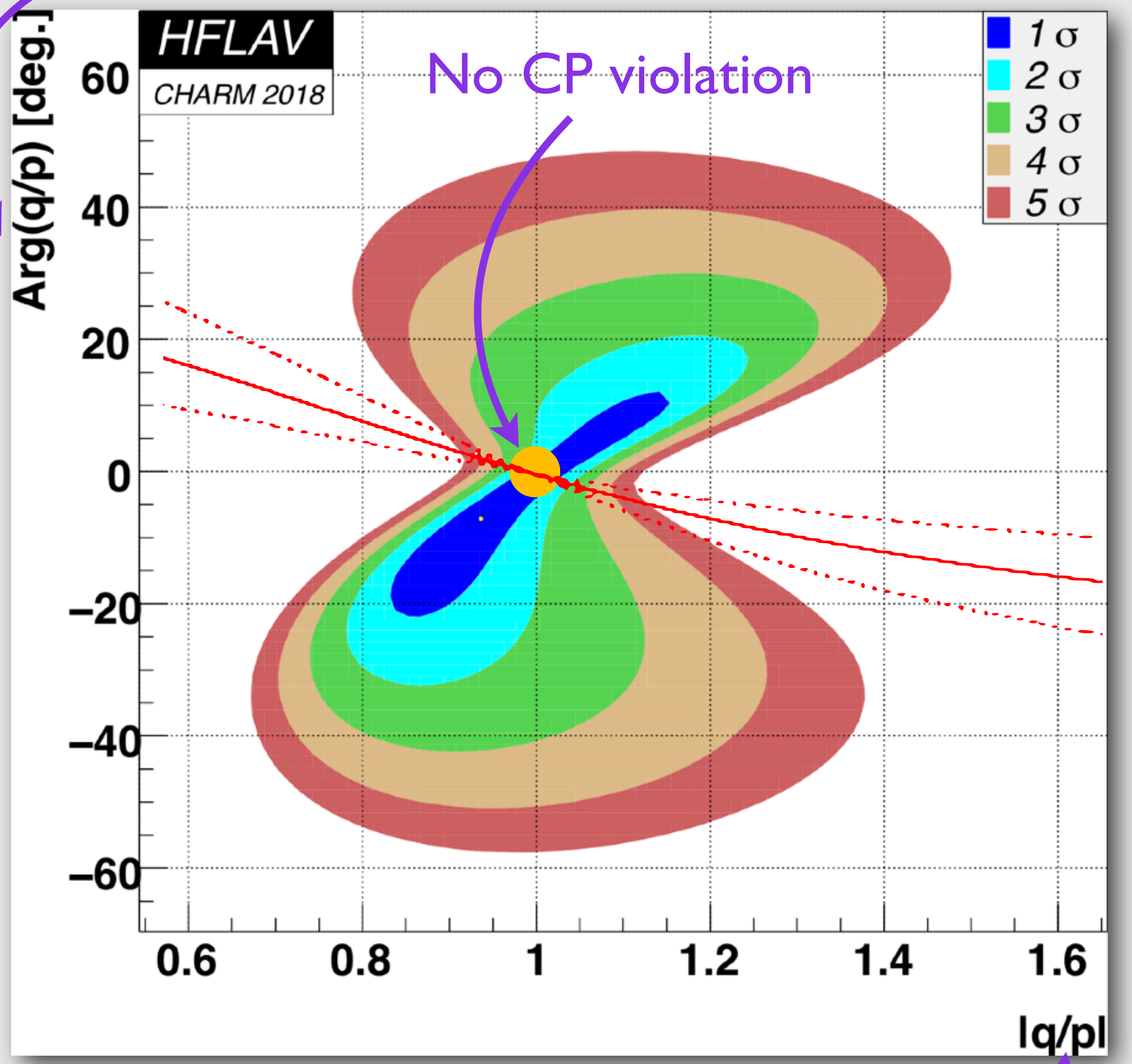
- No sign of CP violation
  …yet



Can we do better?

- Superweak constraint
  - ➡ Assumes no new decay-specific weak phase
  - ➡ Cuichini et al. (2007)
  - ➡ Kagan, Sokoloff (2009)
- Reducing to 3 parameters
  - ➡ $\tan\Phi \approx (1-|q/p|)x/y$
- Consider WS measurement with $\Phi \approx 0$
  - ➡ $y'^{\pm} = |q/p|^{\pm 1}(y' \cos\Phi \mp x' \sin\Phi)$
- Different parametrisation
  - ➡ $x_{12}, y_{12}, \Phi_{12}$
- Current sensitivity already very good
  - ➡ $\sigma(\Phi_{12}) = 1.7°$

CP violating weak phase



Asymmetry in mixing rate

Can we do better?

- Superweak constraint
  - ➡ Assumes no new decay-specific weak phase
  - ➡ Cuichini et al. (2007)
  - ➡ Kagan, Sokoloff (2009)
- Reducing to 3 parameters
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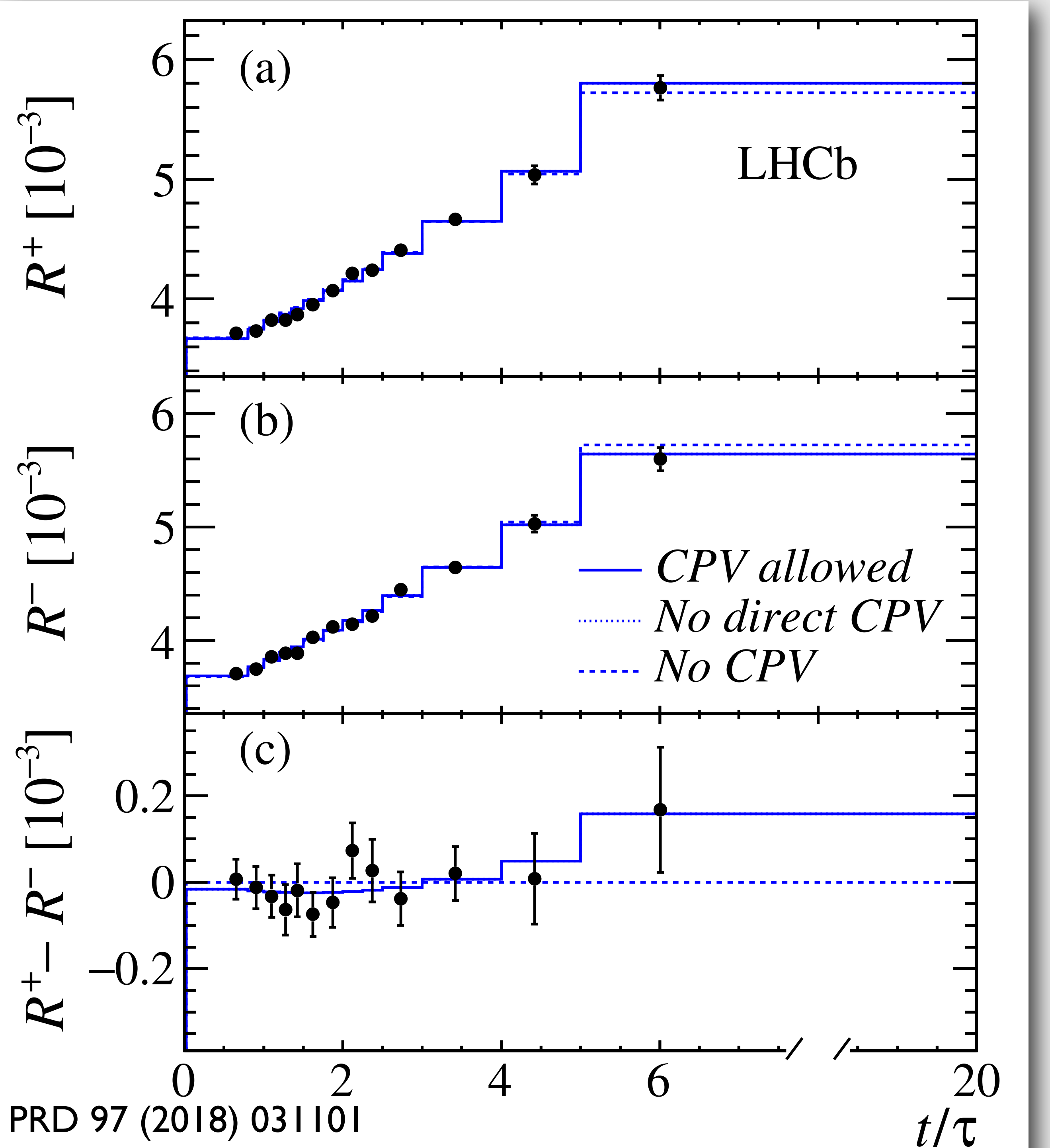
- Consider WS measurement with $\Phi \approx 0$
  - ➡ $y'^{\pm} = |q/p|^{\pm 1}(y' \cos\Phi \mp x' \sin\Phi)$
- Different parametrisation
  - ➡ $x_{12}, y_{12}, \Phi_{12}$
- Current sensitivity already very good
  - ➡ $\sigma(\Phi_{12}) = 1.7°$



PRD 97 (2018) 031101

Can we do better?

- Superweak constraint
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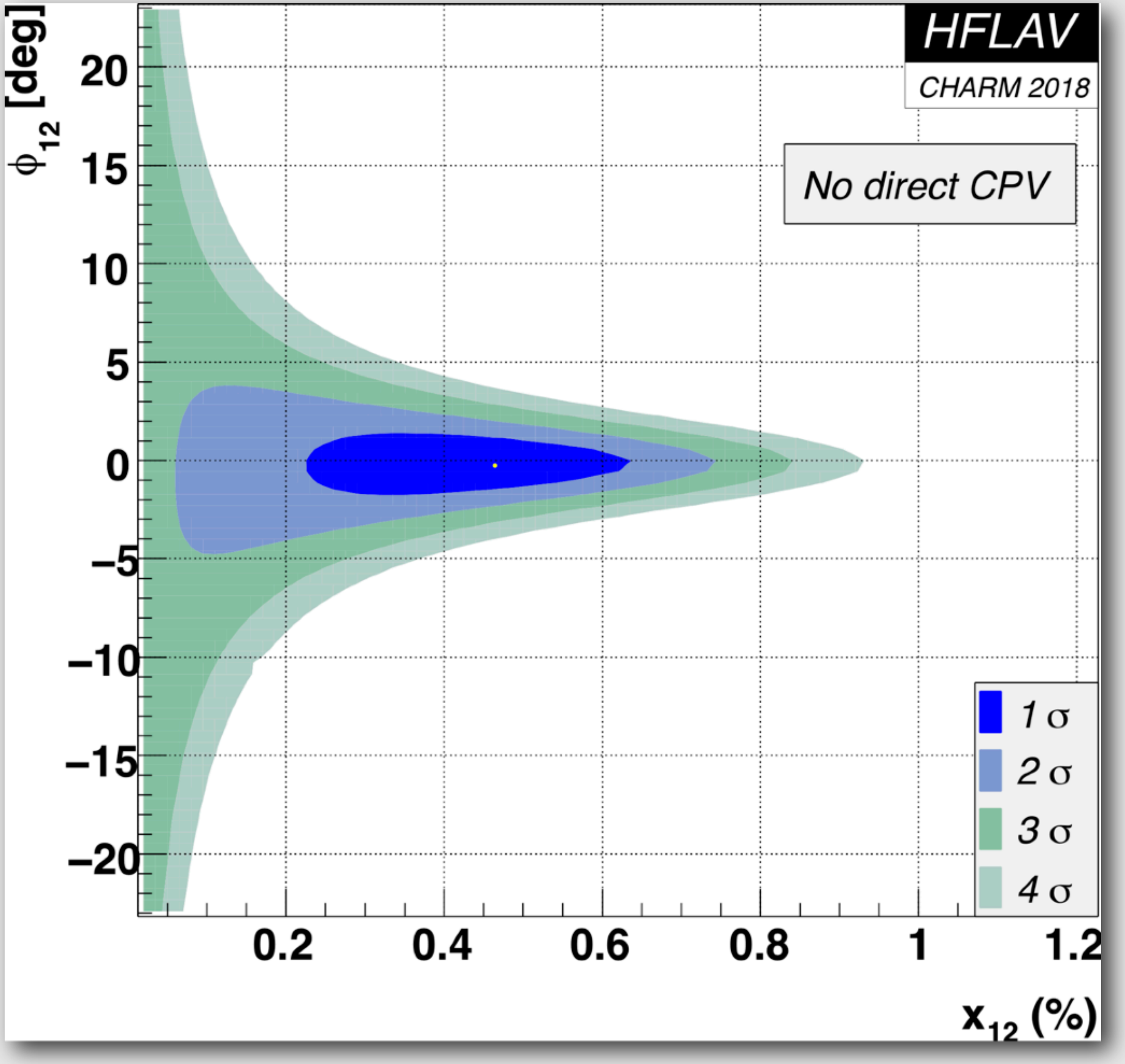
  - ➡ Kagan, Sokoloff (2009)
- Reducing to 3 parameters
  - ➡ $\tan\Phi \approx (1-|q/p|)x/y$
- Consider WS measurement with $\Phi \approx 0$
  - ➡ $y'^{\pm} = |q/p|^{\pm 1}(y' \cos\Phi \mp x' \sin\Phi)$
- Different parametrisation
  - ➡ x_{12}, y_{12}, Φ_{12}
- Current sensitivity already very good
  - ➡ $\sigma(\Phi_{12}) = 1.7°$



Mixing and indirect CPV

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- Mixing by now well established
  - ➡ y > 0: CP-even eigenstate is shorter lived than CP-odd
  - ➡ x > 0?: mass splitting not yet clear
- CP violation
  - ➡ Powerful constraints without hints for CPV
  - ➡ Now entering regime of BSM predictions
- Require combination of measurements to access theory parameters
- Super-weak constraint can help discover CP violation

Lecture 4

Lecture 4

- Introduction to direct CP violation
- Two-body
    - ➡ (D)ACP
    - ➡ Sum rules