Quo vadis charm physics?

Marco Gersabeck
(The University of Manchester)

Heavy Flavour 2016, Ardbeg, 14 July 2016

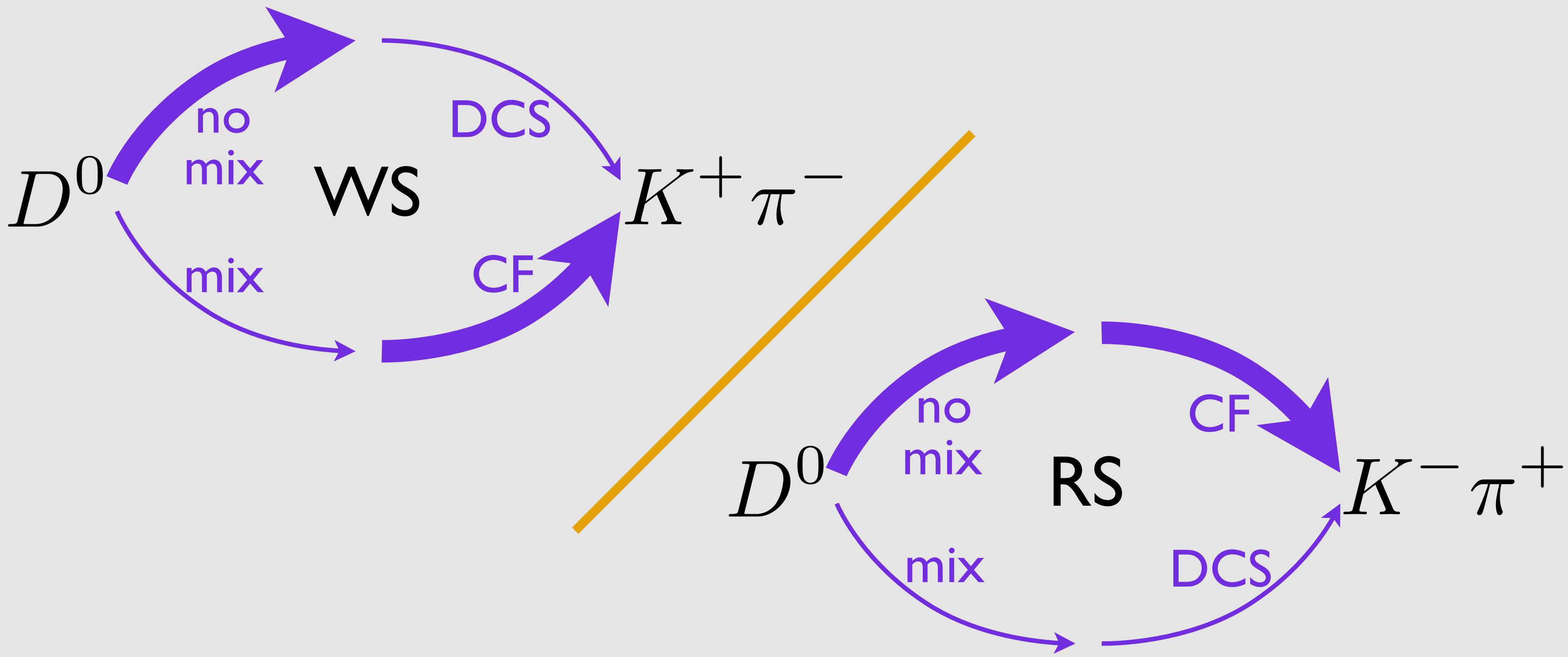
MANCHESTER 1824
The University of Manchester

Outline

- Mixing
- Indirect CPV
- Direct CPV
- Rare decays

Mixing discovery

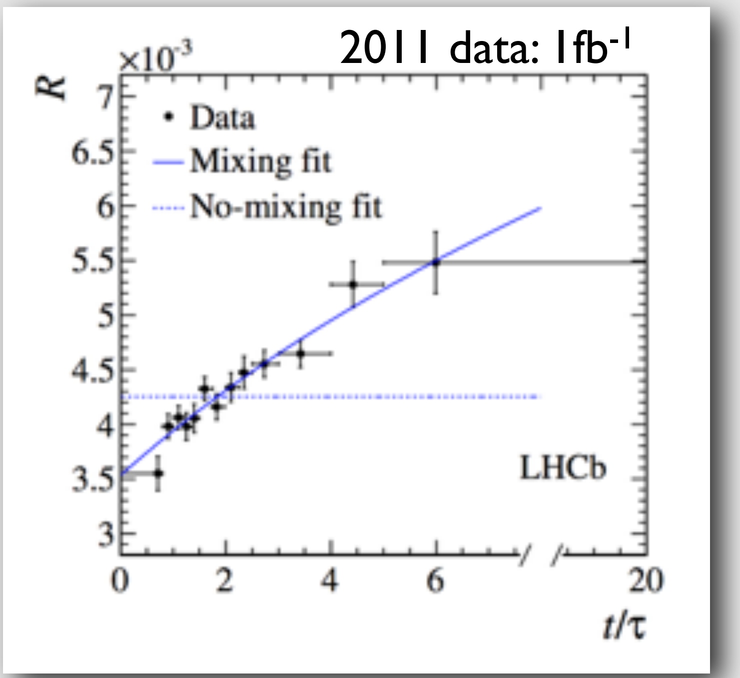
PRL 110 (2013) 101802



Using roughly 8.4×10^6 RS and 3.6×10^4 WS candidates

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

- Mixing established with 2007 B-factory measurements
- Here: first single-experiment measurement with >5σ
- Rotation of mixing parameters by strong phase difference between CF and DCS amplitudes: x,y → x',y'

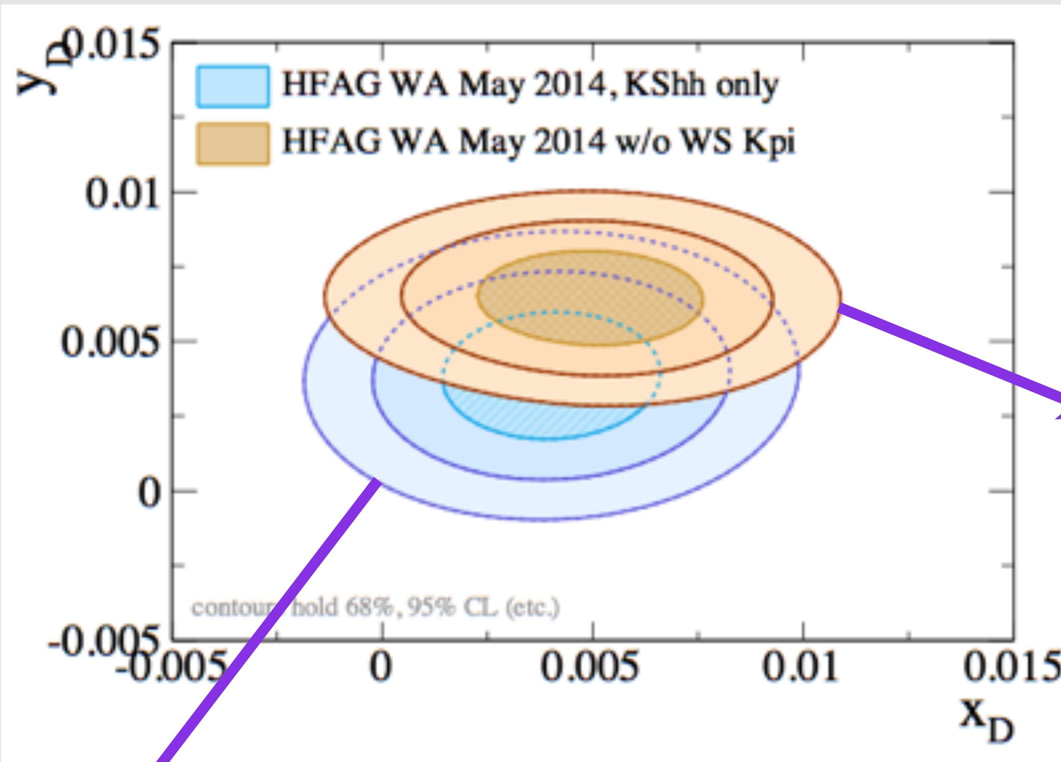


The University of Manchester

On strong phases

- Measurements of strong phases are only possible with quantum-entangled charm states
  - ➡ $\psi(3770) \to D\bar{D}$
- Only running experiment
  - ➡ BESIII at BEPC collider in Beijing
- Essential input to exploit large LHCb charm samples fully
  - ➡ Need best possible sensitivity to measure tiny effects in charm

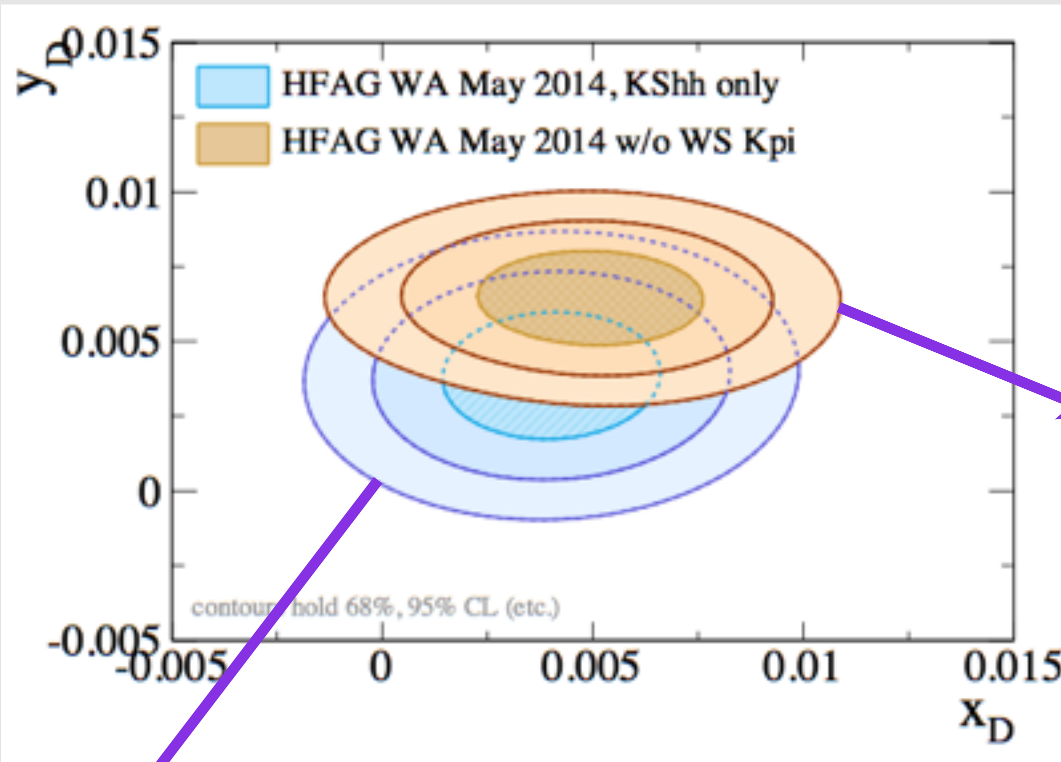
World average decoded



Adding y_{CP} mostly constrains y

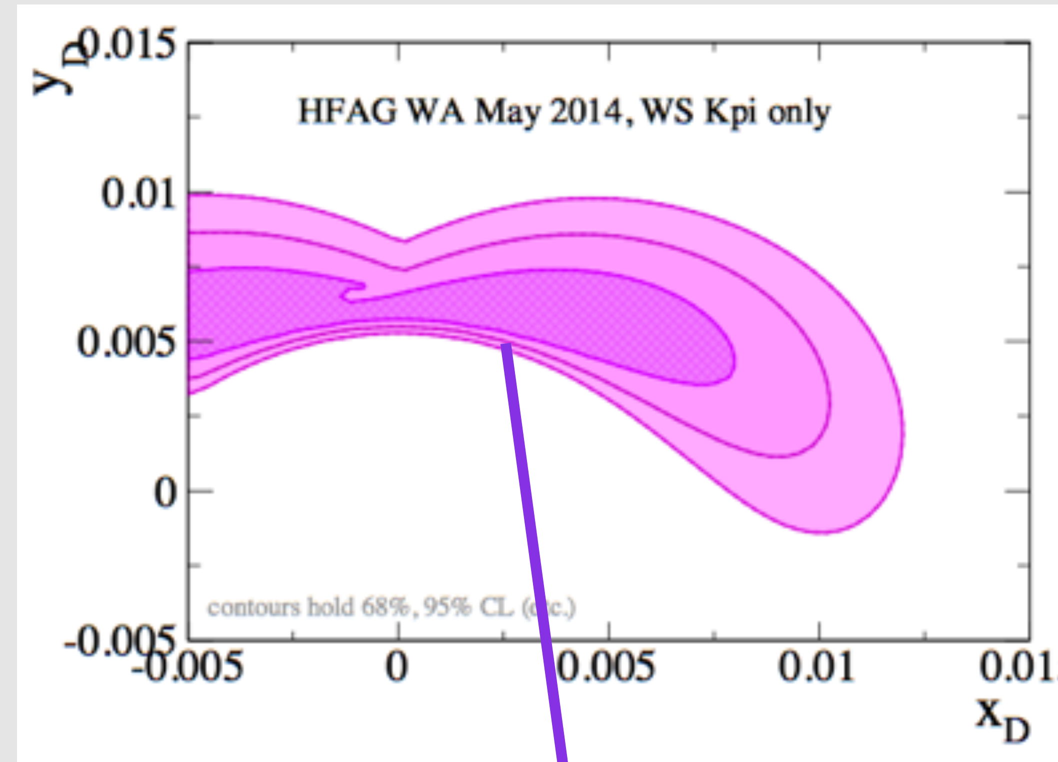
x & y measured directly

World average decoded



Adding y_{CP} mostly constrains y

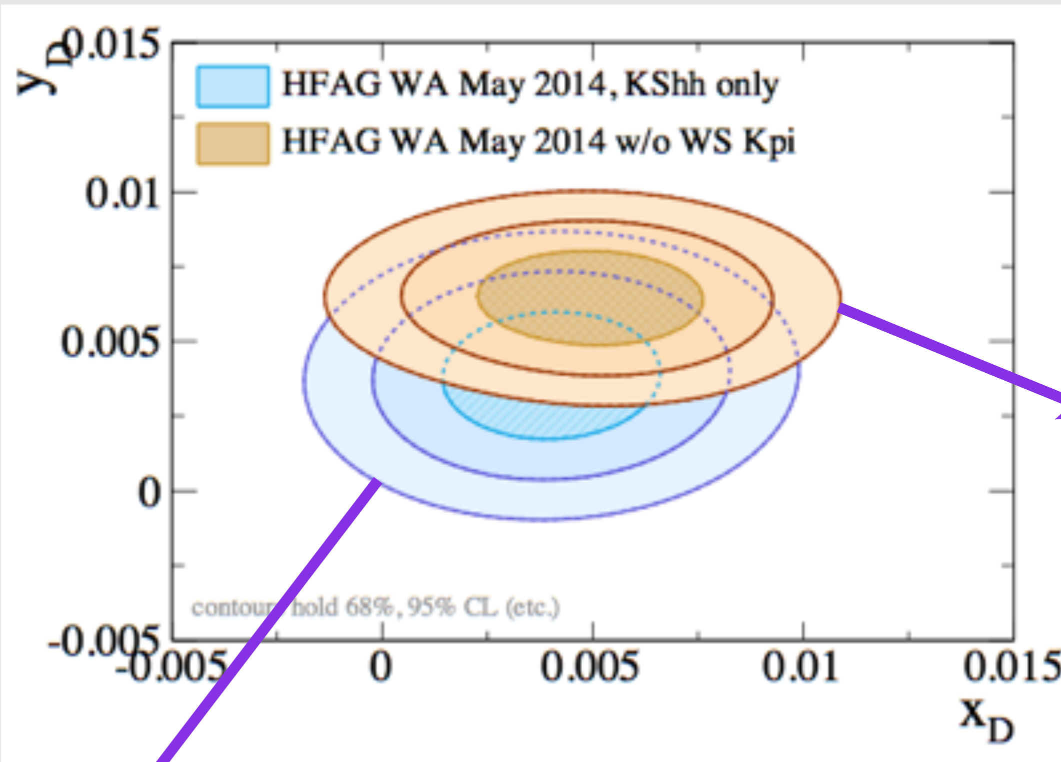
x & y measured directly

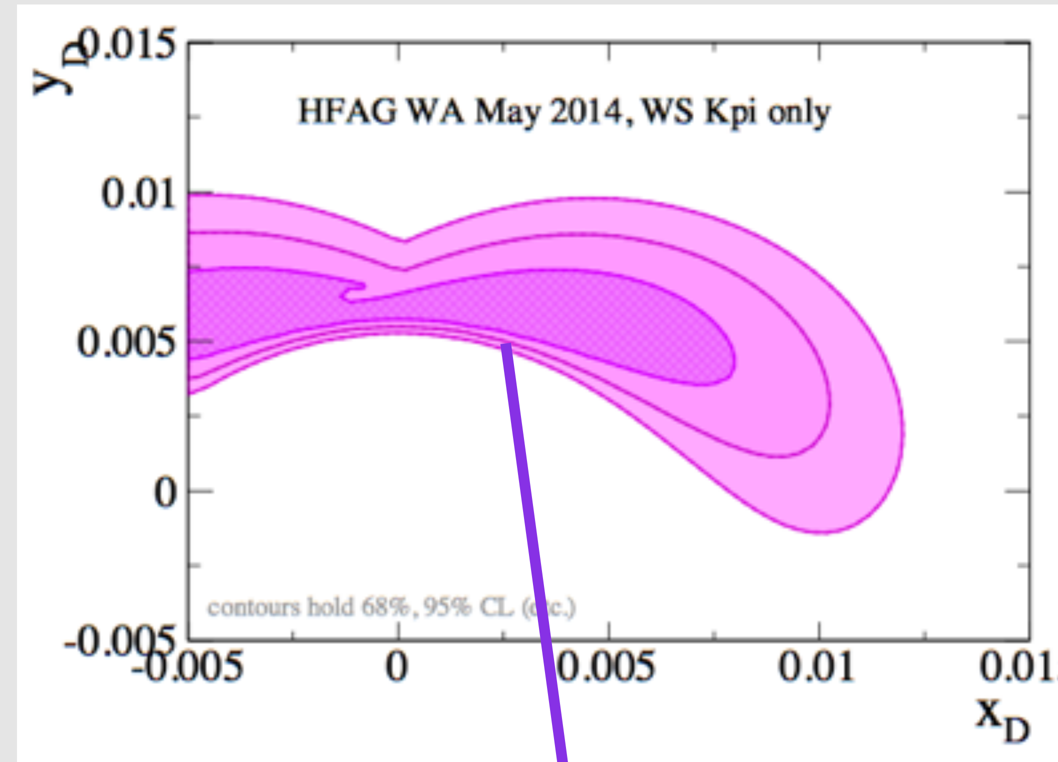


x^2+y^2 measures a ring

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

World average decoded

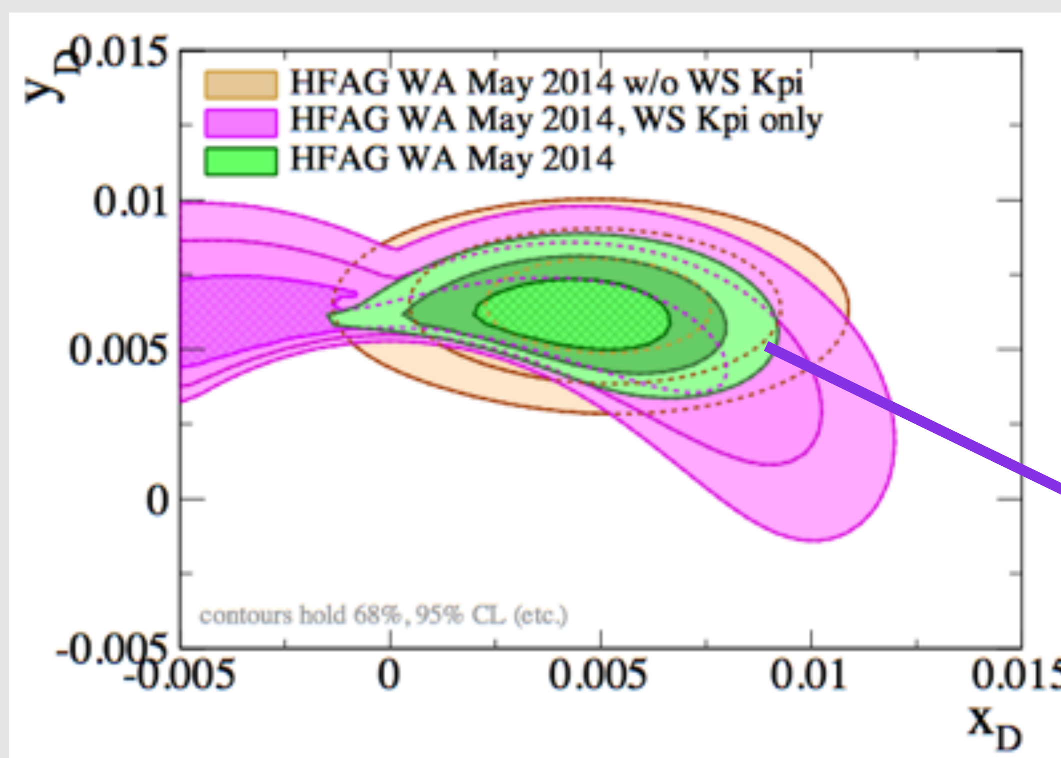




Adding y_{CP} mostly constrains y

x & y measured directly

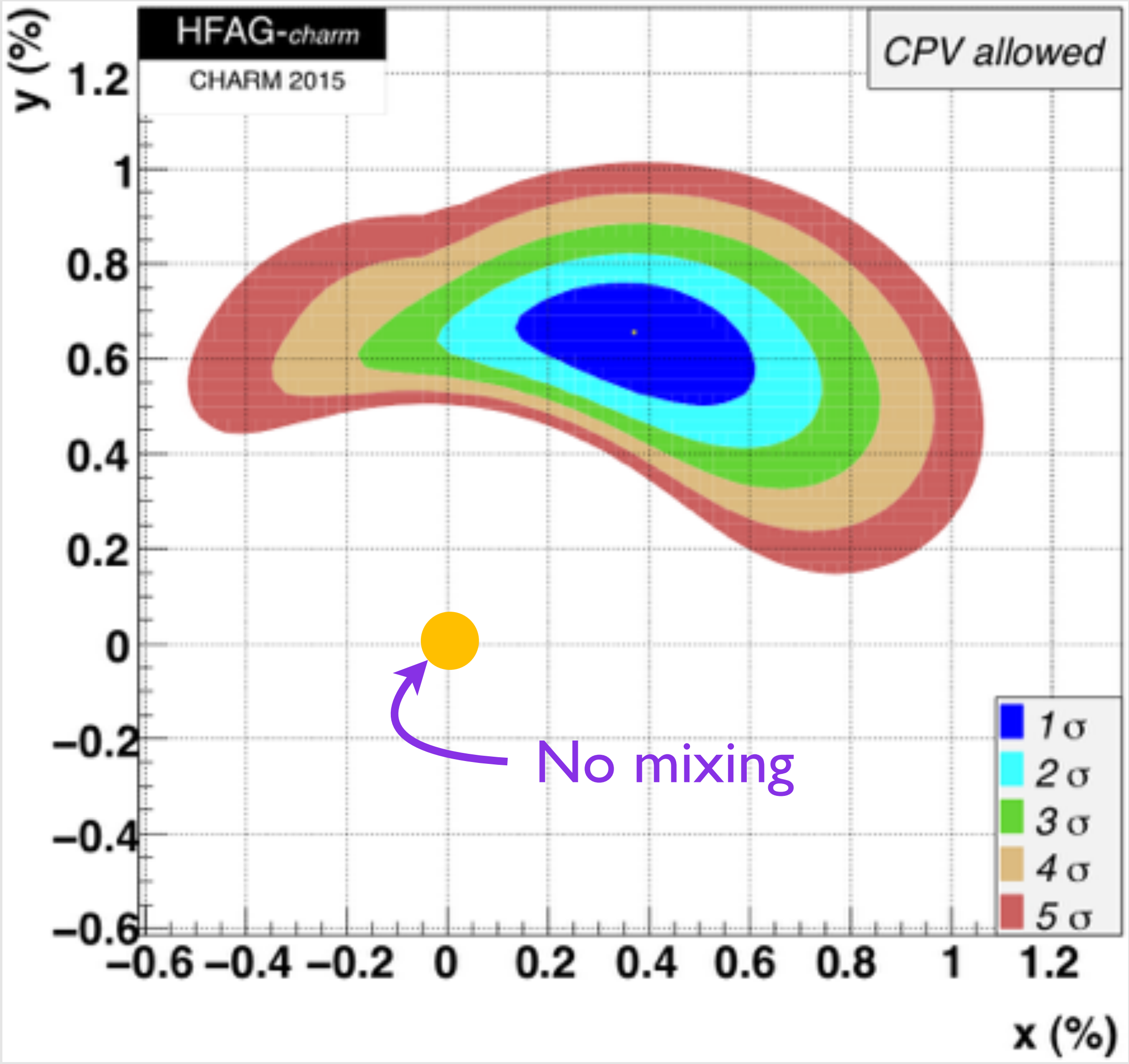
x^2+y^2 measures a ring
y′ mostly adds information on y ($\delta_{K\pi}$ near 0)



Full average following intersection of contours

MANCHESTER 1824
The University of Manchester

Mixing overview



- Mixing established
  - ➡ x still unknown

The University of Manchester

Theory

- What are we measuring here?
- No precise theory prediction in sight
- Dearly missing: Lattice input
  - ➡ Martinelli @ June 2016 LHCb week: Working on mixing with $D^0 \to \leq 3$-body
  - ➡ Full predictions are extremely challenging
  - ➡ Need to ensure predictions are available when Belle-II & LHCb upgrade results come in around early/mid 2020s

Mixing-related CP violation

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

Mixing:

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

$y \equiv (\Gamma_2 - \Gamma_1)/2\Gamma$

CP violation:

$|q/p| \neq 0$

$\phi \equiv \arg(q/p) \neq 0, \pi$

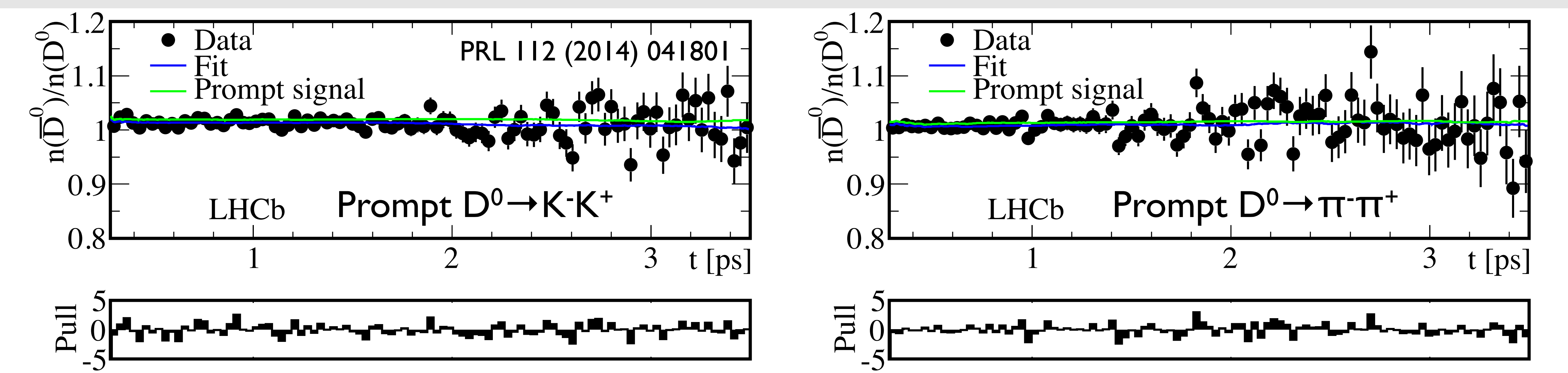
Indirect CP violation:

$$a_{CP}^{ind} = -a_m \, y \cos\phi - x \sin\phi$$

$$\text{with } a_m \approx \pm(|{}^q/{}_p|^2 - 1)$$

Indirect CP violation

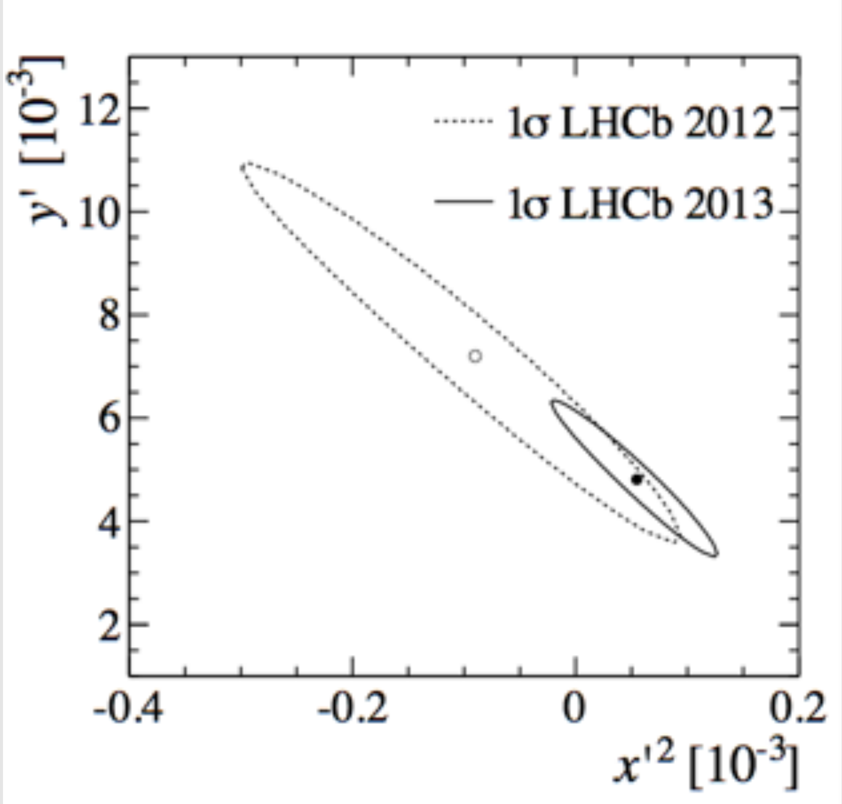
- Measurements based on $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decays
- Measure asymmetries of effective lifetimes of decays to CP eigenstates:
  - ➡ $A_\Gamma \approx a_m\, y \cos\phi + x \sin\phi \equiv -a_{CP}^{ind}$
- Measures ability of both mass eigenstates to decay to CP eigenstate
- Prompt D^{*+}-tagged, 1fb^{-1} [PRL 112 (2014) 041801]
  - ➡ $A_\Gamma(KK) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3}$; $A_\Gamma(\pi\pi) = (0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$
- D from semi-leptonic B decays, μ^+-tagged, 3 fb^{-1} [JHEP 04 (2015) 043]
  - ➡ $A_\Gamma(KK) = (-1.34 \pm 0.77 \pm 0.30) \times 10^{-3}$; $A_\Gamma(\pi\pi) = (-0.92 \pm 1.45 \pm 0.29) \times 10^{-3}$



CP violation with DCS

PRL 111 (2013) 251801

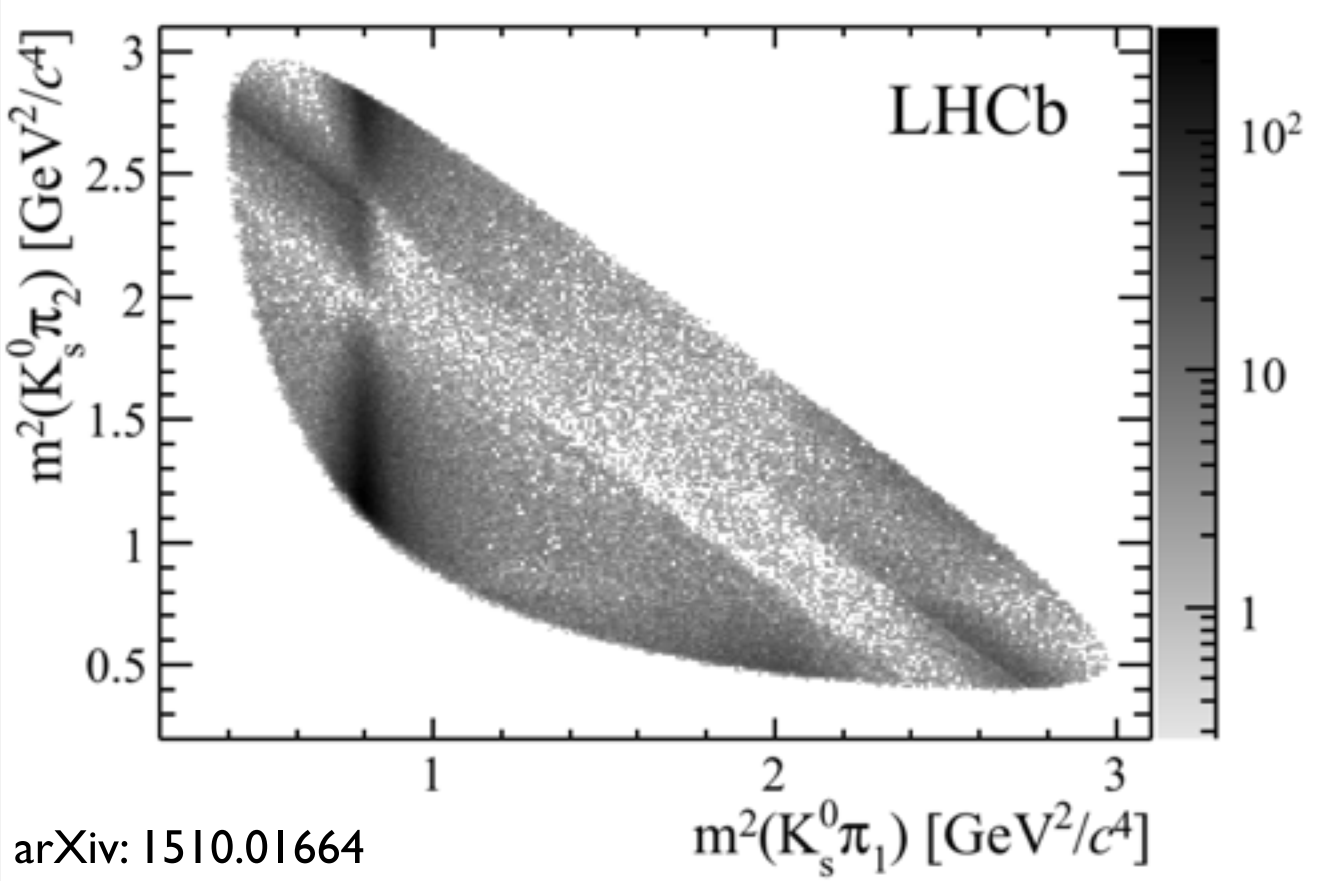
- D→Kπ again
- Update with 3 fb^{-1}
- Split by flavour to search for CP violation
  - ➡ $x'^{\pm}=|q/p|^{\pm 1}(x' \cos\Phi \pm y' \sin\Phi)$
  - ➡ $y'^{\pm}=|q/p|^{\pm 1}(y' \cos\Phi \mp x' \sin\Phi)$
- Very good sensitivity to |q/p| for small ϕ
- No indication for CP violation



R_D^+	$[10^{-3}]$	$3.545 \pm 0.082 \pm 0.048$
y'^+	$[10^{-3}]$	$5.1 \pm 1.2 \pm 0.7$
x'^{2+}	$[10^{-5}]$	$4.9 \pm 6.0 \pm 3.6$
R_D^-	$[10^{-3}]$	$3.591 \pm 0.081 \pm 0.048$
y'^-	$[10^{-3}]$	$4.5 \pm 1.2 \pm 0.7$
x'^{2-}	$[10^{-5}]$	$6.0 \pm 5.8 \pm 3.6$

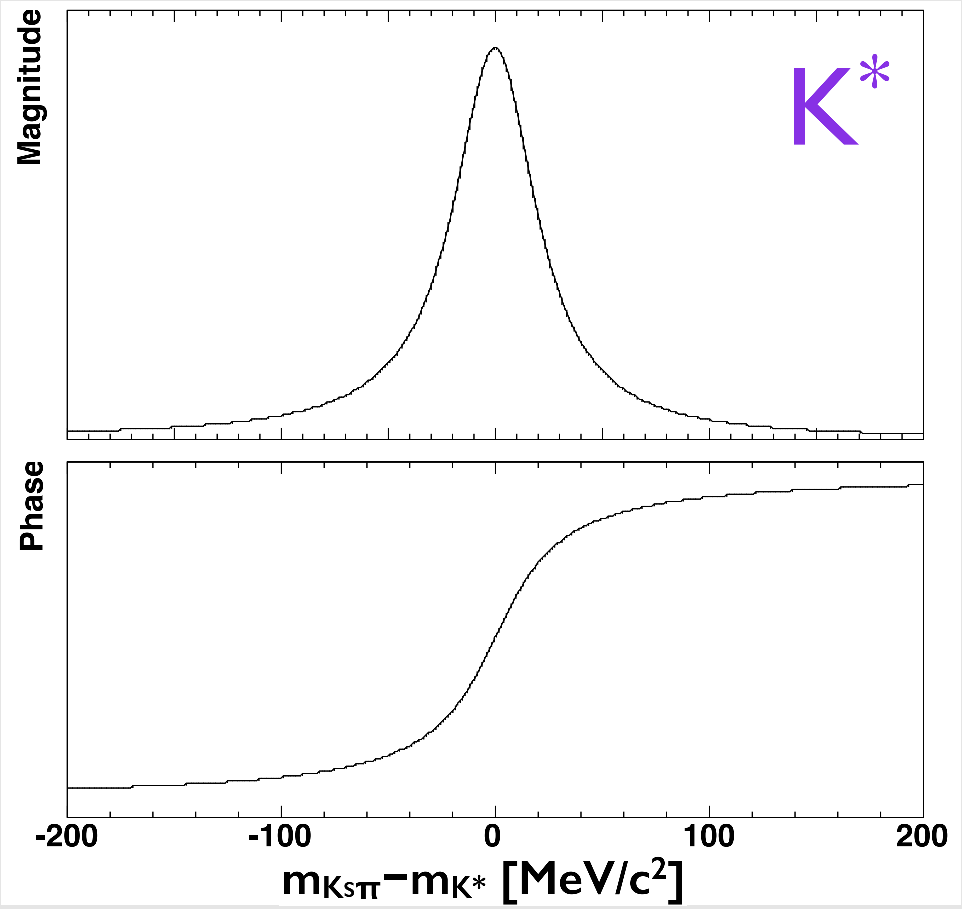
Dalitz plots

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

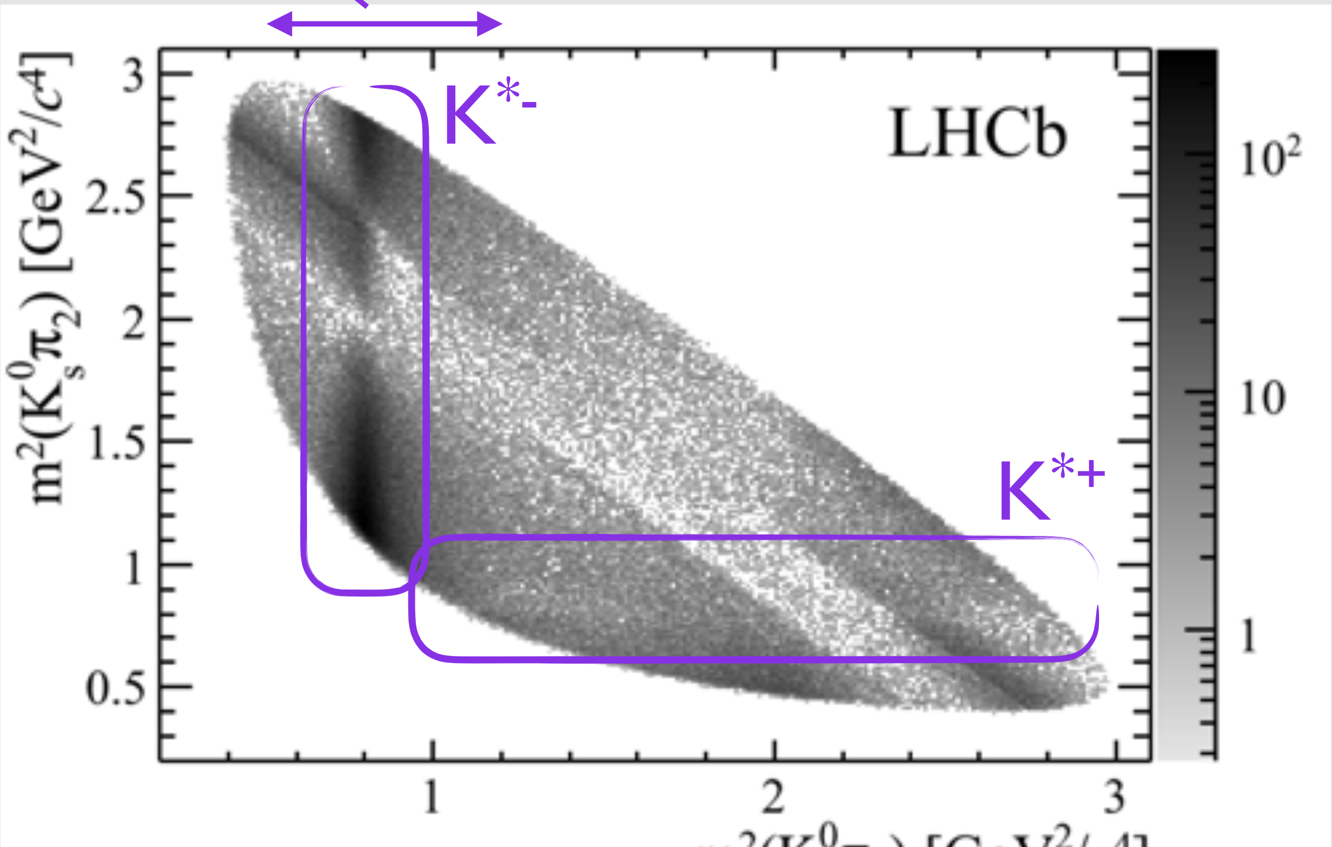


arXiv: 1510.01664

Dalitz plots



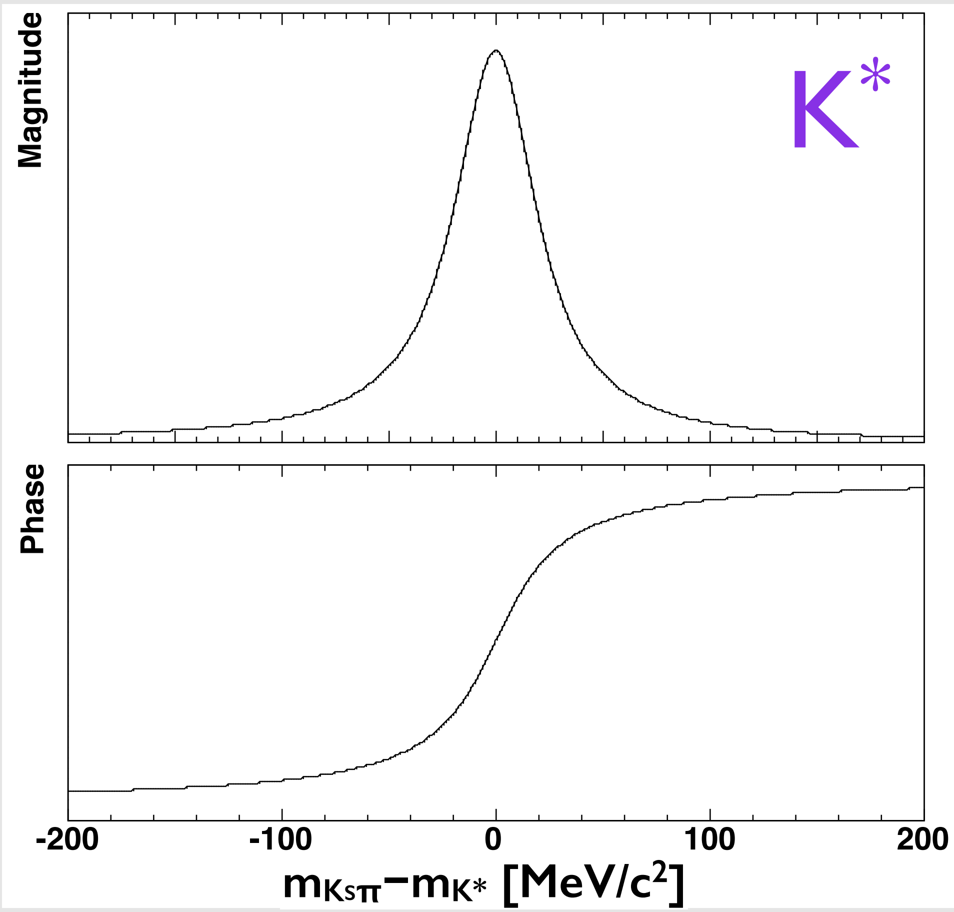
$D^0 \rightarrow K_S\pi^-\pi^+$



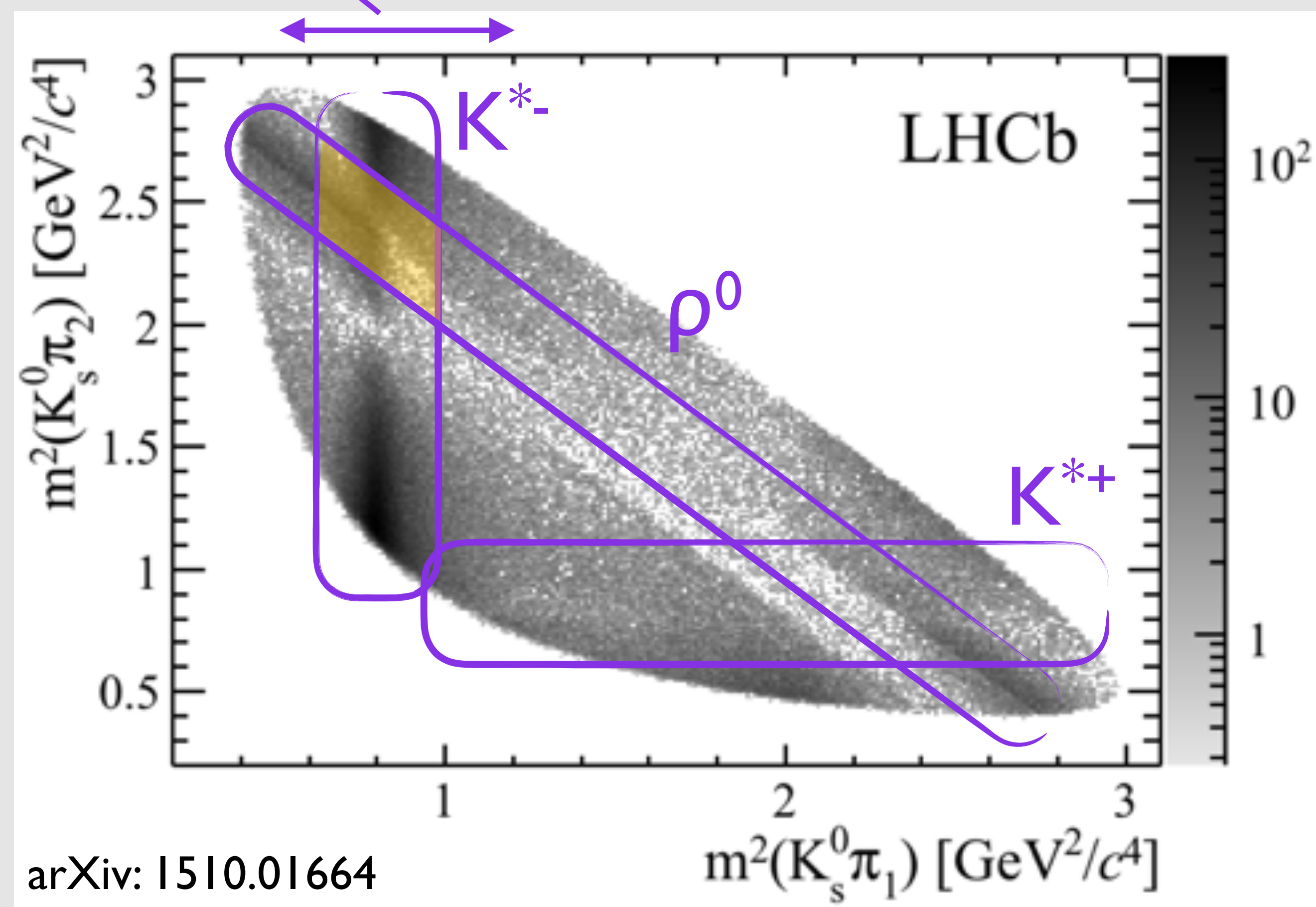
arXiv: 1510.01664

Dalitz plots

MANCHESTER 1824
The University of Manchester



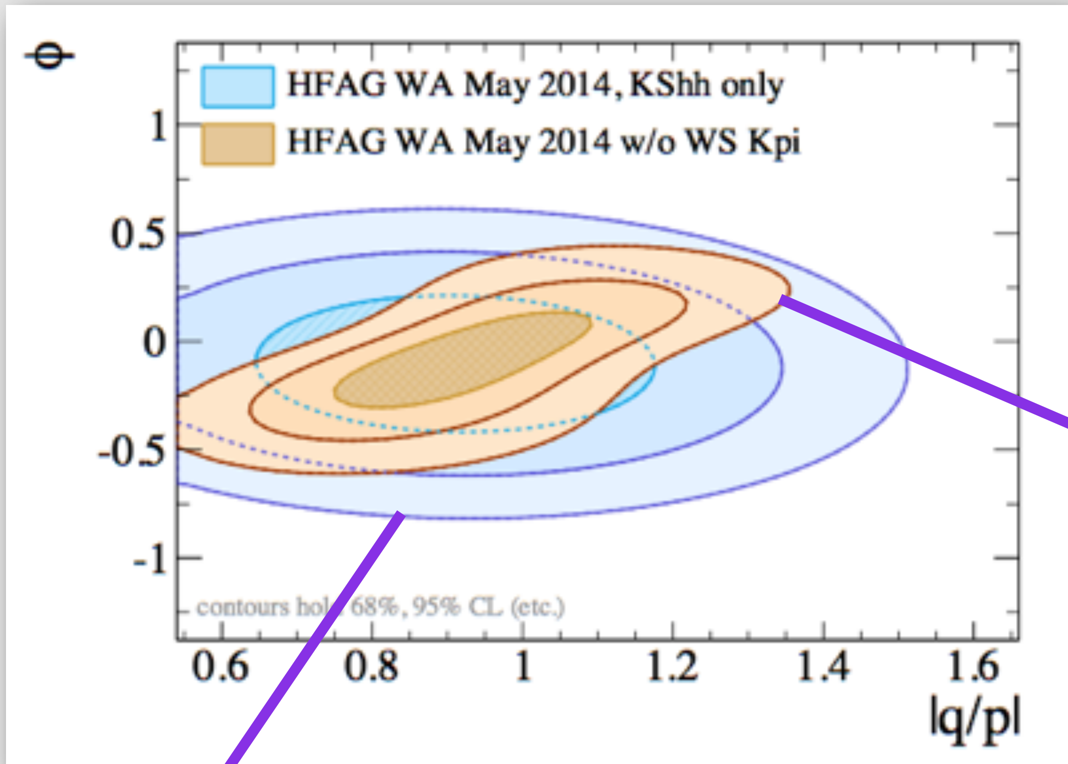
$D^0 \rightarrow K_S \pi^- \pi^+$



- Dalitz plot is a sum of complex amplitudes $A_{tot} = \sum A_r$, with r summing over resonances
- Interference regions contain rapid phase variation
- Mixing sensitivity e.g. through $K^{*+}\pi^-$ and $K^{*-}\pi^+$ resonances

- CP violation requires non-zero strong phases
  - ➡ Plenty phase variation available
- Direct access to x, y, |q/p|, ϕ
  - ➡ Decay-time dependent Dalitz plot analysis
- Run 1 results expected soon

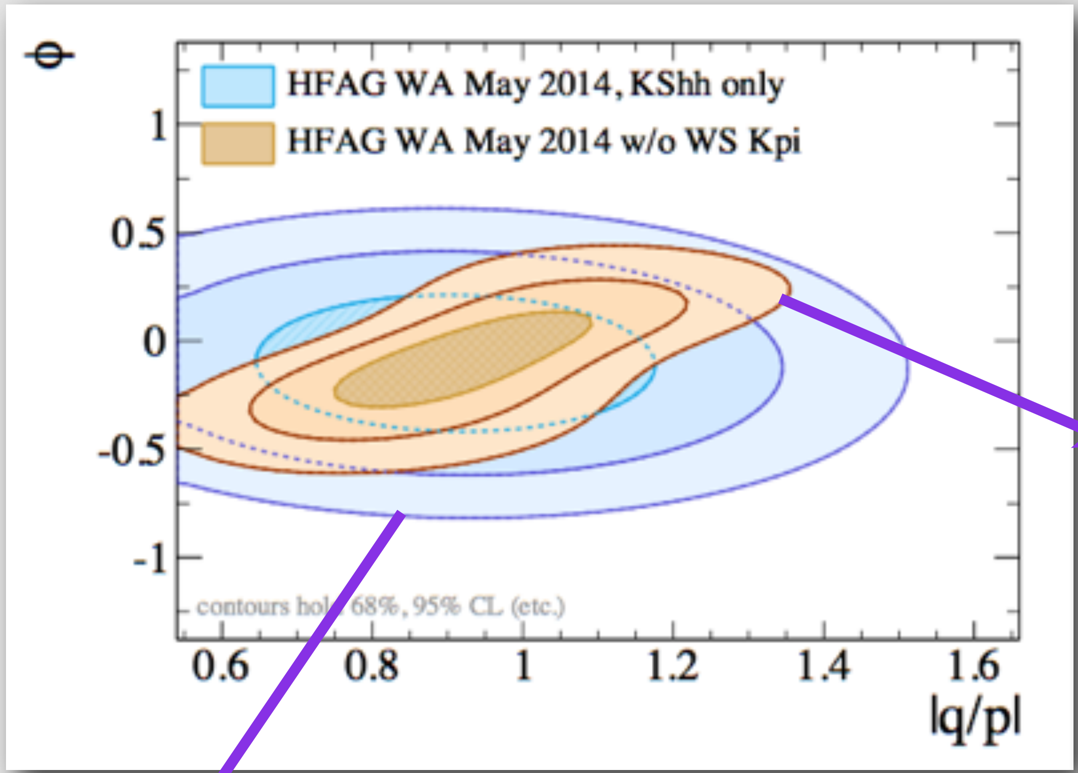
Contributions

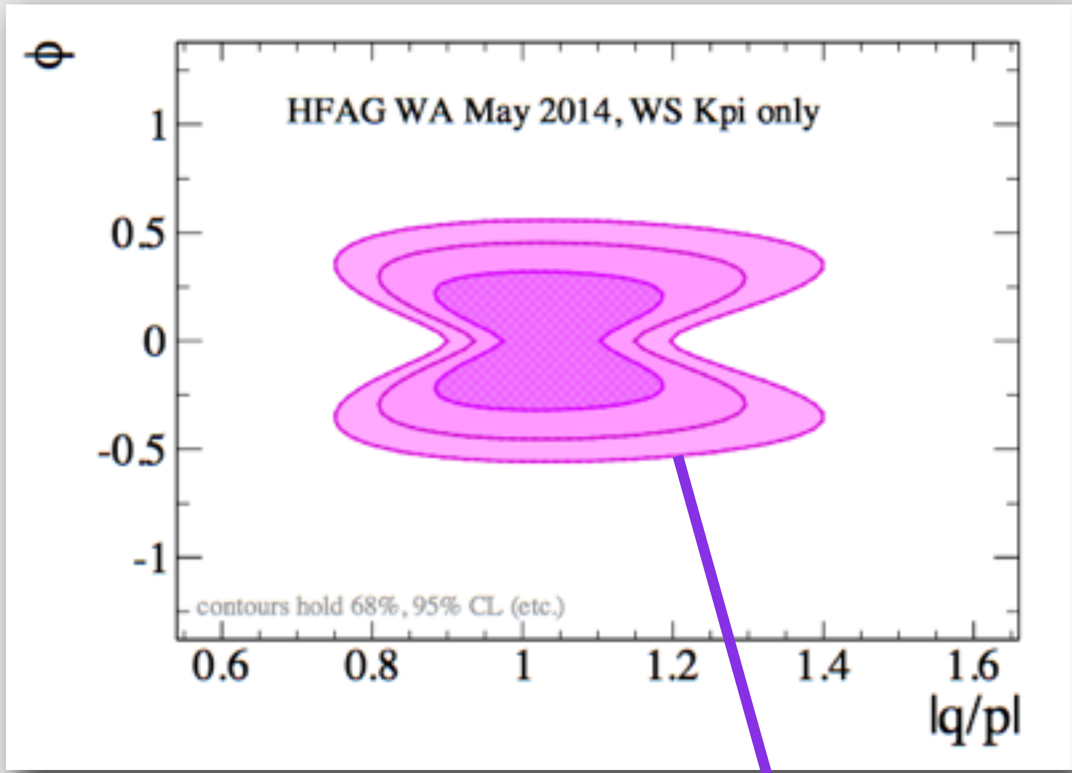


Precise constraints if x and y provided, mostly from A_Γ

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

Contributions





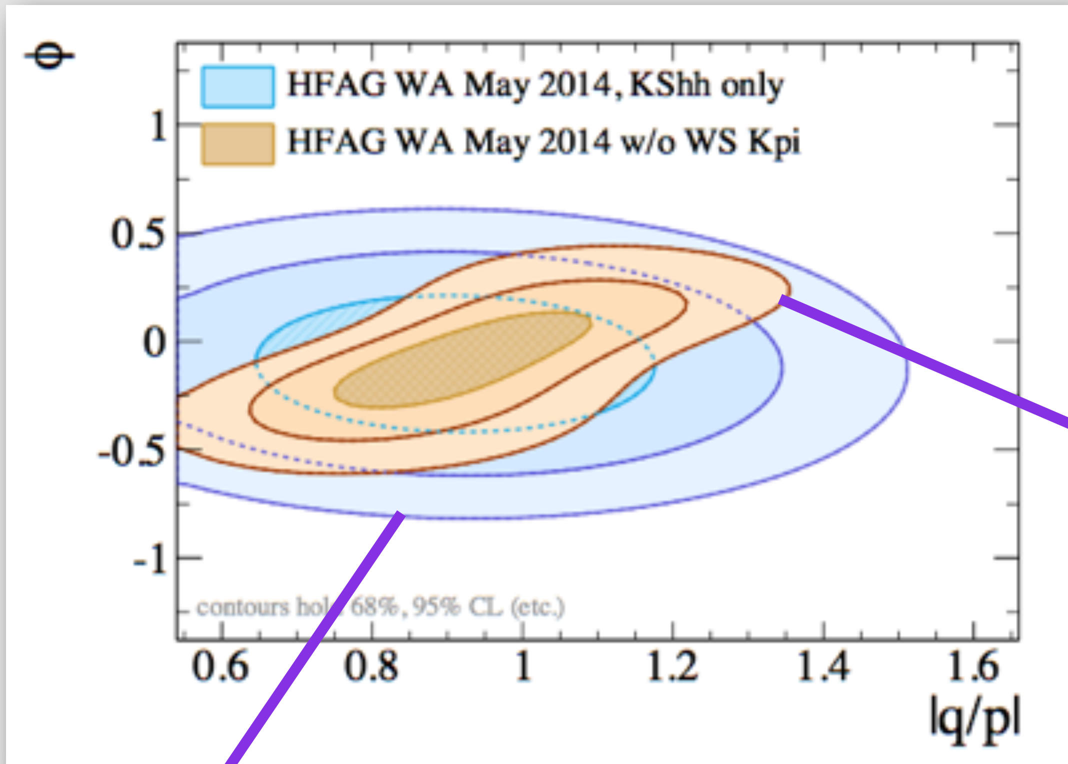
Precise constraints if x and y provided, mostly from A_Γ

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

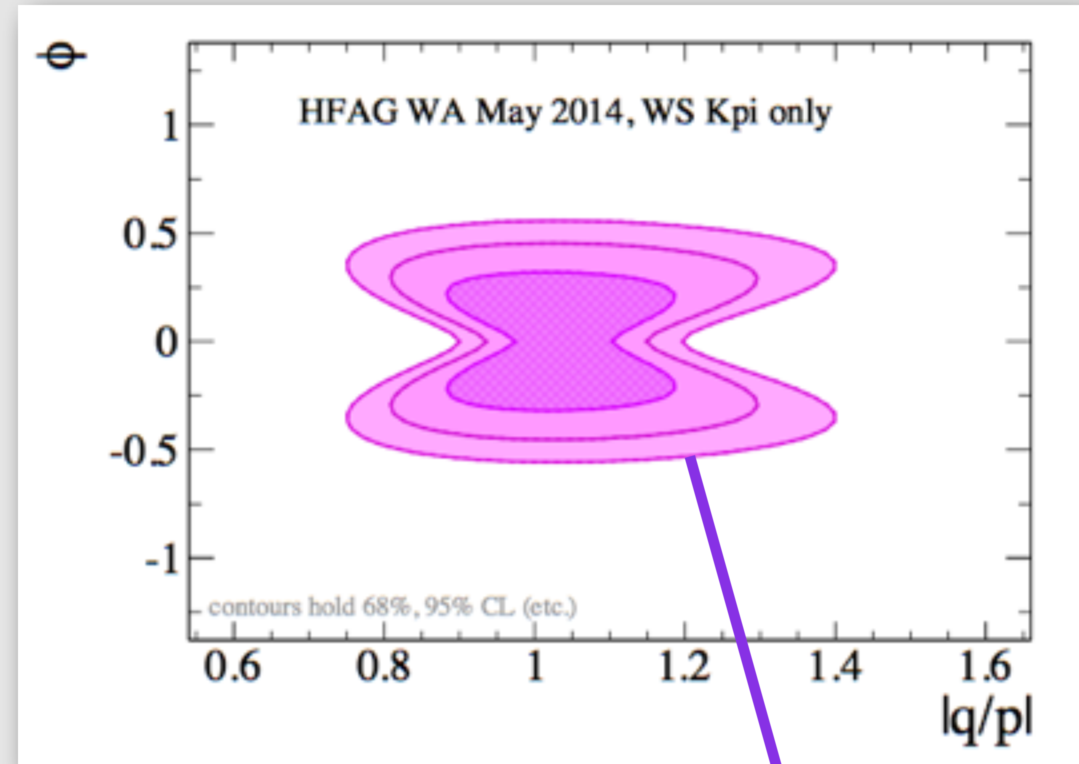
WS Kπ: symmetric in φ, good sensitivity to |q/p| for small φ

MANCHESTER 1824
The University of Manchester

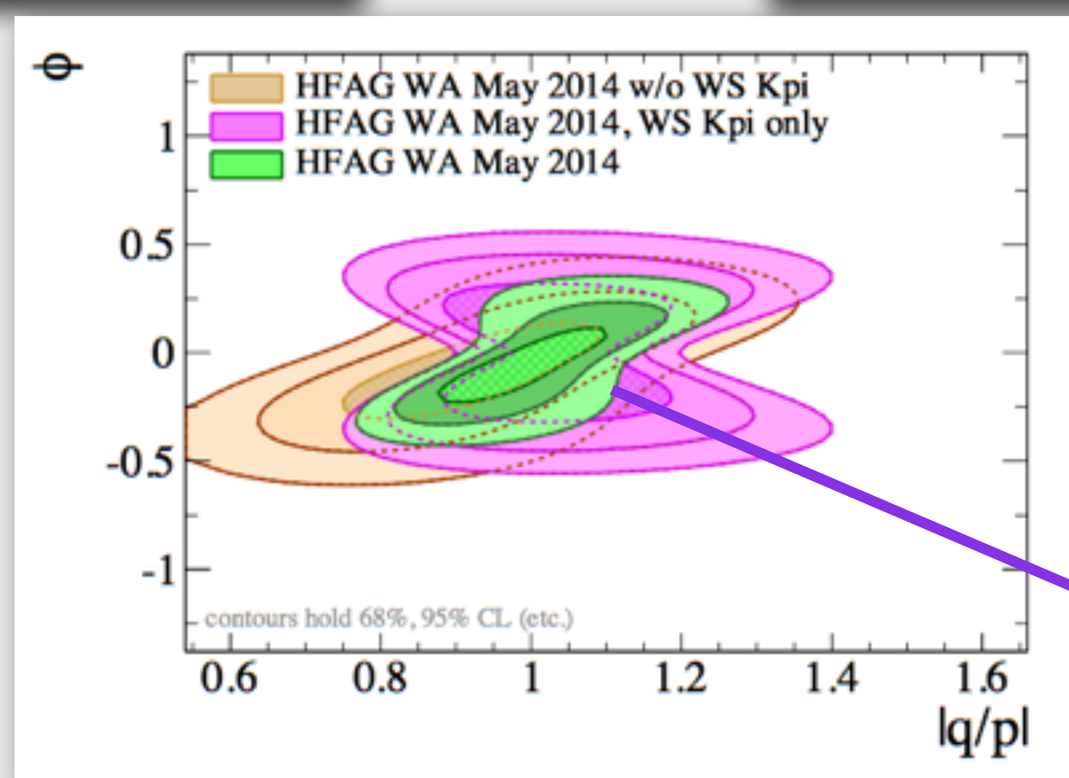
Contributions



Precise constraints if x and y provided, mostly from A_Γ



Direct access to |q/p| and φ from K_Shh



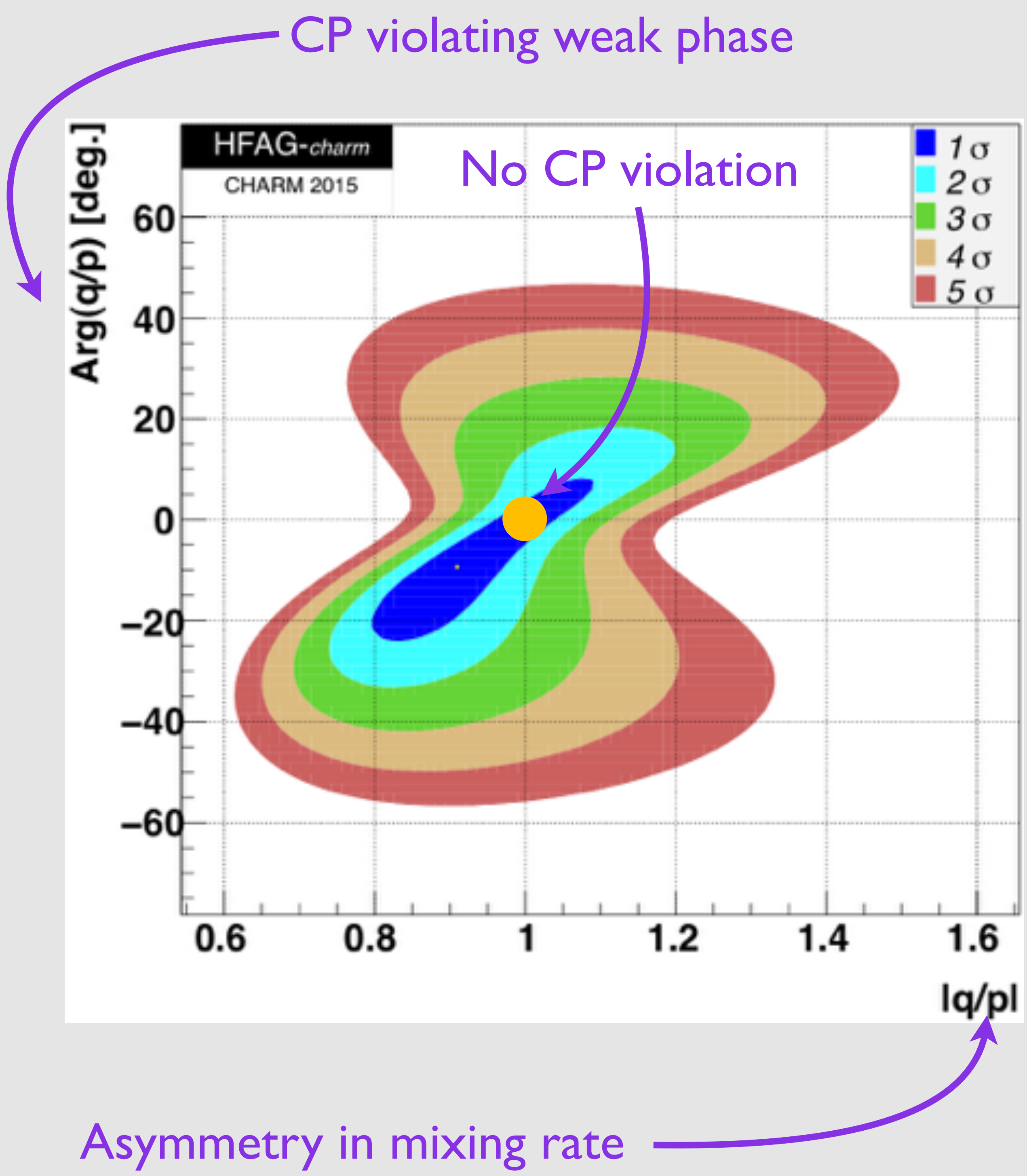
WS Kπ: symmetric in φ,

good sensitivity to |q/p| for small φ

Full average following intersection of contours

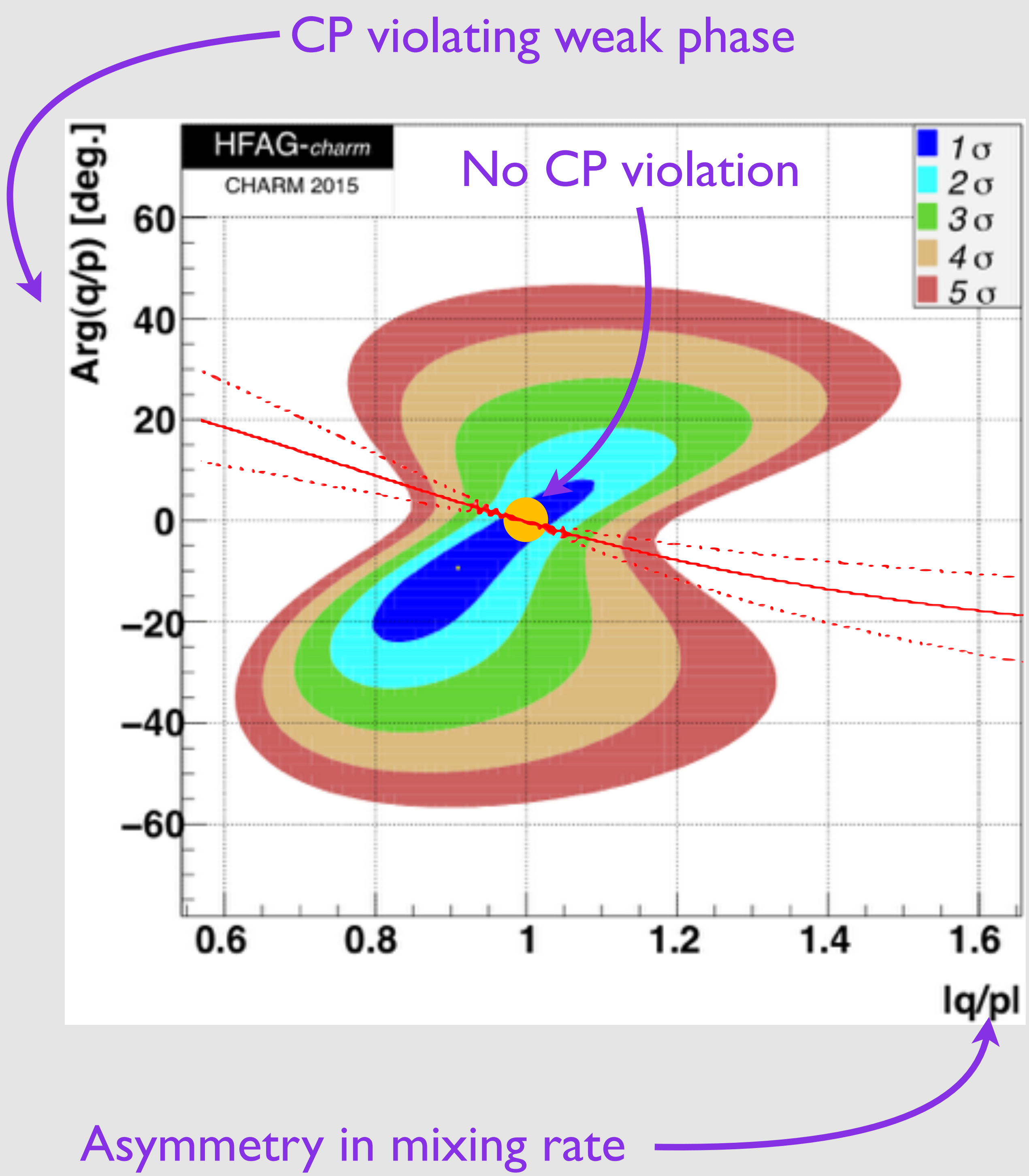
CP violation overview

- No sign of CP violation



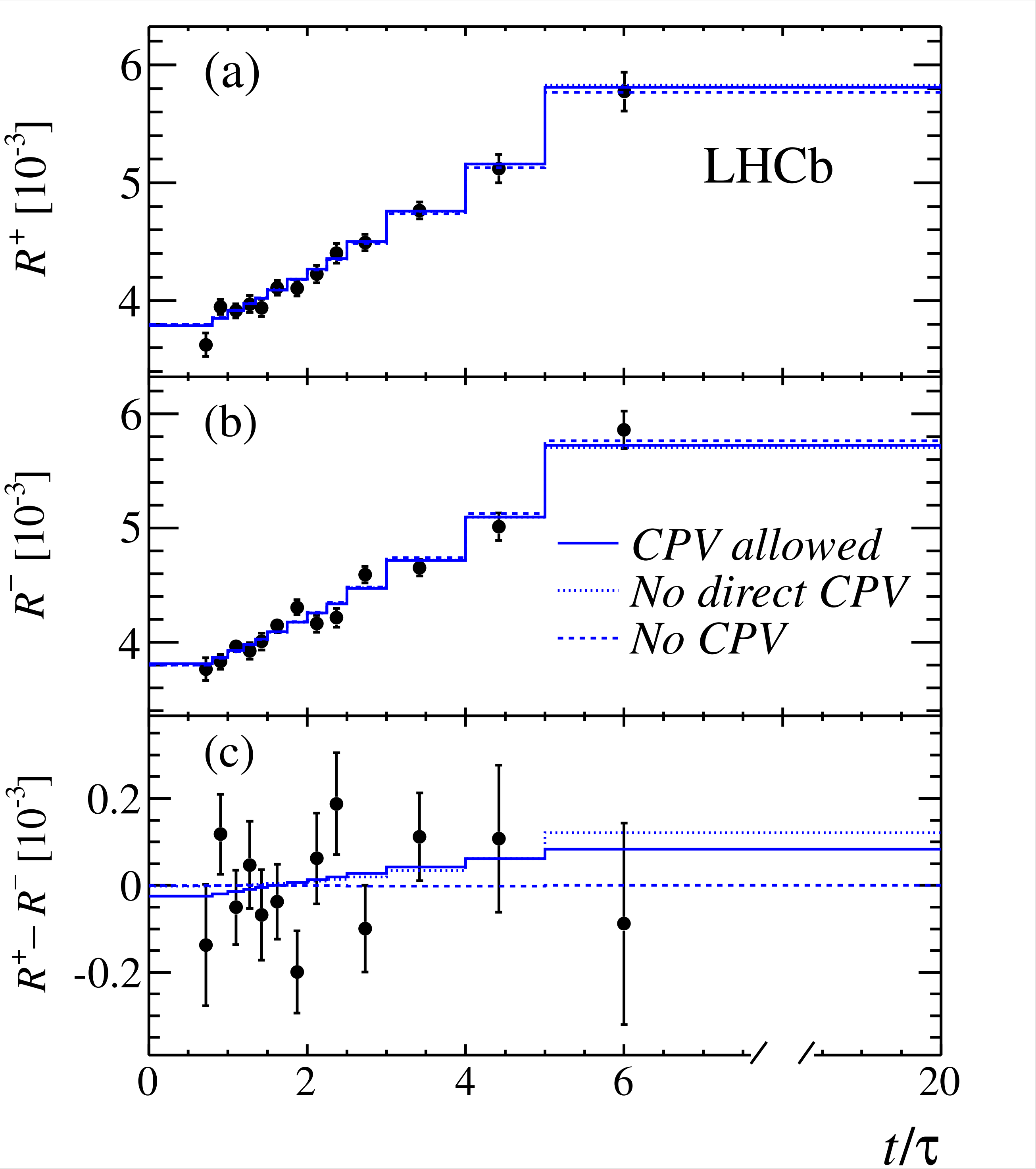
Can we do better?

- Superweak constraint
  - ➡ Assumes no new 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
  - ➡ $\sigma(\Phi_{12}) = 1.7°$



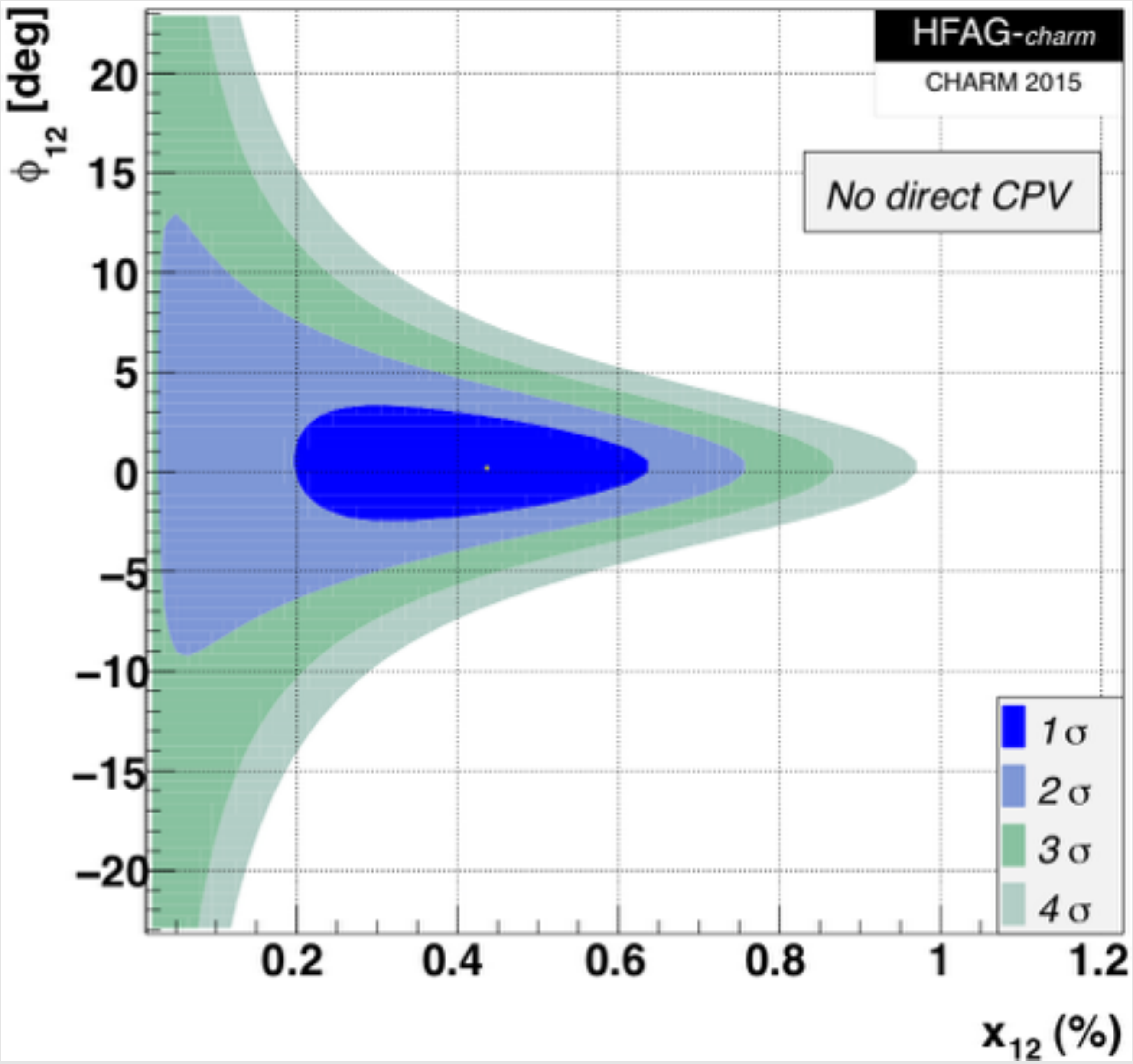
Can we do better?

- Superweak constraint
  - ➡ Assumes no new 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
  - ➡ $\sigma(\Phi_{12}) = 1.7°$



Can we do better?

- Superweak constraint
  - ➡ Assumes no new 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
  - ➡ $\sigma(\Phi_{12}) = 1.7°$



MANCHESTER 1824
The University of Manchester

Is there more?

- Additional potentially powerful channels available
  - ➡ e.g. $D^0 \to K\pi\pi\pi$, $D \to K\pi\pi^0$
- Require time-dependent phase space analyses similar to $D^0 \to K_S\pi\pi$
- Can LHCb exploit these?
  - ➡ Need phase-space model or measurement of CP content (CLEOc/BESIII)
  - ➡ Can sufficient purity be achieved in suppressed channels?
- Will Belle-II have enough data to be competitive?

Mixing in $D^0 \to K\pi\pi\pi$

PRL 116 (2016) 241801

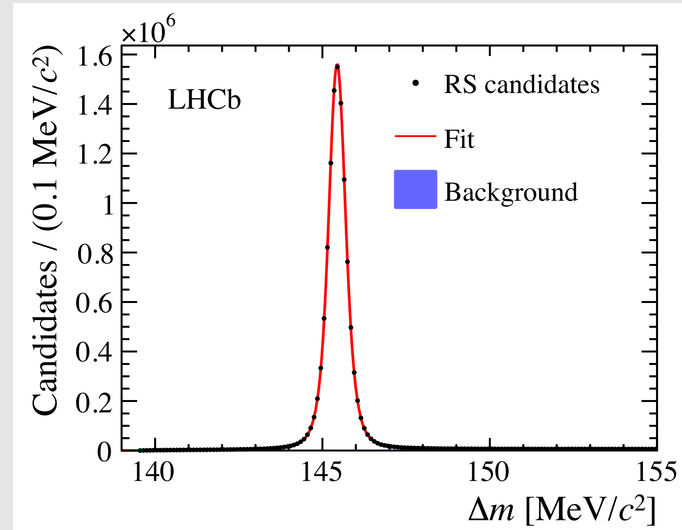
- Measure phase-space integrated WS/RS ratio in bins of decay time
- Clear observation of mixing (8.2σ)

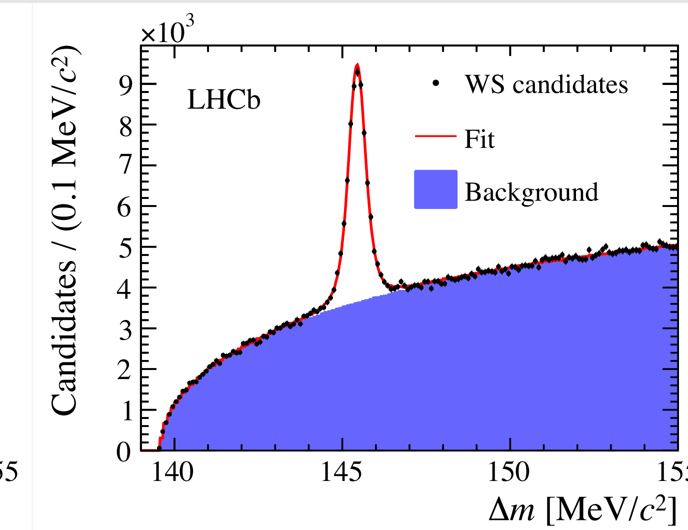
phase-space averaged strong phase differences

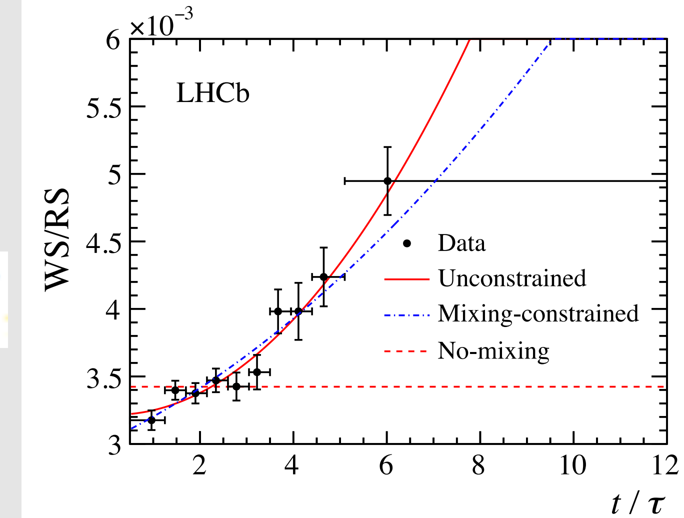
$$R_D^{K3\pi} e^{-i\delta_D^{K3\pi}} \equiv \langle \cos\delta \rangle + i \langle \sin\delta \rangle$$

$$R(t) = \frac{\Gamma[D^0 \to K^+\pi^-\pi^+\pi^-](t)}{\Gamma[D^0 \to K^-\pi^+\pi^-\pi^+](t)} \approx \left(r_D^{K3\pi}\right)^2 - r_D^{K3\pi} R_D^{K3\pi} \cdot y'_{K3\pi} \frac{t}{\tau} + \frac{x^2+y^2}{4}\left(\frac{t}{\tau}\right)^2$$

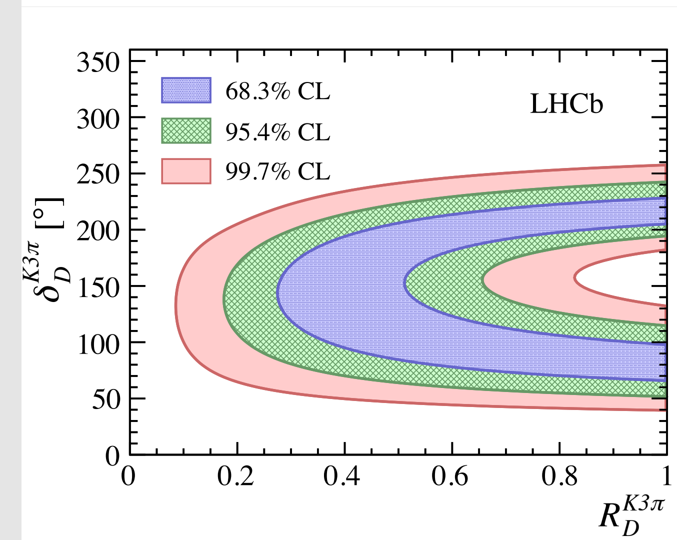
$$y'_{K3\pi} \equiv y \cos\delta_D^{K3\pi} - x \sin\delta_D^{K3\pi}$$







- Can obtain constraints on R & δ from fit including external mixing input
  - ➡ Useful for CKM γ measurements
- 3 observables, 5 parameters
  - ➡ Phase-space dependent analysis would have more impact on mixing parameters

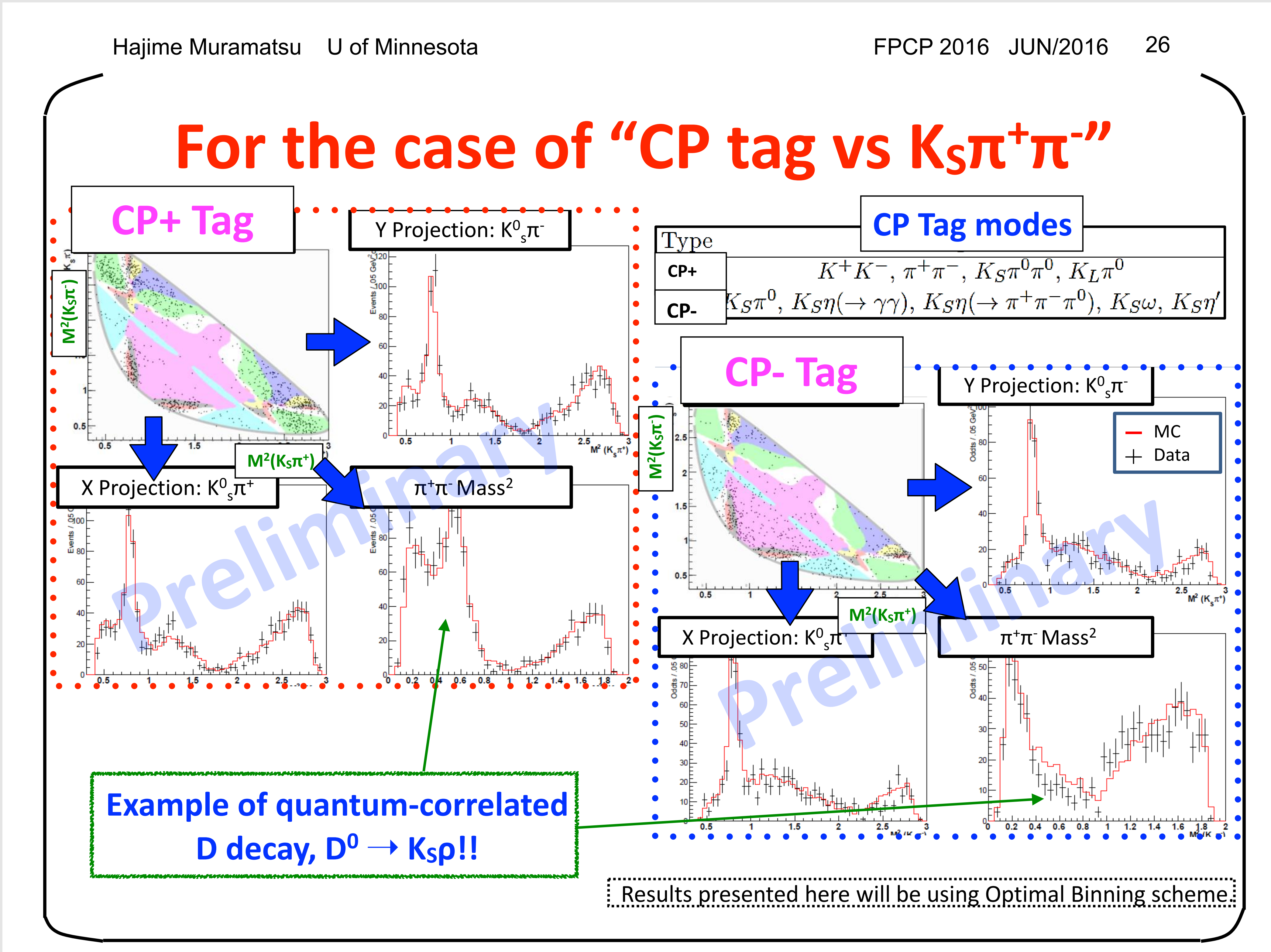


MANCHESTER 1824
The University of Manchester

Phase-space models

- Models to describe multi-body decay phase-space relevant to many mixing and CPV analyses
- Pure isobar models lead to unsatisfactory results
- Few alternatives, which will be insufficient for high-precision datasets
- Need effort from across the community
  - ➡ Bigi @ June 2016 LHCb week:
    Combine input from hadrodynamics and high energy
  - ➡ Need to collaborate across experiments:
    Joint efforts from low and high-energy experiments

BESIII CP content in $K_S\pi\pi$ - I

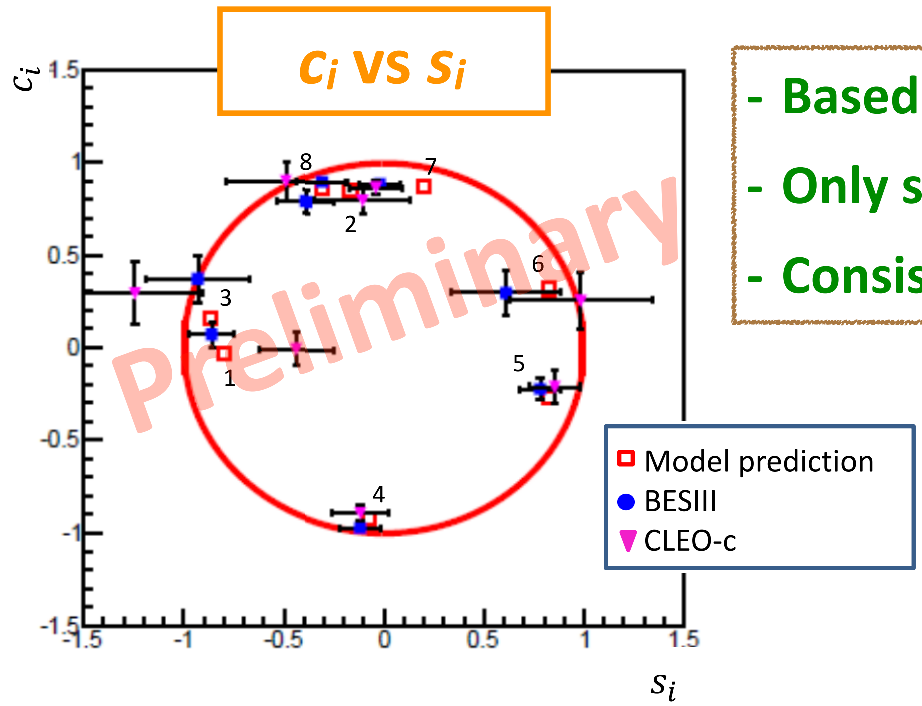


Type	
CP+	K^+K^-, $\pi^+\pi^-$, $K_S\pi^0\pi^0$, $K_L\pi^0$
CP-	$K_S\pi^0$, $K_S\eta(\to\gamma\gamma)$, $K_S\eta(\to\pi^+\pi^-\pi^0)$, $K_S\omega$, $K_S\eta'$

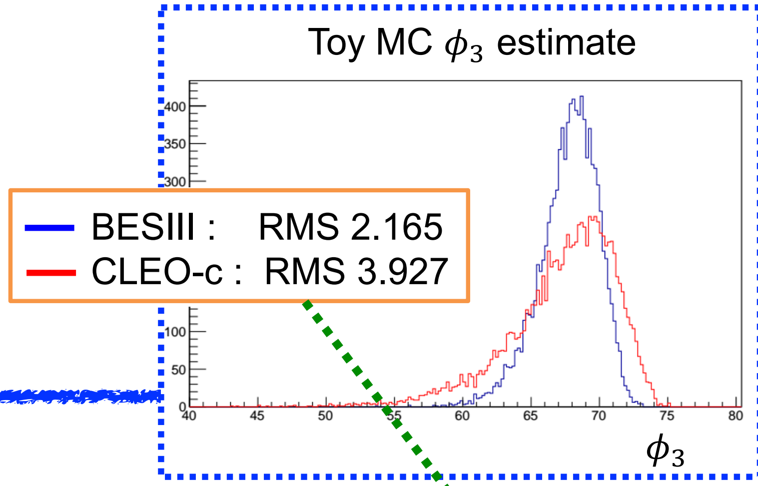
BESIII CP content in $K_S\pi\pi$ - II

Hajime Muramatsu U of Minnesota FPCP 2016 JUN/2016 27

BESIII: Results on c_i and s_i



- Based on BESIII 2.93fb^{-1} at E_{cm} = 3.773 GeV.
- Only statistical errors are shown.
- Consistent with the previous CLEO measurement.



- What this result could do to the γ/ϕ_3 is, if we take the Belle's Dalitz result (PRD85, 112014 (2012)),

  γ (in degrees) = $77.3^{+15.1}_{-14.9}$ (stat.) ± 4.2 (syst.) ± 4.3 (c_i/s_i) → ± 2.4 (c_i/s_i)

  We expect the uncertainly would be reduced by ~45%

- Very important inputs for the future analyses by LHCb and Belle II, where the statistical sensitivity starts to reach ~1~2 degrees.

MANCHESTER 1824
The University of Manchester

Connection to B

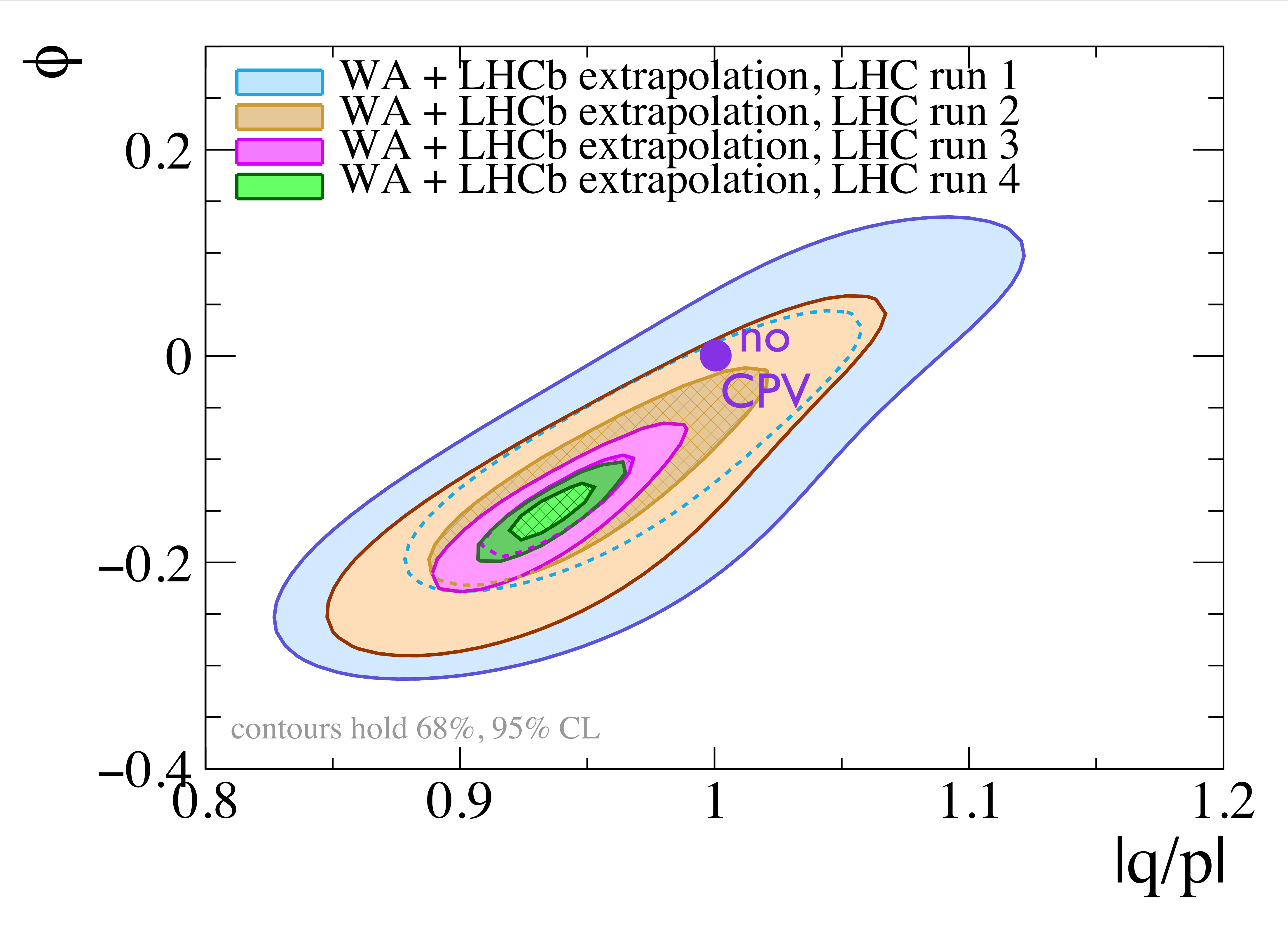
- CKM angle γ measurements
- Charm mixing constraints important
- For multi-body D final states
  - ➡ Similar requirements to charm measurements
  - ➡ BESIII impact on gamma uncertainty from $K_S\pi\pi$ nearly 50%
    - Can we get more and other channels?

Future sensitivities

- Scaling sensitivities with $\sqrt{N}$
  - ➡ Assumes scaling of systematic uncertainties
  - ➡ Ignores potential improvements in selections and analyses
- Δa_{CP}: uncertainty 10^{-4} at 50 fb^{-1}
- Mixing and indirect CPV sensitivities of current world average + LHCb

Run	x [10^{-3}]	y [10^{-3}]	|q/p| [10^{-3}]	ϕ [mrad]	
1	1.22	0.53	59	89	
2	0.92	0.37	44	70	
3	0.42	0.15	20 30	33 26	Belle II @ 50/ab
4	0.25	0.09	**12**	**20**	from Paolini, FPCP16

The need for the upgrade



MANCHESTER 1824
The University of Manchester

Direct CP violation

Direct CP violation:

$$a_{CP}^{dir} \equiv \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\bar{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\bar{D}^0 \rightarrow f)}$$

The Δa_{CP} saga*

- What is Δa_{CP}?

$$\Delta a_{CP} \equiv a_{CP}(K^- K^+) - a_{CP}(\pi^- \pi^+) = a_{\rm raw}(K^- K^+) - a_{\rm raw}(\pi^- \pi^+).$$

- Interplay of direct and indirect CP violation

$$\Delta a_{CP} = \Delta a_{CP}^{\rm dir}\left(1 + y_{CP}\frac{\overline{\langle t \rangle}}{\tau}\right) + \overline{A}_{\Gamma}\frac{\Delta\langle t \rangle}{\tau},$$

- Individual asymmetries are expected to have opposite sign due to CKM structure

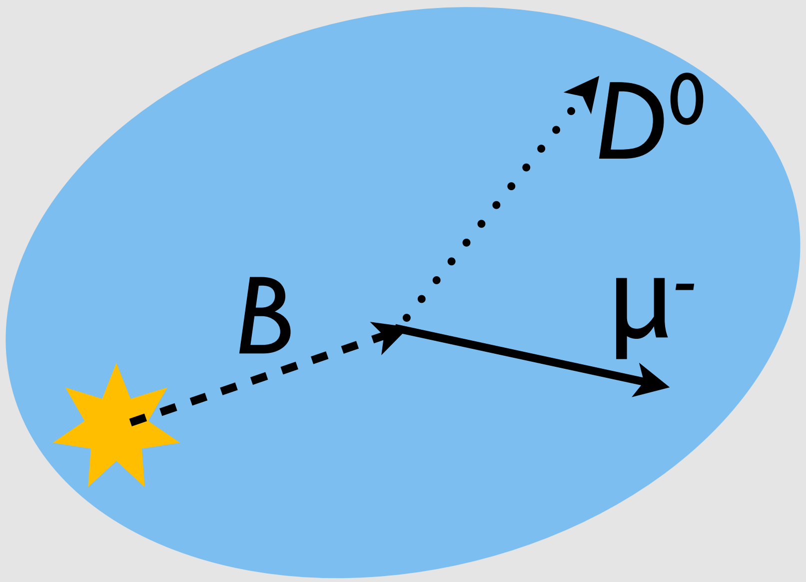
$$A(\overline{D}^0 \to \pi^+\pi^-, K^+K^-) = \mp\tfrac{1}{2}\left(V_{cs}V_{us}^* - V_{cd}V_{ud}^*\right)(T \pm \delta S) - V_{cb}V_{ub}^*\left(P \mp \tfrac{1}{2}\delta P\right),$$

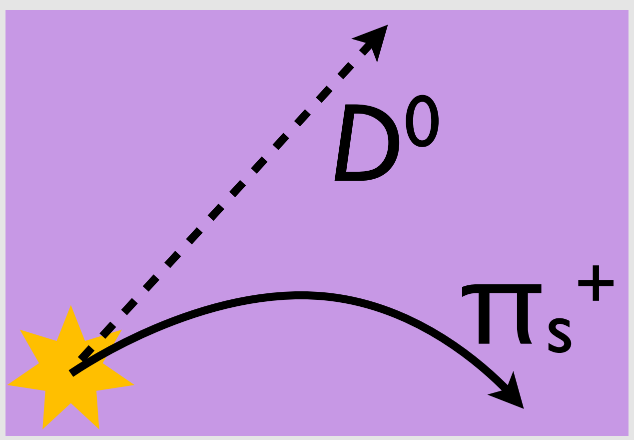
*after A. Lenz @ CHARM 2013, arXiv:1311.6447

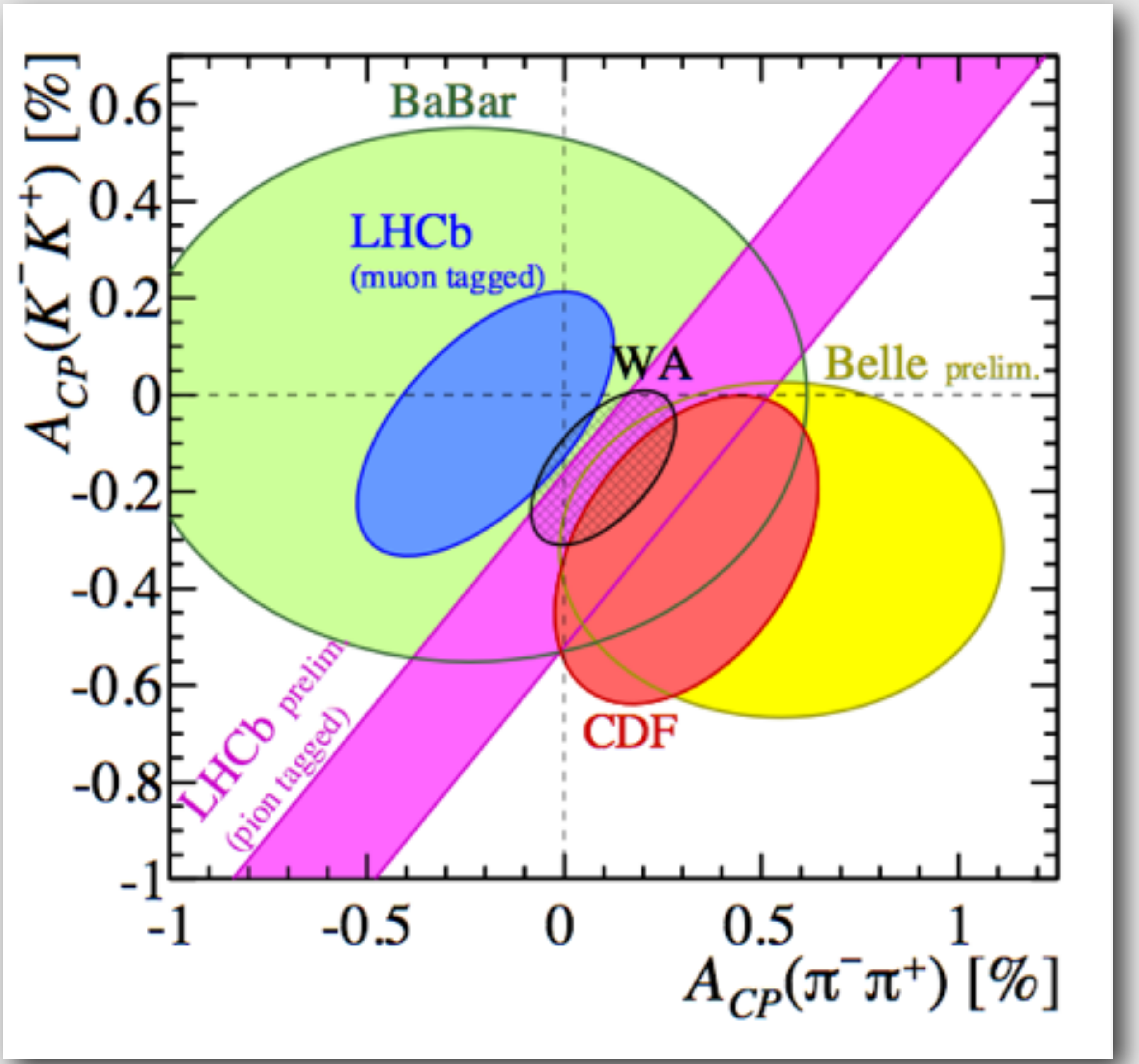
EPJC 73 (2013) 2373

(Δ)a_{CP} results

- Ignoring contribution from indirect CPV







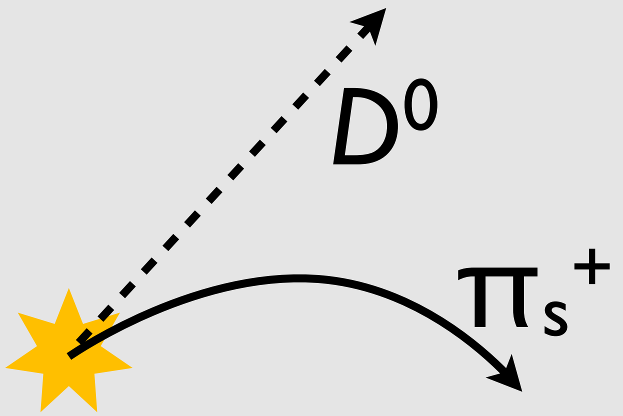
$$a_{CP}(K^-K^+) = (-0.06 \pm 0.15\,(\text{stat}) \pm 0.10\,(\text{syst}))\%\,,$$

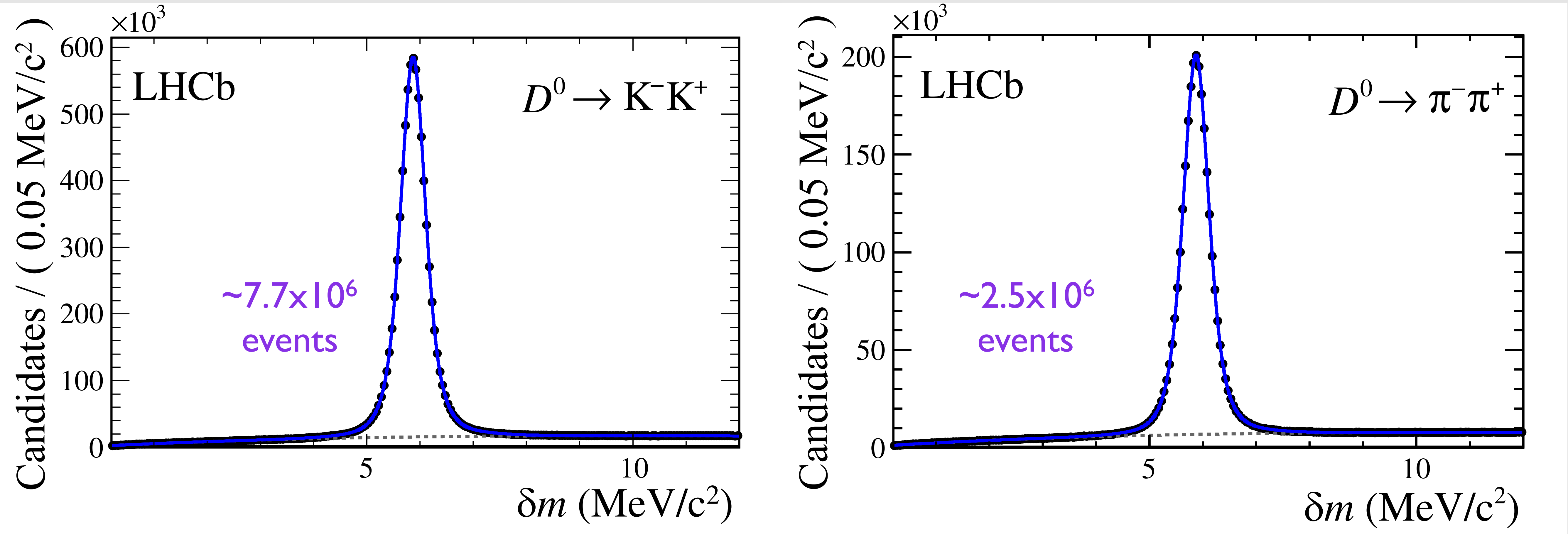
JHEP 07 (2014) 014

Latest results

PRL 116 (2016) 191601

- D*-tagged (2011+12 data)
- Completes Run 1 Δa_{CP} analyses
- Fit $\delta m = m(D^{*+}) - m(D^0)$





Systematic uncertainties

PRL 116 (2016) 191601

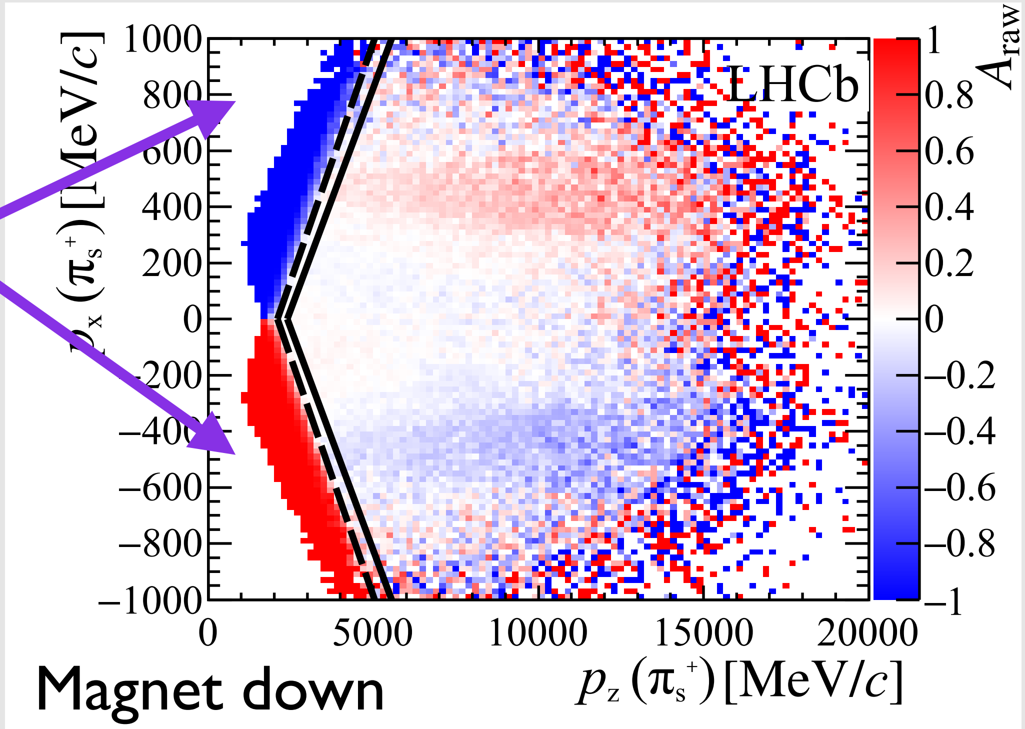
Source	uncertainty [%]
Fit Model	0.016
Multiple candidates	0.015
Peaking background	0.011
Reweighting	0.004
Fiducial cut	0.017
Secondaries	0.004
Total	0.030

Test alternative signal and background models, extend fitting range

Exclude smaller edge & beam pipe regions; select events closer to the high-asymmetry regions

Reject randomly events with multiple candidates, keep only one candidate

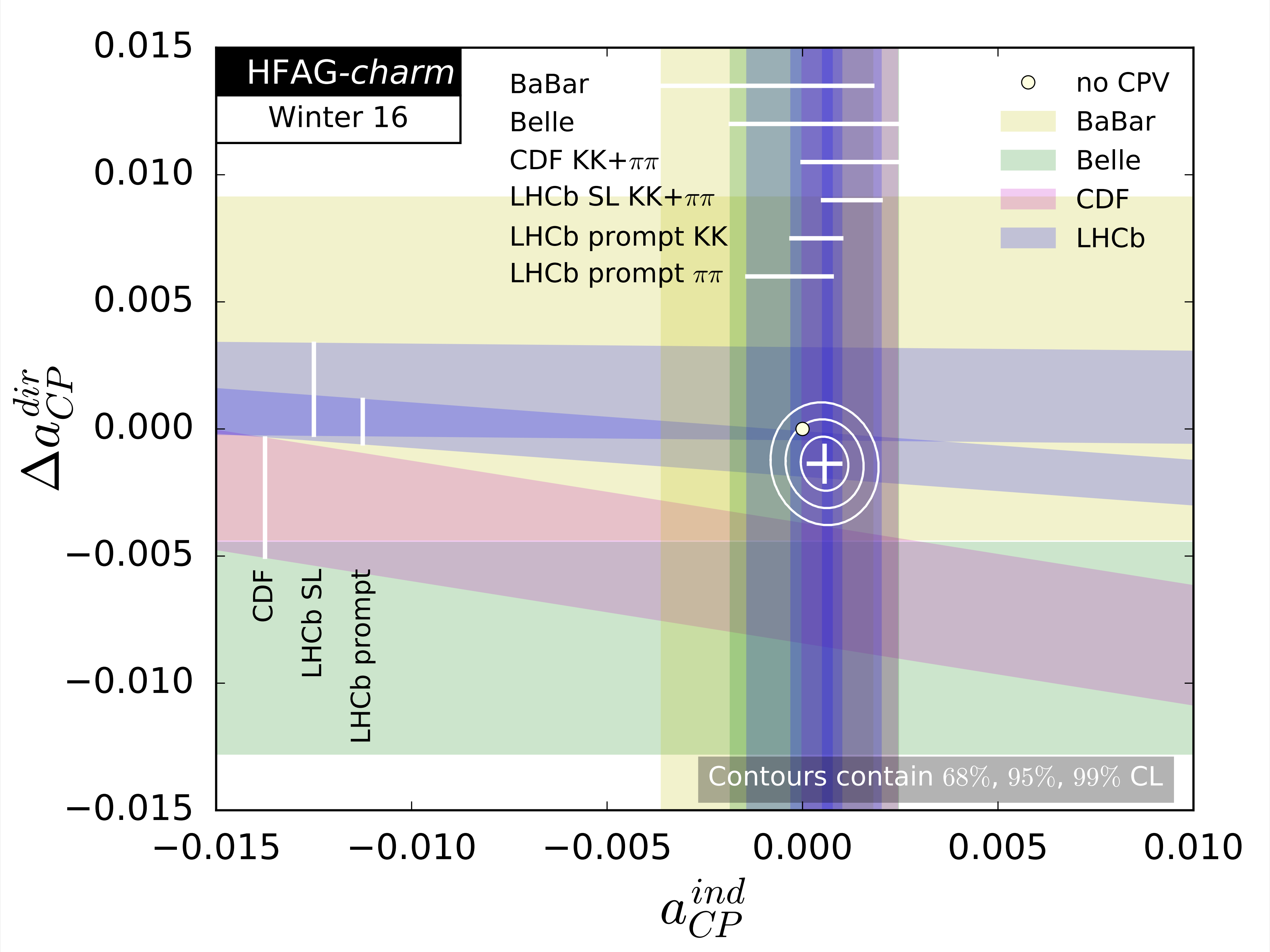
reject



$$\Delta a_{CP} = (-0.10 \pm 0.08_{stat} \pm 0.03_{syst})\%$$

The most precise measurement of a time-integrated CP asymmetry in the charm sector

Latest HFAG averages



a_{CP}^{ind} = (0.056 ± 0.040)%

Δa_{CP}^{dir} = (-0.137 ± 0.070)%

Compatible with CP symmetry at 6.5% CL

MANCHESTER 1824
The University of Manchester

What's next?

- More individual asymmetries
  - ➡ Requires control of production and detection asymmetries
- CPV in (charm) baryons
  - ➡ Requires knowledge of proton detection asymmetry
- Relying on large Cabibbo-favoured control samples
  - ➡ Require detailed understanding of subtle detector effects
  - ➡ Analyses will never be plug (data) and play (publish)
- General aim
  - ➡ Measure CP asymmetries in as many complementary channels as possible
  - ➡ Keep in mind interplay of direct and indirect CPV observables

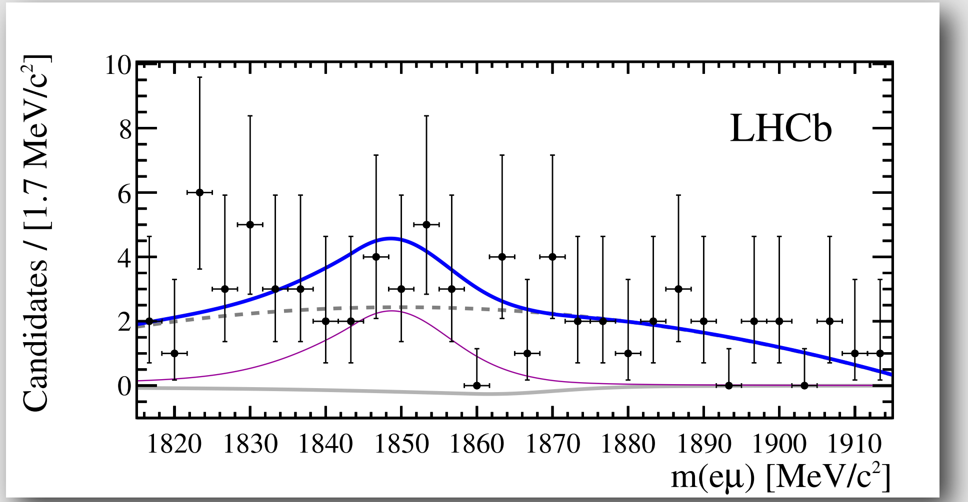

Rare
decays

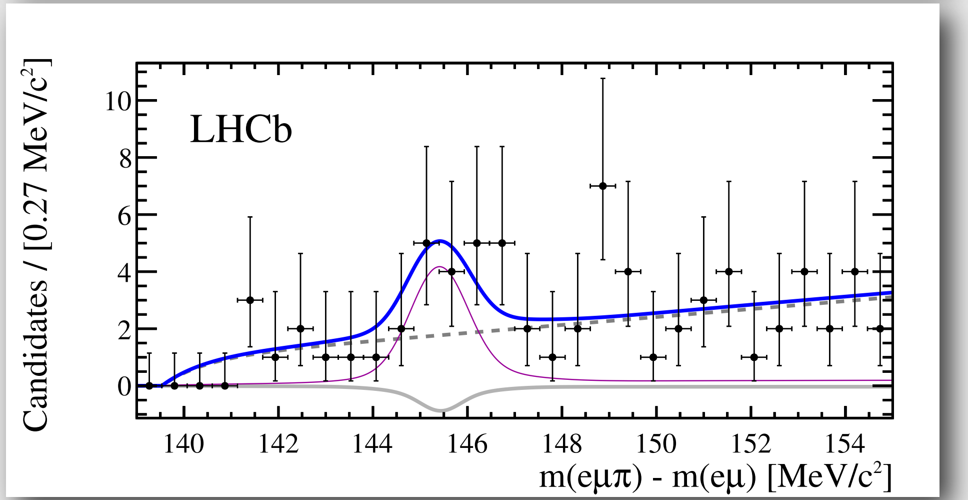
MANCHESTER 1824
The University of Manchester

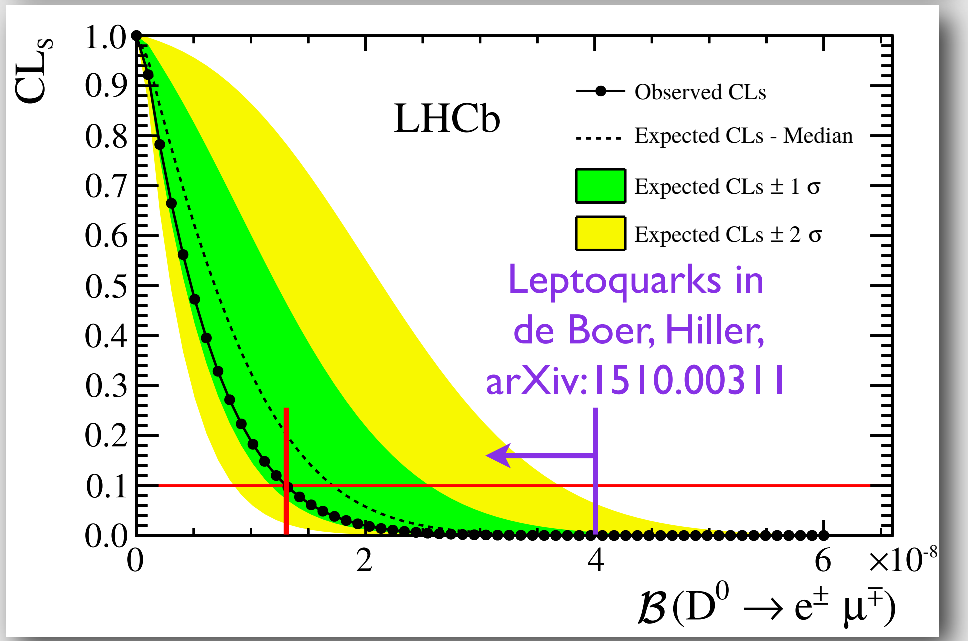
Rare and charming

Phys. Lett. B745 (2016) 167

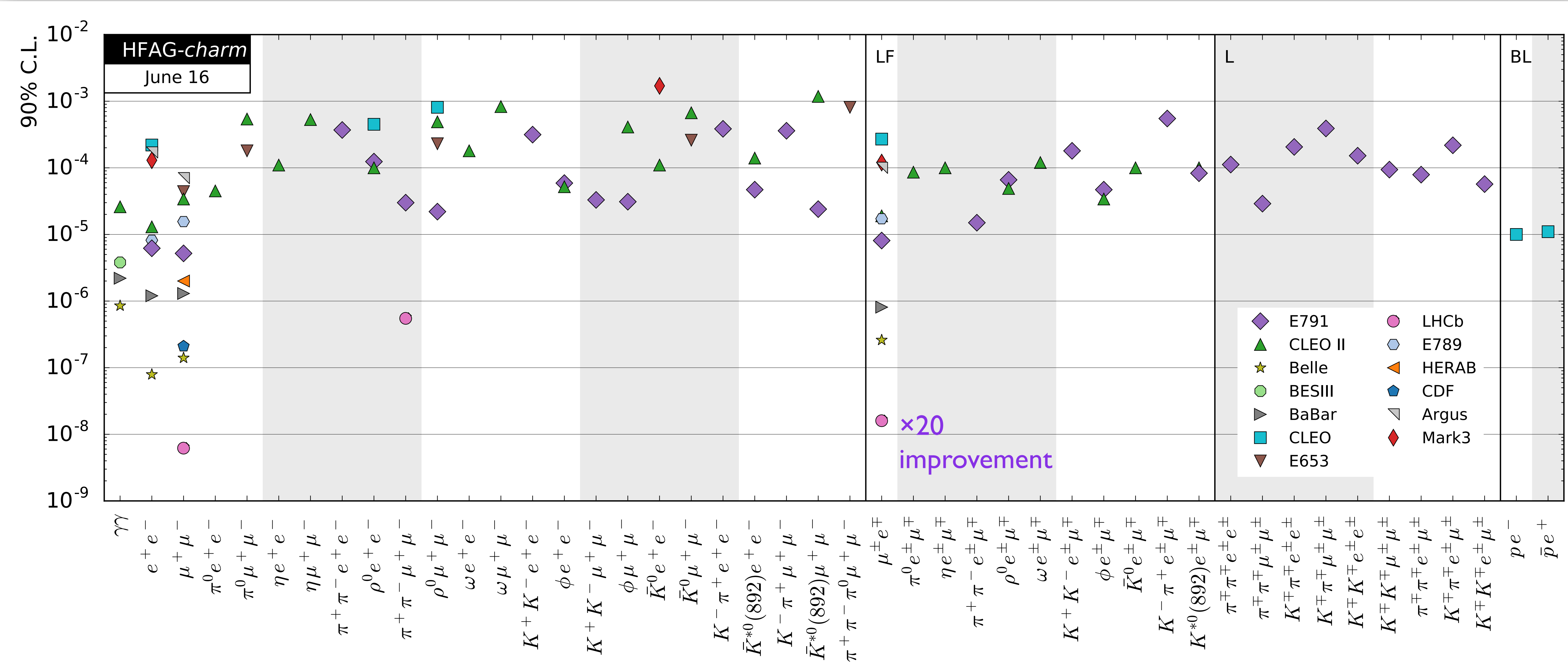
- Search for $D^0 \rightarrow e^{\pm}\mu^{\mp}$
- Normalised to $D^0 \rightarrow K^{-}\pi^{+}$
- BDT selection to suppress combinatorial background
  - ➡ Analysis in 3 bins of BDT output
- Peaking background $D^0 \rightarrow \pi^{-}\pi^{+}$
- Limit set via CL_s method
  - ➡ 1.3×10^{-8} at 90% CL







Rare charm overview



- $D^0 \to e^+\mu^-$
  - ➡ More than one order of magnitude improvement
  - ➡ Not far behind $D^0 \to \mu^+\mu^-$
- First charm decay into electrons, many more to follow
- Other possibilities arise
  - ➡ e.g. lepton universality tests

The University of Manchester

Future challenges

MANCHESTER 1824
The University of Manchester

Challenges ahead

- Challenges driven by charm
  - ➡ Expect e.g. $O(10^{10})$ reconstructed $D^0 \to K\pi$ by Run 4
- Data size
  - ➡ No storage capacity for full event information
  - ➡ Need to store high statistics samples with reduced information
    - Crucial to ensure all necessary information available
  - ➡ Need to maintain high selection efficiency and purity
- Simulation
  - ➡ May become increasingly important to understand data features
  - ➡ Generating very large samples that accurately describe detector effects will be key

MANCHESTER 1824
The University of Manchester

More work…

- Analysis processing
  - ➡ Most fits have 50-100 parameters
  - ➡ Unbinned fits may be prohibitively slow
  - ➡ Often benefiting from data-driven checks with control samples
    - Can we afford to collect larger control samples?
  - ➡ Can commercial computing help?
  - ➡ Can we learn from colleagues (astronomy, meteorology, …)?
- Systematic uncertainties
  - ➡ Second order effects may become important
  - ➡ Decay-time dependence of detector effects
  - ➡ Detection asymmetries

Conclusions

- Charm mixing long established
  - ➡ Sign of x should be confirmed soon by LHCb
- No hint for indirect CP violation
  - ➡ Tight constraints with superweak approximation
- No hint for direct CP violation
- Future work
  - ➡ Improvement of phase-space models
  - ➡ Measurement of CP content in phase space
  - ➡ Explore new decay modes
- LHCb exploring reach in rare decays
  - ➡ Also for electrons in final state
- Significant technical challenges ahead
  - ➡ Several solutions for LHCb upgrade already being commissioned

Thank you!

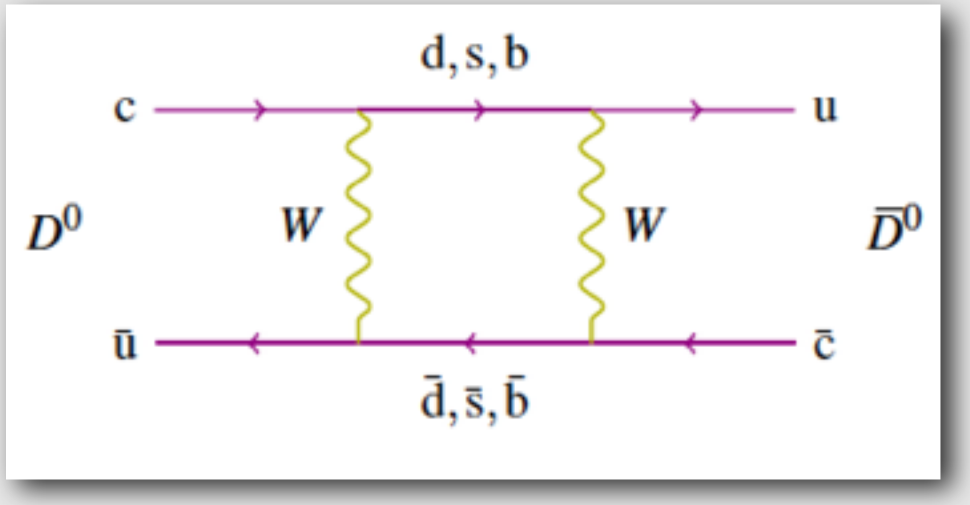
The University of Manchester

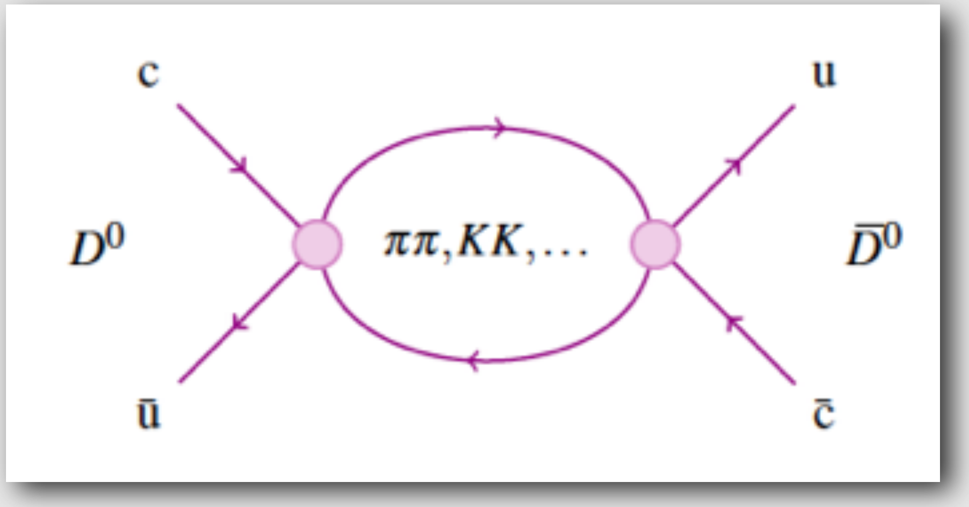
BACKUP

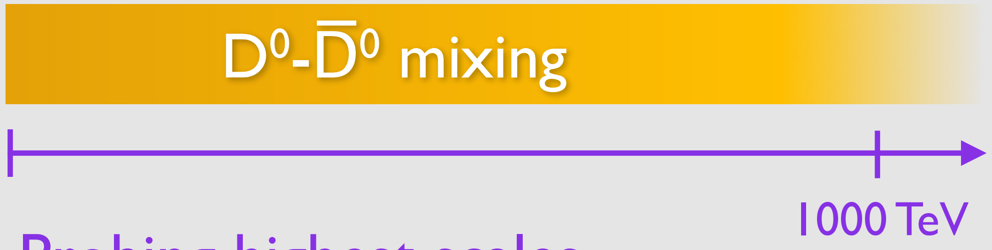
MANCHESTER 1824
The University of Manchester

Charm: hardly a triangle

- Only up-type quark to form weakly decaying hadrons
  - ➡ Unique physics access
- Mixing
  - ➡ Huge cancellations
  - ➡ Theoretically difficult
- CP violation
  - ➡ Predictions even smaller
- Need highest precision
- Huge LHCb dataset
  - ➡ Blessing and a curse







Probing highest scales

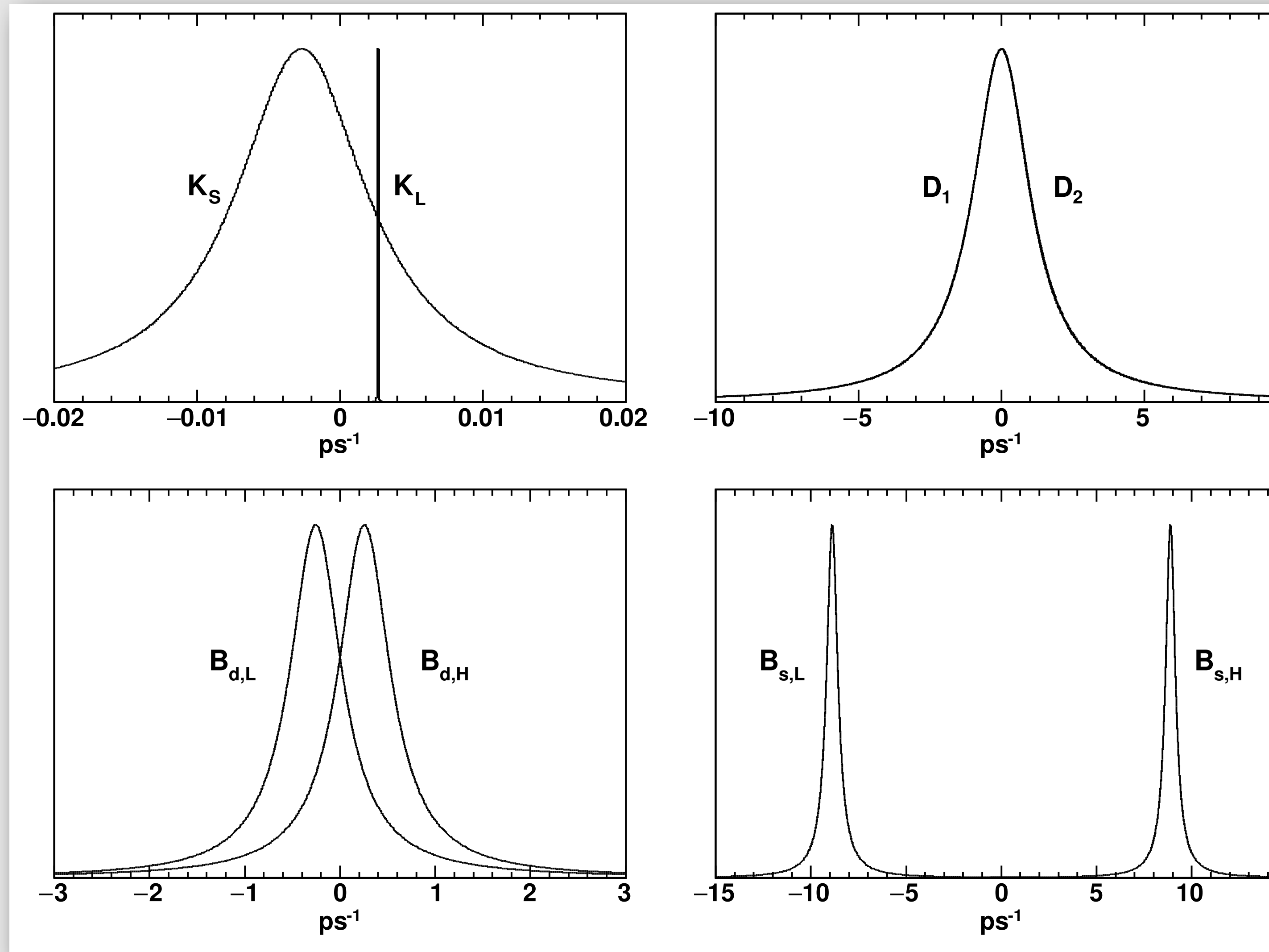
→ Isidori, Nir, Perez, ARNPS 60 (2010) 355

Mixing

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

Mass eigenstates

Flavour eigenstates

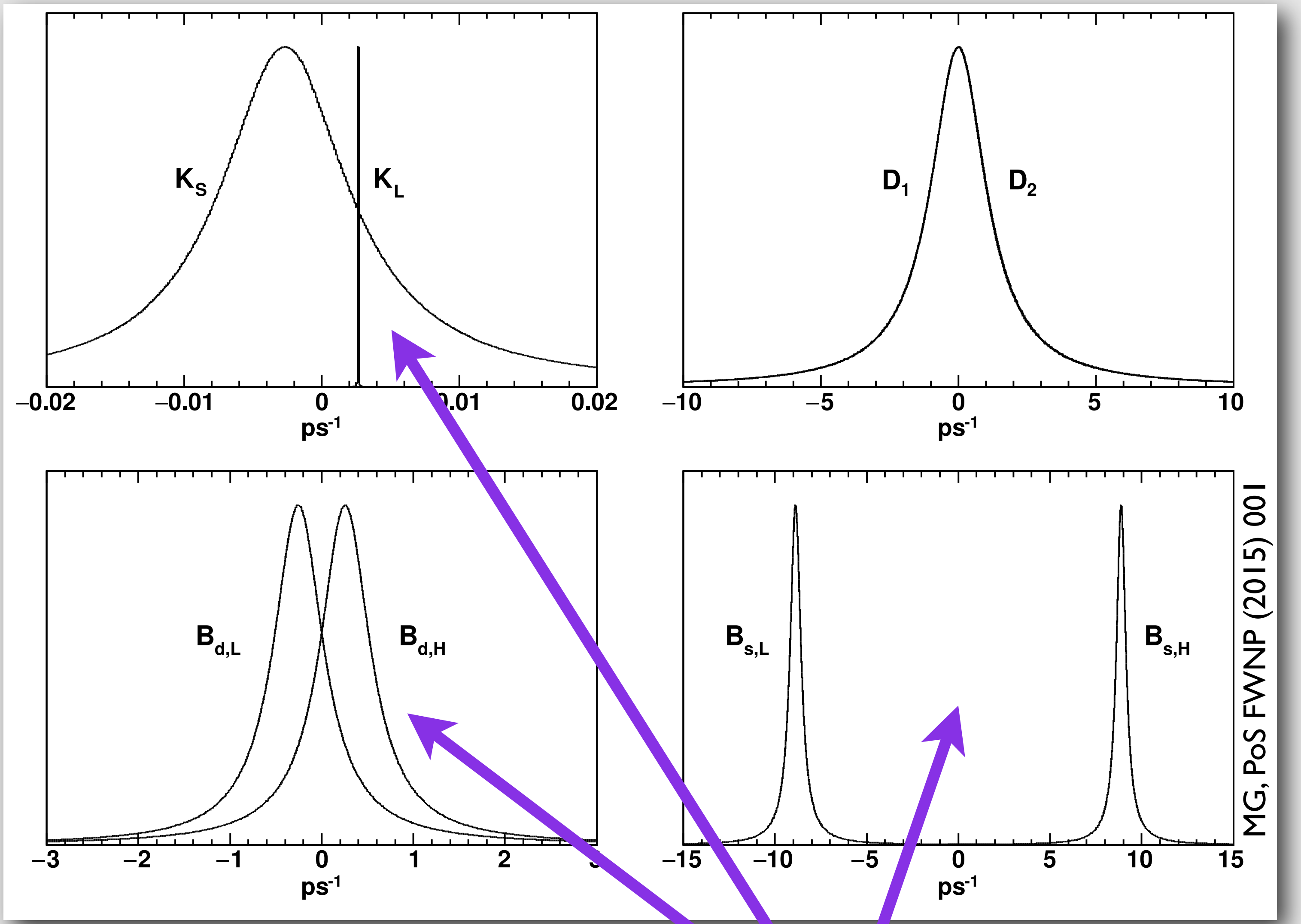


MG, PoS FWNP (2015) 001

Mixing

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

Mass eigenstates   Flavour eigenstates



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

Mass difference

→ Oscillation

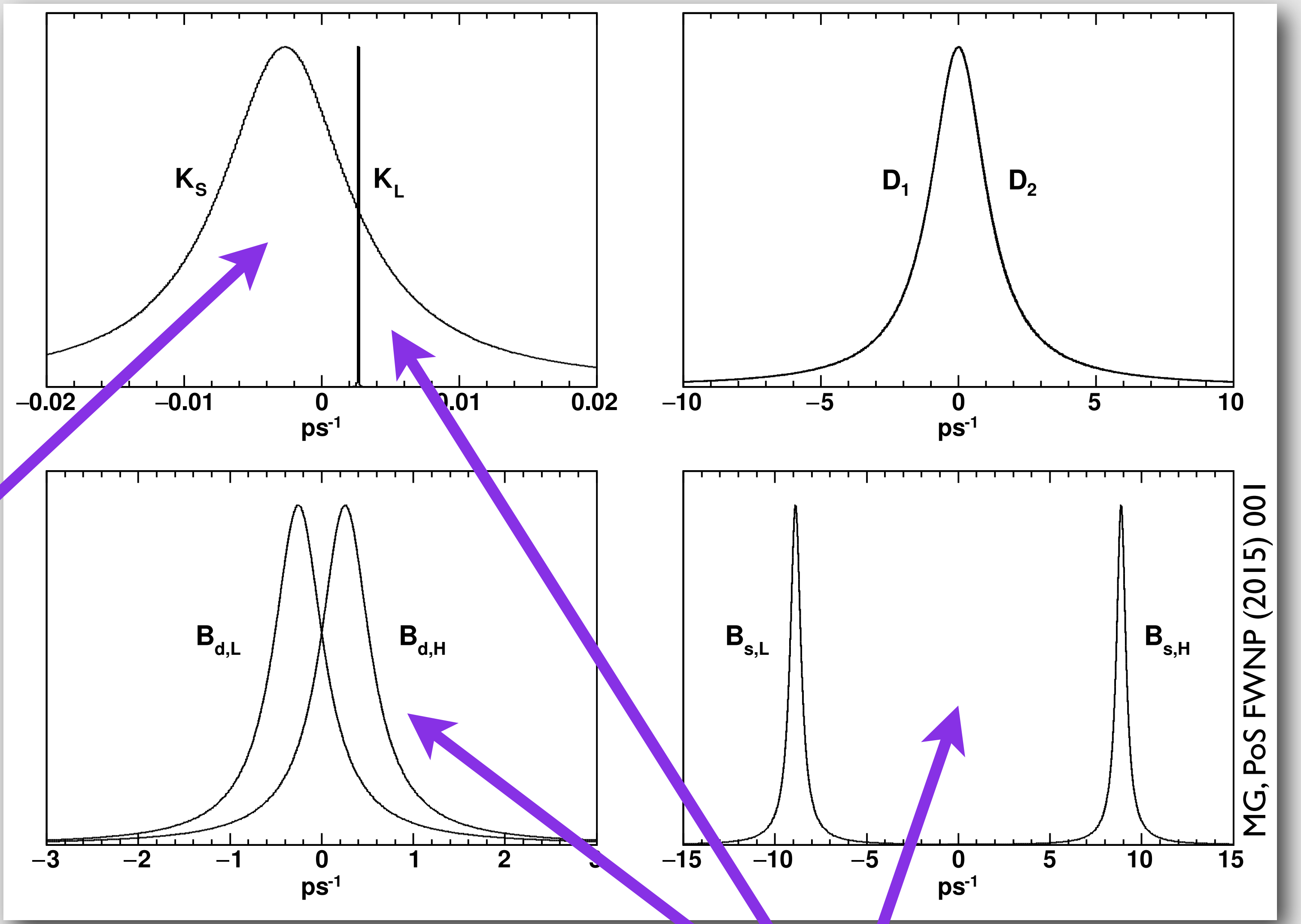
$$\Delta m \equiv m_2 - m_1$$

$$x \equiv \Delta m/\Gamma$$

Mixing

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

Mass eigenstates — Flavour eigenstates



Width difference

→ Lifetime difference

$$\Delta\Gamma \equiv \Gamma_2 - \Gamma_1 \qquad y \equiv \Delta\Gamma/(2\Gamma)$$

Mass difference

→ Oscillation

$$\Delta m \equiv m_2 - m_1$$

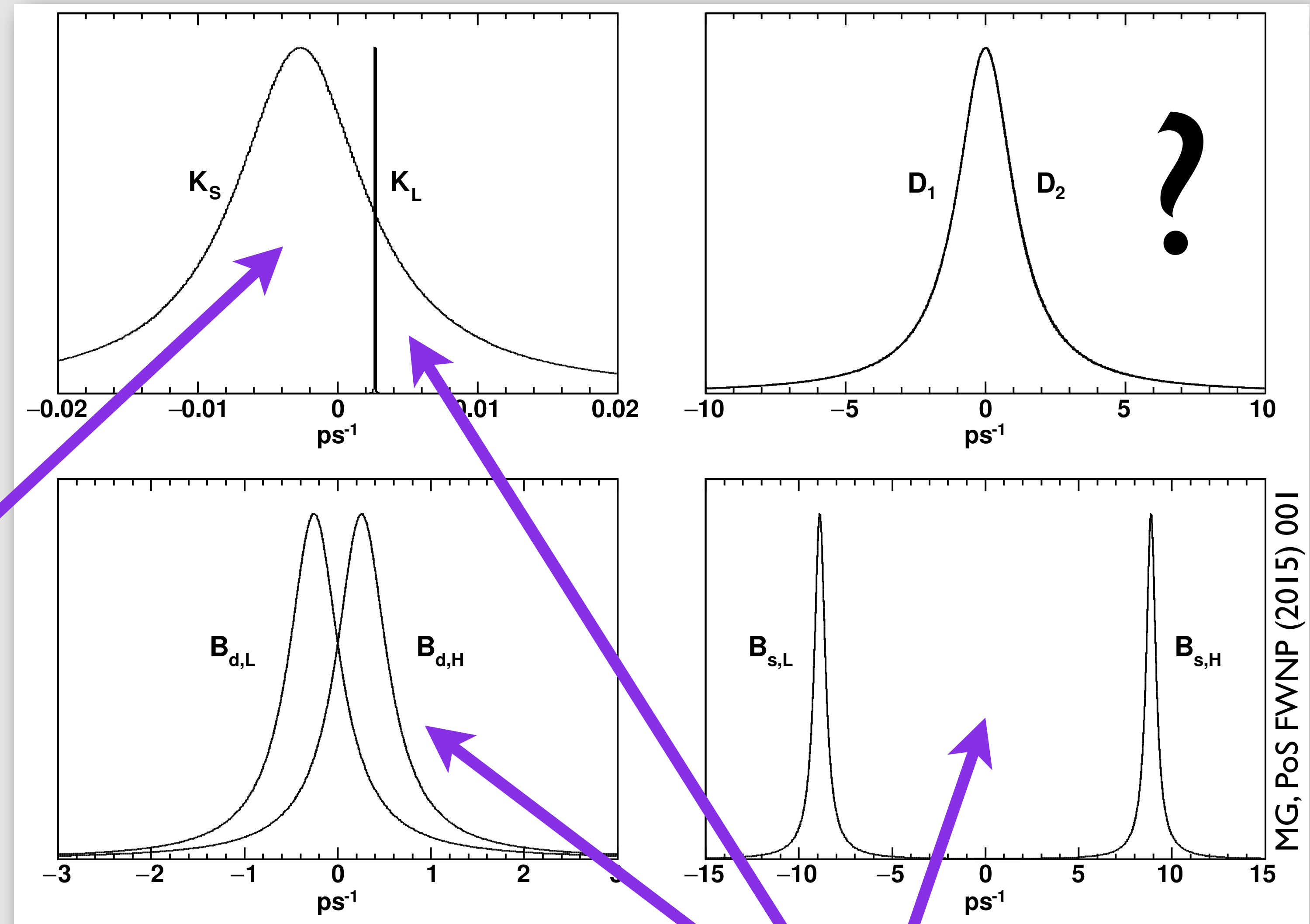
$$x \equiv \Delta m/\Gamma$$

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

Mixing

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

Mass eigenstates   Flavour eigenstates



Width difference

→ Lifetime difference

$\Delta\Gamma \equiv \Gamma_2 - \Gamma_1$ $y \equiv \Delta\Gamma/(2\Gamma)$

Mass difference

→ Oscillation

$\Delta m \equiv m_2 - m_1$

$x \equiv \Delta m/\Gamma$

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

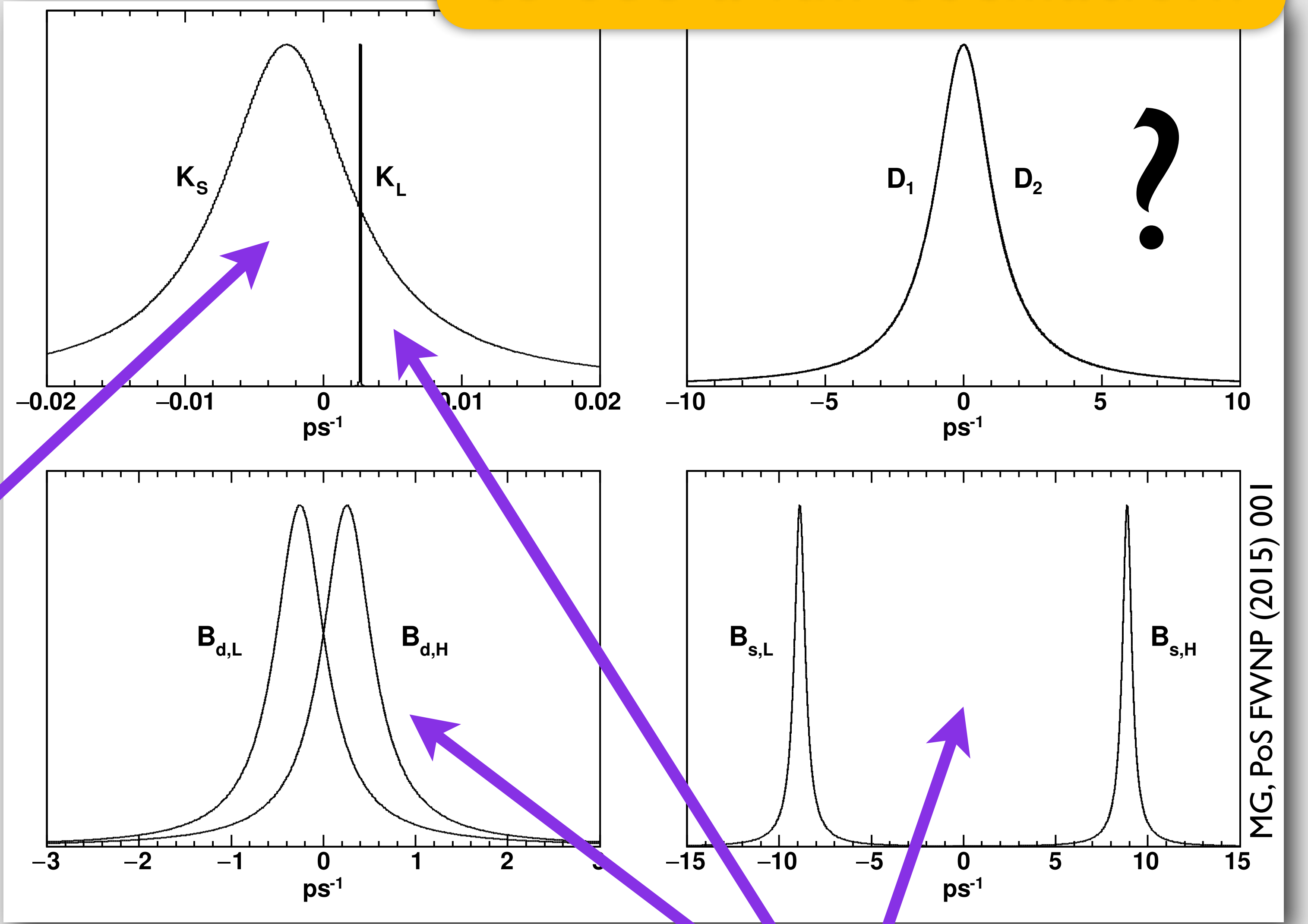
Mixing

Charm mixing:
Need ~1000 lifetimes to see a full oscillation!

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

Mass eigenstates

Flavour eigenstates



Width difference
→ Lifetime difference

$$\Delta\Gamma \equiv \Gamma_2 - \Gamma_1$$

$$y \equiv \Delta\Gamma/(2\Gamma)$$

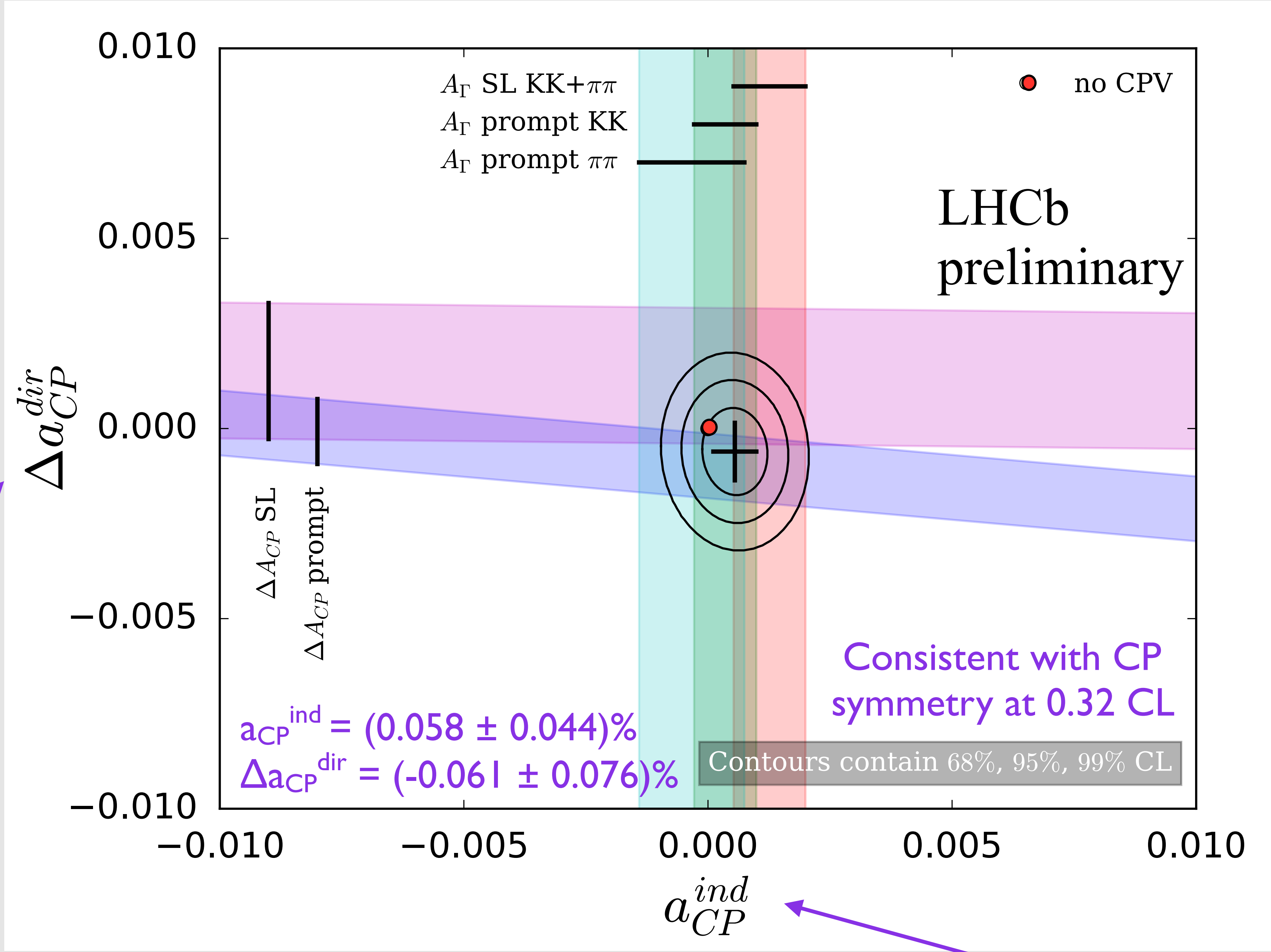
$$P(M^0 \to \overline{M}^0, t) = \frac{1}{2}\left|\frac{q}{p}\right|^2 e^{-\Gamma t}(\cosh(y\Gamma t) - \cos(x\Gamma t))$$

Mass difference
→ Oscillation

$$\Delta m \equiv m_2 - m_1$$

$$x \equiv \Delta m/\Gamma$$

LHCb summary of CPV searches in $D^0 \to h^+h^-$



$$\Delta A_{CP} \equiv A_{CP}(KK) - A_{CP}(\pi\pi)$$
$$\approx \Delta a_{CP}^{dir} \left(1 + y_{CP} \,\overline{\langle t \rangle}/\tau\right) + a_{CP}^{ind}\, \Delta\langle t \rangle/\tau$$

$A_\Gamma \approx -a_{CP}^{ind}$

slide from E. Gersabeck, CERN EP seminar, 19/1/16

MANCHESTER 1824 The University of Manchester

Extrapolations

Run	$\sqrt{s}$ in TeV	L in fb^{-1}	ε_{trig}	L_{eq}	**ΣL_{eq}**
1 (2011)	7	1	1	1	**1**
1 (2012)	8	2	1	2.3	**3.3**
2	13	5	0.5	4.6	**7.9**
3	14	15	2	60	**68**
4	14	25	2	100	**168**

- Calculate equivalent luminosities to 7 TeV
- Extrapolate signal yields accordingly
- Based on existing run-1 measurements where available

MANCHESTER 1824
The University of Manchester

Future charm measurements

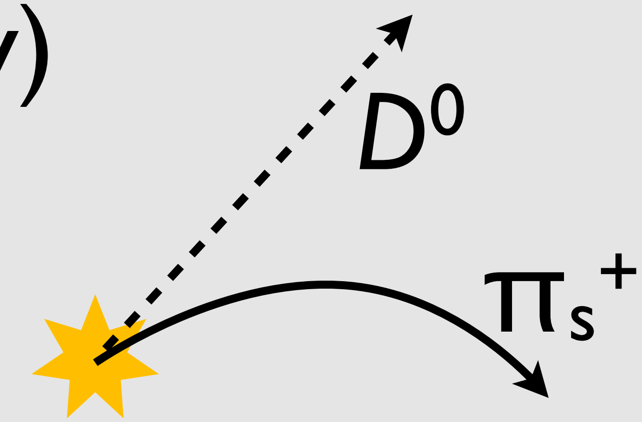
- A_Γ, WS $K\pi$, ΔA_{CP}
  - ➡ Inherently robust against systematics due to cancellations
  - ➡ Not all at the same level, but no limiting uncertainty known
- $y_{CP} \equiv \tau_{K\pi}/\tau_{KK} - 1 \approx y$
  - ➡ Comparison of two different final states
  - ➡ Less robust but controllable if lifetime bias easier to account for
- $K_S\pi\pi$
  - ➡ Leading systematics are either model uncertainties or measurements of CP content at threshold
  - ➡ Relies on input from BESIII

Results

- D*-tagged (2011 data, preliminary)

$$\Delta a_{CP} = (-0.34 \pm 0.15\,(\text{stat.}) \pm 0.10\,(\text{syst.}))\%\,.$$

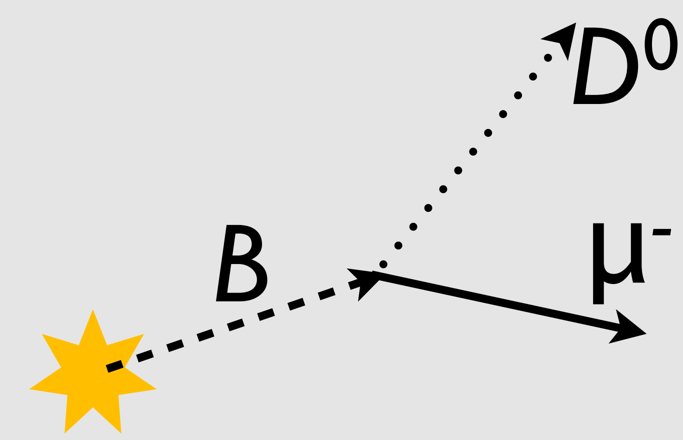
LHCb-CONF-2013-003



- muon-tagged (2011+12 data)

$$\Delta a_{CP} = (+0.14 \pm 0.16\,(\text{stat}) \pm 0.08\,(\text{syst}))\%\,,$$

JHEP 07 (2014) 014



Individual asymmetries

$a_{raw}(K^-K^+)$ $a_{CP}(K^-K^+)$ $a_P(B)$ $a_D(\mu^+)$

measure ← $a_{raw}(K^-K^+)$

want ← $a_{CP}(K^-K^+)$

Individual asymmetries

$a_{raw}(K^-K^+)$ $a_{CP}(K^-K^+)$ $a_P(B)$ $a_D(\mu^+)$

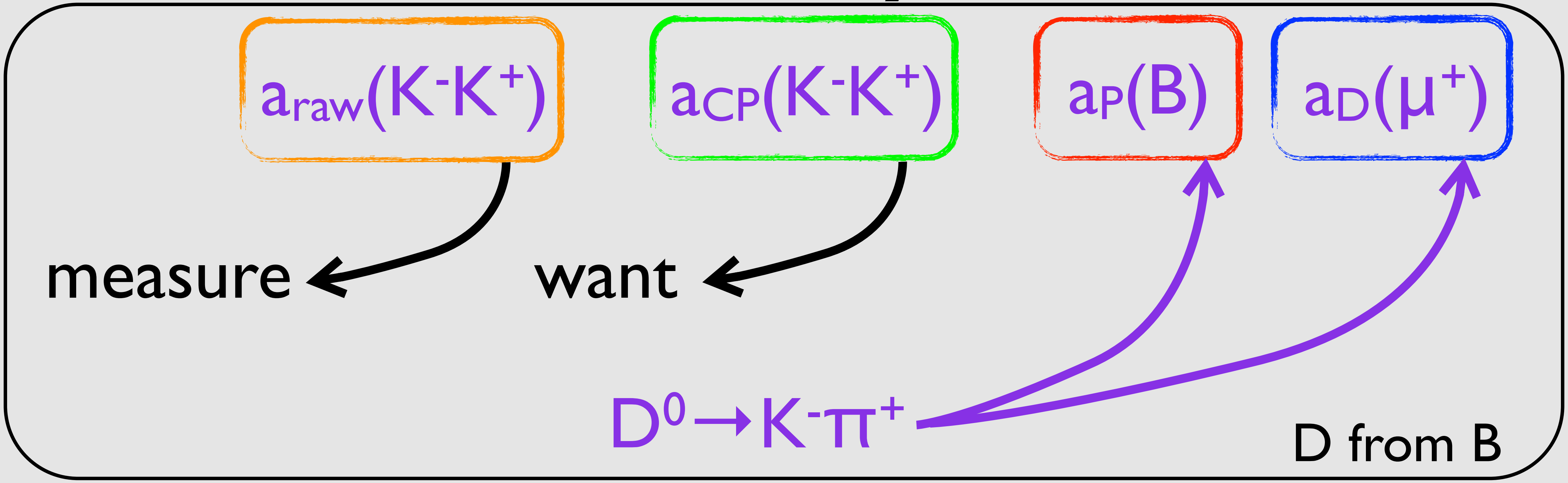
measure ← $a_{raw}(K^-K^+)$

want ← $a_{CP}(K^-K^+)$

D from B

MANCHESTER 1824
The University of Manchester

Individual asymmetries



Individual asymmetries

$a_{raw}(K^-K^+)$ $a_{CP}(K^-K^+)$ $a_P(B)$ $a_D(\mu^+)$

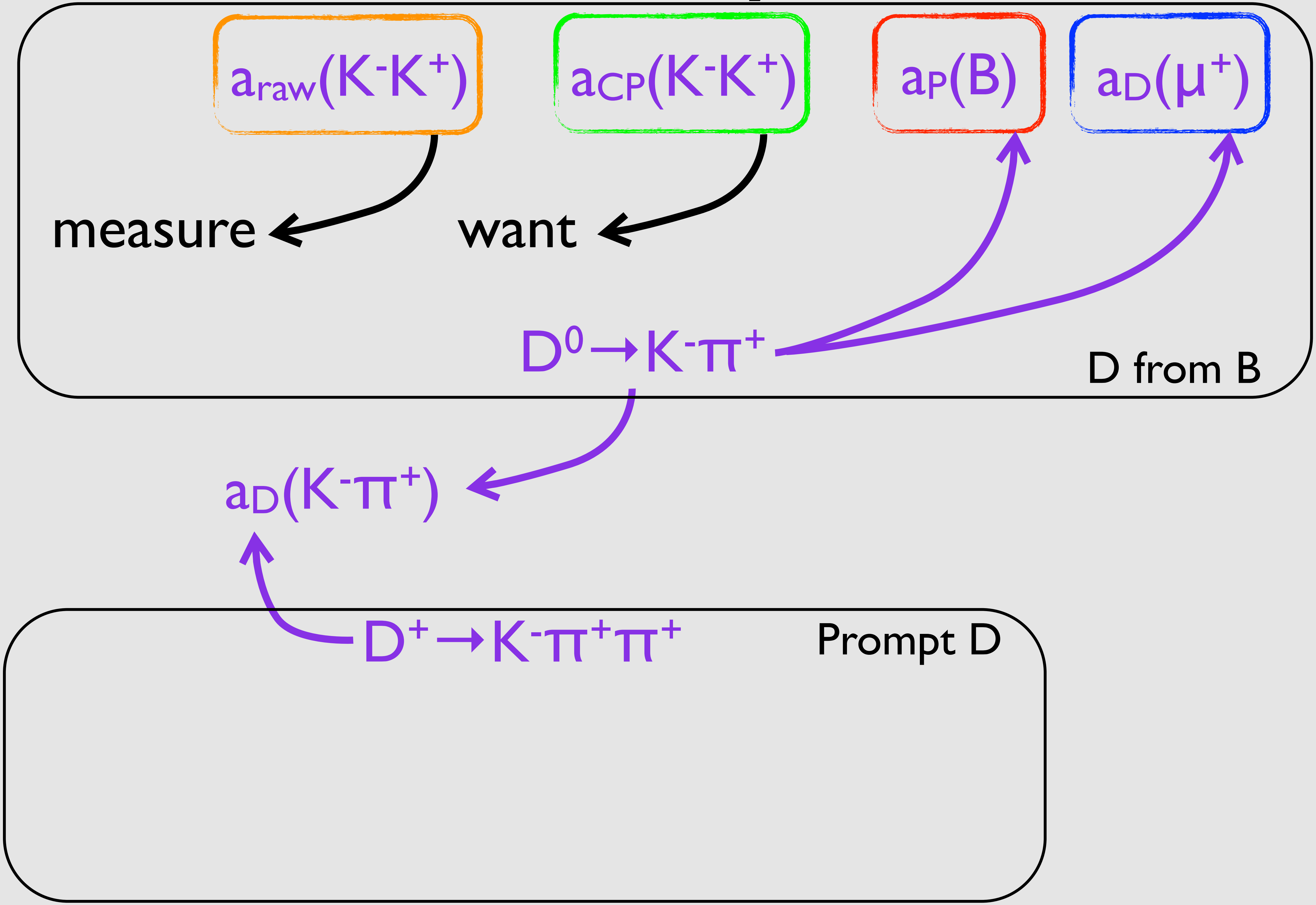
measure want

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

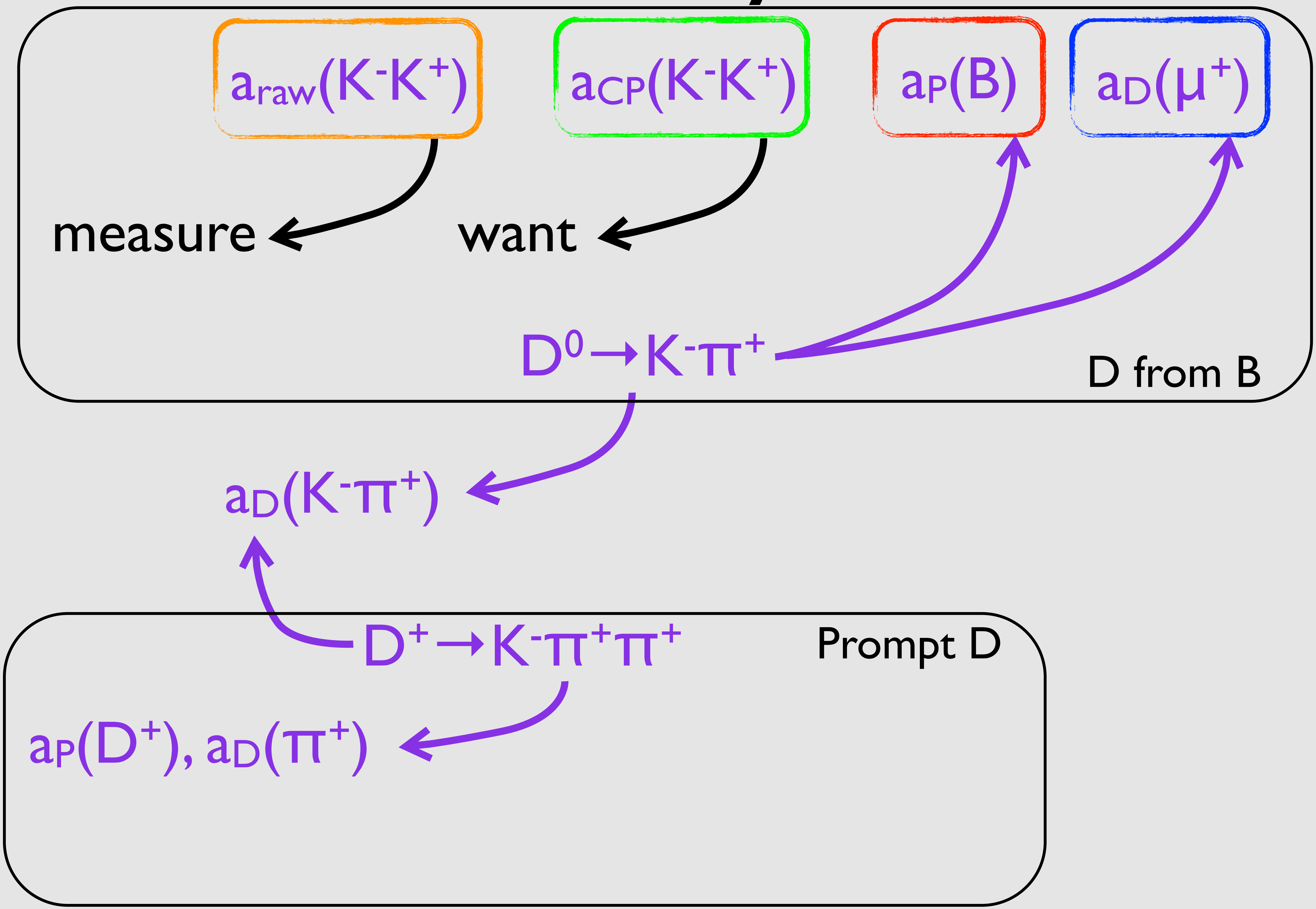
D from B

$a_D(K^-\pi^+)$

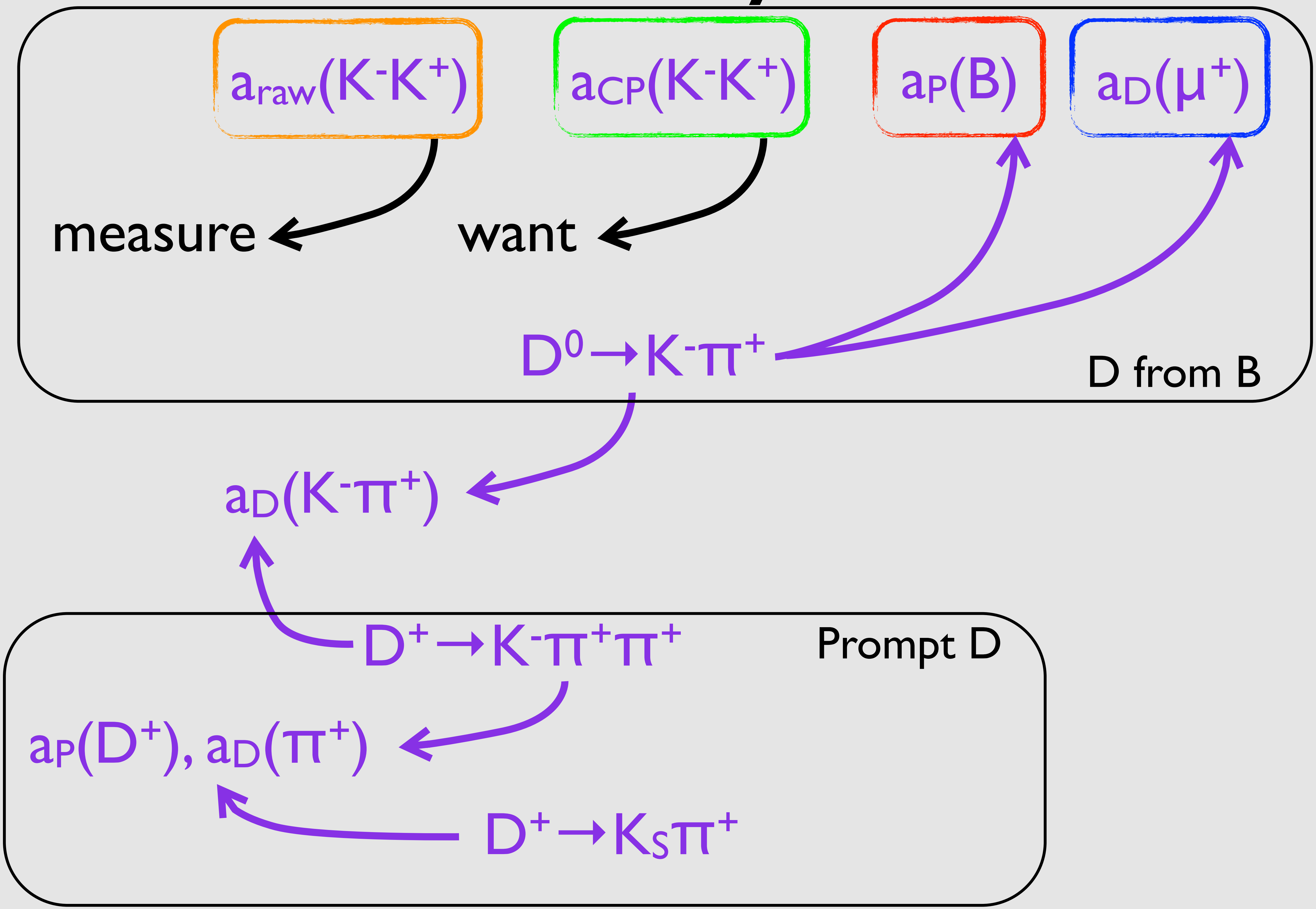
Individual asymmetries



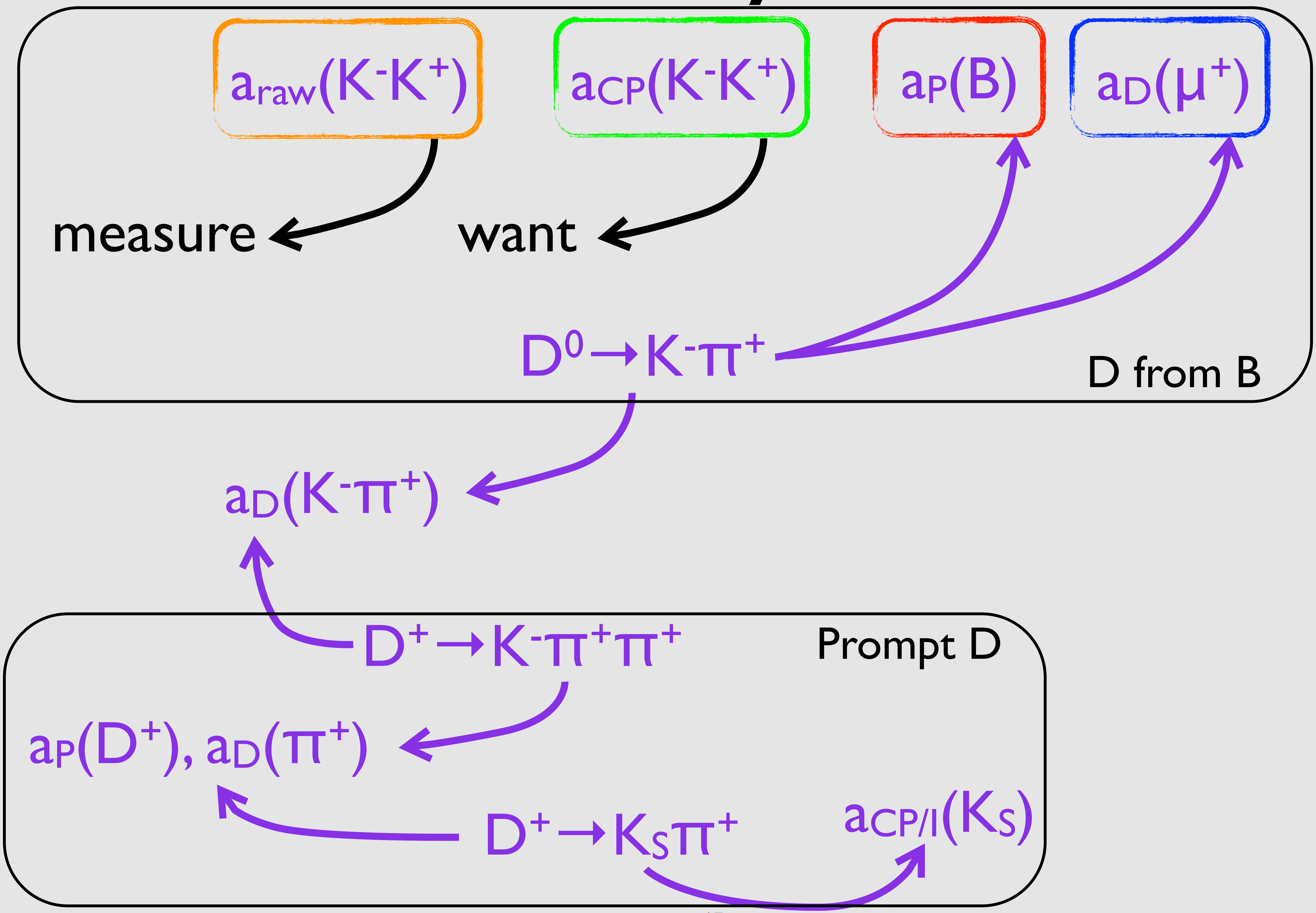
Individual asymmetries



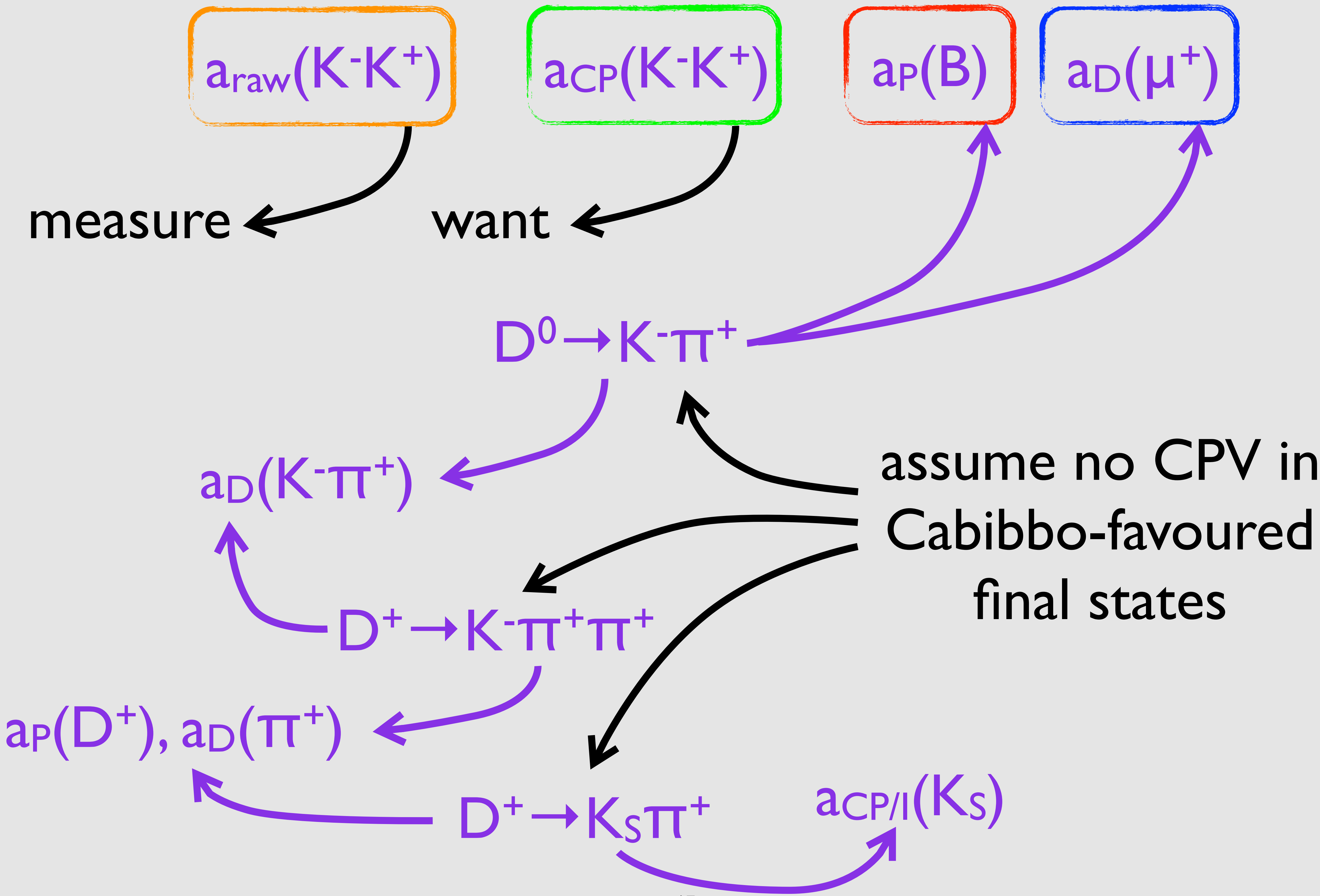
Individual asymmetries



Individual asymmetries



Individual asymmetries



- 1.5mb x 3/fb = 4.5e12 in acc/y in Run 1
  - ➡ 1e8 D->Kpi selected (0.05% effy)
- 3mb x 2/fb = 6e12 in acc/y Run 2
- 1.5e13 in acc/y in Run 3
  - ➡ 2e9 in 3 years (0.1% eff)
- 1e14 in acc/y in Run 4/5
  - ➡ 4e9/y selected (0.1% efficiency)