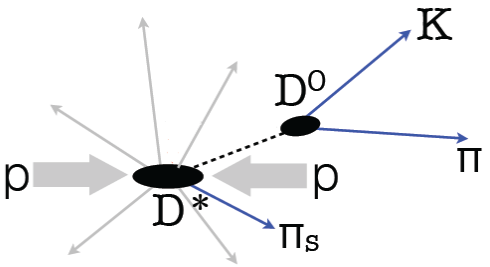


CP Violation Measurement in Wrong-Sign $D^0 \to K^+\pi^-$ Decays*

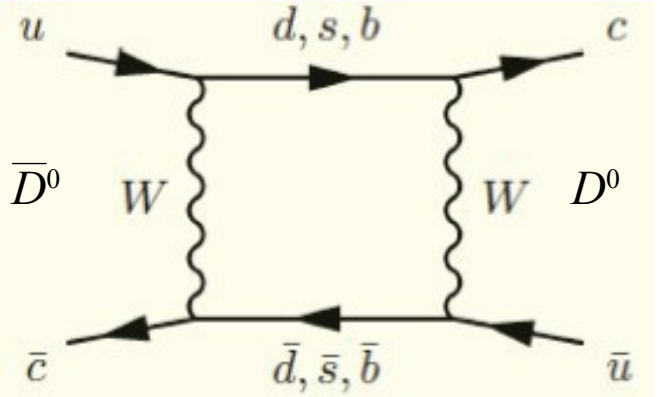
Liang Sun
University of Cincinnati
(On behalf of the LHCb collaboration)

8 – 10 January 2014, Krakow, Poland

PRL 111,251801

Mixing and CPV in $D^0 - \overline{D}^0$

- Charm mixing: unique probe of mixing in the up-type quark system
  - Mass eigenstates are related to their flavor eigenstates via $|D_{1,2}> \equiv p|D^0> \pm q|\overline{D}^0>$, with $|q|^2 + |p|^2 \equiv 1$
    - If indirect CPV is conserved, $|q/p| = 1$, $\phi \equiv \arg(q/p) = 0$
  - Mixing parameters based on the mass and width differences: $x \equiv (m_2 - m_1)/\Gamma$, $y \equiv (\Gamma_2 - \Gamma_1)/2\Gamma$, with $\Gamma \equiv (\Gamma_2 + \Gamma_1)/2$
- In the SM, expecting
  - x, y ~ 1% or less
  - CPV ~ 1% or less
- Observation of enhanced CPV in the charm sector would be a clear indication of new physics



Short-distance contribution

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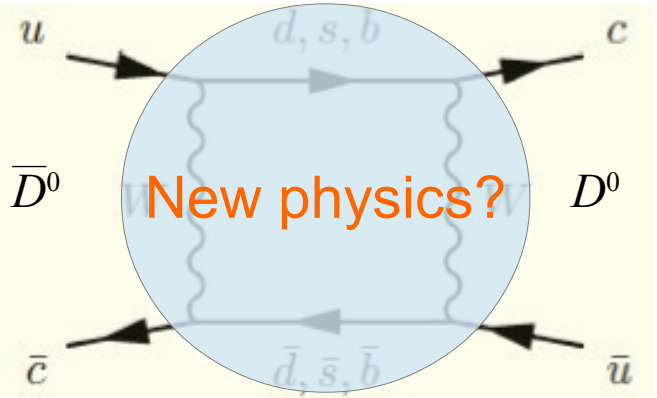
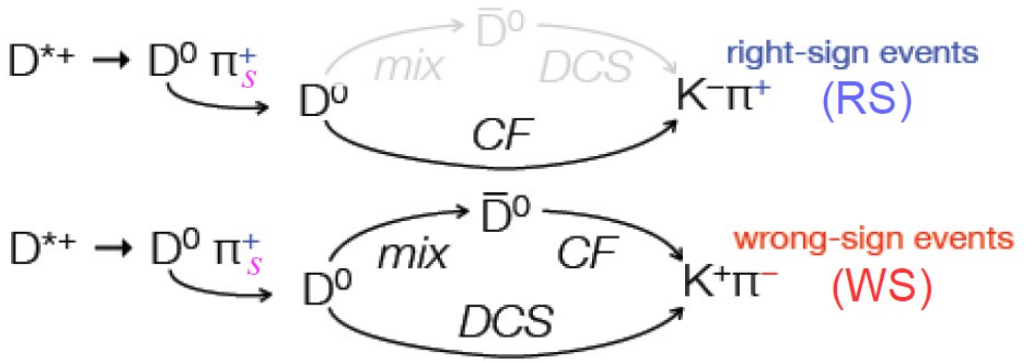


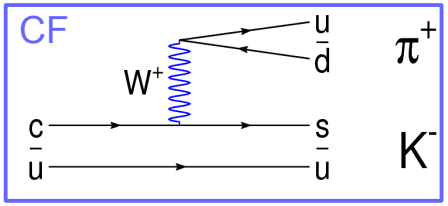
Short-distance contribution

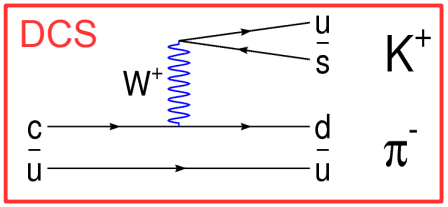
NP might manifest in the loop

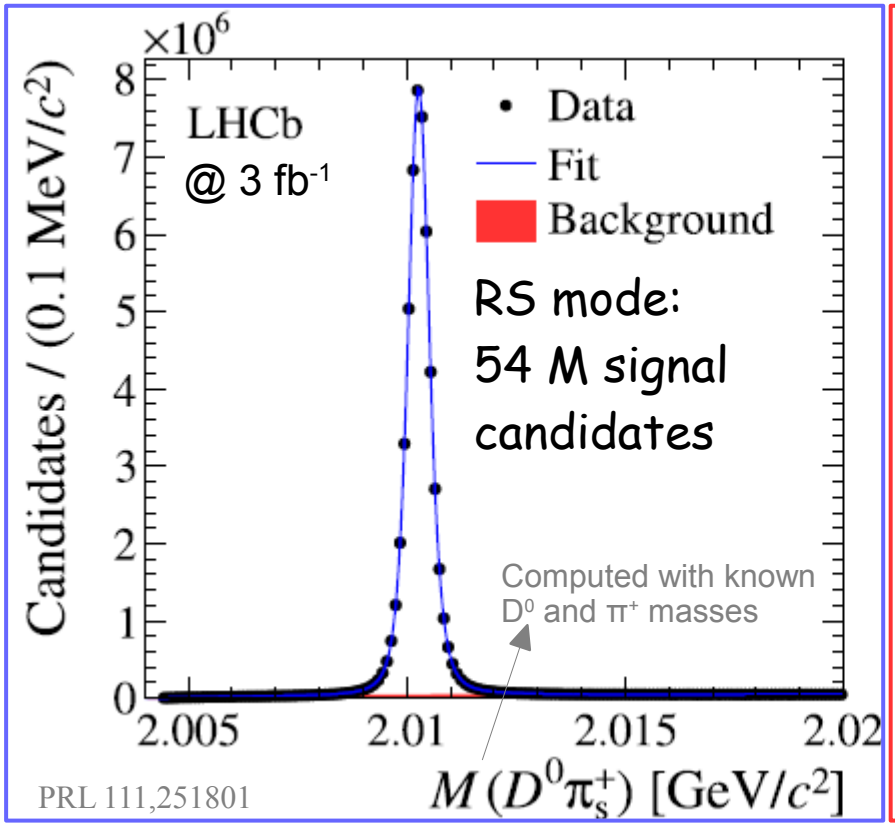
Signal extraction of $D^0 \to K\pi$

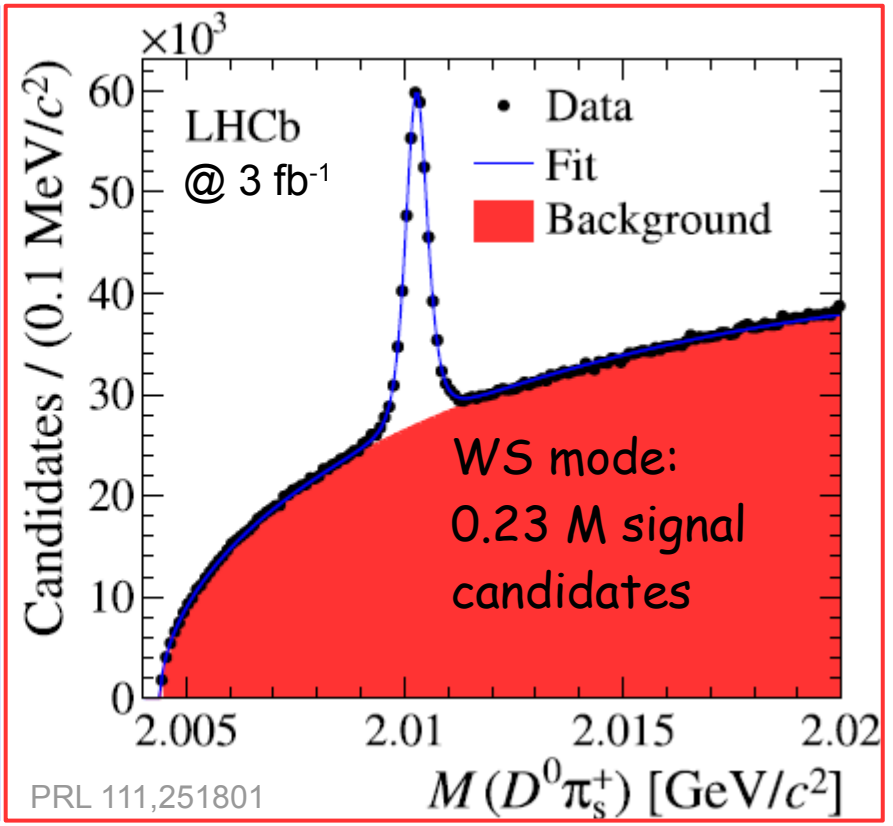
D^0 flavor is tagged by the "soft" pion from D*











Decay-time-dependent WS/RS ratios

- In the limit of x, y « 1, and assuming no CPV, the WS/RS yield ratio *R* varies with D^0 decay time *t* as:

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

τ: known D^0 lifetime R_D*: the ratio of DCS to CF decay rates*

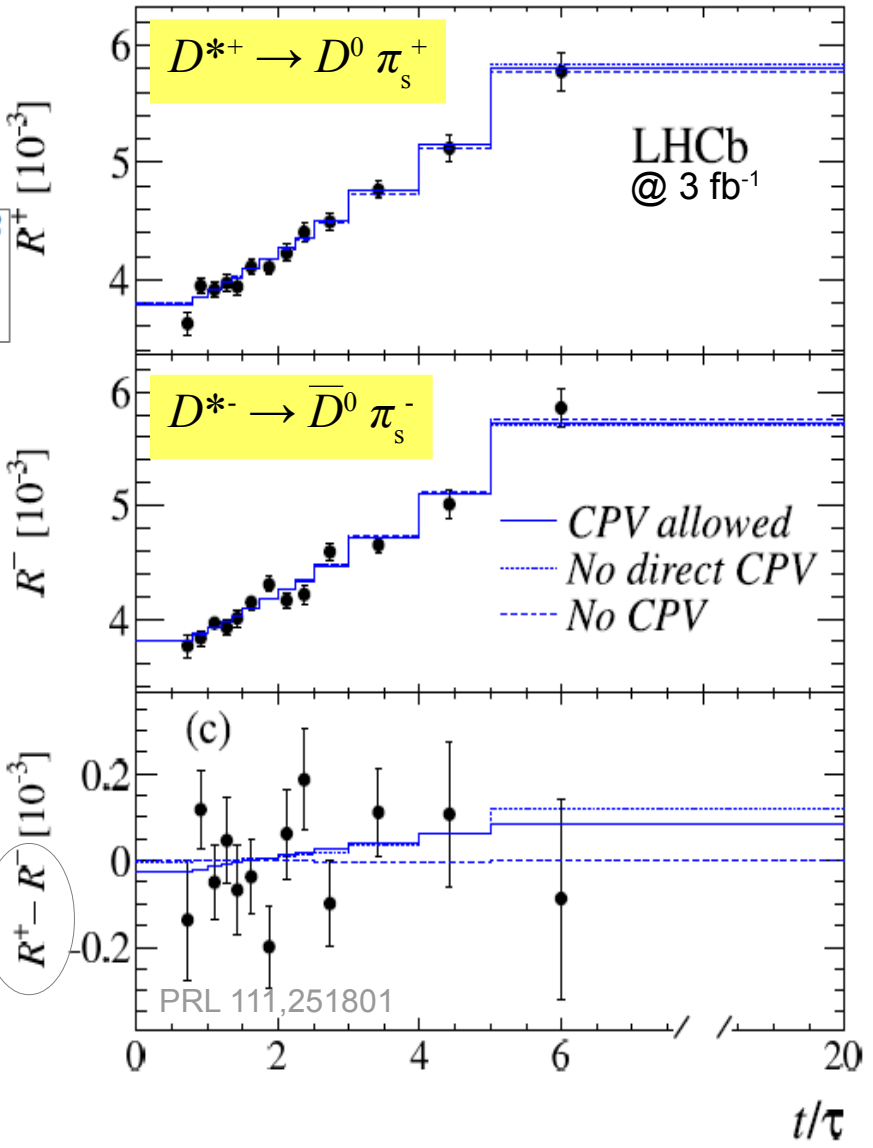
$x' \equiv x\cos\delta + y\sin\delta,\ y' \equiv y\cos\delta - x\sin\delta$

δ: strong phase difference btwn DCS and CF amplitudes

- We now write separately for D^0 (R^+) and $\overline{D}^0$ (R^-) to search for CPV:

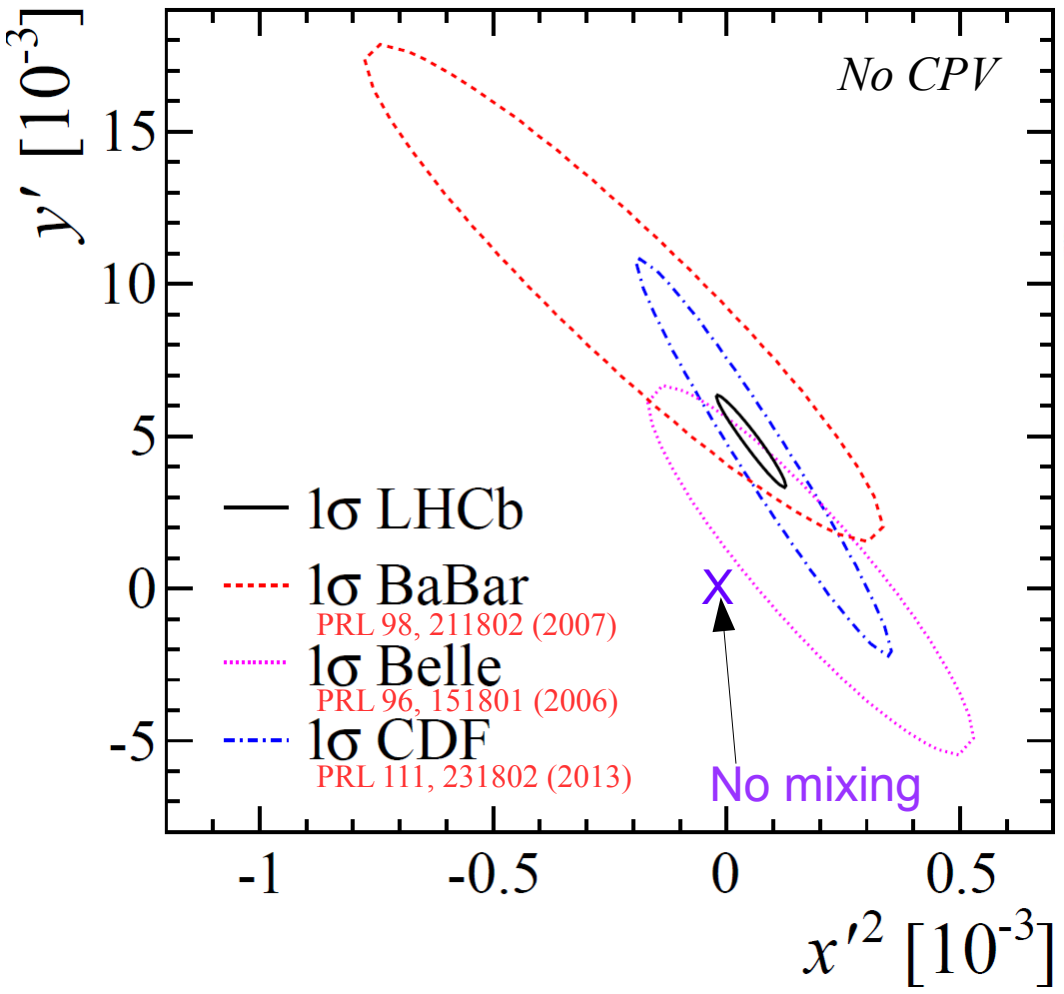
$$R^{\pm}(t) \approx R_D^{\pm} + \sqrt{R_D^{\pm}}\, y'^{\pm} \frac{t}{\tau} + \frac{x'^{2\pm} + y'^{2\pm}}{4} \left(\frac{t}{\tau}\right)^2$$

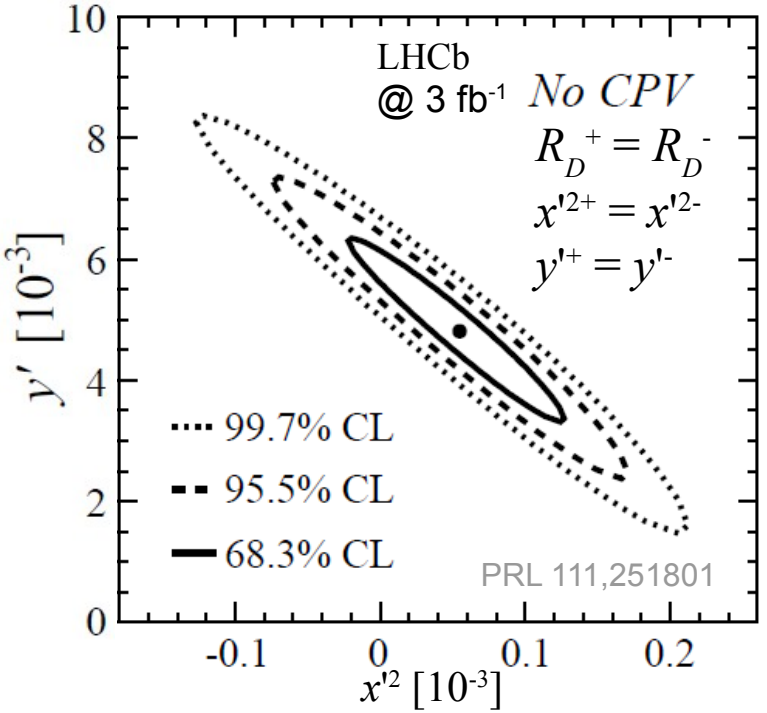
- Mixing parameters ($R_D^{\pm}$, $x'^{2\pm}$, $y'^{\pm}$) are measured separately in D^0 and $\overline{D}^0$ samples



Efficiency-corrected ratios accounting for the (decay-*time-independent, ~1%*) asymmetry in detection efficiency between $K^+\pi^-$ and $K^-\pi^+$

Mixing results



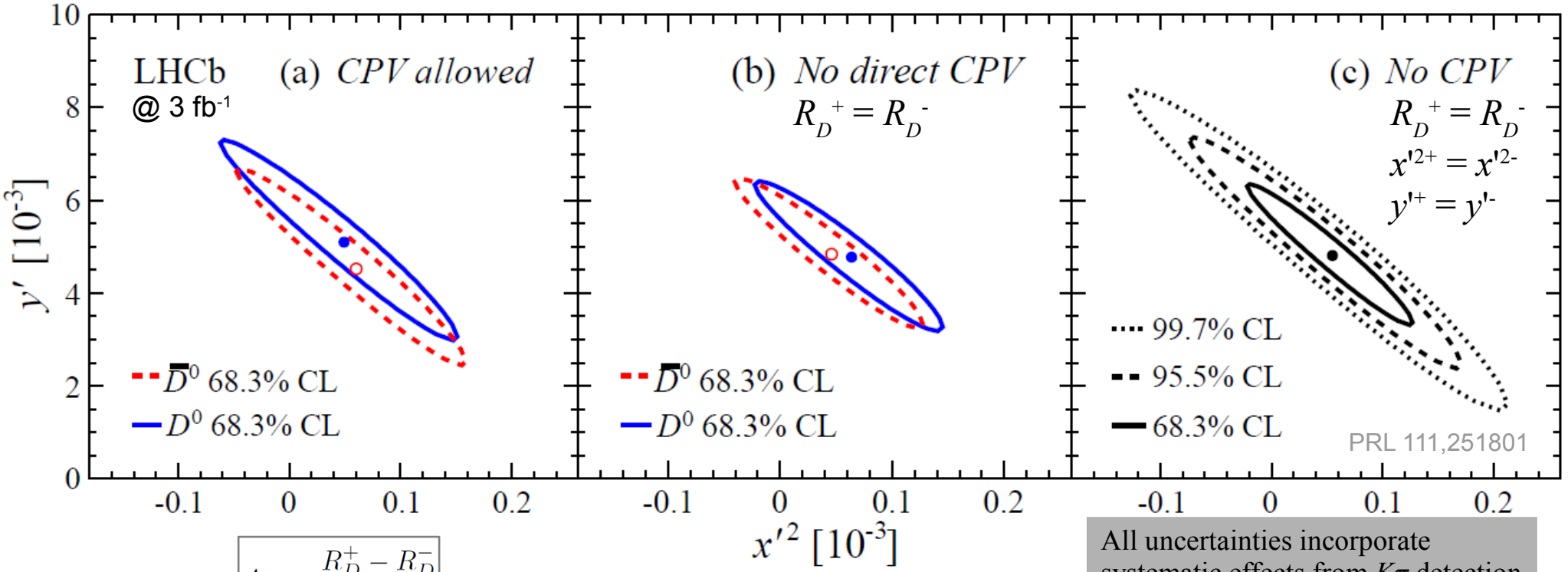


All uncertainties incorporate systematic effects from secondary D decays, etc

R_D	$[10^{-3}]$	3.568 ± 0.066
y'	$[10^{-3}]$	4.81 ± 1.00
x'^2	$[10^{-5}]$	5.5 ± 4.9
χ^2/ndf		86.41/101

LHCb mixing results are consistent with those from other experiments

Mixing and CPV results



$$A_D = \frac{R_D^+ - R_D^-}{R_D^+ + R_D^-}$$

All uncertainties incorporate systematic effects from $K\pi$ detection asymmetry, secondary D decays, etc

Direct and indirect CP violation			no direct CP violation			no CP violation		
R_D	$[10^{-3}]$	3.568 ± 0.066	R_D	$[10^{-3}]$	3.568 ± 0.066	R_D	$[10^{-3}]$	3.568 ± 0.066
A_D	$[10^{-2}]$	-0.7 ± 1.9	y'^+	$[10^{-3}]$	4.78 ± 1.07	y'	$[10^{-3}]$	4.81 ± 1.00
y'^+	$[10^{-3}]$	5.1 ± 1.4	x'^{2+}	$[10^{-5}]$	6.4 ± 5.5	x'^2	$[10^{-5}]$	5.5 ± 4.9
x'^{2+}	$[10^{-5}]$	4.9 ± 7.0	y'^-	$[10^{-3}]$	4.83 ± 1.07	χ^2/ndf		86.41/101
y'^-	$[10^{-3}]$	4.5 ± 1.4	x'^{2-}	$[10^{-5}]$	4.6 ± 5.5			
x'^{2-}	$[10^{-5}]$	6.0 ± 6.8	χ^2/ndf		85.99/99			
χ^2/ndf		85.87/98						

Results are consistent with CP conservation

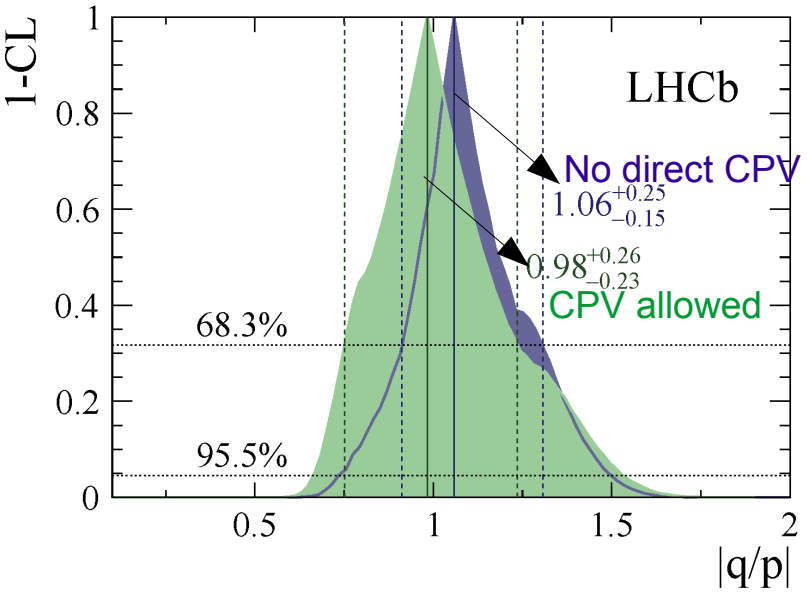
Interpretation of the LHCb results

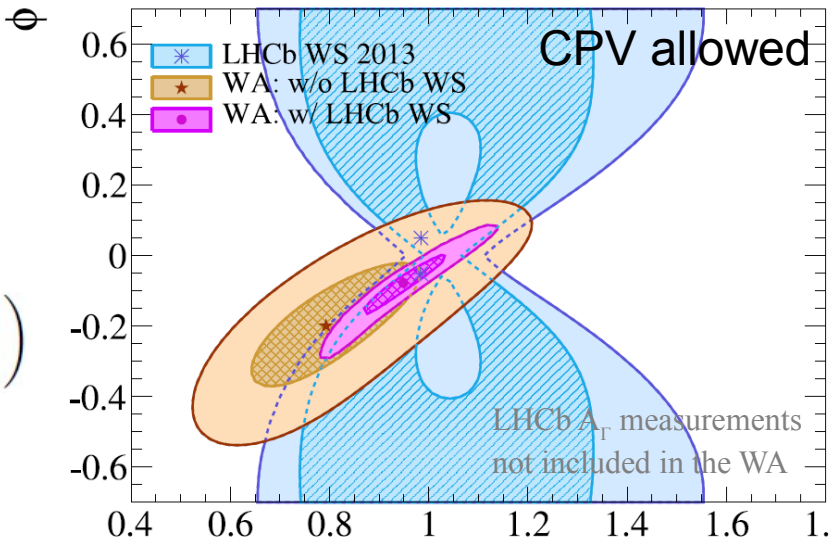
- Using only the LHCb results, and with the constraints of:

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

$$\phi = \arg\left(\frac{q}{p}\right)$$

- The 68.3% C.L. constraints
  - 0.75 < |q/p| < 1.24 for all CPV allowed
  - 0.91 < |q/p| < 1.31 for the case without direct CPV
- The LHCb results contribute in the global fits for $D^0 - \overline{D}^0$ mixing
- In the case without direct CPV, the superweak relationship* $\phi = \tan^{-1}\left(\frac{1-|q/p|^2}{1+|q/p|^2}\frac{x}{y}\right)$ is applicable, and |q/p| can be constrained with precision of ~1%





World averages with and without the LHCb results

* A. L. Kagan, M. D. Sokoloff, PRD 80, 076008 (2009)

Summary

- LHCb now provides the WS mixing and CPV measurements with unprecedented level of precision
- Neither direct CPV or CPV in D^0 – $\overline{D}^0$ mixing is observed, being consistent with SM
- The LHCb CPV results are capable of playing an important role in constraining |q/p|

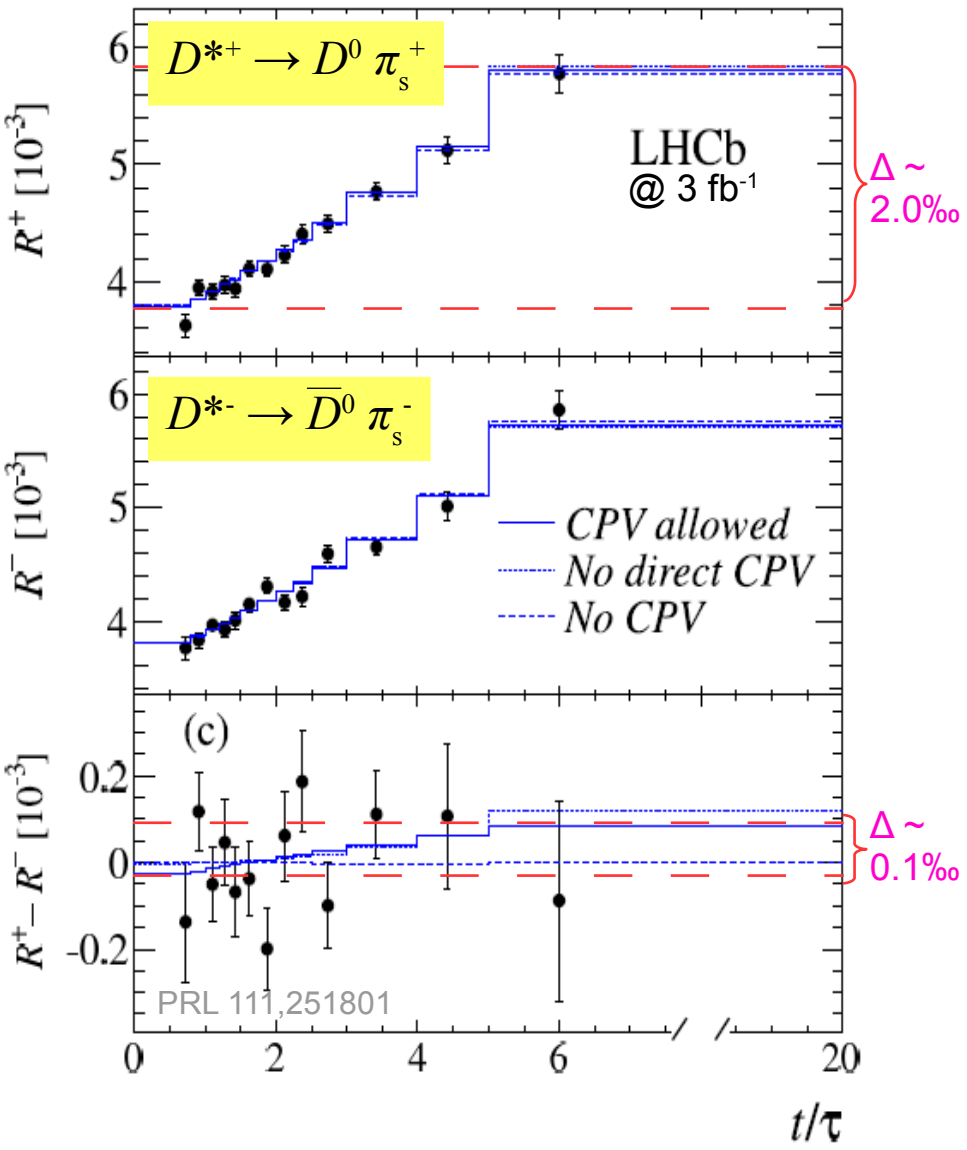
Backup Slides

WS/RS ratio versus D^0 decay time

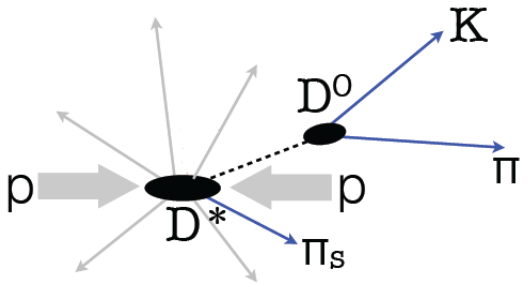
$$R^{\pm}(t) \approx R_D^{\pm} + \sqrt{R_D^{\pm}}\, y'^{\pm}\, \frac{t}{\tau} + \frac{x'^{2\pm} + y'^{2\pm}}{4} \left(\frac{t}{\tau}\right)^2$$

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

- Fit the WS/RS ratio as a function of decay time under three hypotheses:
  - No CPV
    - $|q/p| = 1,\ \phi \equiv \arg(q/p) = 0$
    - $R_D^{+} = R_D^{-},\ x'^{2+} = x'^{2-},\ y'^{+} = y'^{-}$
  - No direct CPV (CPV in mixing allowed)
    - $R_D^{+} = R_D^{-}$
  - CPV allowed (for the direct and indirect CPV)



LHCb detector



Hardware trigger system for hadrons: based on large E_T depositions in the hadron Cal.

Tracking system:
$\Delta p/p$ = 0.4-0.6% @ 5-100 GeV/c, corresponding to ~8 MeV/c^2 mass resolution for D → Kπ

Requiring $|M(K\pi) - M(D^0)| < 24$ MeV/c^2

Muon

EM + Hadron Calorimeters

RICH2

IT+OT

Magnet

TT

RICH1

VELO

RICH detectors:
Good K/π separation for p < 100 GeV/c with mis-ID rate at a few percent

Silicon Vertex Locator:
20 μm impact parameter (IP) resolution, corresponding to ~0.1τ decay-time resolution for D → Kπ