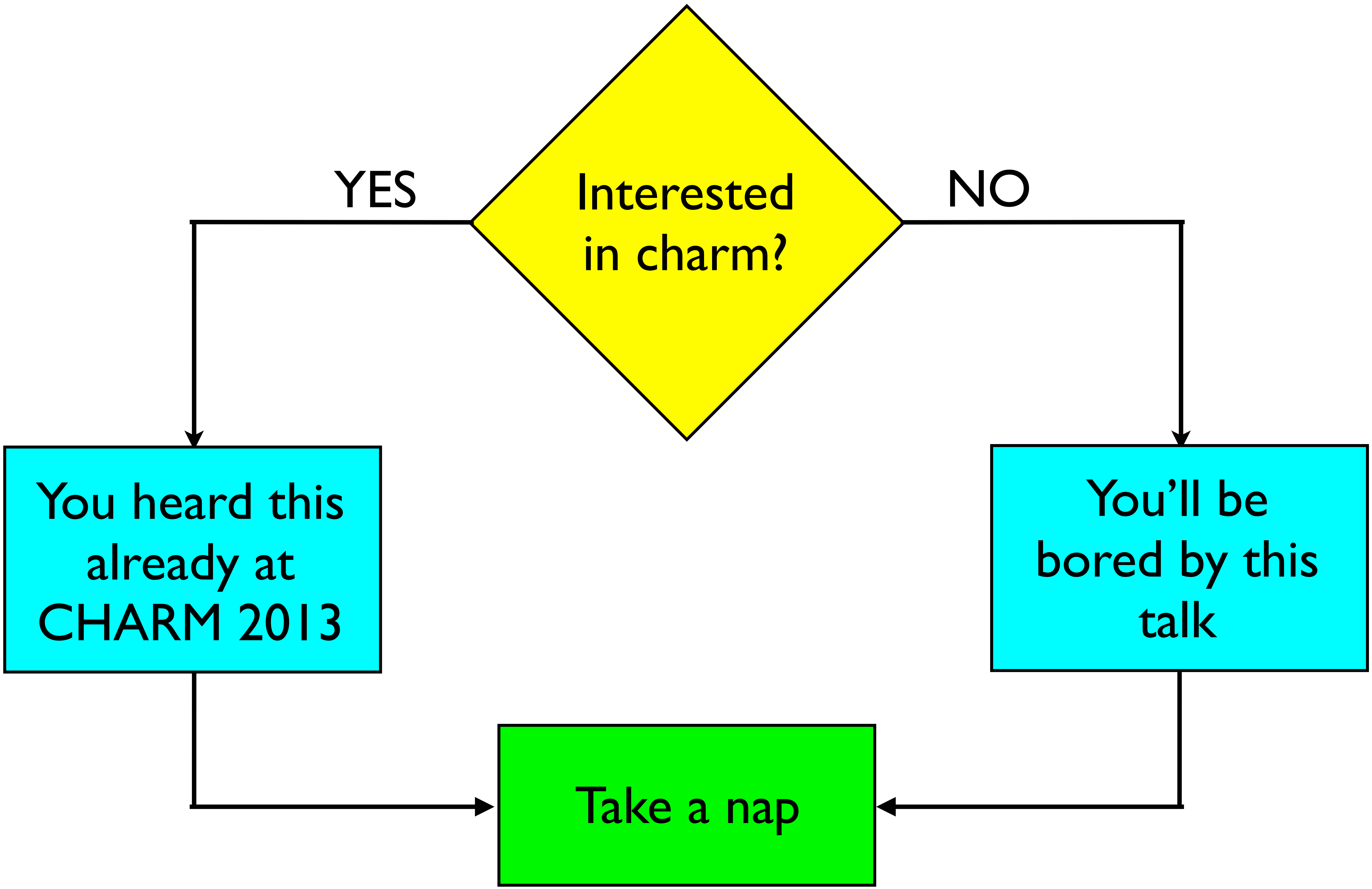
Charm CP violation & mixing

Mat Charles (Oxford & UPMC)

Overview



YES
Interested in charm?
NO
You heard this already at CHARM 2013
You'll be bored by this talk
Take a nap

Overview

- Mixing & time-dependent searches for indirect CPV
- Time-integrated searches for direct CPV

Mixing & indirect CPV

- Old news:
  - LHCb & CDF measurements of mixing in $D^0 \to K^+ \pi^-$ (WS)
  - BABAR & Belle measurements of mixing & CPV in $D^0 \to h^+ h^-$
- New news:
  - LHCb measurement of CPV in $D^0 \to h^+ h^-$
  - LHCb measurement of mixing & CPV in $D^0 \to K^+ \pi^-$ (WS)
  - Belle measurement of mixing & CPV in $D^0 \to K_S h^+ h^-$

Standard mixing formalism

Mixing occurs for neutral mesons $M^0 = K^0, D^0, B^0, B_s{}^0$

Decompose into mass eigenstates $|M_{1,2}\rangle$:

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

$$|M_{1,2}(t)\rangle = e^{-i(m_{1,2} - i\Gamma_{1,2}/2)t}|M_{1,2}(t=0)\rangle$$

... and we can invert to get $|M^0(t)\rangle$ given $m_{1,2}$, $\Gamma_{1,2}$, q/p...

General time evolution:

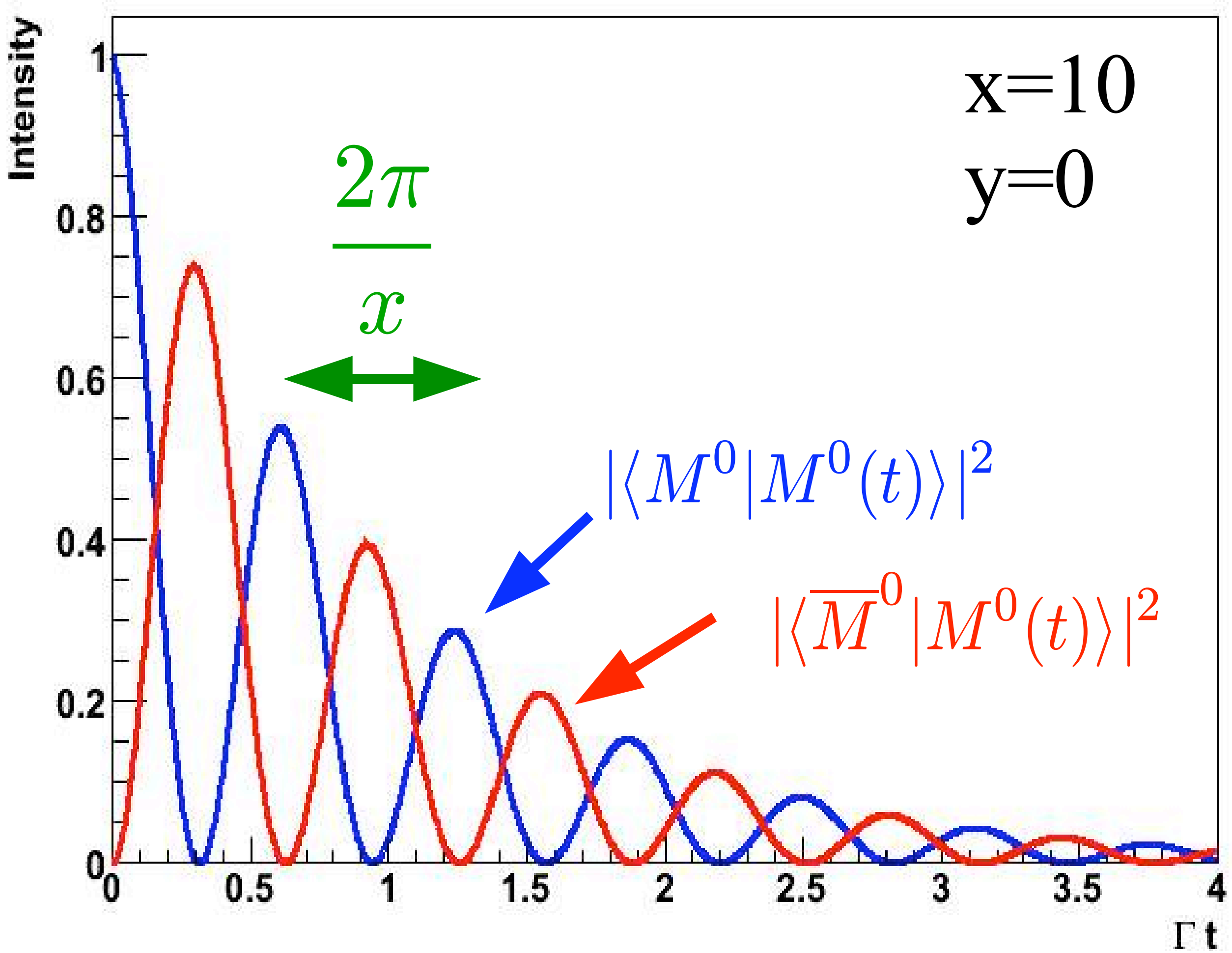
$$\begin{aligned}
|M(t)\rangle &= \frac{1}{2p}\left[e^{-i(m_1 - \frac{i}{2}\Gamma_1)t}(p|M\rangle + q|\overline{M}\rangle) + e^{-i(m_2 - \frac{i}{2}\Gamma_2)t}(p|M\rangle - q|\overline{M}\rangle)\right] \\
|\overline{M}(t)\rangle &= \frac{1}{2q}\left[e^{-i(m_1 - \frac{i}{2}\Gamma_1)t}(p|M\rangle + q|\overline{M}\rangle) - e^{-i(m_2 - \frac{i}{2}\Gamma_2)t}(p|M\rangle - q|\overline{M}\rangle)\right]
\end{aligned}$$

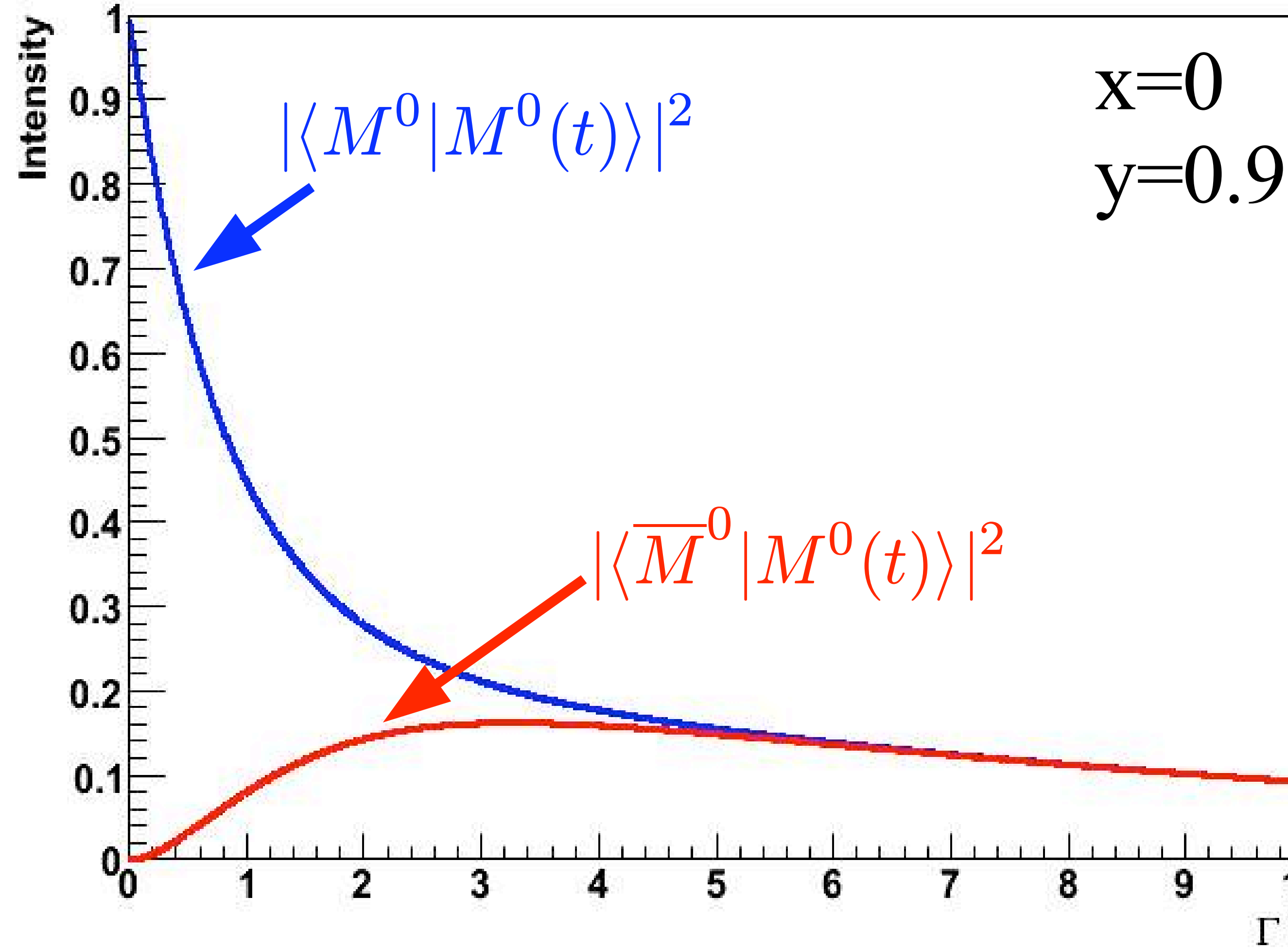
Cartoon of mixing

For convenience, define:

$$\Gamma = \frac{\Gamma_2 + \Gamma_1}{2} \qquad x = \frac{m_1 - m_2}{\Gamma} \qquad y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$$

and $R_M = \dfrac{x^2 + y^2}{2}$

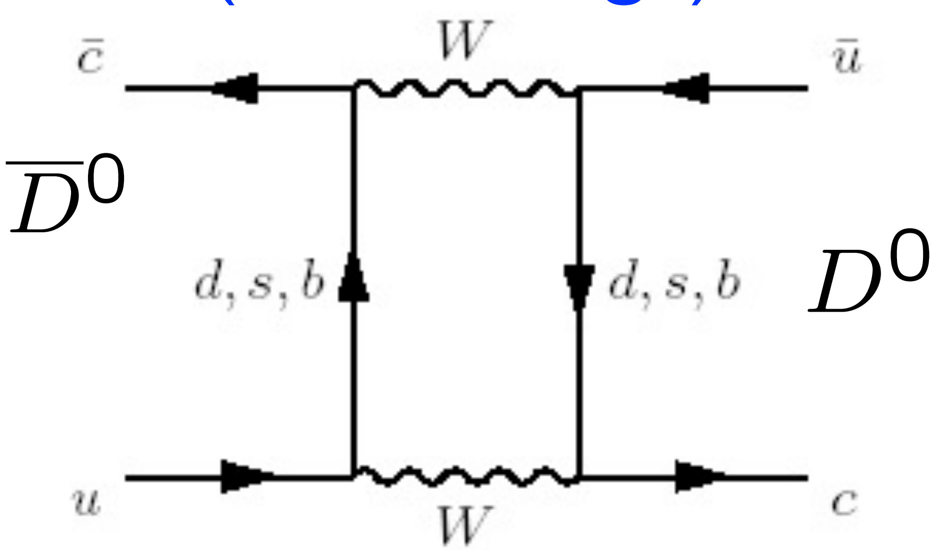




Mixing in charmed mesons

Charm mixing small compared to other mesons in SM:

Mixing via box diagram (short-range)



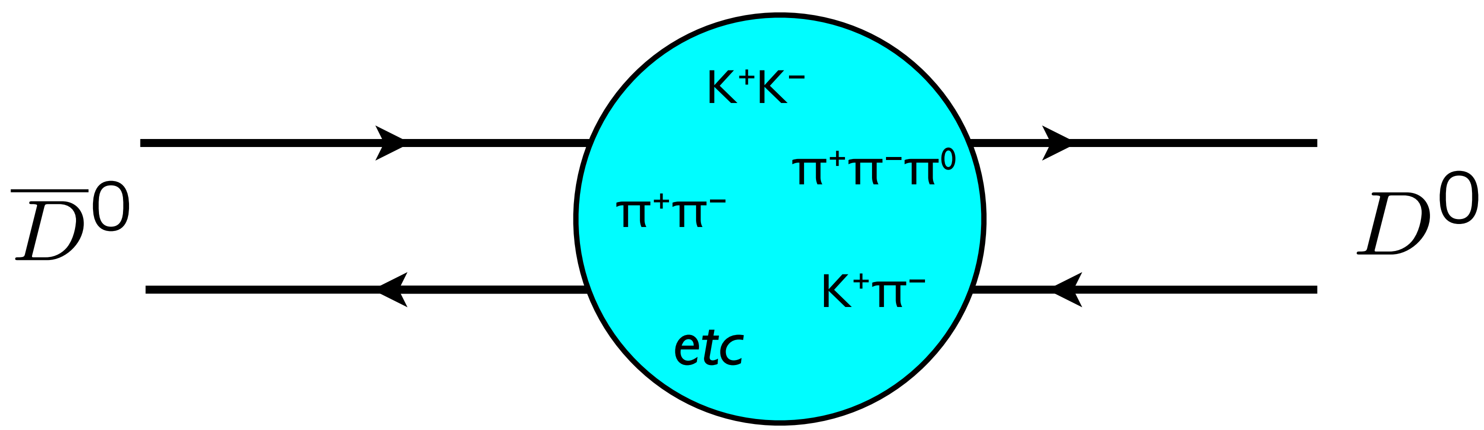
Contributes mainly to x

Intermediate b: CKM-suppressed
Intermediate d,s: GIM-suppressed

$$x \propto \frac{(m_s^2 - m_d^2)^2}{m_c^2} \sim 10^{-5}$$

Tiny!

Mixing via hadronic intermediate states (long-range)



Non-perturbative; hard to predict SM contribution.

Currently: $|x| \leq 0.01$, $|y| \leq 0.01$ – less tiny!

e.g. PRD 69,114021 (Falk, Grossman, Ligeti, Nir & Petrov)

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CP violation

- 3 types of CP violation:
  - In decay: amplitudes for a process and its conjugate differ
  - In mixing: rate of $D^0 \to \overline{D}^0$ and $\overline{D}^0 \to D^0$ differ
  - In interference between mixing and decay diagrams

Direct

Indirect

- In the SM, indirect CP violation in charm is expected to be very small and universal between CP eigenstates
  - Perhaps $O(10^{-3})$ for CPV parameters => $O(10^{-5})$ for observables like A_Γ
- Direct CP violation can be larger in SM, very dependent on final state (therefore we must search wherever we can)
  - Negligible in Cabibbo-favoured modes (SM tree dominates everything)
  - In generic singly-Cabibbo-suppressed modes: up to $O(10^{-3})$ plausible
- Both can be enhanced by NP, in principle up to O(%)

Bianco, Fabbri, Benson & Bigi, Riv. Nuovo. Cim 26N7 (2003)
Grossman, Kagan & Nir, PRD 75, 036008 (2007)
Bigi, arXiv:0907.2950

Bobrowski, Lenz, Riedl & Rorhwild, JHEP 03 009 (2010)
Bigi, Blanke, Buras & Recksiegel, JHEP 0907 097 (2009)

CPV in charm not yet discovered

Mixing and indirect CPV

- D^0 mesons undergo mixing like K^0, B^0, $B_s{}^0$
- But unlike the others, D^0 mixing is small.
  - Mixing parameters x, y order of 10^{-2}
- First seen by BABAR & Belle in 2007
- Now well-established: multiple results exclude no-mixing hypothesis by > 5σ
- Smallness of mixing parameters makes CP asymmetries doubly small, e.g.

CP-violating terms < 10^{-2} in SM

$$2A_\Gamma = (|q/p| - |p/q|)\, y \cos\phi - (|q/p| + |p/q|)\, x \sin\phi$$

(neglecting direct CPV)

Mixing parameters $O(10^{-2})$

Observable asymmetry < 10^{-4} in SM

Mixing via CP eigenstates

Define $y_{CP} = \frac{\tau(K^-\pi^+)}{\tau(K^+K^-)} - 1$

$D^0 \to K^- \pi^+$: Mixture of CP states

$D^0 \to K^- K^+$: CP-even eigenstate

y_{CP} related to y and CP parameters by:

$$y_{CP} = y\cos\phi - \frac{1}{2}A_M x \sin\phi$$

$A_M \neq 0$: CPV in mixing (asymmetry in R_M between D^0 and D^0)

$\cos\phi \neq 1$: CPV in interference between mixing and decay

CP observable A_Γ defined as:

$$A_\Gamma = \frac{\tau(\overline{D}^0 \to K^-K^+) - \tau(D^0 \to K^-K^+)}{\tau(\overline{D}^0 \to K^-K^+) + \tau(D^0 \to K^-K^+)}$$

$$2A_\Gamma = (|q/p| - |p/q|)\, y\cos\phi - (|q/p| + |p/q|)\, x\sin\phi$$

(neglecting direct CPV)

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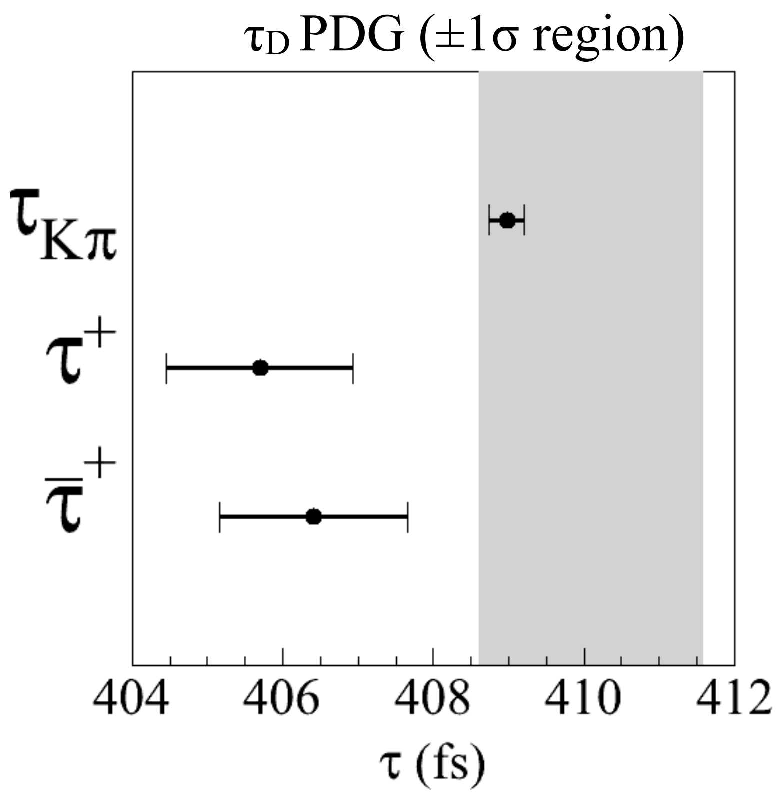
BABAR & Belle measurements



468 fb^{-1} PRD 87, 012004 (2013)

$$y_{CP} = [0.720 \pm 0.180(\text{stat}) \pm 0.124(\text{syst})]\%$$

$$\Delta Y = [0.088 \pm 0.255(\text{stat}) \pm 0.058(\text{syst})]\%$$

- no mixing hypothesis excluded at 3.3 σ level
- no CPV observed

$$y_{CP} = (+1.11 \pm 0.22 \pm 0.11)\%$$

$$A_\Gamma = (-0.03 \pm 0.20 \pm 0.08)\%$$

977 fb^{-1} preliminary
arXiv:1212.3478

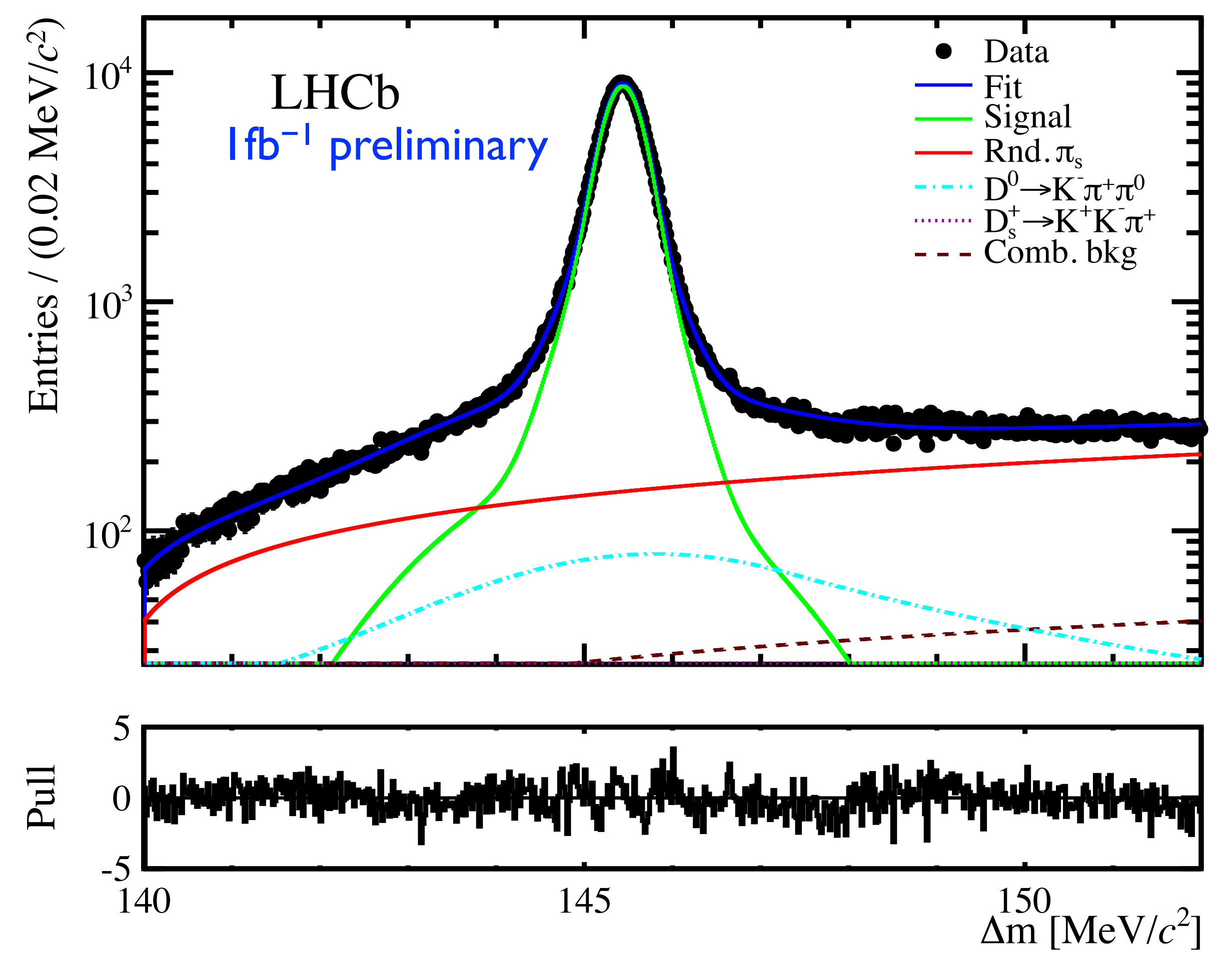
New LHCb measurement

- New result at CHARM on 2011 data (1fb^{-1})
- Uses two complementary methods:
  - Multidimensional fit to { m(h$^+$h$^-$), Δm, t, ln(IPχ^2) } floating A_Γ directly
  - Divide into bins of t, fit $D^0/\bar{D}^0$ ratio in each bin separately
- First method is more sophisticated (uses swimming) and ultimately has better precision -- but more moving parts
- Second method simpler

$$A_\Gamma(K^+K^-) = (-0.35 \pm 0.62 \pm 0.12) \times 10^{-3}$$
$$A_\Gamma(\pi^+\pi^-) = (+0.33 \pm 1.06 \pm 0.14) \times 10^{-3}$$

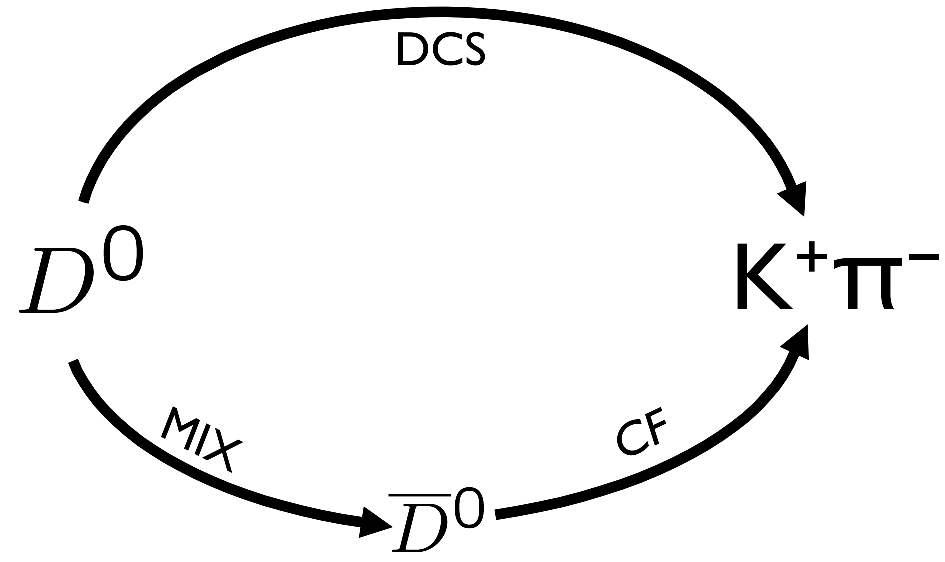
1fb^{-1} preliminary

No sign of indirect CPV in this analysis.



LHCB-PAPER-2013-054-001

Mixing via wrong-sign decays



δ: strong phase between DCS and CF amplitudes

$x' = x\cos\delta + y\sin\delta$
$y' = y\cos\delta - x\sin\delta$

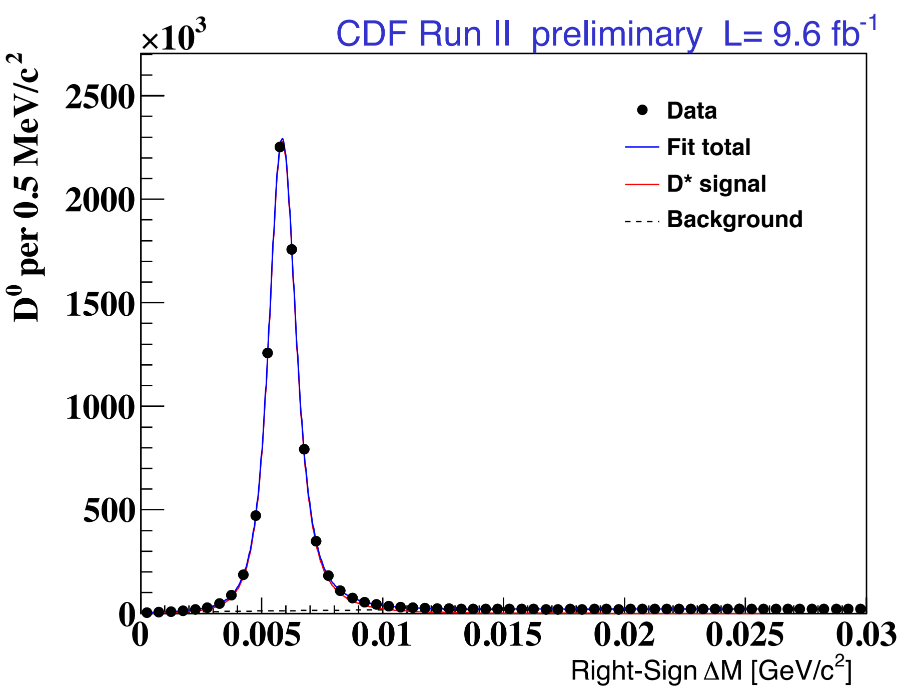
$$\Gamma_{WS}(t) = e^{-\Gamma t}\left(\underbrace{R_D}_{\text{DCS}} + \underbrace{y'\sqrt{R_D}}_{\text{Interference}}(\Gamma t) + \underbrace{\frac{x'^2+y'^2}{4}}_{\text{Mixing}}(\Gamma t)^2\right)$$

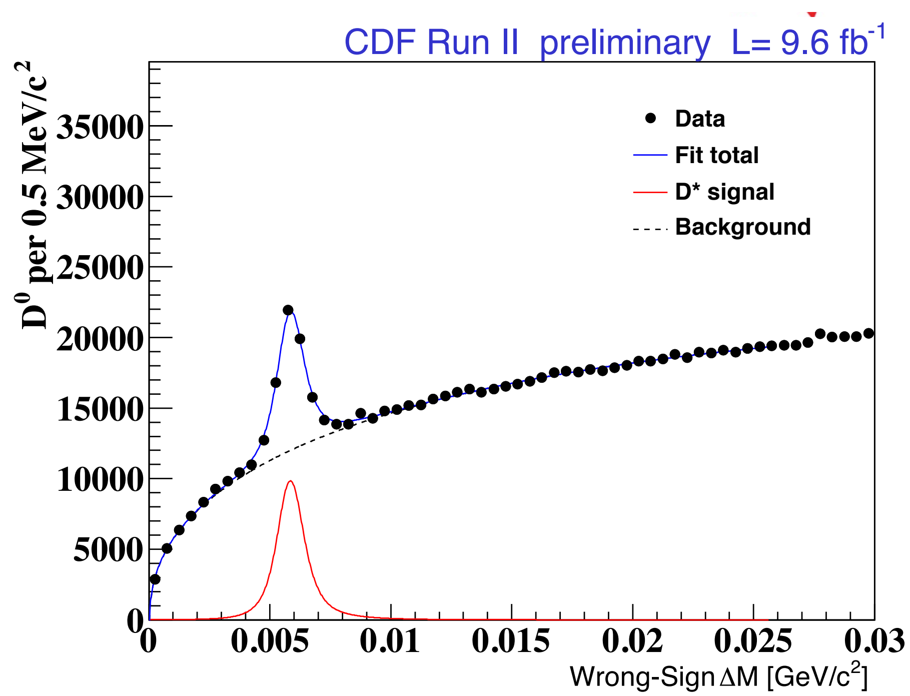
[Limit of |x| ≪ 1, |y| ≪ 1, and no CPV.]

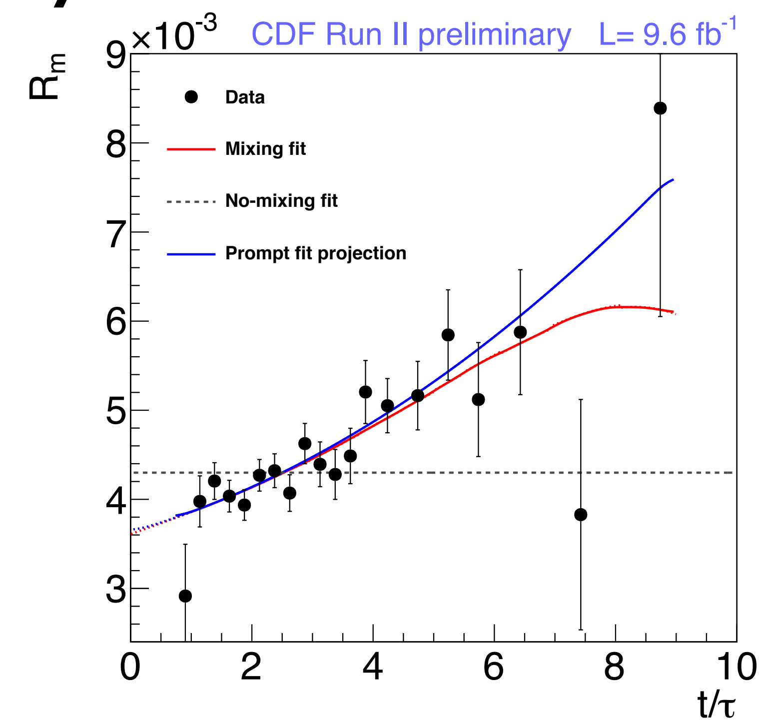
- $D^0 \rightarrow K^+\pi^-$ simplest, but can also use $K\pi\pi^0$, $K\pi\pi\pi$, etc
  - different strong phases; also coherence term for multi-body final states

Recent LHCb & CDF mixing results

- Divide data into bins of time
- Fit $D^0/\overline{D}^0$ ratio in each bin separately
- Beautiful, clean method -- v. robust against systematics





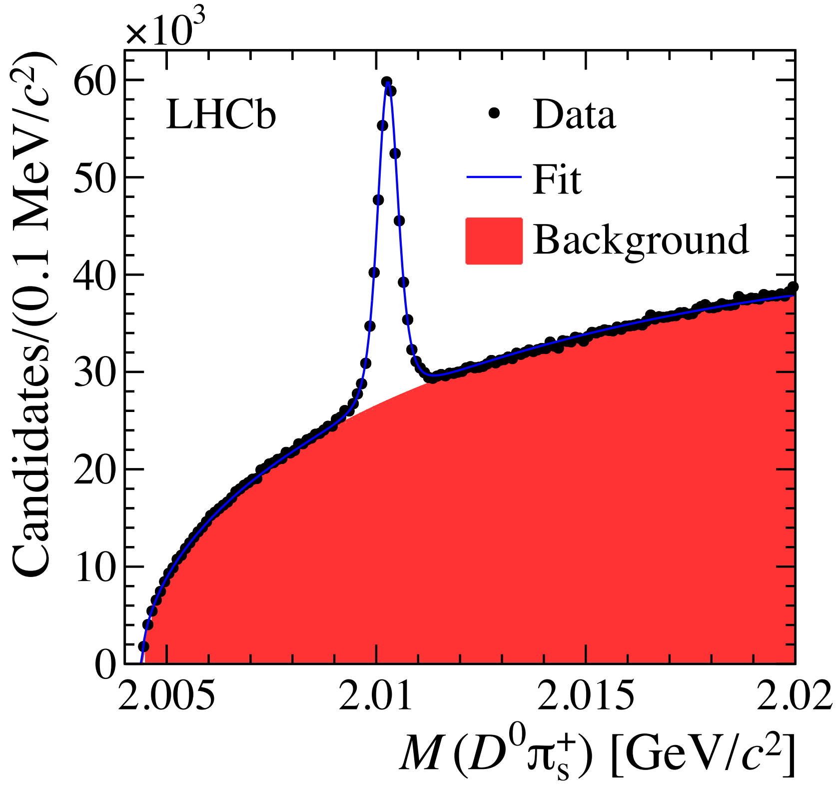


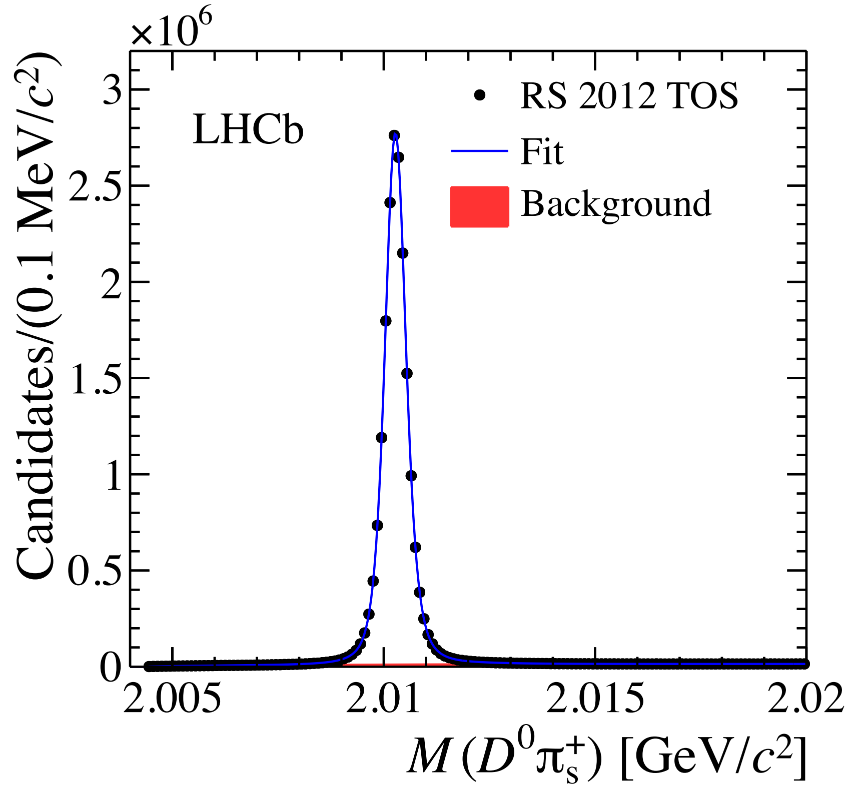
Expt.	$R_D(10^{-3})$	$y'\ (10^{-3})$	$x'^2\ (10^{-3})$	σ no mixing
CDF (now)	3.51 ± 0.35	4.3 ± 4.3	0.08 ± 0.18	6.1 (preliminary)
Belle [11]	3.64 ± 0.17	$0.6\ ^{+4.0}_{-3.9}$	$0.18\ ^{+0.21}_{-0.23}$	2.0
BABAR[2]	3.03 ± 0.19	9.7 ± 5.4	-0.22 ± 0.37	3.9
CDF [4]	3.04 ± 0.55	8.5 ± 7.6	-0.12 ± 0.35	3.8
LHCb [6]	3.52 ± 0.15	7.2 ± 2.4	-0.09 ± 0.13	9.1

LHCb: PRL 110, 101802 (2013)
CDF Note 10990

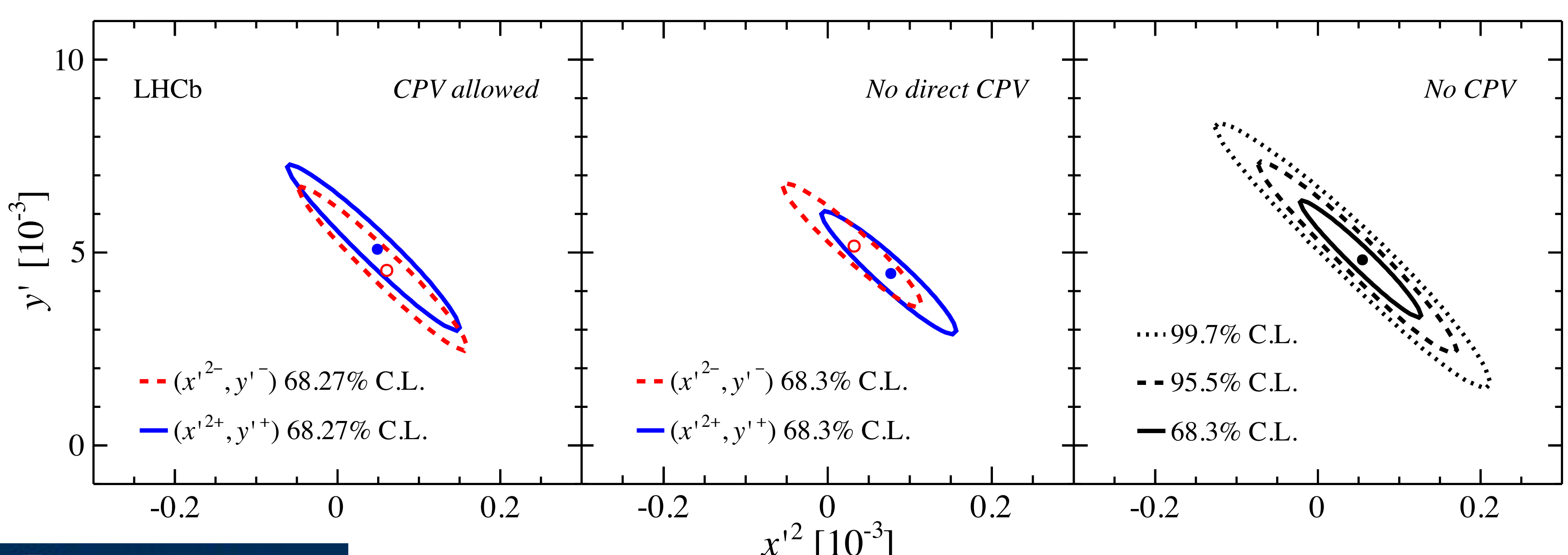
Brand new LHCb result

- New at CHARM: full 2011+2012 prompt D^{*+} sample (3/fb)
- Adds CPV search (fit D^{*+}, D^{*-} separately)





No *CP* violation	
R_D $[10^{-3}]$	$3.568 \pm 0.058 \pm 0.033$
y' $[10^{-3}]$	$4.81 \pm 0.85 \pm 0.53$
x'^2 $[10^{-5}]$	$5.5 \pm 4.2 \pm 2.6$
χ^2/ndf	$87.45/101$
No direct *CP* violation	
R_D $[10^{-3}]$	$3.568 \pm 0.058 \pm 0.033$
y'^+ $[10^{-3}]$	$4.46 \pm 0.89 \pm 0.57$
x'^{2+} $[10^{-5}]$	$7.7 \pm 4.6 \pm 2.9$
y'^- $[10^{-3}]$	$5.17 \pm 0.89 \pm 0.58$
x'^{2-} $[10^{-5}]$	$3.2 \pm 4.7 \pm 3.0$
χ^2/ndf	$86.32/99$
Direct and indirect *CP* violation	
R_D $[10^{-3}]$	$3.568 \pm 0.058 \pm 0.033$
A_D $[10^{-2}]$	$-1.3 \pm 1.6 \pm 0.9$
y'^+ $[10^{-3}]$	$5.1 \pm 1.2 \pm 0.7$
x'^{2+} $[10^{-5}]$	$4.9 \pm 6.0 \pm 3.6$
y'^- $[10^{-3}]$	$4.5 \pm 1.2 \pm 0.7$
x'^{2-} $[10^{-5}]$	$6.0 \pm 5.8 \pm 3.6$
χ^2/ndf	$85.87/98$



No sign of indirect CPV in this analysis.

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LHCb-PAPER-2013-053 (preliminary)

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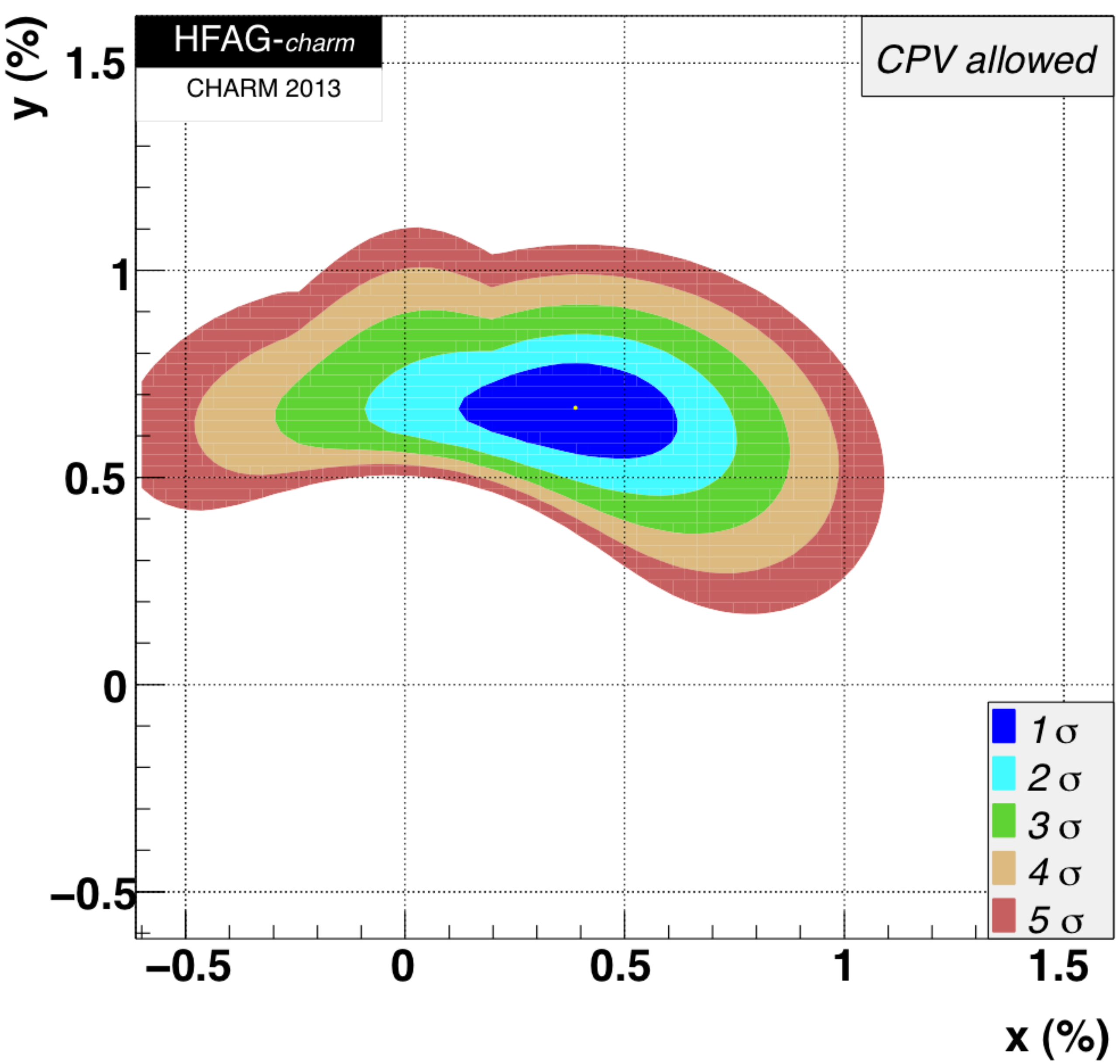
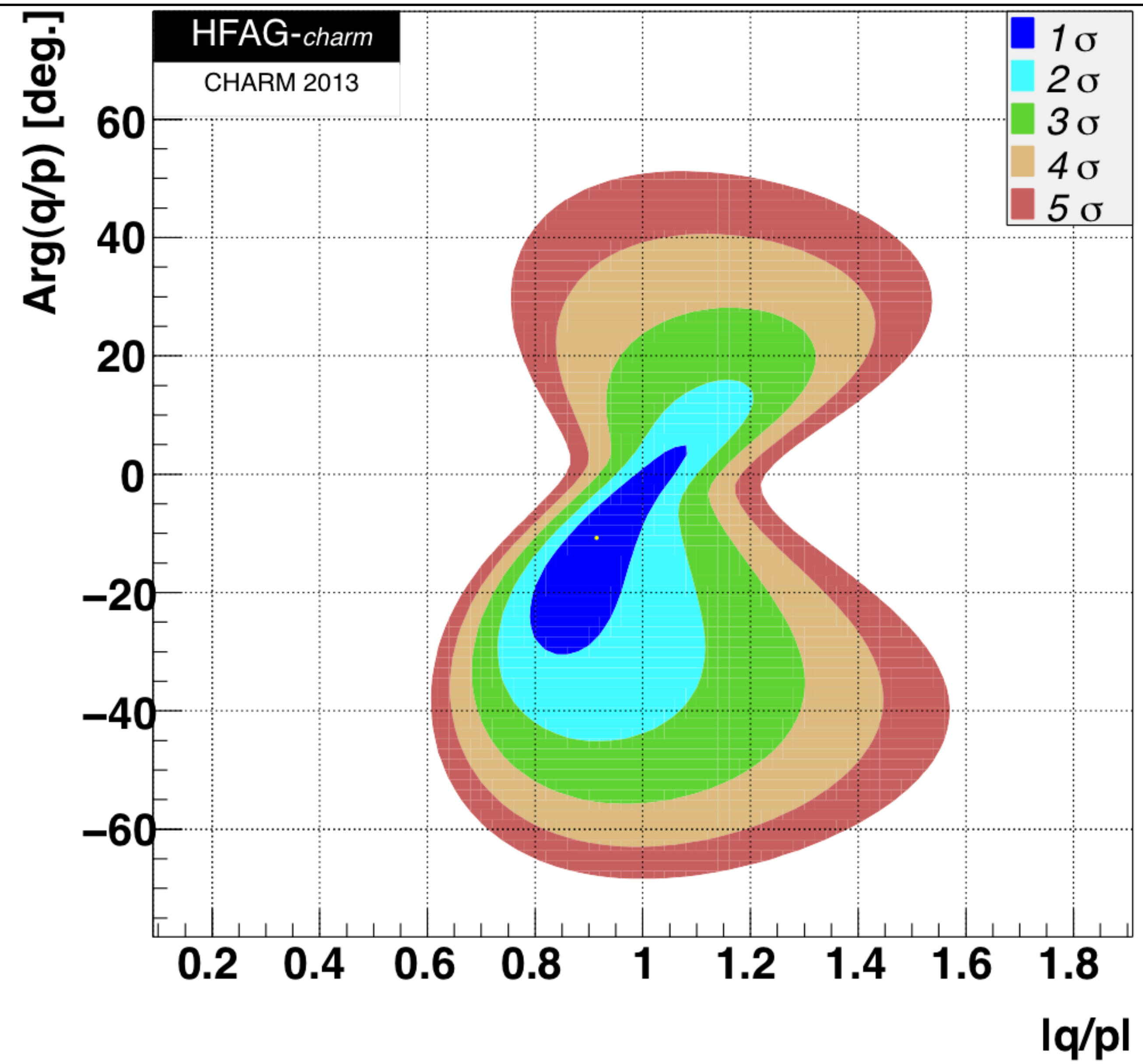
New HFAG averages





CPV-allowed plot, no mixing (x,y) = (0,0) point: $\Delta\chi^2 > 300$

No CPV (|q/p|, φ*) = (1,0) point:* $\Delta\chi^2 = 1.479$*, CL = 0.48 , consistent with no CPV*

Alan Schwartz, CHARM 2013

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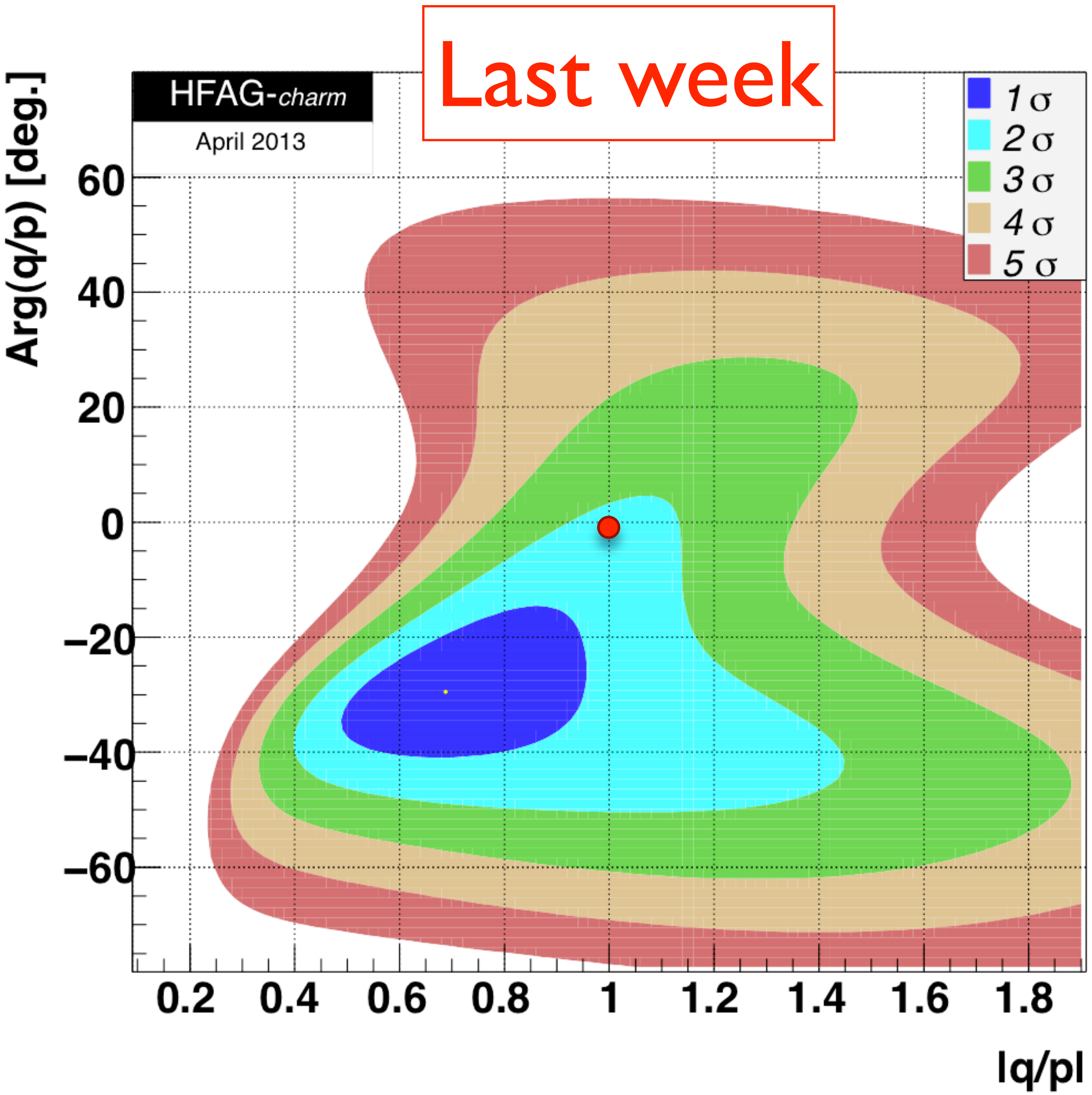
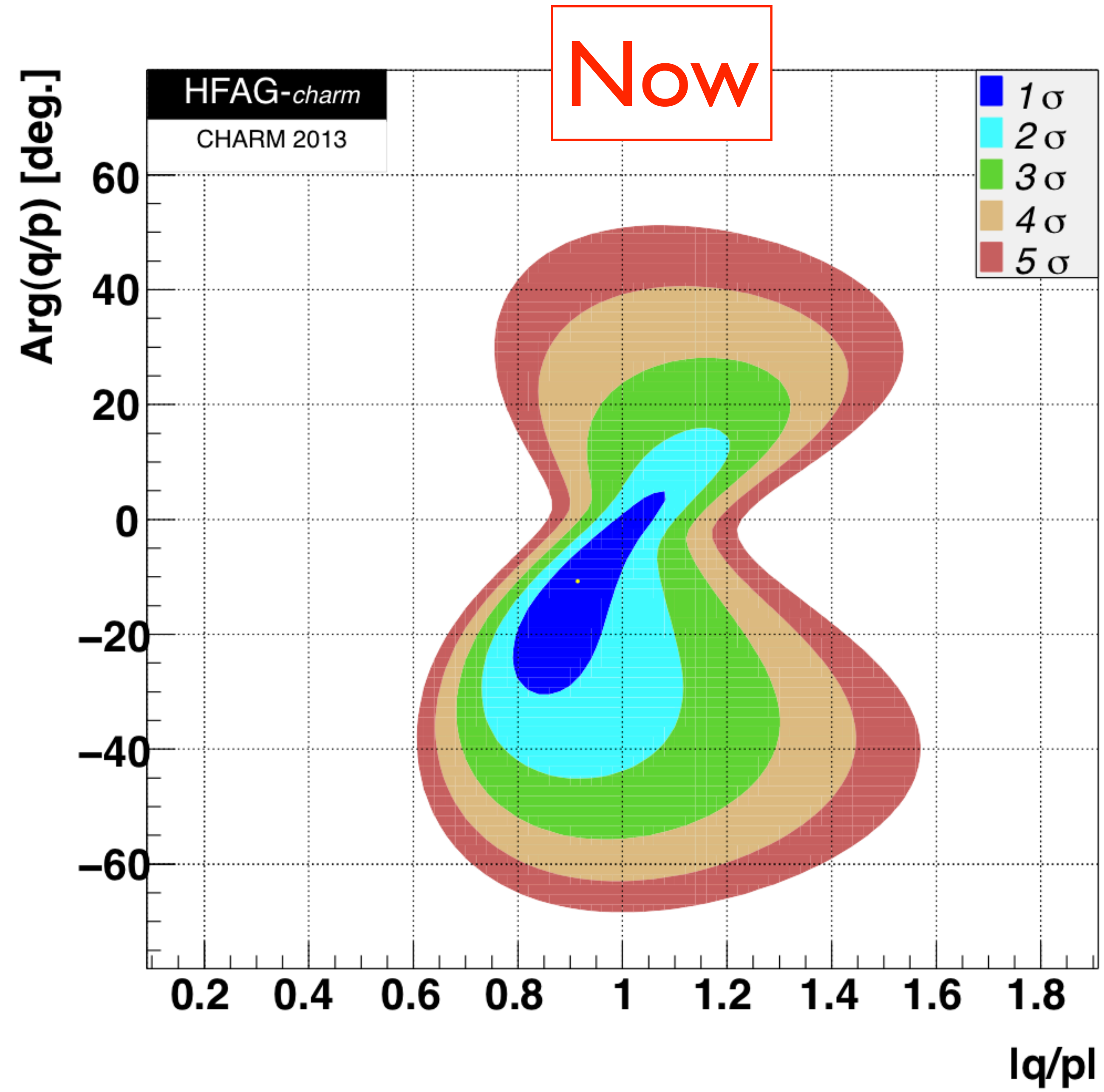
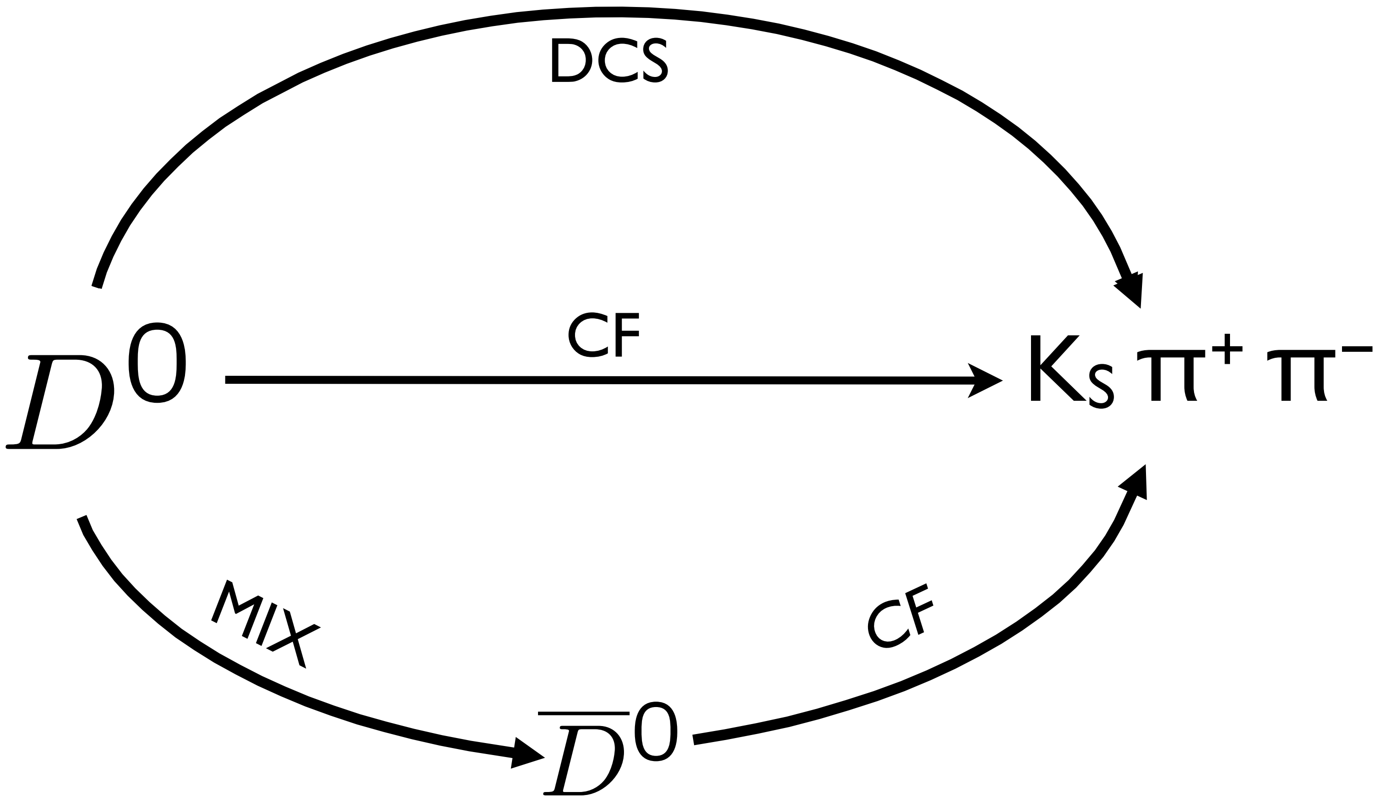
Before & after CHARM

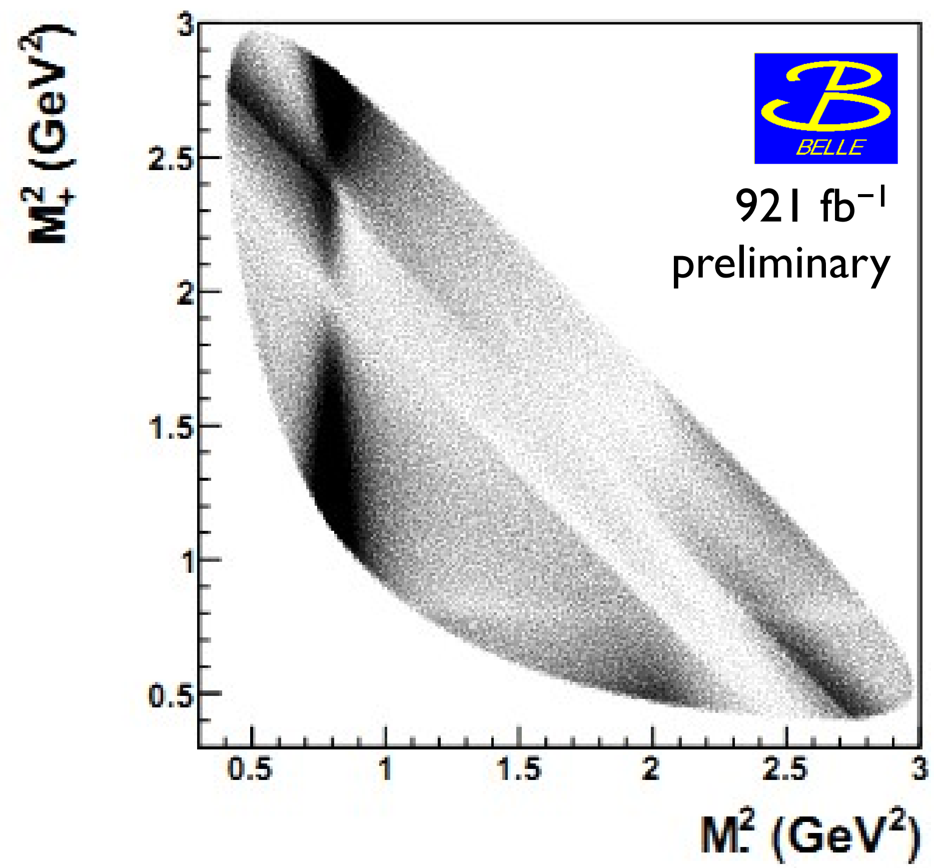




Same scale for both plots.
New LHCb results greatly shrink allowed region.

Time-dependent Dalitz plot





- For KSππ, many paths open -- and they interfere:
  - CF decay to flavour-specific final state (e.g. $K^{*-}\pi^+$)
  - DCS decay to flavour-specific final state (e.g. $K^{*+}\pi^-$)
  - Mixing + CF decay to flavour-specific final state (e.g. $K^{*+}\pi^-$)
  - Decay to CP eigenstate (e.g. $K_S\,\rho^0$)
- Amplitude analysis gives relative phases, so can get x, y directly (not just x', y')

Brand new Belle result

- New at CHARM: time-dependent amplitude analysis
  - P-, D-wave contributions modeled as BWs (isobar-style)
  - ππ S-wave modeled with K-matrix
  - Kπ S-wave modeled with LASS parameterization

921 fb^{-1} preliminary
Not yet included in HFAG average

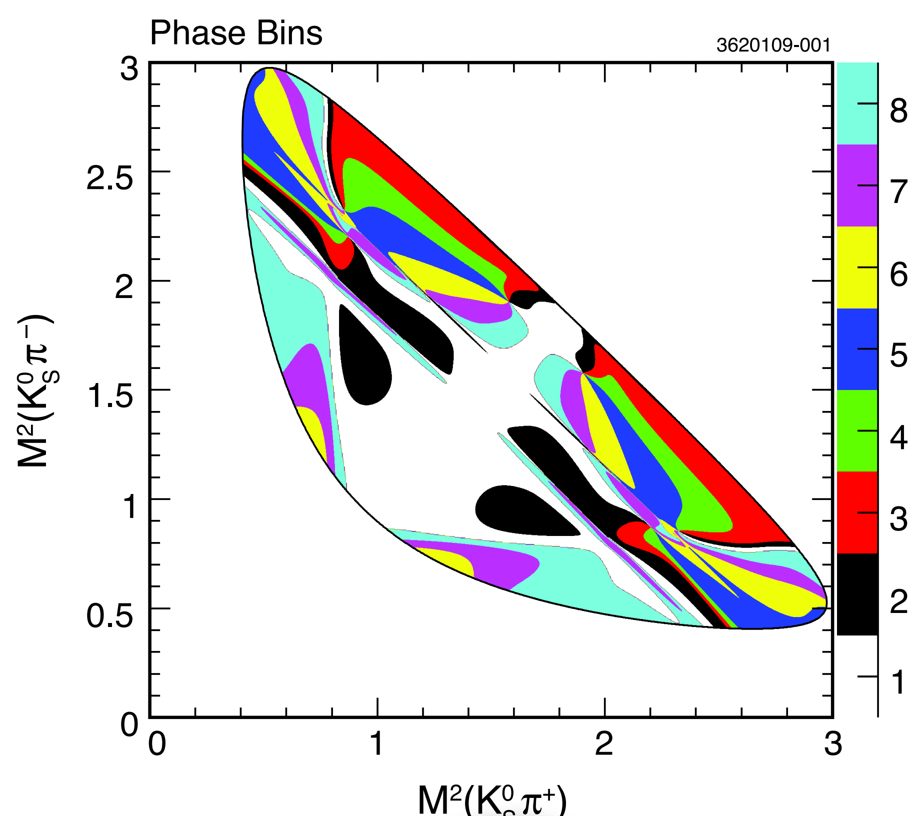
Fit case	Parameter	Fit new result	Belle 2007
No CPV	$x(\%)$	$0.56 \pm 0.19^{+0.03+0.06}_{-0.09-0.09}$	$0.80 \pm 0.29^{+0.09+0.10}_{-0.07-0.14}$
	$y(\%)$	$0.30 \pm 0.15^{+0.04+0.03}_{-0.05-0.06}$	$0.33 \pm 0.24^{+0.08+0.06}_{-0.12-0.08}$
No dCPV	$\lvert q/p \rvert$	$0.90^{+0.16+0.05+0.06}_{-0.15-0.04-0.05}$	$0.86^{+0.30+0.06}_{-0.29-0.03} \pm 0.08$
	$\arg q/p(^o)$	$-6 \pm 11^{+3+3}_{-3-4}$	$-14^{+16+5+2}_{-18-3-4}$

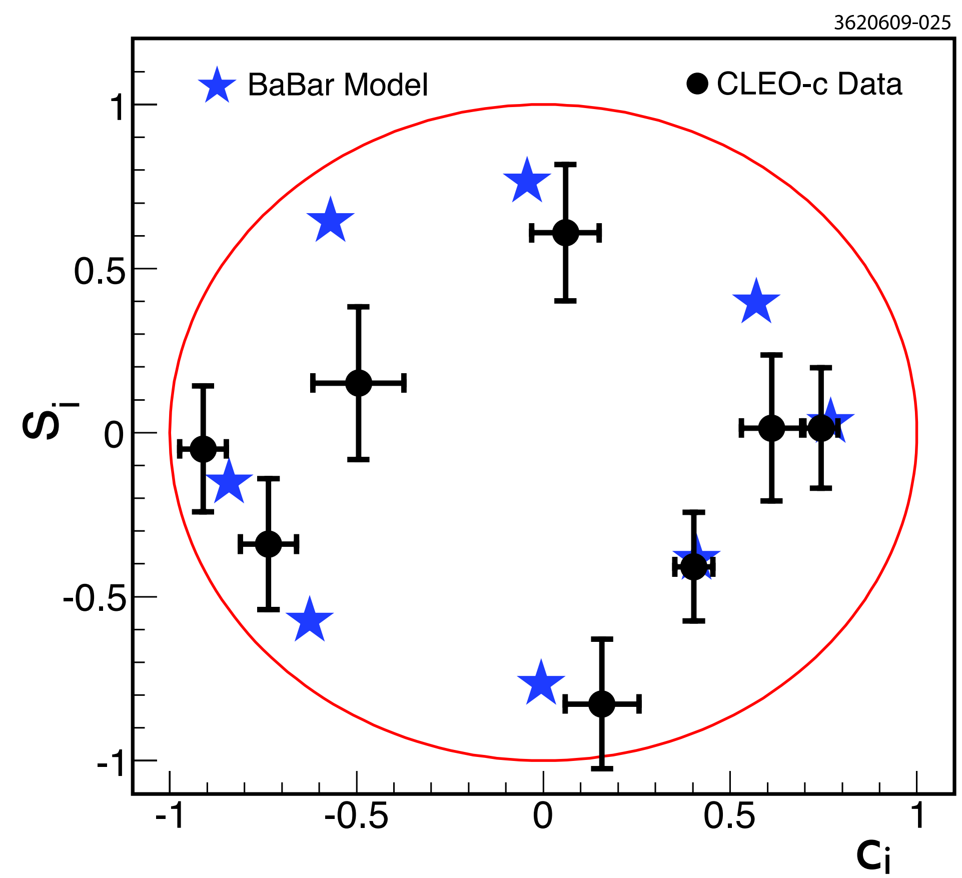
stat, sys, model errors

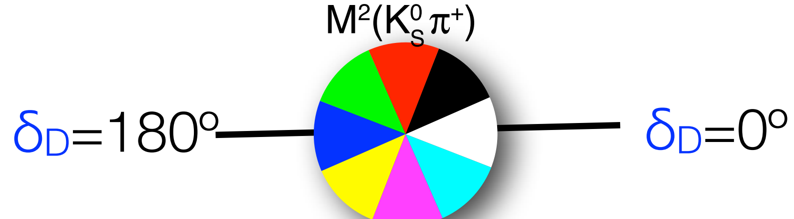
No sign of indirect CPV in this analysis.

Another path

- Belle result uses an amplitude model
- Alternative: model-independent approach taking CLEO measurements of strong phase differences as input.
- Promising, especially:
  - ... for medium-term at LHCb
  - ... if more precise measurements from BES-III and, later, charm factory







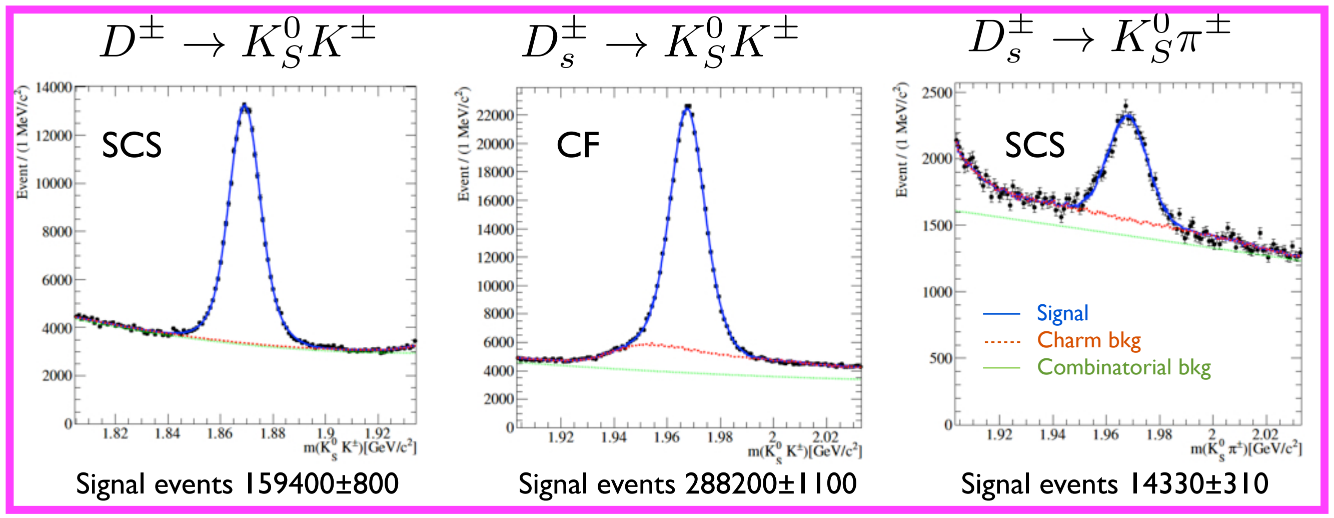
CLEO-c: PRD 80, 032002 (2009)

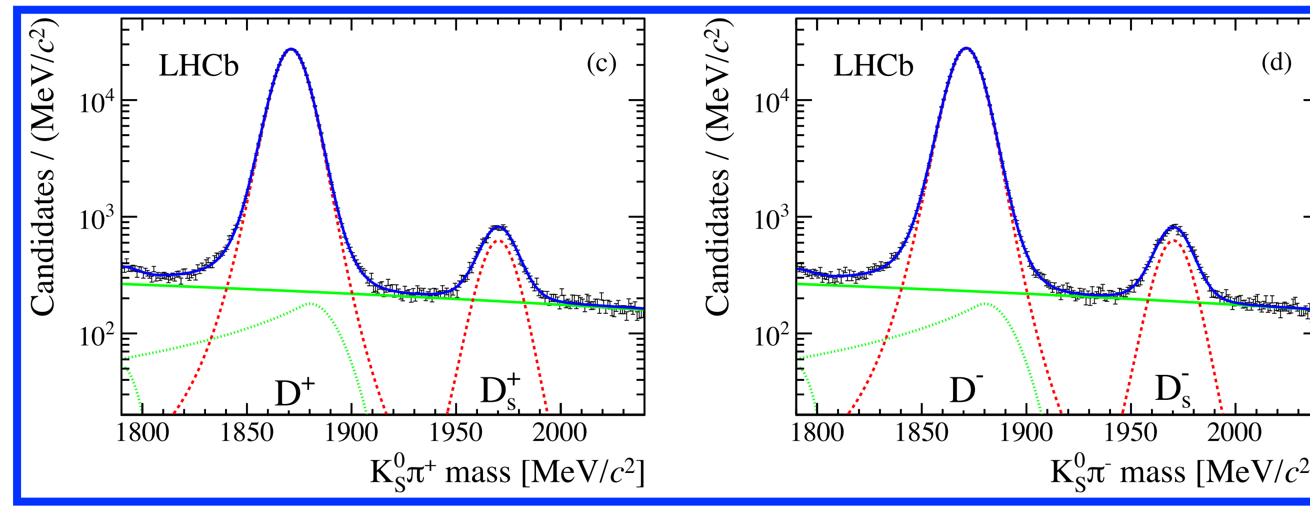
Direct CPV

- Cocktail of new & recent results:
  - BABAR: $D_{(s)}^+ \to K_S h^+$
  - Belle: $D^+ \to K_S K^+$
  - LHCb: $D_s^+ \to K_S \pi^+$ & $D^+ \to \phi \pi^+$
  - BABAR: $D^+ \to K^- K^+ \pi^+$
  - LHCb: $D^0 \to K^- K^+ \pi^- \pi^+, \pi^- \pi^+ \pi^- \pi^+$
  - ΔA_{CP}

$D_{(s)}^{+} \rightarrow K_S h^{+}$

- Caution: some CPV expected from the kaon system.
  - This has to be subtracted out.
  - For BABAR & Belle, see full effect: (0.332 ± 0.006)%
  - At LHCb, K_S lifetime acceptance => reduced by factor 10



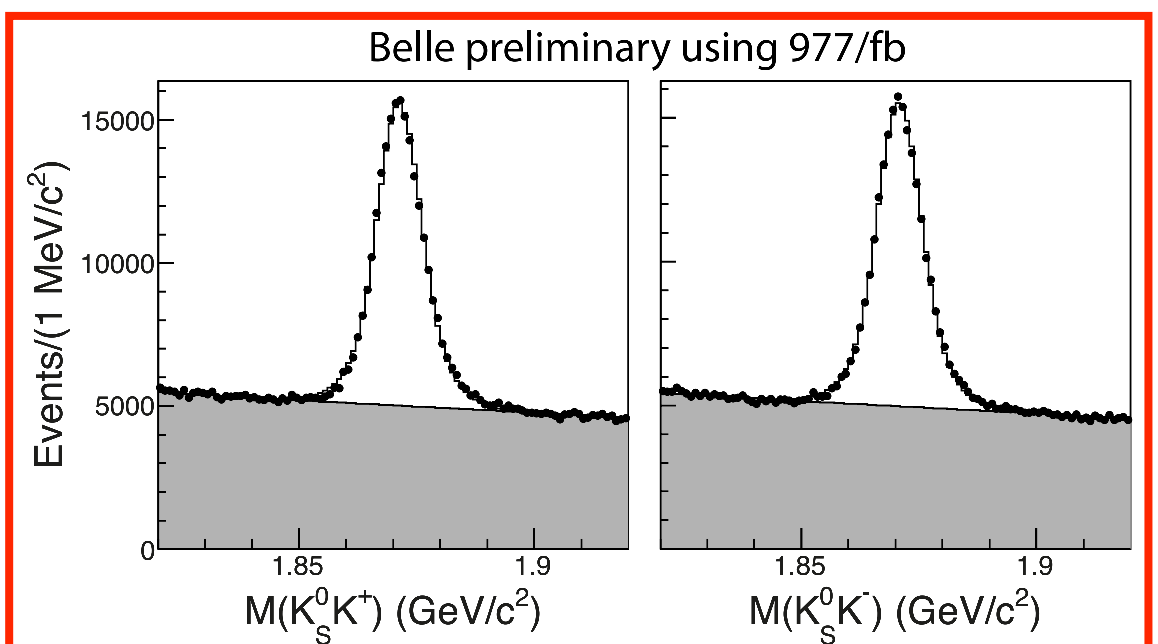


BABAR

PRD 87, 052012 (2013)

LHCb

JHEP 1306, 112 (2013)



Belle

JHEP 1302, 098 (2013)

PRL 109, 021601 (2012) + erratum

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$D_{(s)}^+ \to K_S h^+$

	$D^+ \to K_S K^+$	$D_s^+ \to K_S \pi^+$
BABAR	$(+0.46 \pm 0.36 \pm 0.25)\%$	$(+0.3 \pm 2.0 \pm 0.3)\%$
Belle	$(+0.08 \pm 0.28 \pm 0.14)\%$	$(+5.45 \pm 2.50 \pm 0.33)\%$
LHCb		$(+0.61 \pm 0.83 \pm 0.14)\%$

SCS

	$D^+ \to K_S \pi^+$	$D_s^+ \to K_S K^+$
BABAR		$(+0.28 \pm 0.23 \pm 0.24)\%$
Belle	$(-0.024 \pm 0.094 \pm 0.067)\%$	$(+0.12 \pm 0.36 \pm 0.22)\%$

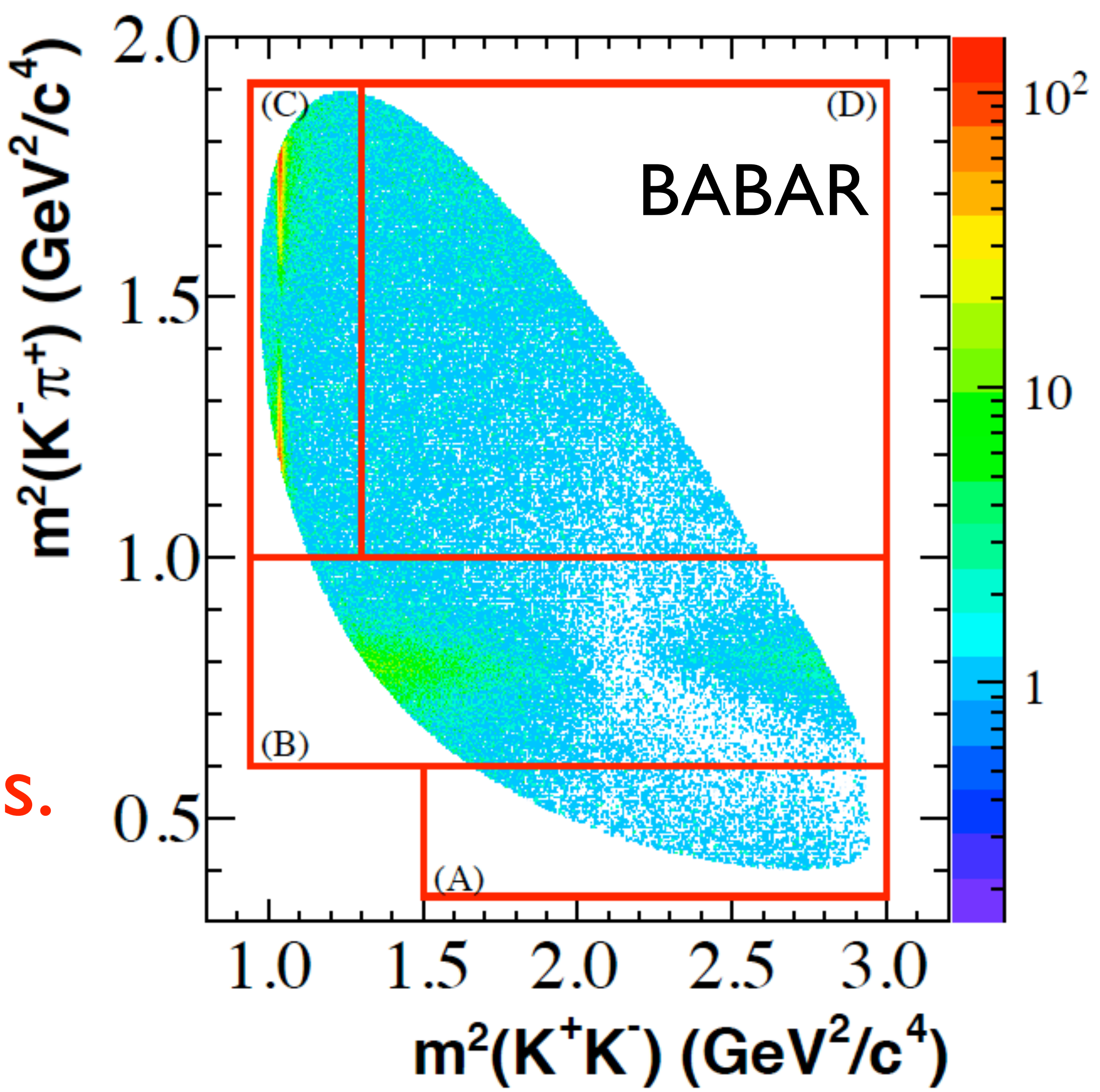
CF

No sign of direct CPV in these analyses.

PRD 87, 052012 (2013)
JHEP 06, 112 (2013)
JHEP 1302, 098 (2013)
PRL 109, 021601 (2012)

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

- Multi-body decay -- many ways to test for CPV
- Very thorough analysis by BABAR did pretty much all of them:
  - Phase-space integrated A_{CP}
  - A_{CP} in big regions of the Dalitz plot
  - Compare distribution with 2D bins
  - Compare distribution with Legendre polynomial moments
  - Compare distribution with model-dependent amplitude fit
- No sign of direct CPV in this analysis.



PRD 87, 052010 (2013)

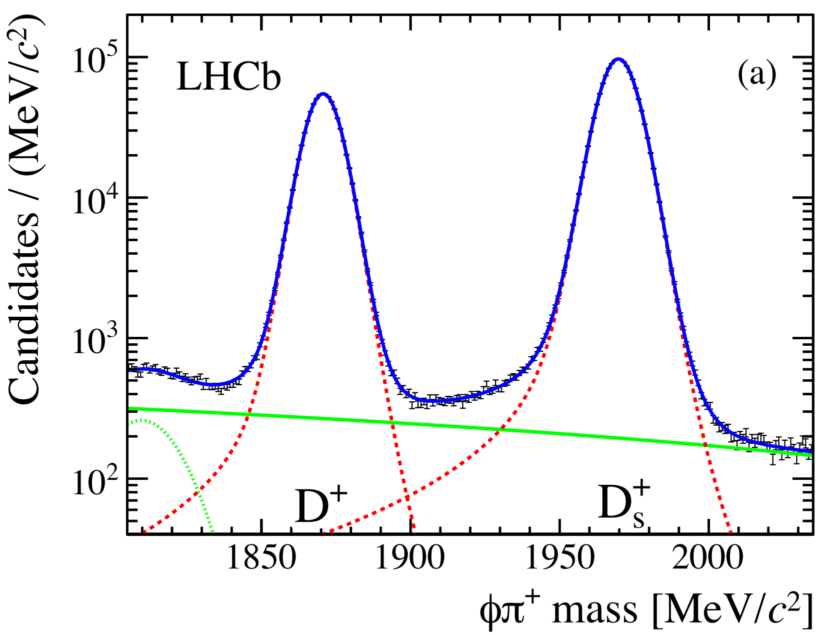
$D^+ \rightarrow K^- K^+ \pi^+$

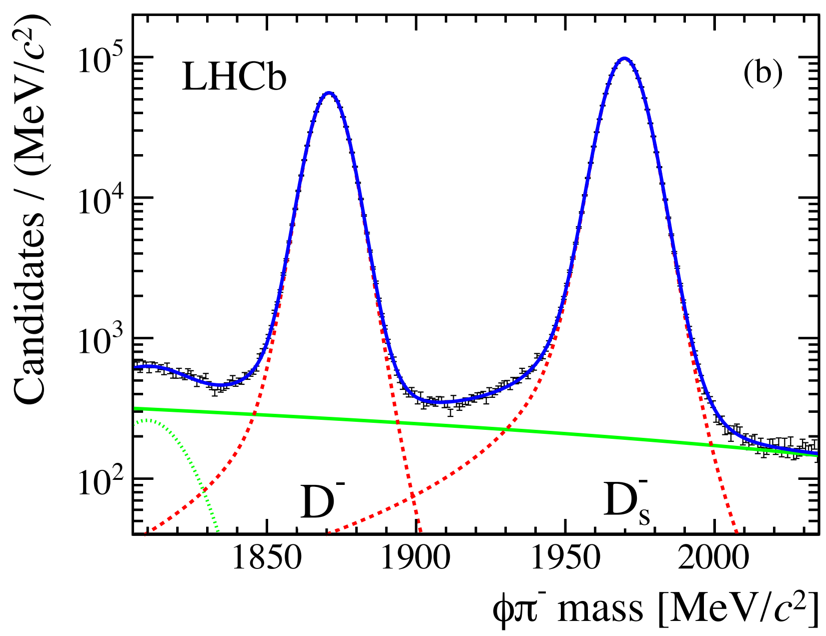
Phys. Rev. D 84, 112008 (2011)

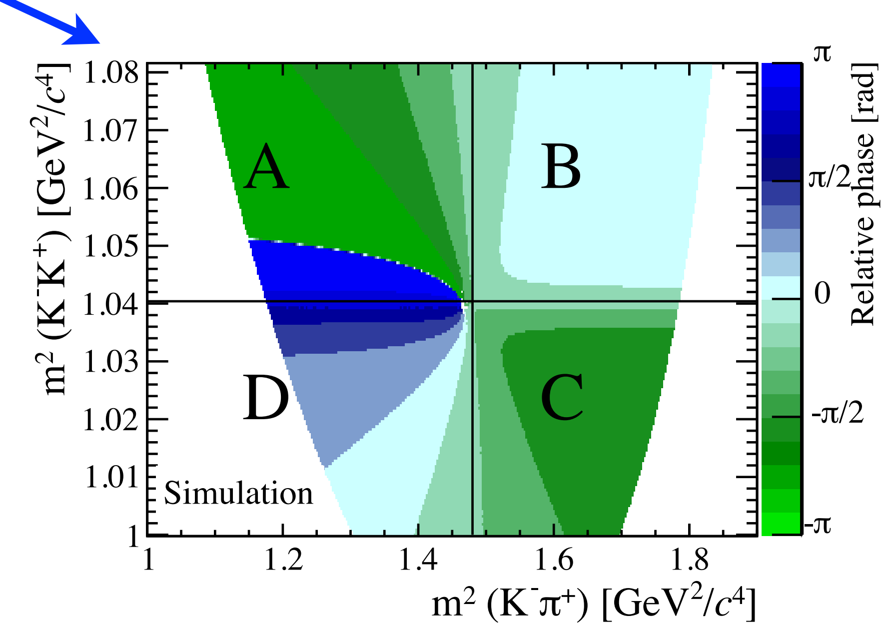
- LHCb studied the Dalitz plot a little while ago with 35/pb.
- Recent result with 1/fb -- but only around the phi: JHEP 1306, 112 (2013)

$$A_{CP}(D^+ \rightarrow \phi\pi^+) = (-0.04 \pm 0.14 \pm 0.14)\%,$$
$$A_{CP}|_S(D^+ \rightarrow \phi\pi^+) = (-0.18 \pm 0.17 \pm 0.18)\%,$$

$$A_{CP}|_S = \frac{1}{2}\left(A^A_{\rm raw} + A^C_{\rm raw} - A^B_{\rm raw} - A^D_{\rm raw}\right).$$



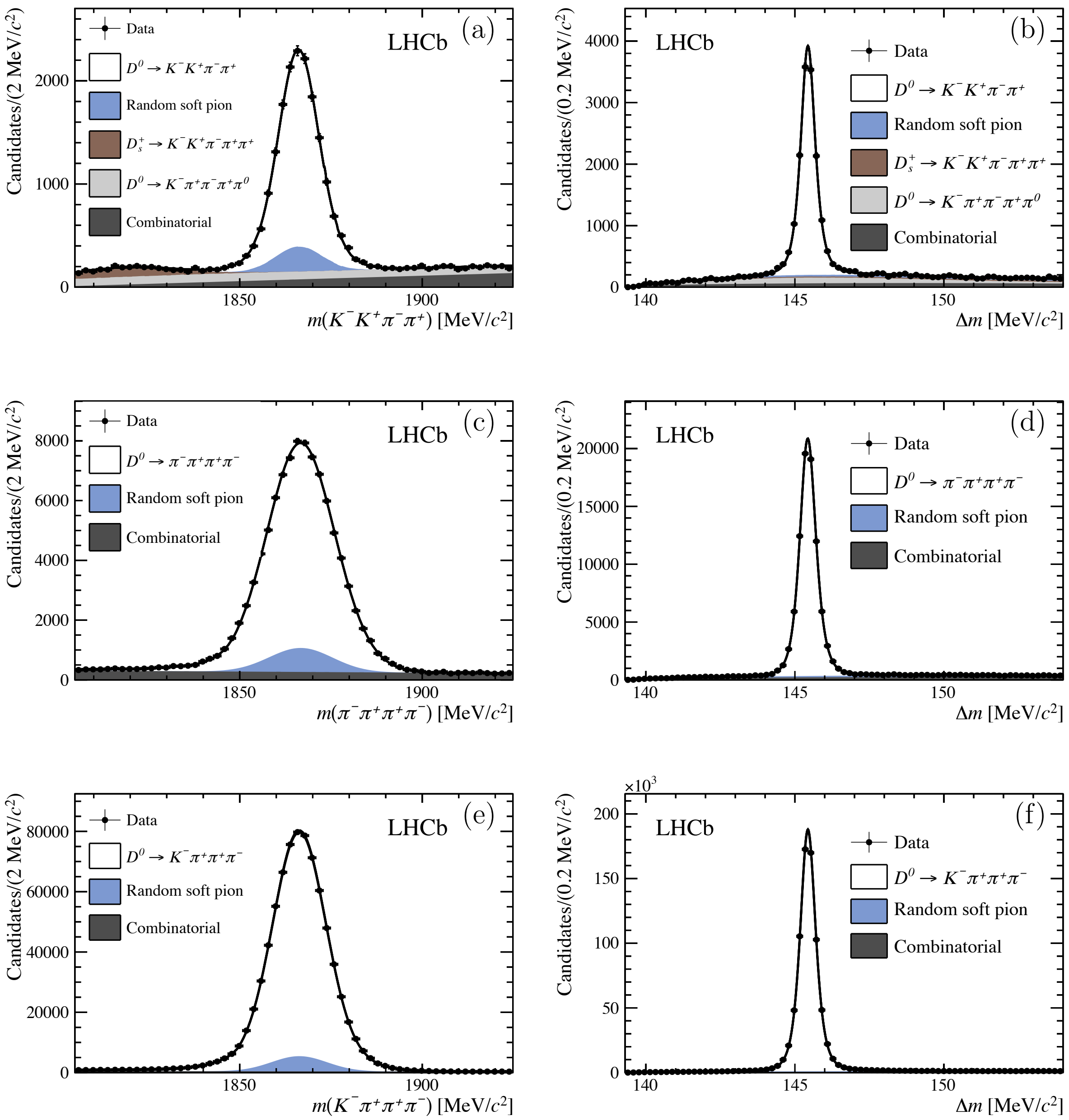




No sign of direct CPV in this analysis.

$D^0 \to h^- h^+ h^- h^+$

- New LHCb analysis with 1/fb, looking for distribution asymmetry with model-independent (binned) method.



With four-body final state, 5D phase space.

$D^0 \to K^-K^+\pi^-\pi^+$			$D^0 \to \pi^-\pi^+\pi^+\pi^-$		
Bins	p-value (%)	χ^2/ndf	Bins	p-value (%)	χ^2/ndf
16	9.1	22.7/15	64	28.8	68.8/63
32	9.1	42.0/31	128	41.0	130.0/127
64	13.1	75.7/63	256	61.7	247.7/255

No sign of direct CPV in this analysis.

LHCb-PAPER-2013-041; arXiv:1308.3189

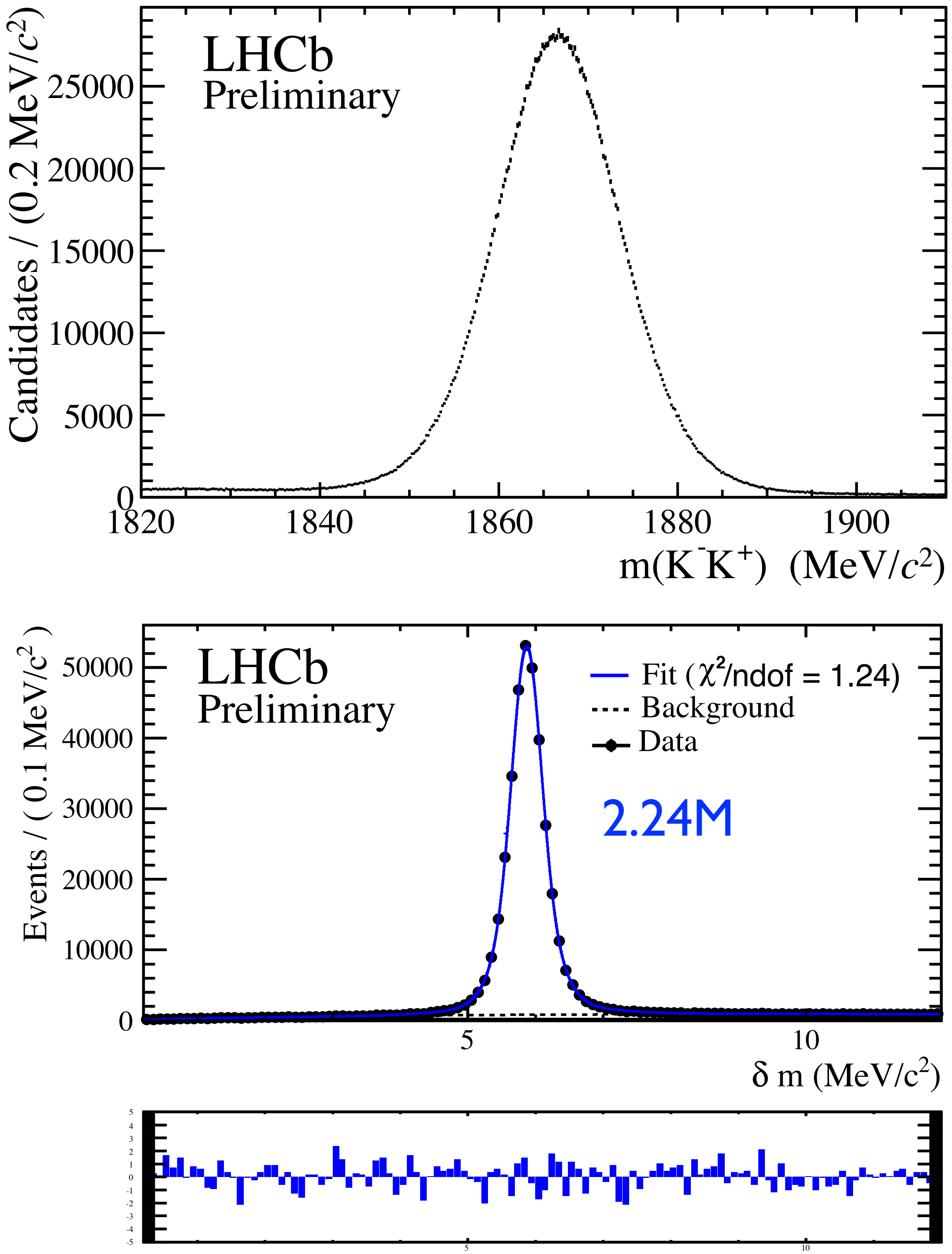
ΔA_{CP}

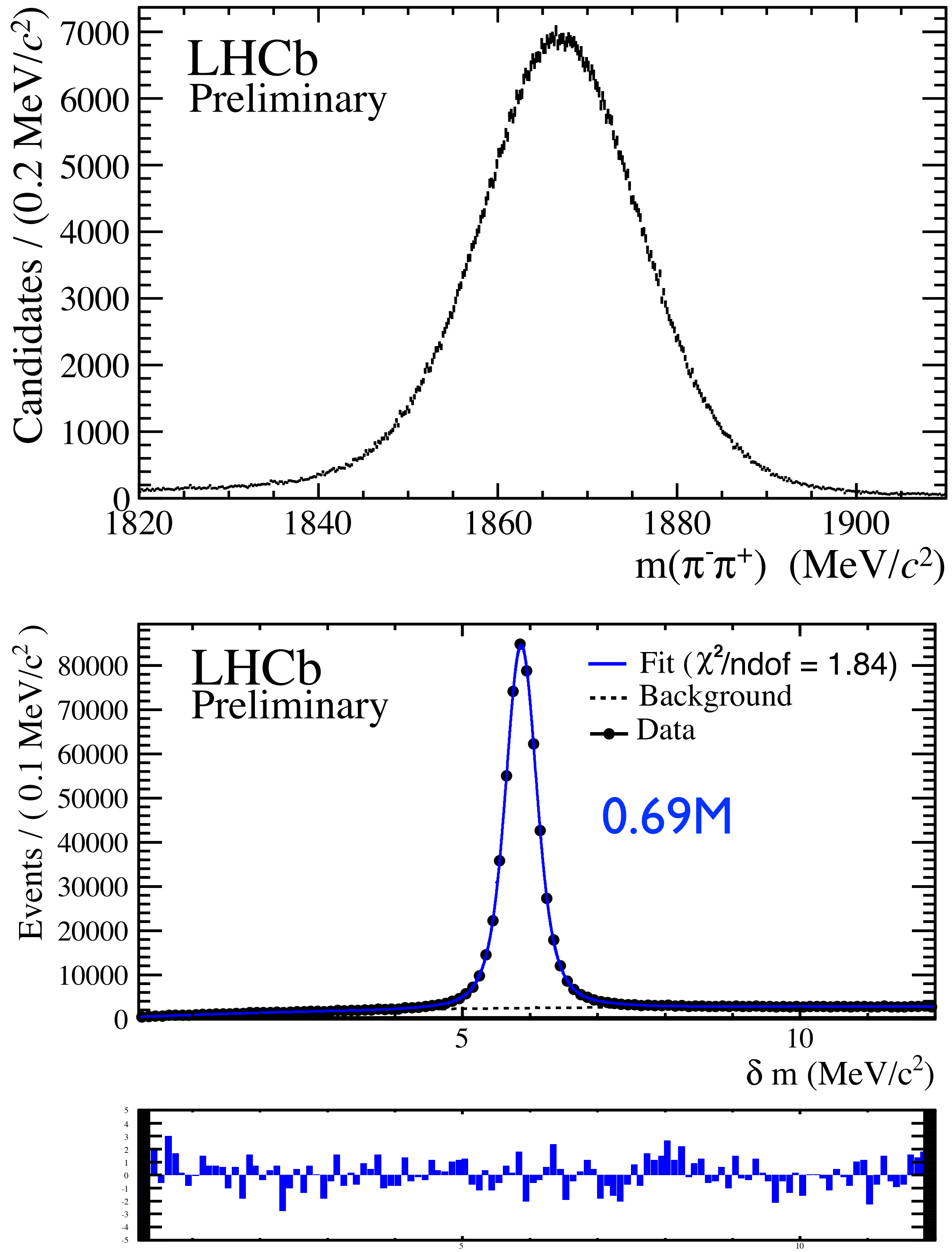
Year	Expt	$A_{CP}(\pi^+\pi^-)$	$A_{CP}(K^+K^-)$	ΔA_{CP}
2008	BABAR ($386\,\mathrm{fb}^{-1}$)	$-0.24 \pm 0.52 \pm 0.22\%$	$+0.00 \pm 0.34 \pm 0.13\%$	$+0.24 \pm 0.62 \pm 0.??\%$
2008	Belle ($540\,\mathrm{fb}^{-1}$)	$+0.43 \pm 0.52 \pm 0.12\%$	$-0.43 \pm 0.30 \pm 0.11\%$	$-0.86 \pm 0.61 \pm 0.??\%$
2012	LHCb prompt ($0.04\,\mathrm{fb}^{-1}$)			$-0.28 \pm 0.70 \pm 0.25\%$
2012	CDF ($5.9\,\mathrm{fb}^{-1}$)	$+0.22 \pm 0.24 \pm 0.11\%$	$-0.24 \pm 0.22 \pm 0.09\%$	$-0.46 \pm 0.33 \pm 0.??\%$
2012	LHCb prompt ($0.6\,\mathrm{fb}^{-1}$)			$-0.82 \pm 0.21 \pm 0.11\%$
2012	CDF ($9.7\,\mathrm{fb}^{-1}$)			$-0.62 \pm 0.21 \pm 0.10\%$
2012	Belle ($1.0\,\mathrm{ab}^{-1}$)	$+0.55 \pm 0.36 \pm 0.09\%$	$-0.32 \pm 0.21 \pm 0.09\%$	$-0.87 \pm 0.43 \pm 0.06\%$
2013	LHCb prompt ($1.0\,\mathrm{fb}^{-1}$)			$-0.34 \pm 0.15 \pm 0.10\%$
2013	LHCb SL ($1.0\,\mathrm{fb}^{-1}$)			$+0.49 \pm 0.30 \pm 0.14\%$

See HFAG site for full list of references.

- Main news this year comes from LHCb:
  - Update of 0.6/fb D^{*+}-tagged analysis to 1.0/fb (with substantial reprocessing)
  - New 1.0/fb muon-tagged analysis
- New central value much closer to zero.

LHCb 1fb^{-1} D^{*+}-tagged





$K^+ K^-$ $\pi^+ \pi^-$

LHCb-CONF-2013-003

LHCb 1fb^{-1} D^{*+}-tagged

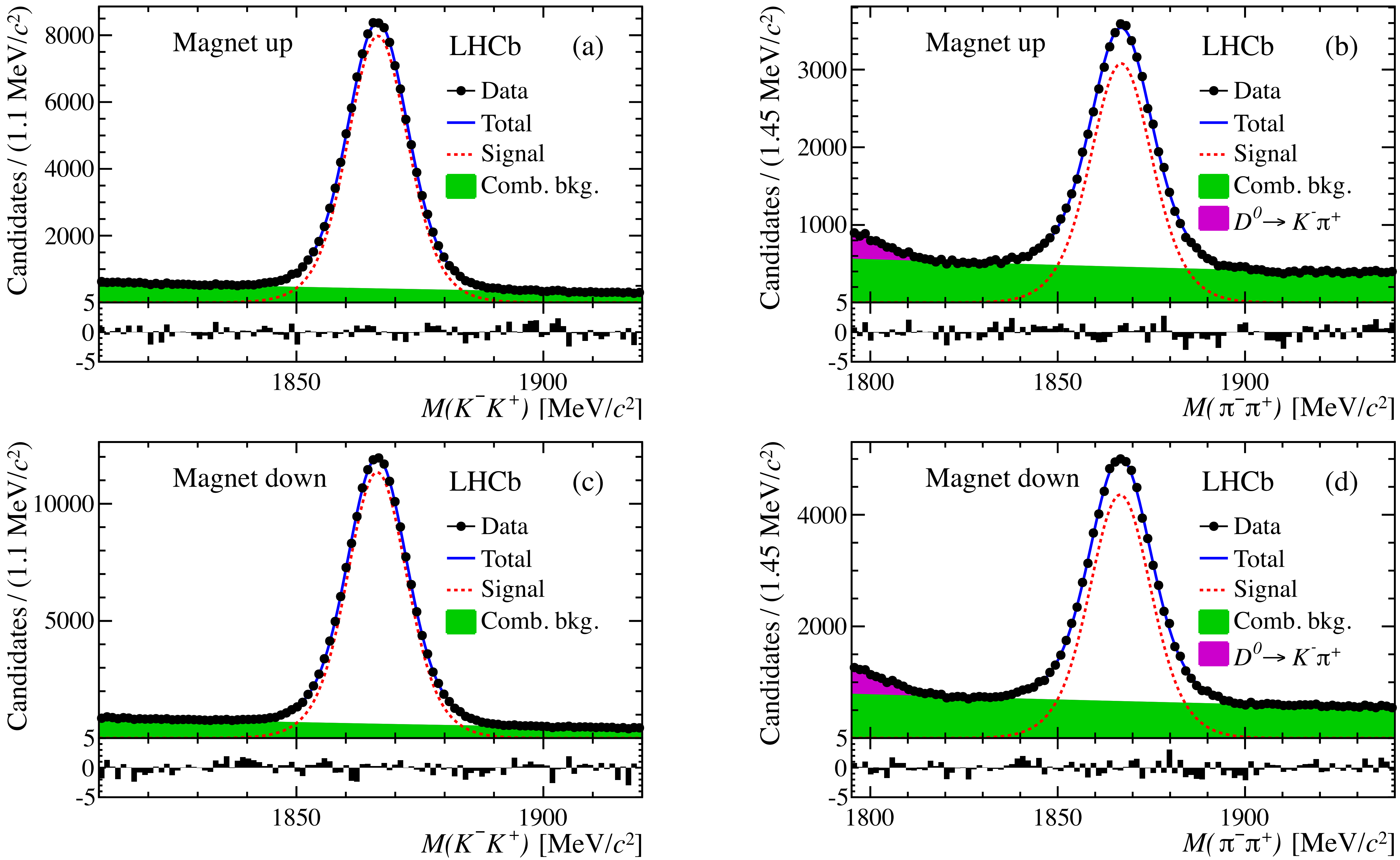
Bottom line:

$$\Delta A_{CP} = -0.34 \pm 0.15 \pm 0.10\%$$

Preliminary

Source	Uncertainty
Fiducial cut	0.02%
Peaking background	0.04%
Fit model	0.03%
Multiple candidates	0.01%
Reweighting	0.01%
Soft pion IP_{χ^2}	0.08%
Total	0.10%

LHCb 1fb^{-1} muon-tagged



K^+K^- (559k) $\pi^+\pi^-$ (222k)

LHCb 1fb^{-1} muon-tagged

Bottom line:

$$\Delta A_{CP} = +0.49 \pm 0.30 \pm 0.14\%$$

Source of uncertainty	Absolute uncertainty
Production asymmetry:	
Difference in b-hadron mixture	0.02%
Difference in B decay time acceptance	0.02%
Production and detection asymmetry:	
Different weighting	0.05%
Background from real D^0 mesons:	
Mistag asymmetry	0.02%
Background from fake D^0 mesons:	
D^0 mass fit model	0.05%
Low-lifetime background in $D^0 \to \pi^-\pi^+$	0.11%
Λ_c^+ background in $D^0 \to K^-K^+$	0.03%
Quadratic sum	0.14%

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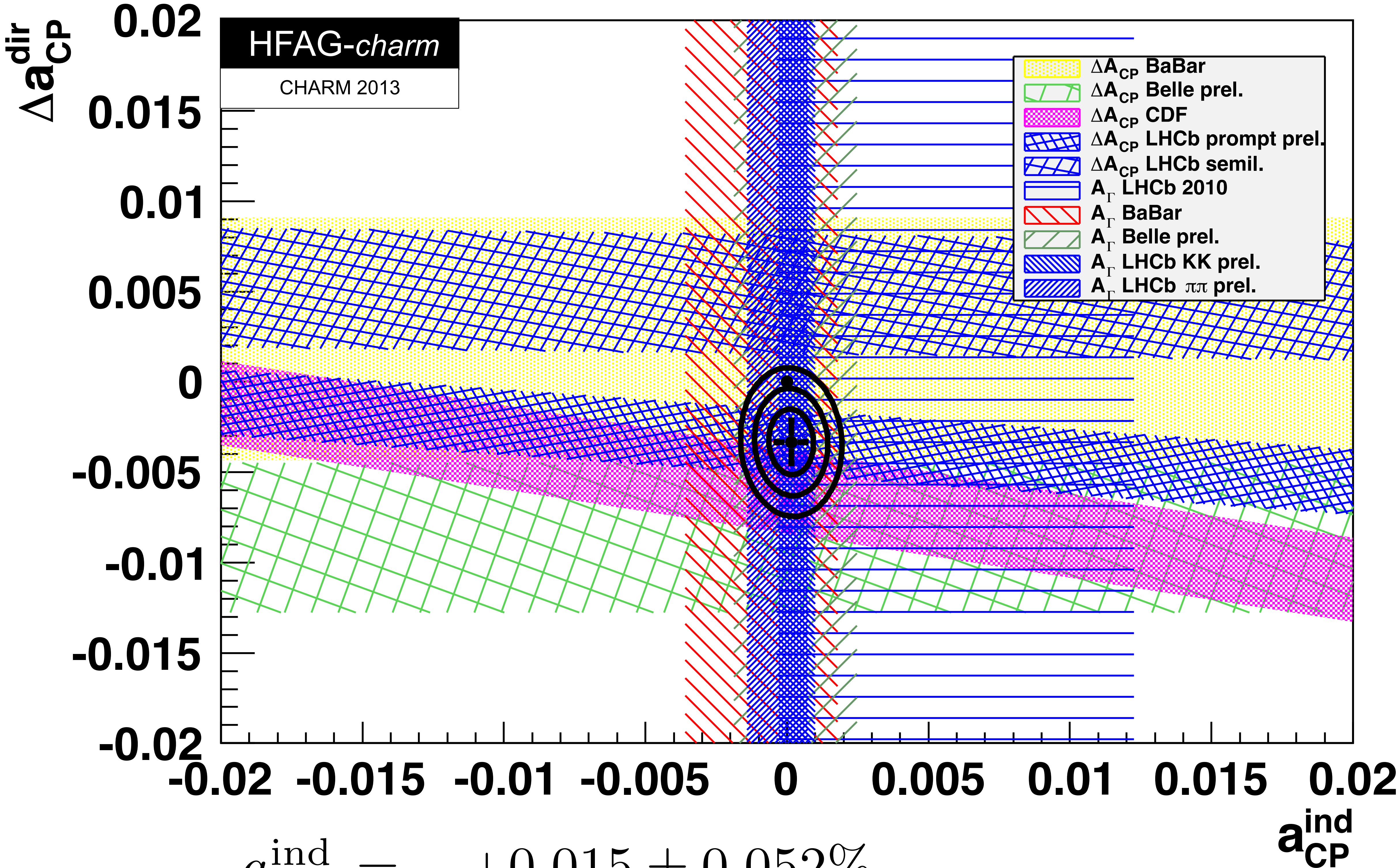
HFAG combination



$$a_{CP}^{\mathrm{ind}} = \quad +0.015 \pm 0.052\%$$

$$a_{CP}^{\mathrm{dir}} = \quad -0.333 \pm 0.120\%$$

Compatible with no CPV at 2.0% CL

No evidence for direct CPV in these analyses.

Summary

- Lots of new developments -- especially at LHCb...
  - new indirect CPV results bring its statistical muscle to bear
  - plethora of direct CPV searches
- ... but also nice results still coming in from $e^+ e^-$ machines.
- After ΔA_{CP} excitement, data depressingly consistent with SM
- But: most LHCb analyses haven't yet used full 3/fb
- ... and before long we'll have new data:
  - Post-LS1 run for LHCb (and, later, upgrade)
  - Belle-II
  - Data still coming in from BES-III
  - Encouraging noises on tau-charm factory

Hmm...


Heineken
open your world*
Heineken
* Ouvrir une Heineken, c'est consommer une bière vendue dans le monde entier.
L'ABUS D'ALCOOL EST DANGEREUX POUR LA SANTÉ. À CONSOMMER AVEC MODÉRATION.


BODDINGTONS. THE CREAM OF MANCHESTER.

LHCb 1fb^{-1} results

- Two analyses on the full 1fb^{-1} 2011 dataset:
  - One D^{*+}-tagged, extending previous 0.6 fb^{-1} analysis
  - One using $\overline{B} \to D^0 \mu^- \overline{\nu}$ [X], entirely new
- The two analyses are essentially independent:
  - Almost no overlap in data samples, so statistically independent
  - Tagging method and associated systematics entirely different
  - Blinded and analyzed separately.
- Will first discuss D^{*+}-tagged analysis (main focus on what changed since previous), then muon-tagged.

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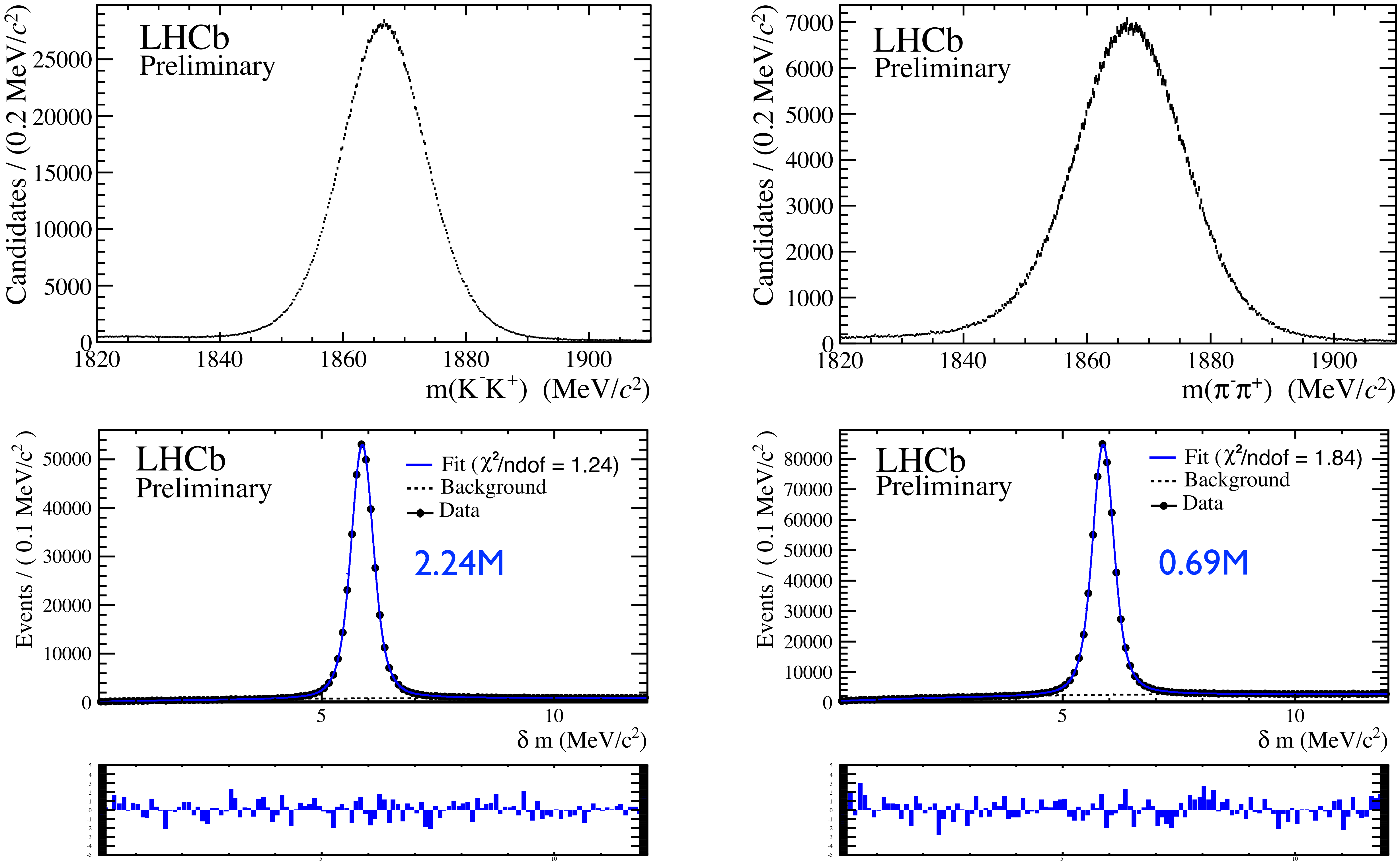
LHCb 1fb^{-1} D^{*+}-tagged



$K^+ K^-$

$\pi^+ \pi^-$

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LHCb-CONF-2013-003

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LHCb 1fb^{-1} D^{*+}-tagged

- What's new?
  - Reprocessing of dataset (from scratch) with improved alignment, calibration, software.
    - Not done specifically for this analysis -- part of long-planned data processing strategy
  - Added 0.4 fb^{-1} of data
  - Replace kinematic binning with weighting à la CDF
  - Added constraint requiring tagging slow pion to originate at PV.

LHCb 1fb^{-1} D^{*+}-tagged

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This has a big effect, especially on the RICH hadron ID.

- About 15% of previous signal lost for both KK and ππ
- About 17%, 34% new signal gained for KK, ππ
- ... and of course quite a lot of churn in the background.

Differences compatible with statistical fluctuations, and the subsample that's common to both processings has almost identical values for ΔA_{CP} in each.

$-0.82 \pm 0.21\% \rightarrow -0.55 \pm 0.21\%$ Preliminary

LHCb 1fb^{-1} D^{*+}-tagged

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In the new 0.4 fb^{-1} alone: $\Delta A_{CP} = -0.28 \pm 0.26\%$

$-0.55 \pm 0.21\% \rightarrow -0.45 \pm 0.16\%$

Preliminary

LHCb 1fb^{-1} D^{*+}-tagged

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  - Added constraint requiring tagging slow pion to originate at PV.

Both methods valid, but weighting allows us to do reduce the number of fits by a large factor.

Change in method turns out to make almost no difference to the value for ΔA_{CP}.

$-0.45 \pm 0.16\% \rightarrow -0.45 \pm 0.17\%$

Preliminary

LHCb 1fb^{-1} D^{*+}-tagged

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  - Reprocessing of dataset (from scratch) with improved alignment, calibration, software.
    - Not done specifically for this analysis -- part of long-planned data processing strategy
  - Added 0.4 fb^{-1} of data
  - Replace kinematic binning with weighting à la CDF
  - Added constraint requiring tagging slow pion to originate at PV.

Statistical precision improves due to better S/B. Expected movement in central value 0.05% from statistics, so this is about a 2σ effect.

$-0.45 \pm 0.17\% \rightarrow -0.34 \pm 0.15\%$ Preliminary

LHCb 1fb^{-1} D^{*+}-tagged

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  - Reprocessing of dataset (from scratch) with improved alignment, calibration, software.
    - Not done specifically for this analysis -- part of long-planned data processing strategy
  - Added 0.4 fb^{-1} of data
  - Replace kinematic binning with weighting à la CDF
  - Added constraint requiring tagging slow pion to originate at PV.

Overall:

Several changes, each moving the central value consistent with statistics and by at most 2σ... but all pushing in the same direction. Consistent with original result being a fluctuation and now seeing regression towards a smaller (zero?) value.

LHCb 1fb^{-1} D^{*+}-tagged

Bottom line:

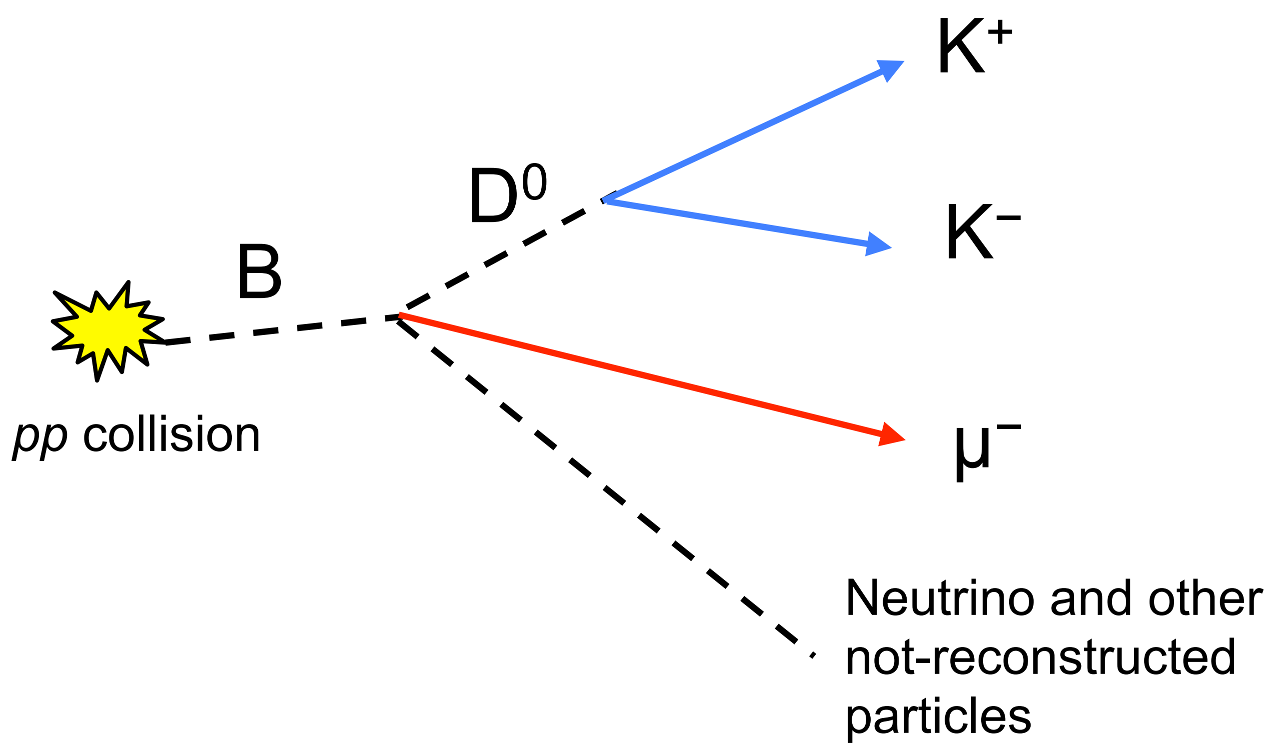
$$\Delta A_{CP} = -0.34 \pm 0.15 \pm 0.10\%$$

Preliminary

Source	Uncertainty
Fiducial cut	0.02%
Peaking background	0.04%
Fit model	0.03%
Multiple candidates	0.01%
Reweighting	0.01%
Soft pion IP_{χ^2}	0.08%
Total	0.10%

LHCb 1fb^{-1} muon-tagged

- Same general idea as past D^{*+}-tagged analyses, but instead look for charm from semileptonic B decays:



- Much smaller production rate ($\sigma_{b\bar{b}}/\sigma_{c\bar{c}} \sim 1/20$) but partly balanced by higher trigger efficiency
  - displaced high-pt muon, secondary D^0 on avg higher in p_t than prompt

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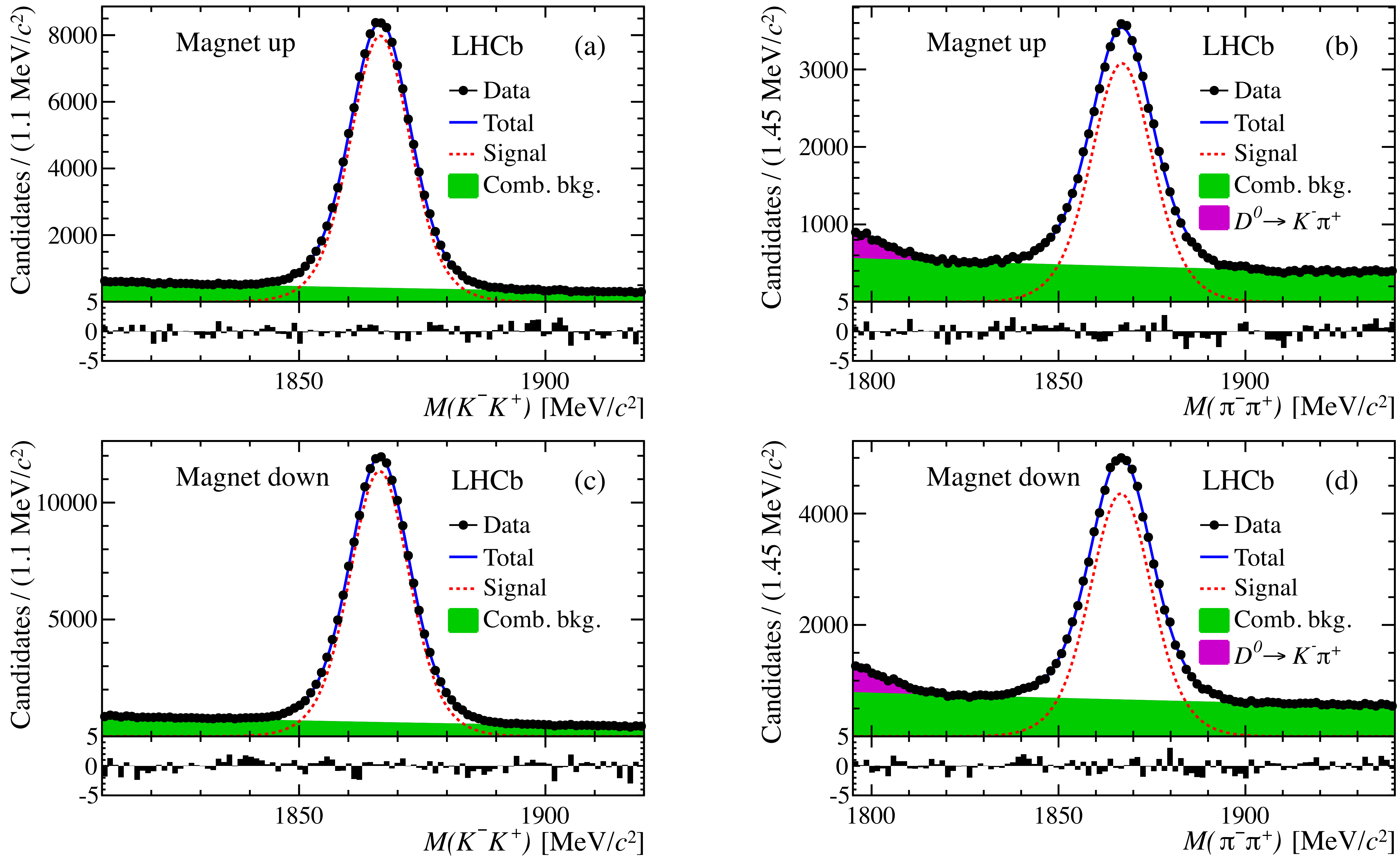
LHCb 1fb^{-1} muon-tagged

- Analysis principles the same, but a few differences:
  - Fit mass of D^0 candidates
  - Correct for mis-tag rate, using CF mode as control.
    - Mistag rate is small and precisely known: $(0.982 \pm 0.012)\%$
    - Helpfully, most sources of confusion/background give the correct tag.
    - Note that this cancels in ΔA_{CP}
  - Weight based on different kinematic variables (no D^{*+})
  - Some nice features of muon tag -- triggering is simpler, kinematics of tag track are friendlier
  - Different backgrounds -- mostly from misreconstructed B decays

LHCb 1fb^{-1} muon-tagged



K^+K^- (559k) $\pi^+\pi^-$ (222k)

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LHCb: Phys. Lett. B723 (2013) 33

LHCb 1fb^{-1} combined

- Naive LHCb combination (assuming negligible indirect CPV):

$$\begin{array}{ll} D^{*+}\text{-tagged} & -0.34 \pm 0.15 \pm 0.10\% \quad \text{(preliminary)} \\ \text{Muon-tagged} & +0.49 \pm 0.30 \pm 0.14\% \\ \text{Combination} & -0.15 \pm 0.16\% \quad \text{(preliminary)} \end{array}$$

- The results are 2.2σ apart (compatible at 3% level)