Mixing and CP violation in charm decays

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on behalf of the LHCb collaboration

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Introduction

- The LHCb experiment was introduced in Monday's session

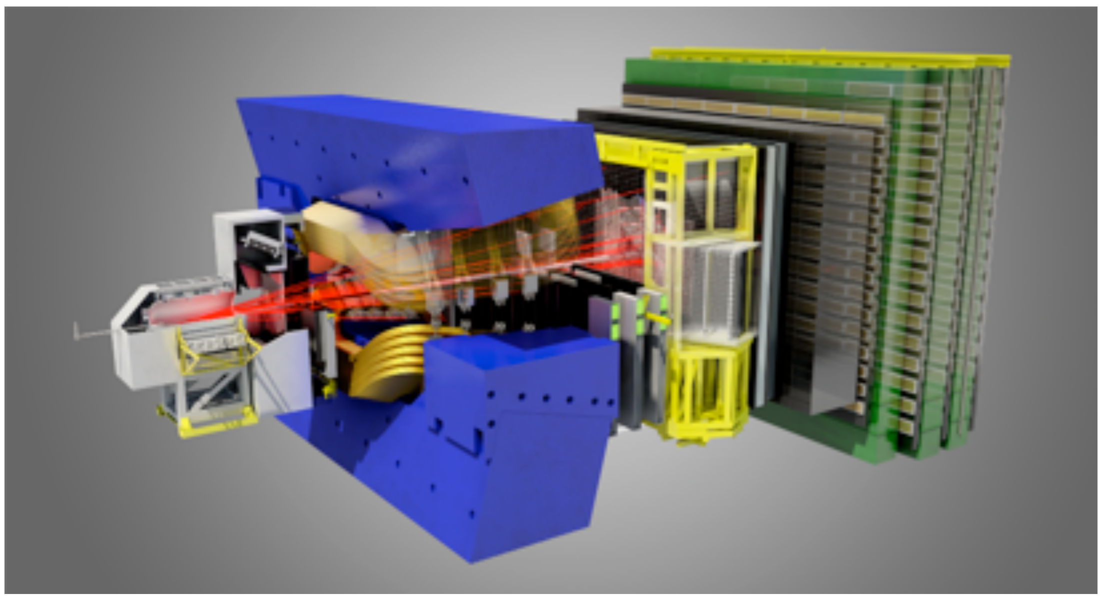
- LHCb has **huge charm samples.** Charm cross section ≈ **20 x b cross section** within the LHCb acceptance:
  - σ(cc)LHCb = 1419 ± 133 μb (arXiv:1302.2864)
  - σ(bb)LHCb = 75.3 ± 14.1 μb (Phys.Lett.B 694, 209)

$\sqrt{s}$ = 7 TeV

- In 1.0fb^{-1} (2011 dataset) roughly **10^{12} $c\bar{c}$** and **10^{11} $b\bar{b}$** produced!

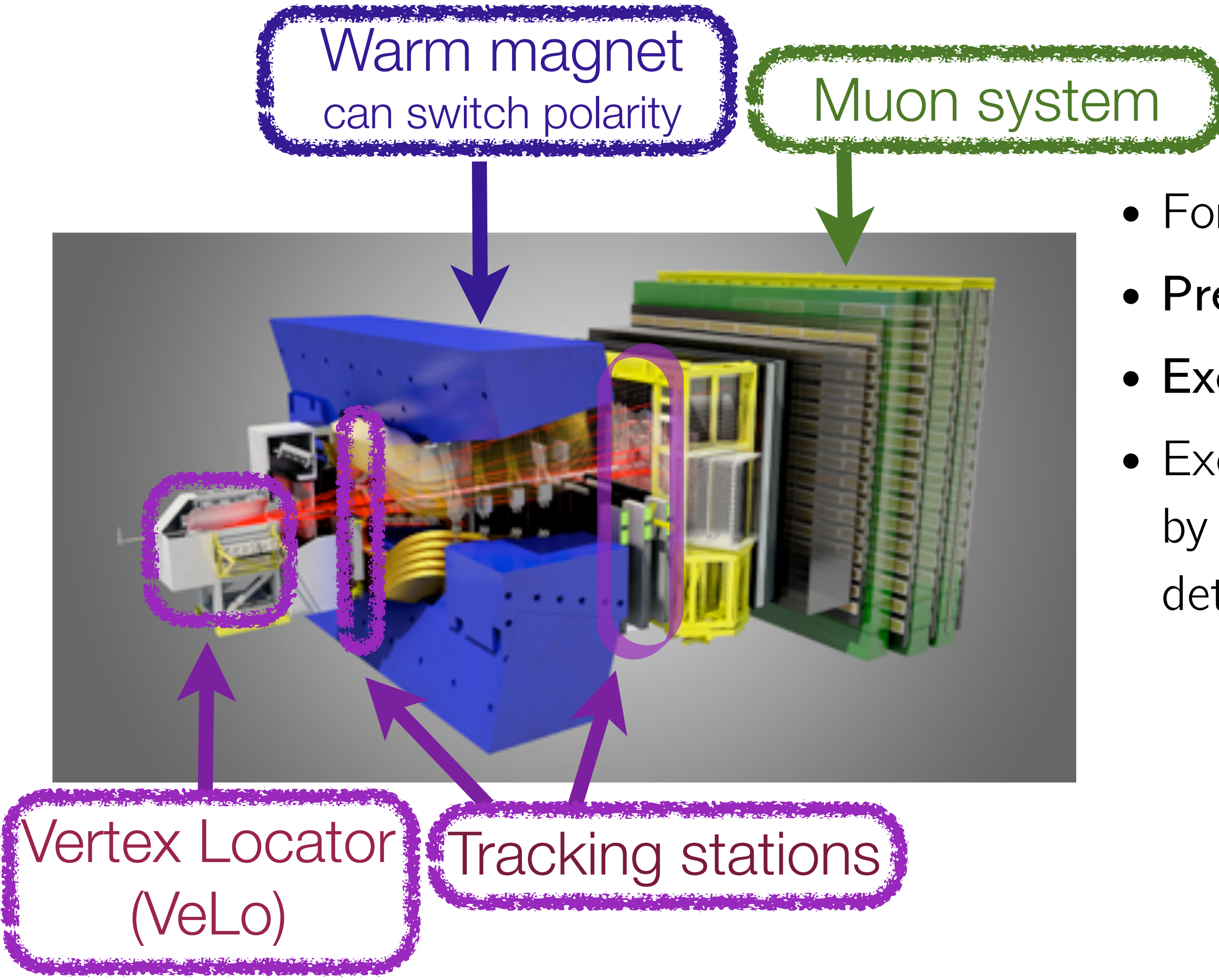
- LHCb can make precision measurements in charm and study loop-sensitive processes.

LHCb detector



- **Forward detector**
- Precision tracking
- Excellent vertex resolution
- Excellent K/π separation provided by two Ring Imaging Cherenkov detectors

LHCb detector



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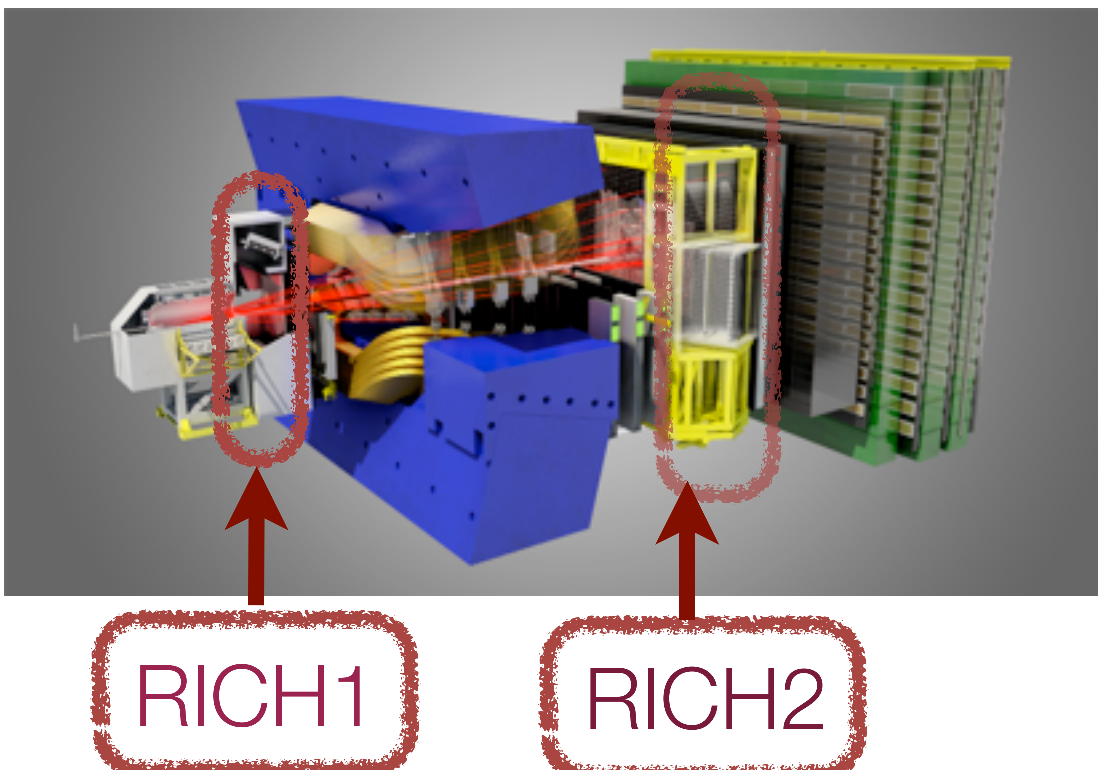
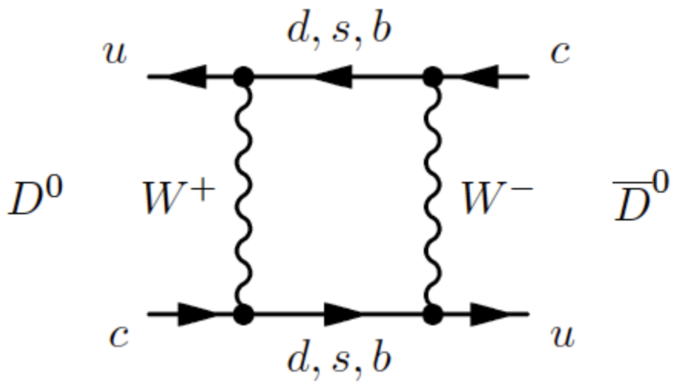
LHCb detector



- Forward detector
- Precision tracking
- Excellent vertex resolution
- **Excellent K/π separation provided by two Ring Imaging Cherenkov detectors**

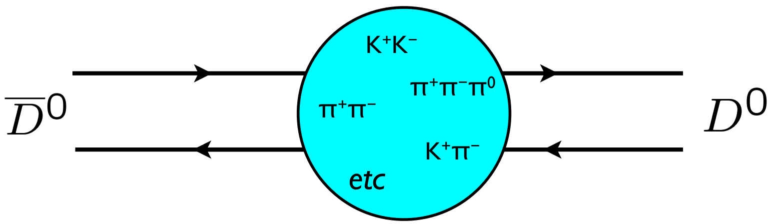
D^0 mixing

- First evidence in 2007 by BaBar and Belle
  - [Phys.Rev.Lett. 98 (2007) 211802,Phys.Rev.Lett. 98 (2007) 211803]



Mixing via box-diagram

Short range



Mixing via hadronic intermediate states

Long range

Time-evolution described by Schrödinger equation:

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \overline{D}^0(t) \end{pmatrix} = (M - i\Gamma)\begin{pmatrix} D^0(t) \\ \overline{D}^0(t) \end{pmatrix}$$

Mass eigenstates are $\mid D_{1,2}\rangle = p \mid D^0\rangle \pm q \mid \overline{D}^0\rangle$

Size of mixing characterised by $x = \frac{m_2 - m_1}{\Gamma}, \qquad y = \frac{\Gamma_2 - \Gamma_1}{2\Gamma}$

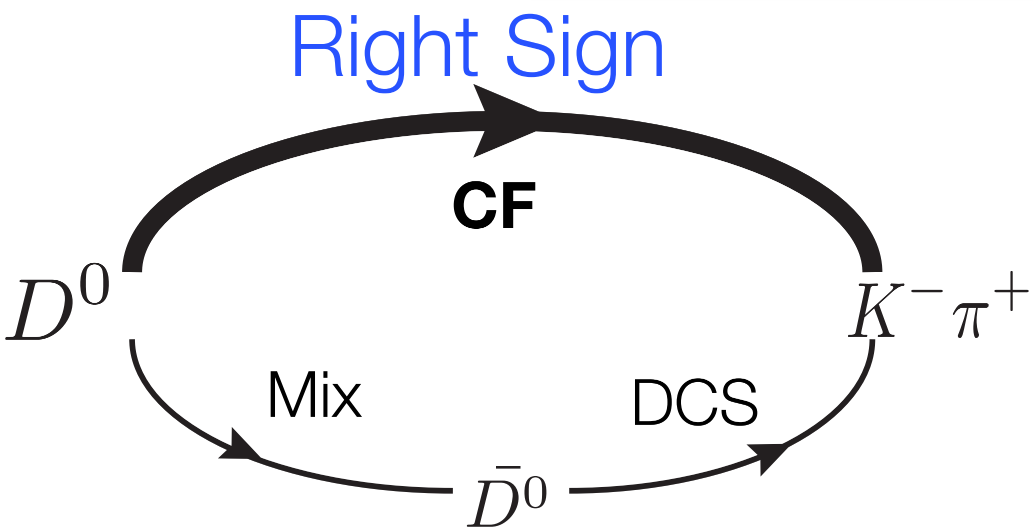
Mixing if **x ≠ 0** or **y ≠ 0**

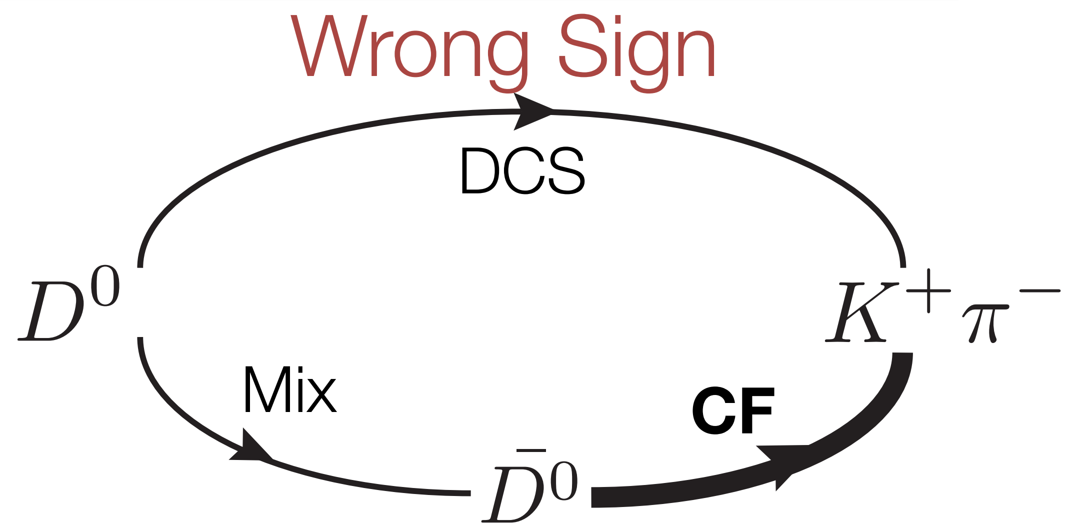
New

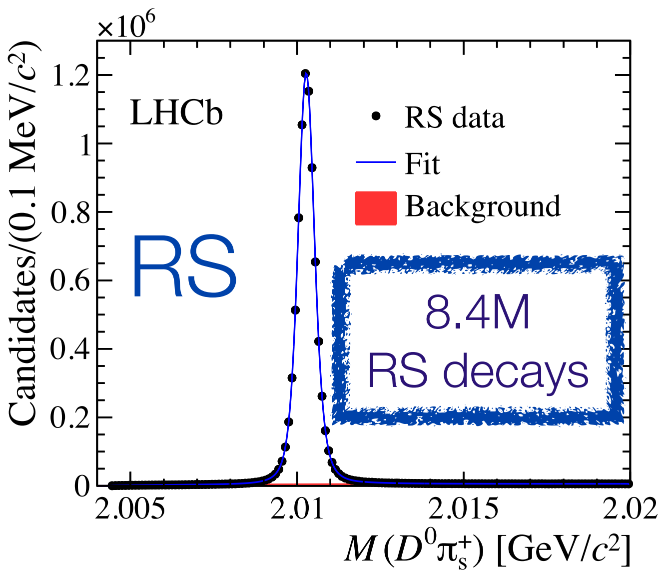
D^0 mixing at LHCb

Phys.Rev.Lett. 110, 101802 (2013)

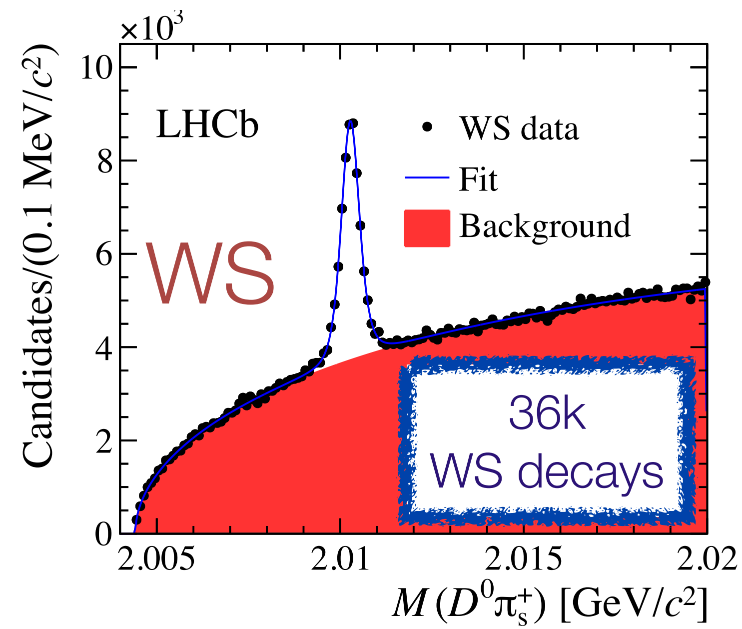
1.0fb^{-1} collected during 2011







- Use $D^{*+} \to D^0(f)\pi_s^+$ to tag the flavour of D^0 before mixing
- 36k WS and 8.4M RS decays
- Divide into 13 D^0 decay time bins



D^0 mixing at LHCb

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- Take the time-dependent ratio of wrong sign to right sign decays

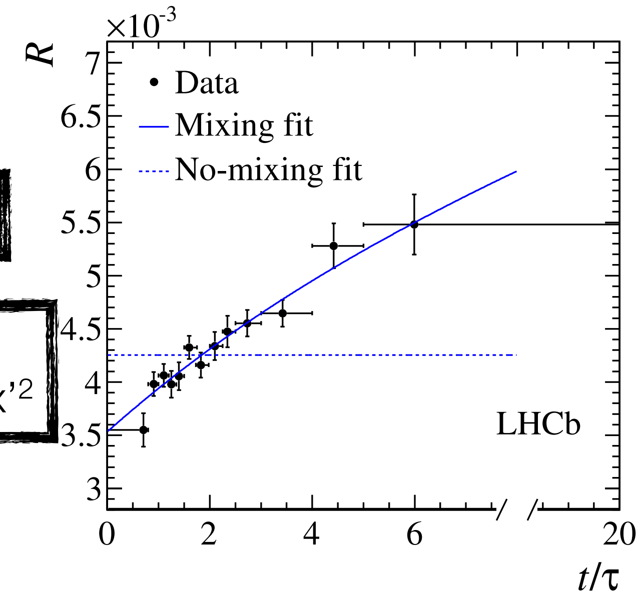
$$R(t) = \frac{N_{WS}(t)}{N_{RS}(t)} \simeq R_D + \sqrt{R_D} y' t + \frac{x'^2 + y'^2}{4} t^2$$

for no CPV

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

Require strong phase δ information so measure y' and x'^{2}

- Most systematics cancel in ratio



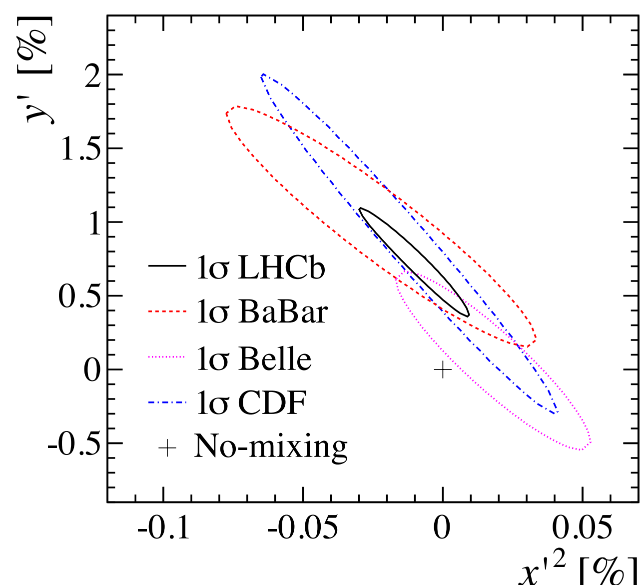
x'^{2} = (-0.09 ± 0.13)×10^{-3}

y' = (7.2 ± 2.4)×10^{-3}

no mixing hypotheses excluded at **9.1σ**

systematics uncertainties 11% of σ(x'^{2}), 10% of σ(y')

- First single measurement with > 5σ significance



LHCb 1σ inc. systematics

Search for direct CPV

Time-integrated CP asymmetry defined as:

$$A_{CP}(f) = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to \bar{f})}{\Gamma(\bar{D} \to f) + \Gamma(D \to \bar{f})}$$

SM predictions do not rule out a few 10^{-3}

NP could enhance up to $\mathcal{O}(10^{-2})$

Phys.Rev. D75 (2007) 036008

Look to measure A_{CP} in:

$D^+ \to \phi\pi^+$

$D_s^+ \to K_s^0\pi^+$

difference between $D^0 \to K^-K^+$ - $D^0 \to \pi^-\pi^+$ (ΔA_{CP})

Analysis techniques

- Magnetic field frequently flipped.
    - Using both 'magnet up' and 'magnet down' data cancels many asymmetries
- Kinematic areas with large detection asymmetries can be removed

LHCB-PAPER-2012-052

$1.0 fb^{-1}$ collected during 2011

CP violation in $D^+ \to \phi\pi^+$ and $D_S^+ \to K_S^0\pi^+$

New

- Define A_{CP} for $D^+ \to \phi\pi^+$

$$A_{CP}(D^+ \to \phi\pi^+) = A_{\rm raw}(D^+ \to \phi\pi^+) - A_{\rm raw}(D^+ \to K_{\rm S}^0\pi^+) + A_{CP}(K^0/\overline{K}^0)$$

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$$A_{\text{raw}} = \frac{N_{D^+} - N_{D^-}}{N_{D^+} + N_{D^-}}$$

LHCB-PAPER-2012-052
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Control channel where CPV is negligible

Cancels detection/production asymmetries

LHCB-PAPER-2012-052

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Correction due to CPV in neutral Kaon system

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LHCB-PAPER-2012-052
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Control channel where CPV is negligible

Correction due to CPV in neutral Kaon system

- Also for $D_s^+ \to K_S^0\pi^+$

$$A_{CP}(D_s^+ \to K_S^0\pi^+) = A_{\rm raw}(D_s^+ \to K_S^0\pi^+) + A_{CP}(K^0/\overline{K}^0) - A_{\rm raw}(D_s^+ \to \phi\pi^+)$$

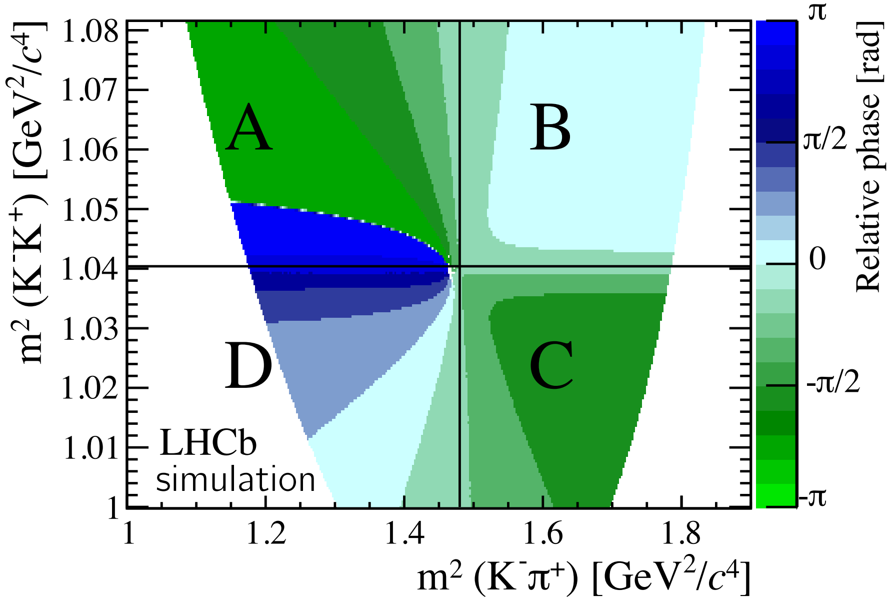
- No mixing in D^+ - any CPV signal = direct CPV

CP violation in $D^+ \rightarrow \phi\pi^+$ and $D_S^+ \rightarrow K_S^0\pi^+$

- Split up phase space across ϕ resonance into 4 bins
  - minimise the strong phase difference across each bin
  - can improve sensitivity to certain CPV
- Define a third variable

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

LHCb simulation



used CLEO to model phase change across ϕ resonance

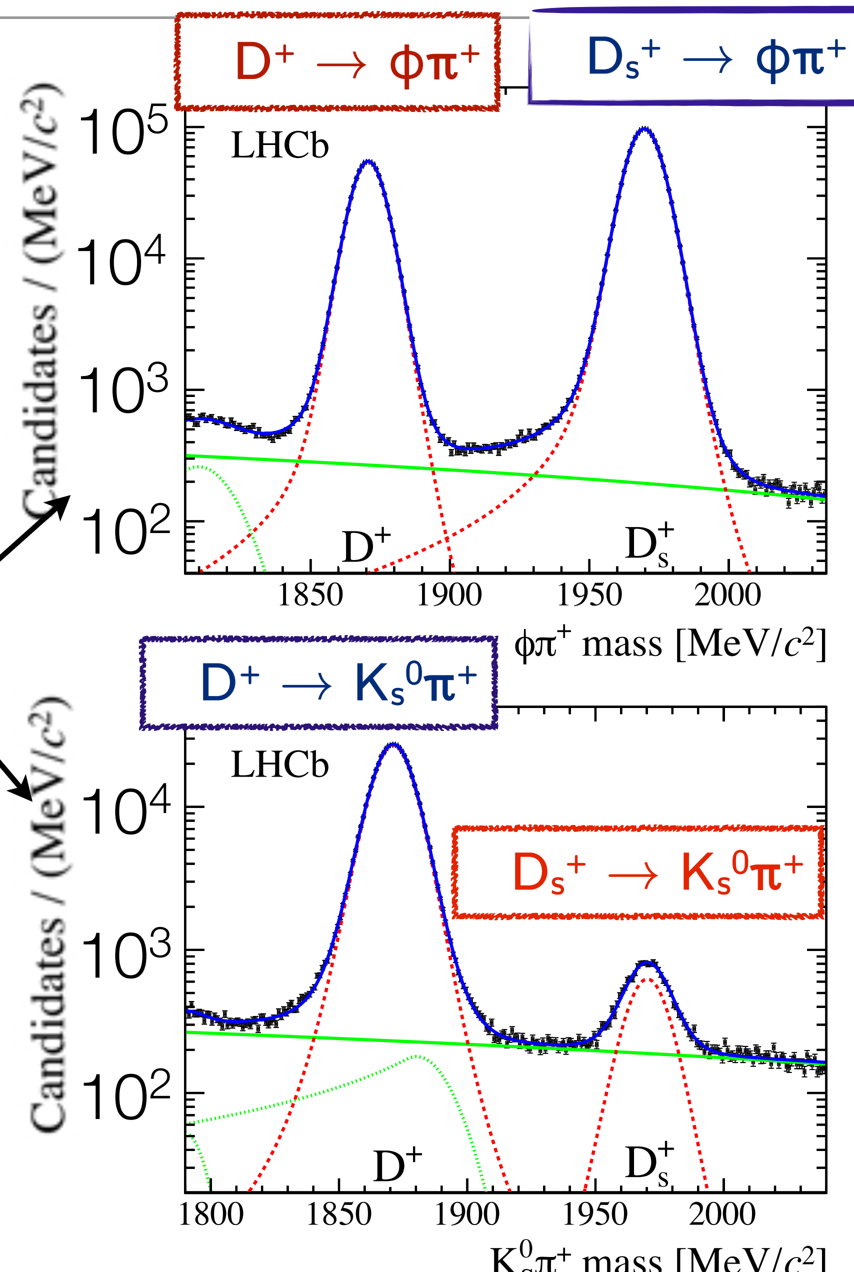
Phys. Rev. D78 (2008) 072003

LHCB-PAPER-2012-052
$1.0 fb^{-1}$ collected during 2011

CP violation in $D^+ \to \phi\pi^+$ and $D_s^+ \to K_S^0\pi^+$

- Very low background levels
  - 1.6M $D^+ \to \phi\pi^+$
  - 3.6M $D^+ \to K_s^0\pi^+$
  - 26K $D_s^+ \to K_s^0\pi^+$
  - 1.1M $D_s^+ \to \phi\pi^+$

Log Scale



LHCB-PAPER-2012-052

1.0fb^{-1} collected during 2011

CP violation in $D^+ \to \phi\pi^+$ and $D_s^+ \to K_S^0\pi^+$

- No evidence of CPV observed

$$A_{CP}(D^+ \to \phi\pi^+) = (-0.04 \pm 0.14 \pm 0.13)\%,$$
$$A_{CP}|_S = (-0.18 \pm 0.17 \pm 0.18)\%,$$
$$A_{CP}(D_s^+ \to K_S^0\pi^+) = (0.61 \pm 0.83 \pm 0.13)\%,$$

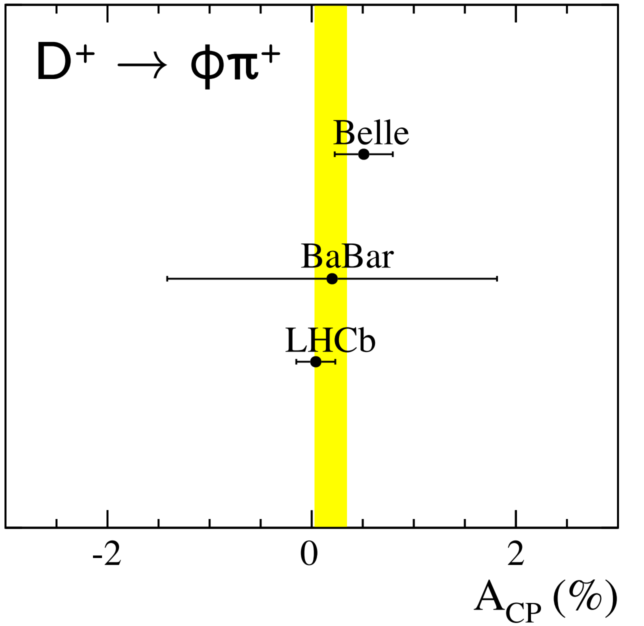
- LHCb most precise measurement to date for both $D_s^+ \to K_s^0\pi^+$ and $D^+ \to \phi\pi^+$

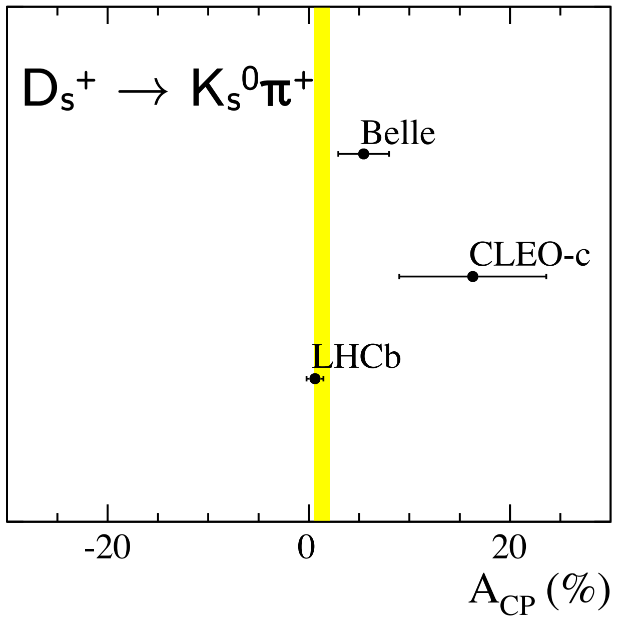
Previous measurements $D^+ \to \phi\pi^+$

- Belle (Phys.Rev.Lett. 108 071801 (2012))
- BaBar (Phys. Rev. D 71, 091101(R) (2005))

Previous measurements $D_s^+ \to K_s^0\pi^+$

- Belle (Phys. Rev. Lett. 104, 181602 (2010))
- CLEO-c (Phys. Rev. D 81, 052013 (2010))



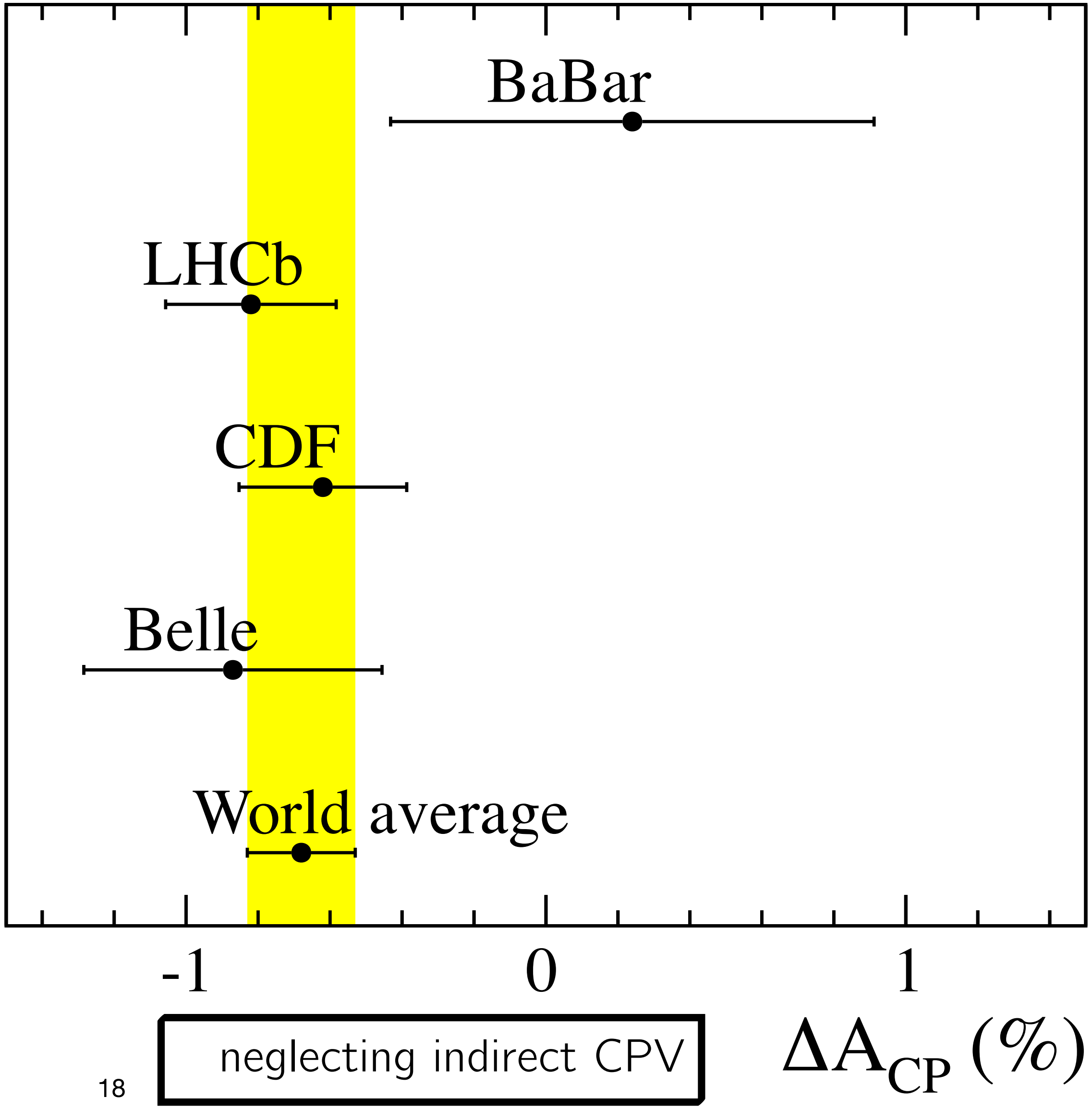


ΔA_{CP} status pre Moriond QCD

$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$

March 2012

- ΔA_{CP} measured by
  - BaBar (Phys. Rev. Lett. 100 (2008))
  - Belle (arXiv:1212.5320)
  - LHCb (Phys. Rev. Lett. 108 (2012))
  - CDF (Phys. Rev. Lett. 109 (2012))
- Latest world average 4.6σ deviation from zero
- Level of CP violation potentially accommodated within SM (arXiv:1202.3795, many more)
- Can also be explained by NP (arXiv:1202.2866, many more)
- Lively debate amongst theorists.



ΔA_{CP} Tagging

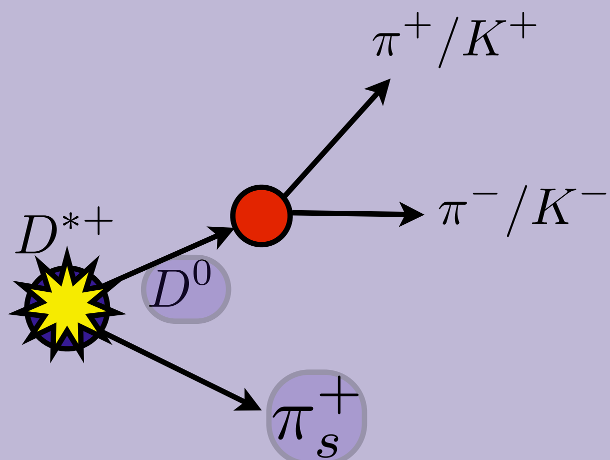
LHCb uses two methods to tag the D^0 flavour

Update

D* decays (Prompt)

Use slow pion from D* decays to tag D flavour $D^{*+} \to D^0 \pi_s^+$ or

$D^{*-} \to \bar{D}^0 \pi_s^-$



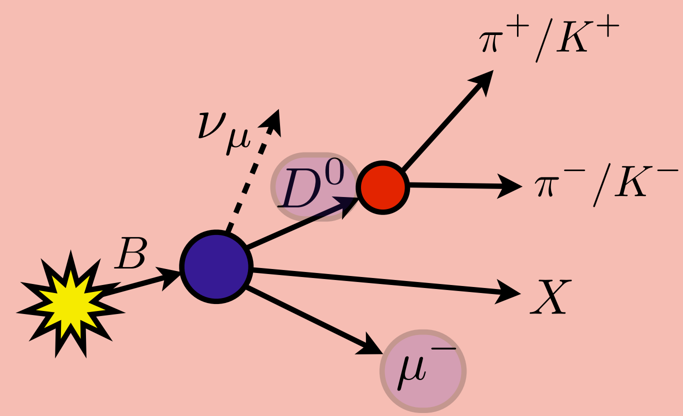
New

Semileptonic B decay(Secondary)

Use muon charge to tag D flavour

$B \to \bar{D}^0 \mu^+ \nu_\mu X$ or

$B \to D^0 \mu^- \nu_\mu X$



ΔA_{CP} from D* decays

- Update of analysis from 2011 **0.6fb^{-1}** $\rightarrow$ **1.0fb^{-1}** (full 2011 dataset)
- Update includes new reconstruction
  - **Improved tracking alignment**
  - **Improved particle identification** from RICH calibration.
- **Constrain the D* vertex to the primary vertex**
  - $\delta m \equiv m(h^+h^-\pi^+) - m(h^+h^-) - m(\pi^+)$.
  - Improves δm resolution by factor ~2.5.
- **Kinematic re-weighting of D* (ensures $D^0 \rightarrow KK$ and $D^0 \rightarrow \pi\pi$ have the same kinematics)**

LHCB-CONF-2013-003

$1.0 fb^{-1}$ collected during 2011

ΔA_{CP} from D^* decays

$$A_{RAW}(f) \simeq A_{CP}(f) + A_D(f) + A_D(\pi_s^+) + A_p(D^{*+})$$

want	f's detection asymmetry	π_s detection asymmetry	Production asymmetry

LHCB-CONF-2013-003

ΔA_{CP} from D* decays

$$A_{RAW}(f) \simeq A_{CP}(f) + A_D(f) + A_D(\pi_s^+) + A_p(D^{*+})$$

want

f's detection asymmetry

π_s detection asymmetry

Production asymmetry

Zero for self-conjugate final states ($K^+K^-/\pi^+\pi^-$)

ΔA_{CP} from D* decays

$$A_{RAW}(f) \simeq A_{CP}(f) + A_D(f) + A_D(\pi_s^+) + A_p(D^{*+})$$

π_s detection asymmetry

Production asymmetry

Taking $A_{RAW}(f) - A_{RAW}(f')$ the production and slow pion detection asymmetries will cancel

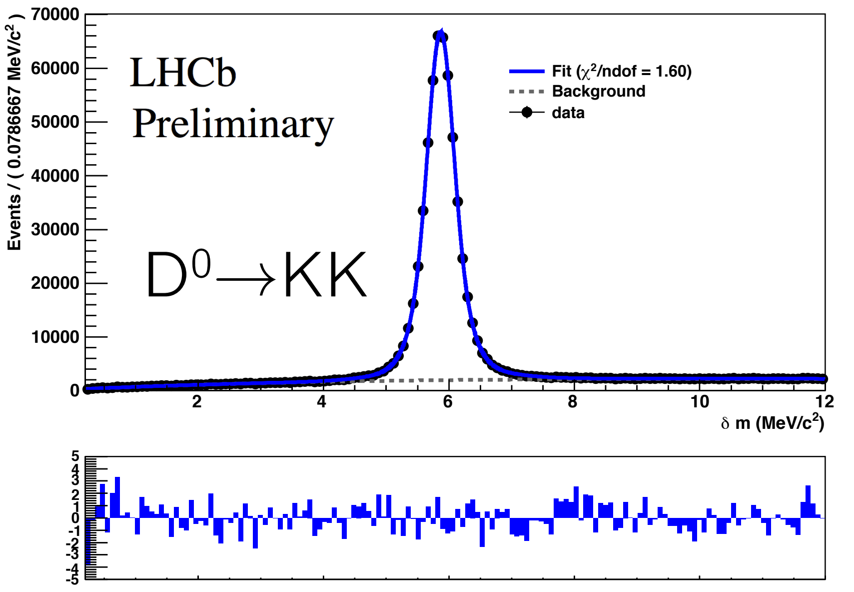
$$A_{RAW}(K^-K^+) - A_{RAW}(\pi^-\pi^+) = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) \equiv \Delta A_{CP}$$

Phys.Rev. D80 (2009) 076008

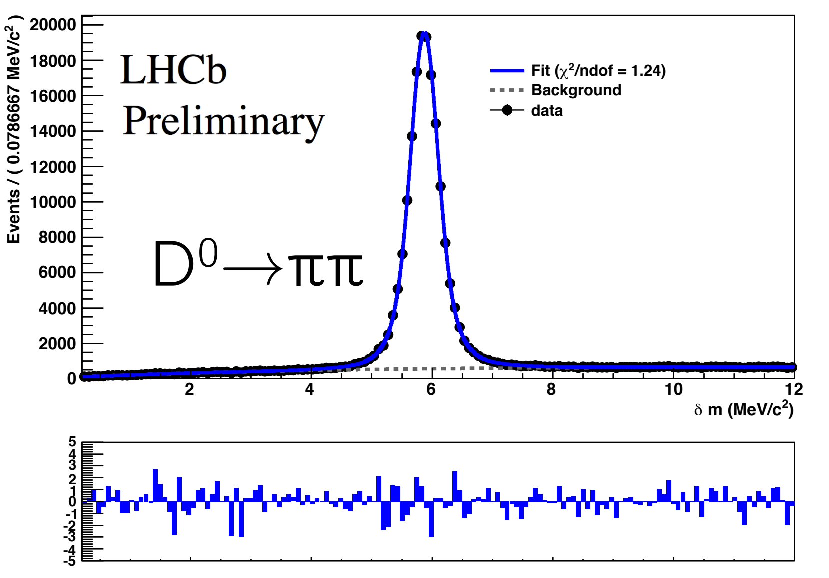
- Indirect and direct CPV can contribute
- Indirect CPV is ~universal
  - Indirect CPV cancels in $A(K^+K^-) - A(\pi^+\pi^-)$ if lifetime acceptance same for KK and ππ
  - If not contribution $A^{ind}[\langle t_{KK}\rangle_{acc} - \langle t_{\pi\pi}\rangle_{acc}]/\tau_0$

ΔA_{CP} from D* decays

- Fit in δm
  - $\delta m \equiv m(h^+h^-\pi^+) - m(h^+h^-) - m(\pi^+)$.



- **Extremely clean signal**
  - 2.2 million $D^0 \rightarrow K^+K^-$ candidates
  - 0.7 million $D^0 \rightarrow \pi^+\pi^-$ candidates



ΔA_{CP} from D^* decays

- Preliminary result

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

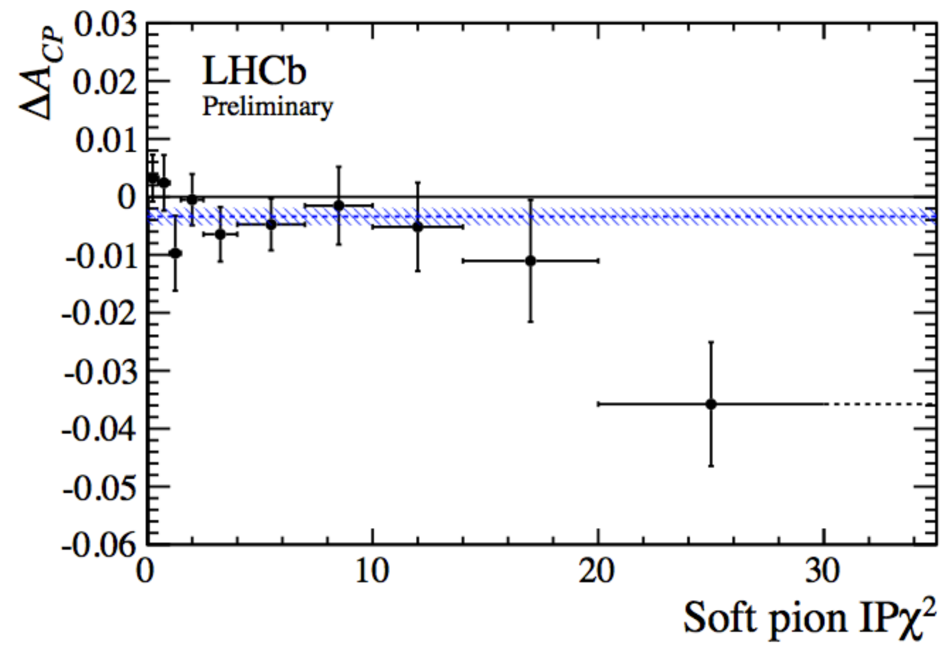
- Considerably closer to zero than previous result
  - **Larger data set**
  - **Improved detector alignment and calibration**
  - Changes in analysis technique
    - **Kinematic re-weighting** (ensures $D^0 \to KK$ and $D^0 \to \pi\pi$ have same kinematics)
    - Improve mass resolution by constraining **D* decay vertex to the primary vertex**

ΔA_{CP} from D* decays

- Preliminary result

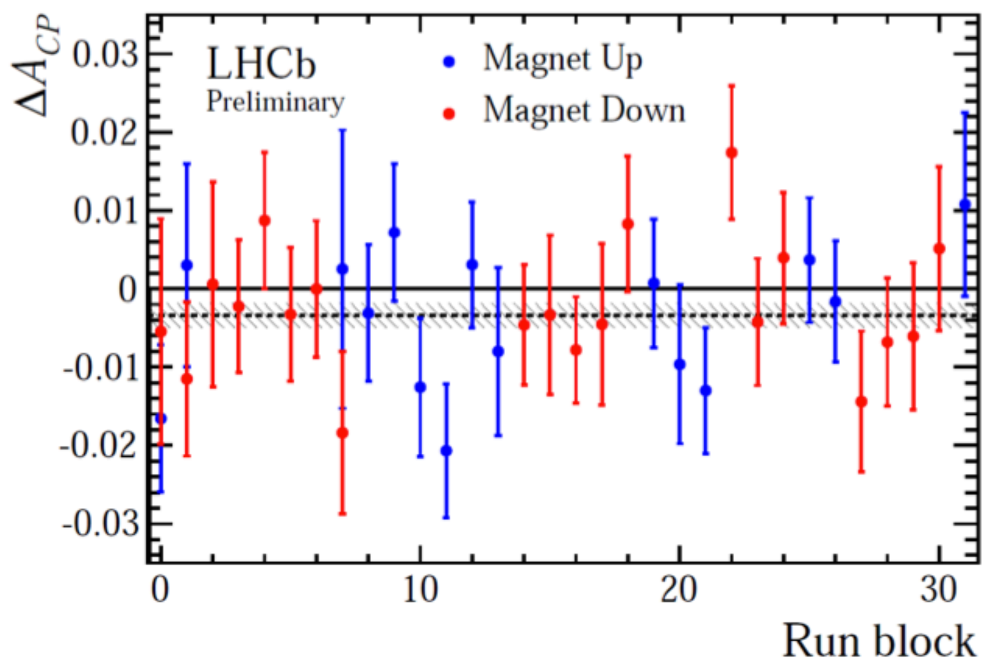
$$\Delta A_{CP} = (-0.34 \pm 0.15\,(\text{stat.}) \pm 0.10\,(\text{syst.}))\%$$

- Source of systematic uncertainties
  - Soft pions with large IPχ^2 for pointing to PV
    - Effect due to multiple scattering
      - Results in poor mass distribution
      - Should not depend on D^0 decay mode
        - Raw asymmetry observed in these candidates
    - Analysis repeated with these candidates removed
    - **Dominant systematic 0.08%**



ΔA_{CP} from D* decays : Cross checks

- ΔA_{CP} stability checked
  - Against time at which data was taken
  - Various reconstructed quantities:
    - D^0 p_T
    - D^0 η
    - D^0 p
    - D^0 decay time
- Analysis performed on large Monte Carlo samples to check for bias
- Many more

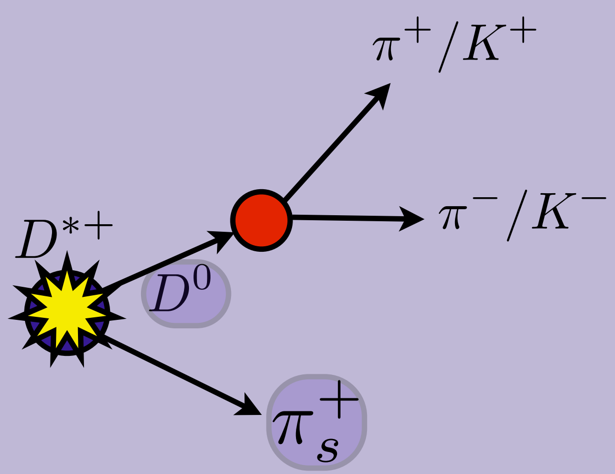


ΔA_{CP} Tagging

LHCb uses two methods to tag the D^0 flavour

D* decays (Prompt)

Use slow pion from D* decays to tag D flavour $D^{*+} \rightarrow D^0 \pi_s^+$ or $D^{*-} \rightarrow \bar{D}^0 \pi_s^-$



Semileptonic B decay(Secondary)

Use muon charge to tag D flavour

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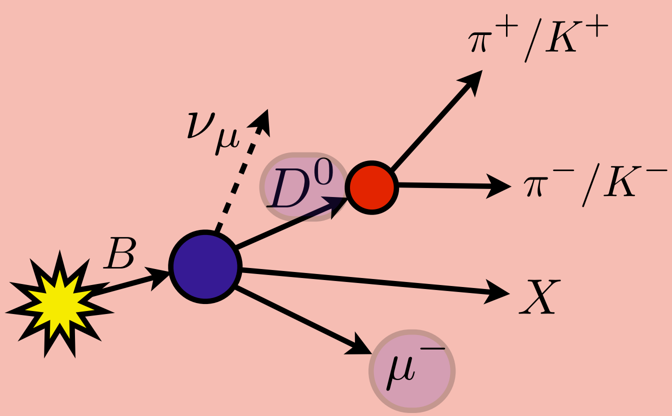


ΔA_{CP} from semileptonic B decays

$$A_{RAW}(f) = A_{CP}(f) + A_D(f) + A_D(\mu^+) + A_p(B)$$

Detection and production asymmetries **independent** from D* analysis

μ detection asymmetry

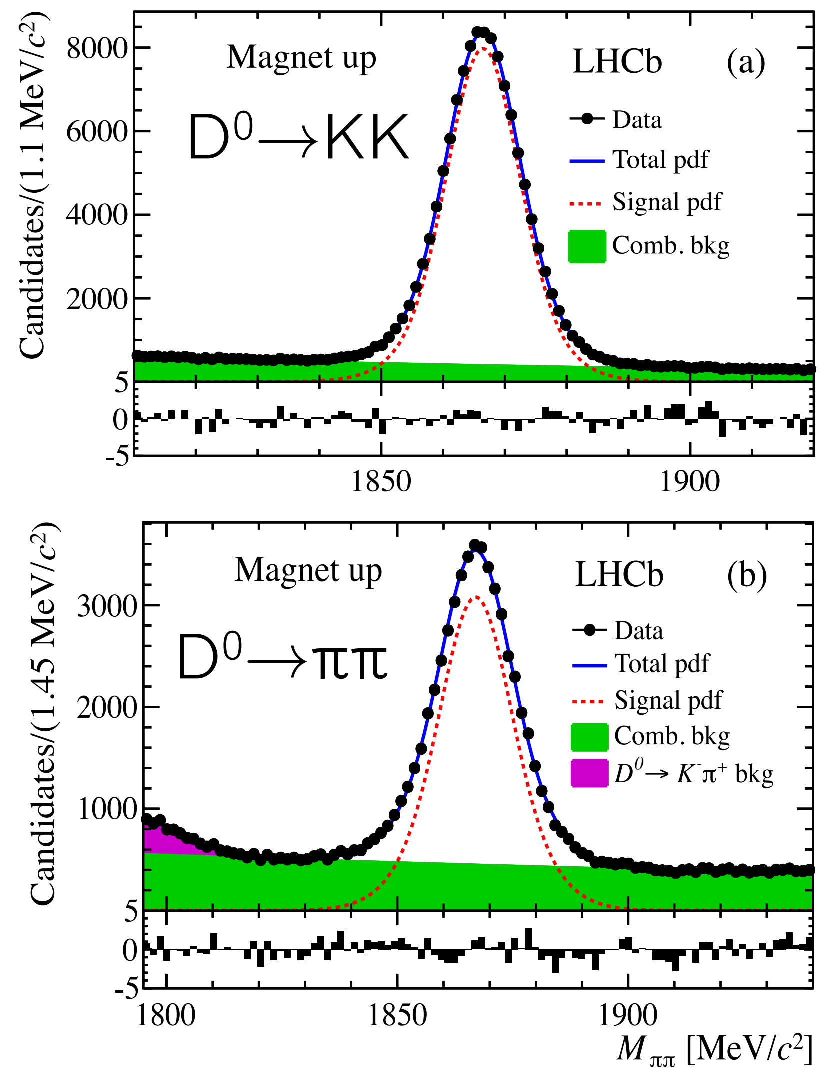
b-hadron production asymmetry

Taking $A_{RAW}(f) - A_{RAW}(f')$ the production and muon detection asymmetries will cancel if kinematics of muon and B meson are the same for both $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$

$$A_{RAW}(K^-K^+) - A_{RAW}(\pi^-\pi^+) = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+) \equiv \Delta A_{CP}$$

ΔA_{CP} from semileptonic B decays

- Clean signal
  - 0.6M $D \rightarrow K^+K^-$ candidates
  - 0.2M $D \rightarrow \pi^+\pi^-$ candidates
- ΔA_{CP} calculated separately for magnet up and magnet down data

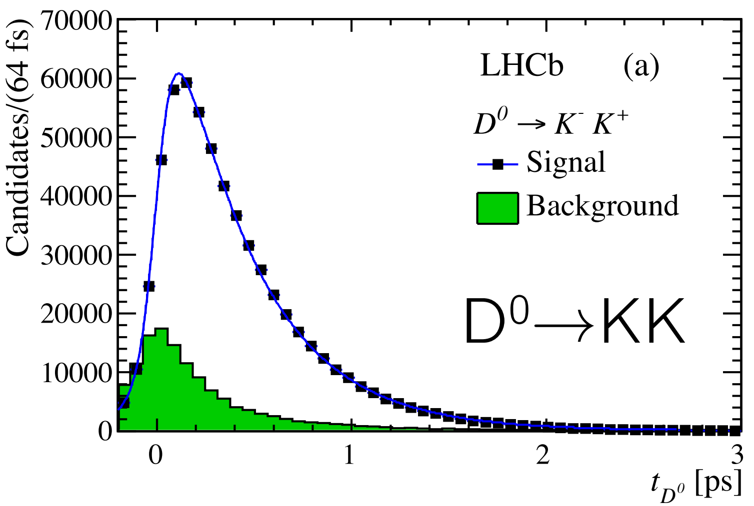


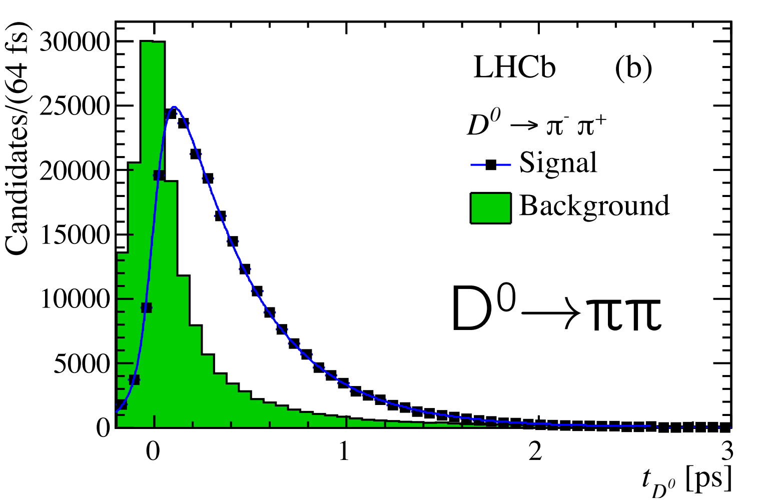
ΔA_{CP} from semileptonic B decays

- Result

$$\Delta A_{CP} = (0.49 \pm 0.30\,(\mathrm{stat}) \pm 0.14\,(\mathrm{syst}))\% \ .$$

- Main source of systematic from low lifetime background in $D^0 \to \pi^+\pi^-$ decays
  - More low lifetime background in $D^0 \to \pi^+\pi^-$ than $D^0 \to K^+K^-$
  - Cut applied at zero decay time in analysis
  - Analysis repeated including negative decay times
  - Systematic uncertainty of 0.11%





Cross checks

- Many cross checks carried out
- ΔA_{CP} stable with
  - reconstructed quantities:
    - D^0 decay time
    - B flight distance
    - reconstructed D^0-μ mass
    - angle between μ and D^0 daughters
    - p_T of D^0 and μ
    - η of D^0 and μ
  - data taking period
  - many more

arXiv:1303.2614

LHCB-CONF-2013-003

Comparison with D* and semileptonic ΔA_{CP}

D* decays (Prompt) Preliminary

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

Semileptonic

$$\Delta A_{CP} = (0.49 \pm 0.30\,(\text{stat}) \pm 0.14\,(\text{syst}))\%$$

- Two measurements compatible a 3% level ($\chi^2 = 4.85$)
- **Statistical correlation** between the two data samples is **negligible**
- **Systematic uncertainties** essentially **uncorrelated**

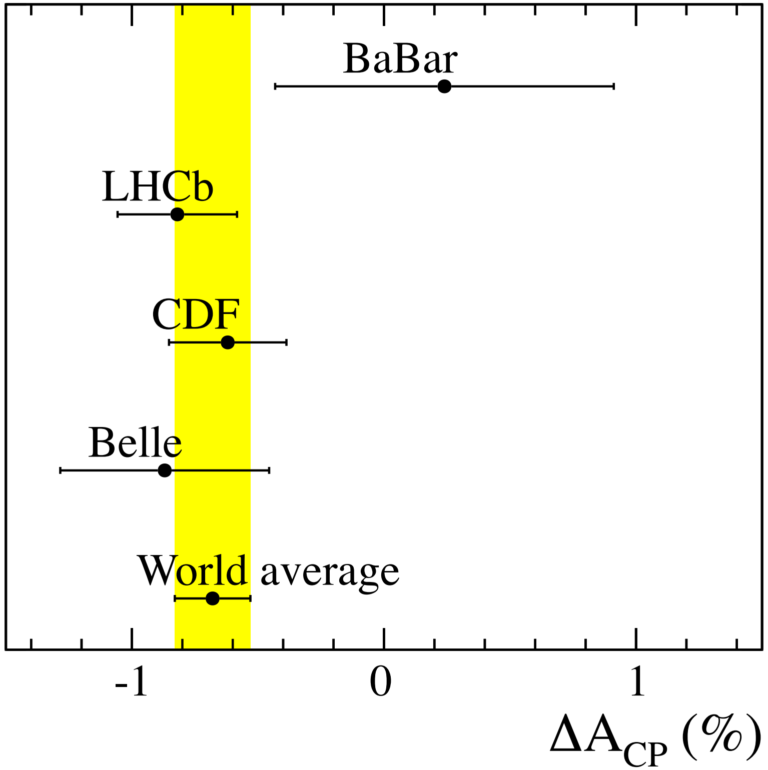
Preliminary combination: $\Delta A_{CP} = [-0.15 \pm 0.16]\,\%$

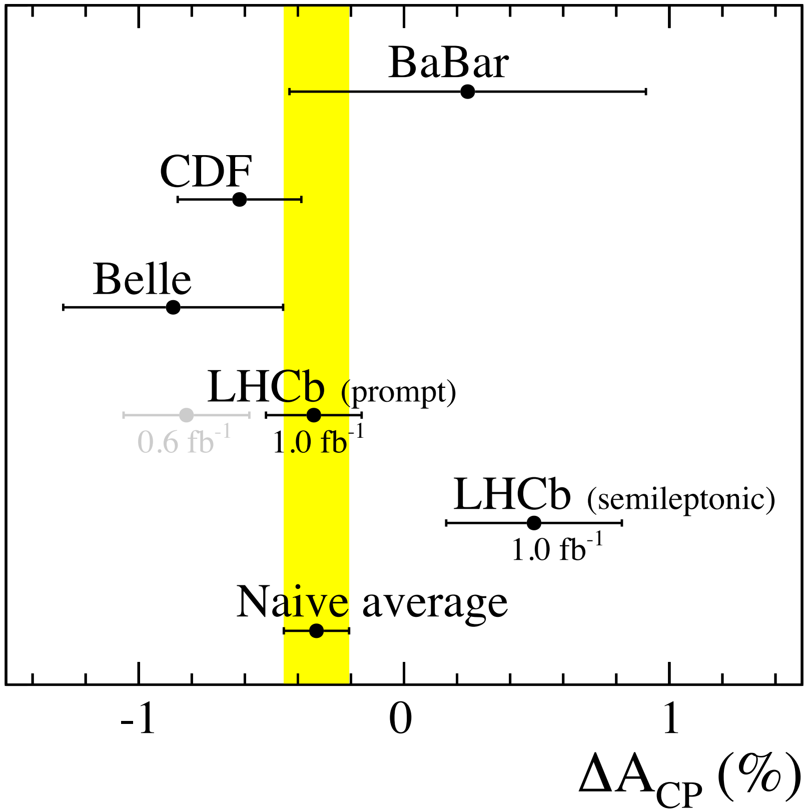
neglects indirect CPV

arXiv:1303.2614
LHCB-CONF-2013-003

ΔA_{CP} Preliminary new world average

- New average includes BaBar, CDF, Belle and new LHCb results





naive average neglecting indirect CPV

Summary

- **D^0 mixing** established at **9.1σ** (Phys.Rev.Lett. 110, 101802 (2013))
- **No CPV observed in $D^+ \to \phi\pi^+$** and **$D_s^+ \to K_s^0\pi^+$** (LHCB-PAPER-2012-052)
- **Measured from D^0 from D^* and D^0 from B decays**
  - **ΔA_{CP} = (−0.34±0.15(stat.)±0.10(syst.))%** preliminary for D* analysis (LHCB-CONF-2013-003)
  - **ΔA_{CP} = (0.49±0.30(stat)±0.14(syst))%** for semileptonic (arXiv:1303.2614)
  - Many cross checks performed
  - Preliminary combination **ΔA_{CP} = [−0.15 ± 0.16] %** (not including indirect CPV)
  - **LHCb results does not confirm 3σ evidence of CP violation in Charm**
- Analyses performed on $1.0 fb^{-1}$
  - **$3 fb^{-1}$ of data recorded at LHCb**
- Many more ongoing charm CP violation searches

Fim

ΔA_{CP} D* comparison to 2011 result

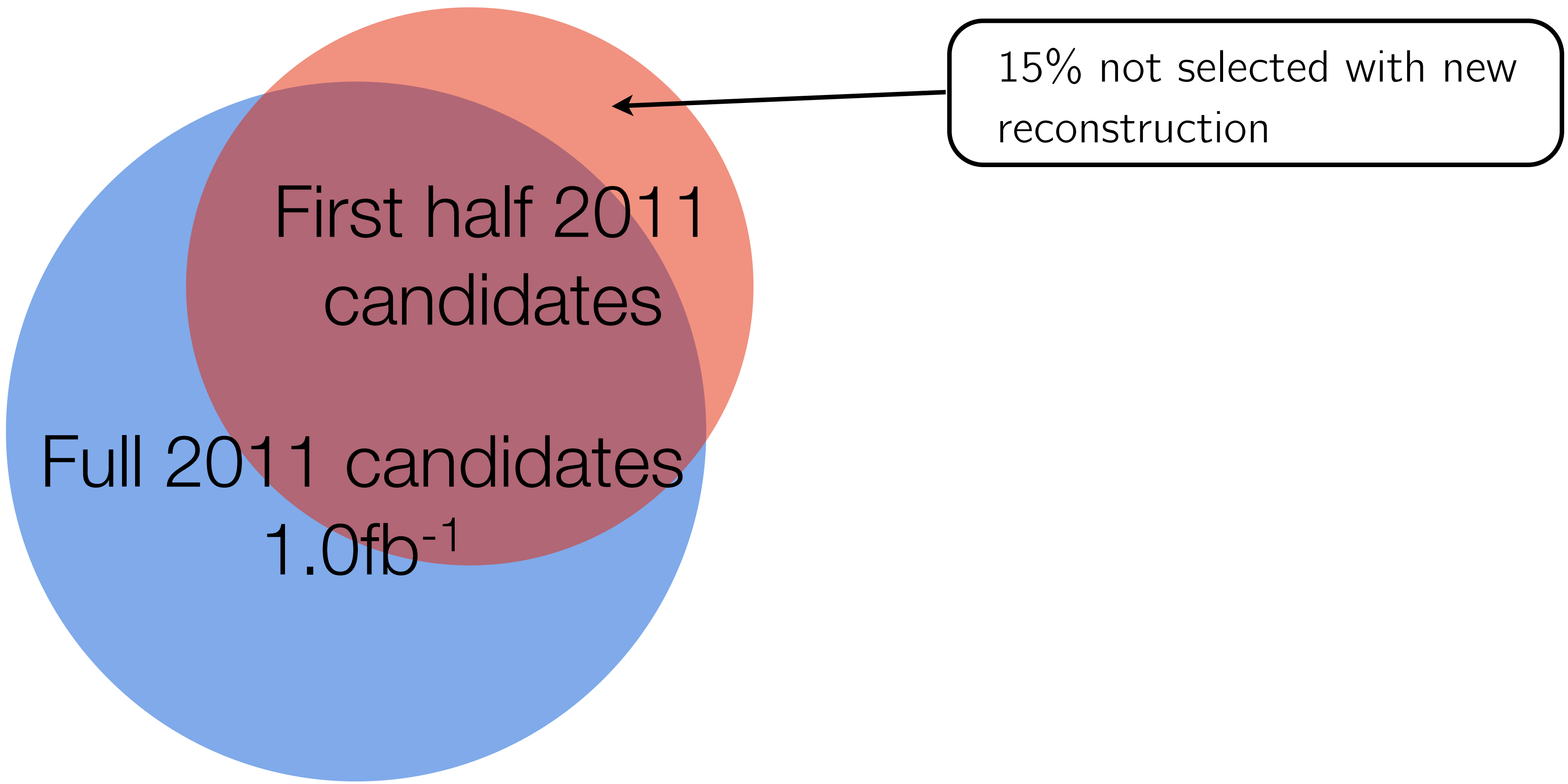
ΔA_{cp} from D* decays comparison to 2011 result

Analysis using method from 2011

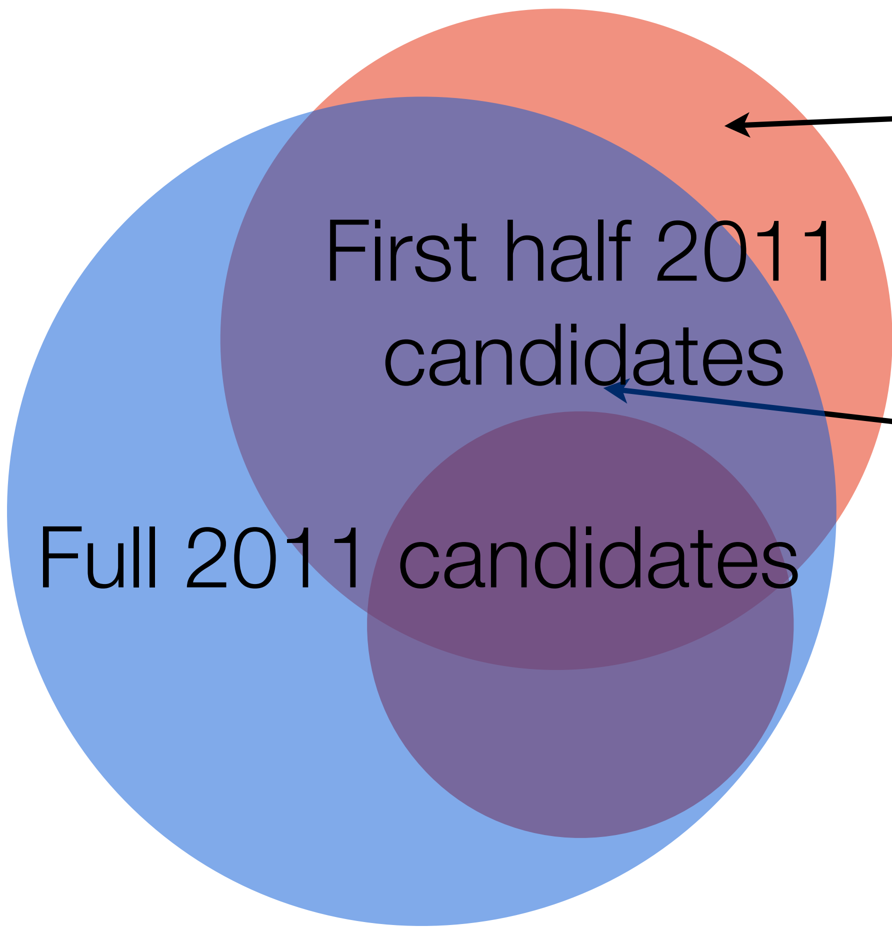
First half 2011 candidates ($600 pb^{-1}$)

ΔA_{CP} from D^* decays comparison to 2011 result

Analysis using method from 2011



ΔA_{CP} from D^* decays comparison to 2011 result



Analysis using method from 2011

15% not selected with new reconstruction

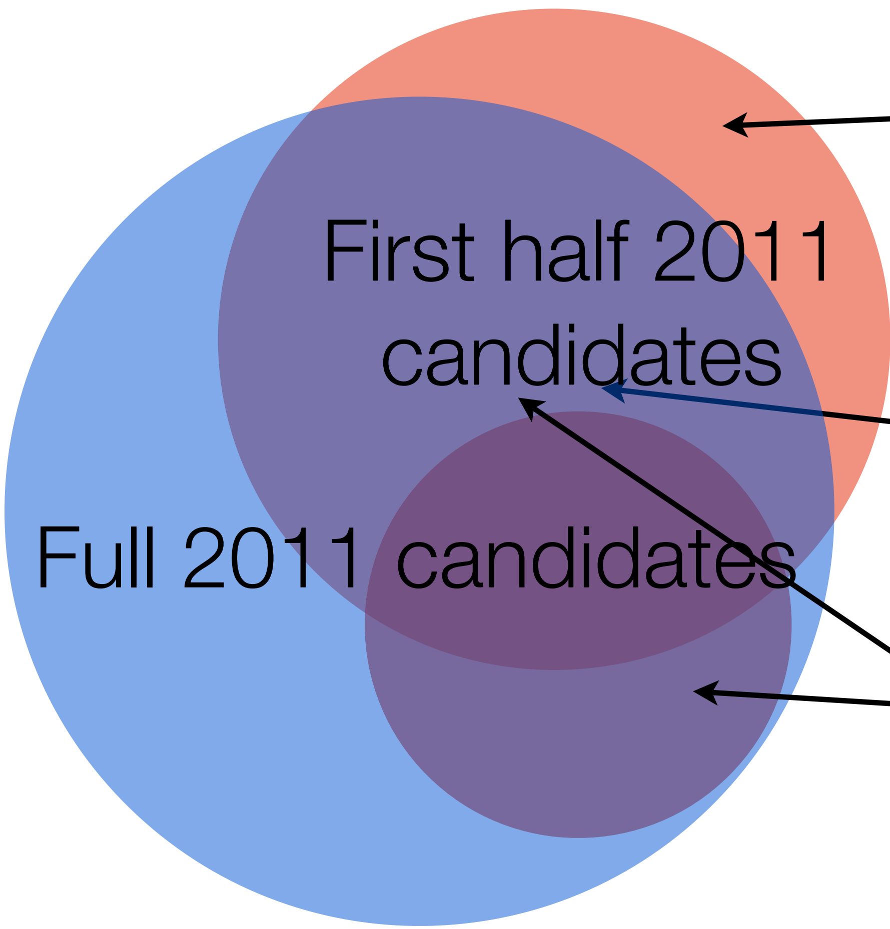
$\Delta A_{CP} = (-0.80 \pm 0.23)\%$

New Reconstruction

$\Delta A_{CP} = (-0.78 \pm 0.23)\%$

ΔA_{CP} from D* decays comparison to 2011 result

Analysis using method from 2011



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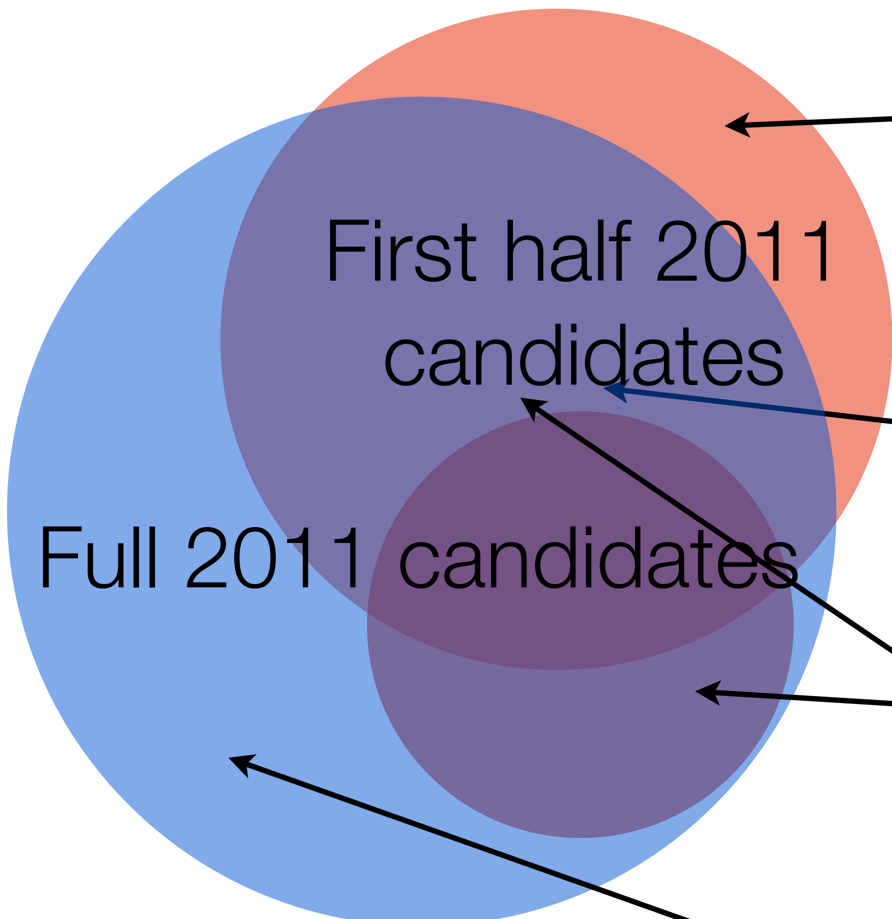
New Reconstruction

$\Delta A_{CP} = (-0.78 \pm 0.23)\%$

first 600 pb^{-1} including additional **17% KK** and **34% ππ** (improved RICH calibration)

ΔA_{CP} from D* decays comparison to 2011 result



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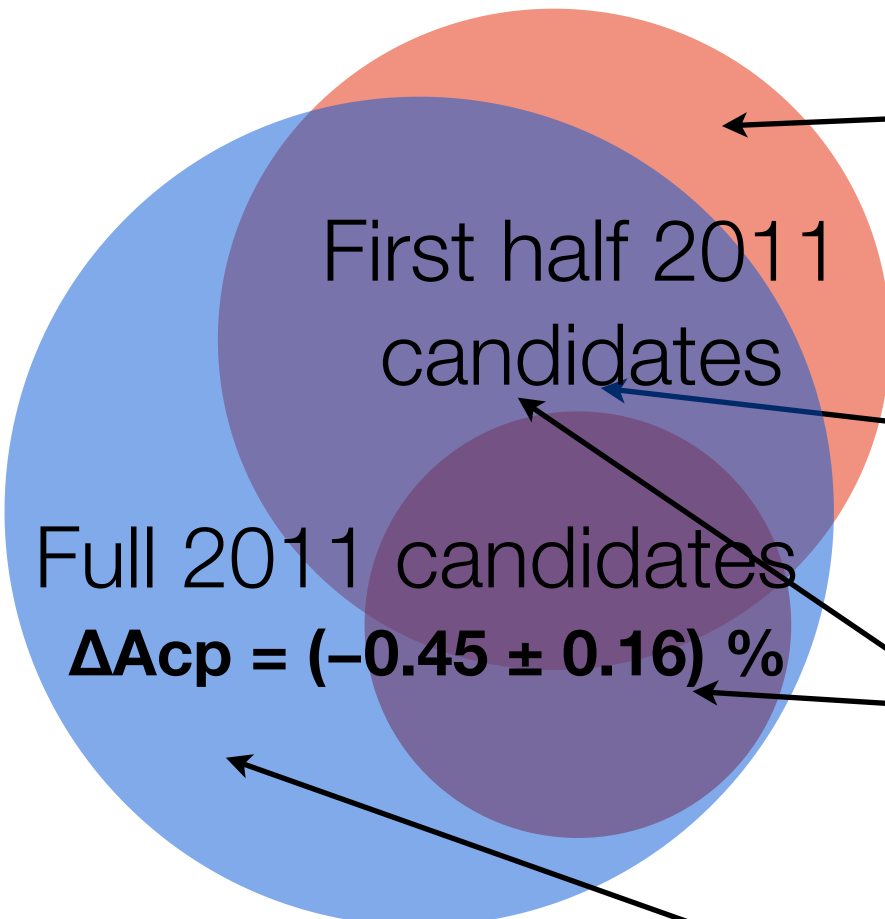
last 400pb^{-1} recorded by LHCb 2011

$\Delta A_{CP} = (-0.28 \pm 0.26)\%$

ΔA_{CP} from D* decays comparison to 2011 result

Analysis using method from 2011



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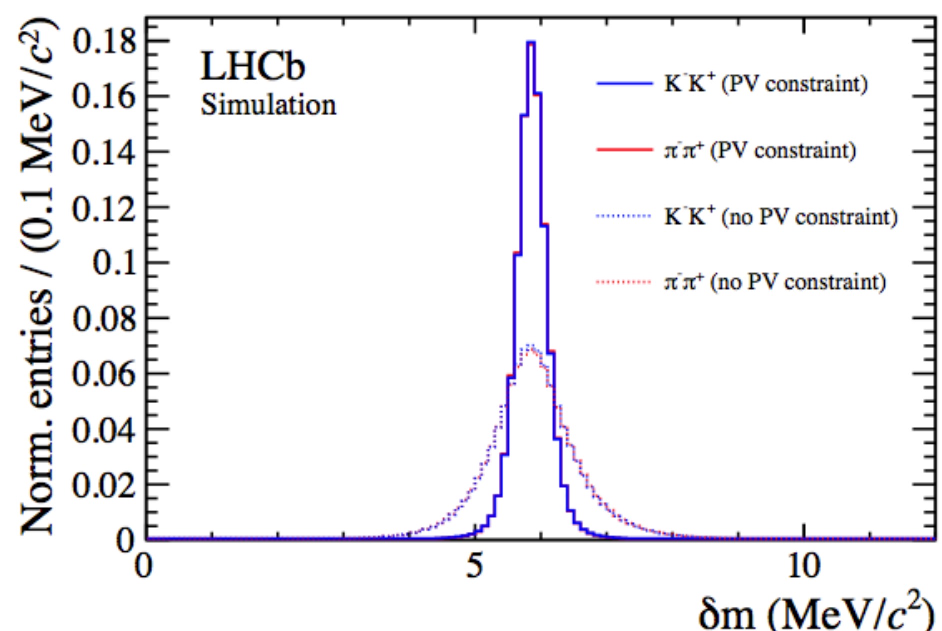
ΔA_{CP} from D* decays

kinematic re-weighting

$\Delta A_{CP} = (-0.45 \pm 0.16)\ \%$ → $\Delta A_{CP} = (-0.45 \pm 0.17)\ \%$

force D* vertex to the Primary Vertex

$\Delta A_{CP} = (-0.45 \pm 0.17)\ \%$ → **$\Delta A_{CP} = (-0.34 \pm 0.15)\ \%$**



ΔA_{CP} from D* decays

ΔA_{CP} from D* decays

- Previous results:

Experiment	ΔA_{CP}	
LHCb	$(-0.82 \pm 0.21 \pm 0.11)\%$	Phys. Rev. Lett. 108 (2012) 111602
CDF	$(-0.62 \pm 0.21 \pm 0.10)\%$	Phys. Rev. Lett. 109 (2012) 111801
Belle	$(-0.87 \pm 0.41 \pm 0.06)\%$	arXiv:1212.5320
BaBar	$(+0.24 \pm 0.62 \pm 0.26)\%$	Phys. Rev. Lett. 100 (2008)

ΔA_{CP} from D^* decays

Analysis technique

- **D^* re-weighted in p and p_T** ($D^0 \to KK$ and $D^0 \to \pi\pi$ same kinematics)
- Break dataset into 4 subsets
  - Hardware trigger (**L0**) on D^0 daughters (Trigger on Signal)
    - **Magnet Up**
    - **Magnet Down**
  - Hardware trigger (**L0**) on other particles from **pp** collision (Trigger Independent of Signal)
    - **Magnet Up**
    - **Magnet Down**
- ΔA_{CP} calculated for each subset and result is weighted average

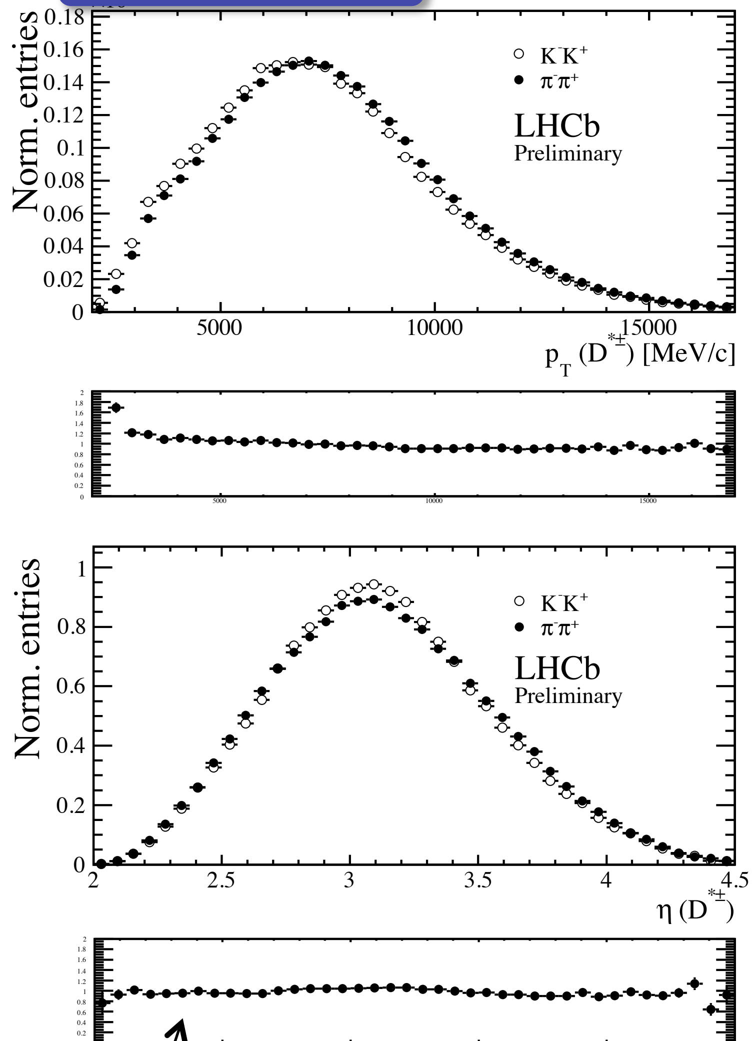
ΔA_{CP} from D^* decays

- Kinematic Re-weighting
- Re-weight D^* candidates so both $D^0 \to KK$ and $D^0 \to \pi\pi$ have the same kinematics

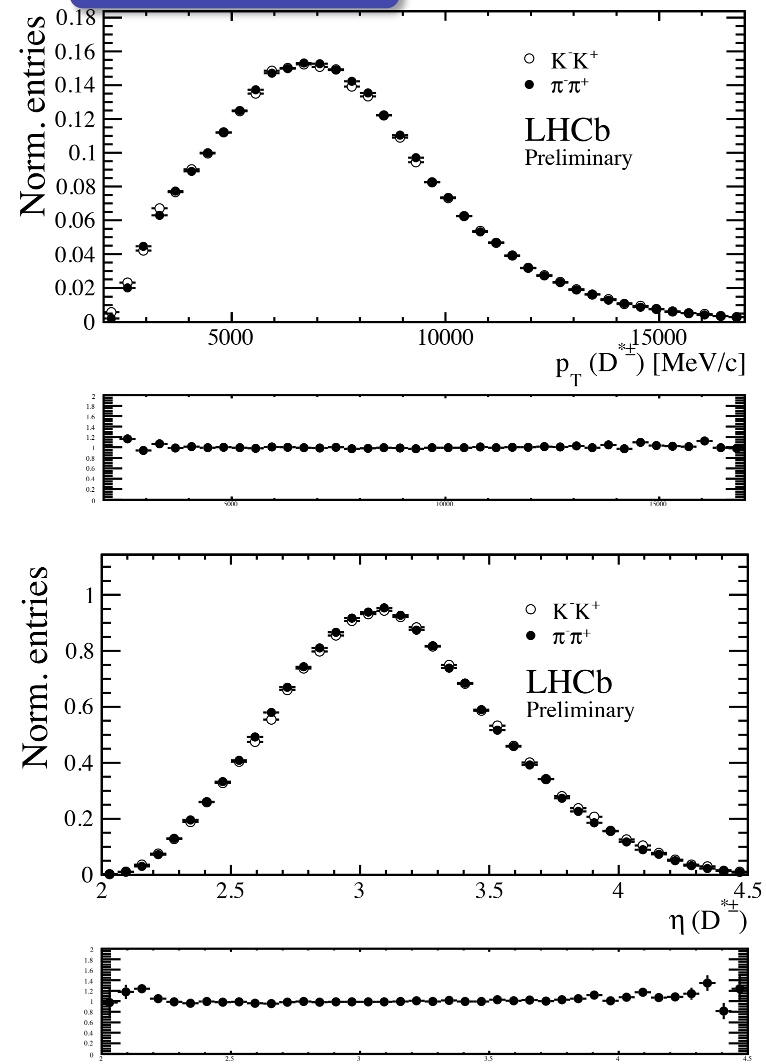
ΔA_{CP} from D* decays

LHCB-CONF-2013-003

Before weighting



After weighting



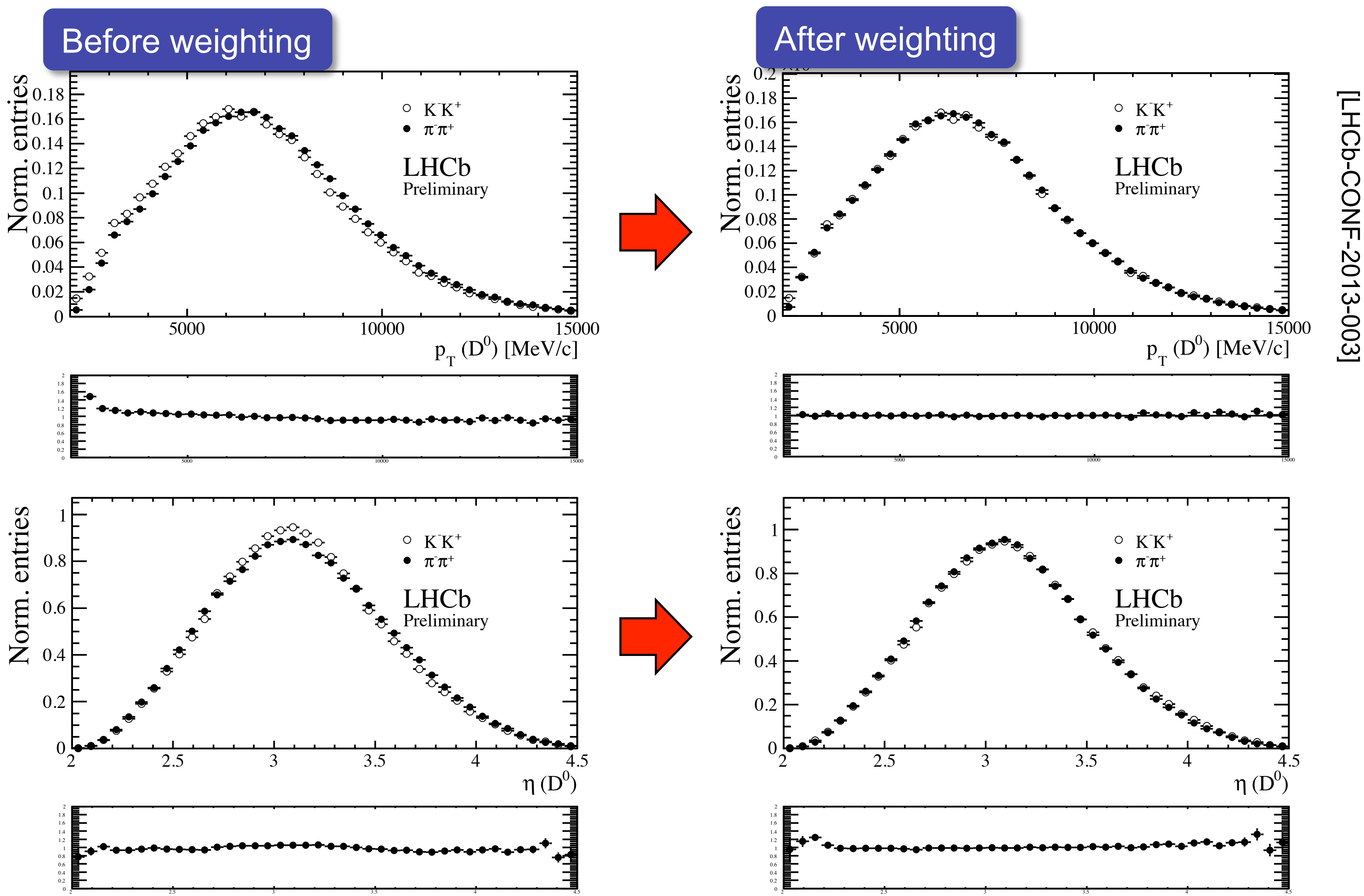
[LHCb-CONF-2013-003]

Only small differences before weighting

Obviously, D* kinematics agree after weighting for D* kinematics

ΔA$_{CP}$ from D* decays

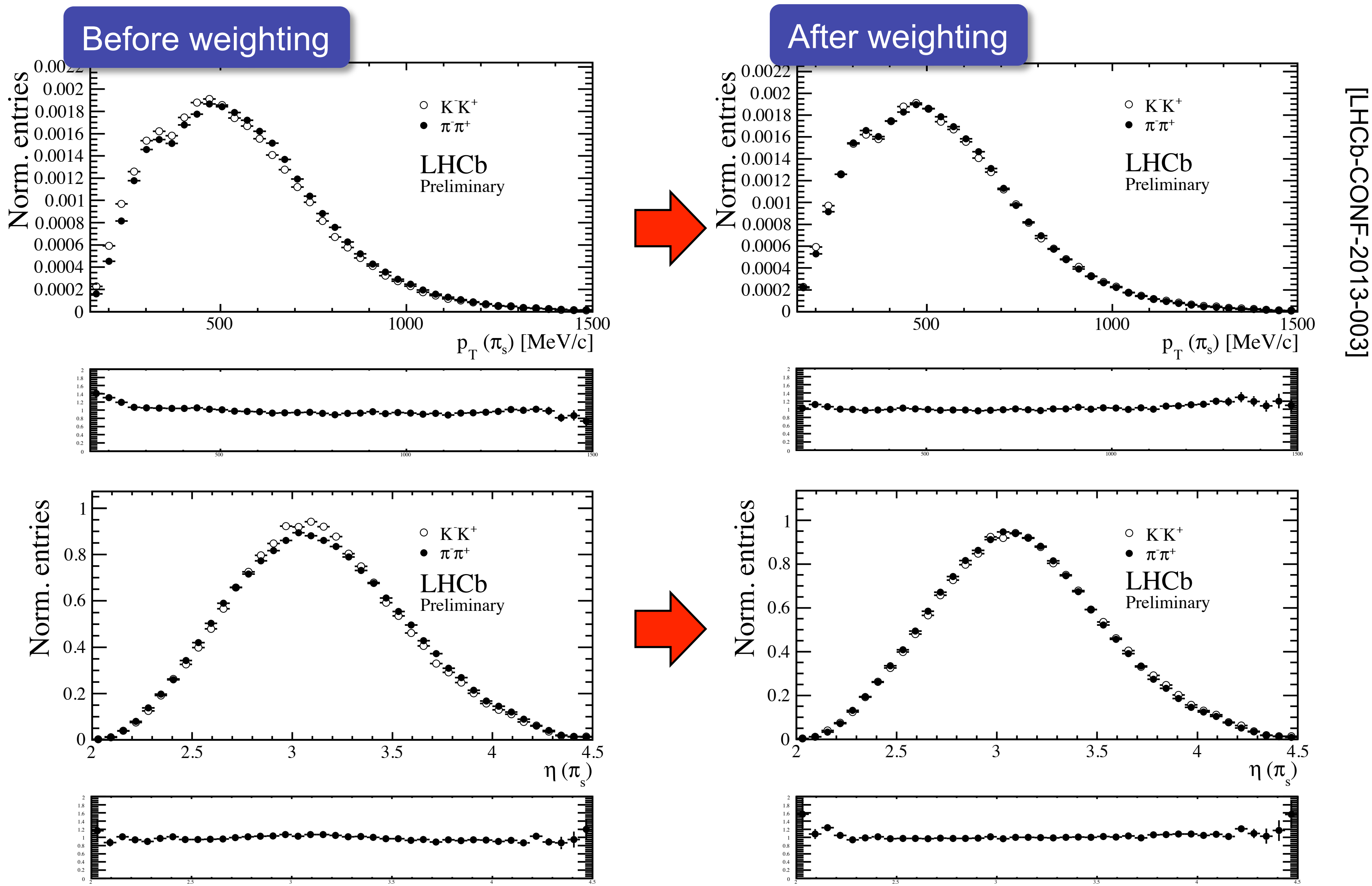
LHCB-CONF-2013-003



Also D^0 distributions agree after weighting for D* kinematics

LHCB-CONF-2013-003

ΔA_{CP} from D* decays



Also slow pion distributions agree after weighting for D* kinematics

ΔA_{CP} from D^* decays : Cross checks

- Effects investigated for systematics
  - Peaking backgrounds
  - Tighter particle ID cuts
  - Different D^* selection
  - Comparing results with and without kinematic re-weighting
- ΔA_{CP} stability checked
  - Against time which data was taken
  - Various reconstructed quantities:
    - D^0 p_T
    - D^0 η
- Analysis performed on large Monte Carlo samples to check for bias
- $\Delta\langle t\rangle/\tau(D^0) = (11.27 \pm 0.13)\%$
- many more

Systematic uncertainties ΔA_{CP}

- Sources of systematic uncertainties for D* analysis

Source	Uncertainty
Multiple candidates	0.01%
Peaking background	0.03%
Fit model	0.03%
Reweighting	0.01%
Soft pion IPχ^2	0.08%
Fiducial cut	0.02%
Total	0.10%

Systematic uncertainties ΔA_{CP}

- Soft pions which do not point to primary vertex (before constraint)
  - Effect due to multiple scattering
    - Results in poor mass distribution
    - Should not depend on D^0 decay mode
      - Raw asymmetry observed in these candidates
  - Analysis repeated with these candidates removed
  - **Dominant systematic 0.08%**

Source	Uncertainty
Multiple candidates	0.01%
Peaking background	0.03%
Fit model	0.03%
Reweighting	0.01%
Soft pion IPχ^2	0.08%
Fiducial cut	0.02%
Total	0.10%

Systematic uncertainties ΔA_{CP}

- Tighter particle identification cut
  - Analysis repeated with tighter particle identification cuts.
- Fiducial cuts
  - Analysis repeated with altered fiducial cuts.
- Re-weighting
  - Re-weighting D^0 such that $D^0 \to \pi^+\pi^-$ and $D^0 \to K^+K^-$ kinematics match.
  - Analysis repeated without kinematic re-weighting.

Source	Uncertainty
Multiple candidates	0.01%
Peaking background	0.03%
Fit model	0.03%
Reweighting	0.01%
Soft pion IPχ^2	0.08%
Fiducial cut	0.02%
Total	0.10%

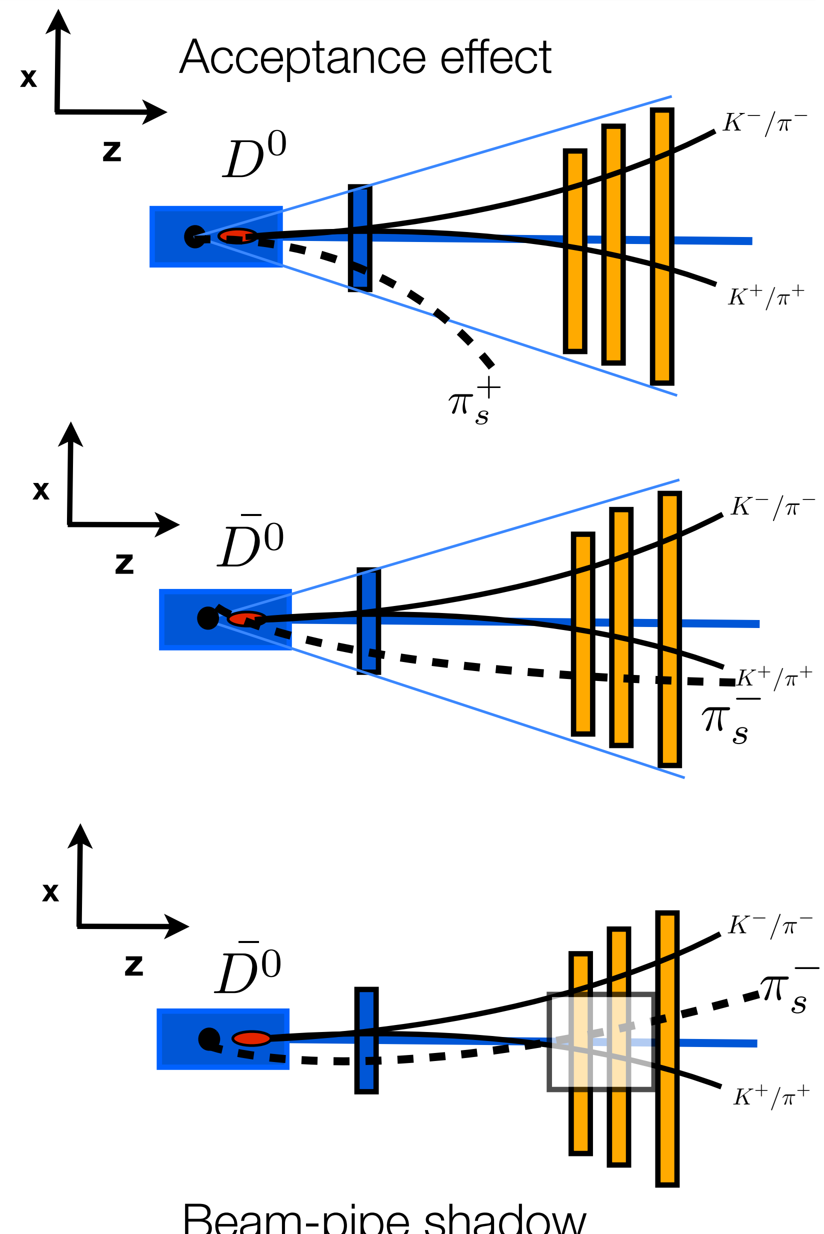
Systematic uncertainties ΔA_{CP}

- Multiple candidates
  - Analysis repeated with a random candidate in events with multiple candidates removed.
- Peaking background
  - D mass peaks used to test for potential peaking background contributions.
- Fit model
  - Analysis repeating with the asymmetry extracted through sideband subtraction instead of a fit.

Source	Uncertainty
Multiple candidates	0.01%
Peaking background	0.03%
Fit model	0.03%
Reweighting	0.01%
Soft pion IPχ^2	0.08%
Fiducial cut	0.02%
Total	0.10%

ΔA$_{CP}$

- Magnetic field induces left/right differences between the D*+ and D*- due to the slow pion
- Acceptance effect at edges of detector
- Beam-pipe shadow
- We remove this asymmetry
- We remove areas of large asymmetry to avoid secondary effects
- Frequently flip the magnetic field
- Detector asymmetries removed in difference between RAW asymmetries



ΔA_{CP}

- Magnetic field induces left/right differences between the D^{*+} and D^{*-} due to the slow pion
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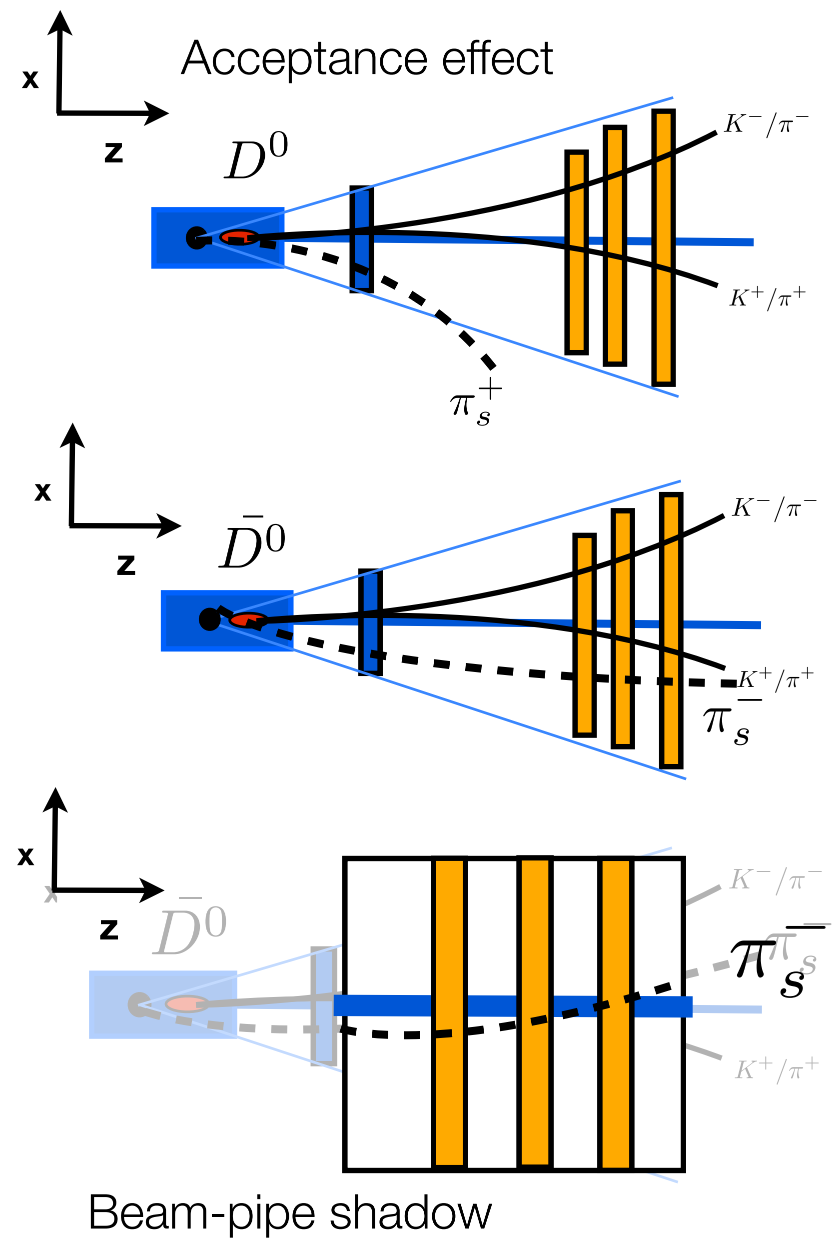
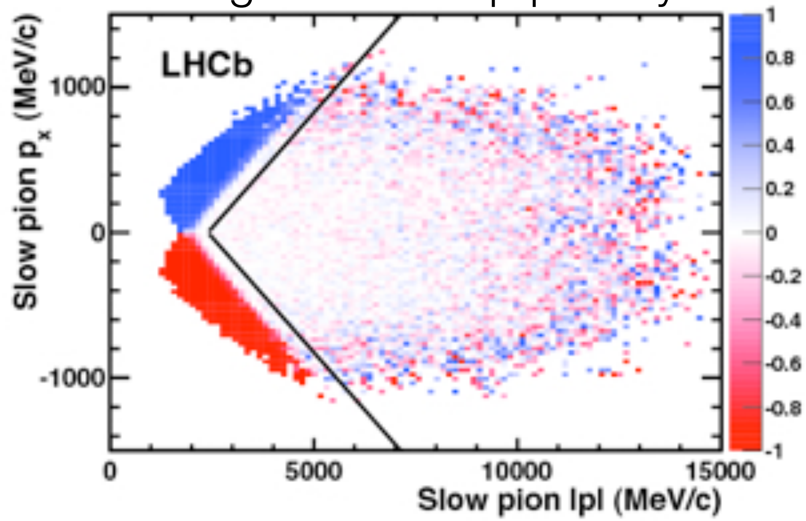


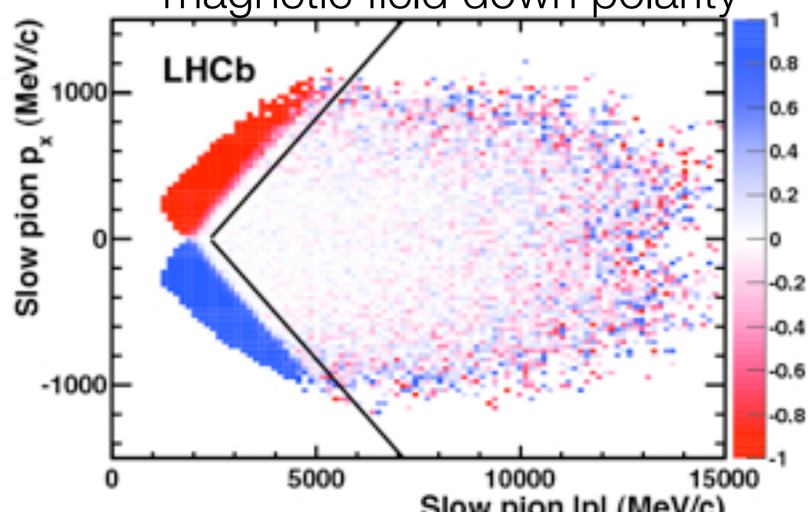
ΔA_{CP}

- Magnetic field induces left/right differences between the D^{*+} and D^{*-} due to the slow pion
    - Acceptance effect at edges of detector
    - Beam-pipe shadow
- We remove this asymmetry
    - We remove areas of large asymmetry to avoid secondary effects
    - Frequently flip the magnetic field
    - Detector asymmetries removed in difference between RAW asymmetries

magnetic field up polarity



magnetic field down polarity

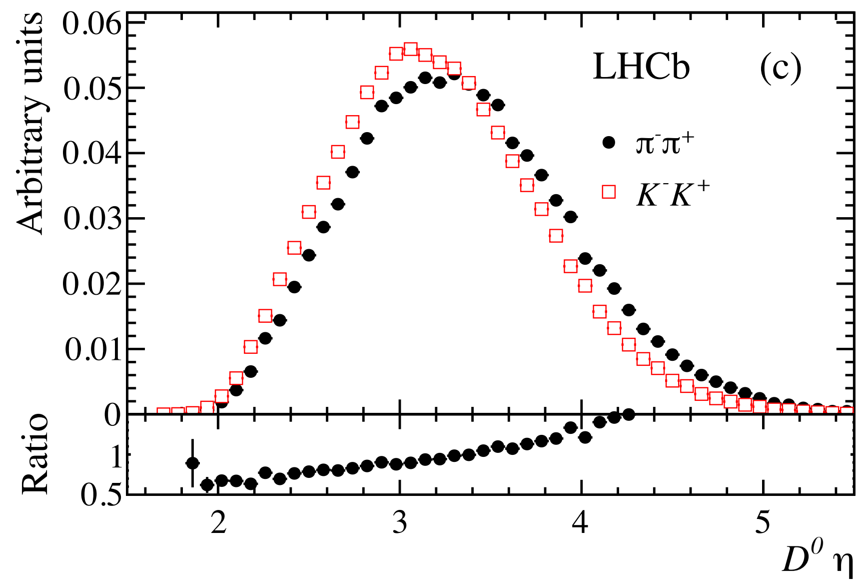


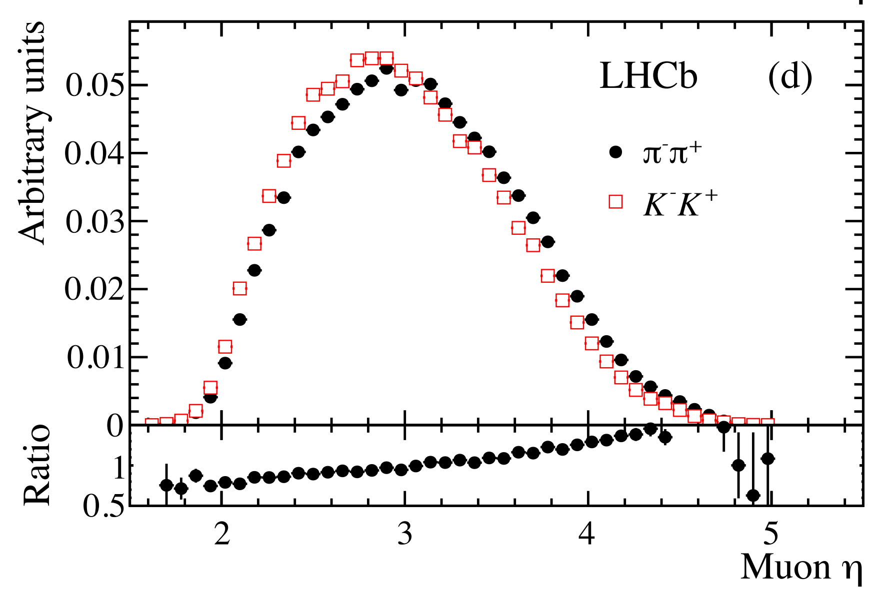
Phys. Rev. Lett. 108 (2012) 111602

ΔA_{CP} from semileptonic B decays

ΔA_{CP} from semileptonic B decays

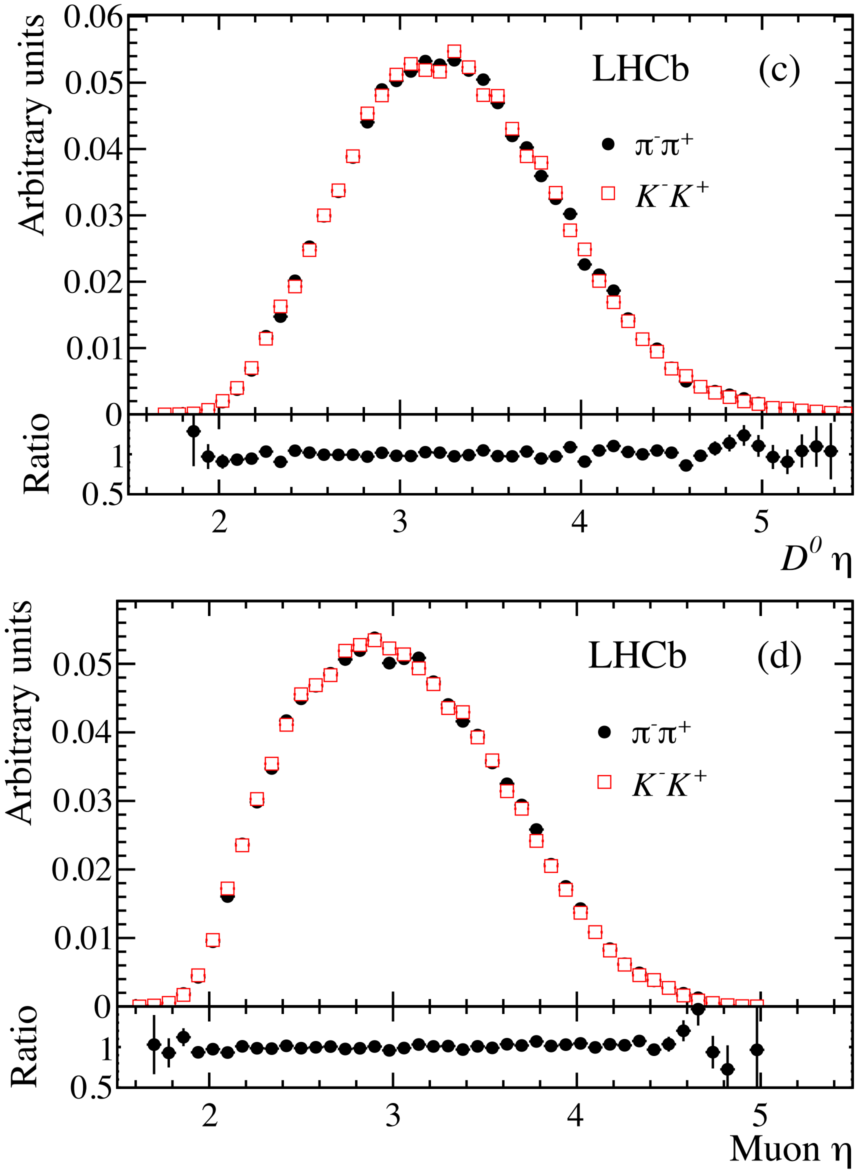
- **D^0 candidates** given weight depending on **p_T and η distribution**





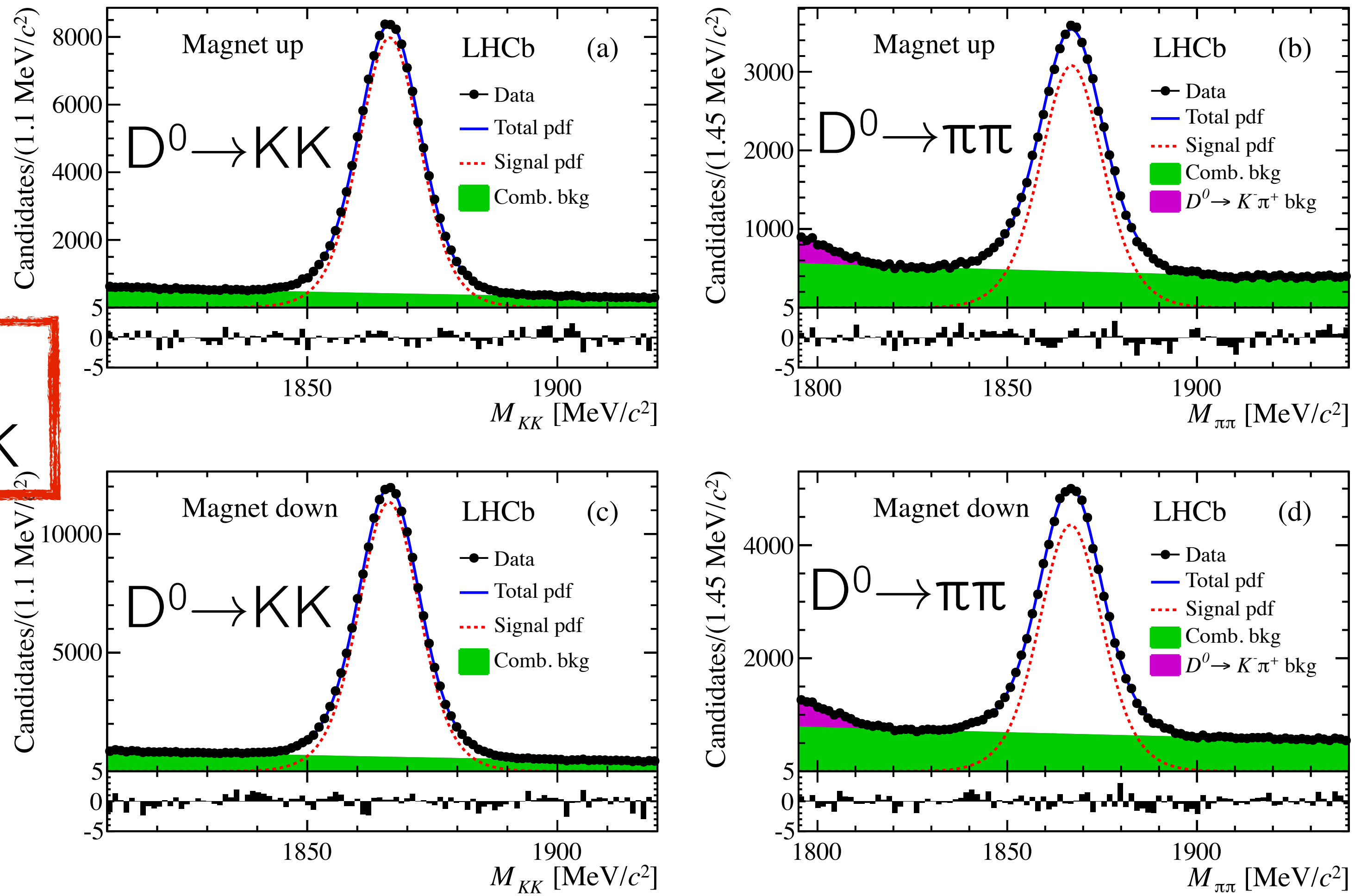
ΔA_{CP} from semileptonic B decays

- **D^0 candidates** given weight depending on **p_T and η distribution**
- **Muon** kinematics also in good agreement after **re-weighting**



ΔA_{CP} from semileptonic B decays

559k
$D^0 \rightarrow KK$



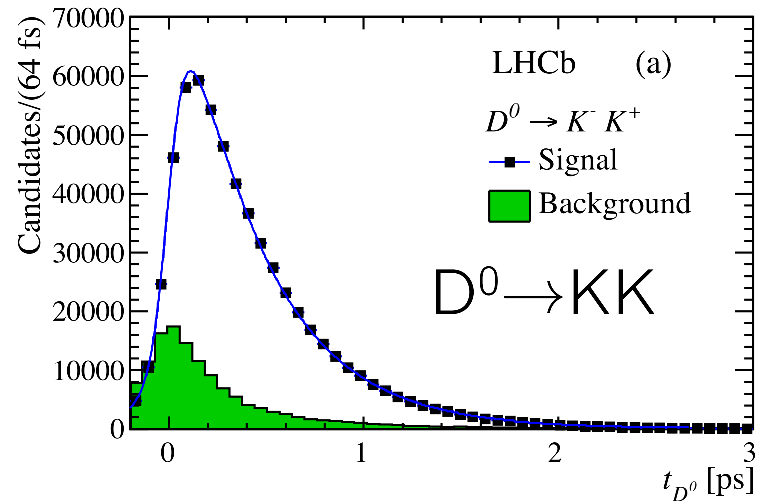
222k
$D^0 \rightarrow \pi\pi$

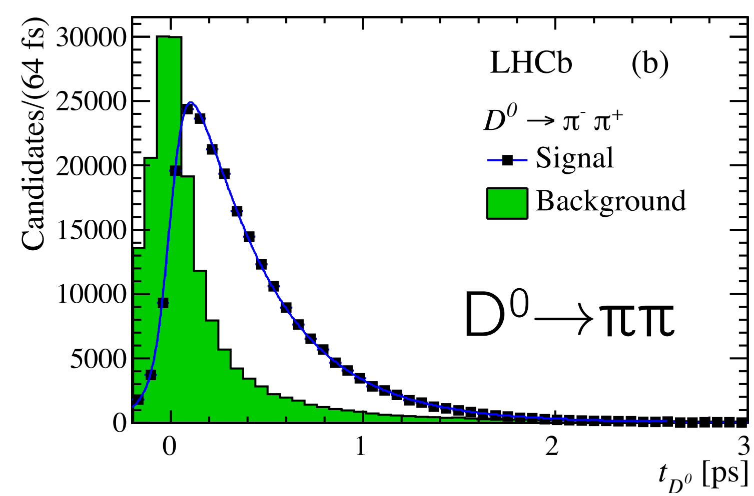
$$\Delta A_{CP} = (0.49 \pm 0.30\,(\mathrm{stat}) \pm 0.14\,(\mathrm{syst}))\%\ .$$

Systematic uncertainties

- Pairing a D^0 with random muon (mistag)
  - Dilutes signal
  - Difference in mistag probability between D^0 and anti-D^0 is (0.006 ± 0.021)%
- Decay Time
  - Decay time acceptance can differ between KK and ππ.
  - Difference in direct and indirect CPV component
  - Small $\Delta\langle t\rangle \rightarrow \Delta A_{CP} = \Delta a_{CP}^{dir}$

$$\Delta\langle t\rangle/\tau(D^0) = 0.018 \pm 0.002\,(\text{stat}) \pm 0.007\,(\text{syst})$$
$$\overline{\langle t\rangle}/\tau(D^0) = 1.062 \pm 0.001\,(\text{stat}) \pm 0.003\,(\text{syst})$$





Contain LHCb acceptance effects

ΔA_{CP} from semileptonic B decays

- Raw asymmetries and ΔA_{CP} split for each magnet polarity

	Magnet up	Magnet down	Mean
$A_{\mathrm{raw}}(K^-K^+)$	-0.39 ± 0.23	-0.20 ± 0.19	-0.29 ± 0.15
$A_{\mathrm{raw}}(\pi^-\pi^+)$	-1.25 ± 0.40	-0.29 ± 0.34	-0.77 ± 0.26
ΔA_{CP}	0.86 ± 0.46	0.09 ± 0.39	0.48 ± 0.30

ΔA$_{CP}$ from semileptonic B decays

- Source of systematic uncertainties

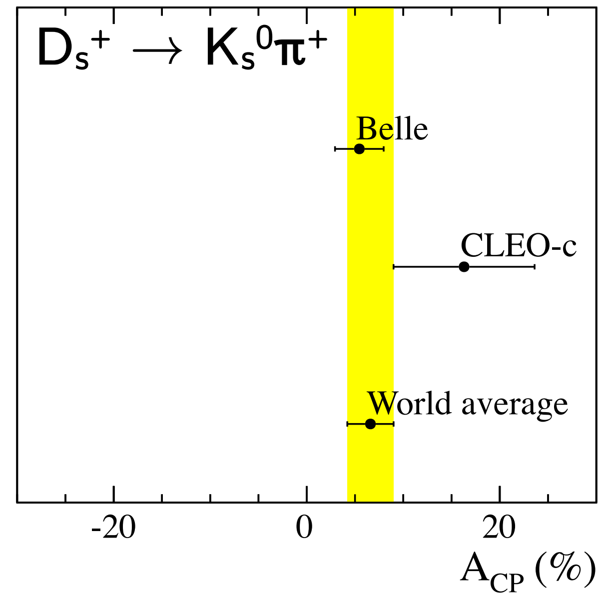
Source of uncertainty	Uncertainty
Production asymmetry:	
Difference in b-hadron mixture	0.02%
Difference in B decay time acceptance	0.02%
Production and detection asymmetry:	
Different weighting	0.05%
Background from real D^0 mesons:	
Mistag asymmetry	0.02%
Background from fake D^0 mesons:	
D^0 mass 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%

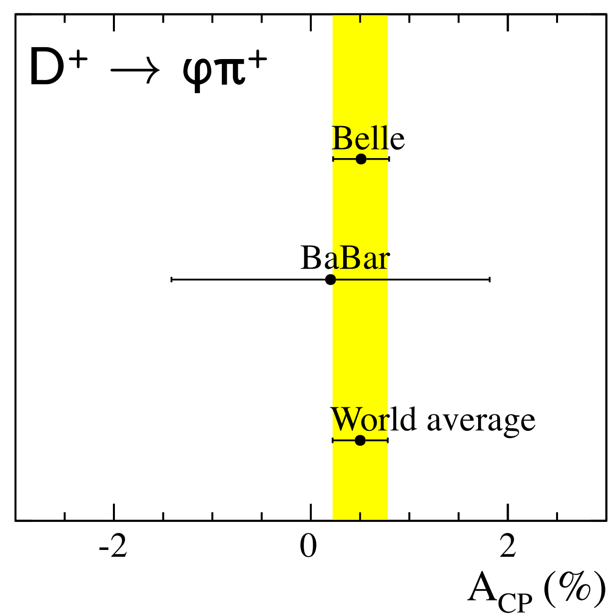
CP violation in $D^+ \to \phi\pi^+$ and $D_s^+ \to K_S^0\pi^+$

CP violation in $D^+ \to \phi\pi^+$ and $D_s^+ \to K_S^0\pi^+$

Current status

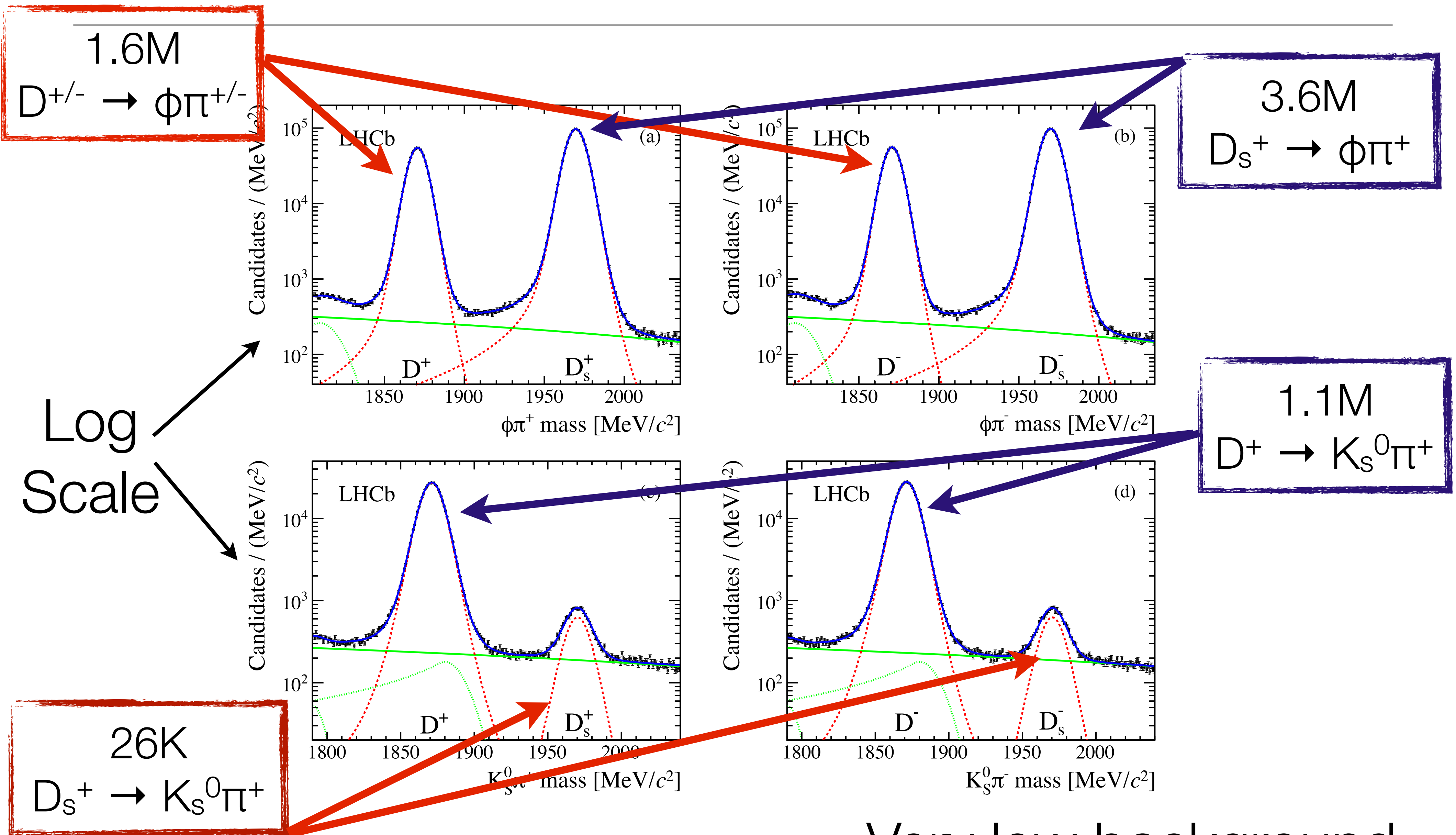
- $D_s^+ \to K_s^0\pi^+$ previously measured by
    - CLEO-c
    - Belle
- $D^+ \to \phi\pi^+$ measured by
    - Belle
    - BaBar





LHCB-PAPER-2012-052
1fb^{-1} collected during 2011

CP violation in $D^+ \to \phi\pi^+$ and $D_S^+ \to K_S^0\pi^+$



Very low background

CP violation in $D^+ \to \phi\pi^+$ and $D_S^+ \to K_S^0\pi^+$

- Main sources of systematic uncertainty
  - Detector efficiency differences (magnet up/magnet down)
  - Uncertainties in background model
  - kaon interaction asymmetries
  - CP violation in the neutral kaon system

Source	A_{CP} (D^+) [%]	A_{CP} (D_s^+) [%]	$A_{CP}\|_S$ [%]
Triggers	0.114	0.114	n/a
D_s^+ control sample size	n/a	n/a	0.169
Kaon asymmetry	0.031	0.002	0.009
Binning	0.029	0.029	n/a
Resolution	0.007	0.006	0.056
Fitting	0.033	0.033	n/a
Kaon *CP* violation	0.028	0.028	n/a
Fiducial effects	0.022	0.022	n/a
Backgrounds	0.008	n/a	0.007
D from *B*	0.003	0.015	0.003
Regeneration	0.010	0.010	n/a
Total	0.132	0.128	0.178

D^0 mixing

D^0 mixing

- Majority of systematic uncertainties cancel in ratio
- Main sources of systematics which do not cancel in ratio
  - Pollution from D^0's from B decays results in wrong time.
  - Some double mis-ID events ($D^0 \to K^- \pi^+$ seen as $D^0 \to K^+ \pi^-$) pollutes WS sample
  - Other sources of uncertainty (production/detection efficiencies) of order 10^{-4} can be neglected.
- Systematics account for ~10% of overall uncertainty