



View of Hamburg, Elias Galli (ca. 1680)

# • Charm CP violation @ LHCb

• **Pietro Marino** on behalf of LHCb collaboration  
SNS & INFN-Pisa



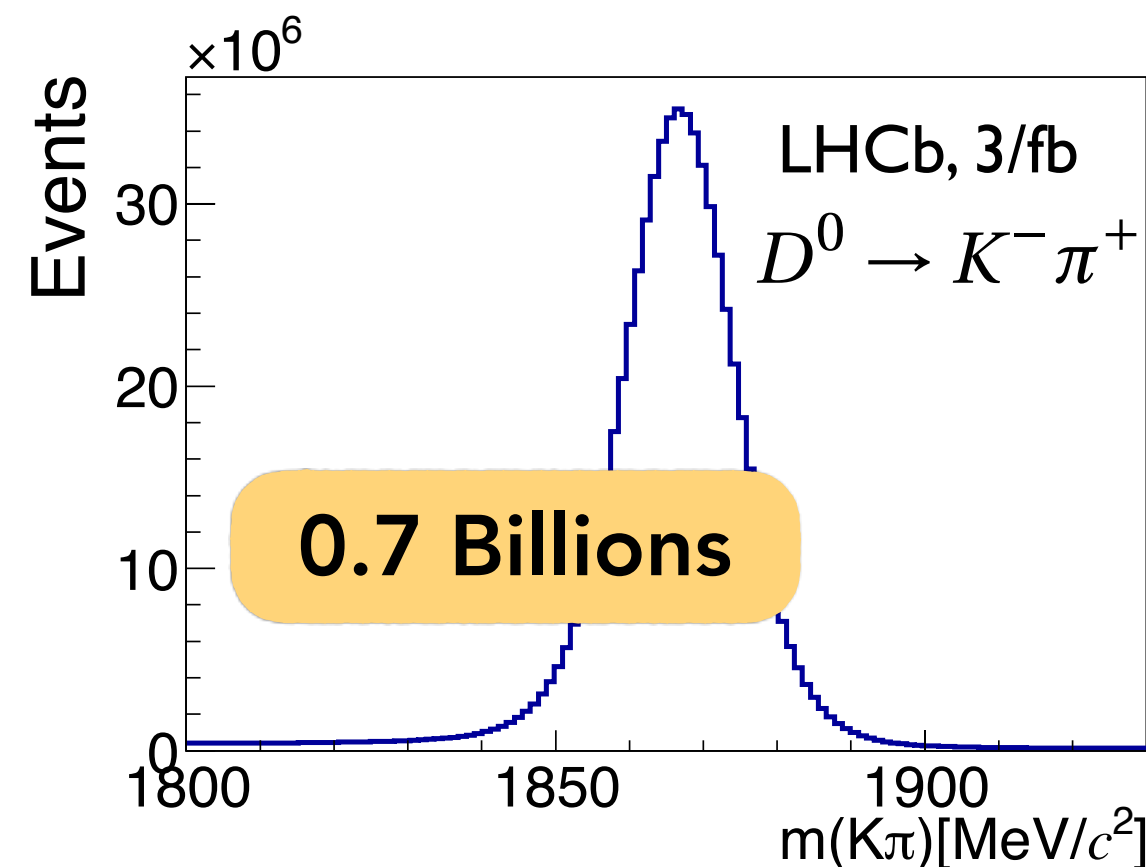
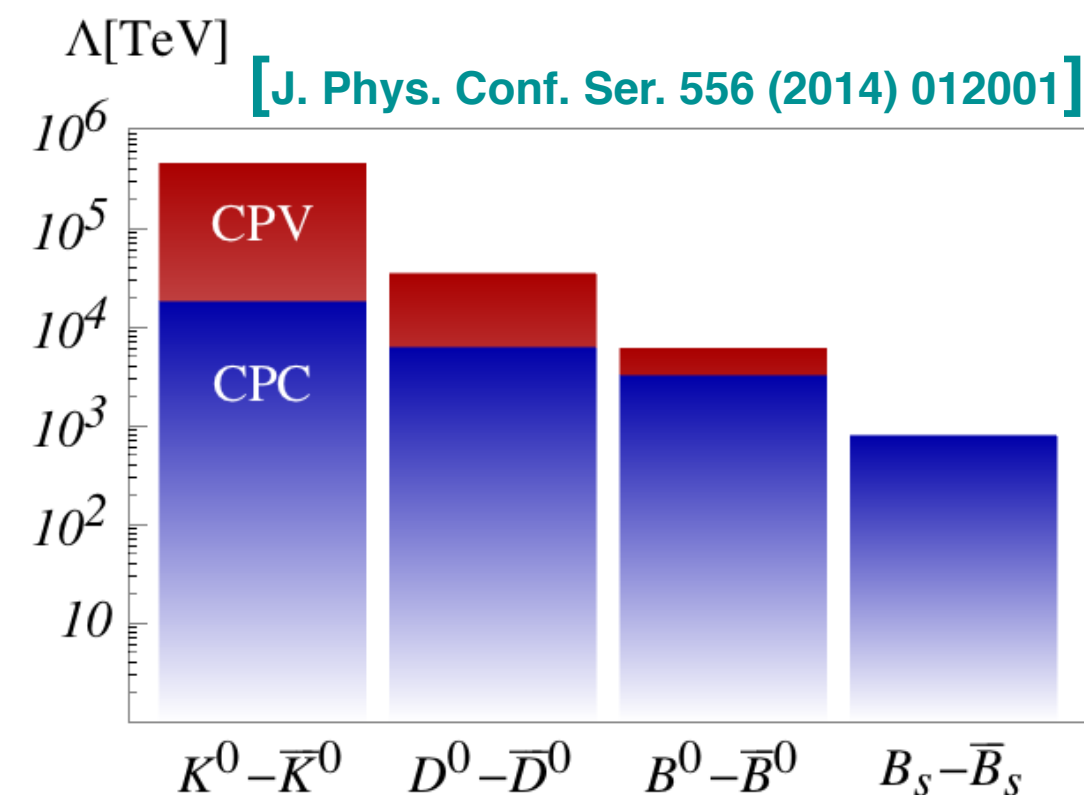
SCUOLA  
NORMALE  
SUPERIORE





# Why is charm charming?

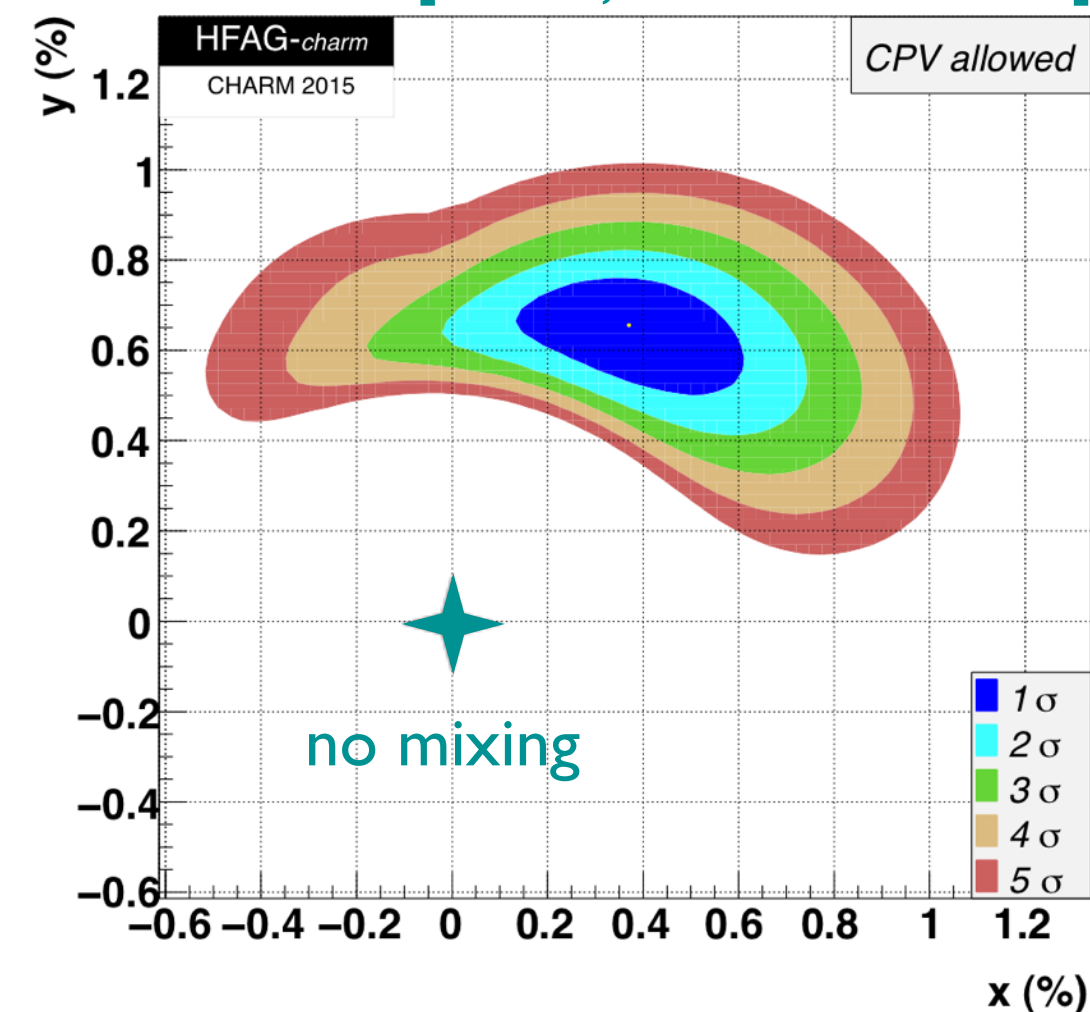
- Unique and powerful probe of BSM flavour effects.
- Charm is an up-type quark:
  - ♦ complementary to  $B$  and  $K$ ;
  - ♦ best bounds on a generic new physics model after the kaon mixing.
- Huge data samples,
  - ♦ LHCb has the opportunity to exploit fully the charm sector as a probe for new physics.
- Charm predictions are complicated:
  - ♦ QCD not perturbative.



# ● Charm mixing and CP violation

[HFAG, arXiv:1412.7515]

- $D^0$  mixing is established.
- CP violation yet unobserved!
  - ◆ Small value expected from SM  $\mathcal{O}(V_{ub}V_{cb}^*/V_{us}V_{cs}^*) \sim \mathcal{O}(10^{-3})$
  - ◆ Sensitivity close to possible BSM contribution (yields  $\sim \mathcal{O}(10^6)$ )



Decay CPV

$$\left| D^0 \rightarrow \text{vertex} \rightarrow f \right|^2 \neq \left| \bar{D}^0 \rightarrow \text{vertex} \rightarrow \bar{f} \right|^2 \leftrightarrow \left| \frac{A_f}{\bar{A}_{\bar{f}}} \right| \neq 1$$

Mixing CPV

$$\left| D^0 \rightarrow \text{vertex} \xrightarrow{\bar{D}^0} \text{vertex} \rightarrow \bar{f} \right|^2 \neq \left| \bar{D}^0 \rightarrow \text{vertex} \xrightarrow{D^0} \text{vertex} \rightarrow f \right|^2 \leftrightarrow \left| \frac{q}{p} \right| \neq 1$$

Inference CPV

$$\left| D^0 \rightarrow \text{vertex} \rightarrow f \right|^2 + \left| D^0 \rightarrow \text{vertex} \xrightarrow{\bar{D}^0} \text{vertex} \rightarrow f \right|^2 \leftrightarrow \arg\left(\frac{q A_f}{p \bar{A}_{\bar{f}}}\right) \neq 0$$

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

$$x \equiv \frac{m_1 - m_2}{\Gamma}, \quad y \equiv \frac{\Gamma_1 - \Gamma_2}{2\Gamma}$$

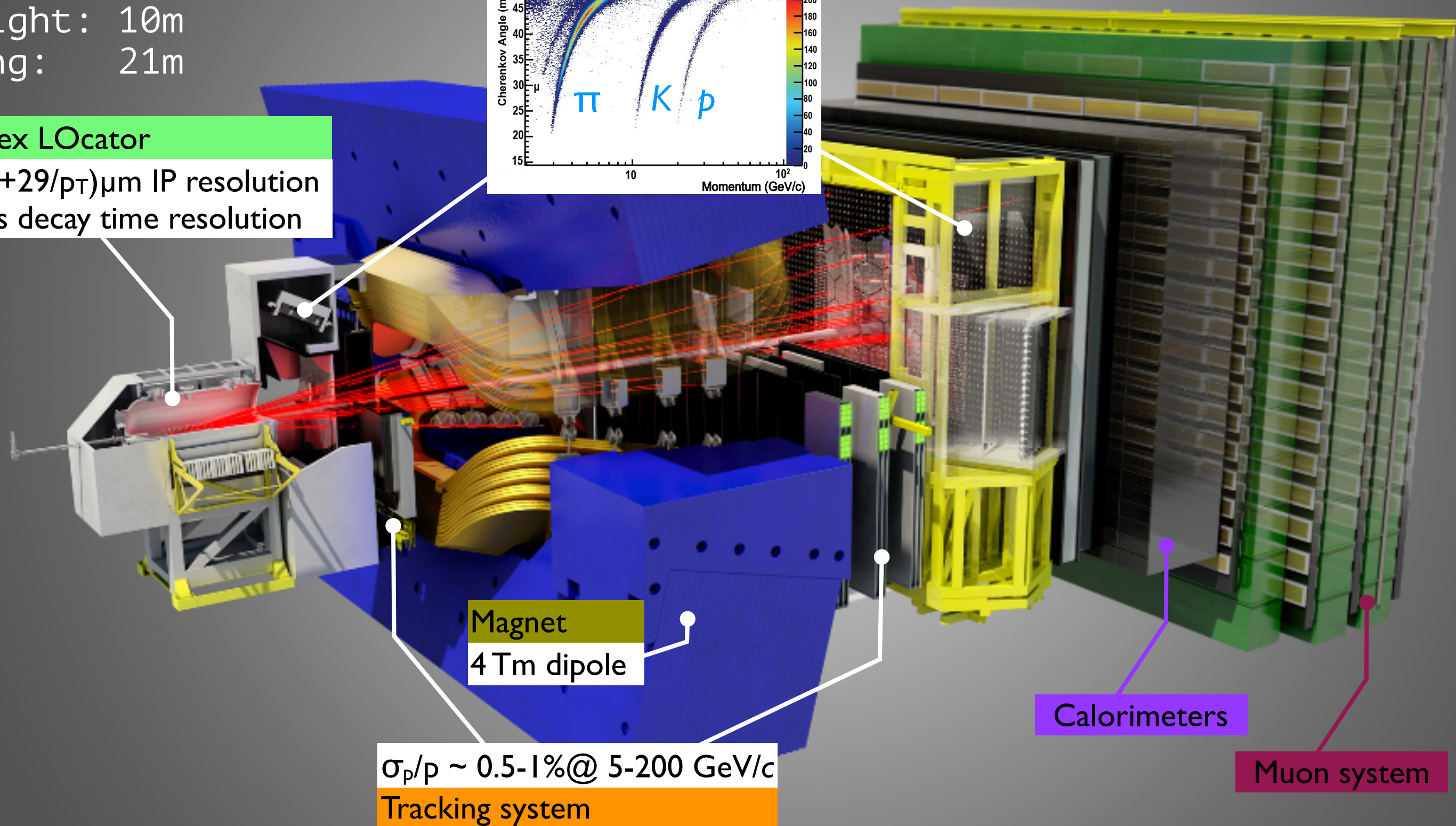
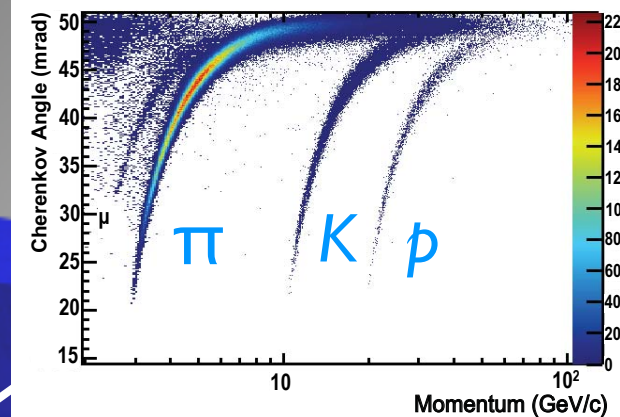
# ● LHCb

Weight: 5600t  
Height: 10m  
Long: 21m

## VERtex LOcator

$\sim(15+29/p_T)\mu\text{m}$  IP resolution  
 $\sim 45\text{fs}$  decay time resolution

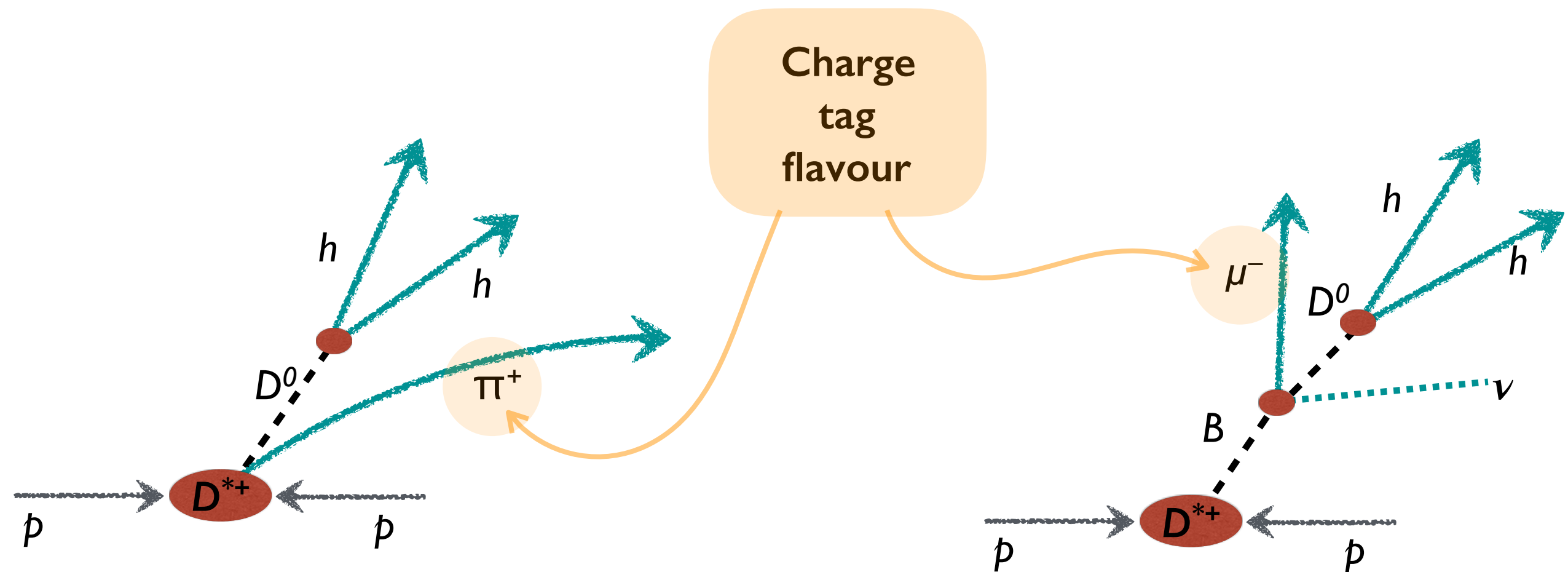
## RICH





# ● Charm flavour tagging

- In order to measure mixing and CPV, it is necessary to identify the flavour of the  $D^0$  meson.
- LHCb exploits two decays:
  - ◆  $D^{*+} \rightarrow D^0 \pi^+$  decays
  - ◆ semi-leptonic  $B$ -decays







# First observation of $D^0$ - $\bar{D}^0$ oscillation in $D^0 \rightarrow K^+ \pi^- \pi^+ \pi^-$

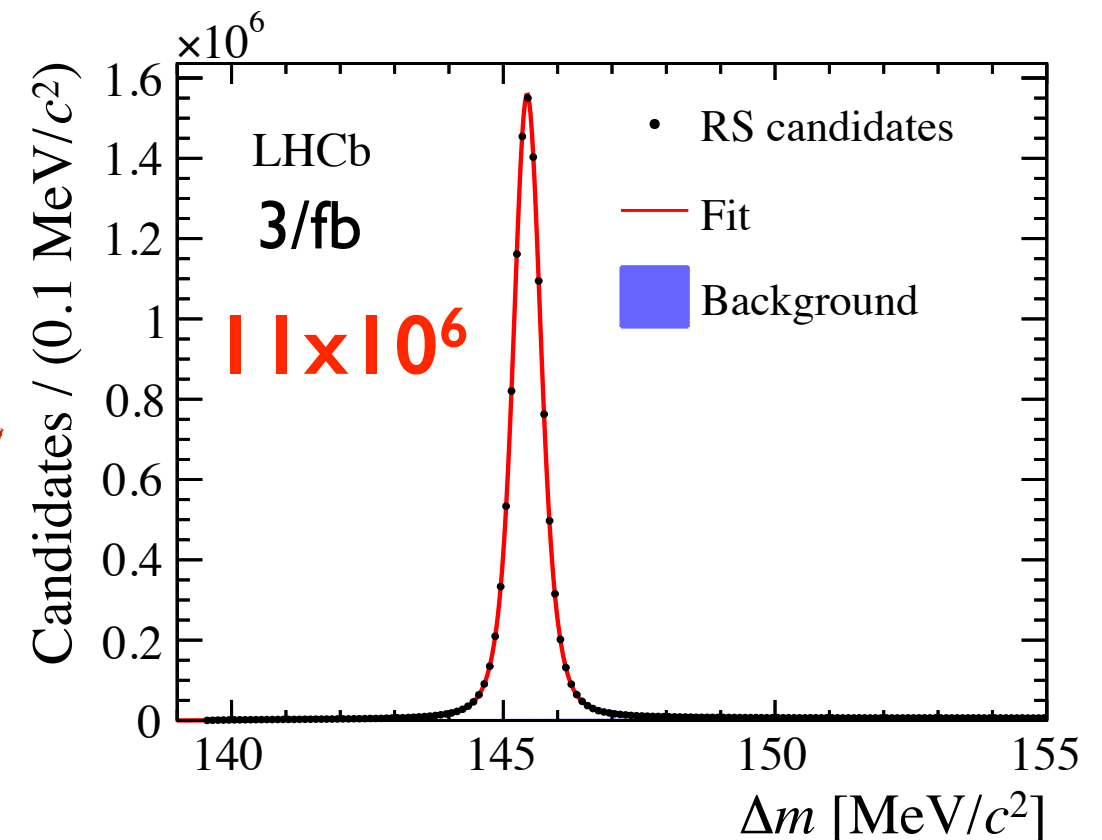
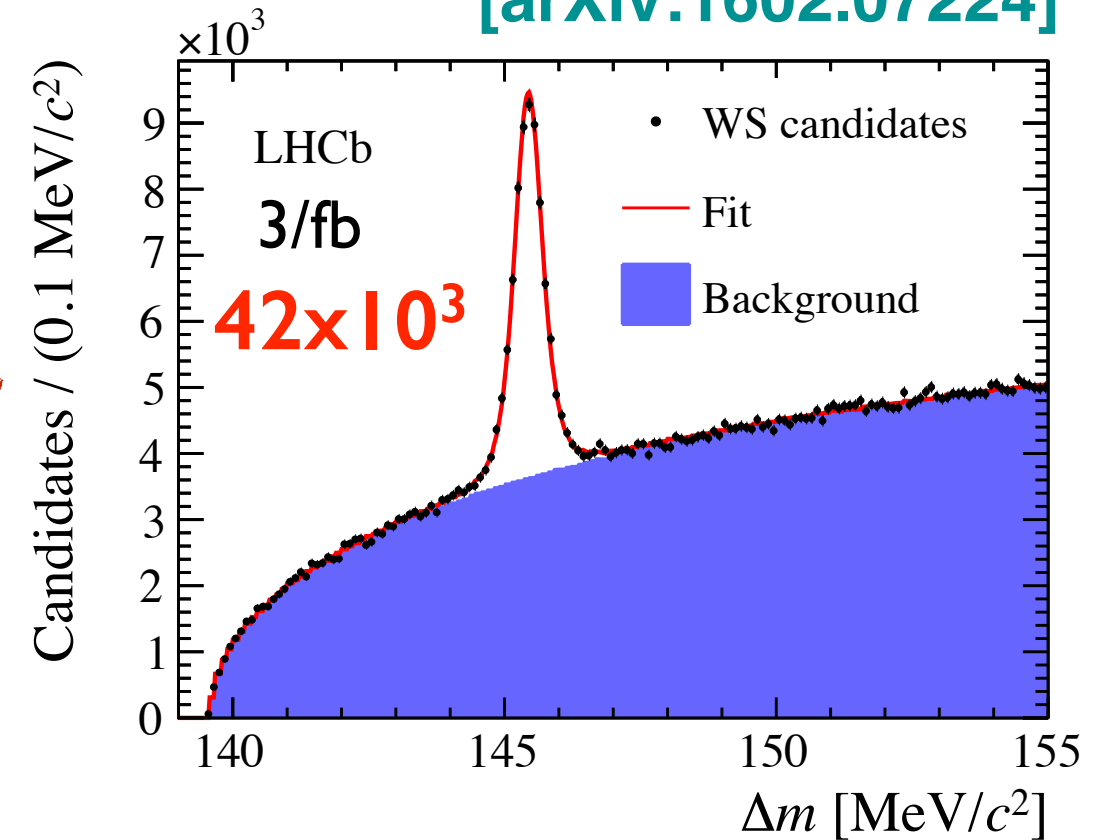
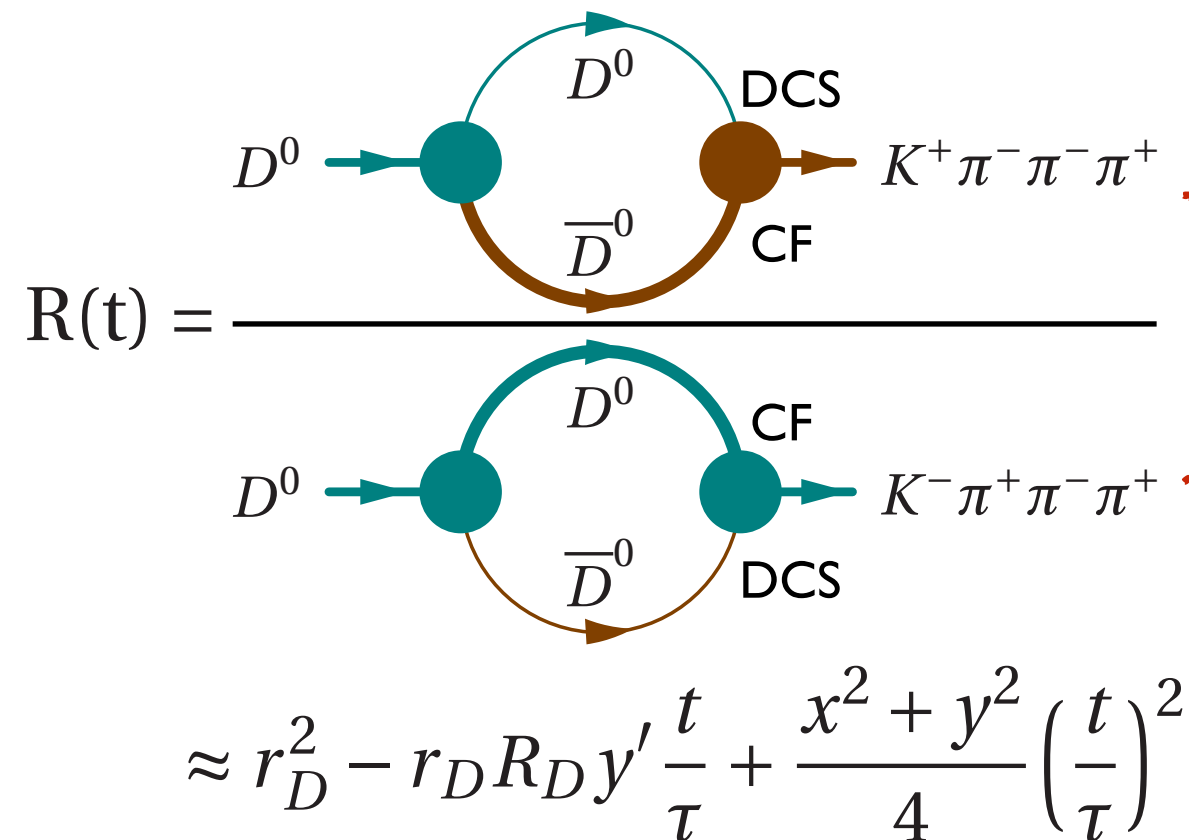
**First observation of  $D^0$  mixing in a multi-body decay**



# • $D^0$ mixing with $D^0 \rightarrow K^+ \pi^- \pi^+ \pi^-$

[arXiv:1602.07224]

- Full Run I data sample (3/fb)
- Challenges:
  - ♦ Five-dimensional phase space parametrisation.
  - ♦ Higher combinatorial background.



$$R_D e^{-i\delta} = \langle \cos \delta \rangle + i \langle \sin \delta \rangle$$

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

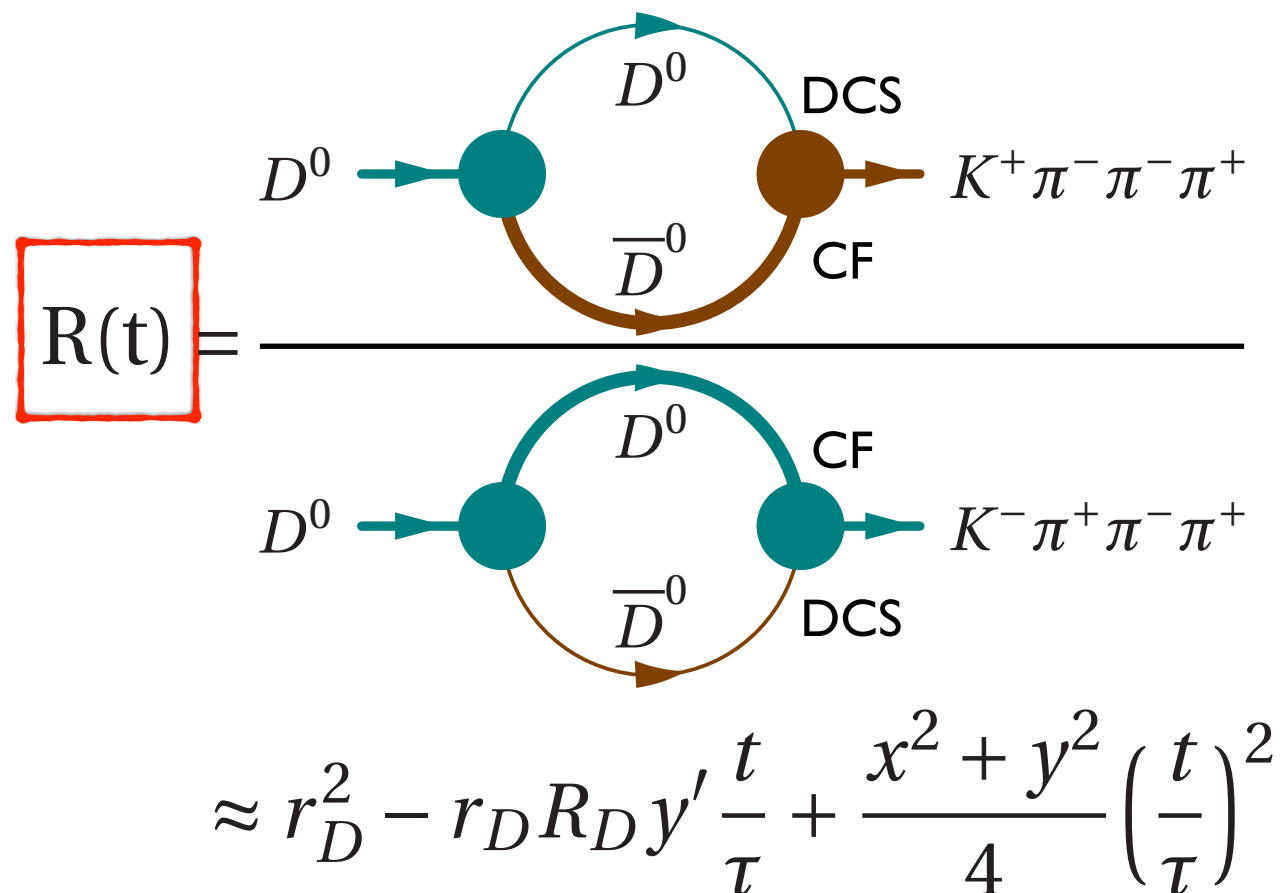
$r_D$  = phase space average DCS/CF ratio amplitudes



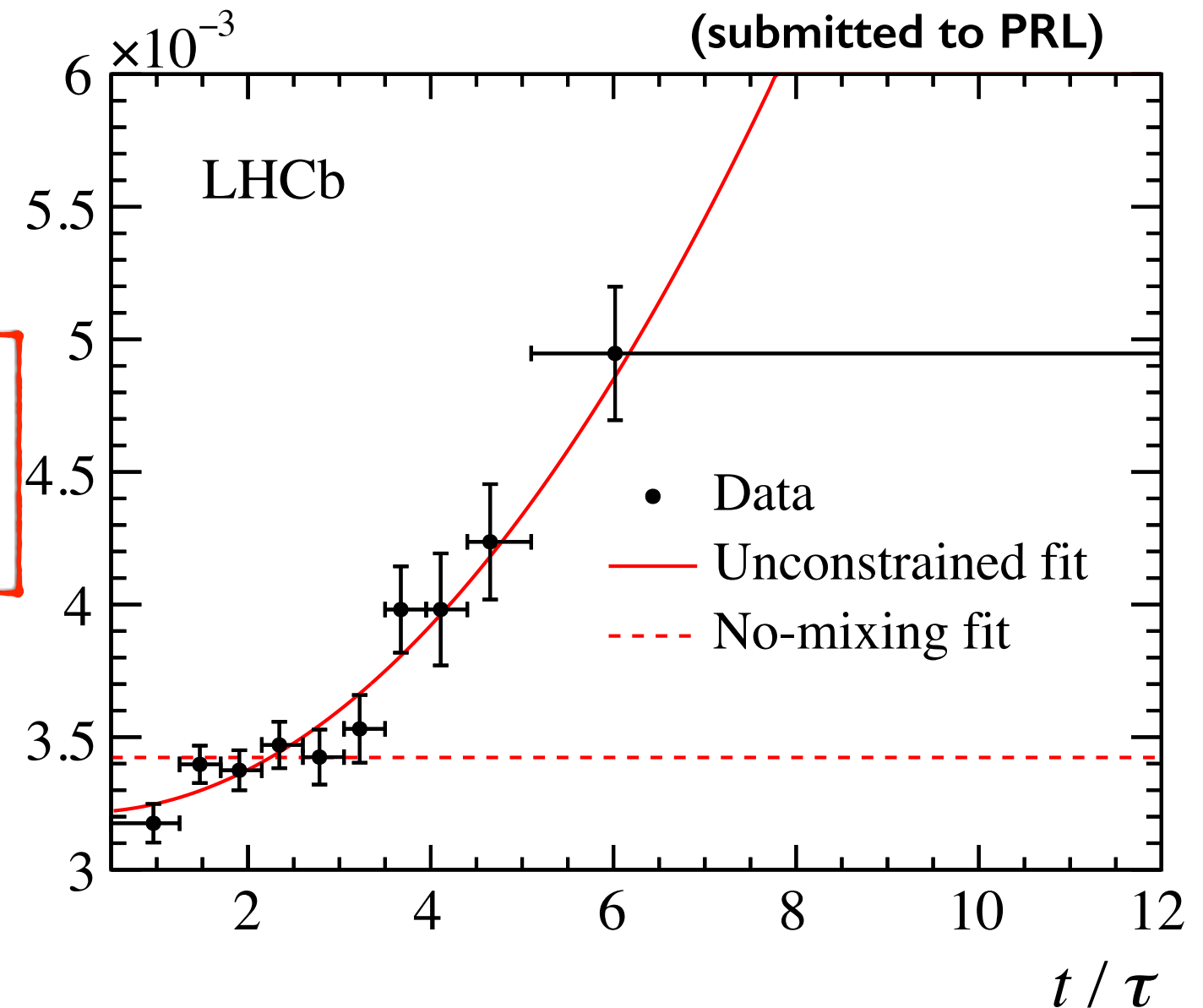
# • $D^0$ mixing with $D^0 \rightarrow K^+ \pi^- \pi^- \pi^+$

[arXiv:1602.07224]

(submitted to PRL)



WS/RS



No mixing hypothesis reject at  $8.2\sigma$

$$r_D = (5.67 \pm 0.12) \times 10^{-2}$$

$$R_D y' = (0.3 \pm 1.8) \times 10^{-3}$$

[arXiv:1602.07224]





# Difference of time-integrated CP asymmetries (a.k.a. $\Delta A_{CP}$ )

# ● Direct CPV in $D^0 \rightarrow h^+ h^-$

[arXiv:1602.03160]

- Time-integrated CP asymmetry:

$$A_{CP}(f) = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\bar{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\bar{D}^0 \rightarrow f)}$$

- Experimentally yields are measured:

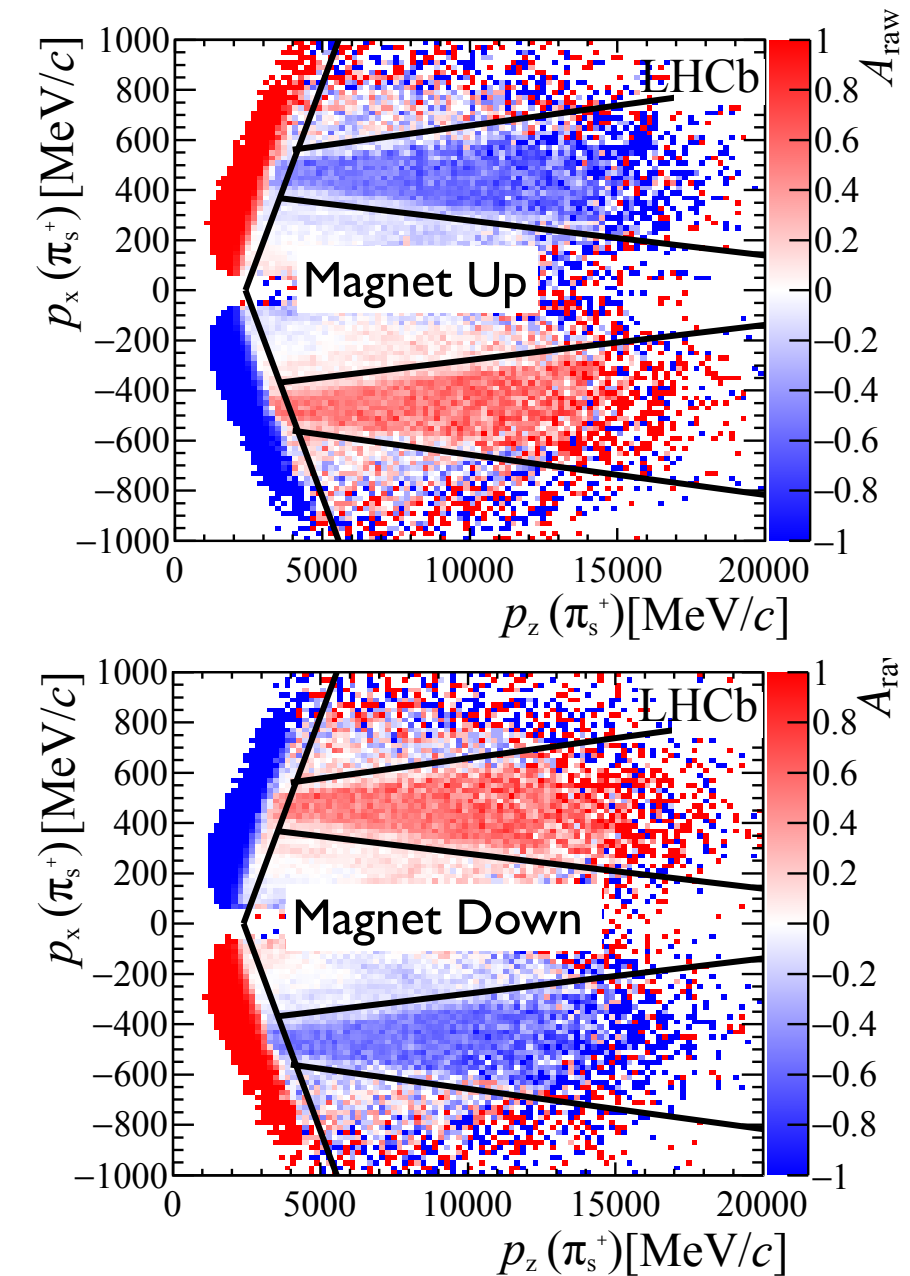
$$A_{\text{raw}}(f) = \frac{N(D^{*+} \rightarrow D^0(\rightarrow f)\pi^+) - N(D^{*-} \rightarrow \bar{D}^0(\rightarrow f)\pi^-)}{N(D^{*+} \rightarrow D^0(\rightarrow f)\pi^+) + N(D^{*-} \rightarrow \bar{D}^0(\rightarrow f)\pi^-)}$$

$$\approx A_{CP}(f) + A_D(f) + A_D(\pi) + A_P(D^*)$$

where

$$\begin{cases} A_D(\pi) & \text{soft-pion (tag) detection asymmetry} \\ A_P(D^*) & D^* \text{ production asymmetry} \\ A_D(f) & \text{final state detection asymmetry, zero for } f = K^+ K^-, \pi^+ \pi^- \end{cases}$$

Fiducial cuts on soft-pion kinematics





# ● Direct CPV in $D^0 \rightarrow h^+ h^-$

- Time-integrated CP violation:

$$A_{CP}(f) = \frac{\Gamma(D^0 \rightarrow f) - \Gamma(\bar{D}^0 \rightarrow f)}{\Gamma(D^0 \rightarrow f) + \Gamma(\bar{D}^0 \rightarrow f)}$$

- Experimentally yields are measured:

$$\begin{aligned} A_{\text{raw}}(f) &= \frac{N(D^{*+} \rightarrow D^0(\rightarrow f)\pi^+) - N(D^{*-} \rightarrow \bar{D}^0(\rightarrow f)\pi^-)}{N(D^{*+} \rightarrow D^0(\rightarrow f)\pi^+) + N(D^{*-} \rightarrow \bar{D}^0(\rightarrow f)\pi^-)} \\ &\approx A_{CP}(f) + A_D(f) + A_D(\pi) + A_P(D^*) \end{aligned}$$

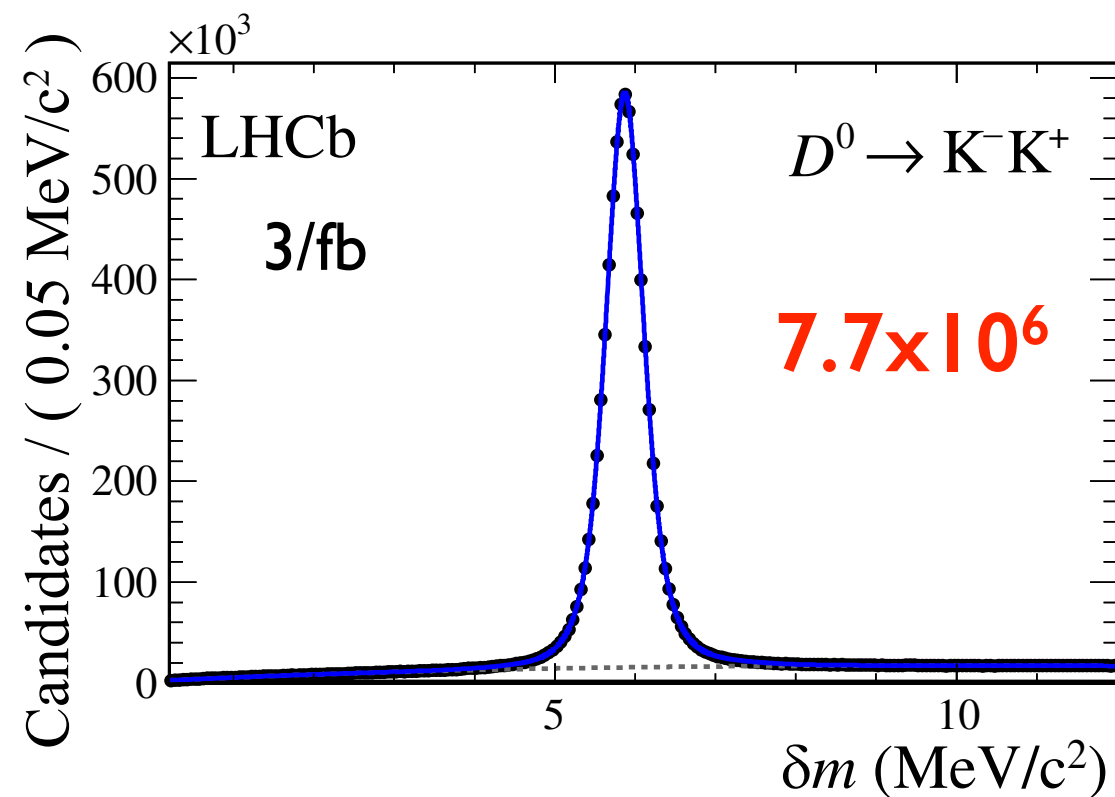
- Challenging keep under control  $A_D$  and  $A_P$  to  $\mathcal{O}(10^{-3})$ . In order to access the CP asymmetry the difference between  $A_{CP}(KK)$  and  $A_{CP}(\pi\pi)$  is exploited:

$$A_{\text{raw}}(KK) \approx A_{CP}(KK) + A_D(\pi) + A_P(D^*)$$

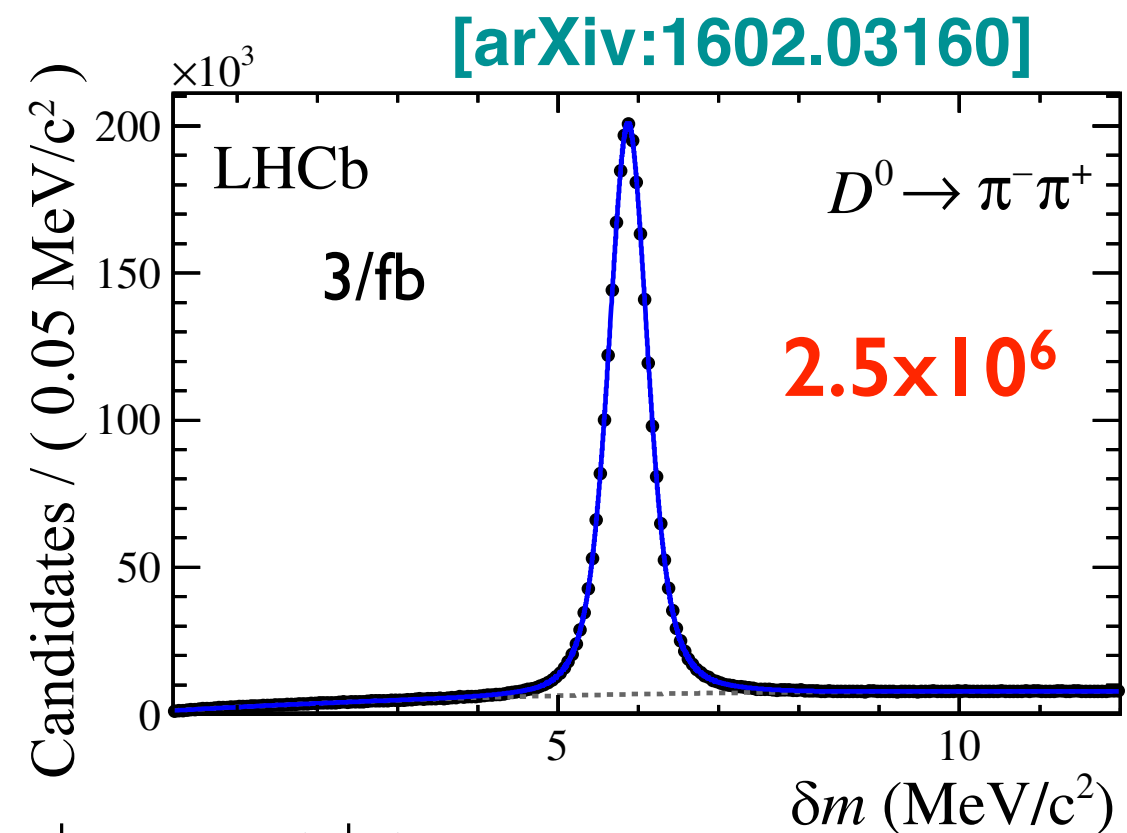
$$A_{\text{raw}}(\pi\pi) \approx A_{CP}(\pi\pi) + A_D(\pi) + A_P(D^*)$$

$$\Delta A_{CP} = A_{\text{raw}}(KK) - A_{\text{raw}}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$

# • $\Delta A_{CP}$ in $D^0 \rightarrow h^+ h^-$ decays



$7.7 \times 10^6$



$2.5 \times 10^6$

[arXiv:1602.03160]

$$\delta m = m(h^+ h^- \pi^+) - m(h^+ h^-) - m_\pi$$

- New measurement with full Run I data sample (3/fb,  $D^{*-}$ -tagged):

$$\Delta A_{CP} = (-0.10 \pm 0.08(\text{stat.}) \pm 0.03(\text{syst.}))\%$$

[arXiv:1602.03160]  
(submitted to PRL)

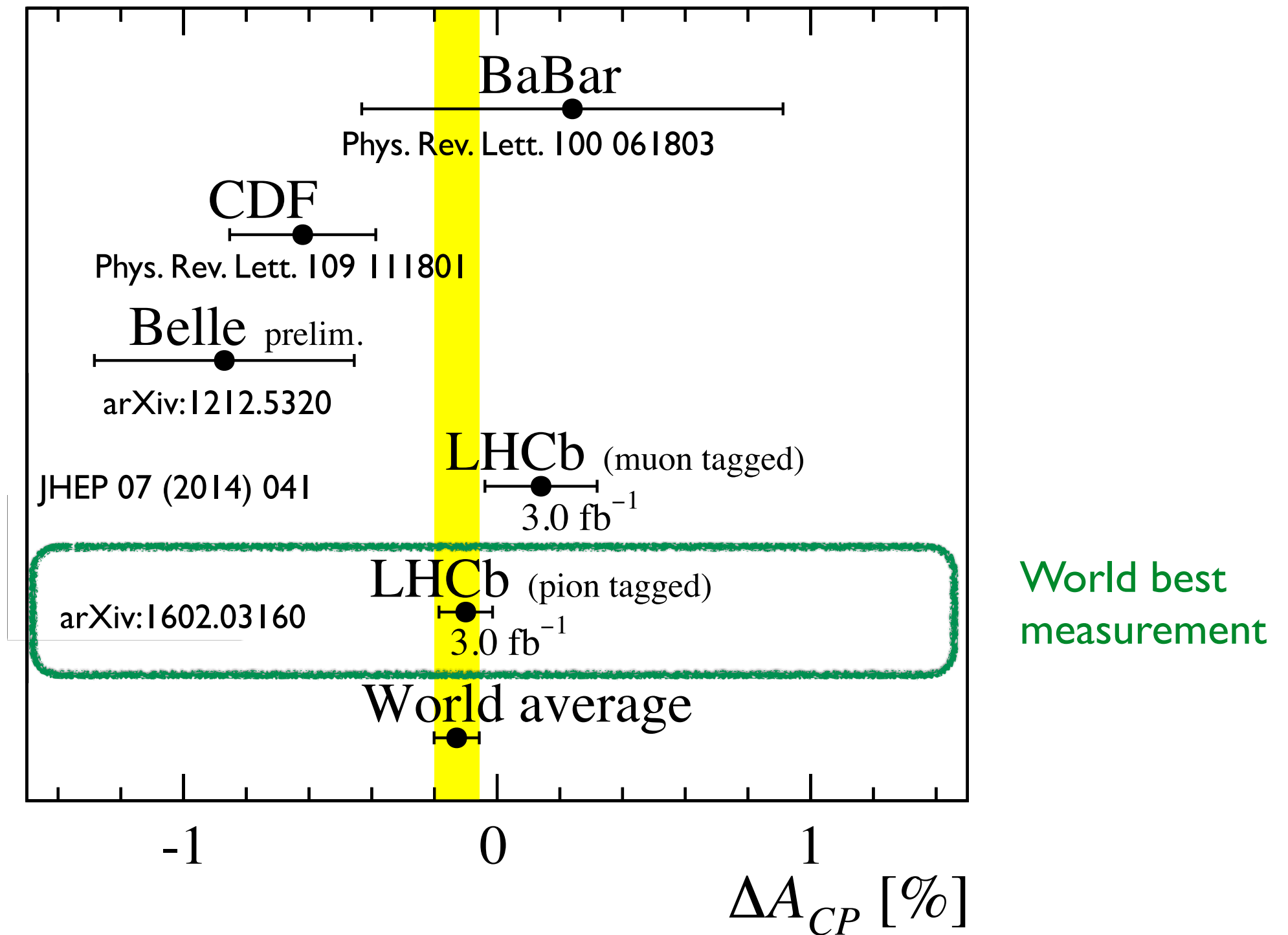
- Semi-leptonic tagged measurement (3/fb):

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

[JHEP 07 (2014) 041]



# ● $\Delta A_{CP}$ state-of-the-art



Naive average (neglecting indirect CPV contribution) =  $(-0.129 \pm 0.072)\%$



# Time dependent CP asymmetry (a.k.a. $A_{\Gamma}$ )



# • $A_\Gamma$ : indirect $CPV$ in $D^0 \rightarrow h^+ h^-$ decays

- Time-dependent  $CP$  asymmetry:

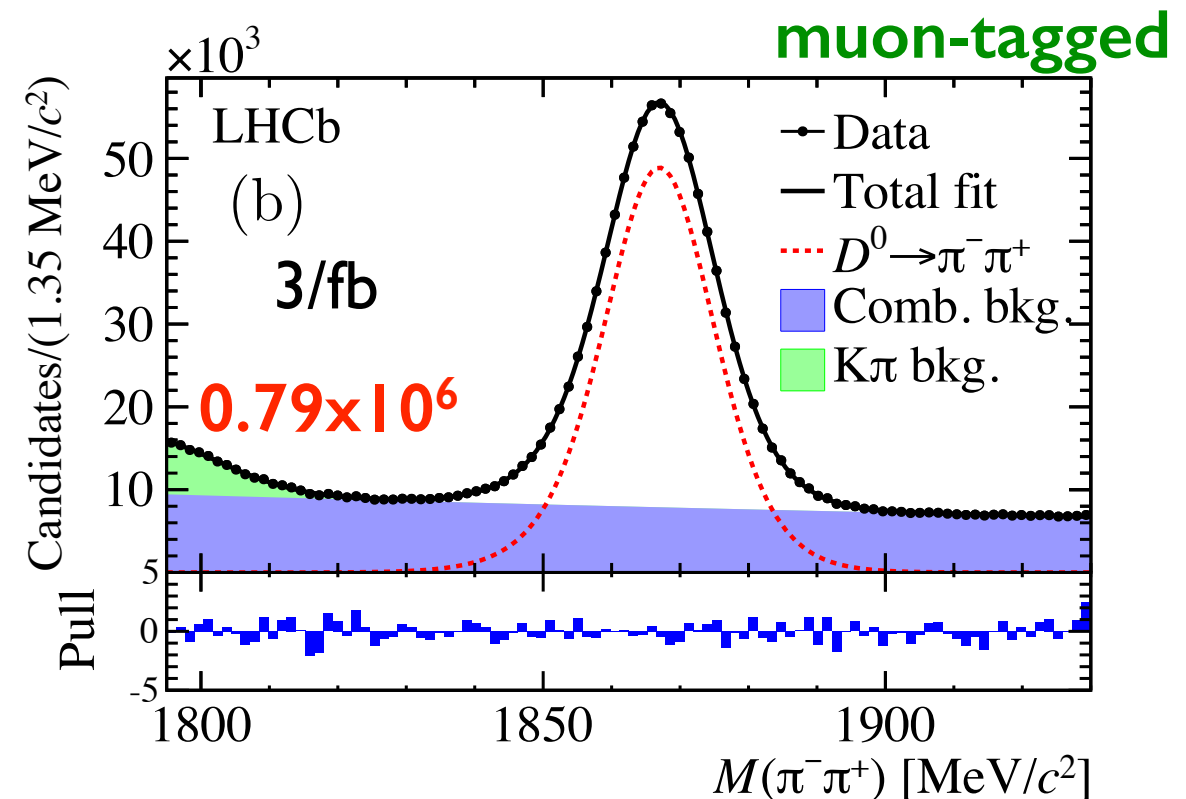
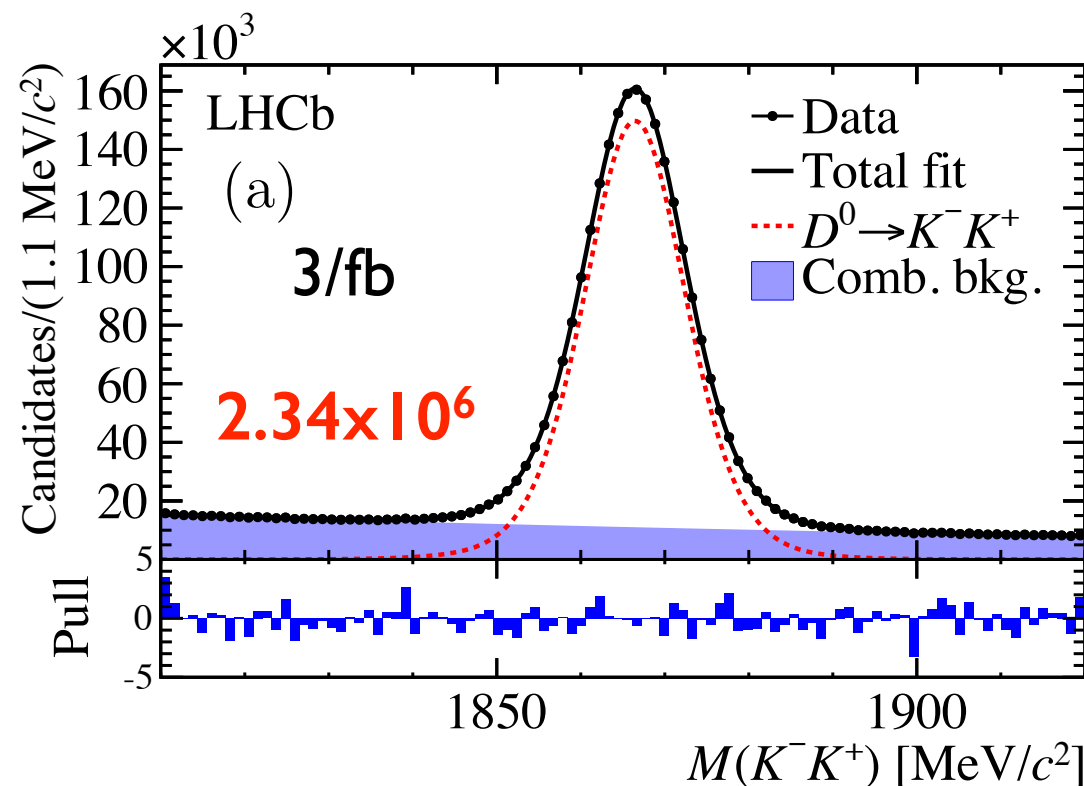
$$A_{CP}(t) = \frac{\Gamma(D^0(t) \rightarrow f) - \Gamma(\bar{D}^0(t) \rightarrow f)}{\Gamma(D^0(t) \rightarrow f) + \Gamma(\bar{D}^0(t) \rightarrow f)} \simeq a_{CP}^{dir} - \frac{t}{\tau_{D^0}} A_\Gamma$$

$$A_m = \left| \frac{q}{p} \right|^2 - 1$$

- $A_\Gamma$  measures  $CPV$  in the mixing ( $A_m$ ) e in the decay ( $A_d$ ):

$$A_d = \left| \frac{\bar{A}_f}{A_f} \right|^2 - 1$$

$$A_\Gamma \simeq \left[ \frac{1}{2} (A_m + A_d) y \cos \phi - x \sin \phi \right]$$



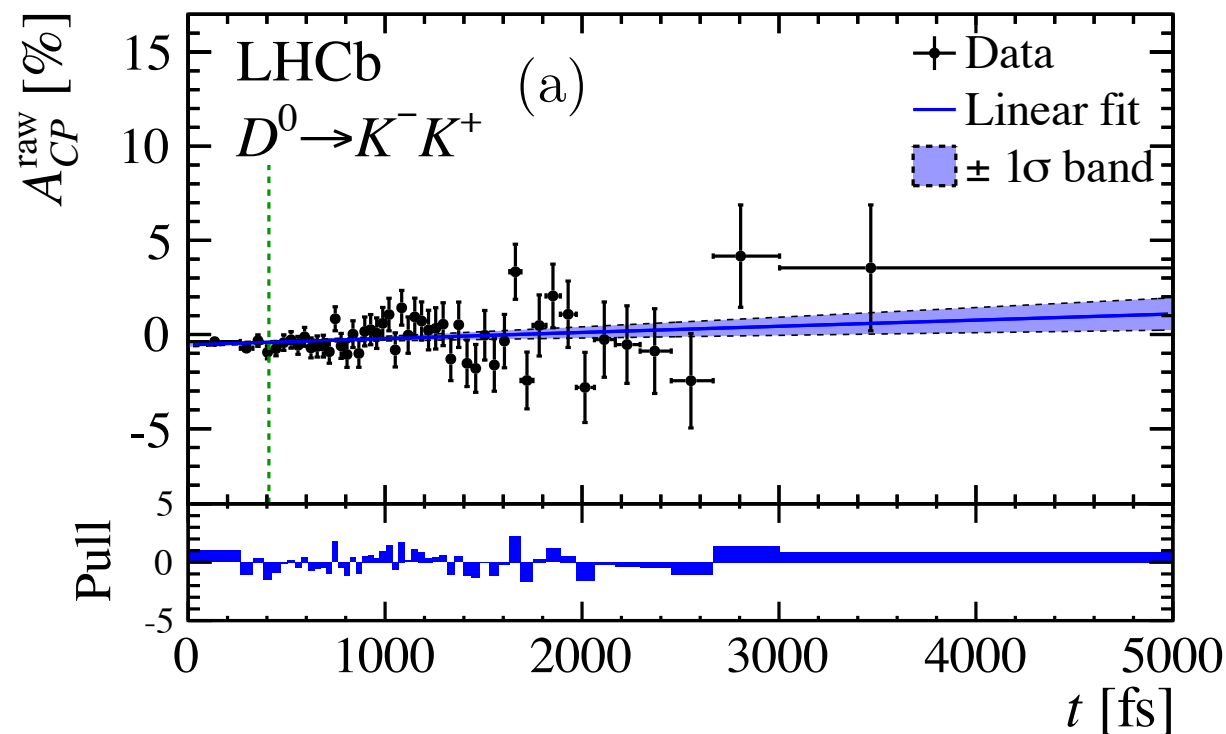
# ● $A_\Gamma$ : indirect $CPV$ in $D^0 \rightarrow h^+ h^-$ decays

- Measure yields asymmetry in various bin of  $D^0$  proper decay time:

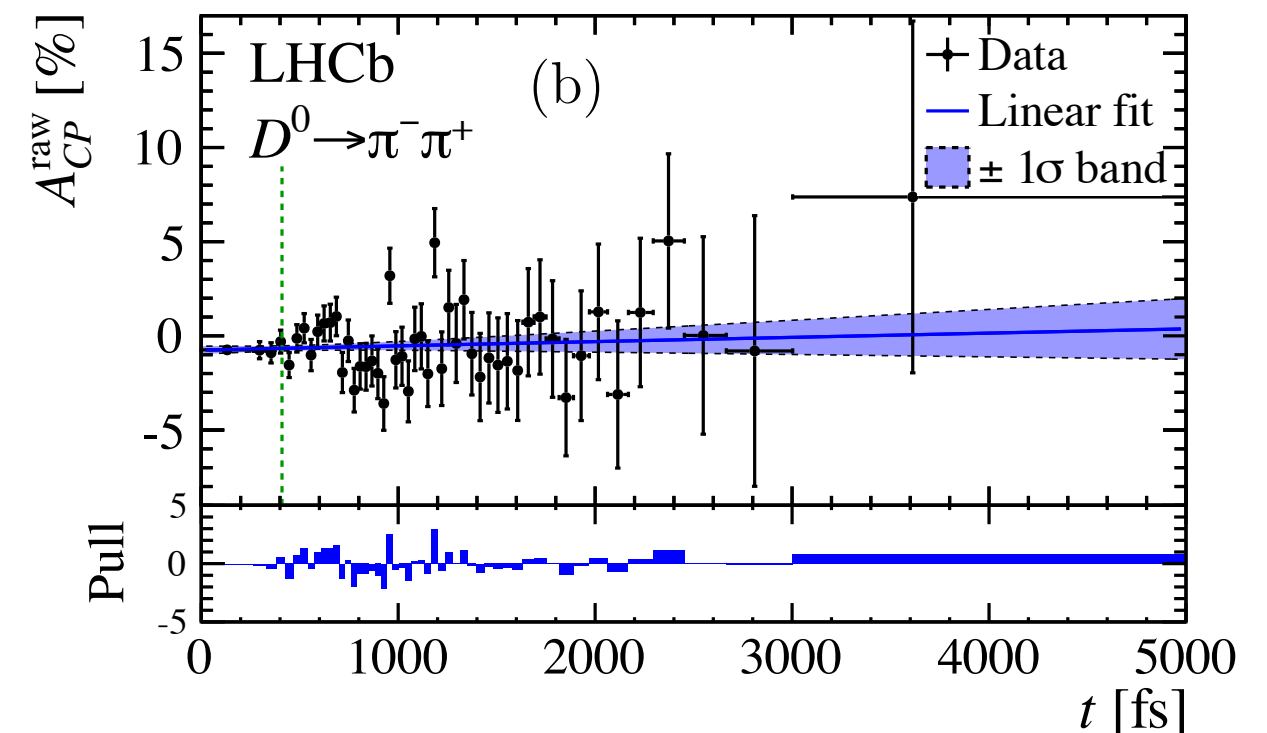
$$A_{\text{raw}}^i = \frac{n_i(D^0 \rightarrow f) - n_i(\bar{D}^0 \rightarrow f)}{n_i(D^0 \rightarrow f) + n_i(\bar{D}^0 \rightarrow f)}; \quad i = 1, \dots, m$$

- Straight line fit of the asymmetry as function of decay time:  $A_{\text{raw}}(t) = A_0 - \frac{t}{\tau_{D^0}} A_\Gamma$ ;
- control sample:  $D^0 \rightarrow K\pi$ , where pseudo- $A_\Gamma(D^0 \rightarrow K\pi) = 0$ .  $A_\Gamma(K^- \pi^+) = (0.009 \pm 0.032)\%$

$$A_\Gamma(K^- K^+) = (-0.134 \pm 0.077_{-0.034}^{+0.026})\%$$

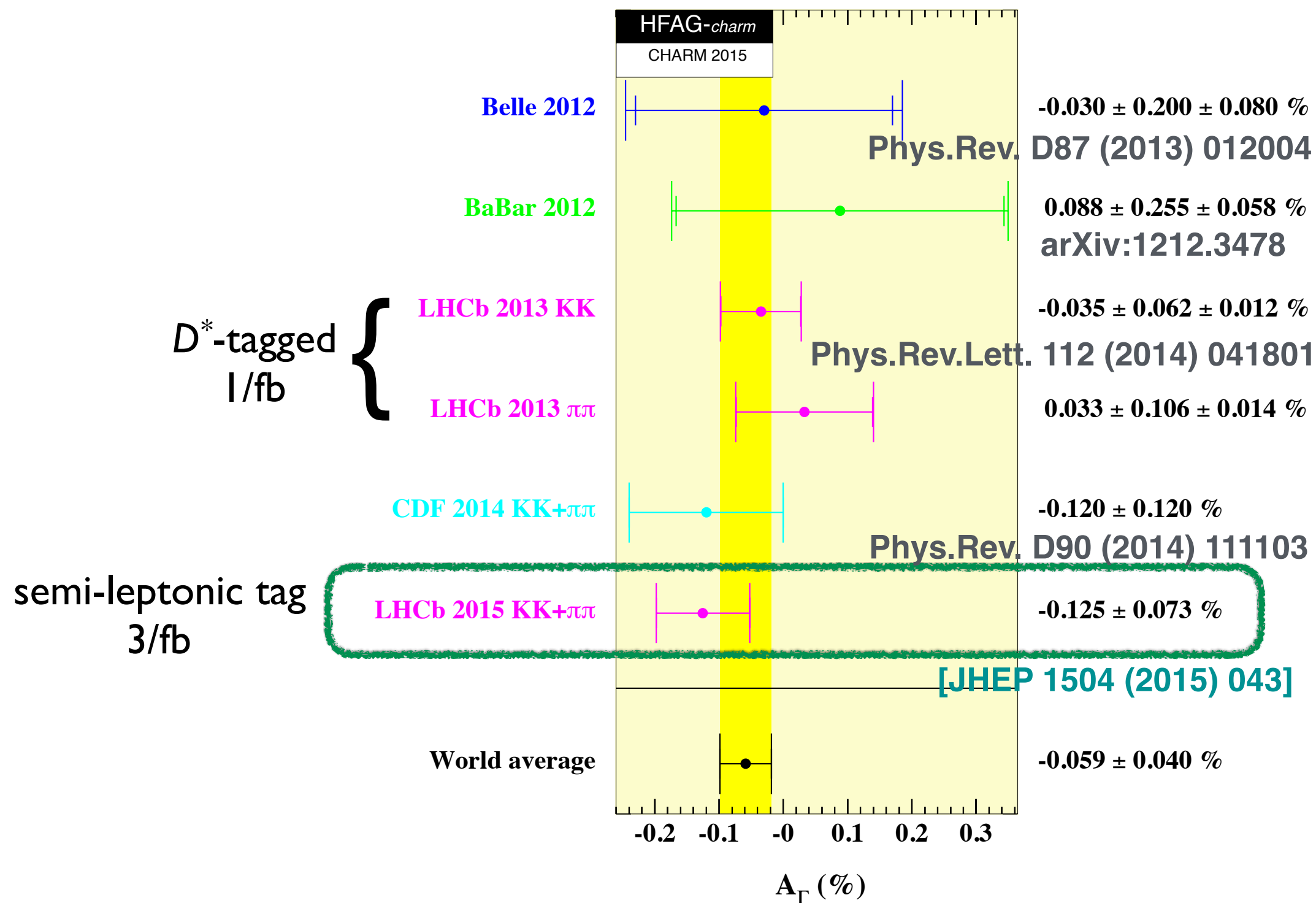


$$A_\Gamma(\pi^- \pi^+) = (-0.092 \pm 0.145_{-0.033}^{+0.025})\%$$





# ● $A_\Gamma$ state-of-the-art



- World best measurement from LHCb  $D^*$ -tagged using 1/fb of integrated luminosity.

# ● LHCb state-of-the-art on $D^0 \rightarrow h^+ h^-$ CPV

- $\Delta A_{CP}$  can be expressed as:

$$\Delta A_{CP} = \Delta a_{CP}^{\text{dir}} \left( 1 + \frac{\overline{\langle t \rangle}}{\tau(D^0)} \right) y_{CP} + \frac{\Delta \langle t \rangle}{\tau(D^0)} a_{CP}^{\text{ind}}$$

$$\frac{\Delta \langle t \rangle}{\tau(D^0)} = 0.1153 \pm 0.0007(\text{stat}) \pm 0.0018(\text{syst})$$

$$\frac{\overline{\langle t \rangle}}{\tau(D^0)} = 2.0949 \pm 0.0004(\text{stat}) \pm 0.0159(\text{syst})$$

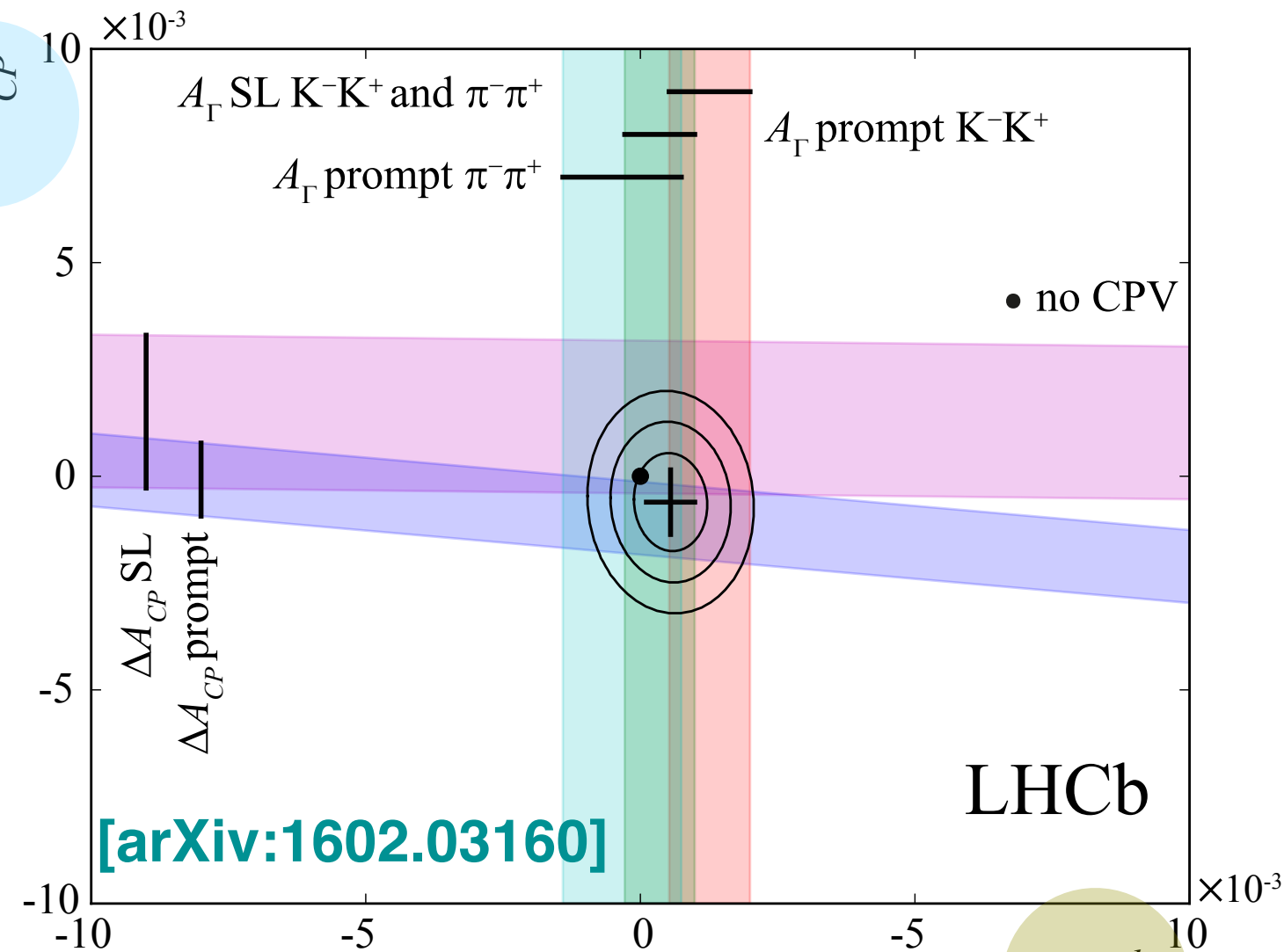
- Using LHCb measurement for:

$$A_{\Gamma} \simeq -a_{CP}^{\text{ind}} \quad [\text{JHEP 04 (2015) 043}]$$

$$y_{CP} = \frac{\Gamma(D^0 \rightarrow h^+ h^-)}{\Gamma(D^0 \rightarrow K^- \pi^+)} - 1 \quad [\text{JHEP 04 (2012) 129}]$$

No CPV hypothesis: p-value 0.32

$$\Delta a_{CP}^{\text{dir}} = (-0.61 \pm 0.76) \cdot 10^{-3} \quad a_{CP}^{\text{ind}} = (-0.58 \pm 0.44) \cdot 10^{-3}$$



# Charm physics @ LHCb

Study of  $D_{sJ}^{(*)+}$  mesons decaying to  $D^{*+}J/\psi$   
 $D^{*0}K^+$  final states



The LHCb collaboration

E-mail: [antimo.pala@cern.ch](mailto:antimo.pala@cern.ch)

ABSTRACT:  
 $pp \rightarrow$



Contents lists available at ScienceDirect

Physics Letters B

[www.elsevier.com/locate/physletb](http://www.elsevier.com/locate/physletb)

Search for the decay  $D^0 \rightarrow \pi^+\pi^-\mu^+\mu^-$

LHCb Collaboration

Measurement of the difference of  
time-integrated  $CP$  asymmetries in  
 $D^0 \rightarrow K^-K^+$  and  $D^0 \rightarrow \pi^-\pi^+$   
decays



In a resonance, is  
sity of  $1.0 \text{ fb}^{-1}$   
al is observed  
nt decay mode

culated to be  
date.  
CC BY license

Selected for a Viewpoint in Physics  
PHYSICAL REVIEW LETTERS

Observation of  $D^0 - \bar{D}^0$  Oscillations

R. Aaij *et al.*\*  
(LHCb Collaboration)  
(Received 6 November 2012; published  
10 March 2013)

week ending  
8 MARCH 2013

First observation of  $D^0 - \bar{D}^0$   
oscillations in  $D^0 \rightarrow K^+\pi^-\pi^+\pi^-$   
decays and measurement of the  
associated coherence parameters

The LHCb collaboration†

Model-independent measurement of  
mixing parameters in  
 $D^0 \rightarrow K_S^0\pi^+\pi^-$  decays



The LHCb collaboration  
E-mail: [matthew.charles@cern.ch](mailto:matthew.charles@cern.ch)

ABSTRACT: A search for the doubly charmed  
is performed with a data sample, corres-  
collisions recorded at a centre-of-mass  
range 3300–3800 MeV/c<sup>2</sup>. The  
cross-section and lifetimes are measured.



Contents lists available at ScienceDirect

Physics Letters B

[www.elsevier.com/locate/physletb](http://www.elsevier.com/locate/physletb)

Search for  $CP$  violation in the decay  $D^+ \rightarrow \pi^-\pi^+\pi^+$

LHCb Collaboration

Search for the rare decay  
 $D^0 \rightarrow \mu^+\mu^-$

The LHCb collaboration†

Abstract

A search for the rare decay  $D^0 \rightarrow \mu^+\mu^-$  is performed using a data sample, corresponding to an integrated luminosity of  $0.9 \text{ fb}^{-1}$ , of  $pp$  collisions collected at a centre-of-mass energy of 7 TeV by the LHCb experiment. The observed number of events is consistent with the background expectations and corresponds to an upper limit of  $B(D^0 \rightarrow \mu^+\mu^-) < 6.2 (7.6) \times 10^{-9}$  at 90% (95%) confidence level. This result represents an improvement of more than a factor twenty with respect to previous measurements.

PHYSICAL REVIEW D 93, 052018 (2016)  
Studies of the resonance structure in  $D^0 \rightarrow K_S^0 K^\pm \pi^\mp$  decays

R. Aaij *et al.*\*  
(LHCb Collaboration)  
(Received 23 September 2015; published 31 March 2016)

Amplitude models are applied to studies of resonance structure in  $D^0 \rightarrow K_S^0 K^\pm \pi^\mp$  decays using  $pp$  collision data corresponding to an integrated luminosity of  $3.0 \text{ fb}^{-1}$  collected by the LHCb experiment. Relative magnitude and phase information is determined, and coherence factors and related observables are computed for both the whole phase space and a restricted region of 100 MeV/c<sup>2</sup> around the  $K^*(892)^\pm$  resonance. Two formulations for the  $K\pi$  S-wave are used, both of which give a good description of the data. The ratio of branching fractions  $B(D^0 \rightarrow K_S^0 K^\pm \pi^\mp)/B(D^0 \rightarrow K_S^0 K^\mp \pi^\pm)$  is measured to be  $0.655 \pm 0.004(\text{stat}) \pm 0.006(\text{syst})$  over the full phase space and  $0.370 \pm 0.003(\text{stat}) \pm 0.012(\text{syst})$  in the restricted region. A search for  $CP$  violation is performed using the amplitude models and no significant effect is found. Predictions from SU(3) flavor symmetry for  $K^*(892)K$  amplitudes of different charges are compared with the amplitude model results.



Contents lists available at ScienceDirect

Physics Letters B

[www.elsevier.com/locate/physletb](http://www.elsevier.com/locate/physletb)

Search for the lepton-flavour violating decay  $D^0 \rightarrow e^\pm \mu^\mp$

LHCb Collaboration

ARTICLE INFO

Article history:  
Received 2 December 2015  
Received in revised form 11 January 2016  
Accepted 17 January 2016  
Available online 19 January 2016  
Editor: H. Weerts

ABSTRACT

A search for the lepton-flavour violating decay  $D^0 \rightarrow e^\pm \mu^\mp$  is made with a dataset corresponding to an integrated luminosity of  $3.0 \text{ fb}^{-1}$  of proton-proton collisions at centre-of-mass energies of 7 TeV and 8 TeV, collected by the LHCb experiment. Candidate  $D^0$  mesons are selected using the decay  $D^{*+} \rightarrow D^0 \pi^+$  and the  $D^0 \rightarrow e^\pm \mu^\mp$  branching fraction is measured using the decay mode  $D^0 \rightarrow K^-\pi^+$  as a normalization channel. No significant excess of  $D^0 \rightarrow e^\pm \mu^\mp$  candidates over the expected background is seen, and a limit is set on the branching fraction,  $B(D^0 \rightarrow e^\pm \mu^\mp) < 1.3 \times 10^{-8}$ , at 90% confidence level. This is an order of magnitude lower than the previous limit and it further constrains the parameter space in some leptoquark models and in supersymmetric models with R-parity violation.  
© 2016 CERN for the benefit of the LHCb Collaboration. Published by Elsevier B.V. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>). Funded by SCOAP<sup>3</sup>.

More Run I results to come ... more charm in Run II and Upgrade

12/4/2016

P. Marino (SNS & INFN-Pi)





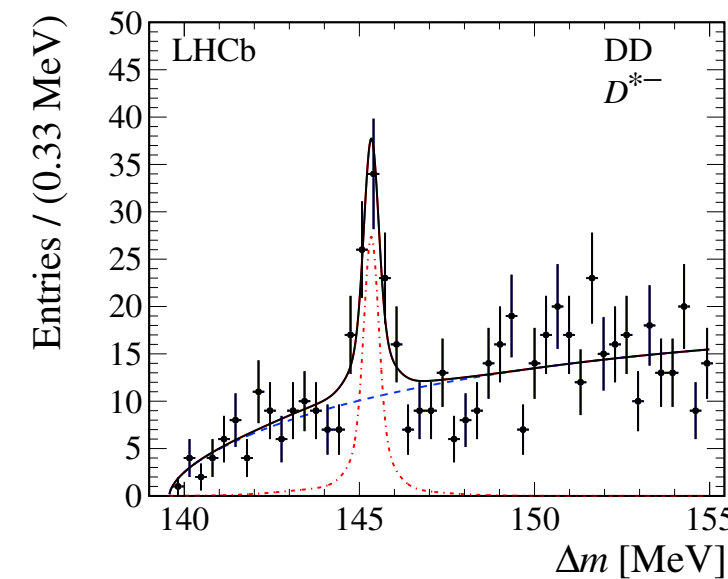
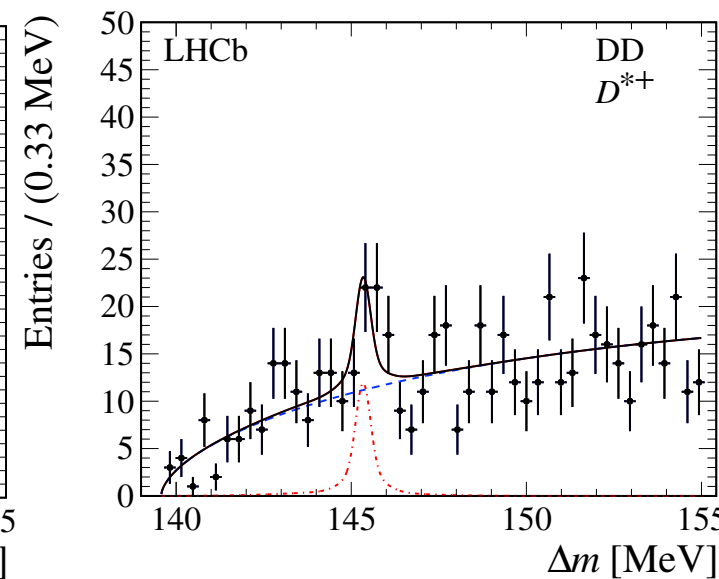
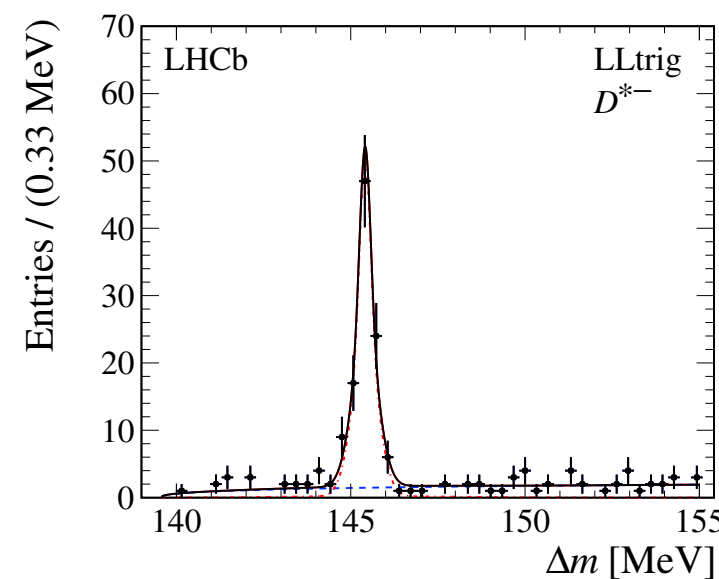
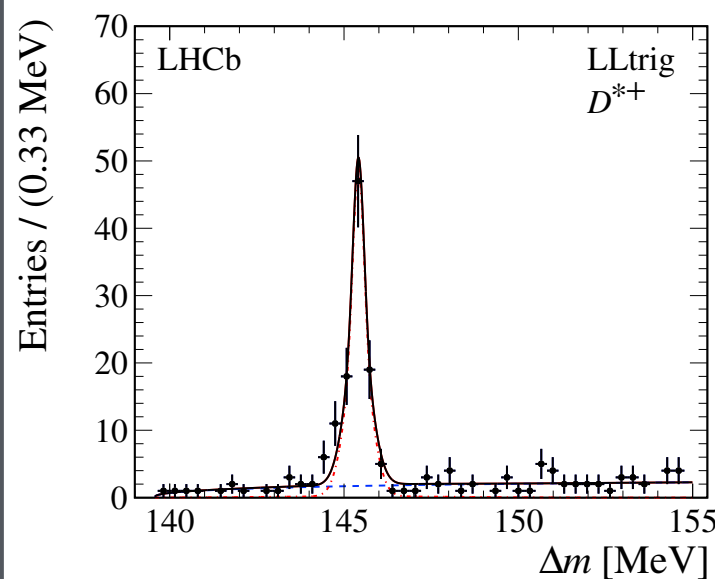
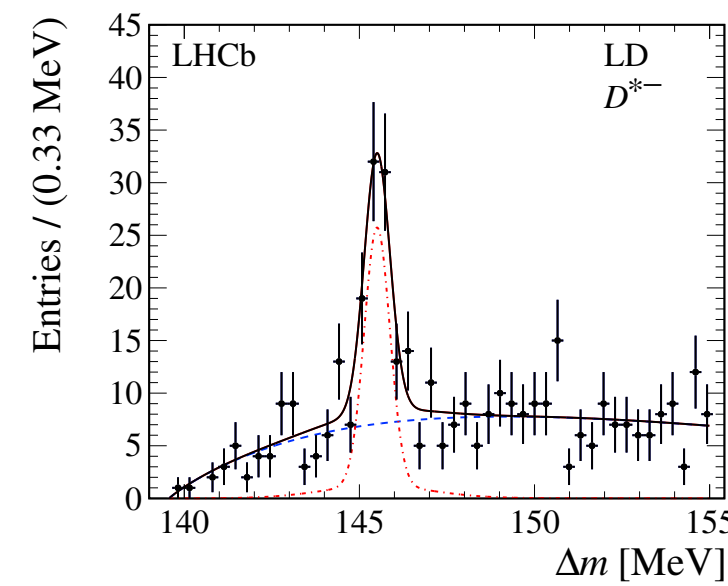
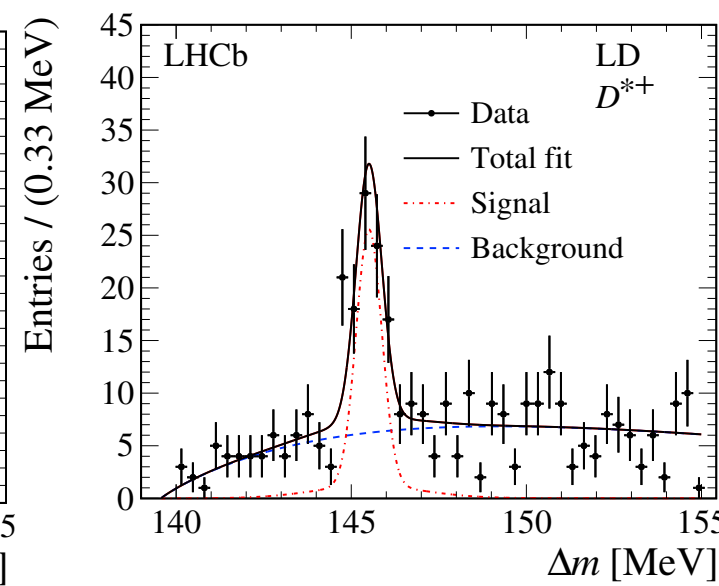
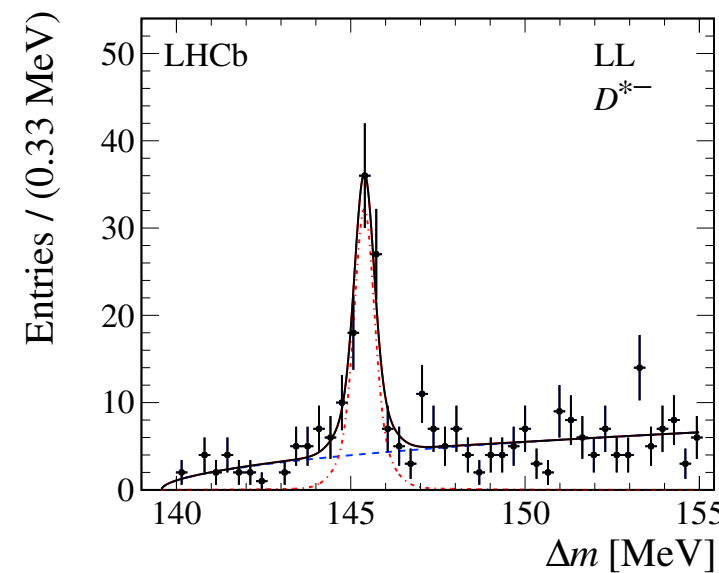
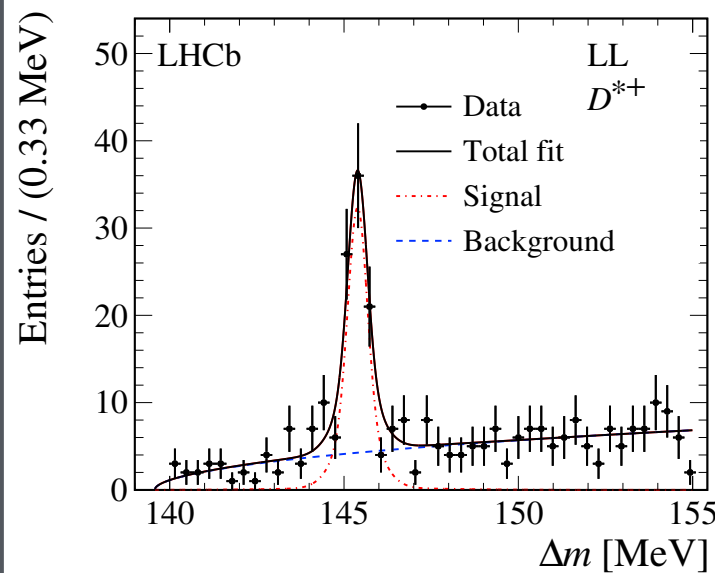
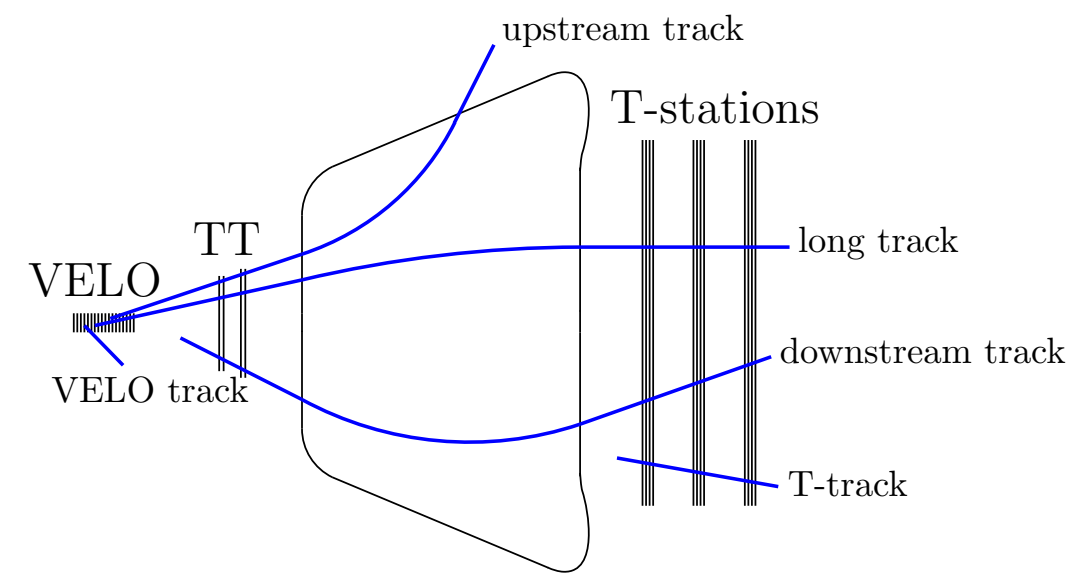
- Backup

# ● LHCb benchmarks

Type	Observable	Current precision	LHCb 2018	Upgrade (50 fb <sup>-1</sup> )	Theory uncertainty
$B_s^0$ mixing	$2\beta_s (B_s^0 \rightarrow J/\psi \phi)$	0.10 [138]	0.025	0.008	$\sim 0.003$
	$2\beta_s (B_s^0 \rightarrow J/\psi f_0(980))$	0.17 [214]	0.045	0.014	$\sim 0.01$
	$a_{sl}^s$	$6.4 \times 10^{-3}$ [43]	$0.6 \times 10^{-3}$	$0.2 \times 10^{-3}$	$0.03 \times 10^{-3}$
Gluonic penguins	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow K^{*0}\bar{K}^{*0})$	–	0.13	0.02	$< 0.02$
	$2\beta_s^{\text{eff}}(B^0 \rightarrow \phi K_S^0)$	0.17 [43]	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\text{eff}}(B_s^0 \rightarrow \phi\gamma)$	–	0.09	0.02	$< 0.01$
	$\tau^{\text{eff}}(B_s^0 \rightarrow \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \rightarrow K^{*0}\mu^+\mu^-; 1 < q^2 < 6 \text{ GeV}^2/c^4)$	0.08 [67]	0.025	0.008	0.02
	$s_0 A_{\text{FB}}(B^0 \rightarrow K^{*0}\mu^+\mu^-)$	25 % [67]	6 %	2 %	7 %
	$A_{\text{I}}(K\mu^+\mu^-; 1 < q^2 < 6 \text{ GeV}^2/c^4)$	0.25 [76]	0.08	0.025	$\sim 0.02$
	$\mathcal{B}(B^+ \rightarrow \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \rightarrow K^+\mu^+\mu^-)$	25 % [85]	8 %	2.5 %	$\sim 10 \%$
Higgs penguins	$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$	$1.5 \times 10^{-9}$ [13]	$0.5 \times 10^{-9}$	$0.15 \times 10^{-9}$	$0.3 \times 10^{-9}$
	$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)/\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$	–	$\sim 100 \%$	$\sim 35 \%$	$\sim 5 \%$
Unitarity triangle angles	$\gamma (B \rightarrow D^{(*)}K^{(*)})$	$\sim 10\text{--}12^\circ$ [244, 258]	$4^\circ$	$0.9^\circ$	negligible
	$\gamma (B_s^0 \rightarrow D_s K)$	–	$11^\circ$	$2.0^\circ$	negligible
	$\beta (B^0 \rightarrow J/\psi K_S^0)$	$0.8^\circ$ [43]	$0.6^\circ$	$0.2^\circ$	negligible
Charm	$A_\Gamma$	$2.3 \times 10^{-3}$ [43]	$0.40 \times 10^{-3}$	$0.07 \times 10^{-3}$	–
$CP$ violation	$\Delta\mathcal{A}_{CP}$	$2.1 \times 10^{-3}$ [18]	$0.65 \times 10^{-3}$	$0.12 \times 10^{-3}$	–

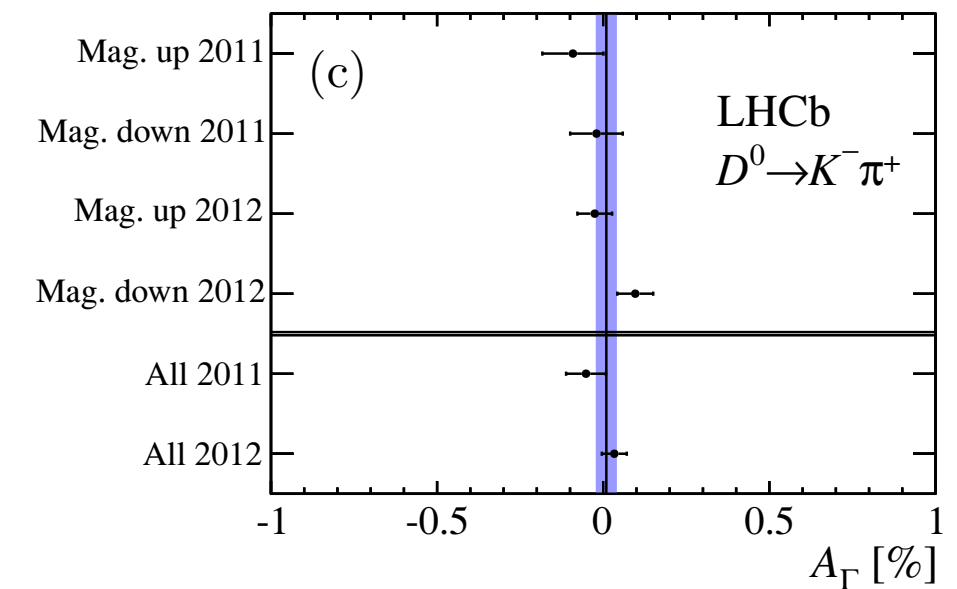
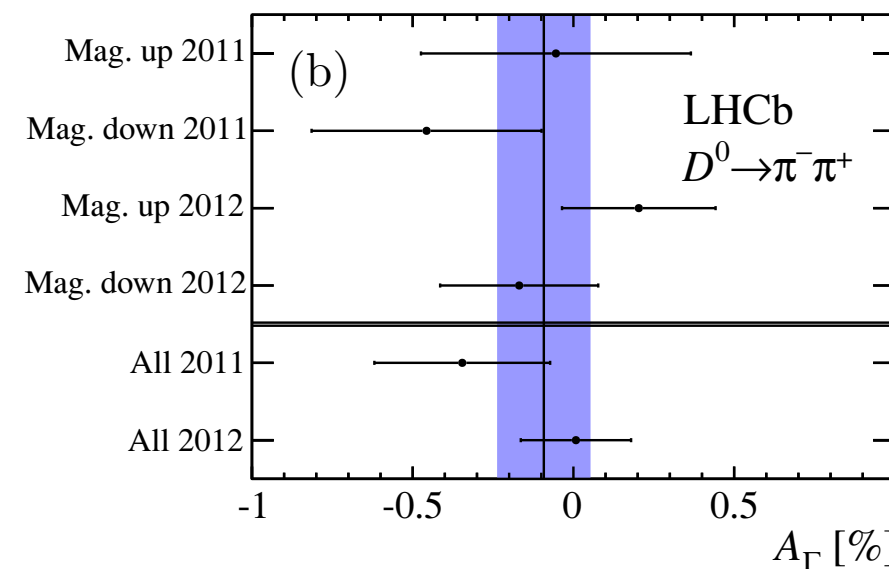
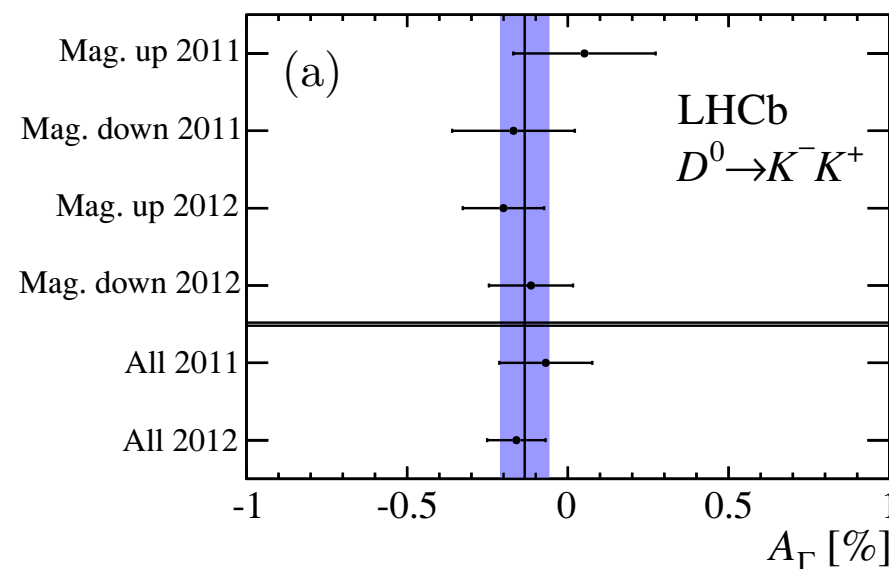
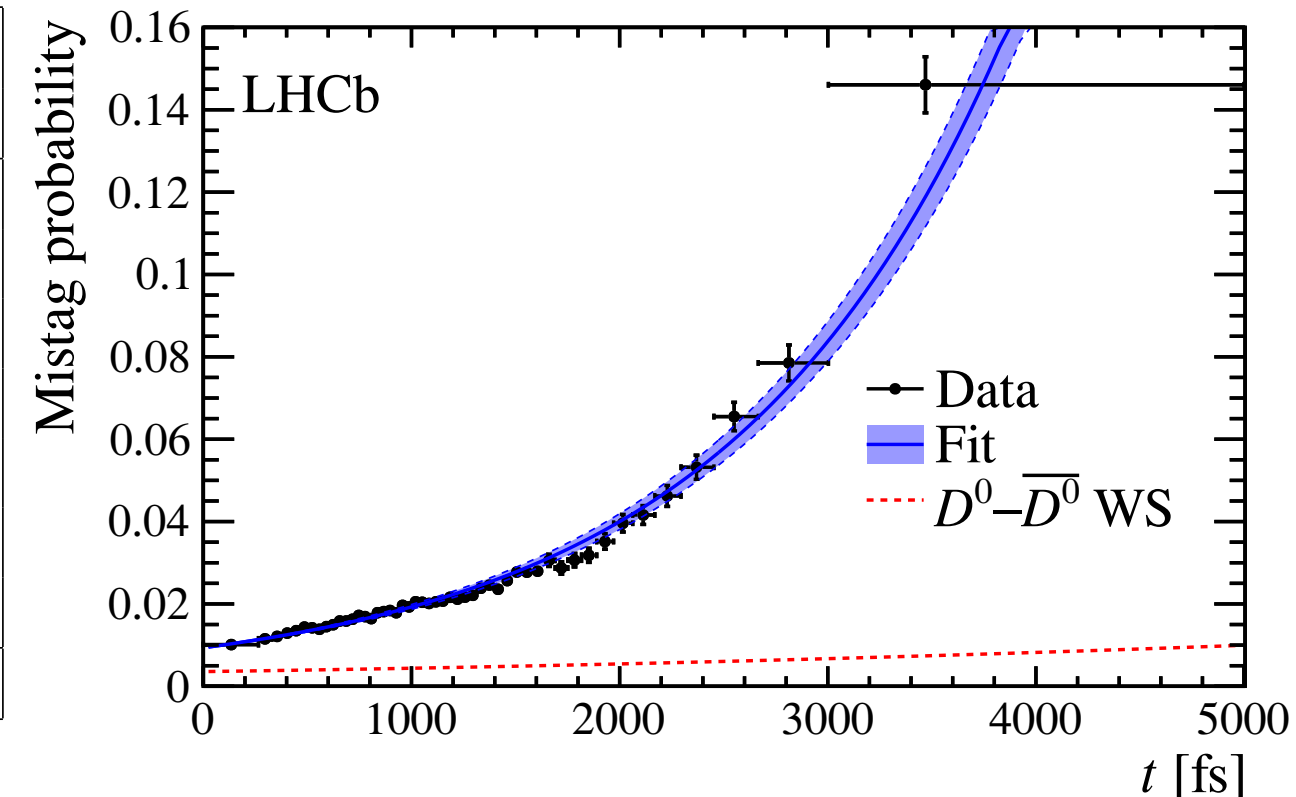
# $D^0 \rightarrow K_s^0 K_s^0$

Category	$N^+$	$N^-$	$\mathcal{A}_{CP}$
LL	$86 \pm 11$	$86 \pm 12$	$0.00 \pm 0.09$
LD	$82 \pm 14$	$83 \pm 13$	$-0.00 \pm 0.11$
DD	$29 \pm 14$	$66 \pm 14$	$-0.39 \pm 0.23$
LLtrig	$96 \pm 11$	$99 \pm 11$	$-0.02 \pm 0.08$
combined			$-0.029 \pm 0.052$



# ● $A_\Gamma$ : indirect $D^0 \rightarrow h^+ h^-$ CPV, systematics

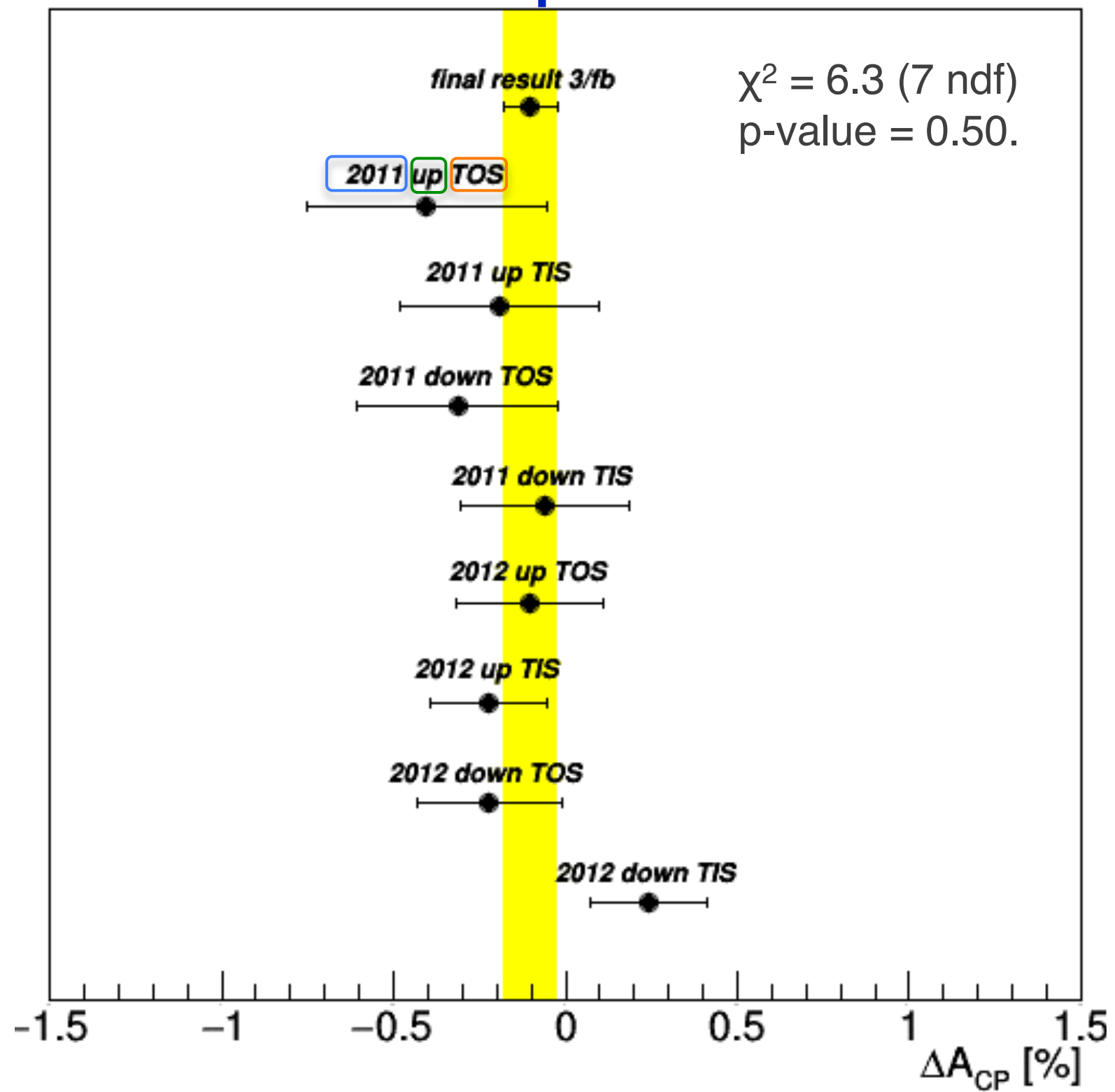
Source of uncertainty	$D^0 \rightarrow K^- K^+$		$D^0 \rightarrow \pi^- \pi^+$	
	constant	scale	constant	scale
Mistag probability	0.006%	0.05	0.008%	0.05
Mistag asymmetry	0.016%		0.016%	
Time-dependent efficiency	0.010%		0.010%	
Detection and production asymmetries	0.010%		0.010%	
$D^0$ mass fit model	0.011%		0.007%	
$D^0$ decay-time resolution		0.09		0.07
$B^0 - \bar{B}^0$ mixing	0.007%		0.007%	
Quadratic sum	0.026%	0.10	0.025%	0.09





# ● Cross-checks

- Data taking year (= different energy 7/8 TeV)
- Magnet Polarity
- Trigger configuration
  - ◆ TOS: trigger on signal
  - ◆ TIS: trigger independent from signal
- cross-checks:
  - ◆  $\pi$ -soft,  $D^0$  kinematics
  - ◆ run number
  - ◆ PID requirements
  - ◆  $D^*$  vertex quality
  - ◆ ...



arXiv:1602.03160

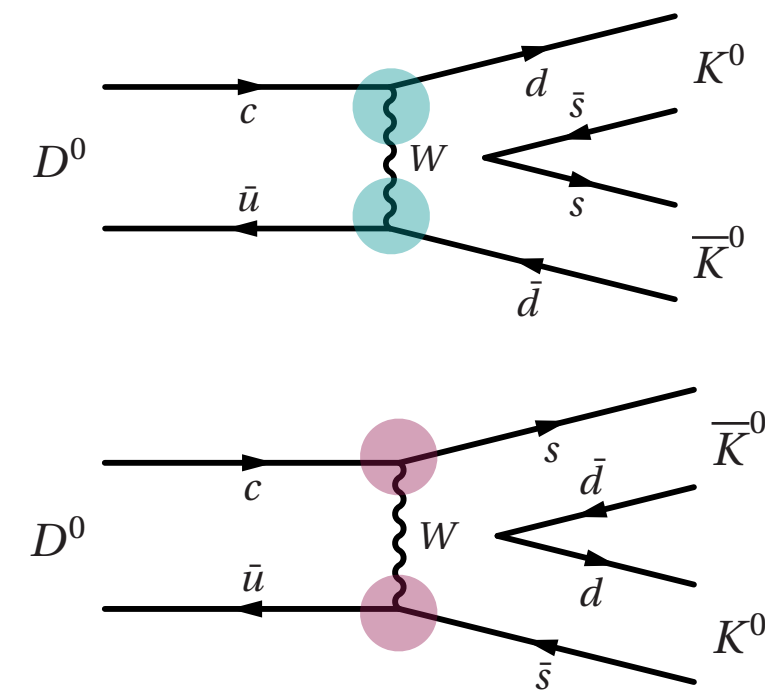
# ● CPV in $D^0 \rightarrow K_s^0 K_s^0$ decays

- Decay dominated by long-distance contributions:

- ◆ short-distance contributions cancel since  $V_{cd}V_{ud}^* \simeq -V_{cs}V_{us}^*$ ,

- ◆ interference terms could give a large contribution to CPV  $\mathcal{O}(1\%)$ ;

[Phys. Rev. D87 (2013) 014024] [Phys. Rev. D92 (2015) 054036]

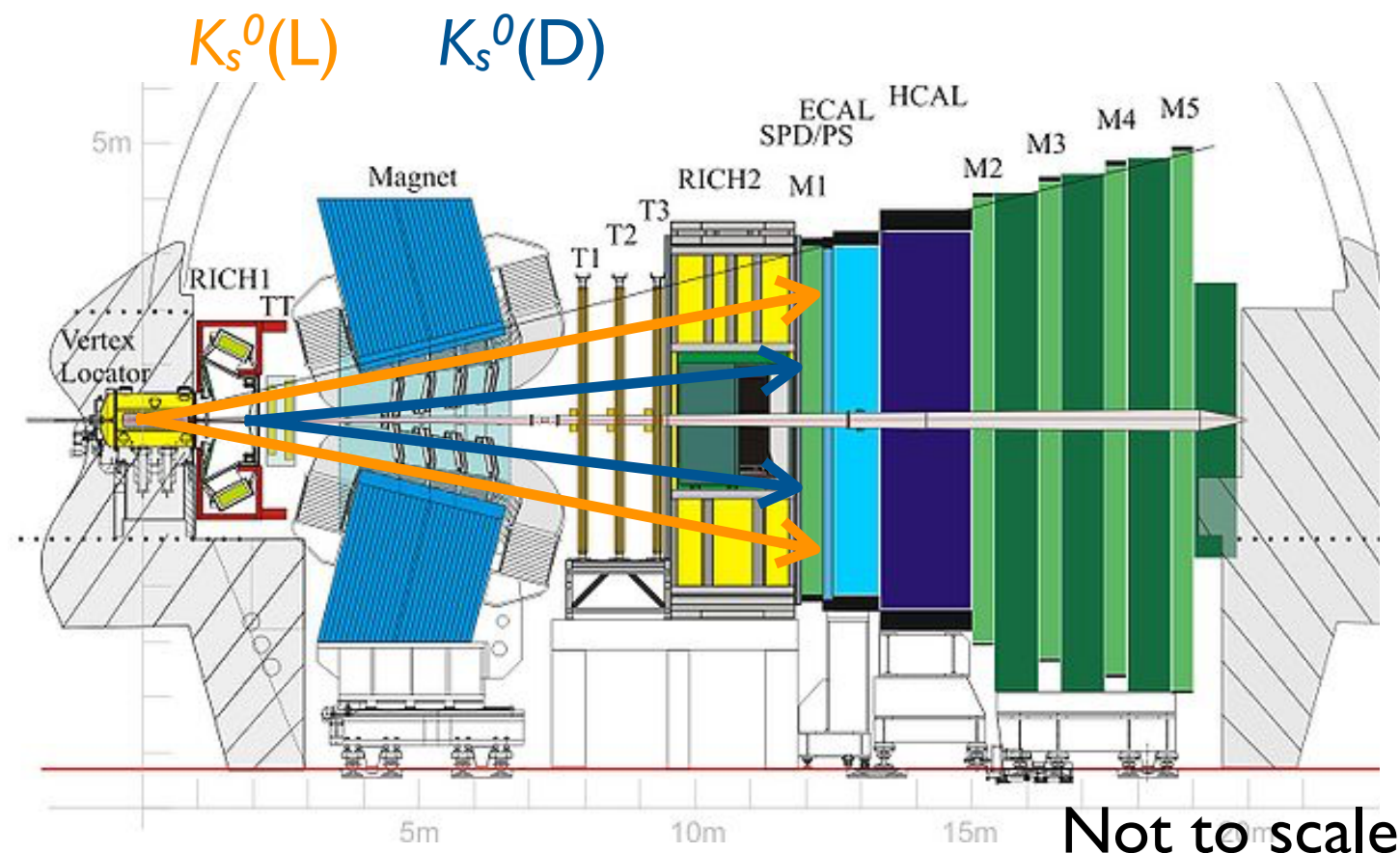


- Challenge: reconstruction of **long-lived** particles,  $K_s^0 \rightarrow \pi^+ \pi^-$ , decaying mainly outside the region of vertex detector (VELO)

- Only one previous measurement from CLEO:

$$A_{CP} = (23 \pm 19)\%$$

[PRD 63 (2011) 071101]



# ● $A_{CP}$ in $D^0 \rightarrow K_s^0 K_s^0$

- Measurement of  $CP$  asymmetry:

$$A_{\text{raw}}(K_s^0 K_s^0) \approx A_{CP}(K_s^0 K_s^0) + A_D(\pi) + A_P(D^*)$$

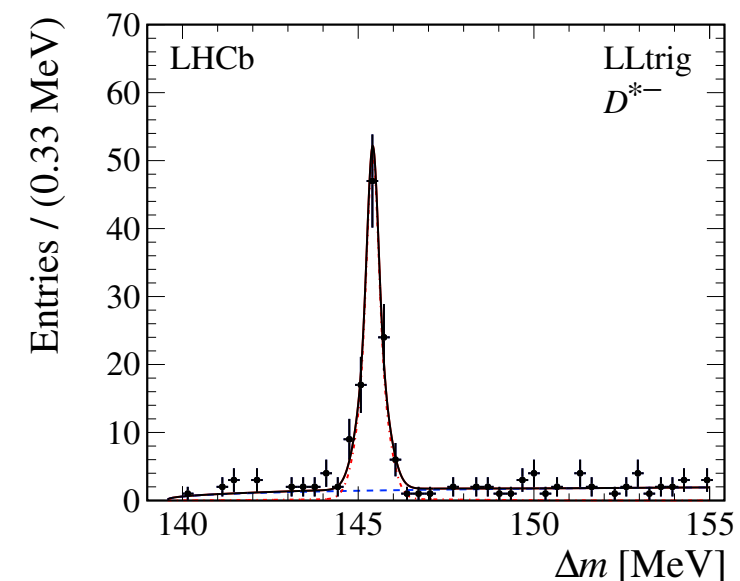
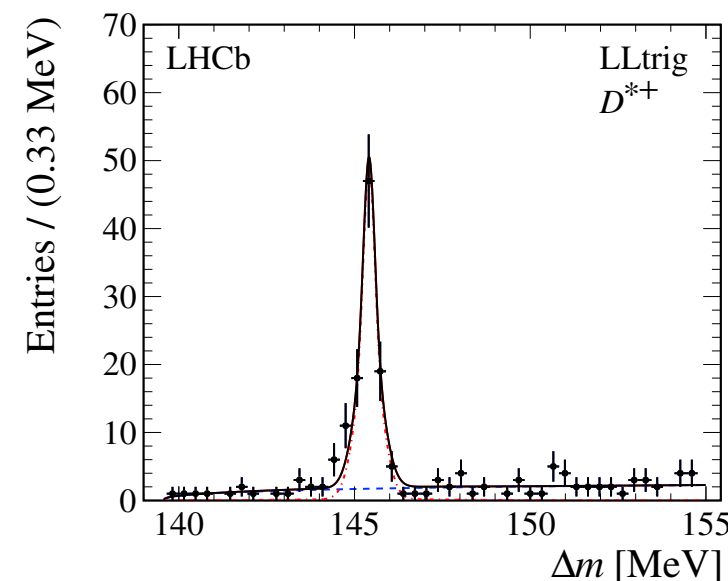
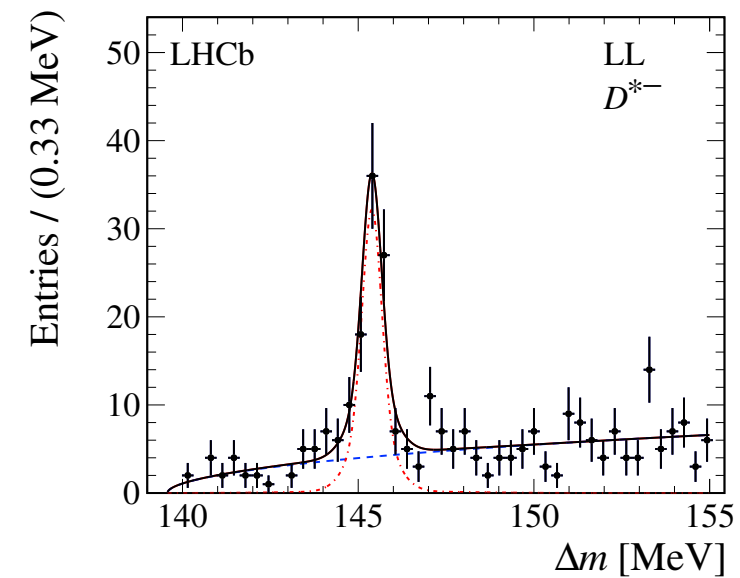
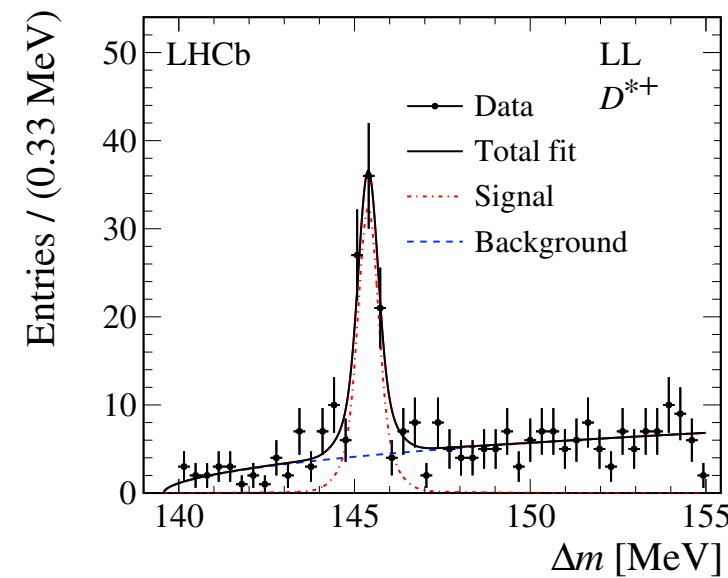
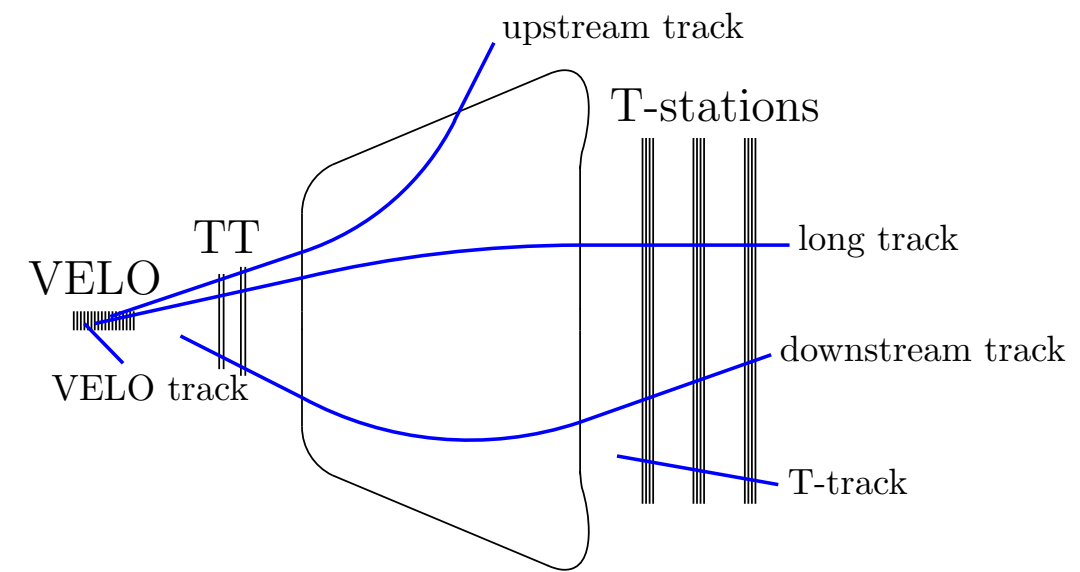
- $D^*$ -tagged decays.
- Detection,  $A_D(\pi)$ , and production,  $A_P(D^*)$ , asymmetries kept under control using  $D^0 \rightarrow K\pi$  control sample;

◆ both  $\mathcal{O}(1\%)$ .

- 600 events with the full Run1 data sample:

$$A_{CP} = -0.029 \pm 0.052(\text{stat.}) \pm 0.022(\text{syst.})$$

- Large improvement with respect to the previous measurement ( $\sim$  factor 4).
- Dedicate trigger in Run2.



$$\Delta m = m(K_s^0 K_s^0 \pi) - m(K_s^0 K_s^0)$$

[JHEP 10 (2015) 055]