Measurement of the CP violation parameter A_Γ in $D^0 \to h^+h^-$ decays at LHCb

[PRL 118, 261803 (2017)]

Pietro Marino

23 August 2017

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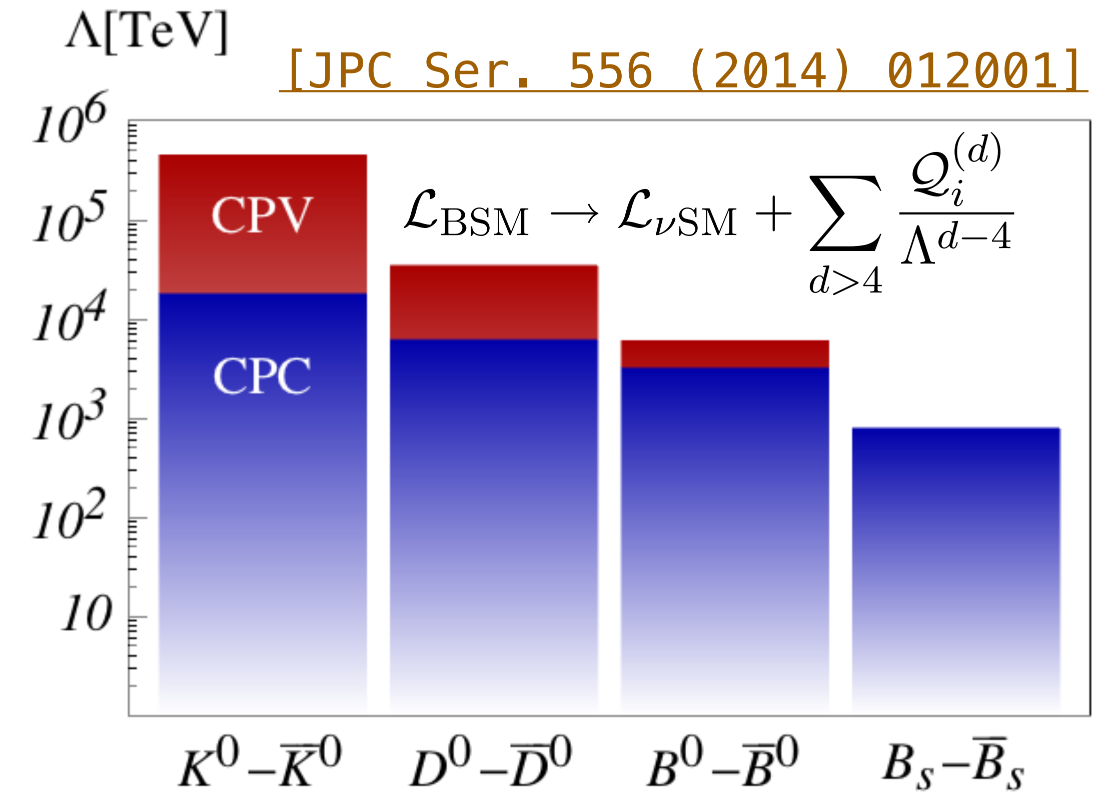
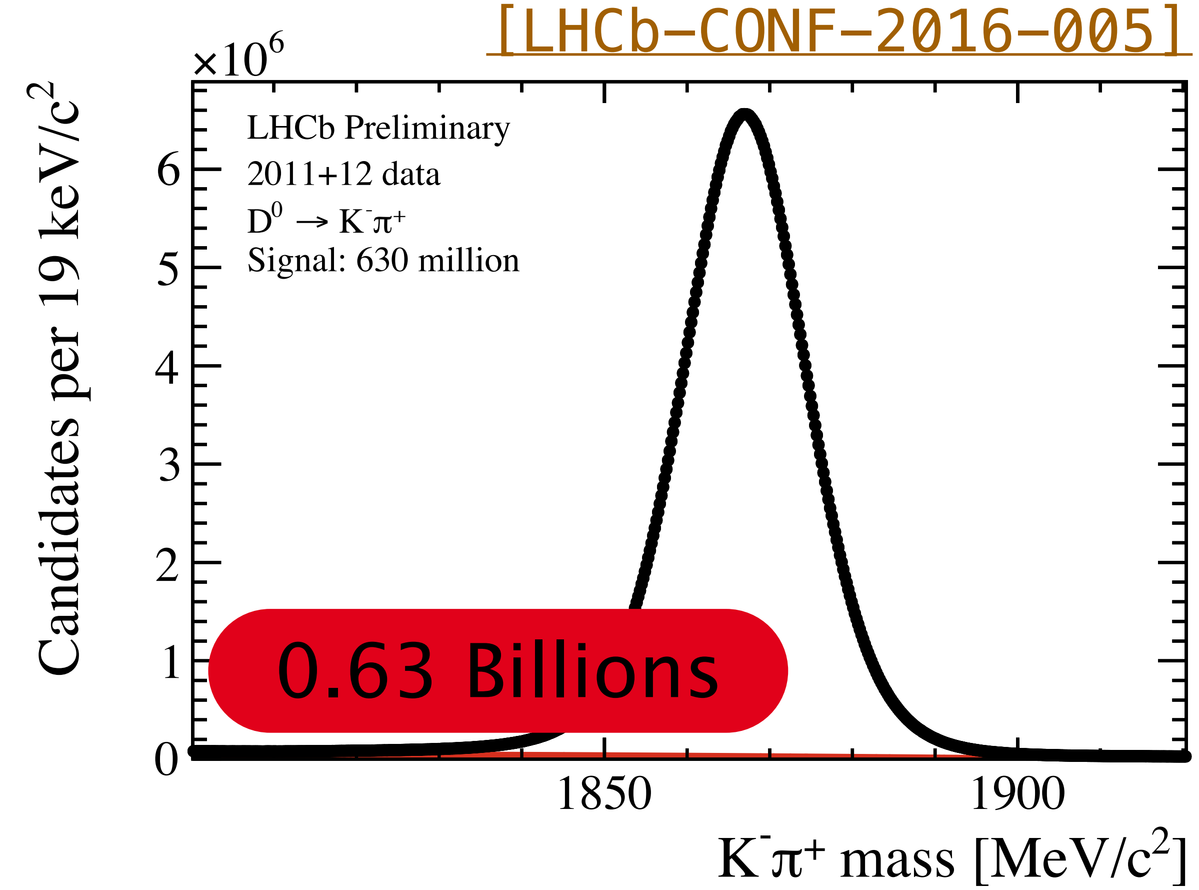
The Charm sector is a unique and powerful probe of SM and beyond

- Up-type quark
  - complements searches done in K and B systems.
- Huge data samples
  - only recently reached sensitivity to probe BSM physics.
- SM predictions are hard
  - push theory tools development.

[JPC Ser. 556 (2014) 012001]



[LHCb-CONF-2016-005]



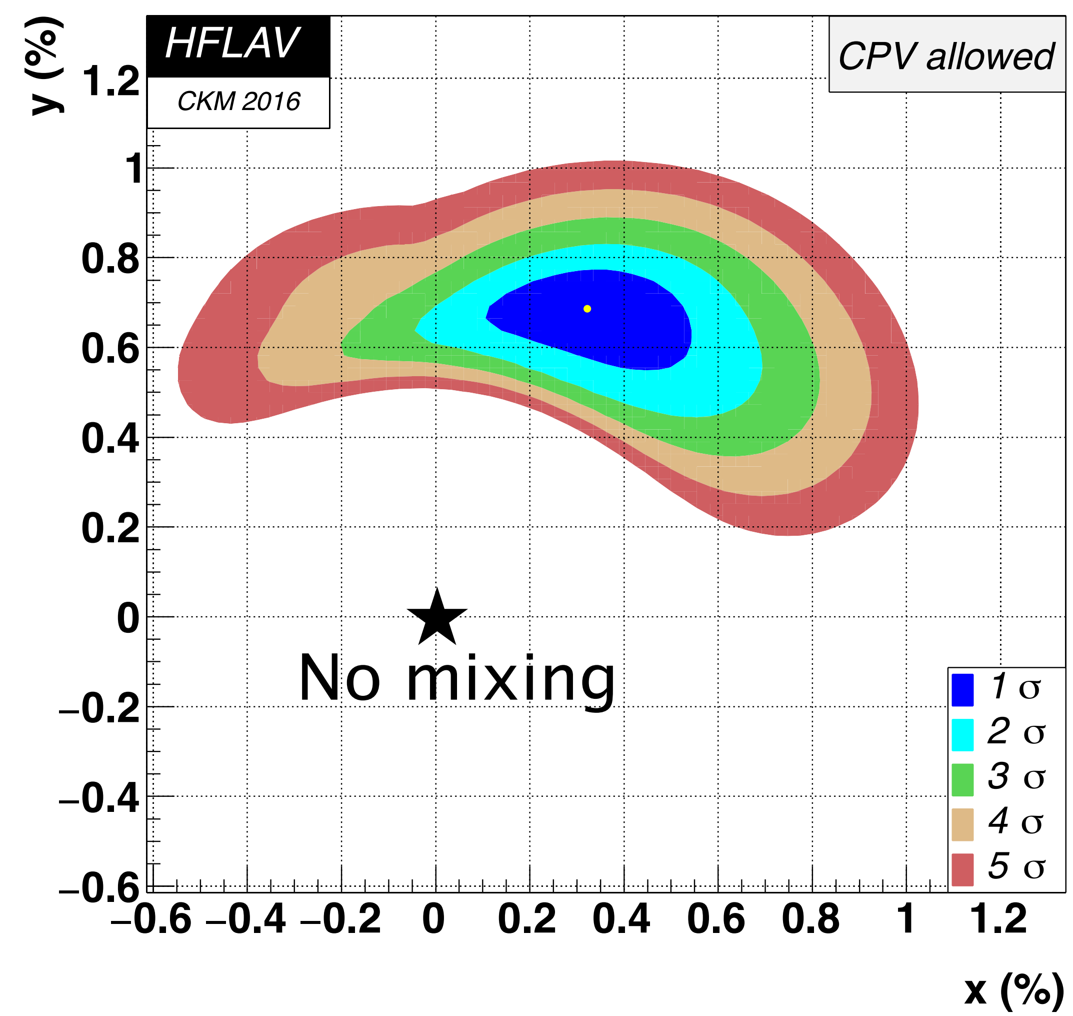
Flavour mixing in the Charm sector is well established

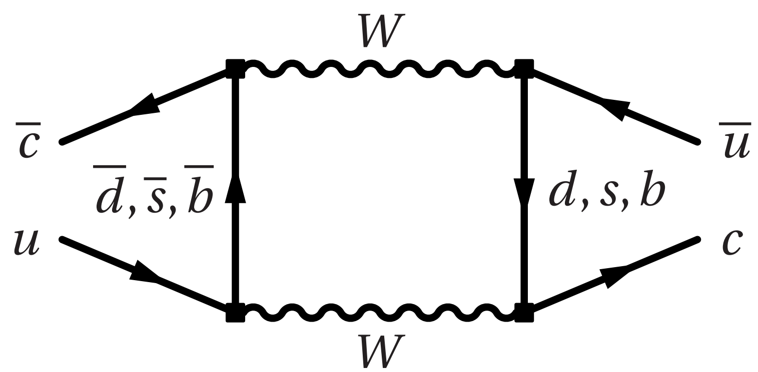
- Mass eigenstates ≠ flavour eigenstates
  $$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$
- Mixing parameters ≲ O(10^{-2}):

  $x = 2(m_1 - m_2)/(\Gamma_1 + \Gamma_2)$

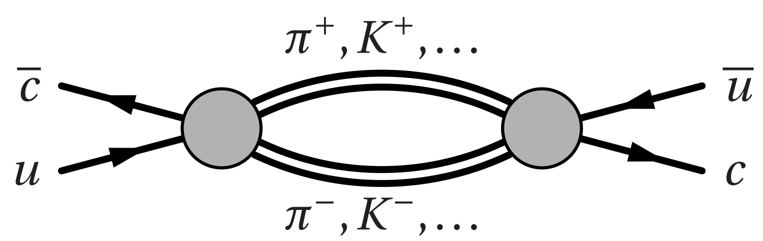
  $y = (\Gamma_1 - \Gamma_2)/(\Gamma_1 + \Gamma_2)$
- SM predictions affected by large uncertainties ~ O(10^{-2} – 10^{-7})

[HFLAV arXiv:1612.07233]





CKM and GIM suppressed in SM

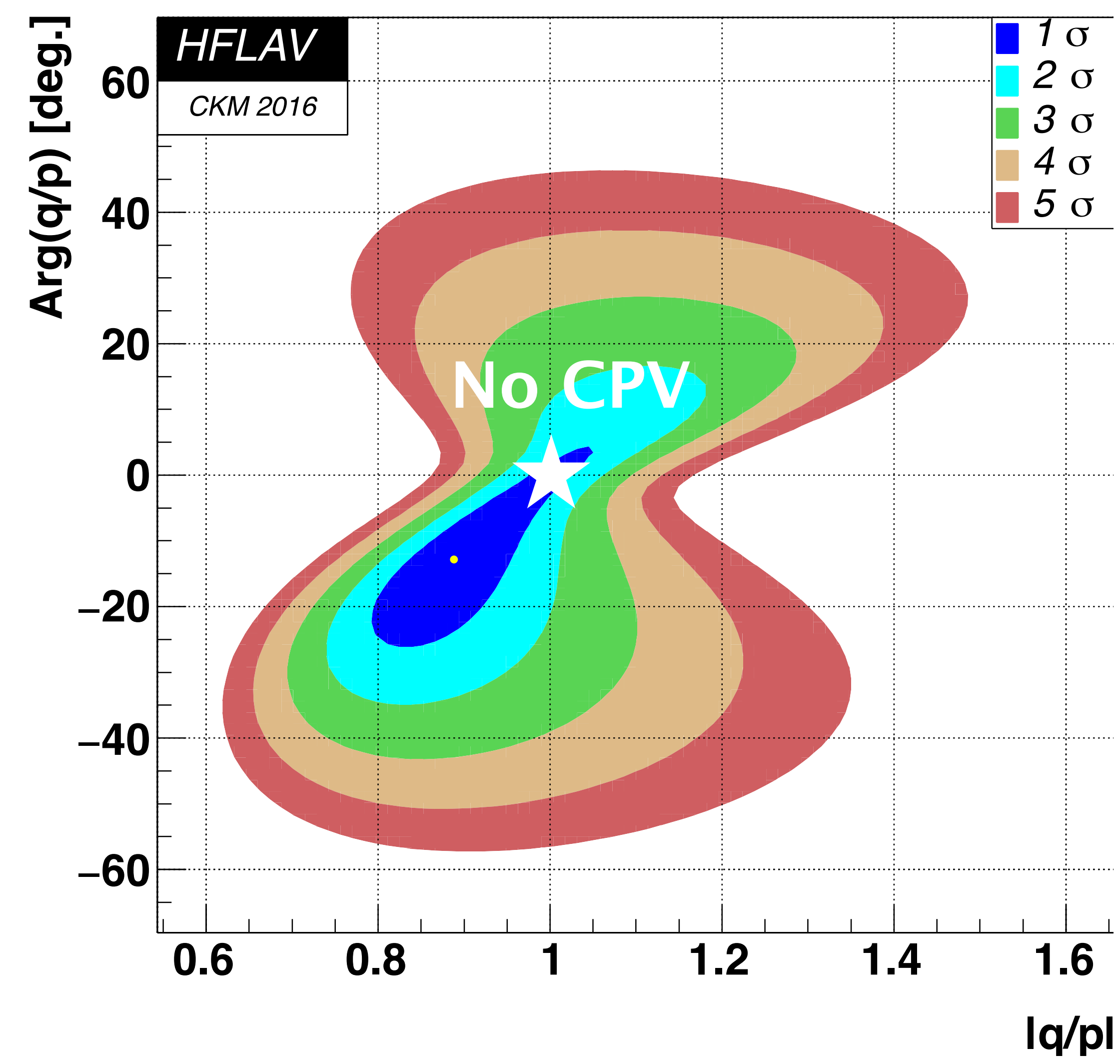


Large theory uncertainties

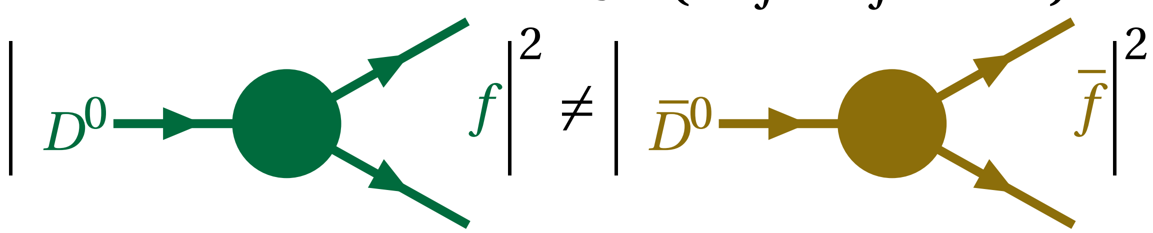
CP violation yet unobserved

- Small value expected from the SM of $O(V_{ub}V_{cb}^{*}/V_{us}V_{cs}^{*}) \lesssim 10^{-3}$.
- Present sensitivity close to the SM expectation.

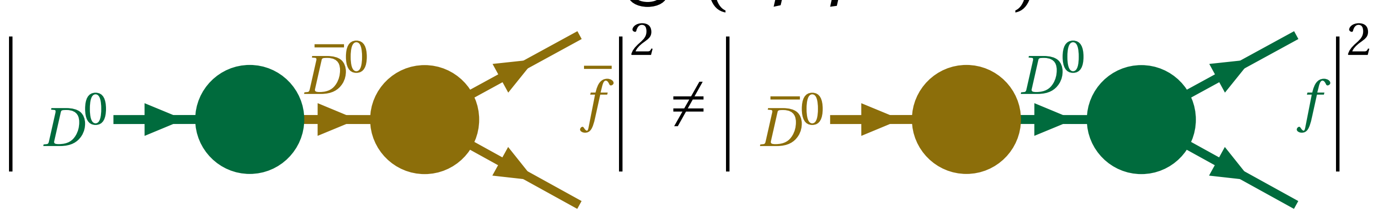
[HFLAV arXiv:1612.07233]



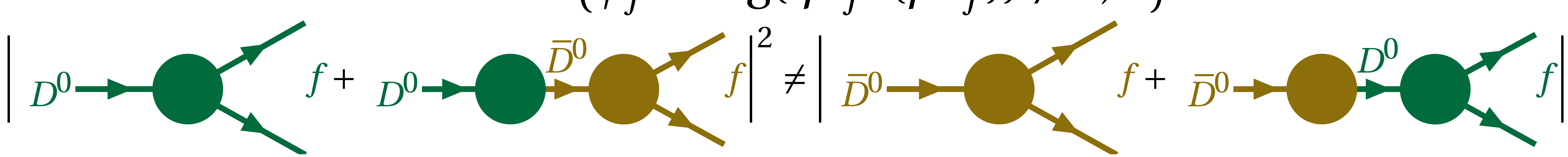
CPV in the decay $(|\bar{A}_f/A_f| \neq 1)$



CPV in the mixing $(|q/p| \neq 1)$



CPV in the interference $(\phi_f = \arg(q\bar{A}_f/(pA_f)) \neq 0, \pi)$



A_Γ is a golden observable to search for CPV

CPV in the mixing $|q/p| \neq 1$

$$A_\Gamma \equiv \frac{\hat{\Gamma}(D^0 \to f) - \hat{\Gamma}(\bar{D}^0 \to f)}{\hat{\Gamma}(D^0 \to f) + \hat{\Gamma}(\bar{D}^0 \to f)} \approx \frac{1}{2}\left[\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) y \cos\phi_f - \left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) x \sin\phi_f\right]$$

CPV in the interference $\phi_f \neq 0, \pi$

where $\hat{\Gamma}$ is the effective decay width for **D⁰→KK** and **D⁰→ππ**.

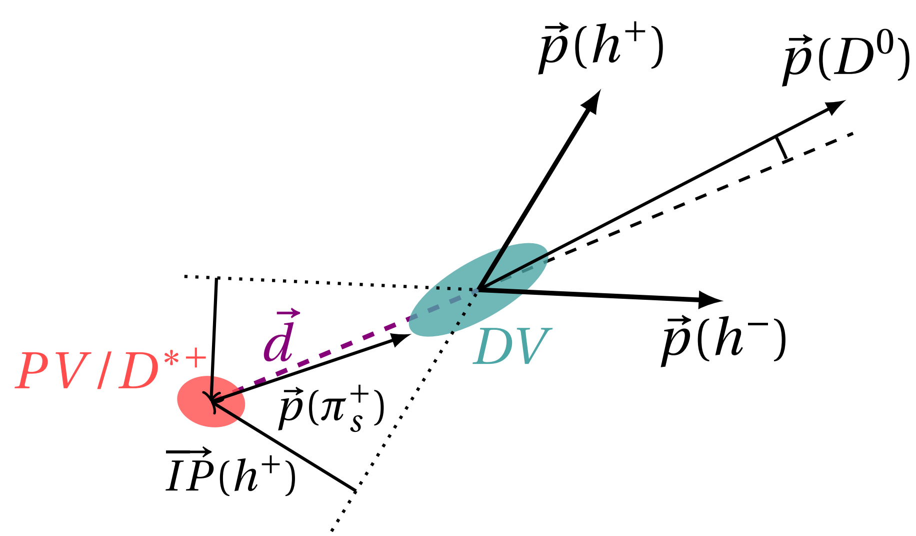
Time-dependent CP asymmetry at the first order in t/τ_D (x,y ~10^{-2})

$$A_{CP}(t) = \frac{\Gamma_{D^0 \to f}(t) - \Gamma_{\bar{D}^0 \to f}(t)}{\Gamma_{D^0 \to f}(t) + \Gamma_{\bar{D}^0 \to f}(t)} \approx A_{CP}^{\mathrm{dir}} + A_{CP}^{\mathrm{ind}} \frac{t}{\tau_D}$$

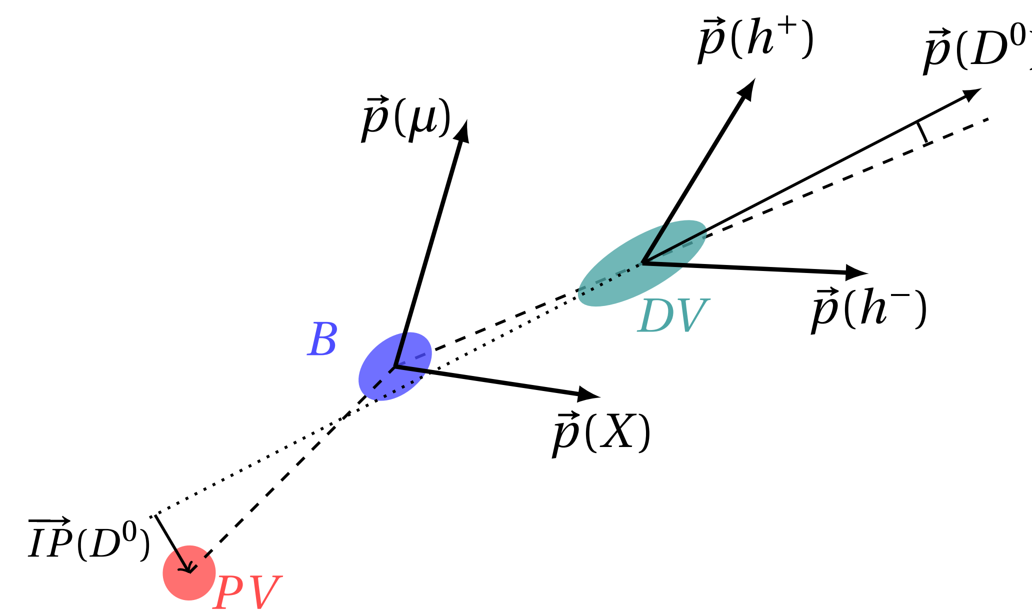
neglecting CPV in the $D^0 \to f$ decay we obtain $A_{CP}^{\mathrm{ind}} = -A_\Gamma$

Flavour identification (tagging) is done through D^{*+} decays

- D^0 meson flavour cannot be determined from the CP-eigenstate final states K^+K^- and $\pi^+\pi^-$.
- D^0 meson production mechanism is exploited.



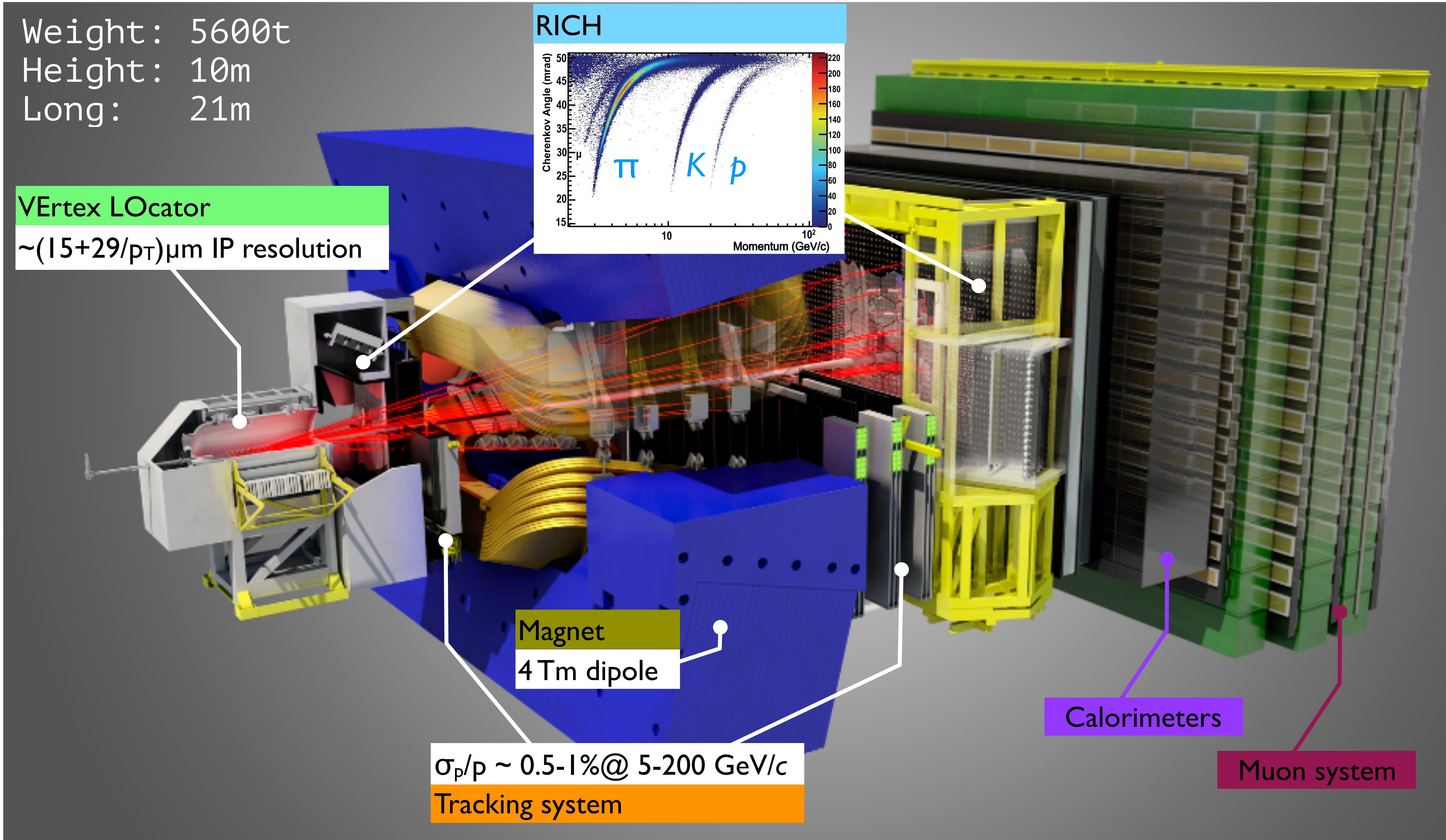
$D^{*+} \to D^0[\to h^+ h'^-]\pi_s^+$
Prompt tag.



$\bar{B} \to D^0[\to h^+ h'^-]\ell^-\bar{\nu}_\ell X$
Semileptonic tag.

[JHEP 04 (2015) 043]

LHCb detector: excellent tracking and particle identification performances



Measurement of A_Γ in $D^0 \rightarrow h^+h^-$ decays at LHCb: analysis strategy

- Measure yield asymmetry in bins of D^0 decay time

Detection asymmetry

$$A_{CP}^{\mathrm{dir}} - A_\Gamma \frac{t}{\tau_D}$$

$$A_{\mathrm{raw}}(t) = \frac{N(t; D^{*+} \rightarrow D^0\pi^+) - N(t; D^{*-} \rightarrow \bar{D}^0\pi^-)}{N(t; D^{*+} \rightarrow D^0\pi^+) + N(t; D^{*-} \rightarrow \bar{D}^0\pi^-)} \approx A_{\mathrm{P}} + A_{\mathrm{D}} + A_{CP}(t)$$

D* production asymmetry

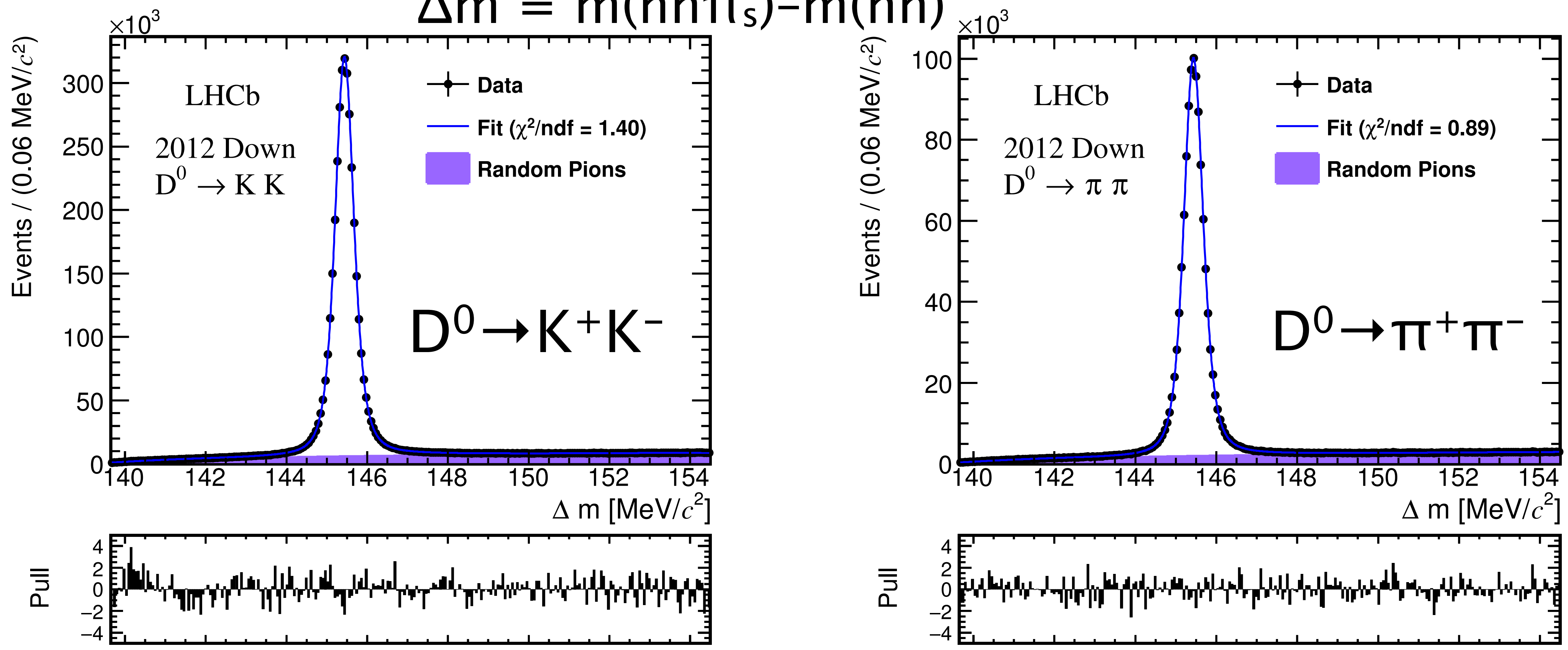
- Correct for detection-induced charge asymmetries.
- Extract A_Γ through a linear fit to decay asymmetry as function of D^0 decay time.

<u>Control sample: CF $D^0 \rightarrow K^-\pi^+$ decay</u> $A_{\mathrm{raw}} = A_{\mathrm{P}} + A_{\mathrm{D}} + A_{CP}^{\mathrm{dir}}$

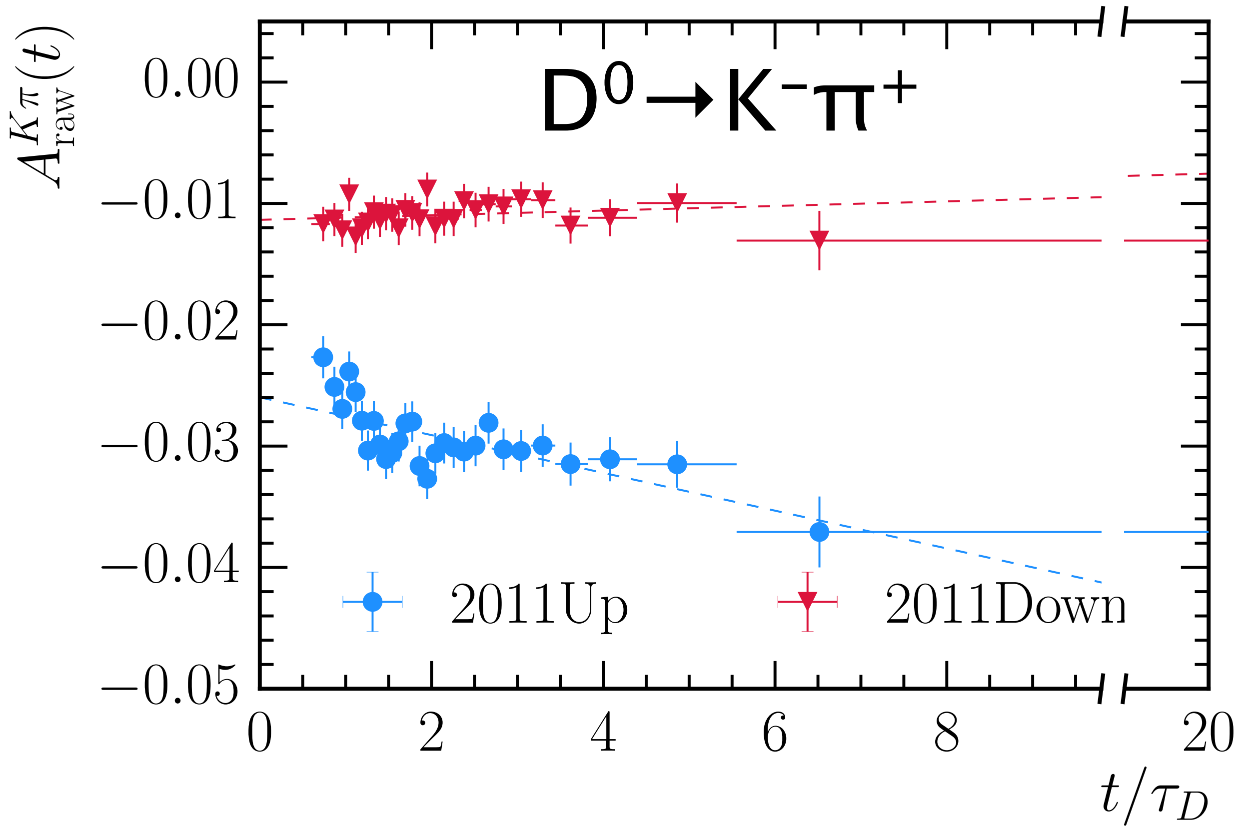
LHCb data at 7 and 8 TeV corresponding to 3/fb

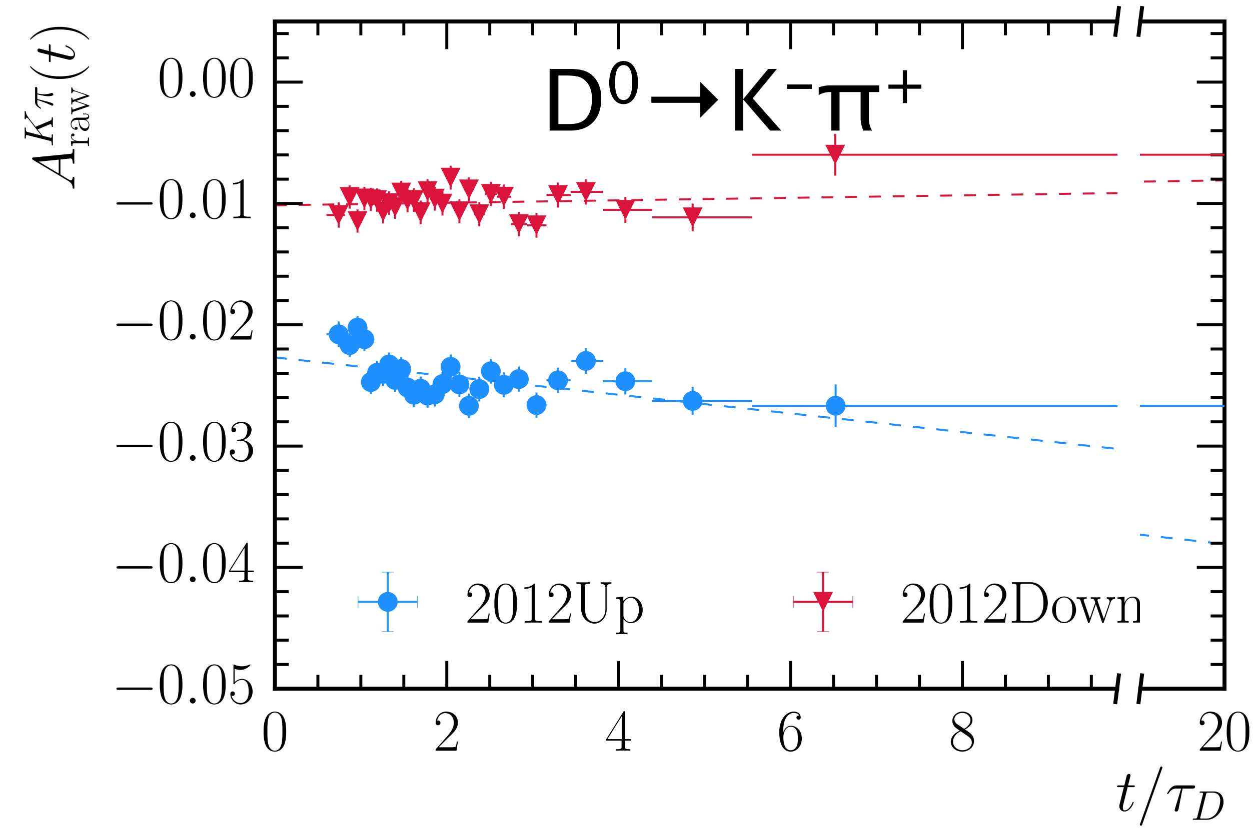
		Yields in Millions		
$\sqrt{s}$	**sample**	**$D^0 \to K^-\pi^+$**	**$D^0 \to K^+K^-$**	**$D^0 \to \pi^+\pi^-$**
7 TeV	2011 Up	10.7	1.2	0.36
7 TeV	2011 Down	15.5	1.7	0.53
8 TeV	2012 Up	30.0	3.3	1.02
8 TeV	2012 Down	31.3	3.4	1.07
	Total	**87.5**	**9.6**	**2.98**

$\Delta m = m(hh\pi_s) - m(hh)$



Control sample A_Γ is incompatible with zero, indication of a time-dependent detector asymmetry



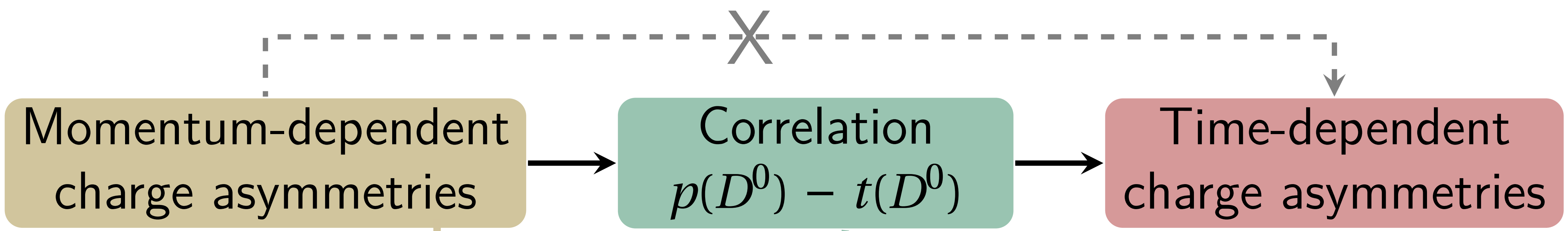


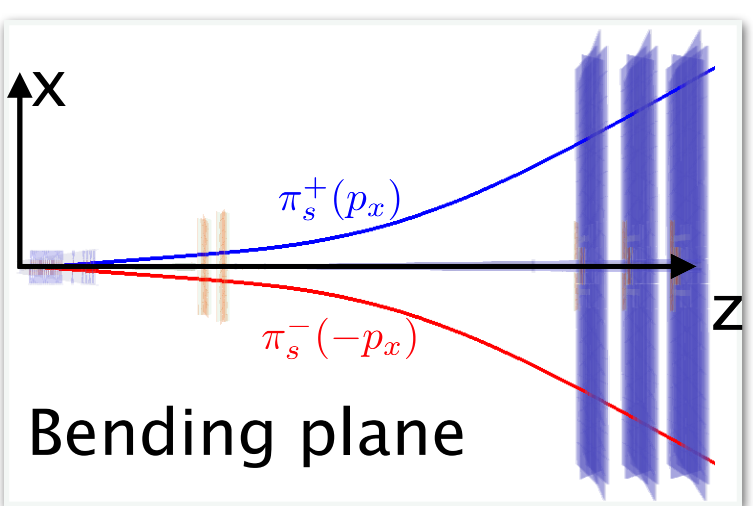
- $A_\Gamma(D^0 \to K^-\pi^+)$ results are **incompatible** with zero and with each others.
- Not even straight lines.

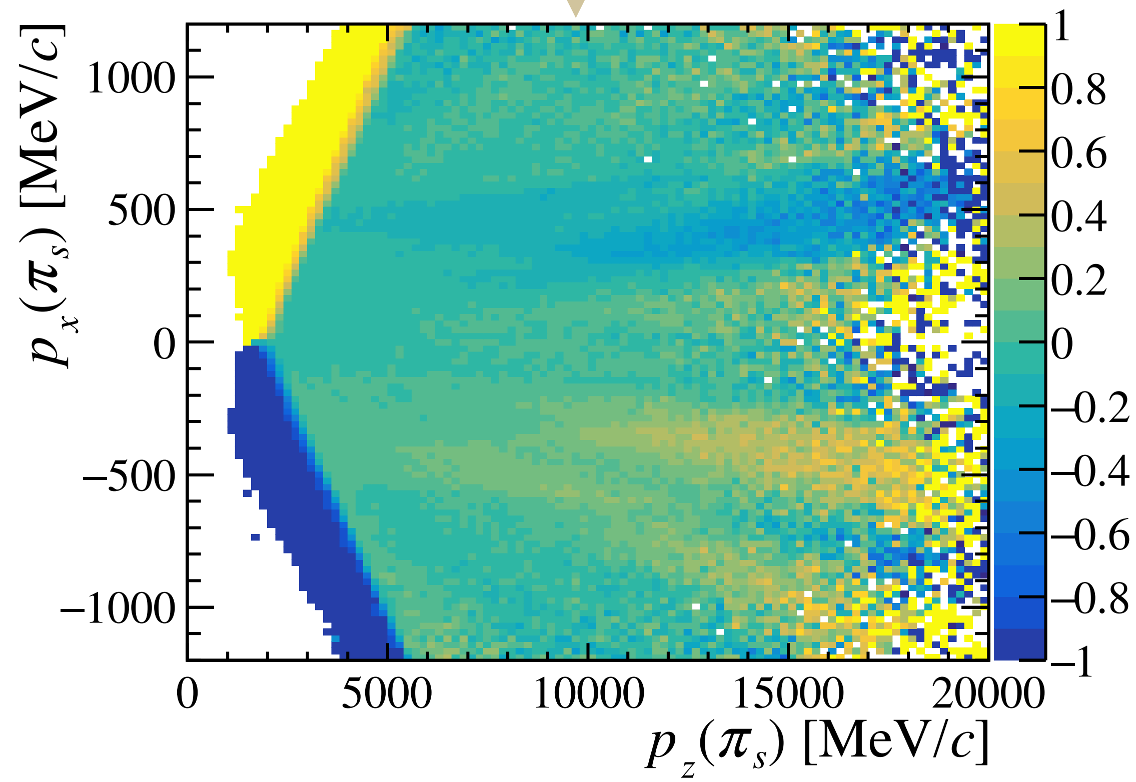
Clear indication of **very dangerous** detection effect.

sample	$A_\Gamma(D^0 \to K^-\pi^+)$ [10^{-3}]
2011 Up	+1.65 ± 0.30
2011 Dw	-0.11 ± 0.25
2012 Up	+0.77 ± 0.18
2012 Dw	-0.06 ± 0.17
Average	-0.41 ± 0.10

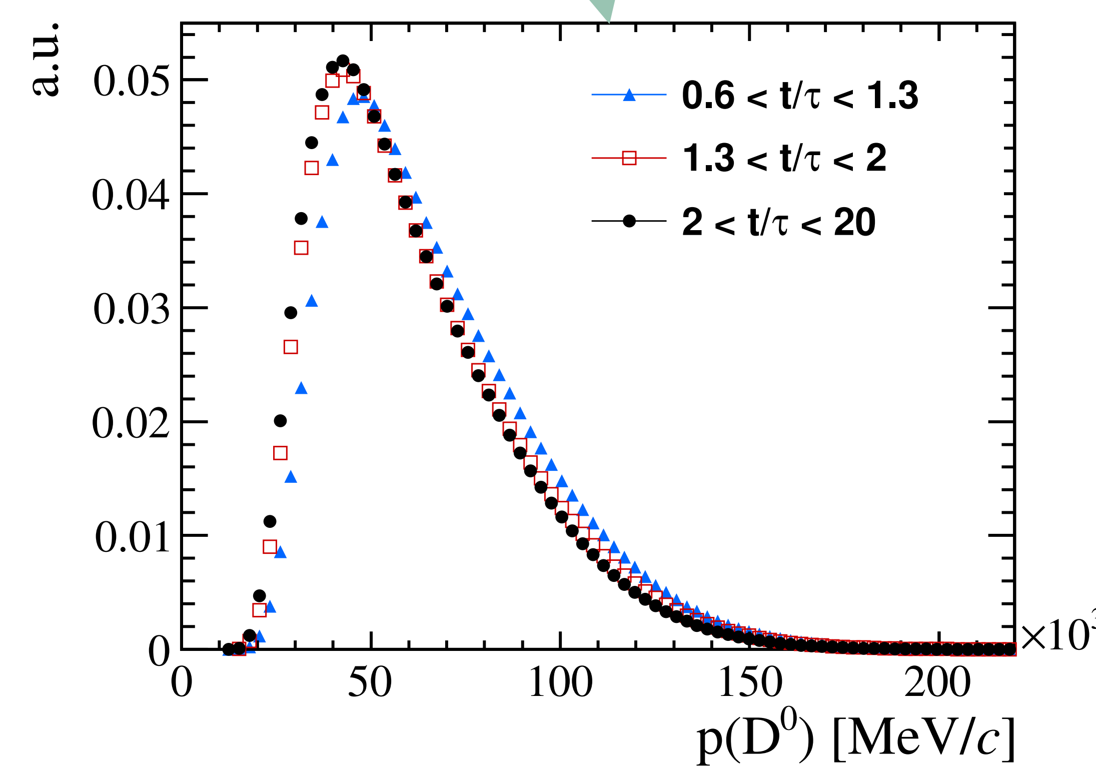
How the momentum-dependent charge asymmetries generate time-dependent charge asymmetries







Soft pion asymmetry in the bending plane (2012Up)



p(D^0) in bins of t(D^0) (2012Up)

Momentum dependency removed by reweighting the soft pion kinematics

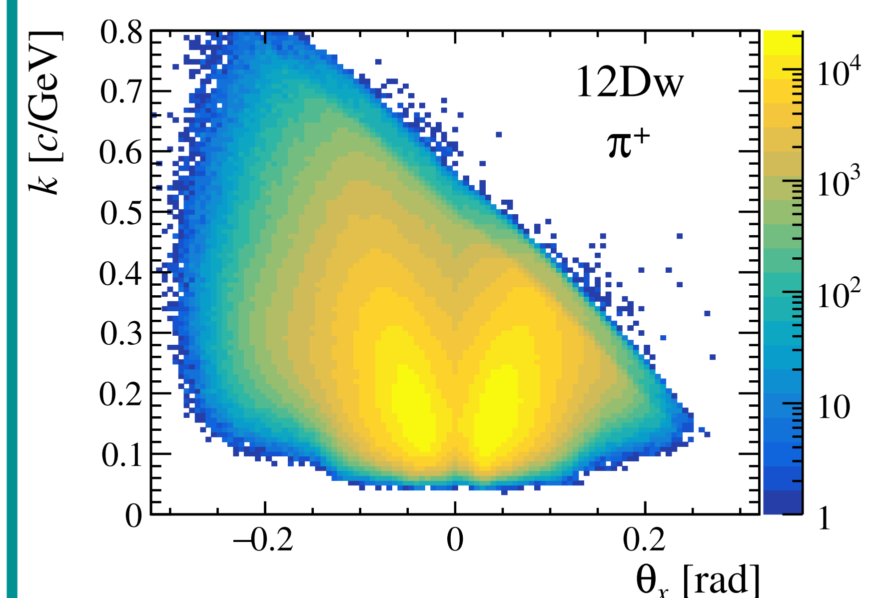
$k = 1/\sqrt{(p_x^2+p_z^2)}$

$\theta_x = \arctan(p_x/p_z)$

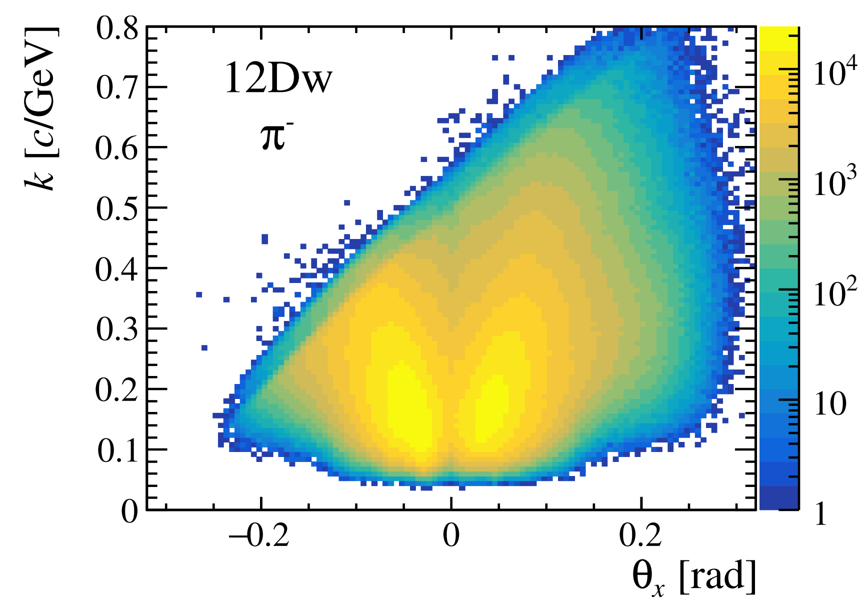
$\theta_y = \arctan(p_y/p_z)$

- Remove any dependency making $\mathbf{n^+(k,\theta_x,\theta_y) = n^-(k,-\theta_x,\theta_y)}$

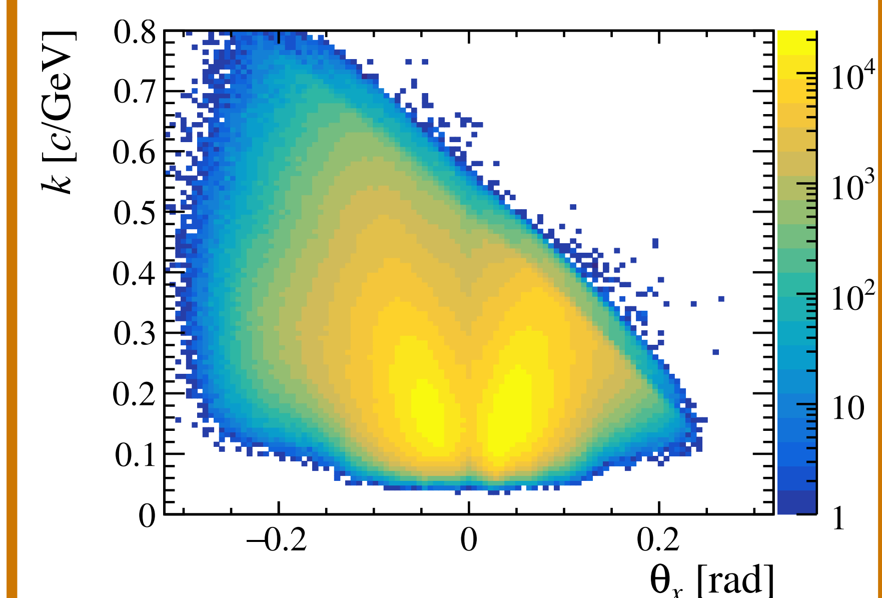
$n^+(k,\theta_x)$



$n^-(k,\theta_x)$



$n^-(k,-\theta_x)$

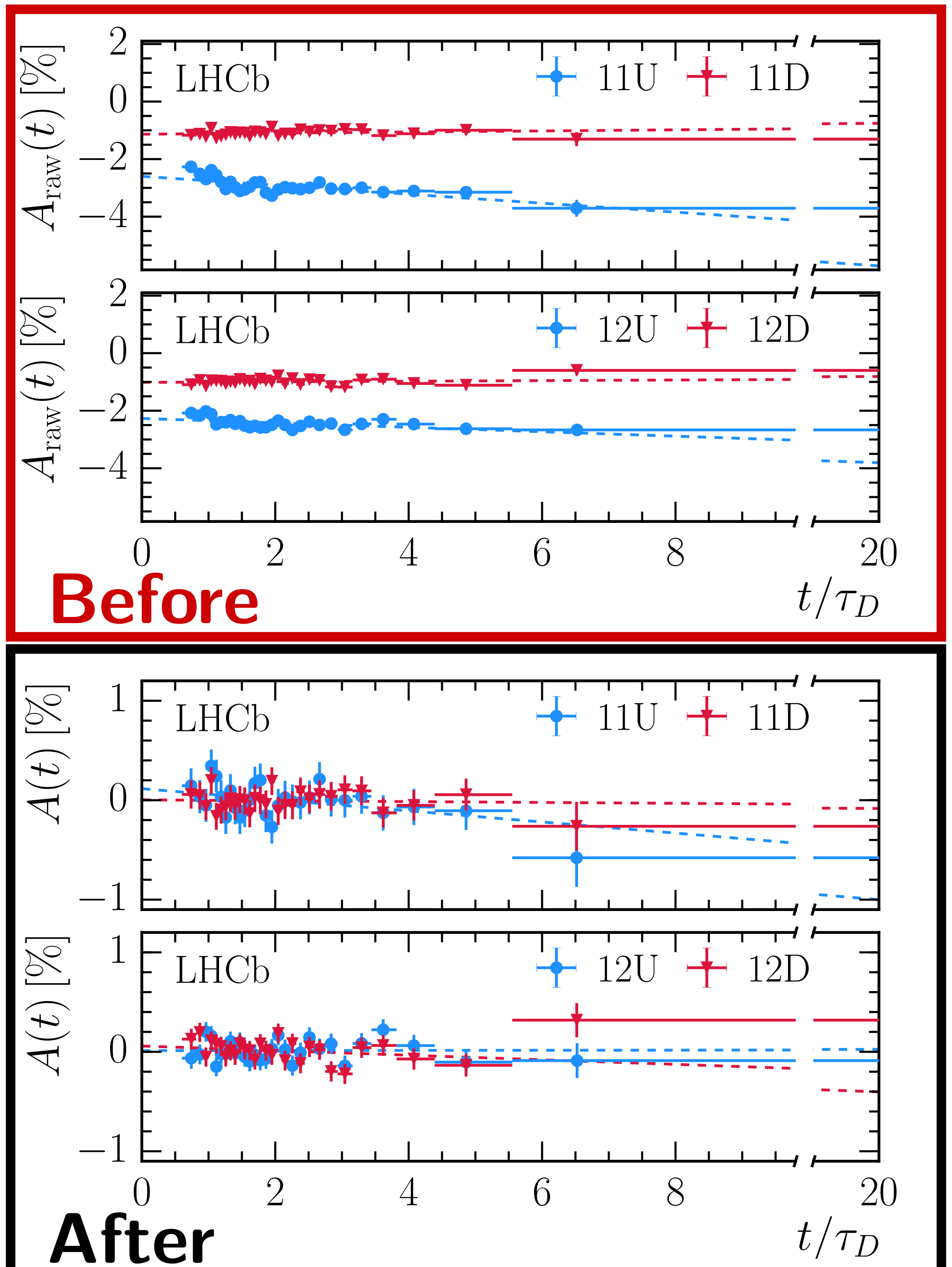


- Each subsample (2 magnet polarity x 2 centre of mass energy) is **independently** reweighted with the ratio

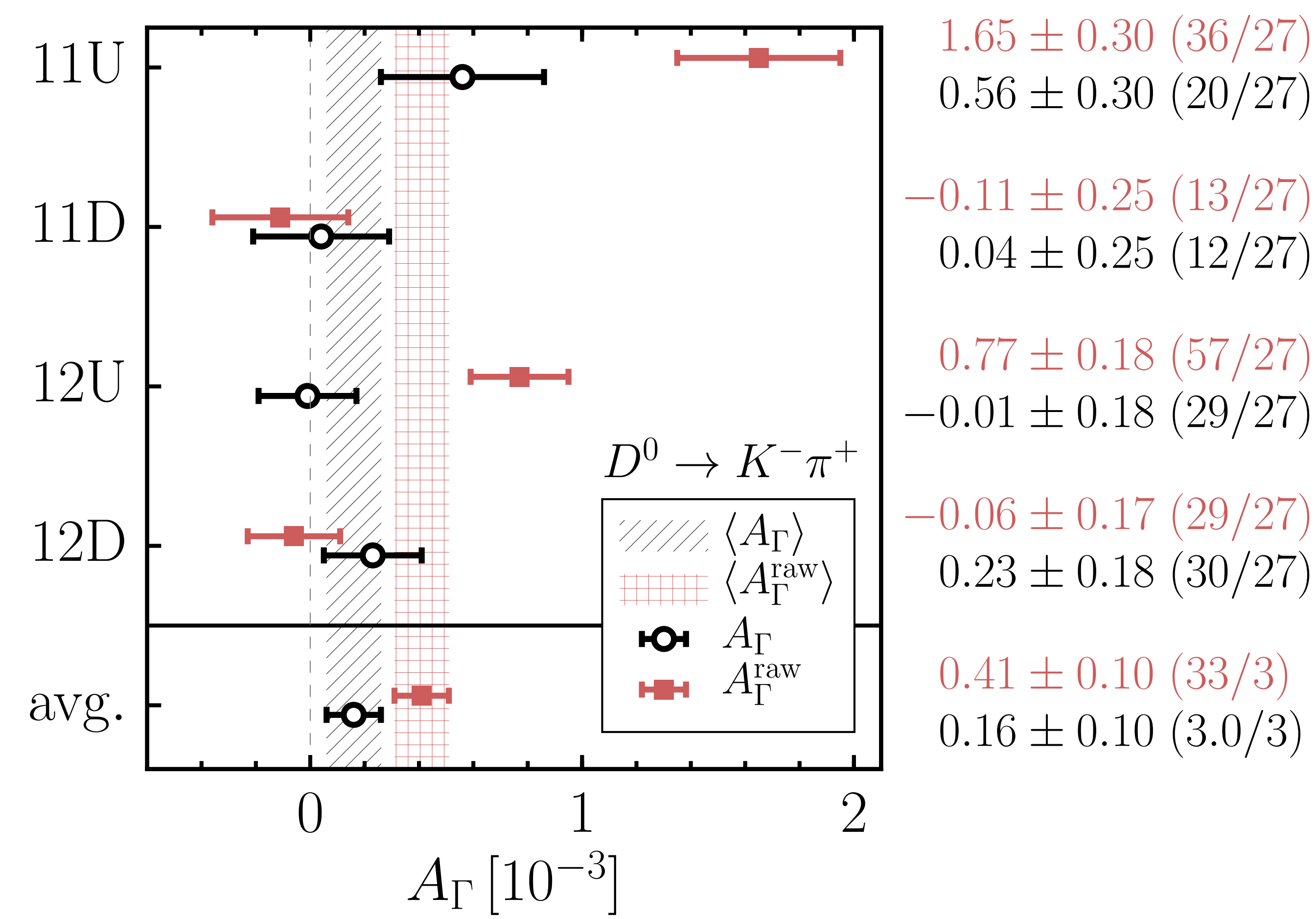
$$\frac{n^+(k,\theta_x,\theta_y)}{n^-(k,-\theta_x,\theta_y)}$$

The devised correction works perfectly

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



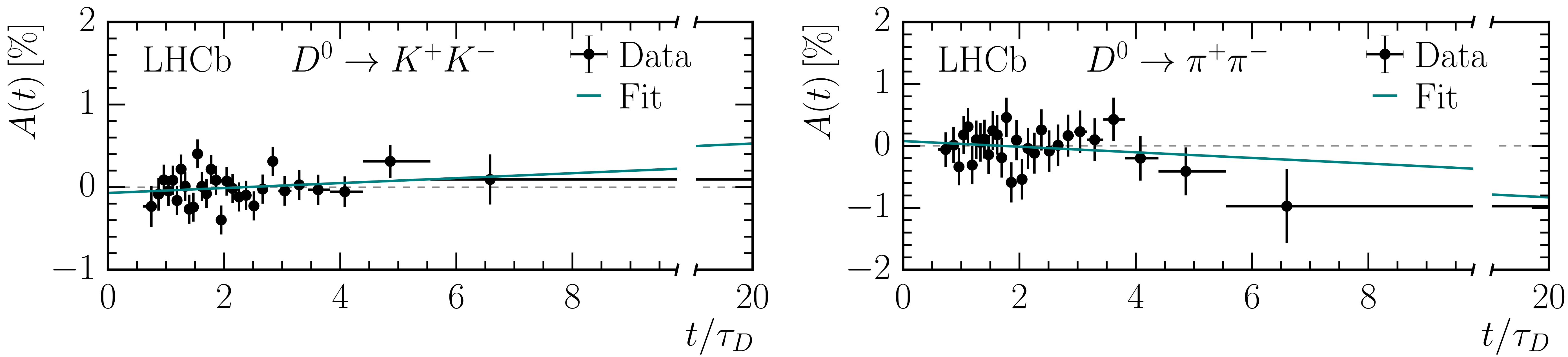
$D^0 \to K^- \pi^+$



- Results **compatible with zero.**
- Results **compatible with each other.**

A_Γ results in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$

[PRL 118, 261803 (2017)]



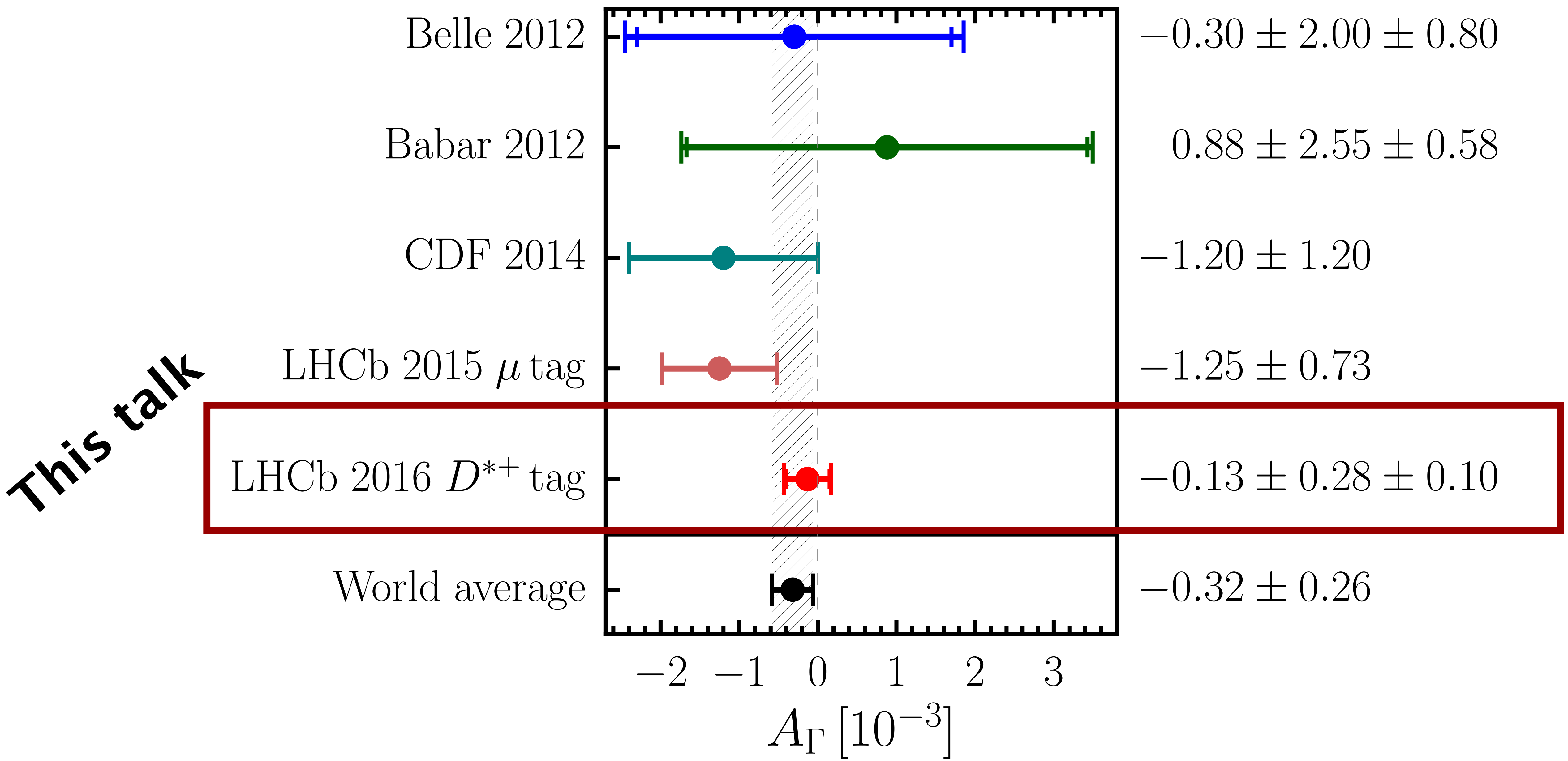
- Same procedure of control sample $D^0 \to K^-\pi^+$

$$A_\Gamma(D^0 \to K^+K^-) = (-0.30 \pm 0.32 \pm 0.10) \times 10^{-3}$$

$$A_\Gamma(D^0 \to \pi^+\pi^-) = (+0.46 \pm 0.58 \pm 0.12) \times 10^{-3}$$

- Main systematic: contribution from secondaries (non–prompt D^*).

The most precise measurement of CP violation in the charm sector [PRL 118, 261803 (2017)]

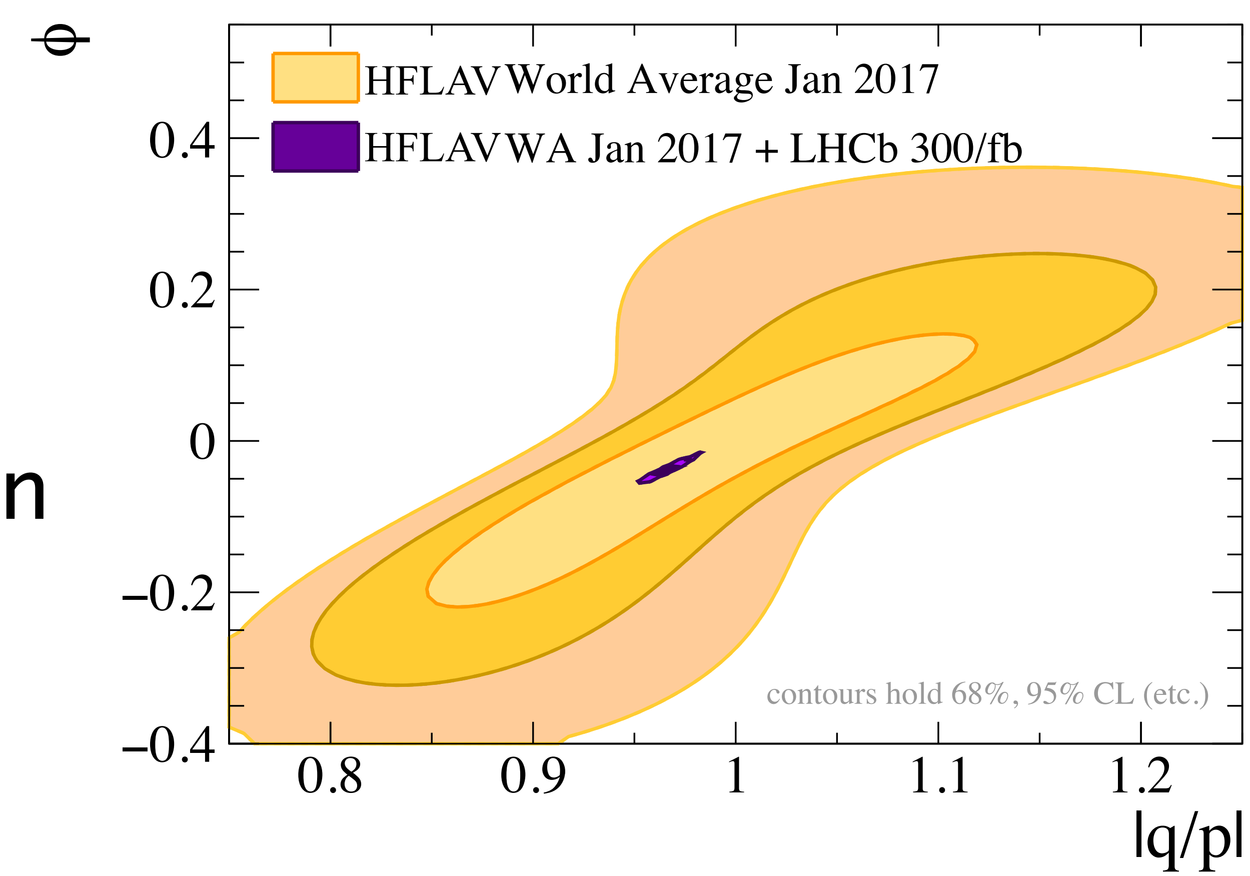


- Yet no CPV observed at $2.6\text{x}10^{-4}$.

LHCb Upgrade and Beyond

- Precision measurements of mixing and CP violation are important tools to **test the SM at energy scales and couplings unaccessible at the energy frontier.**
- Analysis update with Run2 data in progress: already the statistics of the Run1.
- Get ready for the LHCb Upgrade (Run3-4, 50fb^{-1}).
- Phase2 upgrade is under discussion (Run5-..., 300 fb^{-1})

[CERN-LHCC-2017-003]



Thanks

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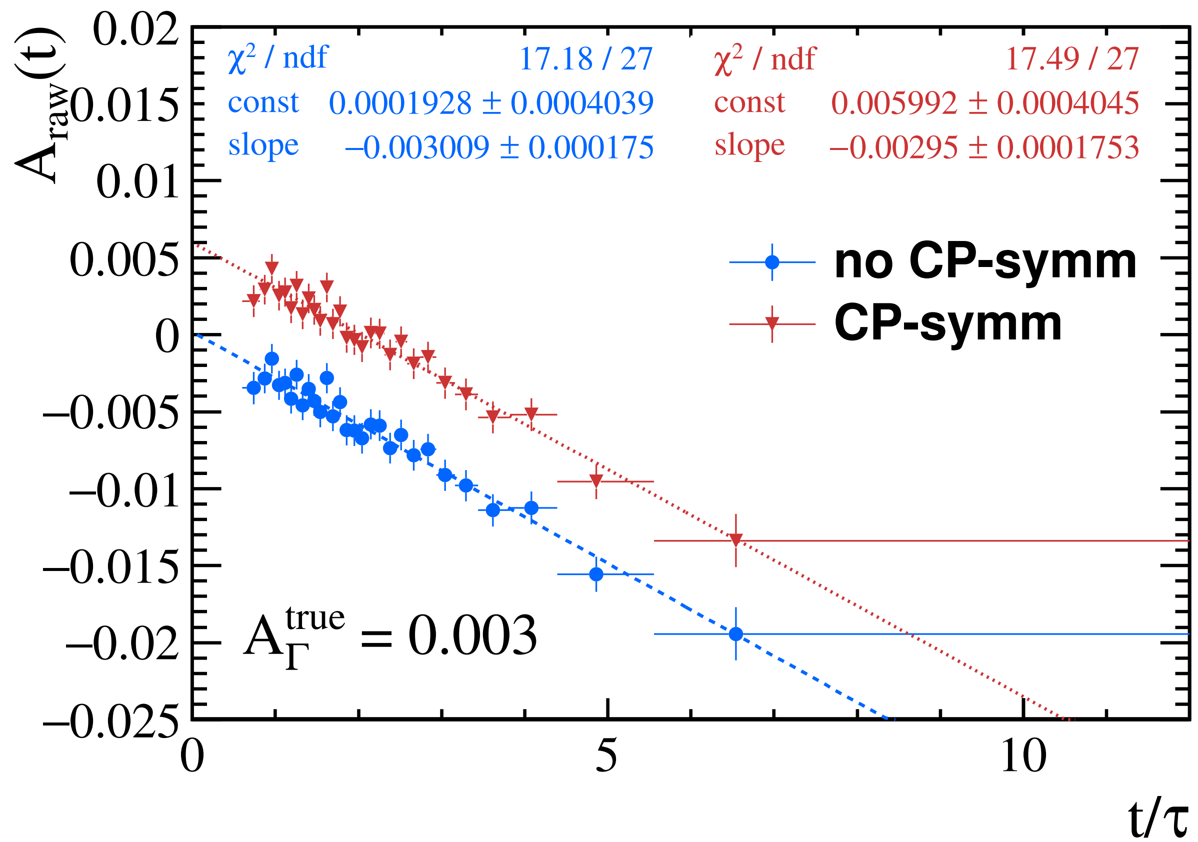
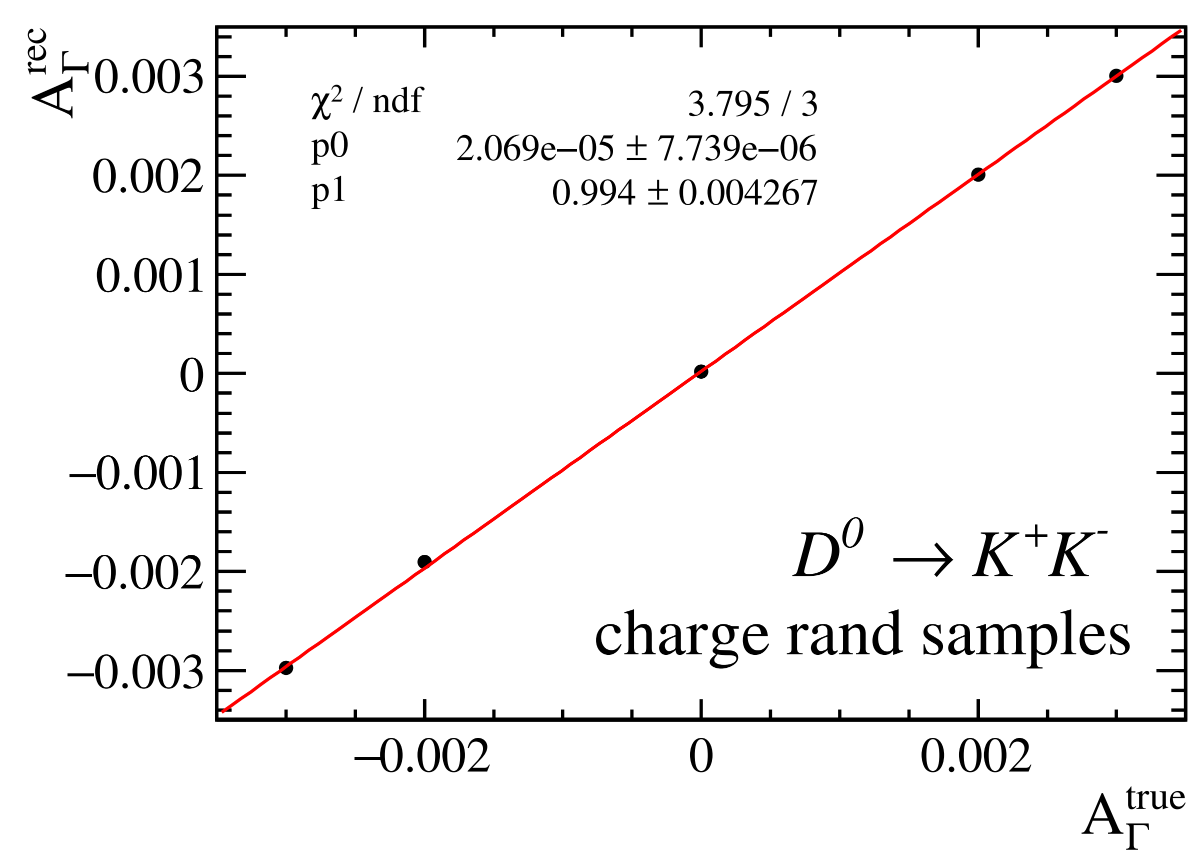
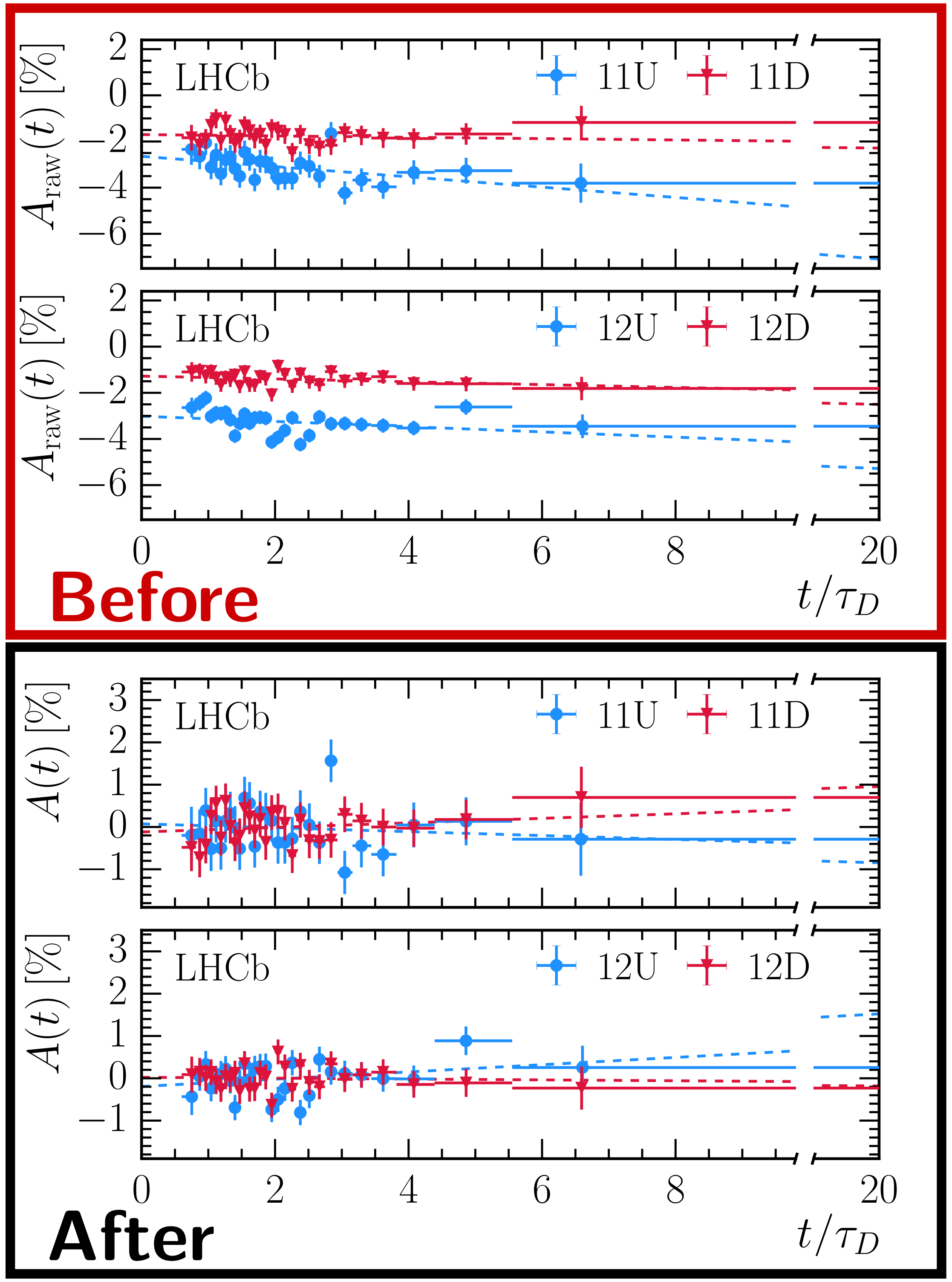
Analysis validation

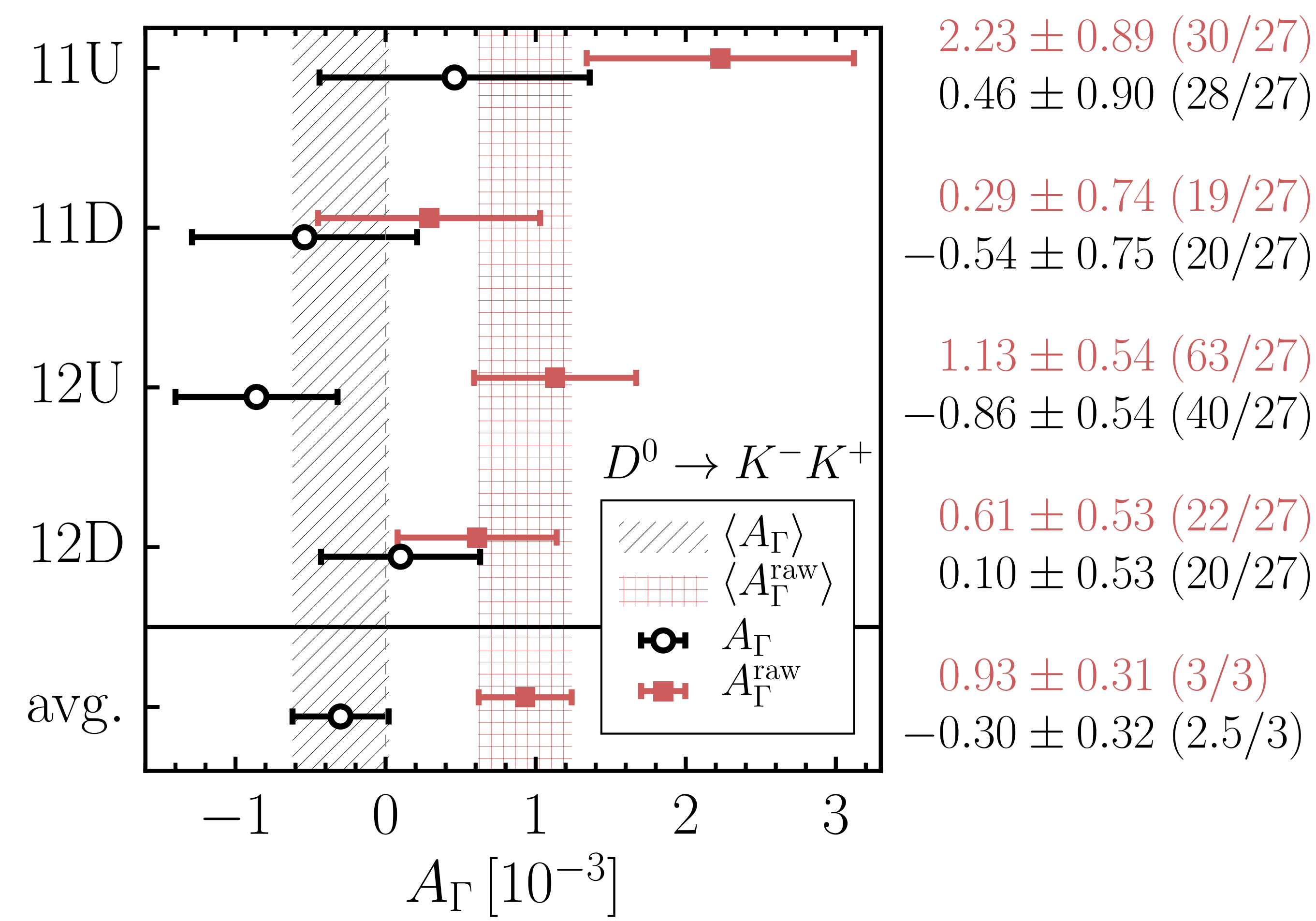
- Several pseudoexperiments have been performed injecting different fake values of A_Γ
- The reconstructed value accurately tracks the input value of A_Γ





$A_\Gamma(D^0 \to K^+K^-)$ results





$A_\Gamma(D^0 \rightarrow \pi^+\pi^-)$ results