# CP violation in charm decays at LHCb

**Giulia Tuci**
**Heidelberg University**

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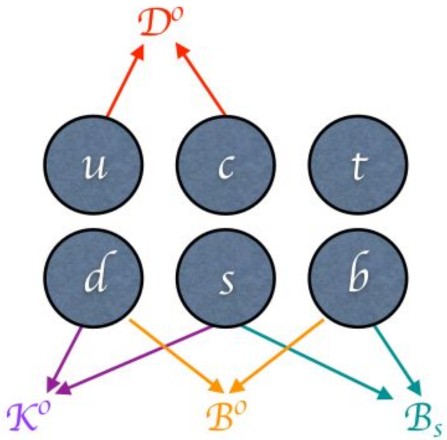
UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386

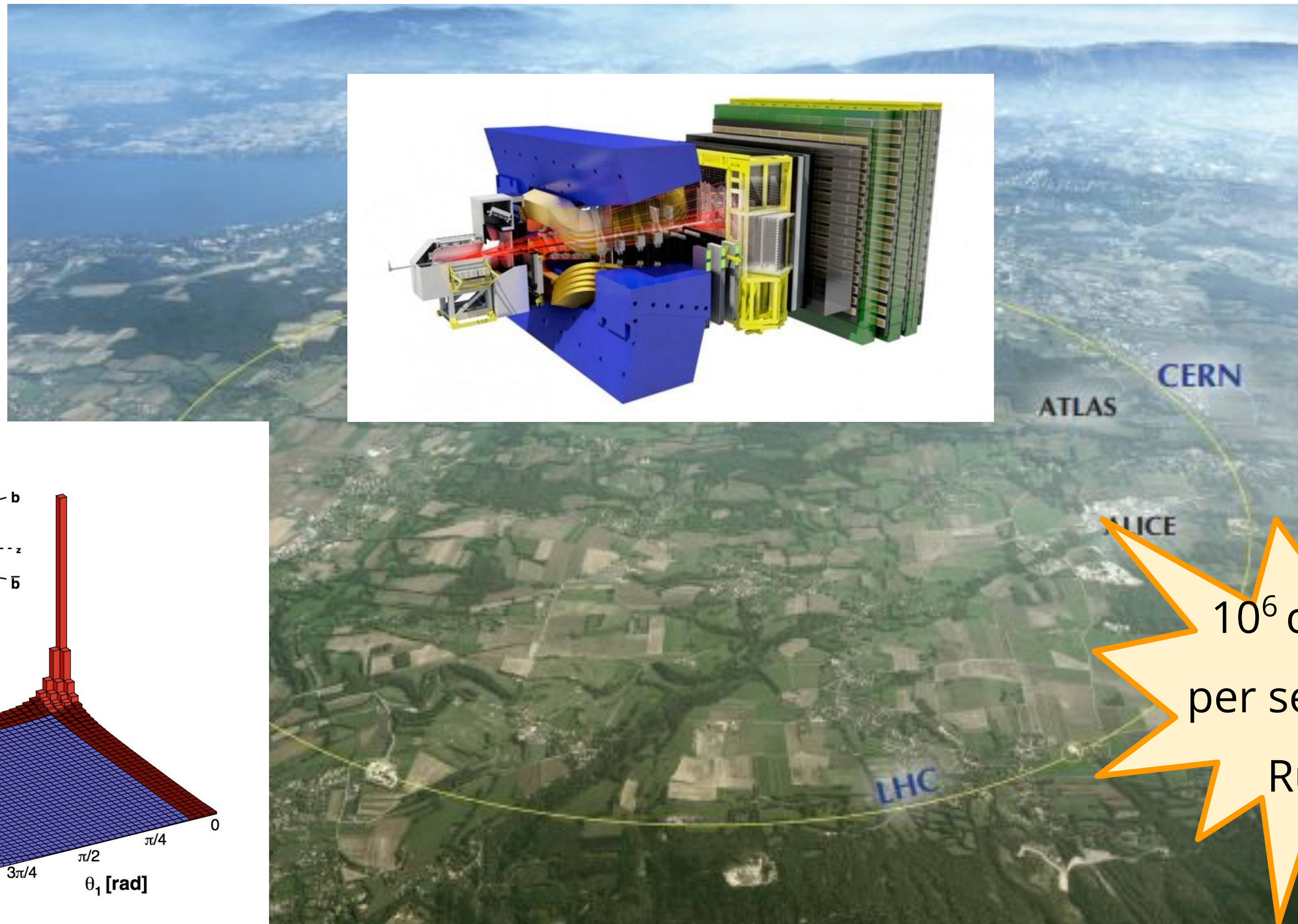
# The charm quark

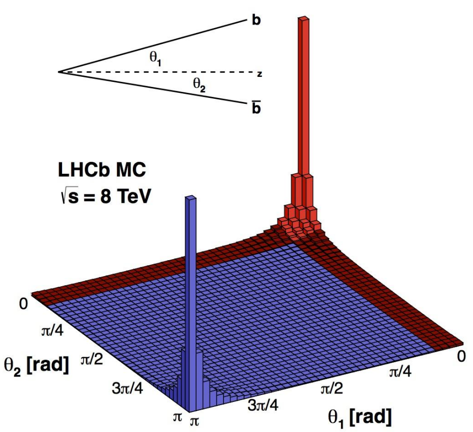
- Charm transitions are a unique portal for obtaining a novel access to flavor dynamics
  - CPV and flavour changing neutral currents extremely suppressed
    $\rightarrow$ CPV expected $\lesssim 10^{-3}$
    $\rightarrow$ powerful probe for new interactions at energy scales $\gg$ colliders' energy
  - Experimentally challenging: smaller effects $\rightarrow$ large statistics and tight control of systematics required



# The LHCb experiment

- **LHCb**: forward spectrometer designed to study *b*- and *c*- hadrons



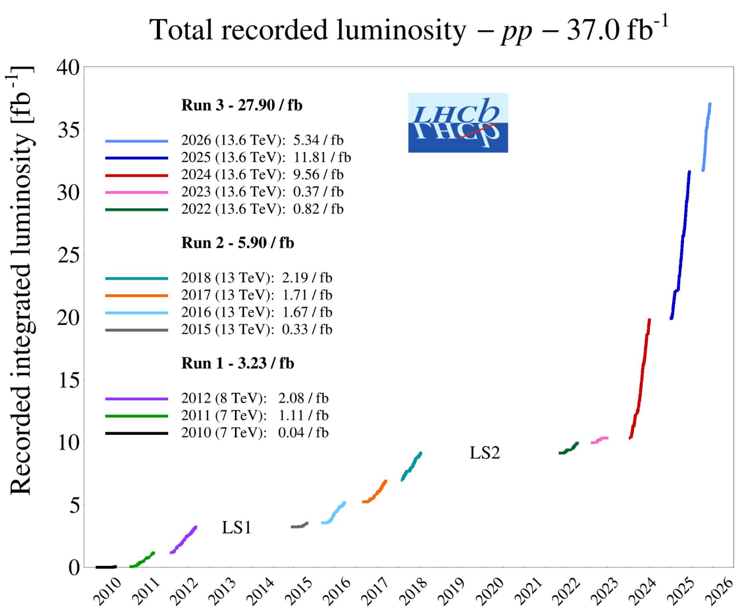

$10^6$ $c\bar{c}$ pairs per second in Run 2

# The need of an upgraded detector

- ❖ LHCb Run 1 and Run 2: huge success!
- ❖ The majority of measurements is statistically limited

  → LHCb Upgrade I: 5x instantaneous luminosity (μ~5.3)

- ❖ Improve physics performance, despite the more challenging environment
  - ➢ New tracking system, improved PID and triggerless readout



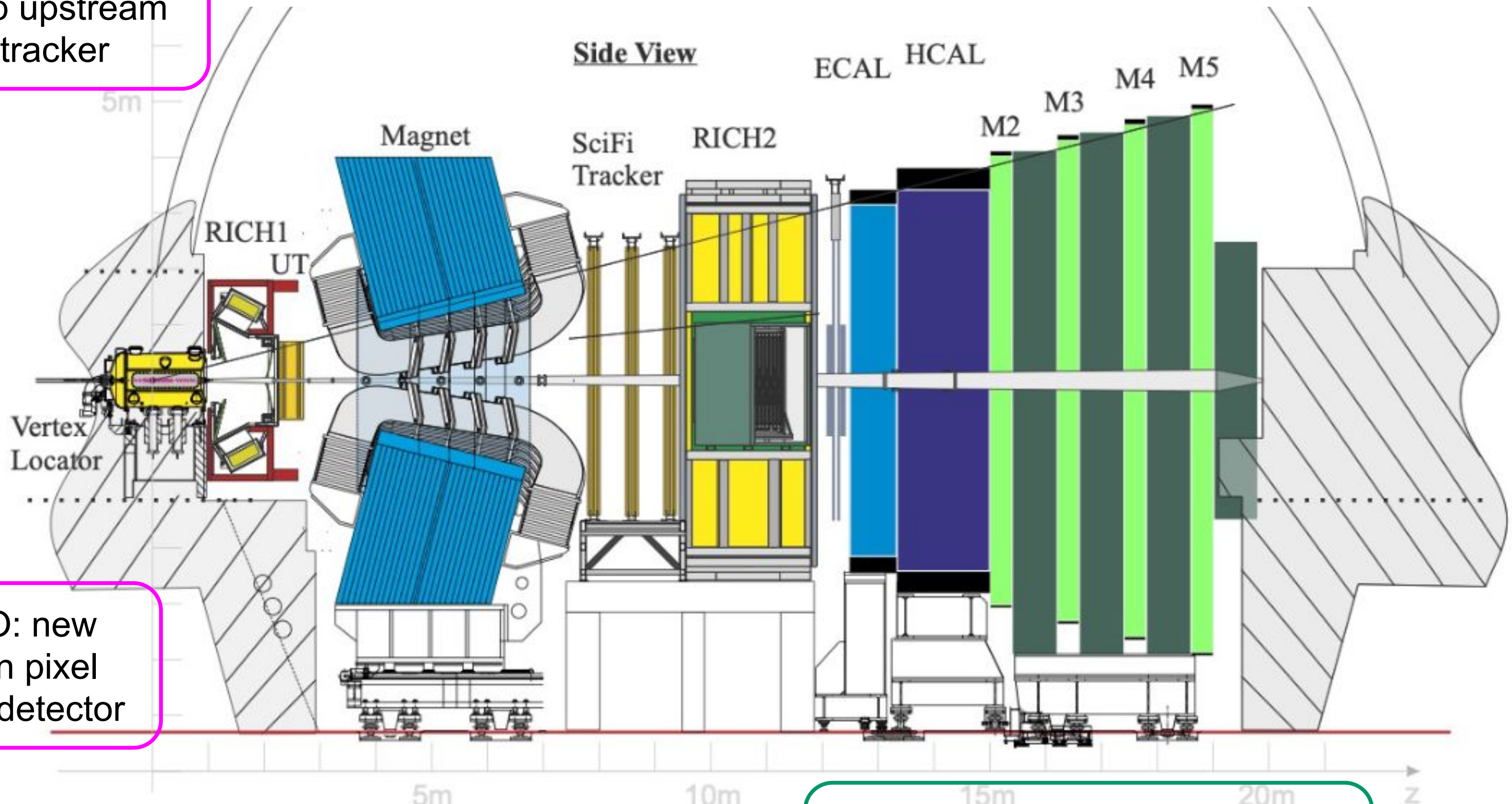
# The upgraded LHCb detector

[JINST 19P05065]

UT: new silicon strip upstream tracker

SciFi: new scintillating fibres tracker

RICH: new mechanics, optics, photodetectors

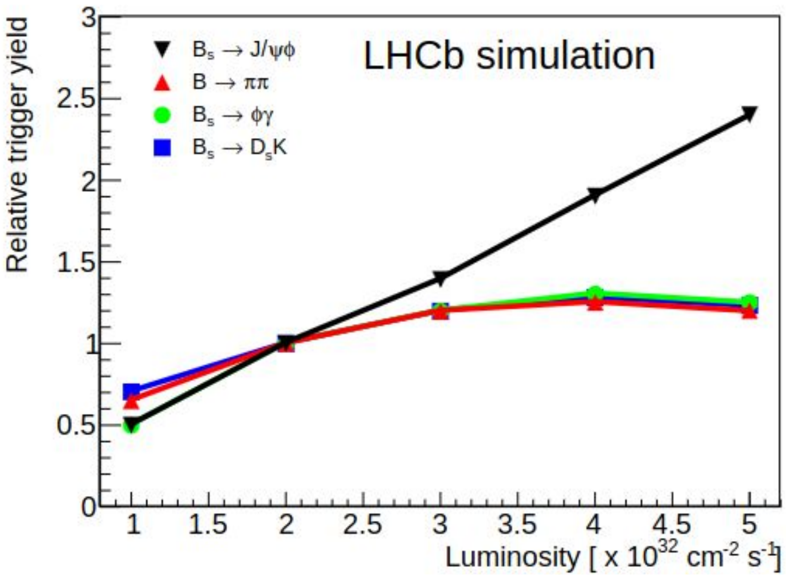



VELO: new silicon pixel vertex detector

New frontend electronics and new DAQ for all sub-detectors!

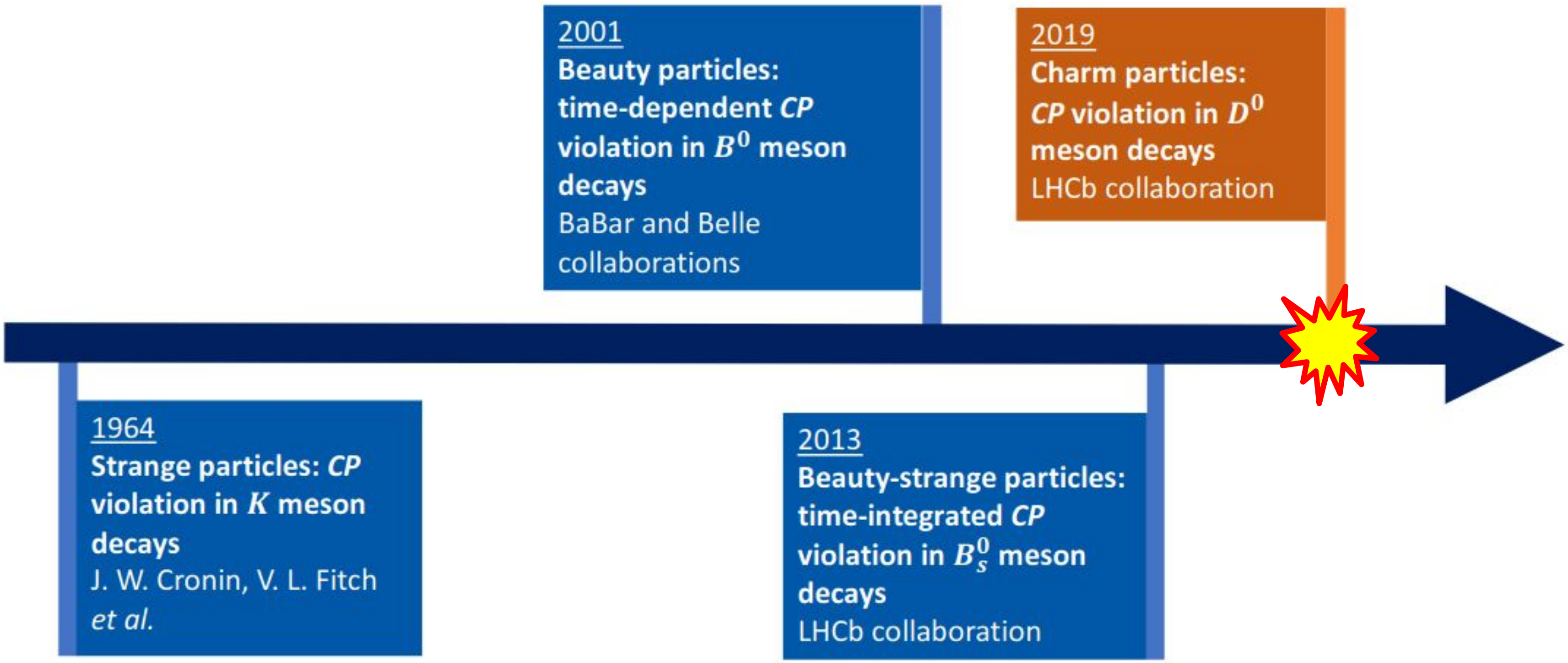
# Trigger system: from Run 1+2 to Run 3

- Trigger strategy in Run 1 + Run 2:
  - Hardware trigger (L0) based on information from calorimeters and muon stations, followed by a software trigger
- Higher instantaneous luminosity in Run 3
  - Information from calorimeters not enough to efficiently select hadronic channels
  - L0 trigger removed → triggerless readout and reconstruction of events at full LHC collision rate



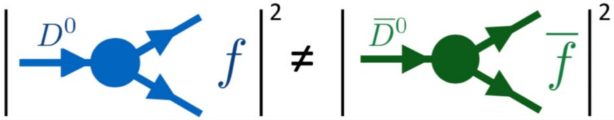

JINST 19P05065

# CPV in charm


2001
Beauty particles:
time-dependent *CP* violation in $B^0$ meson decays
BaBar and Belle collaborations
2019
Charm particles:
*CP* violation in $D^0$ meson decays
LHCb collaboration
1964
Strange particles: *CP* violation in $K$ meson decays
J. W. Cronin, V. L. Fitch *et al.*
2013
Beauty-strange particles:
time-integrated *CP* violation in $B_s^0$ meson decays
LHCb collaboration

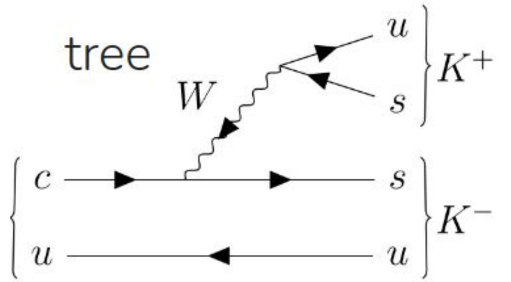
# Types of CPV

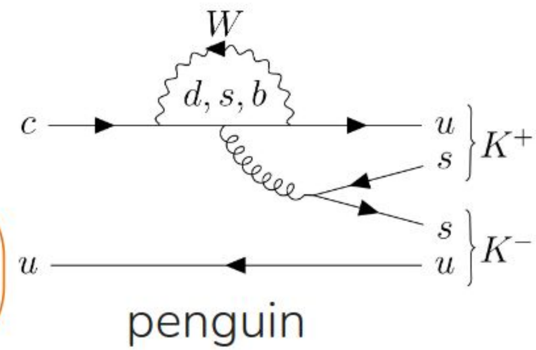
- <u>CPV in the decay</u>




$$\mathcal{A}(M \to f) = |a_1| e^{i(\delta_1 + \phi_1)} + |a_2| e^{i(\delta_2 + \phi_2)}$$

$$\mathcal{A}(\overline{M} \to \overline{f}) = |a_1| e^{i(\delta_1 - \phi_1)} + |a_2| e^{i(\delta_2 - \phi_2)}$$




$$a_f^d = \frac{|\mathcal{A}(M \to f)|^2 - |\mathcal{A}(\overline{M} \to \overline{f})|^2}{|\mathcal{A}(M \to f)|^2 + |\mathcal{A}(\overline{M} \to \overline{f})|^2} \propto \sin(\phi_2 - \phi_1) \sin(\delta_2 - \delta_1)$$

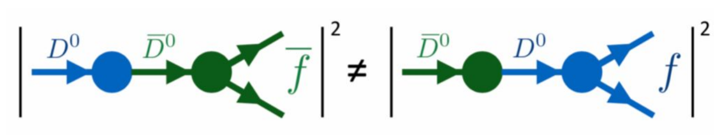
Need at least two interfering amplitudes with different weak and strong phases

# Types of CPV (2)

- Weak interactions violate flavour conservation → flavoured neutral meson oscillate:

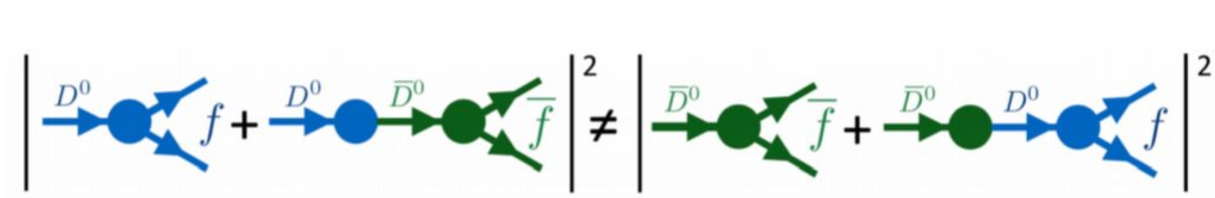
$$i\frac{\partial}{\partial t}\begin{pmatrix} M^0(t) \\ \overline{M}^0(t) \end{pmatrix} = \left[\begin{pmatrix} M & M_{12} \\ M_{12}^* & M \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma & \Gamma_{12} \\ \Gamma_{12}^* & \Gamma \end{pmatrix}\right]\begin{pmatrix} M^0(t) \\ \overline{M}^0(t) \end{pmatrix}$$

- <u>CPV in mixing</u>



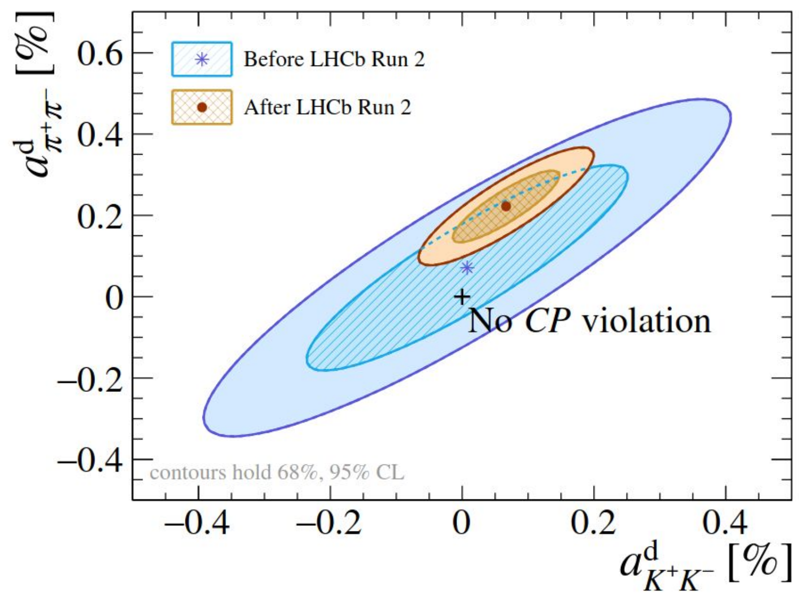
$$\arg\left(\frac{M_{12}}{\Gamma_{12}}\right) = \phi_2^M - \phi_2^\Gamma \neq 0$$

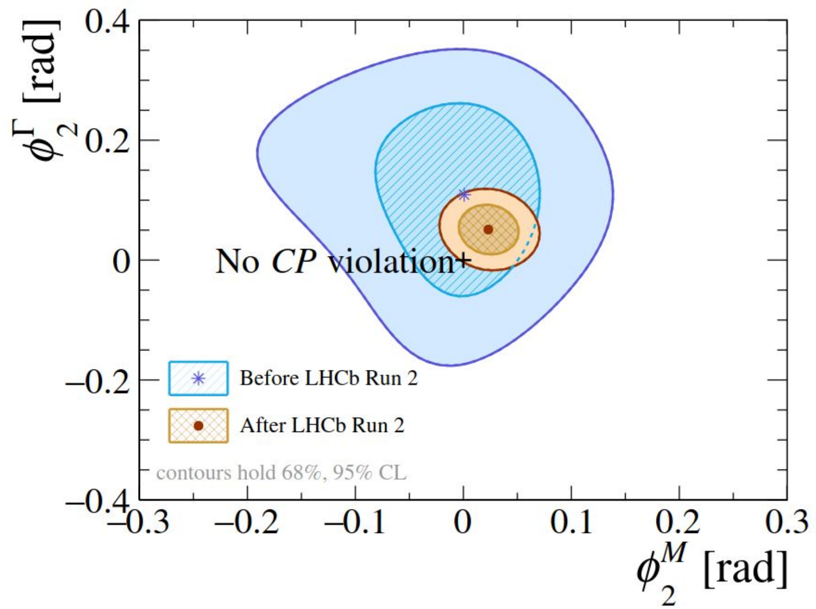
- <u>CPV in the interference between decay and mixing</u>



# CPV in charm: state of the art

- **CPV in charm observed by LHCb in 2019** PRL122. 211803
  - $\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-15.4 \pm 2.9) \times 10^{-4}$ (5.3σ)
- Then, evidence that this is mainly coming from $D^0 \to \pi^+\pi^-$ decays
  - $a^d_{\pi\pi} = (23.2 \pm 5.2) \times 10^{-4}$ (3.8σ) PRL131.091802



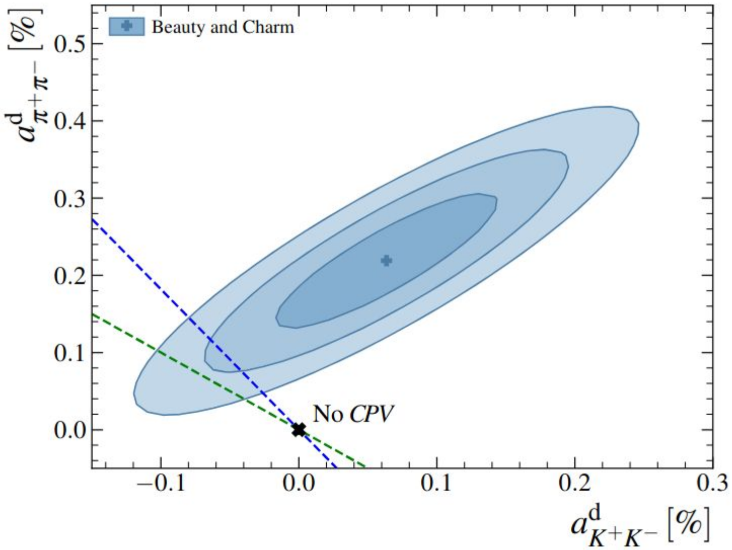




charm-fitter

# CPV in charm: state of the art

- Is U-spin a good symmetry?

LHCb-CONF-2024-004



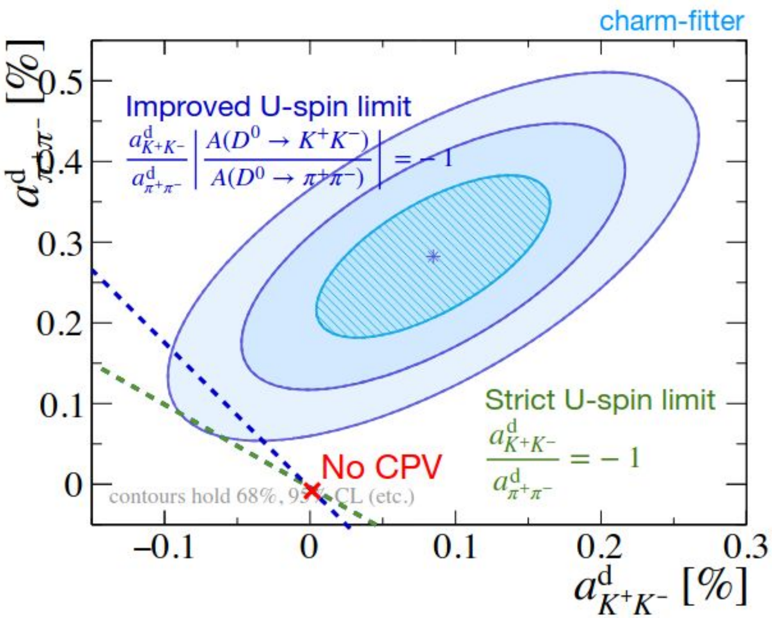

Strict U-spin limit: $\dfrac{a^{d}_{K^+K^-}}{a^{d}_{\pi^+\pi^-}} = -1$

Improved U-spin limit: $\dfrac{a^{d}_{K^+K^-}}{a^{d}_{\pi^+\pi^-}} \left| \dfrac{A(D^0 \to K^+K^-)}{A(D^0 \to \pi^+\pi^-)} \right| = -1$

- Measured CPV → $\left|\dfrac{P}{T}\right| \sin(\delta_P - \delta_T) = O(1)$
  - SM or not? Theoretical interpretation is debated
- More data → more precision → clarify physics picture

# How do we determine $a_d$ from $A^{CP}$ measurements?

see also T.Pajero and K.Vos slides @ CKM 2025




$$a^d_{K^+K^-} = (\ 8.5 \pm 5.3) \times 10^{-4}$$
$$a^d_{\pi^+\pi^-} = (28.2 \pm 6.6) \times 10^{-4}$$

Kagan Silvestrini 2001.07207

$$x_{12} \equiv \frac{2|M_{12}|}{\Gamma}, \quad y_{12} \equiv \frac{|\Gamma_{12}|}{\Gamma}$$

$$\phi_f^M \equiv \arg\left(M_{12}\frac{A_f}{\bar{A}_f}\right) \qquad \phi_f^\Gamma \equiv \arg\left(\Gamma_{12}\frac{A_f}{\bar{A}_f}\right)$$

$$A^f_{CP}(t) \approx a^d_f + \Delta Y_f \frac{t}{\tau_{D^0}}$$

arg(P/T)

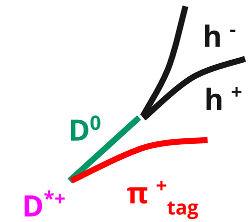
$$\Delta Y_f \approx -x_{12}\sin\phi_2^M + y_{12}a^d_f + x_{12}a^d_f\cot\delta_f$$

# How can we measure CPV in charm?

Very small mixing

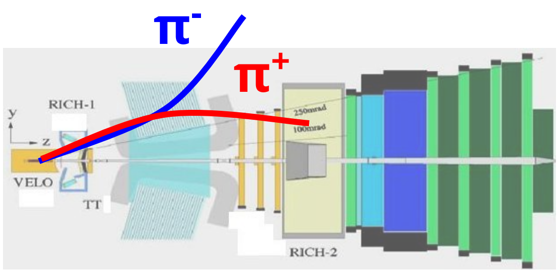
$$A_{CP}(t) = \frac{\Gamma(D^0(t)\to f) - \Gamma(\overline{D}^0(t)\to f)}{\Gamma(D^0(t)\to f) + \Gamma(\overline{D}^0(t)\to f)} \approx a^f_{\text{dir}} + \Delta Y_f \frac{t}{\tau_D}$$

$$\mathcal{A}^{raw} \equiv \frac{N_{D^0} - N_{\bar{D}^0}}{N_{D^0} + N_{\bar{D}^0}}$$




$$A_{\text{raw}}(f,t) = A_{CP}(f,t) + A_D(\pi_s^+, p(t)) + A_P(D^{*+}, p(t))$$

Production asymmetry: initial state pp is not CP symmetric

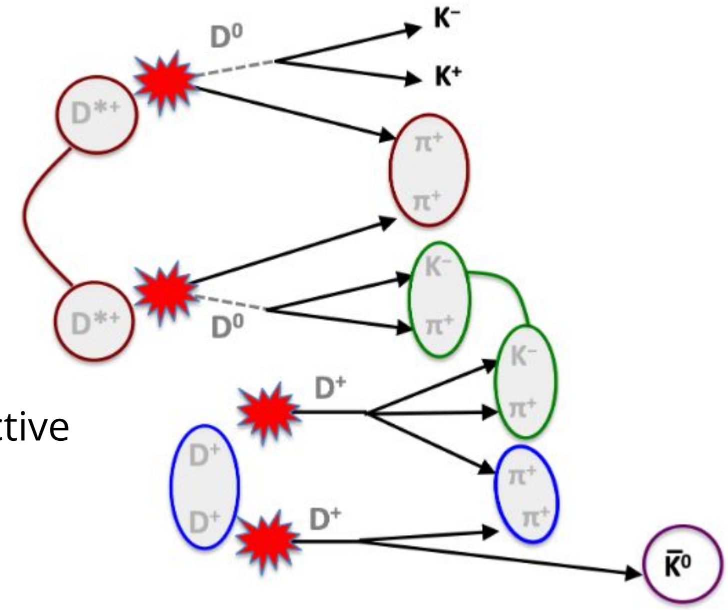



Asymmetric detector acceptance + material interaction different for particles/antiparticles

# From $\Delta A^{CP}$ to $A^{CP}$ ($D^0 \to K^+K^-$)

PRL131.091802

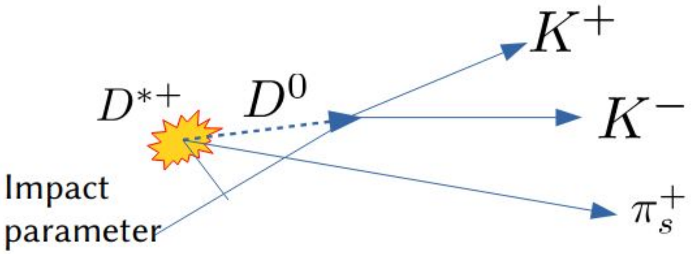
- New in Run 2: two independent ways to cancel nuisance asymmetries
  - $D^0 \to K^-\pi^+$, $D^+ \to K^-\pi^+\pi^+$, $D^+ \to \overline{K}^0\pi^+$
  - $D^0 \to K^-\pi^+$, $D_s^+ \to \Phi\pi^+$, $D_s^+ \to \overline{K}^0K^+$
  - ~40% improvement of $\sigma_{stat}$



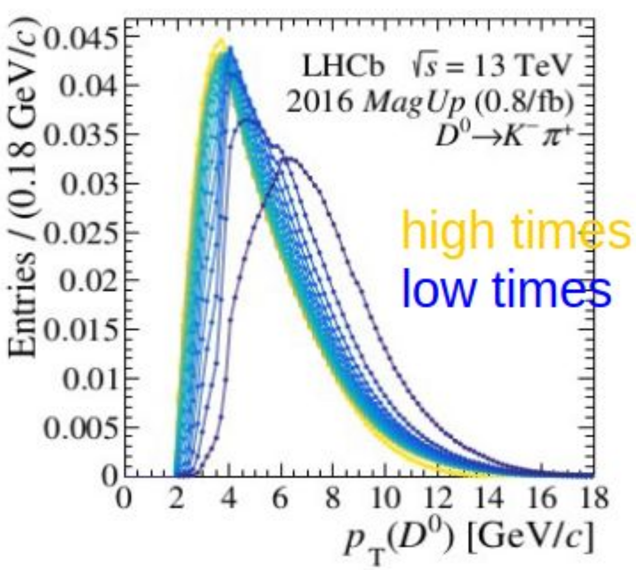

- Main systematic uncertainties
  - Kinematic reweighting → reduces also effective yield
  - Secondary contamination pp→ $H^b \to H^c$ : interplay between suppression and understanding of residual effect
  - Knowledge of detector material → need accurate model in simulation and/or new data-driven approaches

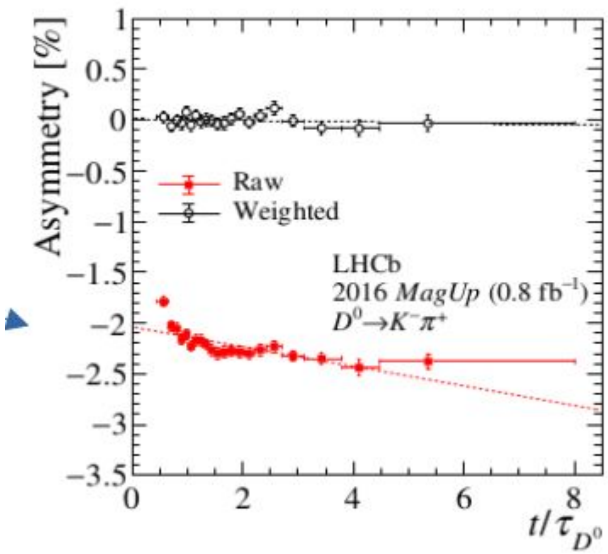
# Detection asymmetries

PRD104072010




- Correlation between decay-time and momentum induced by trigger requirements
  - → fakes time-dependent CPV
- Weighting of $D^0$ and anti-$D^0$, and $\pi^+$ and $\pi^-$ momentum distributions to equalise kinematics
  - Procedure validate with control mode: Cabibbo-favoured $D^0 \to K^-\pi^+$



# First LHCb results in Run 3

- “Measurements of charmed meson and antimeson production asymmetries at 13.6 TeV” (data collected in 2022 and 2023) JHEP10(2025)050

- “Measurement of CP asymmetry in $D^0 \to K_S^0 K_S^0$ decays with the upgraded LHCb detector” (data collected in 2024) JHEP02(2026)253

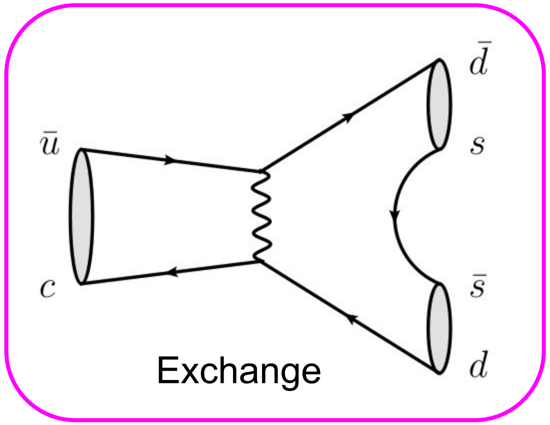
# The $D^0 \to K_S^0 K_S^0$ decay channel

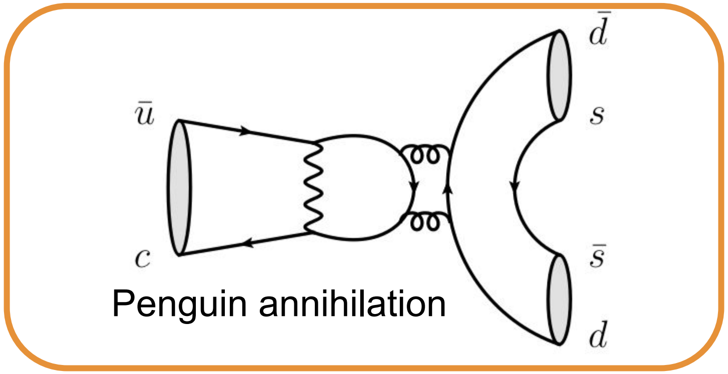
- In $D^0 \to K_S^0 K_S^0$ decay channel $A_{CP}$ could be as large as ~1% PRD 92 (2015) 054036

$$\frac{|\mathcal{A}|^2 - |\bar{\mathcal{A}}|^2}{|\mathcal{A}|^2 + |\bar{\mathcal{A}}|^2} = Im\frac{\lambda_b}{(\lambda_s - \lambda_d)} Im\frac{A_b}{A_{sd}}$$

$$\lambda_q \equiv V_{cq}^* V_{uq}$$

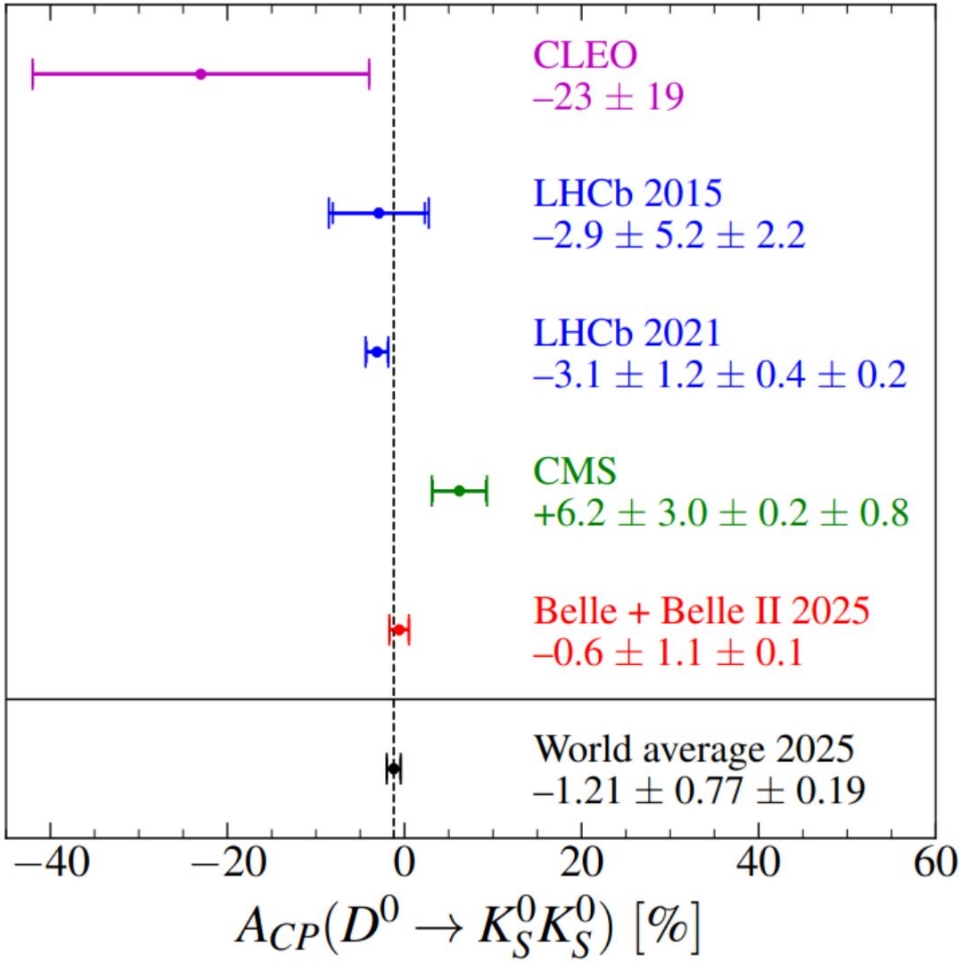
$(\lambda_s - \lambda_d)$: ~$10^{-3}$




- Conversely, some theory fits to data constrain the exchange contribution and predict small $A_{CP}(K_S^0 K_S^0) \simeq 0.35 \cdot A_{CP}(\pi^+\pi^-) = O(10^{-4})$ PRD 99(2019)113001

# $D^0 \to K_S^0 K_S^0$ : experimental status




CLEO: PRD 63 071101

LHCb Run 1: JHEP 10(2015)055

LHCb Run 2: PRD 104 L031102

CMS: EPJC s10052-024-13244

Belle + Belle II: PRD 112 012017(2025)

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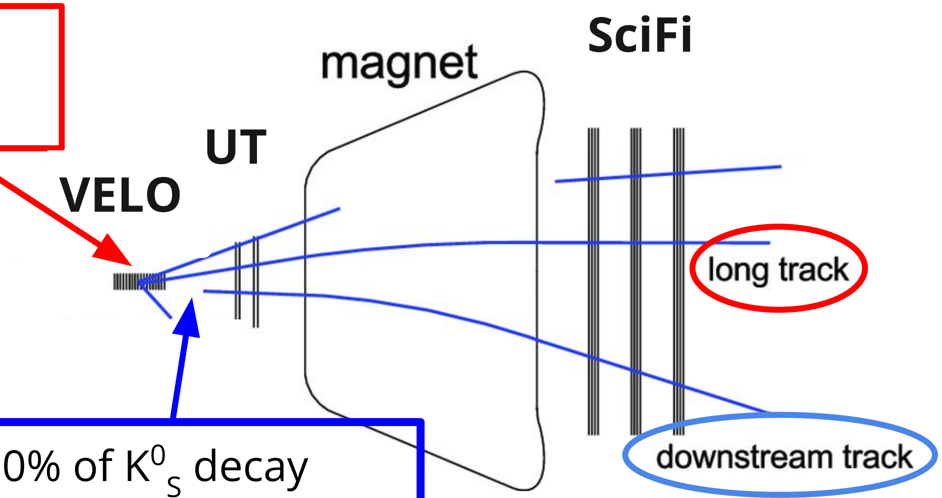
# $D^0 \rightarrow K^0_S K^0_S$ @ LHCb

~ 30% of $K^0_S$ decay inside the VELO



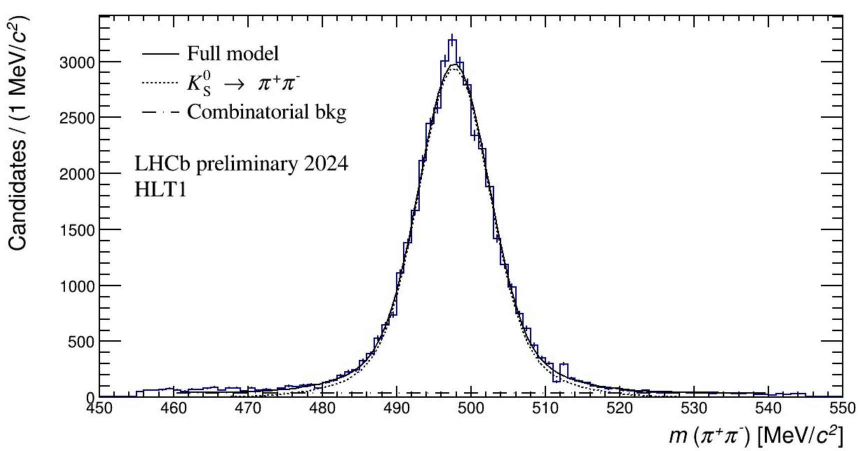

~ 60% of $K^0_S$ decay between VELO and UT

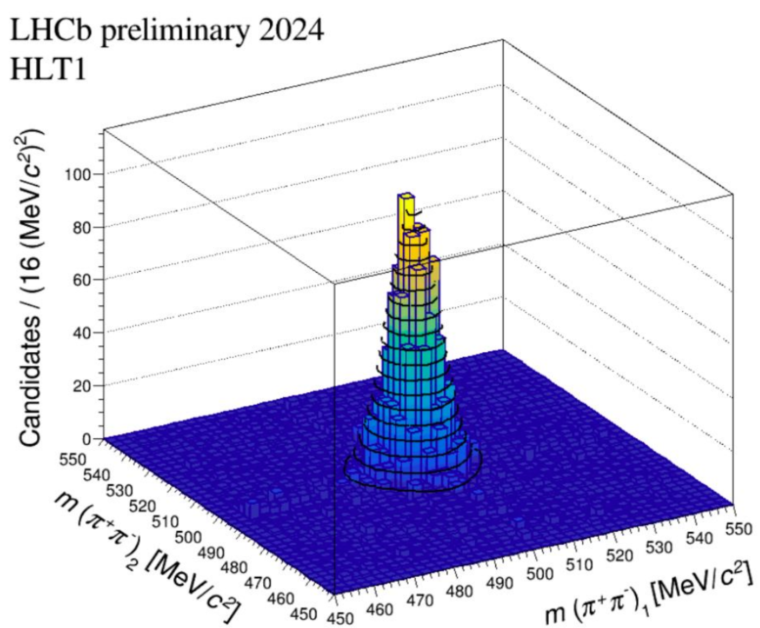
- ❖ $K_S^0$ are difficult to select at trigger level
  - ➢ No downstream tracking at HLT1 (in Run1, Run 2 and the majority of 2024 data-taking)
  - ➢ Different topology w.r.t. b- and c- hadrons even when they decay inside VELO acceptance

# Selecting $K_S^0$ at the first trigger level

LHCb-FIGURE-2024-013

- Software trigger → flexibility in design selections
  - $K_S^0$ candidates reconstructed directly at the first level of the trigger!
  - Dedicated selections to collect single $K_S^0$ and pairs of $K_S^0$ → increase efficiency in selecting decays like $D^0 \to K_S^0 K_S^0$
  - No other LHC experiment does this

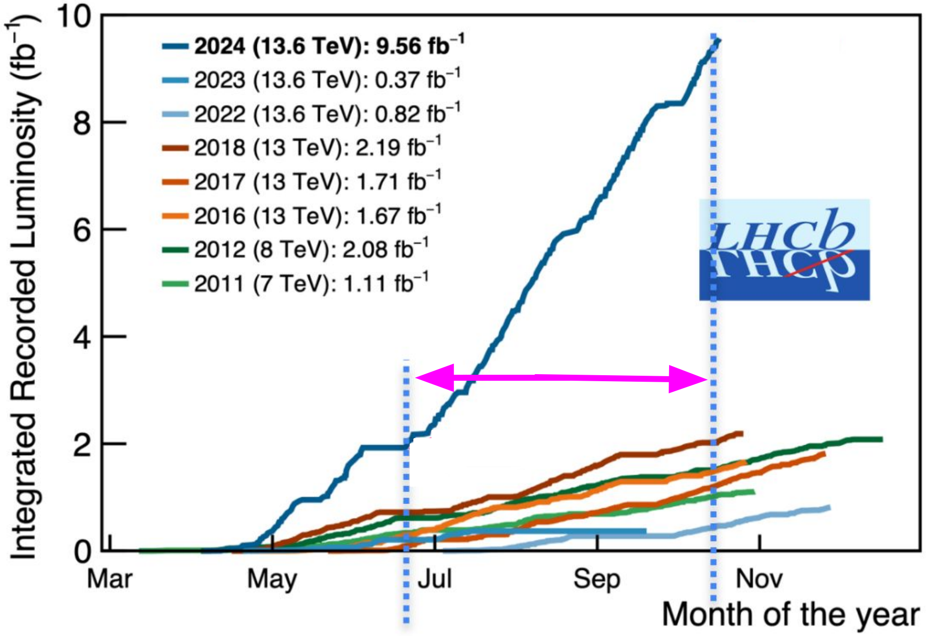


# Dataset

- ❖ Sample used here is 6.2 $fb^{-1}$ of best quality, final trigger configuration, design luminosity (or close to it)
- ❖ Split into 8 subsamples by running conditions
  - ➢ Each subsample analyzed separately

| Data block | $\int \mathcal{L}dt$ [$fb^{-1}$] |
|---|---|
| A | 0.7 |
| B | 0.7 |
| C | 0.6 |
| D | 1.1 |
| E | 1.1 |
| F | 0.9 |
| G | 0.7 |
| H | 0.4 |
| Total | 6.2 |



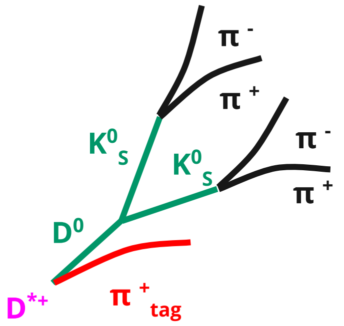
# Methodology

- Time-integrated measurement. Quantity to be measured:

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

- Experimentally

$$\mathcal{A}^{raw} \equiv \frac{N_{D^0} - N_{\bar{D}^0}}{N_{D^0} + N_{\bar{D}^0}}$$




- $D^{*+} \to D^0\pi^+$ decay used to tag $D^0$

Production asymmetry: initial state pp is not CP symmetric

$$N(D^0 \to K^0_S K^0_S) \propto \sigma(D^{*+})\,\epsilon(\pi^+)\,\Gamma(D^0 \to K^0_S K^0_S)$$

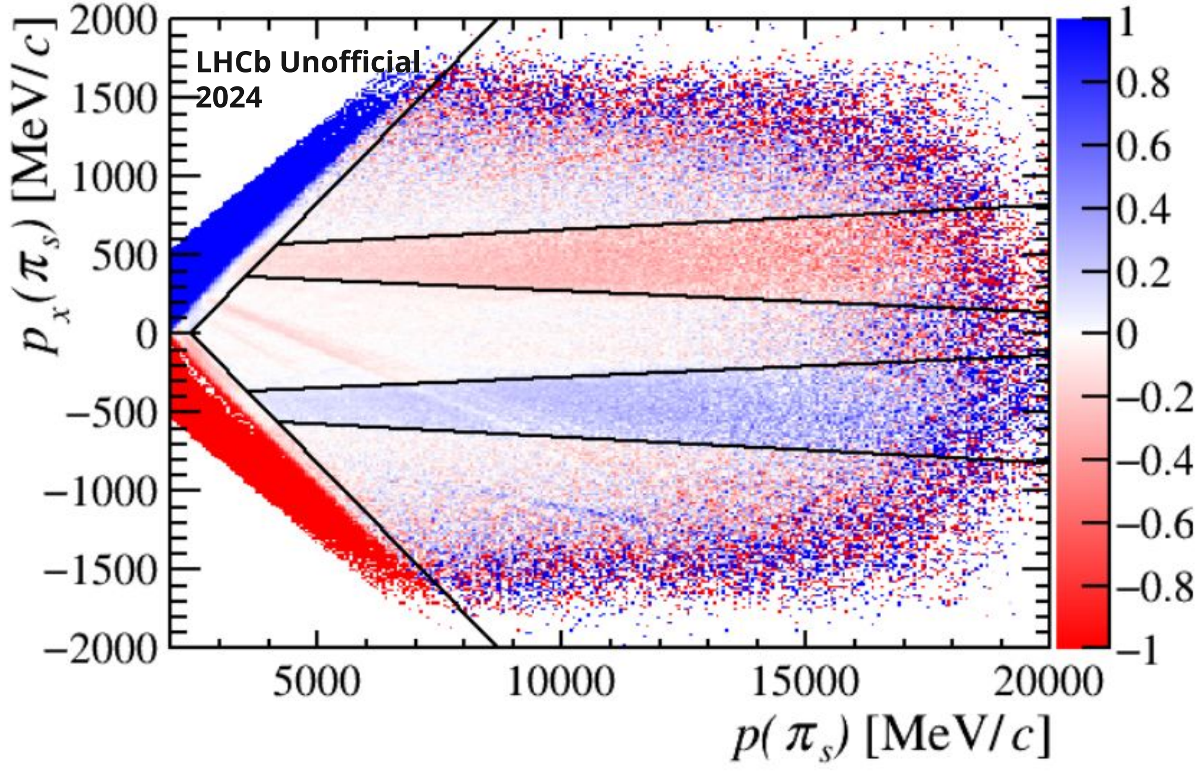
$$\neq \qquad \neq$$

$$N(\bar{D}^0 \to K^0_S K^0_S) \propto \sigma(D^{*-})\,\epsilon(\pi^-)\,\Gamma(\bar{D}^0 \to K^0_S K^0_S)$$

Asymmetric detector acceptance + material interaction different for particles/antiparticles

# Methodology (2)

- $D^0 \to K_S^0\pi\pi$ ($D^*$-tagged) is used as a calibration channel
  - Same final state particles as signal (5 pions)
  - Same HLT1 trigger as signal ($K_S^0$ trigger) → best possible calibration of spurious asymmetries



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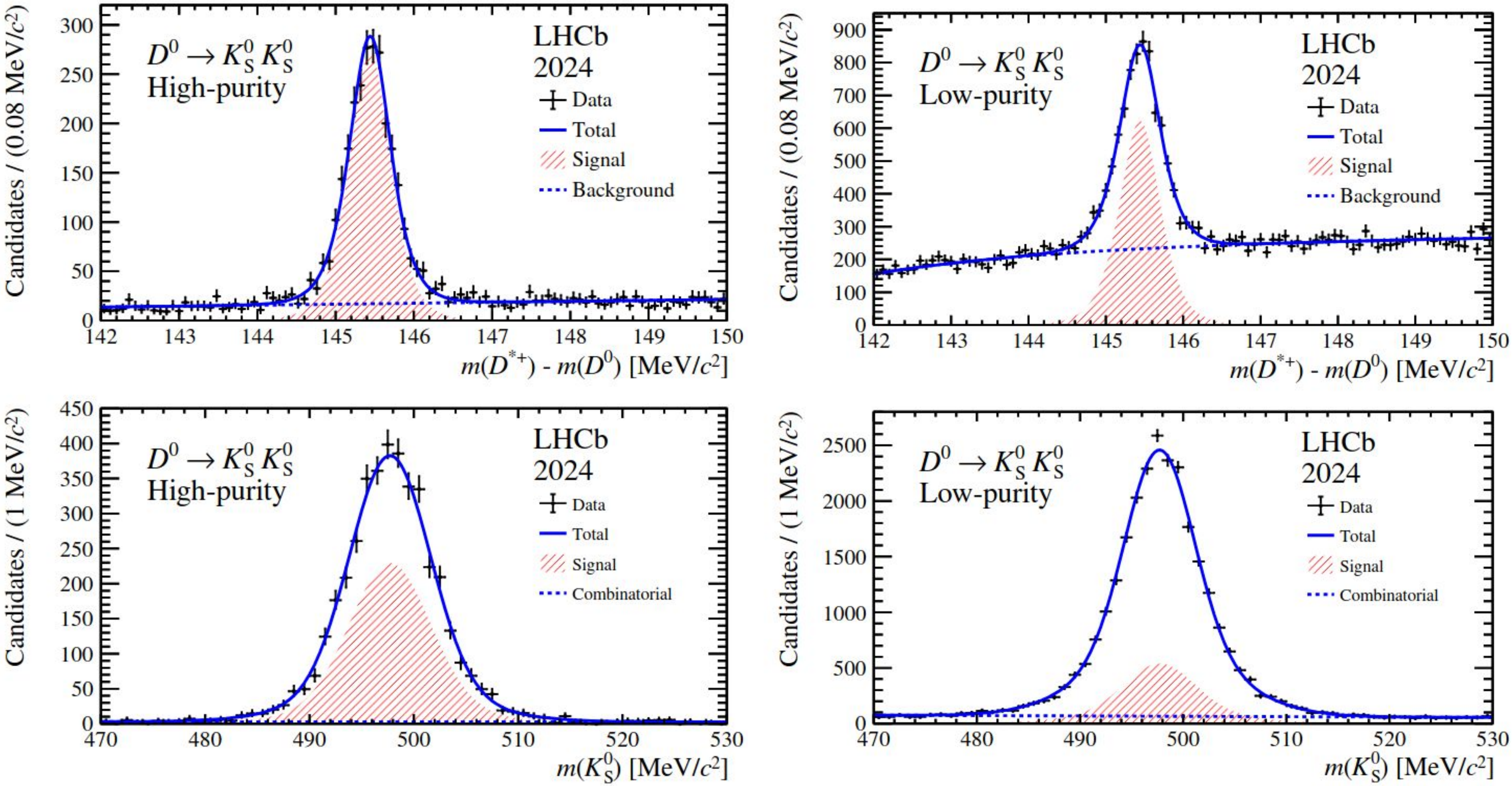
- Yields extracted via a multidimensional fit to $\Delta m = m(D^{*+}) - m(D^0)$ and the two $m(K^0_S)$

- Restrict to "easiest" category of candidates for faster result
  - Only $K_S^0$ decaying inside VELO
  - This will be revisited for the final Run 3 result with full data sample

# Mass distributions

❖ Two bins with different purity defined according to a MVA classifier

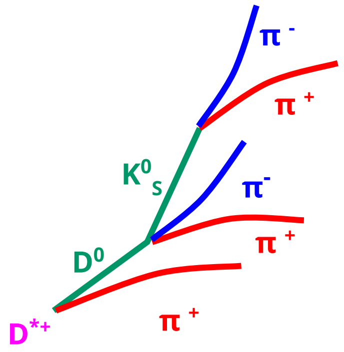


# Yields

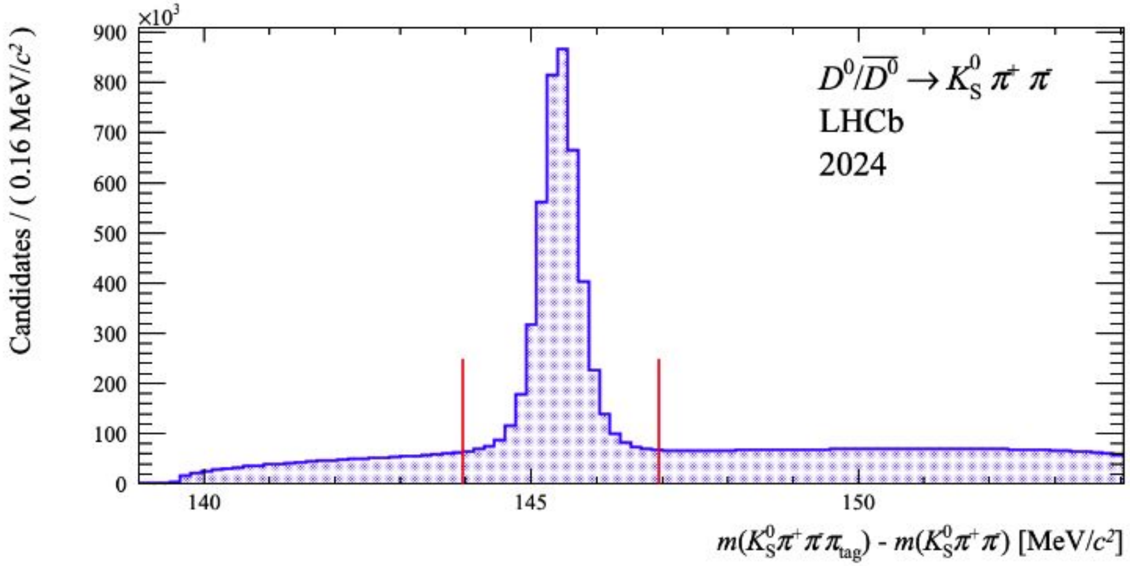
- Total signal yield: 15,676 ± 229
- → Largest existing $D^*$-tag sample!
  - LHCb Run 2 ~8000 candidates
  - Belle ~4000 candidates
  - Belle II ~2200 candidates
  - CMS ~2000 candidates
  - 19k non-D* sample collected by Belle and Belle II, but with much more background
- LHCb Run2 : 5400 candidates ($6fb^{-1}$) if considering only $K_S^0$ decaying in the VELO → **x3 efficiency gain (new trigger) with a x5 instantaneous luminosity**

  → **decays collected at rate ~15 times larger**

# Calibration sample

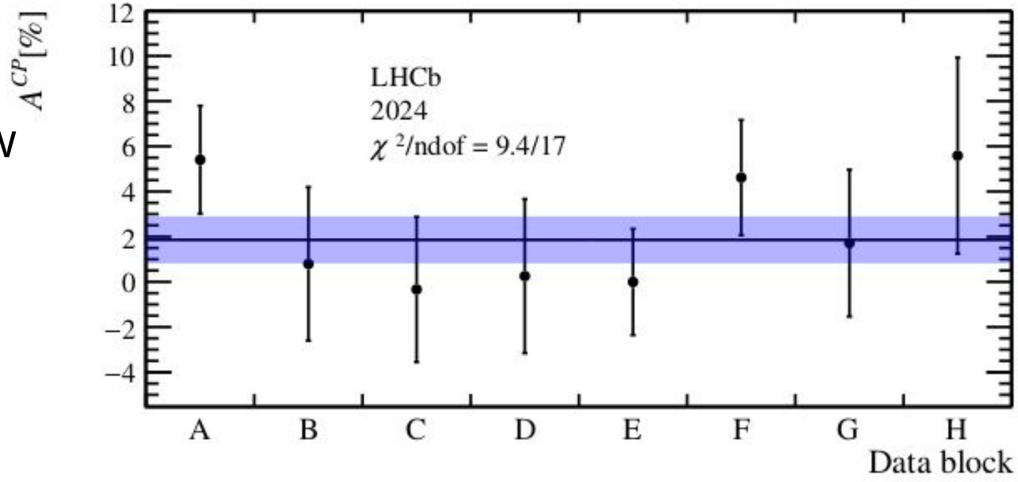



- $D^0 \rightarrow K_S^0 \pi\pi$ sample
  - HLT1: $K_S^0$ trigger
  - HLT2: Dedicated selection without cuts related to $D^{*+}/D^0$ vertex position (different resolution in signal)
- Yield/pb$^{-1}$: ~750 $D^0 \rightarrow K_S^0 \pi\pi$ (S/B ~ 10) vs 2.5 $D^0 \rightarrow K_S^0 K_S^0$



# Results

- Results for each subsample, calibrated and averaged over Low Purity and High Purity bins. All compatible

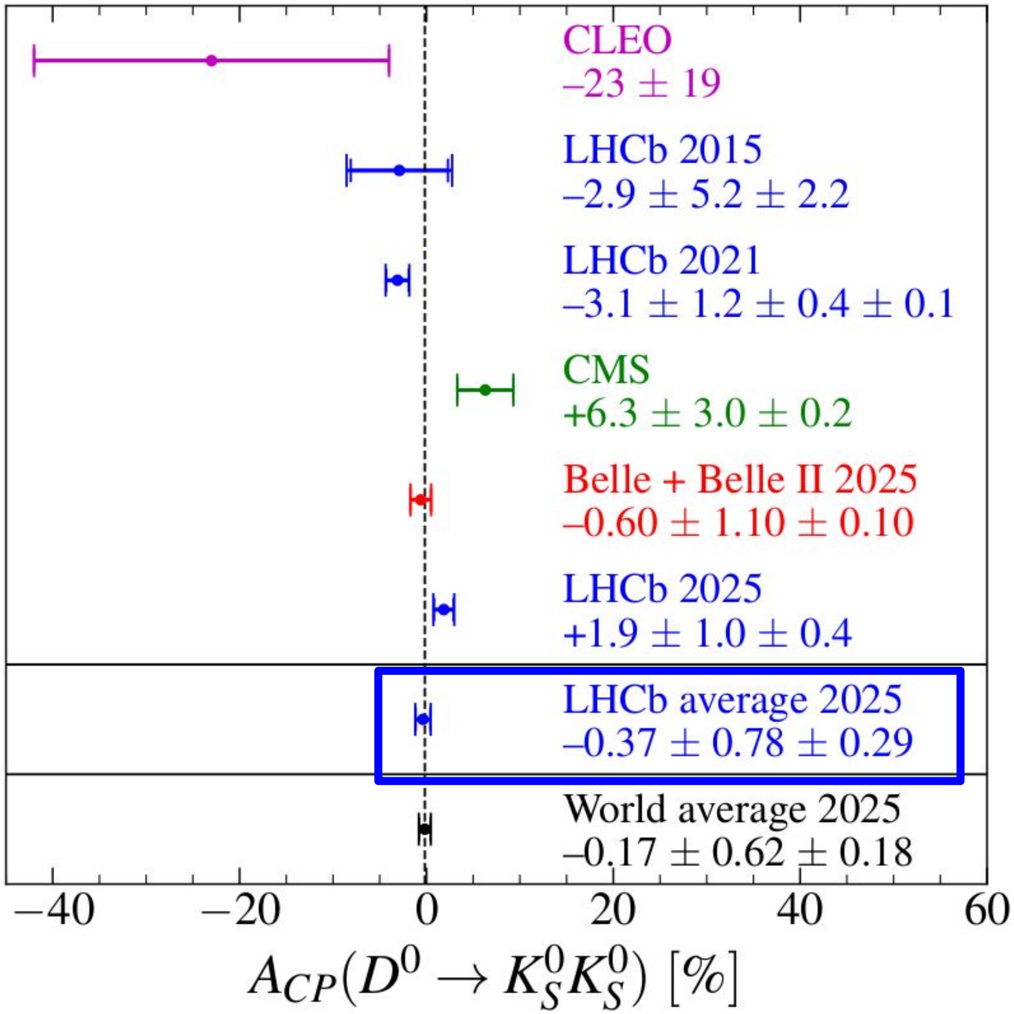



- Global average yields the result:

$$A_{CP}(D^0 \to K_S^0 K_S^0) = (1.86 \pm 1.04 \pm 0.41)\%$$

- World's best result from a single experiment!

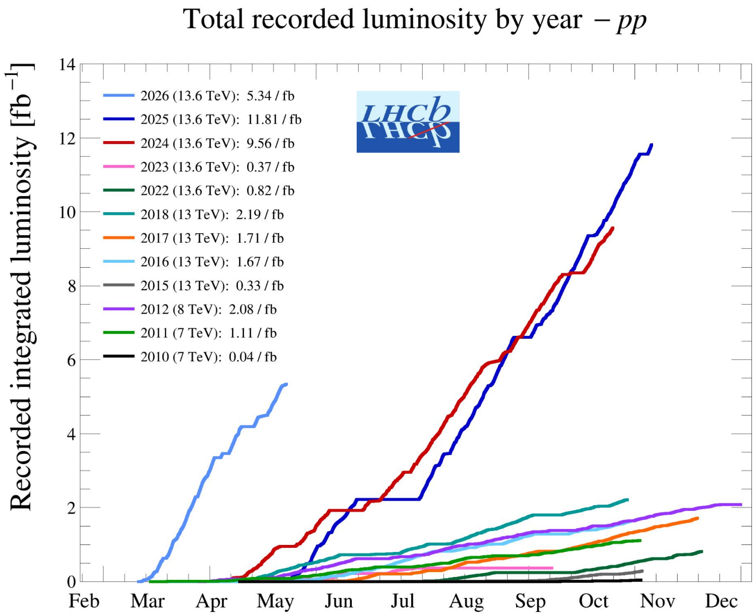
# Results (2)




- Compatible with no CPV
- Compatible with previous WA
- Marginal agreement with previous LHCb results
  - p-value of combination ~1.2%
  - 2.9 σ from Run 2 measurement
- New WA compatible with no CPV with a 0.65% uncertainty
- → Approaching interesting region of sensitivity

charm-fitter

# Future prospects




- Analysed 6.2 fb$^{-1}$ of data (2024)
  - Much more data is already available!

- Only $K_S^0$ candidates decaying in the VELO acceptance considered in this analysis
  - Further improvements expected from the inclusion of downstream candidates → new dedicated HLT1 trigger line from 2025

# Conclusions

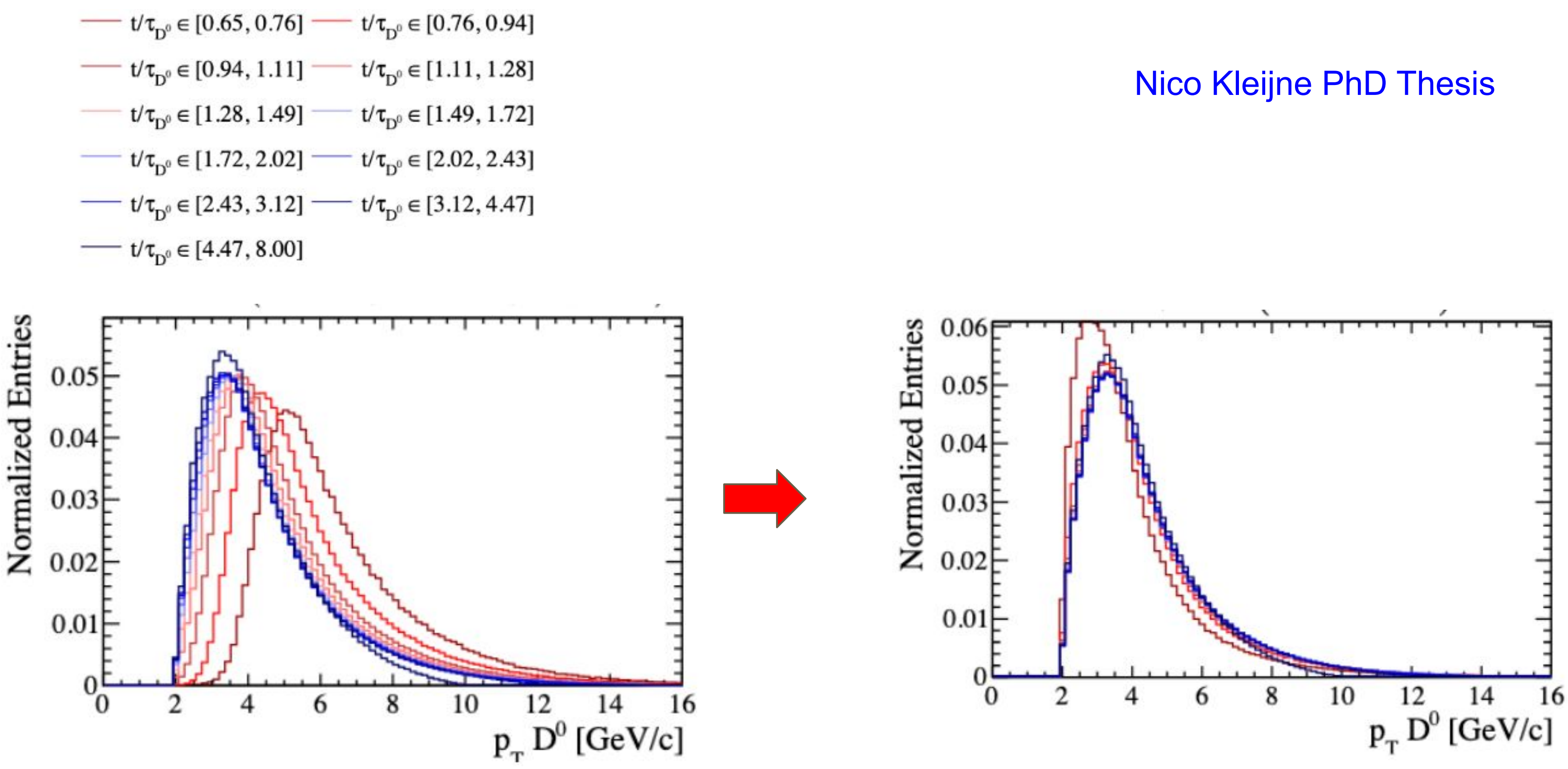
- ❖ Many new results on charm physics in the last years, but still a lot to explore
  - ➢ Hunting CPV in mixing
  - ➢ Need to clarify if the size of observed CPV in the decay is compatible or not with SM expectations
- ❖ Detectors and techniques are improving, much more data has been collected → **Unprecedented precision in CPV measurements in charm can be now achieved**
- ❖ Stay tuned for new results!

# Backup slides

# Not only more yields...

❖ Dedicated trigger selections developed to reduce correlations between decay-time and momentum → better control of systematic uncertainties

Nico Kleijne PhD Thesis



# Overview of current results

https://lhcbproject.web.cern.ch/lhcbproject/Publications/p/Summary_Charm.html

## CPV in decay

### Two-body final state

**$\Delta A^{CP}$ & $A^{CP}$ ($D^0 \to h^+h^-$):**

PRL 122(2019)211803

LHCb-PAPER-2022-024

**$D_{(s)}^+ \to \eta^{(\prime)}\pi^+$:**

LHCb-PAPER-2021-051

**$D^0 \to K_S^0 K_S^0$:**

PRD 104(2021)L031102

**$D_{(s)}^+ \to K_S^0 h^+$:**

PRL 122(2019)191803

**$D_{(s)}^+ \to \eta h^+, h^+\pi^0$:**

JHEP 06(2021)019

### Multi-body final state

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

JHEP 06(2013)112

**$D^+ \to \pi^+\pi^-\pi^0$:**

PLB 740(2015)158

**$D^+ \to \pi^+\pi^-\pi^+$:**

PLB 728(2014)585

**$\Lambda_c^+ \to p h^+ h^-$:**

JHEP 03(2018)182

**$D^0 \to K^-K^+\pi^-\pi^+, \pi^-\pi^+\pi^-\pi^+$:**

JHEP 02(2019)126

**$\Xi_c^+ \to pK^-\pi^+$:**

PRD 102(2020)071101(R)

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

PRL 128(2022)221801

## Mixing + mixing-induced CPV

**$A_\Gamma(D^0 \to h^+h^-)$:**

PRD 104(2021)072010

**$y_{CP}(D^0 \to h^+h^-)$:**

PRD 105(2022)092013

**WS $D^0 \to K^+\pi^-$:**

PRD 97(2018)031101

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

PRL 116(2016)241801

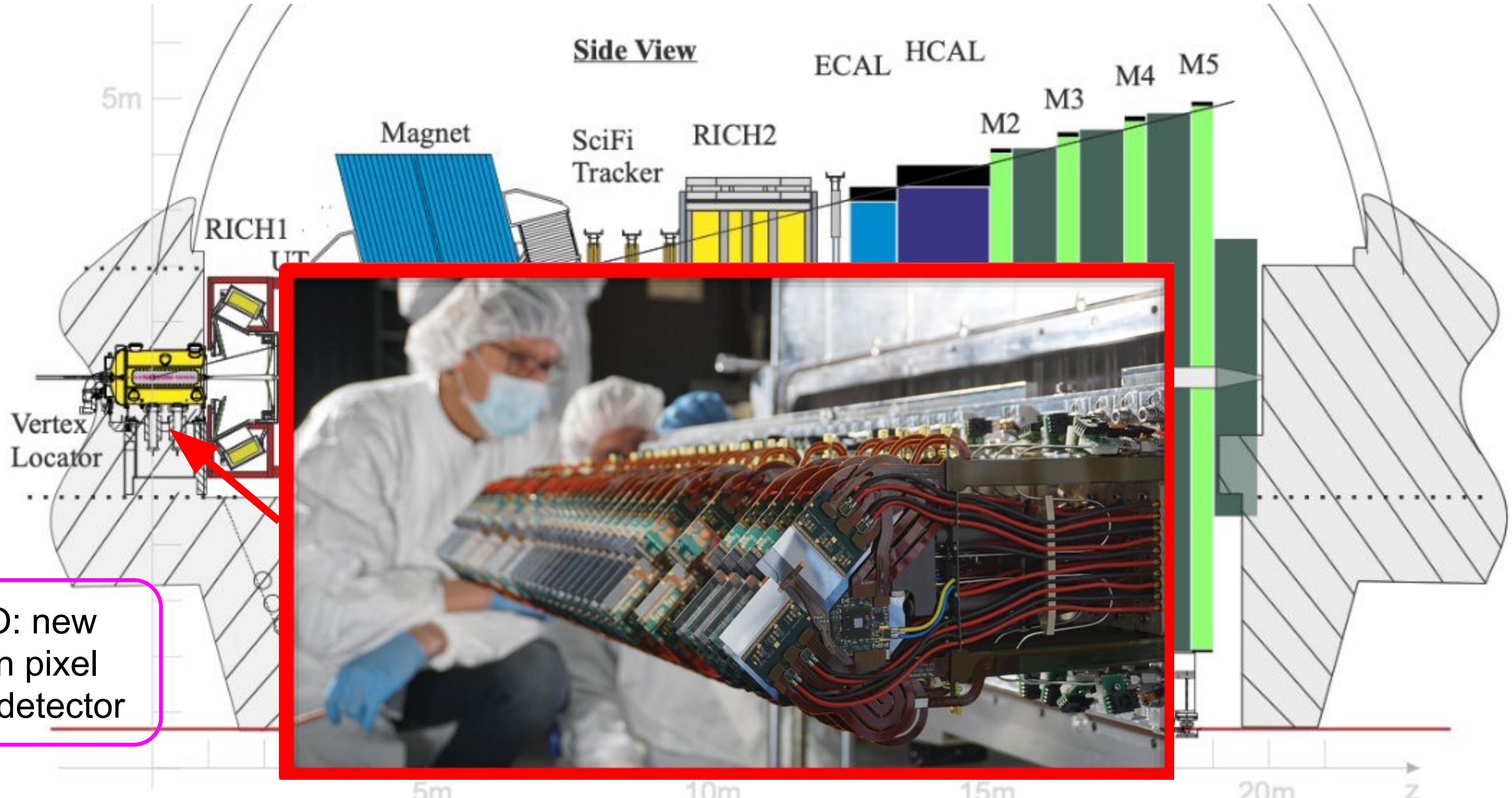
**$D^0 \to K_S^0\pi^+\pi^-$:**

PRL 127(2021)111801

LHCb-PAPER-2022-020

# The upgraded LHCb detector

JINST 19P05065

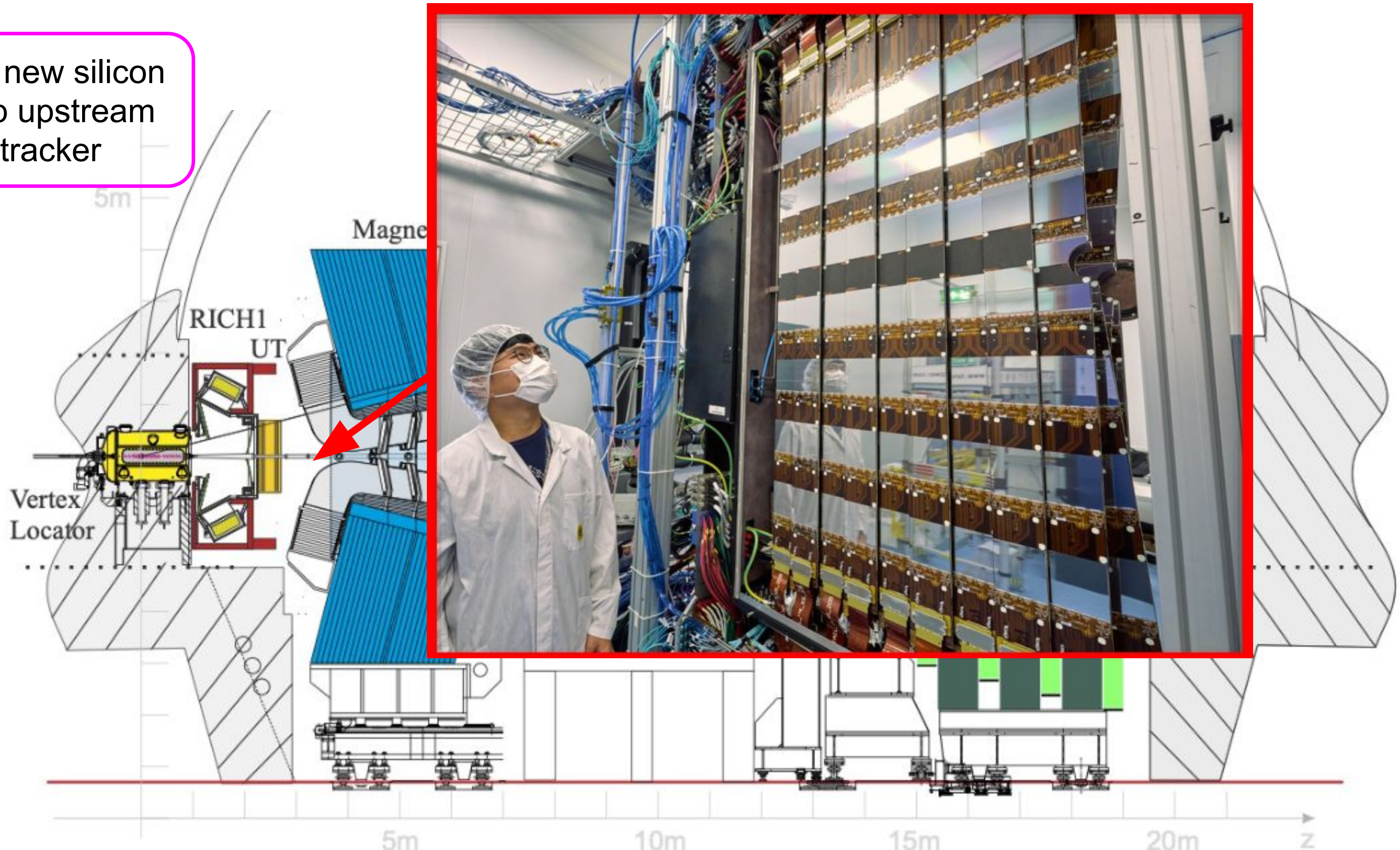



VELO: new silicon pixel vertex detector

# The upgraded LHCb detector

JINST 19P05065

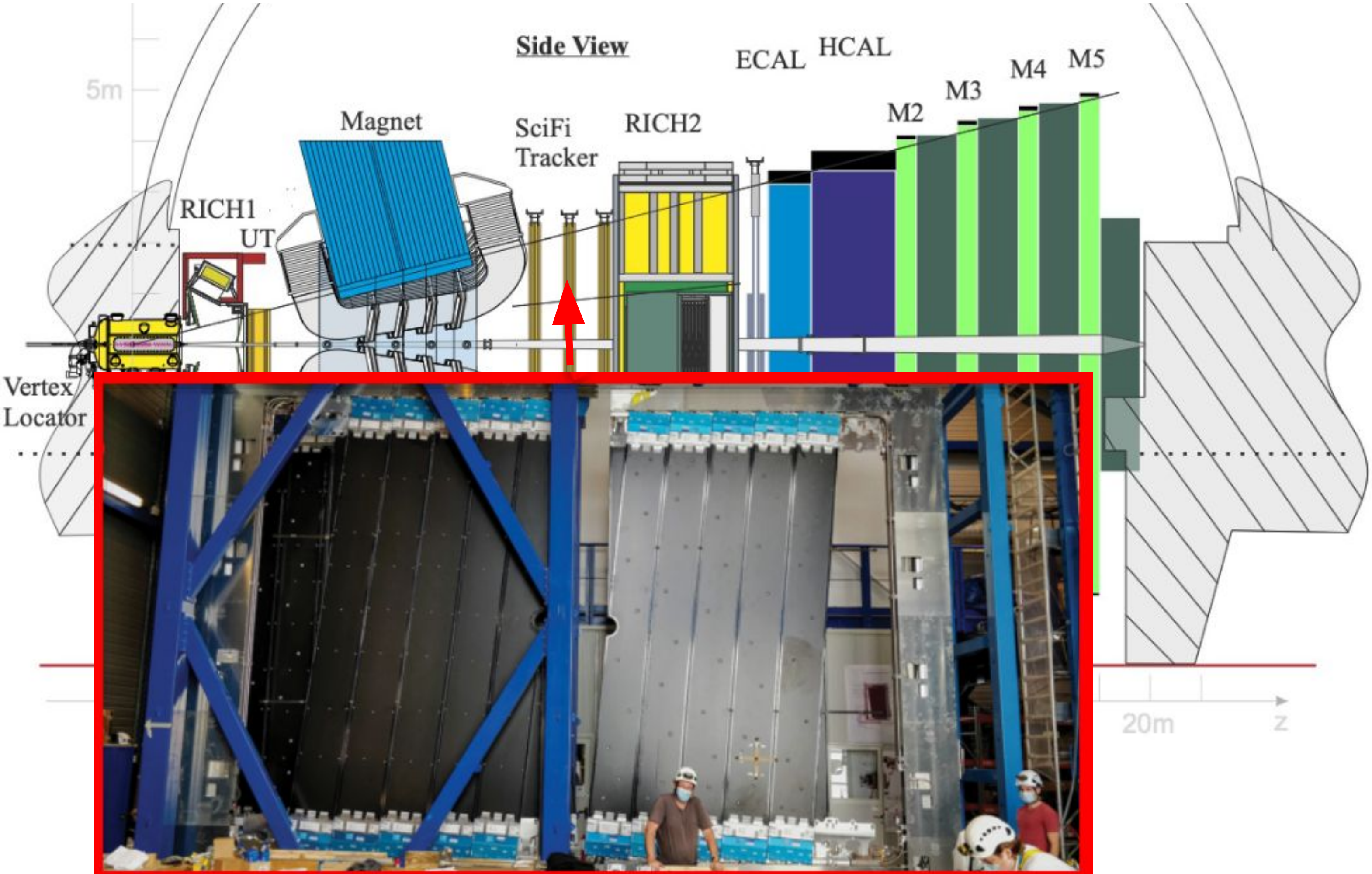
UT: new silicon strip upstream tracker



# The upgraded LHCb detector

JINST 19P05065

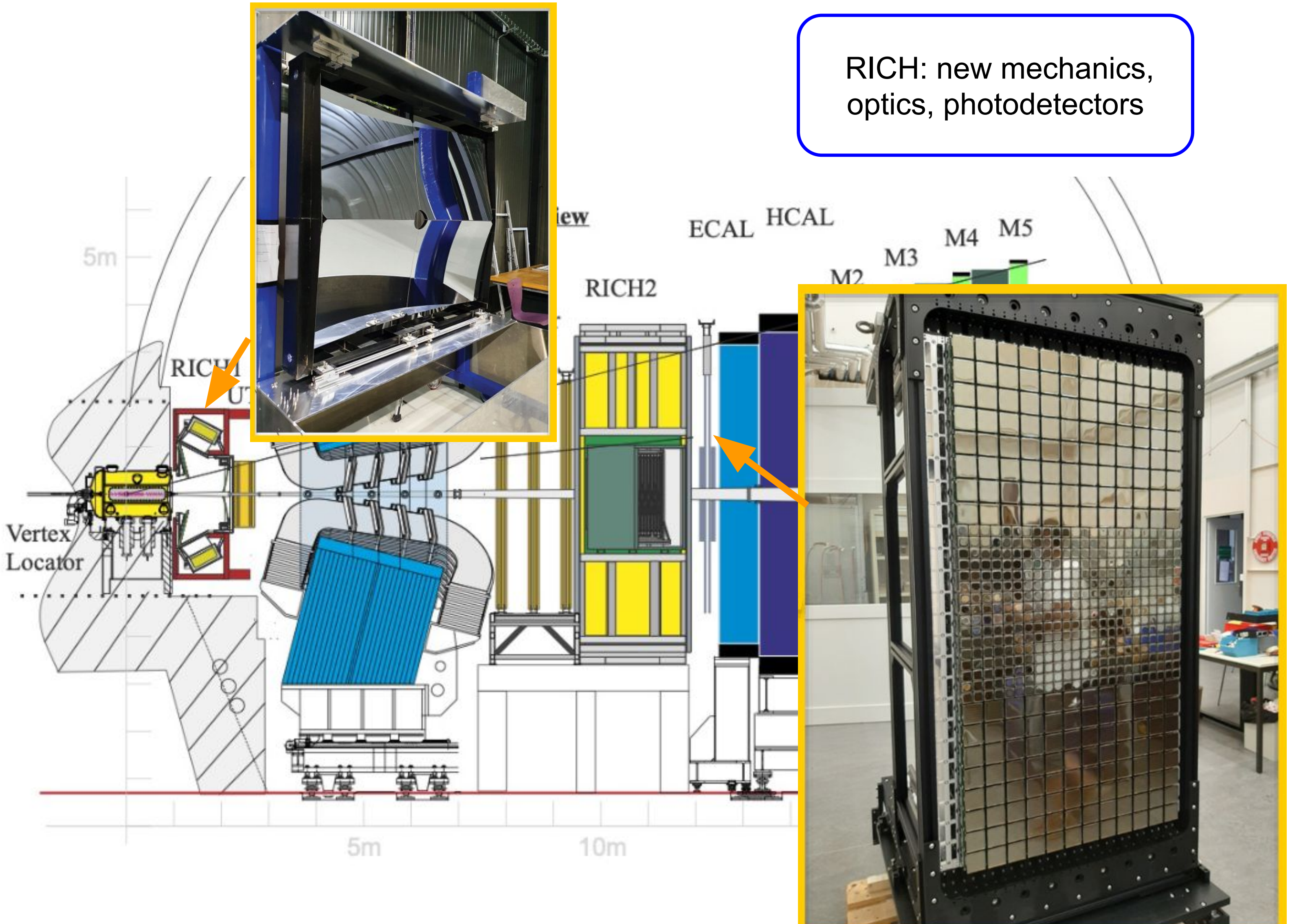
SciFi: new scintillating fibres tracker



# The upgraded LHCb detector

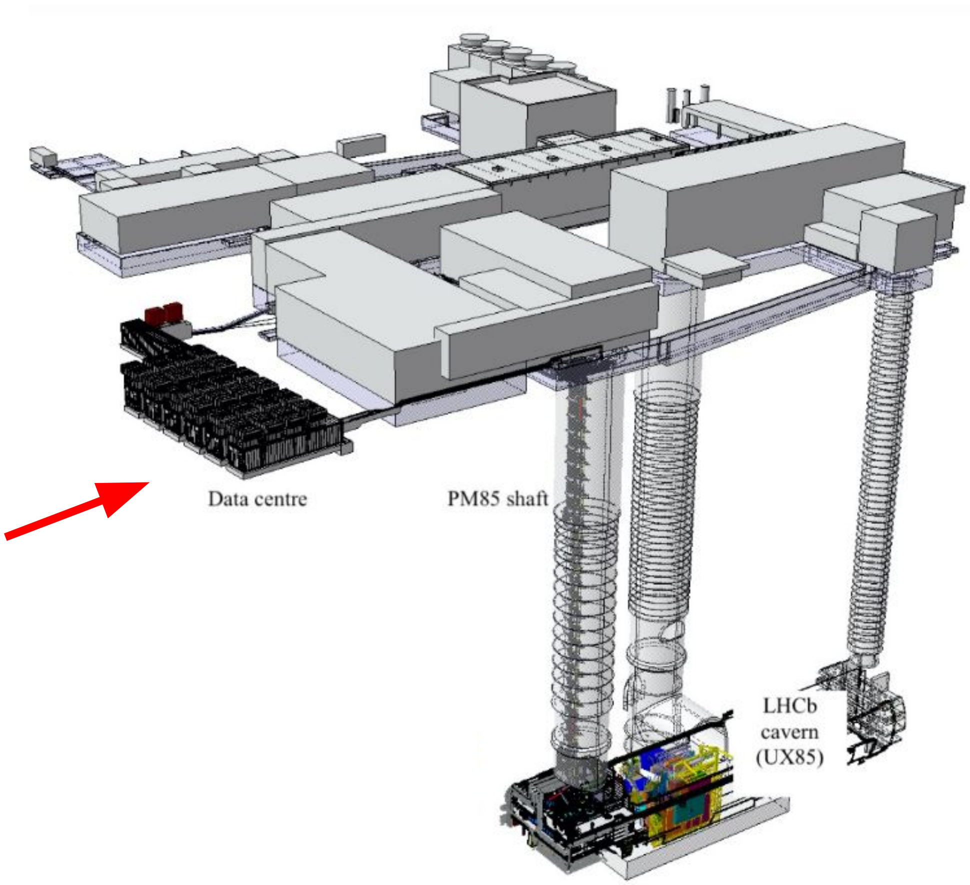
JINST 19P05065

RICH: new mechanics, optics, photodetectors



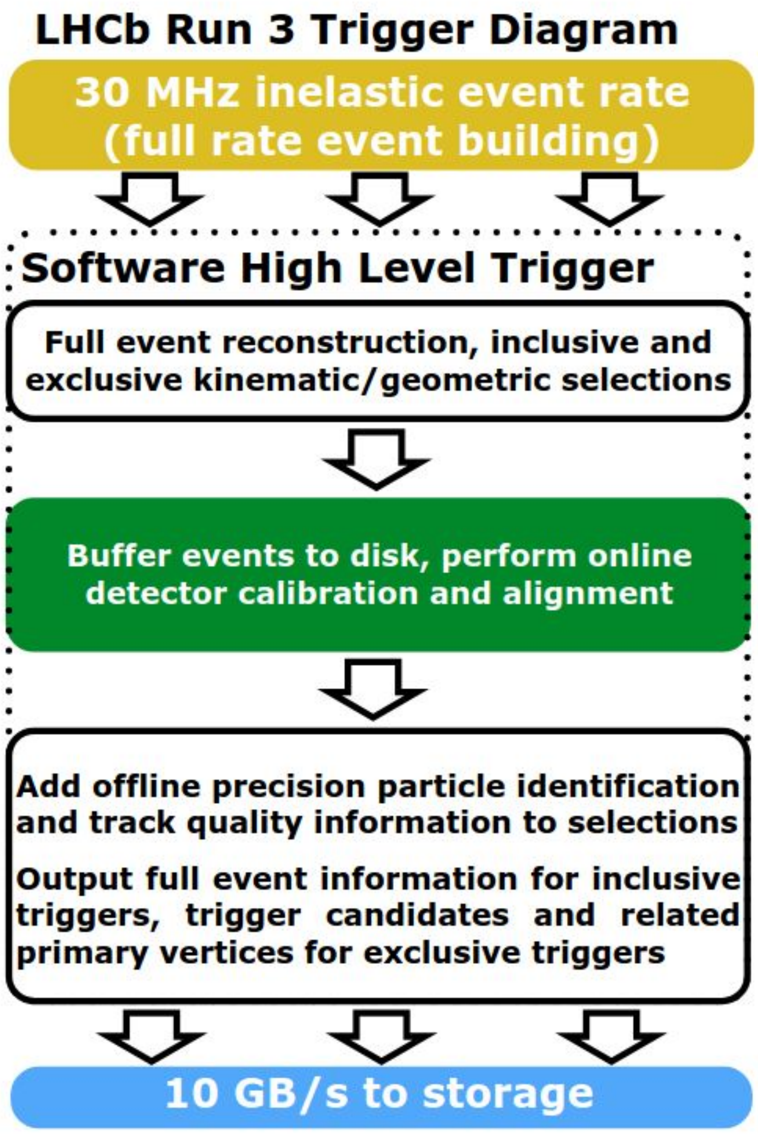
# The upgraded LHCb detector

JINST 19P05065




New frontend electronics and new DAQ for all sub-detectors!

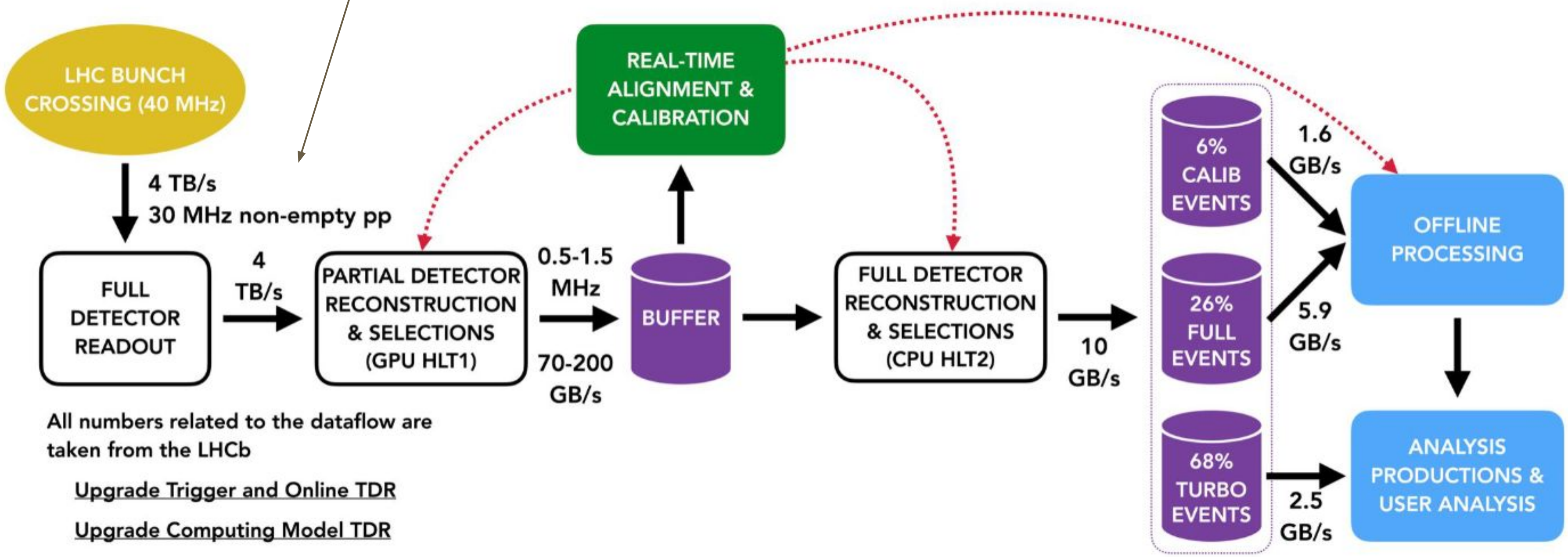
# Trigger in Run 3



# Data flow

Largest data rates in HEP so far!

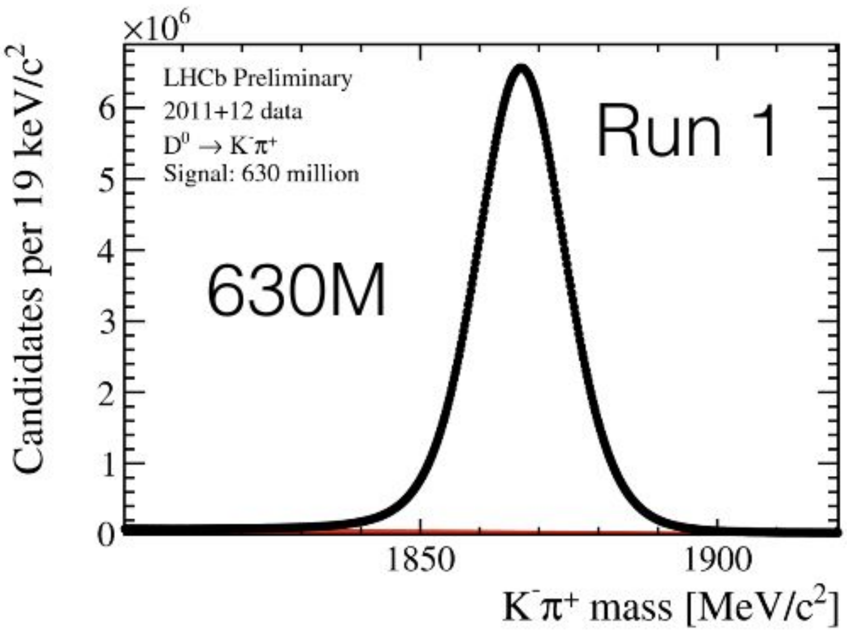
LHCb-FIGURE-2020-016



# LHC: a charm factory

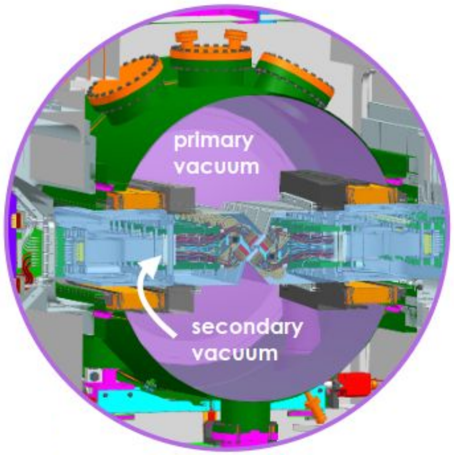
$10^6$ $c\bar{c}$ pairs per second in Run 2

- In LHCb acceptance:
  - $\sigma(pp \to c\bar{c}X) \sim 2.4$ mb ($\sqrt{s} = 13$ TeV) JHEP 03(2016)159
  - $\sigma(pp \to b\bar{b}X) \sim 0.1$mb ($\sqrt{s} = 13$ TeV)
- Data needs to be properly saved on disk → trigger
  - ~1 billion $D^0$ decays collected in Run 1 + Run 2



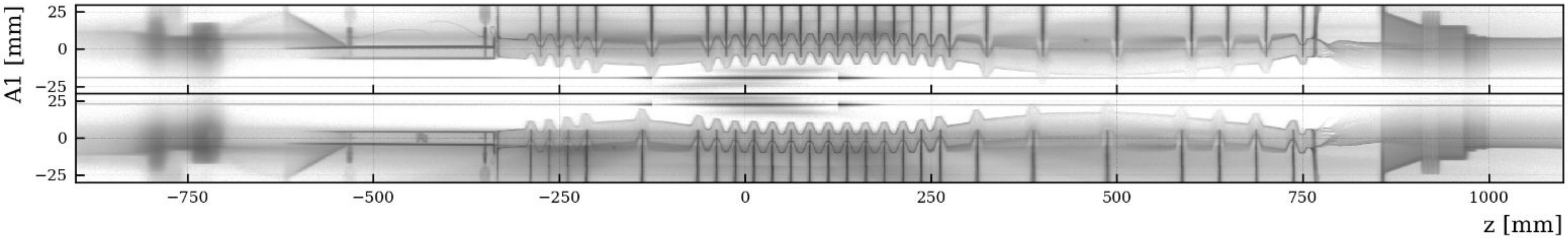
# Start of Run 3: a rollercoaster ride

- **2022**
  - ➢ all detectors installed but UT
  - ➢ local commissioning of subdetectors
  - ➢ global commissioning of trigger, alignment and calibration
  - ➢ VELO routinely closed in the last couple of months




- **2023**
  - ➢ LHC vacuum incident in the VELO in Jan: operated with VELO aperture of 49 mm
  - ➢ UT completed installation

LHCb Upgrade detector seminar



# New trigger system: implications for charm decays

- 1) Charge asymmetries
  - L0 trigger for hadrons in Run 2: information from the calorimeter
  - Calorimeter is quite coarse: many particles fall in the same cell
  - Cannot combine efficiencies for single tracks to determine efficiency of a decay
  - Difficult to evaluate trigger induced asymmetries in CPV measurements
  - Not a problem anymore in Run 3: L0 trigger removed

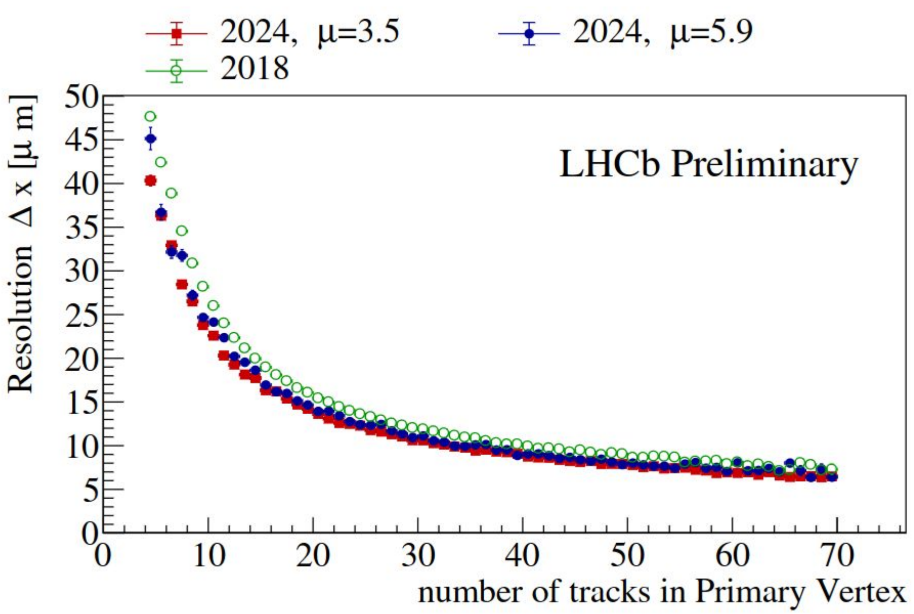
# The vertex detector

- Charm and beauty hadrons:
  - $\tau \sim O(0.1\text{-}1\ \mathrm{ps})$
  - Can fly several mm before decaying: distinctive feature to select them
- High resolution vertex detector
  - Silicon pixels → high granularity, single hit resolution ~13 μm
- VELO is separated from the primary vacuum by the 1.1m long thin walled “RF box”
- 3.5 mm clearance from the beam and 900 μm clearance from the sensors
- → aperture is so small that during LHC injection the VELO halves and boxes must be retracted

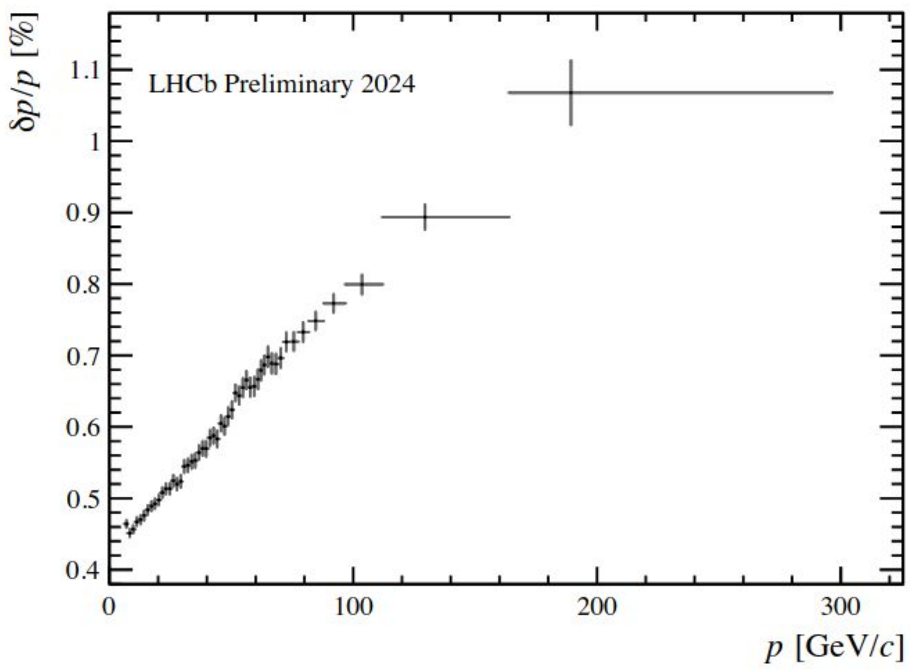
# On the rise: excellent performance in 2024

- PV resolution better than Run 2!
- Momentum resolution between 0.4% and 1.1%

LHCb-FIGURE-2024-011



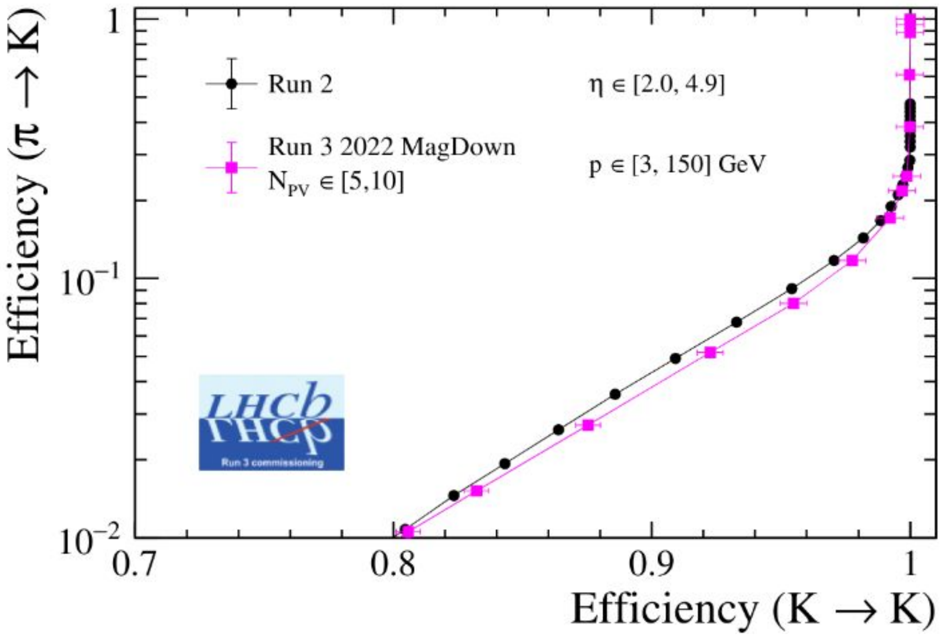

LHCb-FIGURE-2024-040

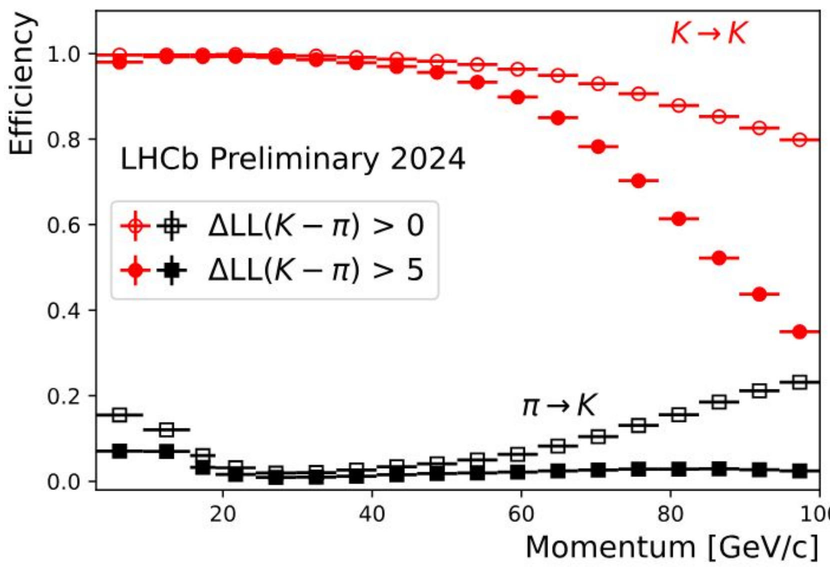


# On the rise: excellent performance in 2024 (2)

❖ Excellent hadron identification in the full range of momentum!

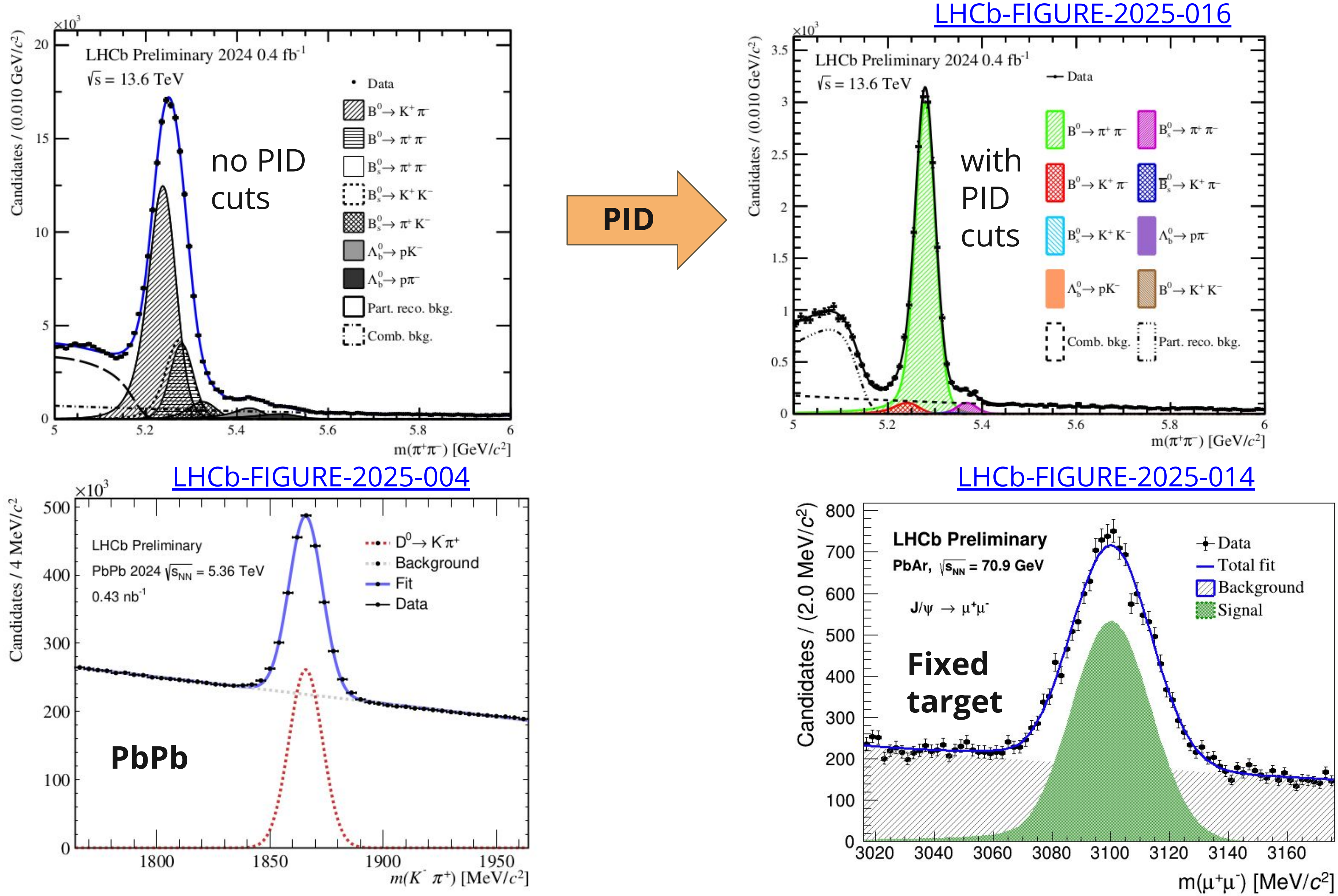
LHCb-FIGURE-2023-019



# On the rise: excellent performance in 2024 (3)

LHCb-FIGURE-2025-016

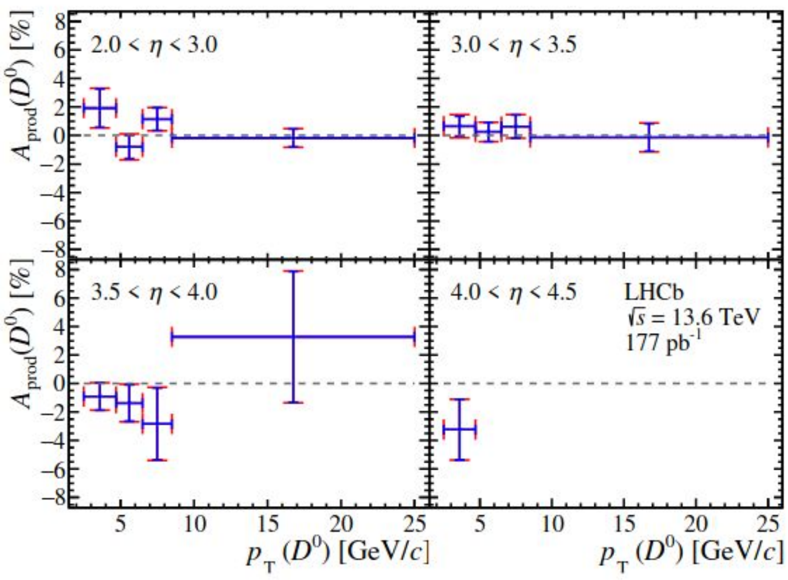


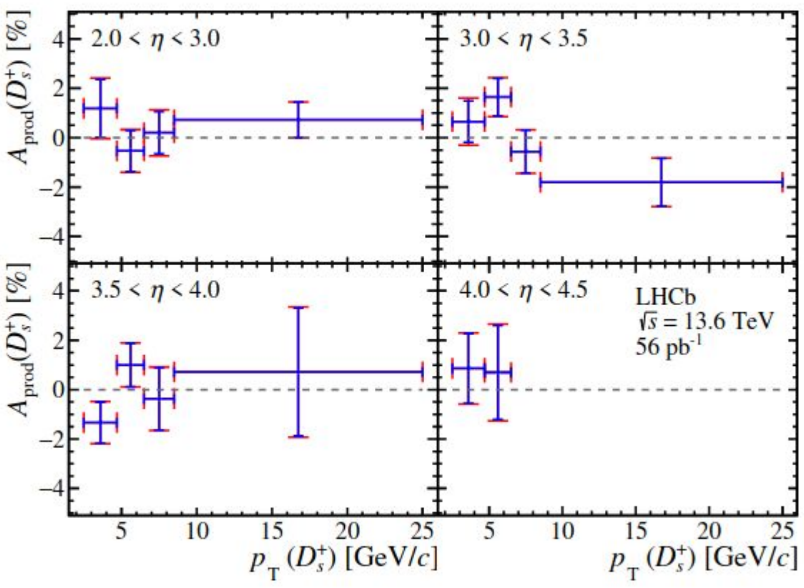

LHCb-FIGURE-2025-004

LHCb-FIGURE-2025-014

# First LHCb results in Run 3

❖ "Measurements of charmed meson and antimeson production asymmetries at 13.6 TeV" (data collected in 2022 and 2023) arXiv:2505.14494

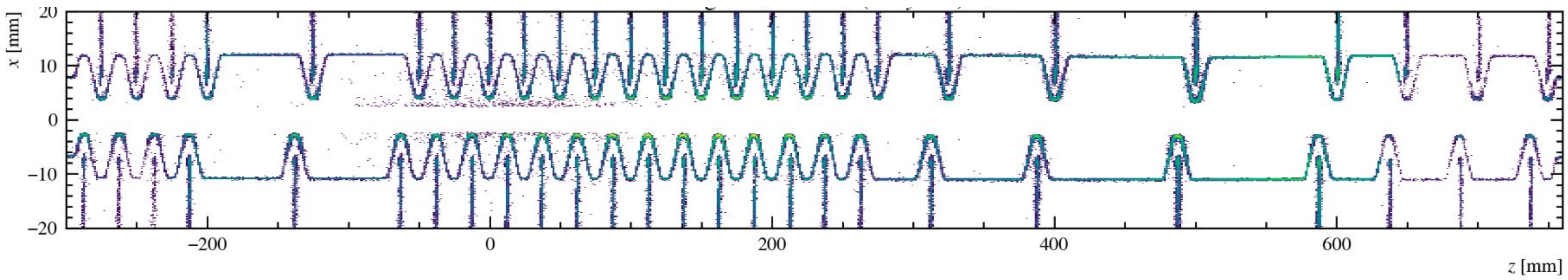


# Data-taking

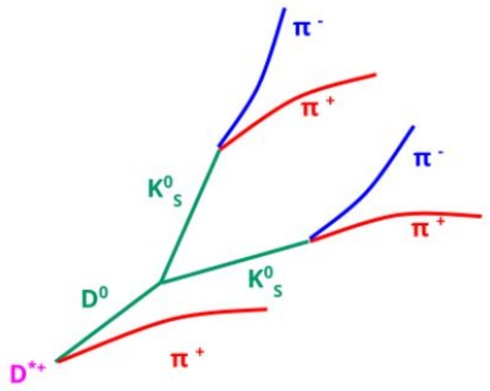
- **2024**
  - VELO RF-box replaced
  - UT included in global data-taking after June TS

**Selfie of the new RF-box and VELO modules with reconstructed hadronic interaction vertices**



# Selections

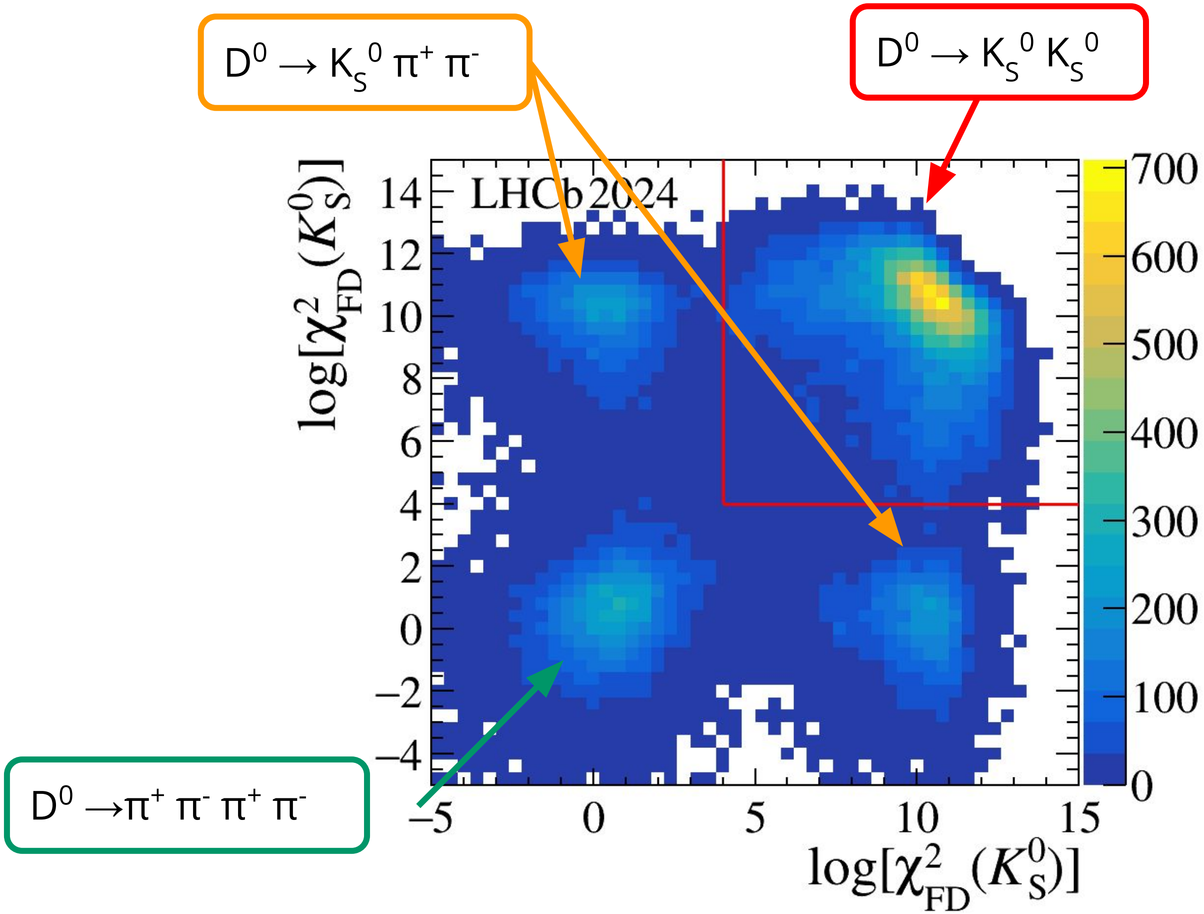
- Trigger:
  - HLT1: single $K_S^0$ with relatively high $p_T$ (>2.45 GeV)
  - HLT2: full decay chain reconstruction

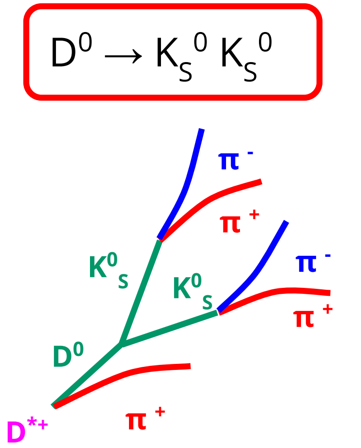


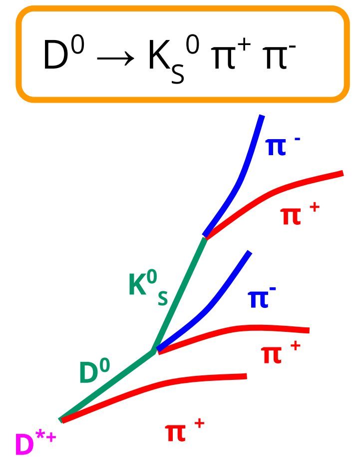

- Offline selection:
  - To remove contribution from other decay channels that can bias the measurement
  - To increase the sensitivity on $A^{CP}$, reducing random combinations of particles which satisfy trigger selections

# Contamination from $D^0 \to K_S^0\pi^+\pi^-$ decays

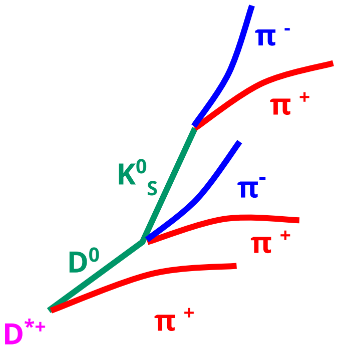
| Decay channel | $\prod \mathcal{B}_i\ (10^{-4})$ |
|---|---|
| $D^0 \to K_S^0 K_S^0,\ K_S^0 \to \pi^+\pi^-$ | $0.68 \pm 0.02$ |
| $D^0 \to K_S^0 \pi^+\pi^-,\ K_S^0 \to \pi^+\pi^-$ | $194. \pm 13.$ |
| $D^0 \to \pi^+\pi^-\pi^+\pi^-$ | $75.6 \pm 2.0$ |



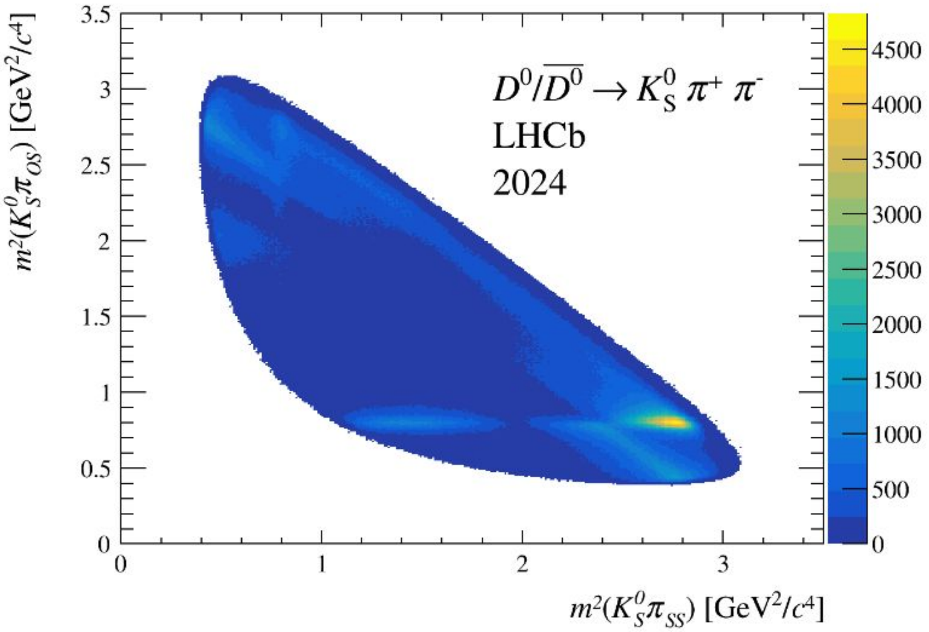



# Calibration sample (2)




- $D^0$ final state in calibration sample is not symmetric
  - Main contribution: $D^0 \rightarrow K^{*-}(892)\pi^+$, $K^{*-}(892) \rightarrow K^0_S\,\pi^-$
- Can introduce a detection asymmetry(not present in the signal sample)
  - Need preliminary re-weight to symmetrize pion pair

    → O(0.1%) correction

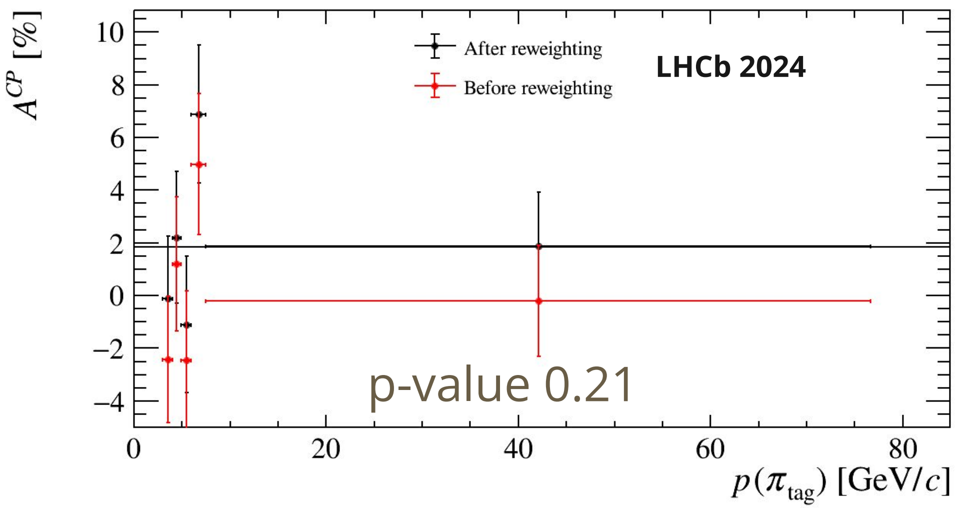


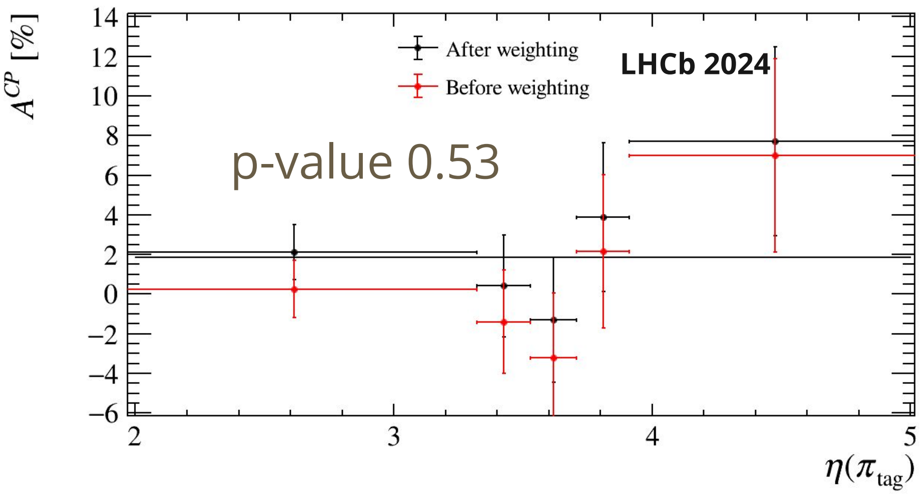
# Systematic uncertainties

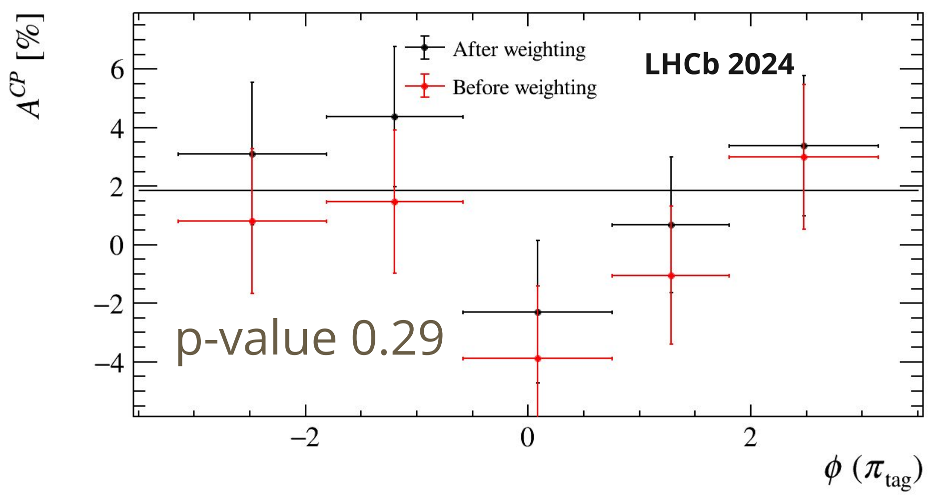
- 1. Fit model
  - $A_{CP}$ sensitivity to model of signal pdf $\rightarrow$ 0.27%
- 2. Cancellation of spurious charge asymmetries
  - Statistical fluctuations of calibration sample $\rightarrow$ 0.24%
  - Choice of k in kNN-based charge calibration $\rightarrow$ 0.20%
- $K^0$ material effects contribution to $A^{raw}$ ($D^0 \rightarrow K_S^0 \pi\pi$)
  - precisely measured in Run 2 detector, expected small
  - measured effect in used sample: $<$ 0.05%
- Total combined systematics $\rightarrow$ 0.41%
- Total statistical uncertainty 1.04%

# Cross-checks

❖ Verified that $A_{CP}$ does not depend on $D^0$, $D^{*+}$, $\pi^+_{tag}$ kinematic quantities



# Cancellation of nuisance asymmetries

- Signal candidates weighted by

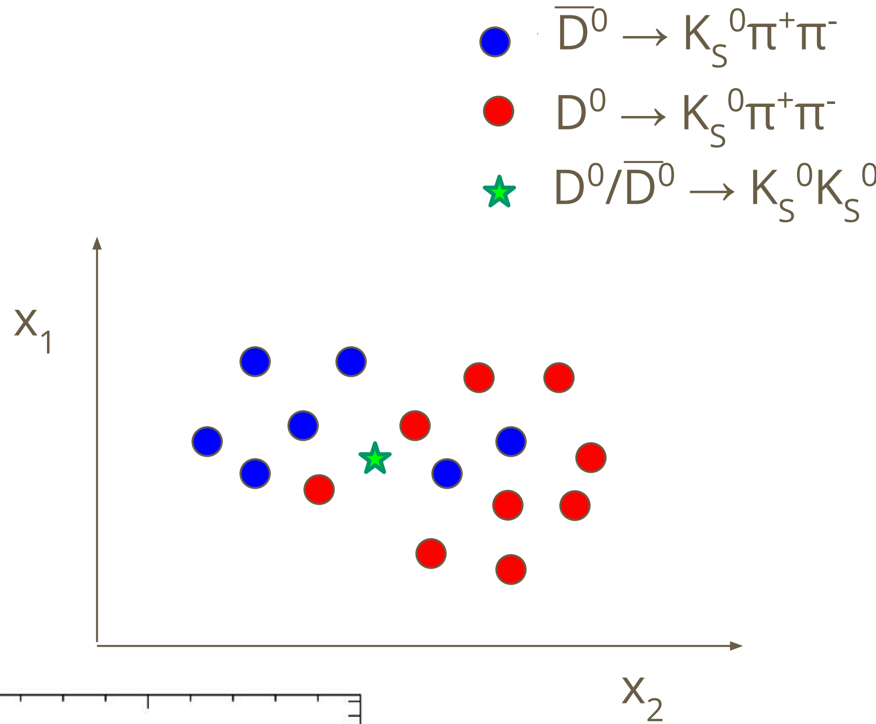
$$w^{\pm}(\vec{p}) = \frac{n_C^{+}(\vec{p}) + n_C^{-}(\vec{p})}{2n_C^{\pm}(\vec{p})}$$

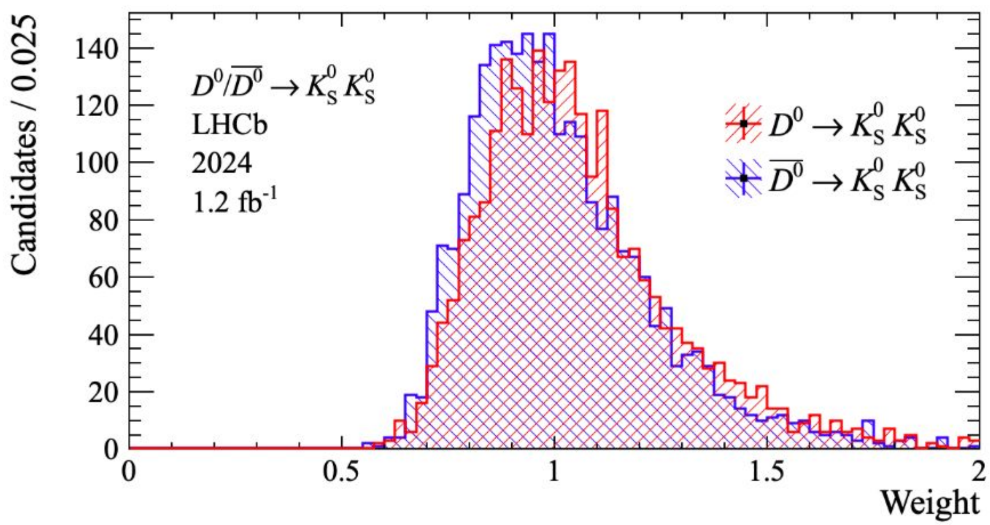
$n_{(C)}^{+-}$ is density of $D^0/\overline{D}^0 \rightarrow K_S^0\pi^+\pi^-$ events in P space (P describes $\pi_{tag}$ kinematics)

- Unbiased estimate of $A_{CP}$ - even in case of large asymmetries

# Cancellation of nuisance asymmetries (2)

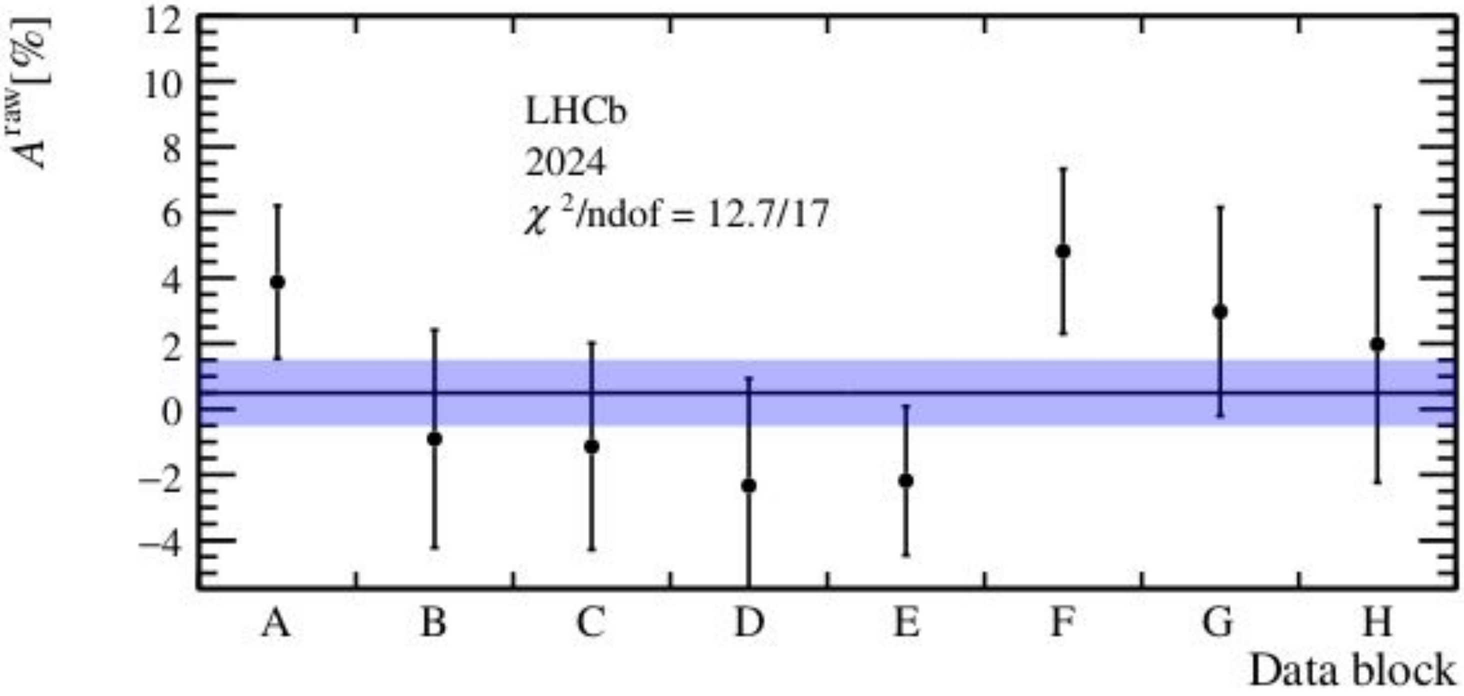
- $n_C/(n_C^+ + n_C^-)$ extracted using kNN algorithm (k=30)
  - kNN output = $n^+/(n^+ + n^-)$
  - k= $n^+ + n^-$
- Distance evaluated in the $p_x(\pi_{tag})$, $p_y(\pi_{tag})$ and $p_z(\pi_{tag})$ space
- Average correction: +1.35%



# Results

Before correcting for production and detection asymmetries



# Results

After correcting for production and detection asymmetries