Charm: Rare, CPV, Mixing

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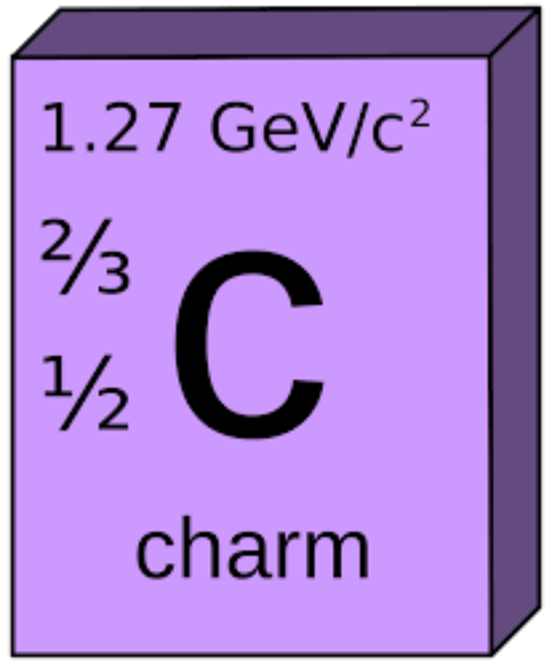
On behalf of the LHCb Collaboration and Belle Collaboration

Physics In Collisions 2024



Charm Physics: Why?

- Charmed hadrons are composed of up-like quark → Complementary studies to B and K hadrons
- Strong suppression of mixing, CPV and rare decays in the SM → Powerful probe for indirect searches of new physics

Relatively large contributions to CP violation or FCNC can reveal new physics

- Recent discovery of CP violation in charm decays in 2019 at LHCb [Phys. Rev. Lett. 122, 211803]
- Difficult theoretical predictions in charm physics due to large QCD corrections

Recent Results at LHCb

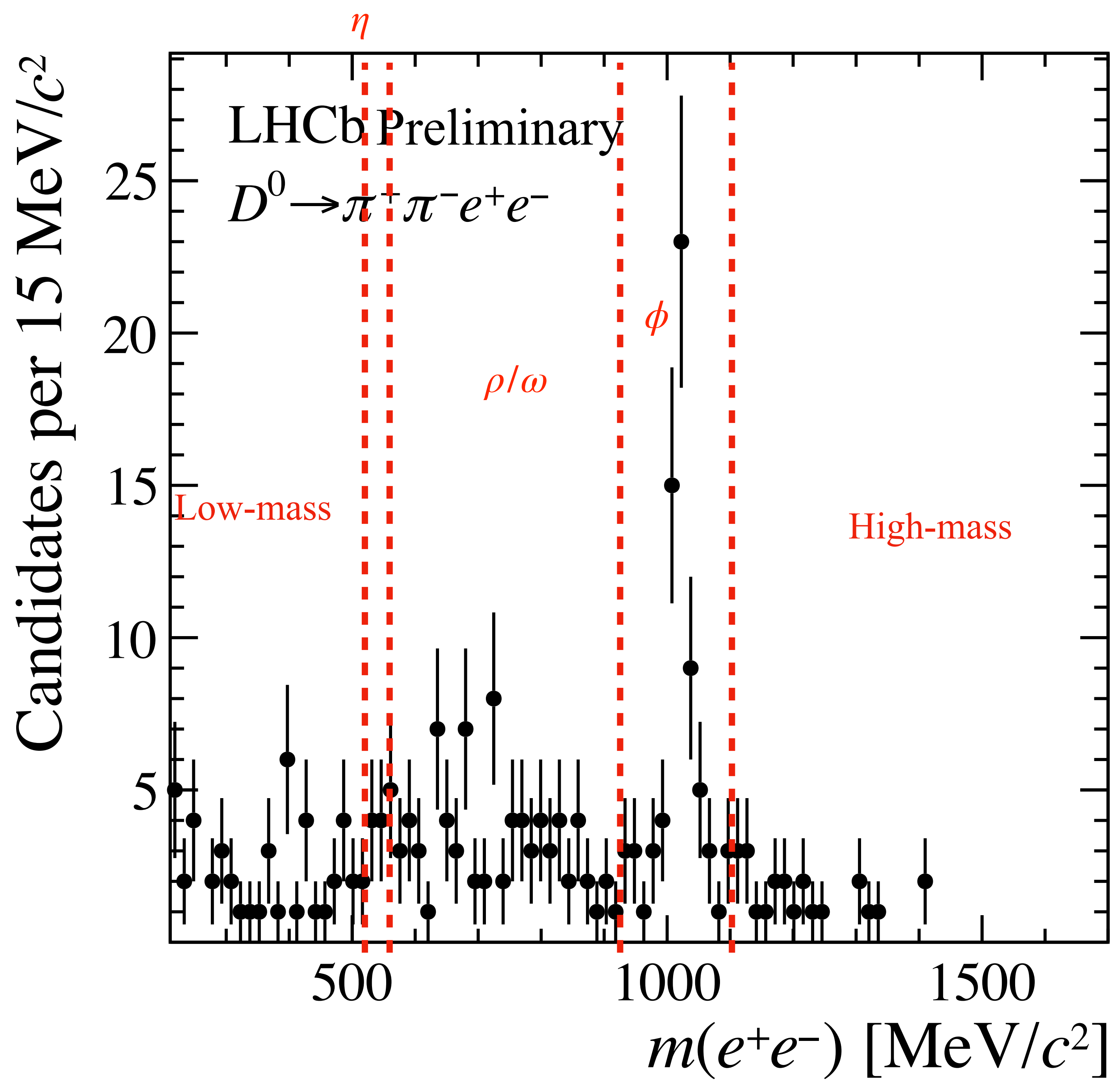
- Rare decays:
  - Search for D^0 mesons decays to $\pi^+\pi^-e^+e^-$ and $K^+K^-e^+e^-$ final states [LHCb-PAPER-2024-047] (Paper in preparation)
  - Search for the rare decay of charmed baryon Λ_c^+ into $p\mu^+\mu^-$ final state [Phys. Rev. D 110, 052007]

- Mixing and CPV:
  - Measurement of $D^0 - \overline{D}^0$ mixing and search for CP violation with $D^0 \to K^+\pi^-$ decays [2407.18001]
  - Search for charge-parity violation in semileptonically tagged $D^0 \to K^+\pi^-$ decays [LHCb-PAPER-2024-044] (Paper in preparation)
  - Measurement of CP violation observables in $D^+ \to K^-K^+\pi^+$ decays [2404.01414]

Searches for Rare Charm Decays

Search for D^0 mesons decays to $\pi^+\pi^-e^+e^-$ and $K^+K^-e^+e^-$ final states

- First LHCb search of electron modes
- Muon modes $D^0 \to h^+h^-\mu^+\mu^-$ observed at LHCb [Phys. Rev. Lett. 119, 181805] → Lepton flavour universality test
- Analysis on full Run 2 dataset (6 fb^{-1})
- Sample divided according to number of Bremsstrahlung photons to control backgrounds
- Branching ratio normalized with $D^0 \to K^-\pi^+e^+e^-$
- Efficiency correction with MC account for data-simulation difference
- D^0 candidates tagged from $D^{*+} \to D^0\pi_s$ for background suppressions
- Main Backgrounds: Combinatorial, Mis-ID from $D^0 \to h^-h'^+\pi^+\pi^-$ and partially reconstructed events due to wrong association of Bremsstrahlung photons

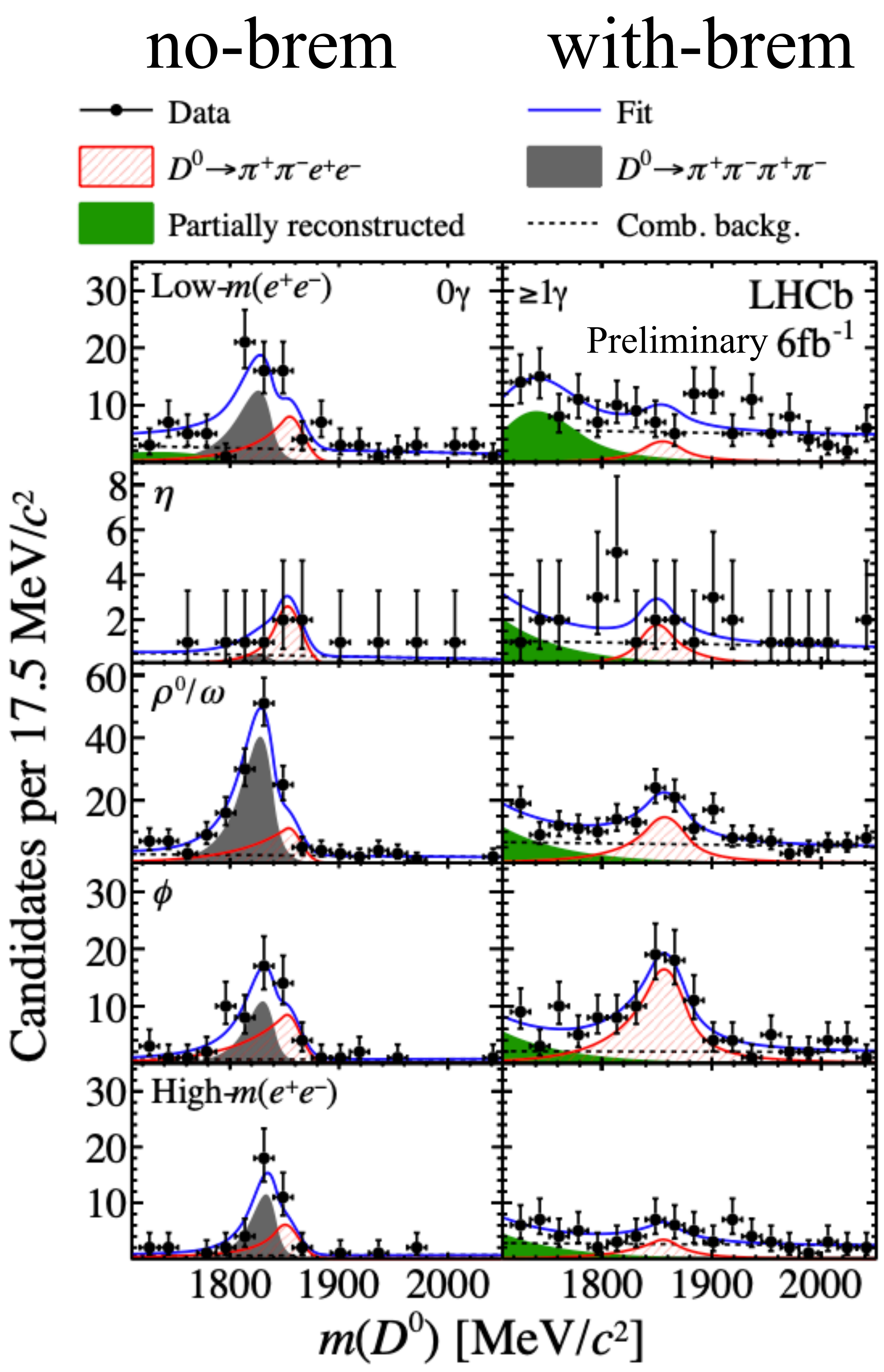


LHCb-PAPER-2024-047 (in preparation)

Results for $D^0 \to \pi^+\pi^-e^+e^-$

- First observation in ρ and ϕ region of dielectron mass
- Branching fractions measured for this decays and upper limits provided for other regions

$D^0 \to \pi^+\pi^-e^+e^-$			
$m(e^+e^-)$ region	$[\text{MeV}/c^2]$	Yield	$\mathcal{S}$
Low mass	211–525	37 ± 13	2.8σ
η	525–565	10 ± 7	1.6σ
ρ^0/ω	565–950	97 ± 21	5.5σ
ϕ	950–1100	100 ± 18	8.1σ
High mass	> 1100	30 ± 11	2.9σ

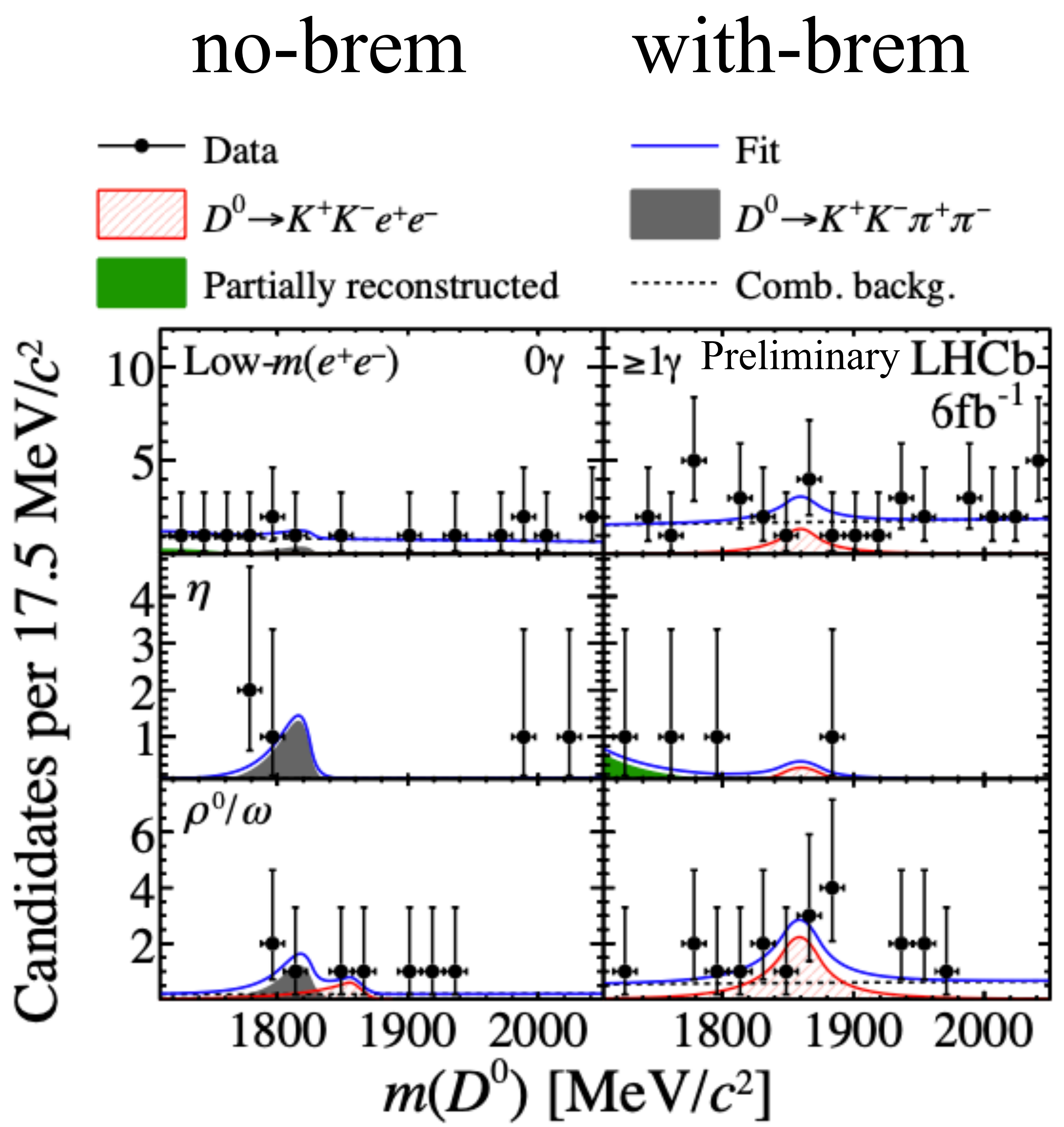


LHCb-PAPER-2024-047 (in preparation)

Results for $D^0 \to K^+K^-e^+e^-$

- No evidence for this decay mode
- Upper limits of branching fractions computed for each bin
- World best precision of upper limits

$D^0 \to K^+K^-e^+e^-$			
m(e^+e^-) region	[MeV/c^2]	Yield	$\mathcal{S}$
Low mass	211–525	4 ± 8	1.2σ
η	525–565	1 ± 2	1.1σ
ρ^0/ω	> 565	12 ± 7	2.2σ



LHCb-PAPER-2024-047 (in preparation)

Results of branching fractions

- Integrating over the full dilepton invariant mass:

$$BF(D^0 \to \pi^+\pi^-e^+e^-) = (13.3 \pm 1.7 \pm 1.7 \pm 1.8) \times 10^{-7}$$

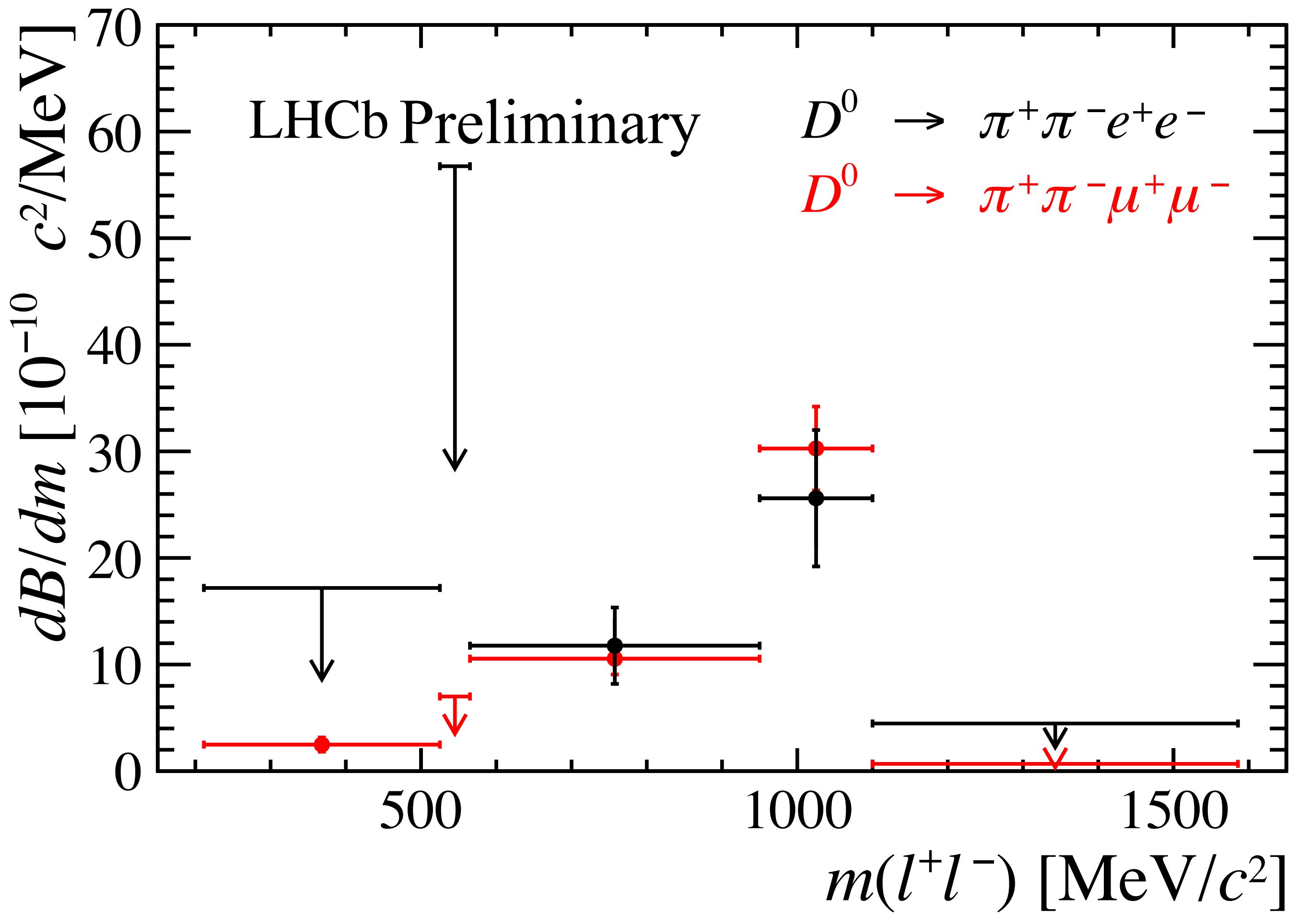
- Results of branching fractions compatible with muon mode at 1.3σ

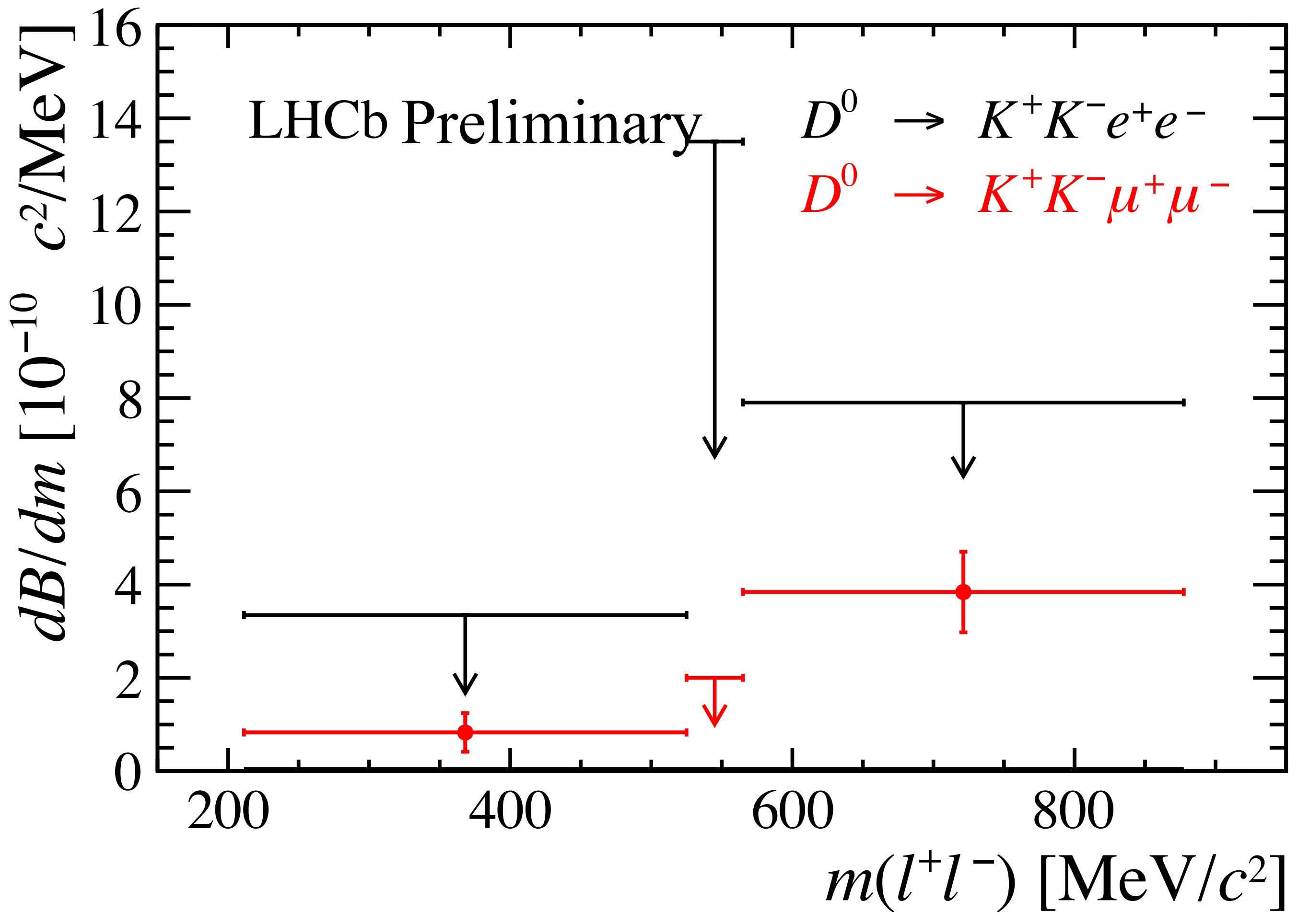
$$BF(D^0 \to \pi^+\pi^-\mu^+\mu^-) = (9.64 \pm 0.48 \pm 0.51 \pm 0.97) \times 10^{-7}$$

Phys. Rev. Lett. 119, 181805

No evidence for lepton flavour universality violation

	$D^0 \to \pi^+\pi^-e^+e^-$	
$m(e^+e^-)$ region	$[\mathrm{MeV}/c^2]$	$\mathcal{B}$ $[10^{-7}]$
Low mass	211–525	$< 4.81\,(5.39)$
η	525–565	$< 2.27\,(2.74)$
ρ^0/ω	565–950	$4.53 \pm 1.00 \pm 0.72 \pm 0.62$
ϕ	950–1100	$3.84 \pm 0.70 \pm 0.39 \pm 0.53$
High mass	> 1100	$< 2.00\,(2.17)$
	$D^0 \to K^+K^-e^+e^-$	
$m(e^+e^-)$ region	$[\mathrm{MeV}/c^2]$	$\mathcal{B}$ $[10^{-7}]$
Low mass	211–525	$< 0.97\,(1.05)$
η	525–565	$< 0.44\,(0.54)$
ρ^0/ω	> 565	$< 2.15\,(2.47)$



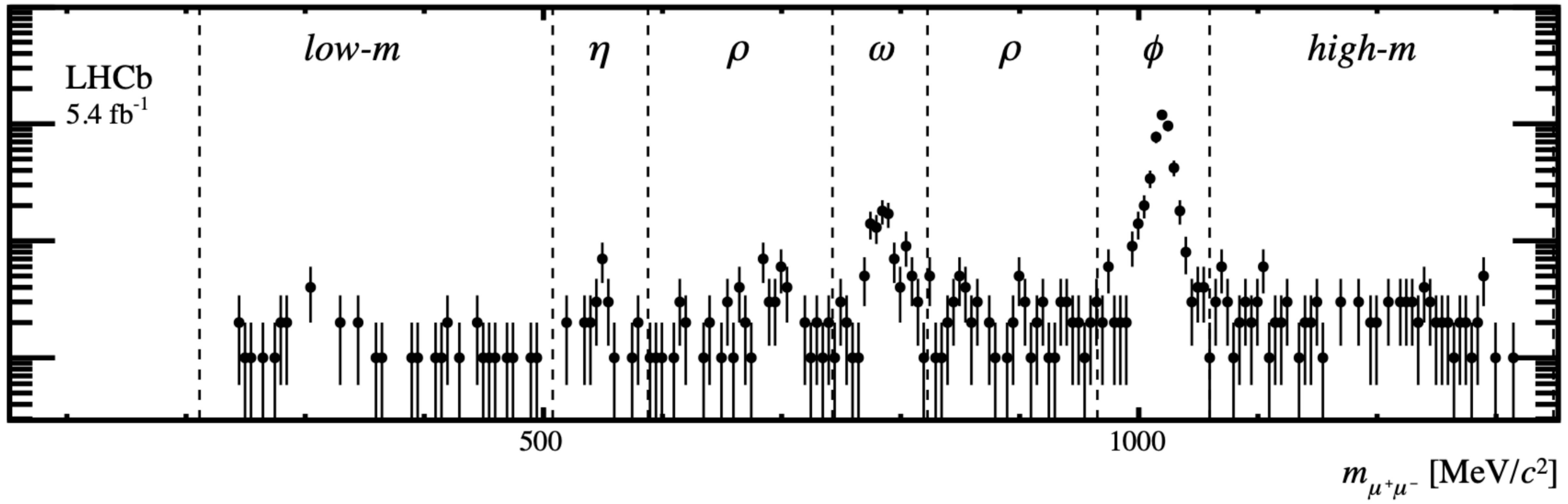


LHCb-PAPER-2024-047 (in preparation)

Search for the rare decay of charmed baryon Λ_c^+ into $p\mu^+\mu^-$ final state

- Short distance (non-resonant) decays in SM heavily suppressed $BF(\Lambda_c^+ \to p\mu\mu) \sim 10^{-8}$
- Long distance (resonant) decays have higher BF i.e. $BF(\Lambda_c^+ \to p\mu\mu) \sim 10^{-6}$
  - Resonances trough ϕ, ρ, η, ω
- Difficult to estimate the contribution of resonance since relative strong phase is unknown
- $\Lambda_c^+ \to p\phi(\to \mu\mu)$ for normalization of BF

- Full Run 2 data set 5.6 fb^{-1}
- Analysis in bins of $m(\mu^+\mu^-)$:



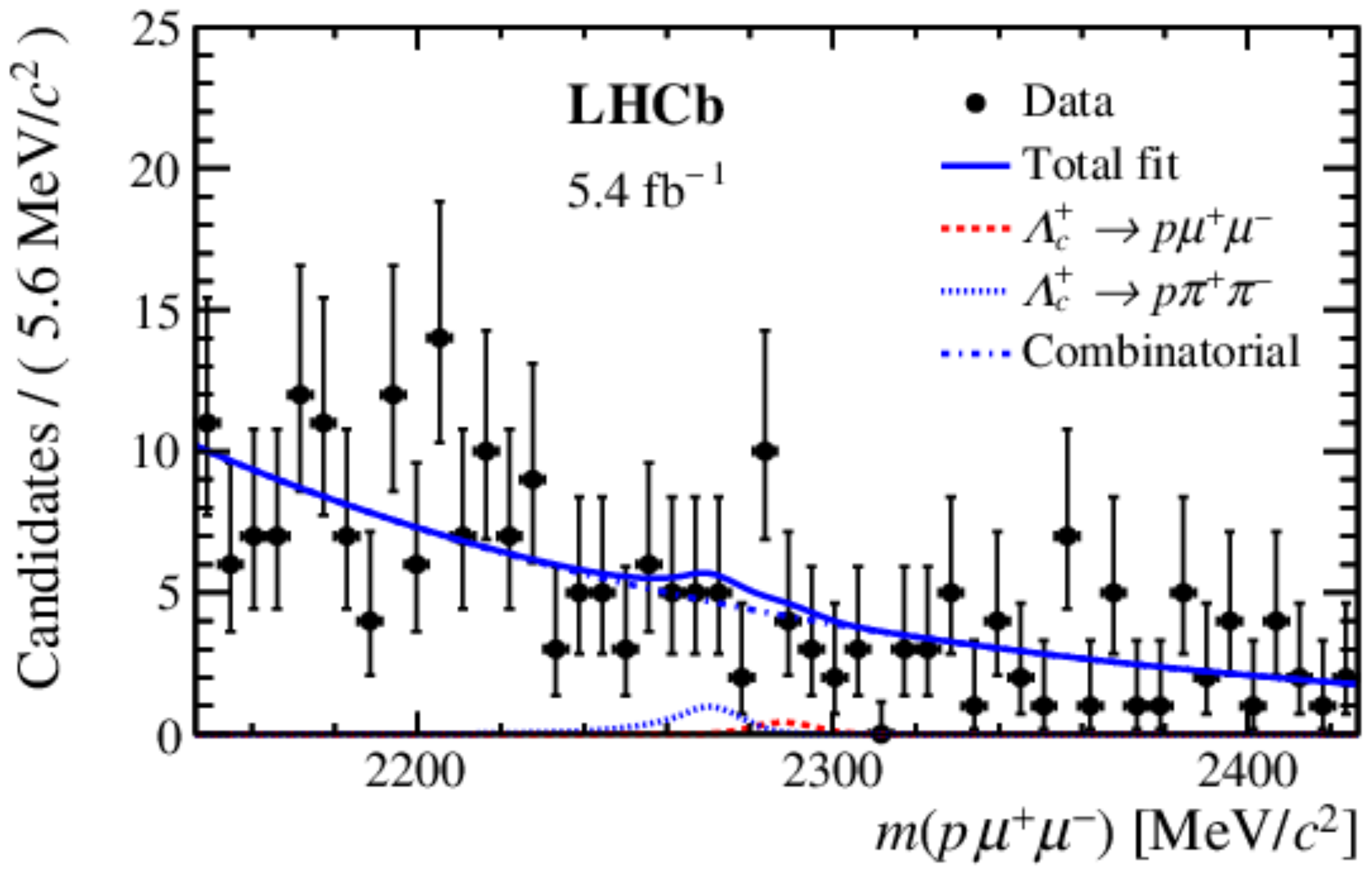
- BDT to exclude combinatorial background using kinematics, topology of daughters, track and vertex isolation
- Mis-ID background due to $\Lambda_c^+ \to p\pi\pi$ with shape parameters estimated from MC

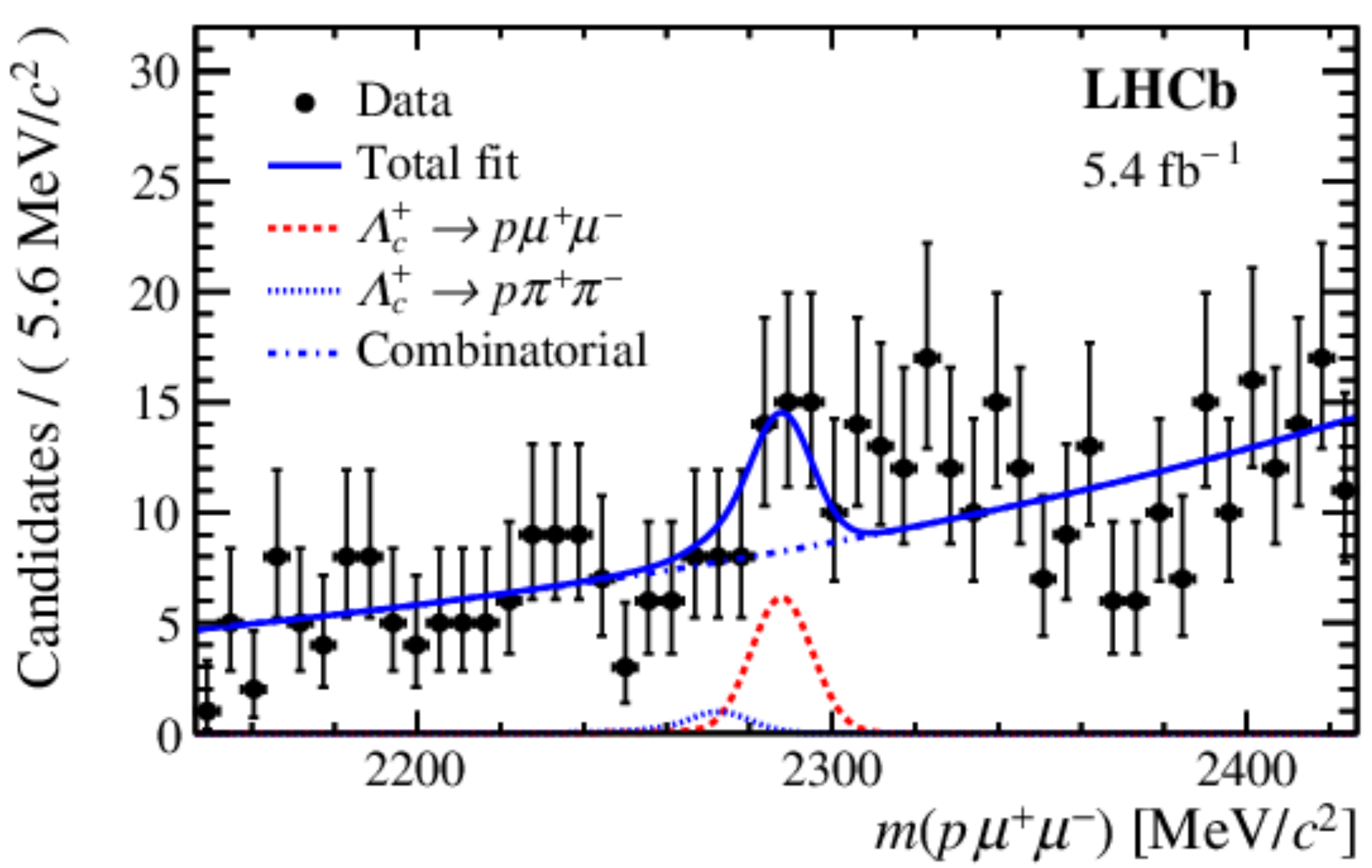
Phys. Rev. D 110, 052007

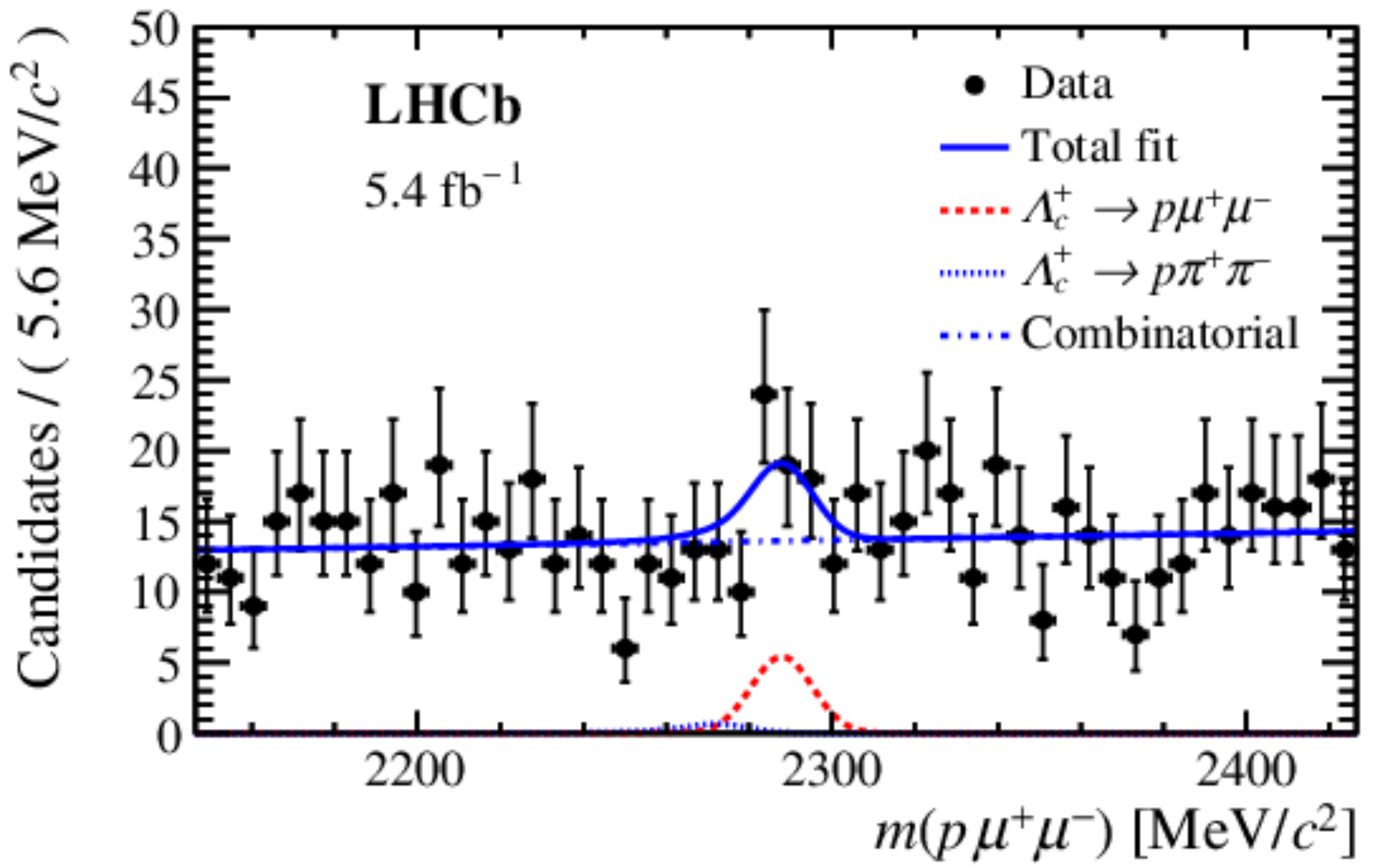
Non-resonant region fits and results

Signal model: Crystal Ball function, Mis-ID background Crystal Ball + Gaussian, Combinatorial: Exponential

Signal and Mis-ID PDFs parameters estimated from MC and fixed in real data



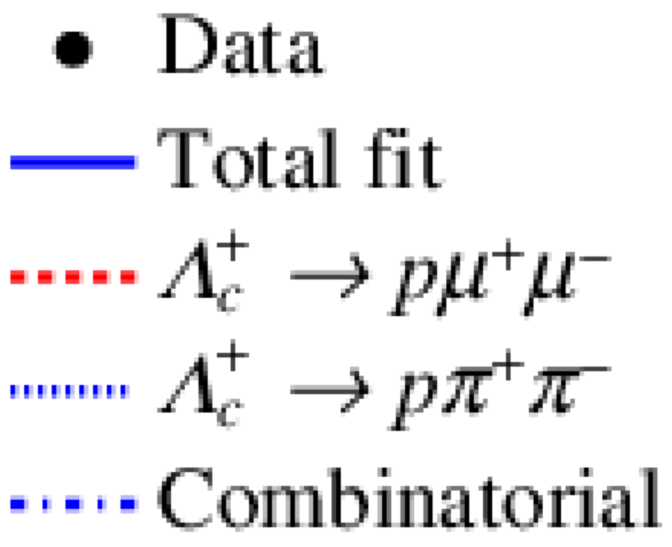


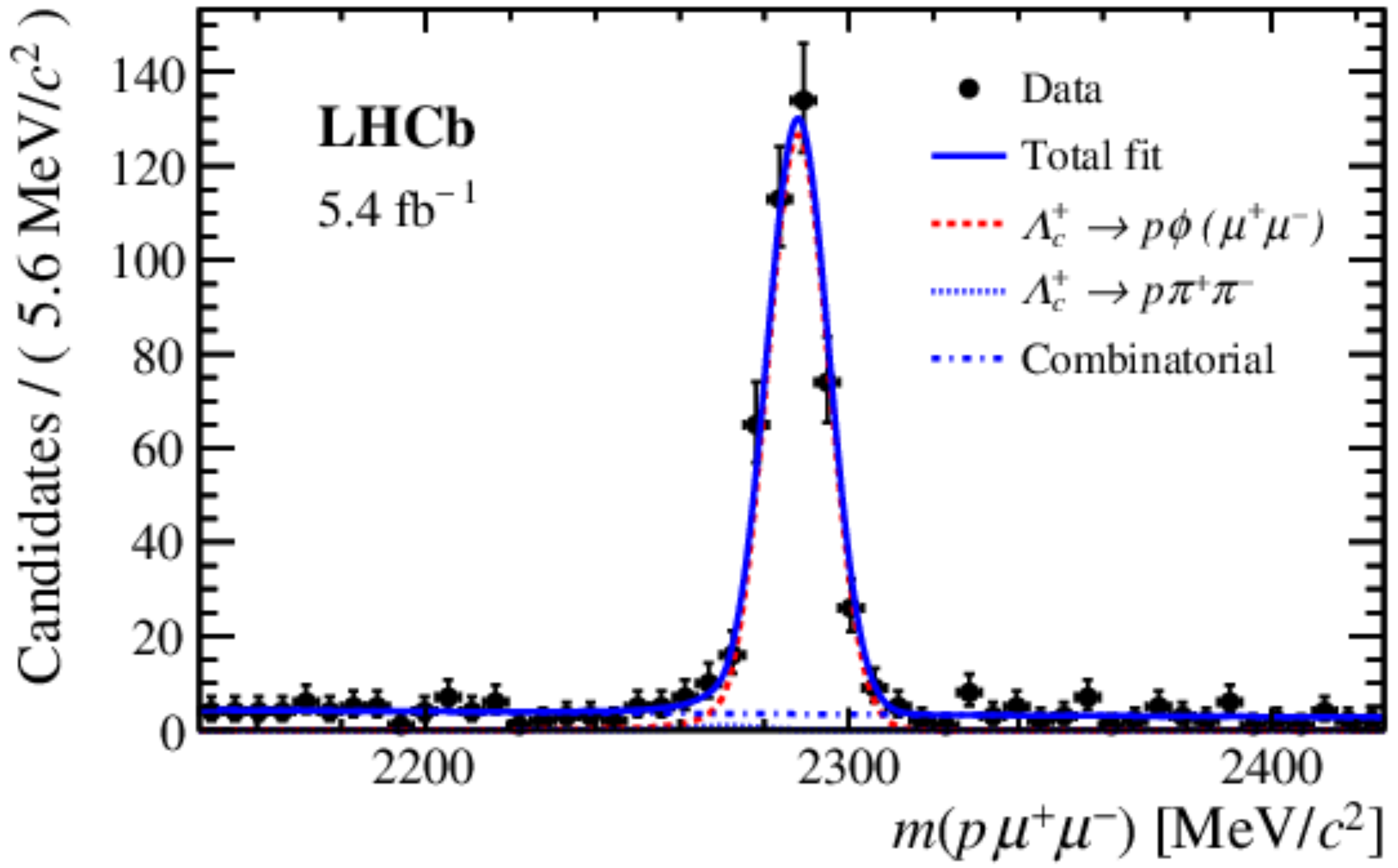


Low-Mass region	High-Mass region	Low+High
$N_{sig} = 1 \pm 5$	$N_{sig} = 21 \pm 8$	$N_{sig} = 18 \pm 10$
0.3σ	2.8σ	2.0σ

Phys. Rev. D 110, 052007

Resonant region fits and results

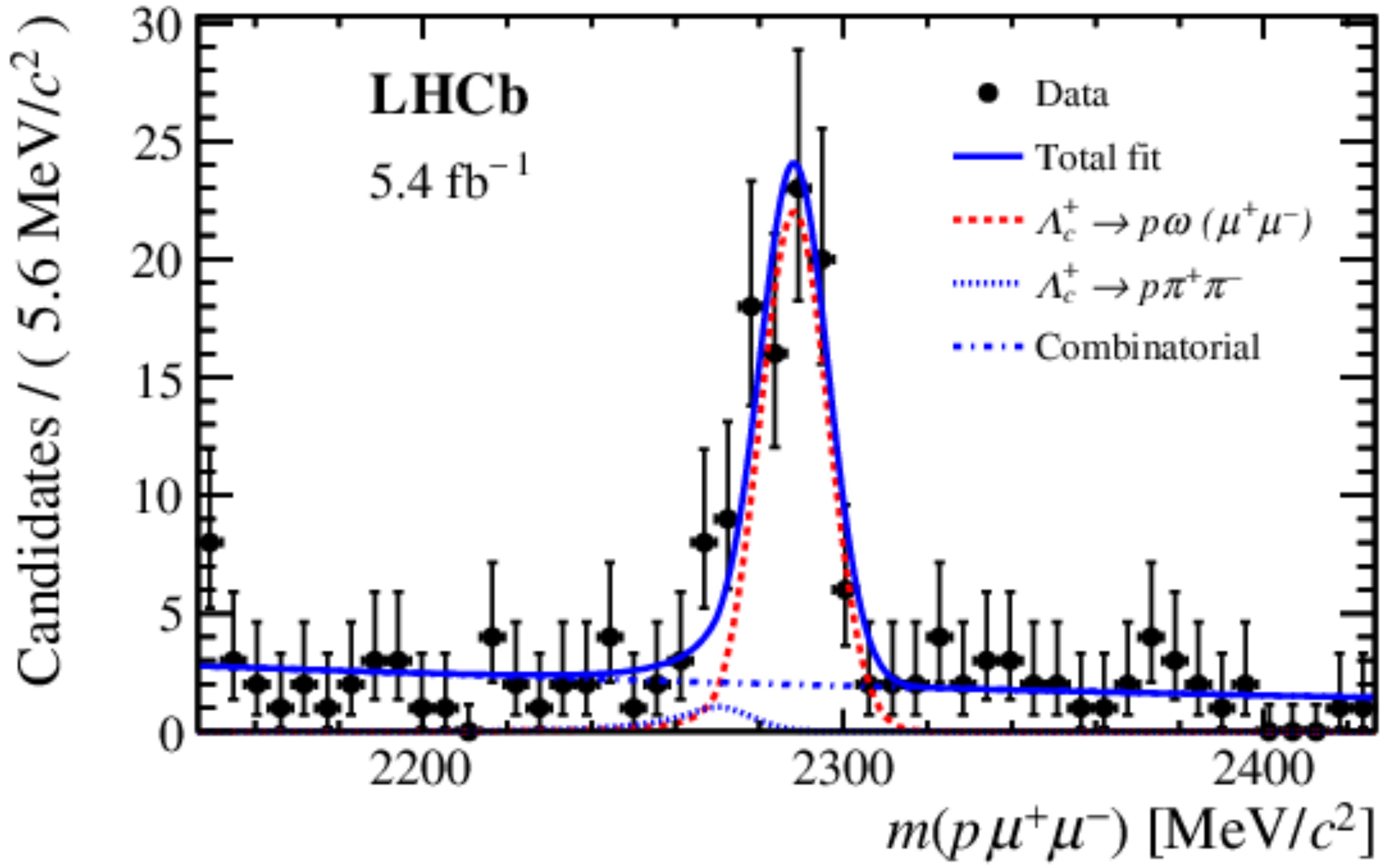




$\Lambda_c \to p\phi$

$N_{sig} = 423 \pm 21$

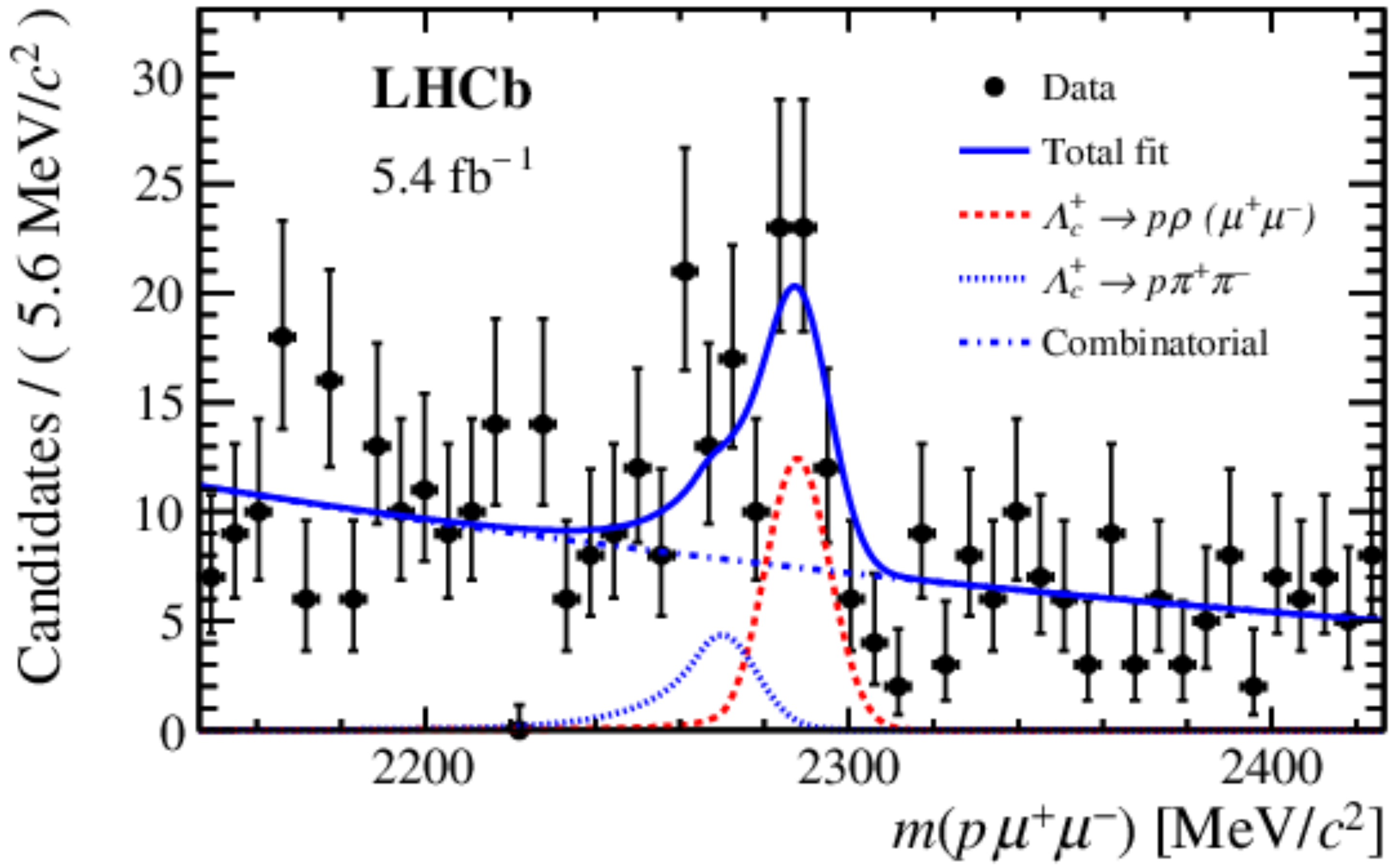
$> 7\sigma$ observation



$\Lambda_c \to p\omega$

$N_{sig} = 81 \pm 10$

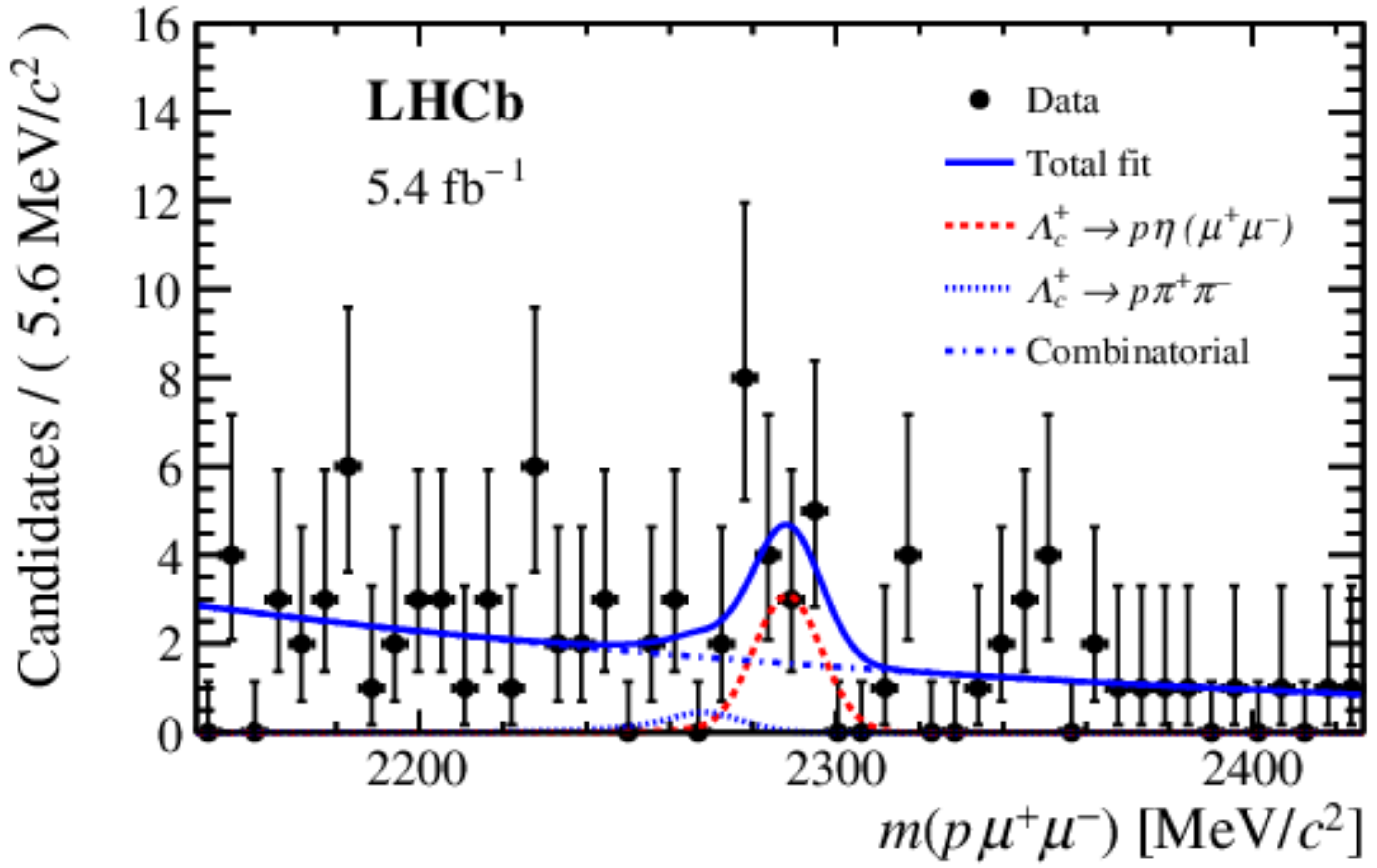
$> 7\sigma$ observation



$\Lambda_c \to p\rho$

$N_{sig} = 43 \pm 10$

5.6σ observation



$\Lambda_c \to p\eta$

$N_{sig} = 11 \pm 5$

3σ

Phys. Rev. D 110, 052007

Results

- No observation in the non-resonant region
- The following upper limits are set:

$$BF(\Lambda_c \to p\mu\mu) < 2.9\ (3.2) \times 10^{-8} \text{ at } 90\,\%\,,(95\%) \text{ CL High+Low}$$

$$BF(\Lambda_c \to p\mu\mu) < 3.0\ (3.3) \times 10^{-8} \text{ at } 90\,\%\,,(95\%) \text{ CL High}$$

$$BF(\Lambda_c \to p\mu\mu) < 0.93\ (1.1) \times 10^{-8} \text{ at } 90\,\%\,,(95\%) \text{ CL Low}$$

$$BF(\Lambda_c \to p\mu\mu) < 7.3\ (8.2) \times 10^{-8} \text{ at } 90\,\%\,,(95\%) \text{ CL extrapolated to the full phase space}$$

- In the resonant regions observation in ϕ, ω, ρ regions
- Resulting branching fractions:

$$BF(\Lambda_c \to p\omega) = \left(9.82 \pm 1.23(\text{stat.}) \pm 0.73(\text{syst.}) \pm 2.79(\text{ext.})\right) \times 10^{-4}$$

$$BF(\Lambda_c \to p\rho) = \left(1.52 \pm 0.34(\text{stat.}) \pm 0.14(\text{syst.}) \pm 0.24(\text{ext.})\right) \times 10^{-3}$$

$$BF(\Lambda_c \to p\eta) = \left(1.67 \pm 0.69(\text{stat.}) \pm 0.23(\text{syst.}) \pm 0.34(\text{ext.})\right) \times 10^{-3}$$

Phys. Rev. D 110, 052007

Mixing and CPV

Mixing of $D^0 - \overline{D}^0$ mesons formalism

- Time evolution can be described with effective hamiltonian

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

- Mixing parameters defined as

$$x_{12} \equiv \frac{2|M_{12}|}{\Gamma} \simeq \frac{\Delta m}{\Gamma}, \; y_{12} \equiv \frac{|\Gamma_{12}|}{\Gamma} \simeq \frac{\Delta\Gamma}{\Gamma}$$

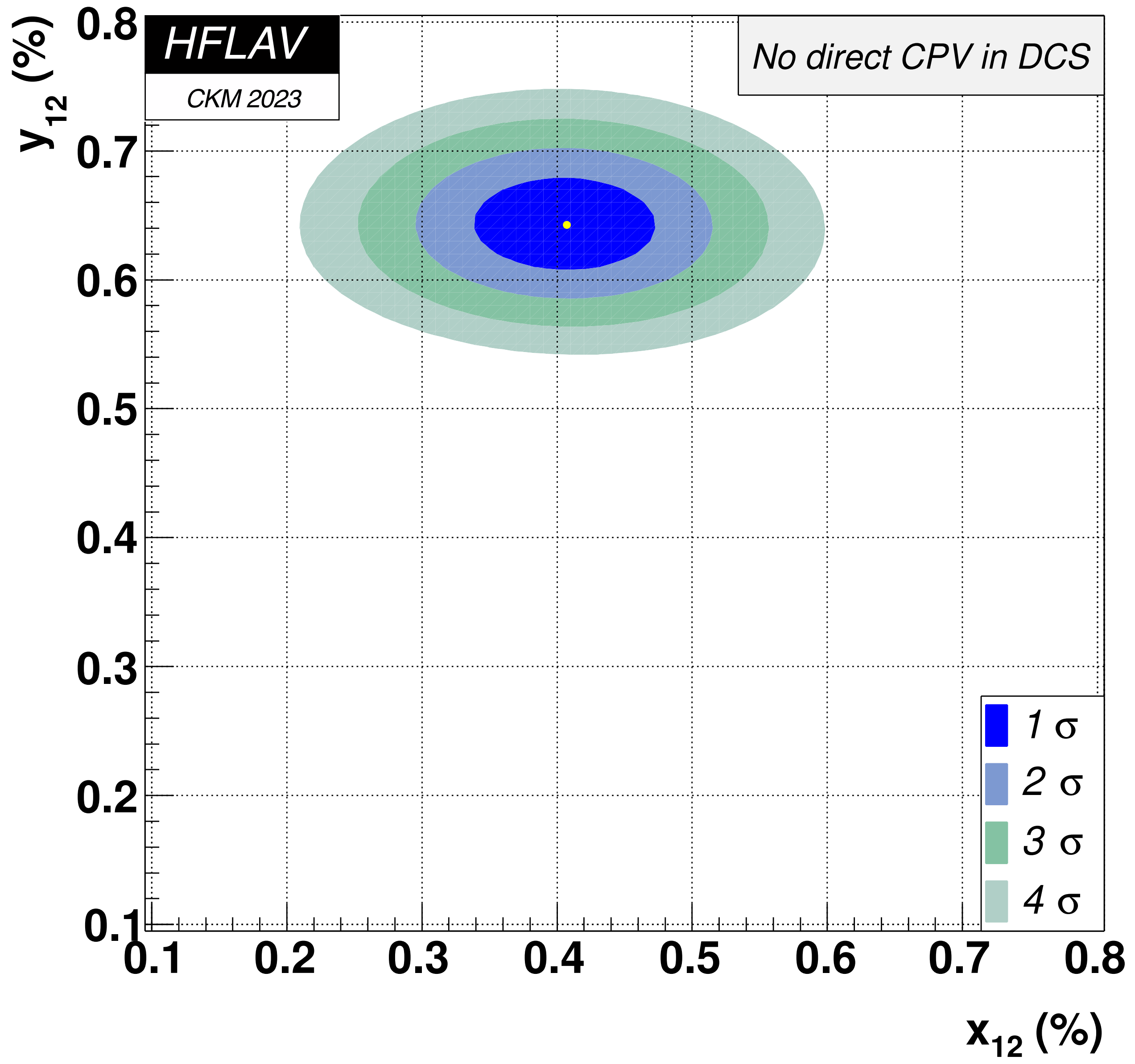
- CP violation in mixing governed by the absorptive and dispersive phase

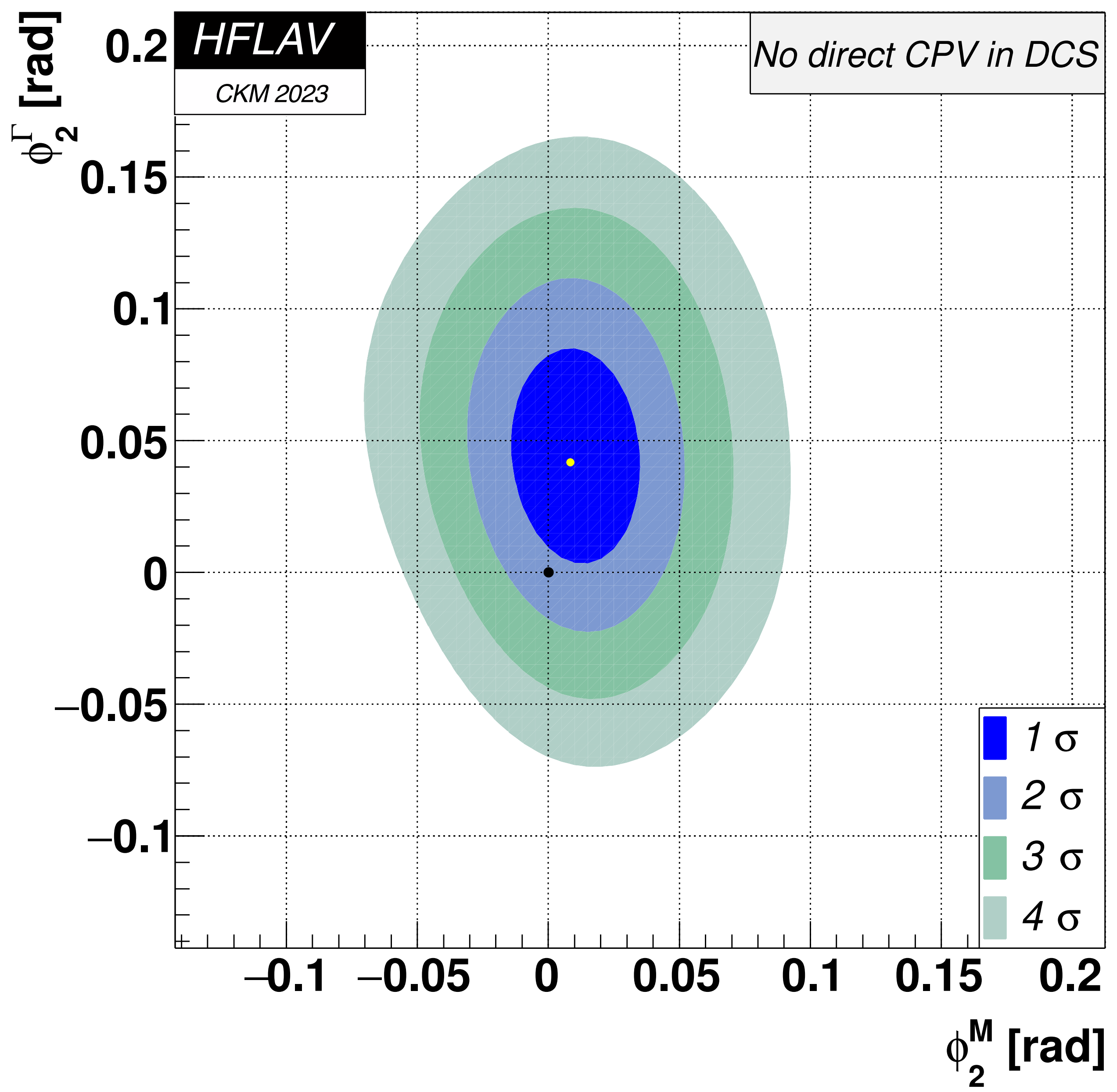
$$\phi_2^M \sim \arg(M_{12}), \; \phi_2^\Gamma \sim arg(\Gamma_{12})$$

- No evidence of CP violation with the current statistical precision
- Global best fit from HFLAV

$$x_{12} = (0.407 \pm 0.044)\,\% \qquad \phi_2^M = (0.48 \pm 0.92)^\circ$$

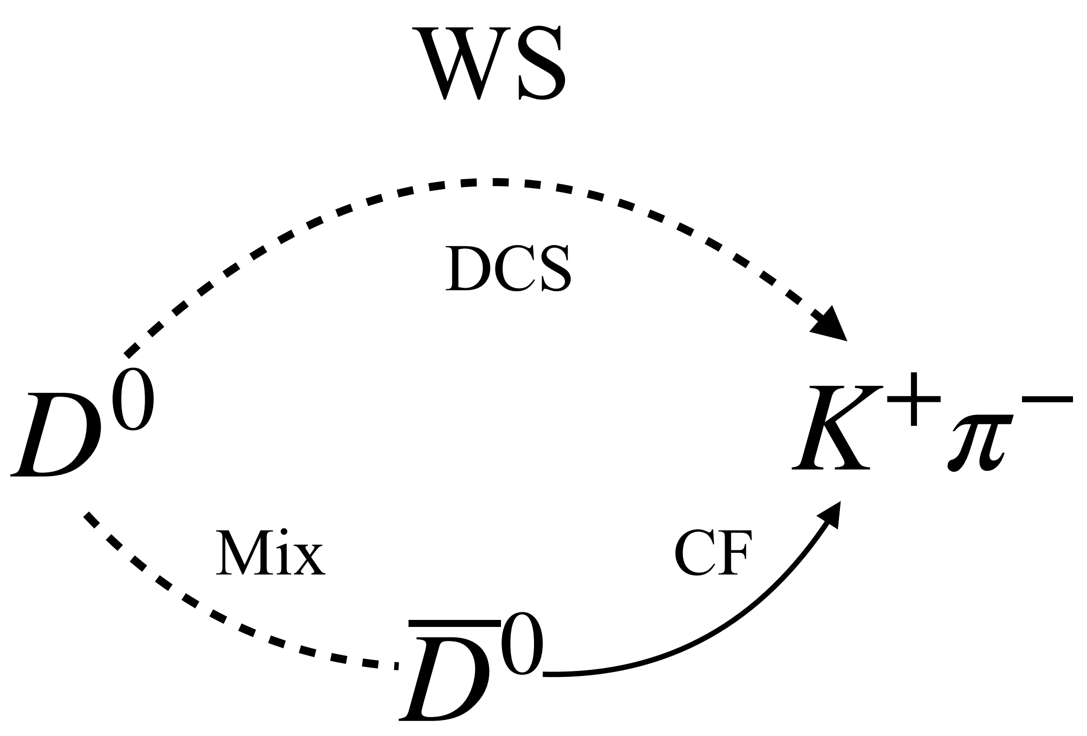
$$y_{12} = (0.641^{+0.024}_{-0.023})\,\% \qquad \phi_2^\Gamma = (2.40^{+1.55}_{-1.54})^\circ$$

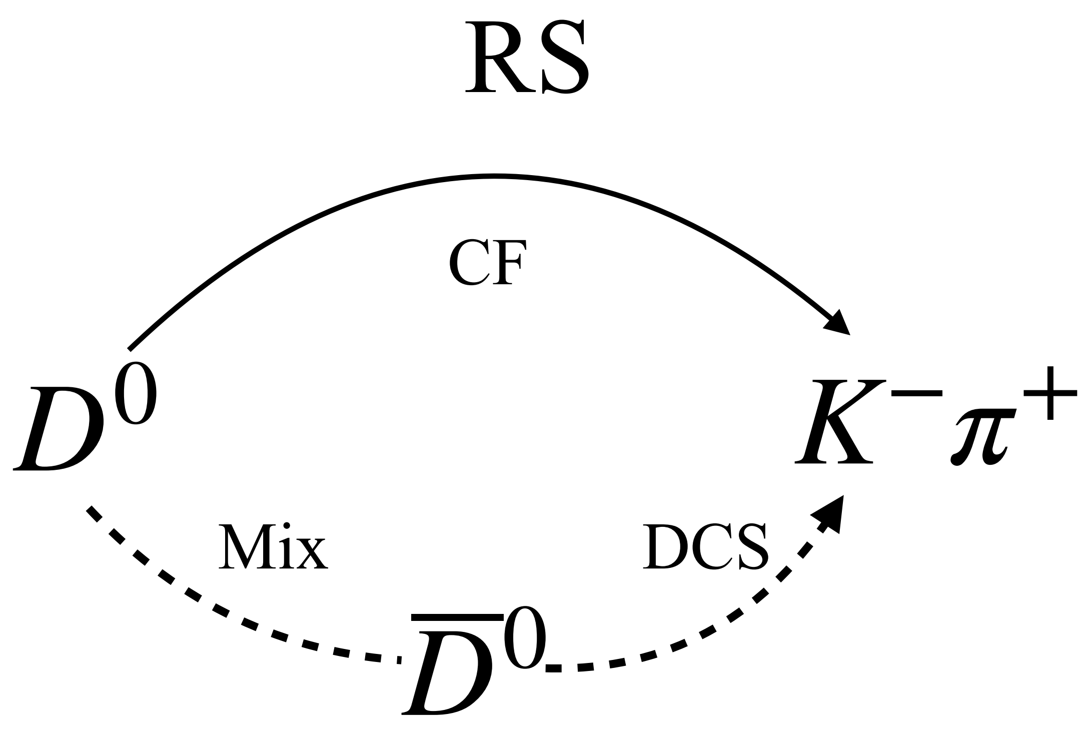




Measurement of $D^0 - \overline{D}^0$ mixing and search for CP violation with $D^0 \to K^+\pi^-$ decays

- D^0 mesons tagged from $D^{*+} \to D^0\pi_s^+$ strong decay, i.e. with the sign of the slow pion
- Final states of interest: Wrong sign (WS) $D^0 \to K^+\pi^-$ and Right sign (RS) $D^0 \to K^-\pi^+$





- Goal to measure the time-dependent ratio of WS/RS

$$R_{K\pi}^{+}(t) = \frac{\Gamma\left(D^0(t) \to K^+\pi^-\right)}{\Gamma\left(\overline{D}^0(t) \to K^+\pi^-\right)} \quad \text{and} \quad R_{K\pi}^{-}(t) = \frac{\Gamma\left(\overline{D}^0(t) \to K^-\pi^+\right)}{\Gamma\left(D^0(t) \to K^-\pi^+\right)}$$

Observables and goals

[2407.18001](2407.18001)

- Decay time dependence of WS/RS ratio in unit of D^0 lifetime can be expressed as

$$R^{\pm}_{K\pi}(t) \simeq R_{K\pi}\left(1 \pm A_{K\pi}\right) + \sqrt{R_{K\pi}\left(1 \pm A_{K\pi}\right)}\left(c_{K\pi} \pm \Delta c_{K\pi}\right) t + \left(c'_{K\pi} \pm \Delta c'_{K\pi}\right) t^2$$

Observables:

- Mixing:
  - $c_{K\pi} \approx y_{12} \cos \phi_f^{\Gamma} \cos \Delta_f + x_{12} \cos \phi_f^M \sin \Delta_f$
  - $c'_{K\pi} \approx \dfrac{y_{12}^2 + x_{12}^2}{4}$

  CP-even

- CPV:
  - $A_{K\pi} \approx a^d_{DCS}$ — decay CPV
  - $\Delta c_{K\pi} \simeq x_{12} \sin \phi_f^M \cos \Delta_f - y_{12} \sin \phi_f^{\Gamma} \sin \Delta_f$ — mixing CPV
  - $\Delta c'_{K\pi} \approx \dfrac{1}{2} x_{12} y_{12} \sin(\phi_f^M - \phi_f^{\Gamma})$ — interference CPV

  CP-odd

- χ^2 fit to sum and difference of measured ratio of WS/RS to extract the observables
- More sensitive on linear coefficient rather than quadratic ones

Phys. Rev. D 103, 053008

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Experimental Strategy

2407.18001

- Full Run 2, 6fb^{-1}
- Sample divided by data taking period, in bins of t and D^0 final states
- Simultaneous binned fit to WS and RS to $m(D^0\pi)$ invariant mass distribution
- Similar fit for $D^0 \to KK$

Challenges

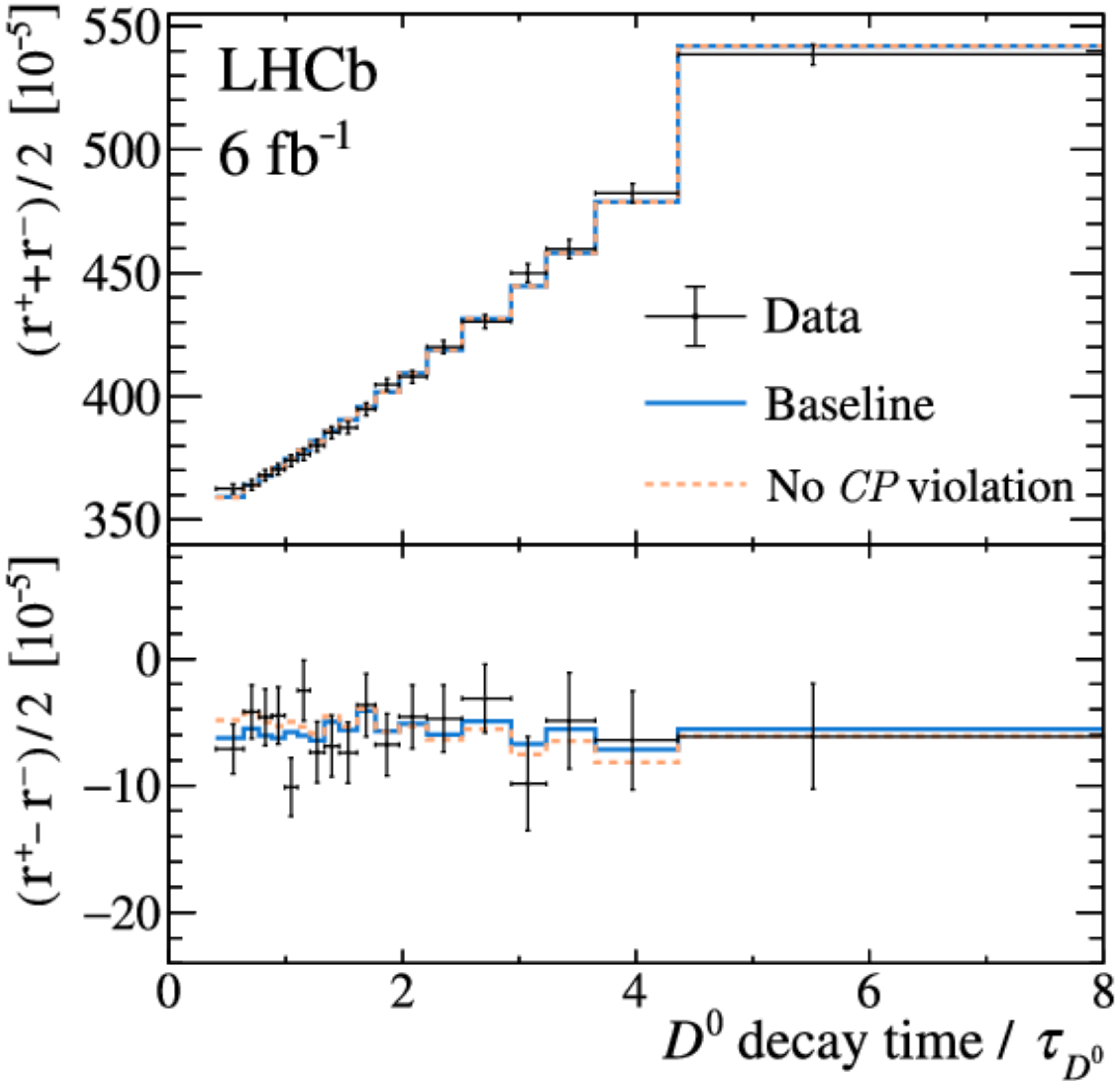
- Misassociation of tracks downstream of the magnet with upstream tracks turns RS soft pions in WS ghost soft pion that peaks in the mass distribution → pure ghost sample used as proxy to model the background
- Bias due to B produced D^{*+} → 2D template fit of t vs IP(D^0) to estimate residual bias
- $D^0 \to KK$ decay employed to cancel instrumental asymmetries

Results

- Uncertainties on observables statistically dominated and improved with respect to previous analysis of a factor 1.6
- First evidence for quadratic term $c'_{K\pi} \neq 0$ at 3.5σ
- All CPV observables compatible with 0: no evidence of CPV in mixing, decay or interference

Parameters		Correlations [%]					
		$R_{K\pi}$	$c_{K\pi}$	$c'_{K\pi}$	$A_{K\pi}$	$\Delta c_{K\pi}$	$\Delta c'_{K\pi}$
$R_{K\pi}$	$(342.7 \pm 1.9) \times 10^{-5}$	100.0	−92.7	80.3	0.9	−0.7	0.2
$c_{K\pi}$	$(52.8 \pm 3.3) \times 10^{-4}$		100.0	−94.2	−1.3	1.2	−0.7
$c'_{K\pi}$	$(12.0 \pm 3.5) \times 10^{-6}$			100.0	0.7	−0.7	0.2
$A_{K\pi}$	$(-6.6 \pm 5.7) \times 10^{-3}$				100.0	−91.9	79.7
$\Delta c_{K\pi}$	$(2.0 \pm 3.4) \times 10^{-4}$					100.0	−94.1
$\Delta c'_{K\pi}$	$(-0.7 \pm 3.6) \times 10^{-6}$						100.0

Run1+2 combination



2407.18001

Search for charge-parity violation in semileptonically tagged $D^0 \to K^+\pi^-$ decays

- D^0 mesons tagged from $D^{*+} \to D^0\pi_s^+$ strong decay with D^{*+} produced in $\overline{B} \to D^{*+}\mu^- X$ decays, i.e. double tag with soft pion and muon
- Similar final state of interest as in the prompt sample and similar approach to the analysis
- Much purer sample, different systematic uncertainties and more sensitivity to lower decay times with respect to the prompt analysis
- Different parametrization of time-dependent ratio of WS/RS with respect to the prompt analysis

$$R^{\pm} = R_D^{\pm} + \sqrt{R_D^{\pm}}\, y'^{\pm} \left(\frac{t}{\tau_{D^0}}\right) + \frac{(x'^{\pm})^2 + (y'^{\pm})^2}{4} \left(\frac{t}{\tau_{D^0}}\right)^2$$

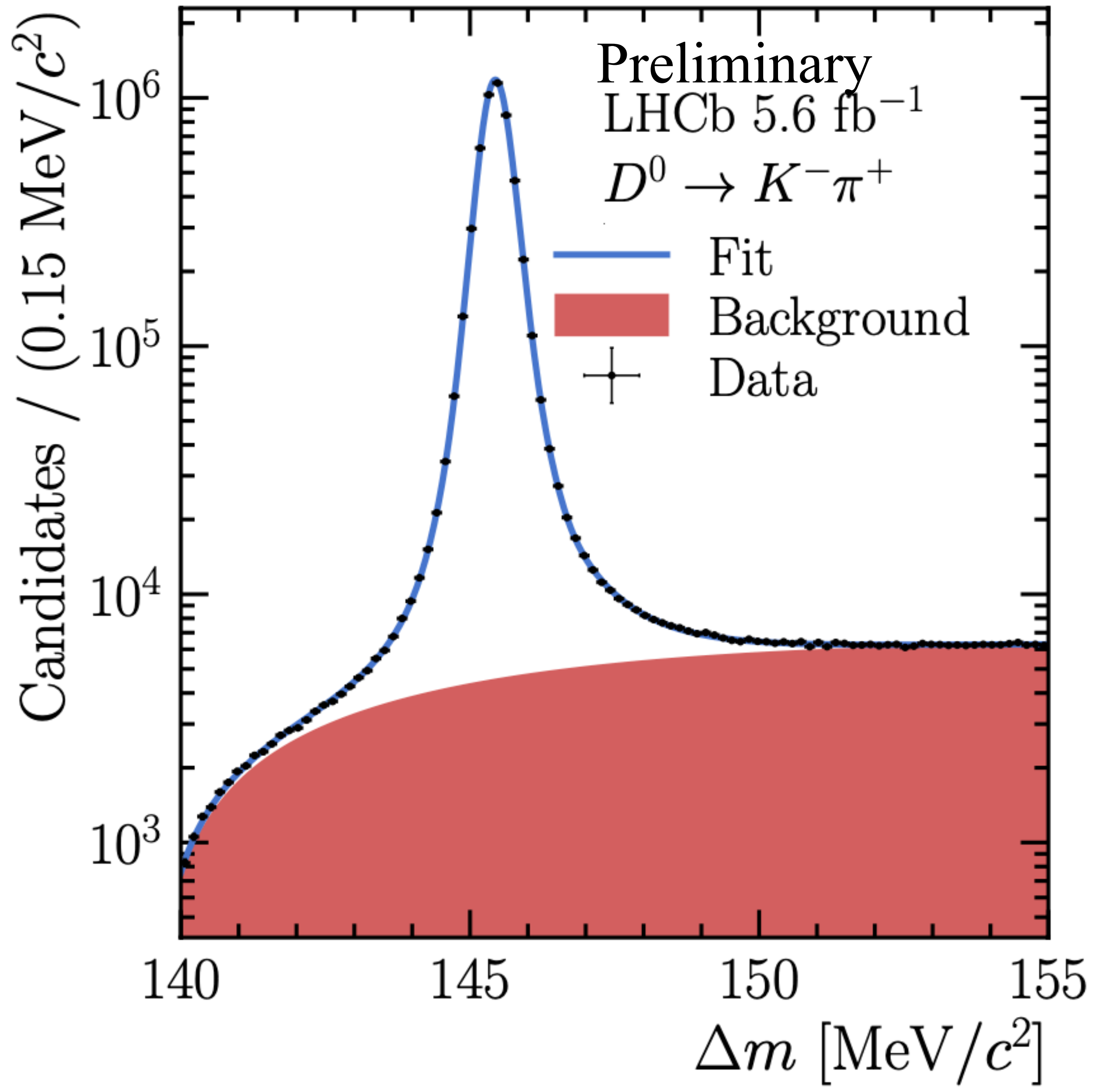
With $x'^{\pm}, y'^{\pm}$ defined as

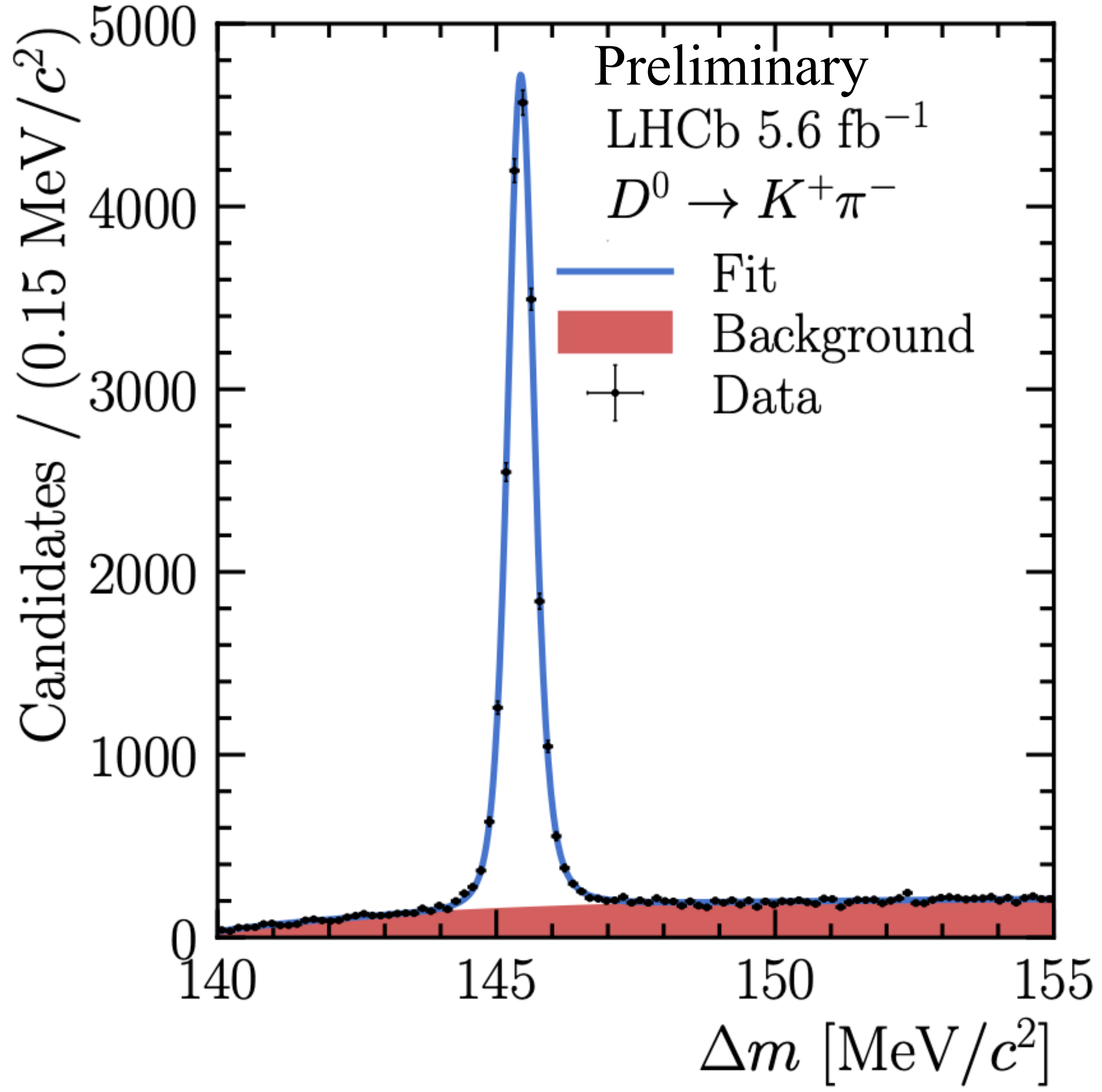
$$\begin{pmatrix} x'^{\pm} \\ y'^{\pm} \end{pmatrix} = |q/p|^{\pm 1} \begin{pmatrix} \cos[\delta \pm \phi] & \sin[\delta \pm \phi] \\ -\sin[\delta \pm \phi] & \cos[\delta \pm \phi] \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

LHCb-PAPER-2024-044 (in preparation)

Dataset and fits

- Run 2 dataset 5.6 fb^{-1}
- Analysis in bins of t in units of D^0 lifetime with similar statistics
- Main background coming from double Mis-ID RS decays contaminating WS sample
- Estimated empirically swapping the mass hypothesis in WS decays and with RS MC samples
- Signal modeled with a Johnson function and three Guassians





LHCb-PAPER-2024-044 (in preparation)

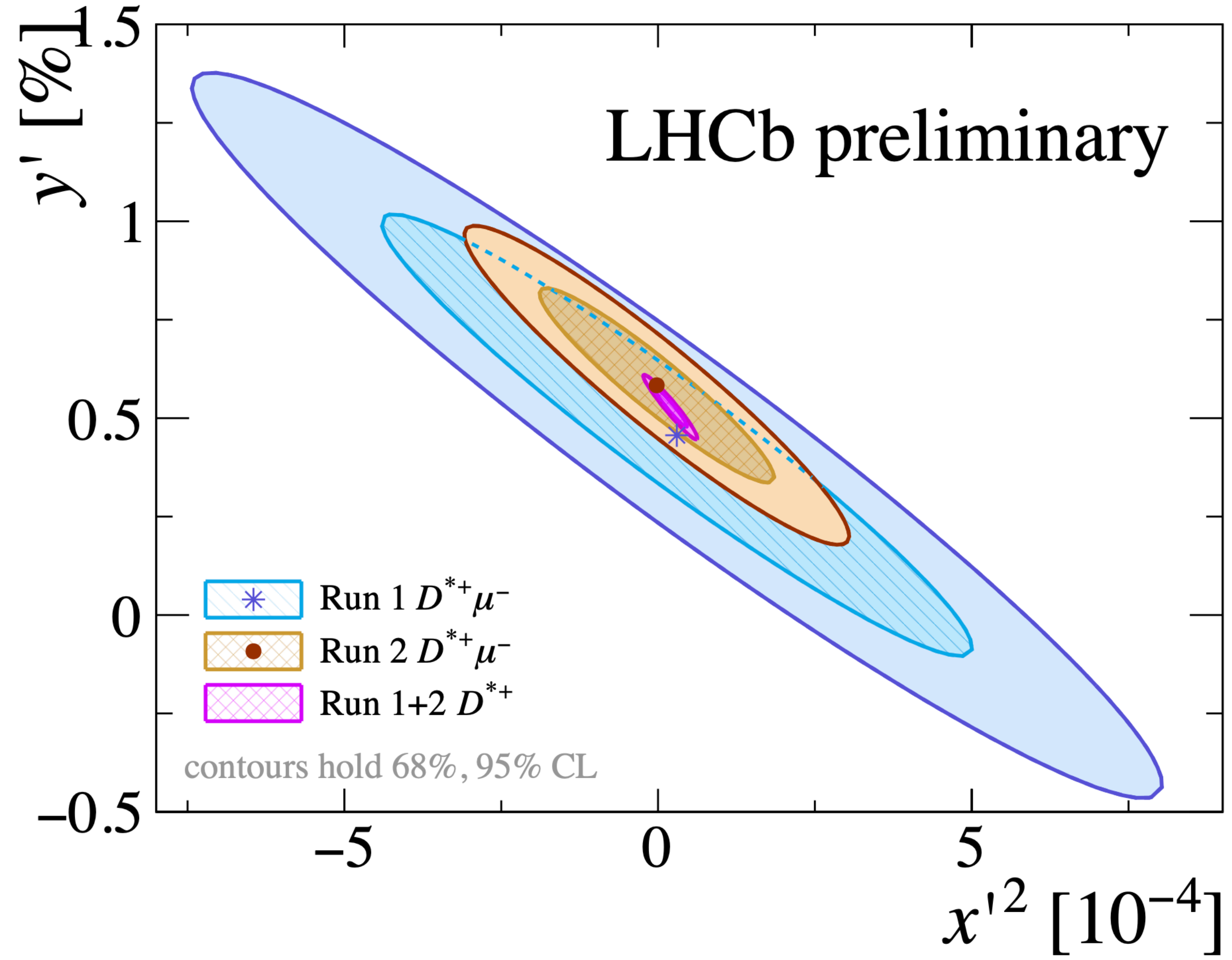
Results

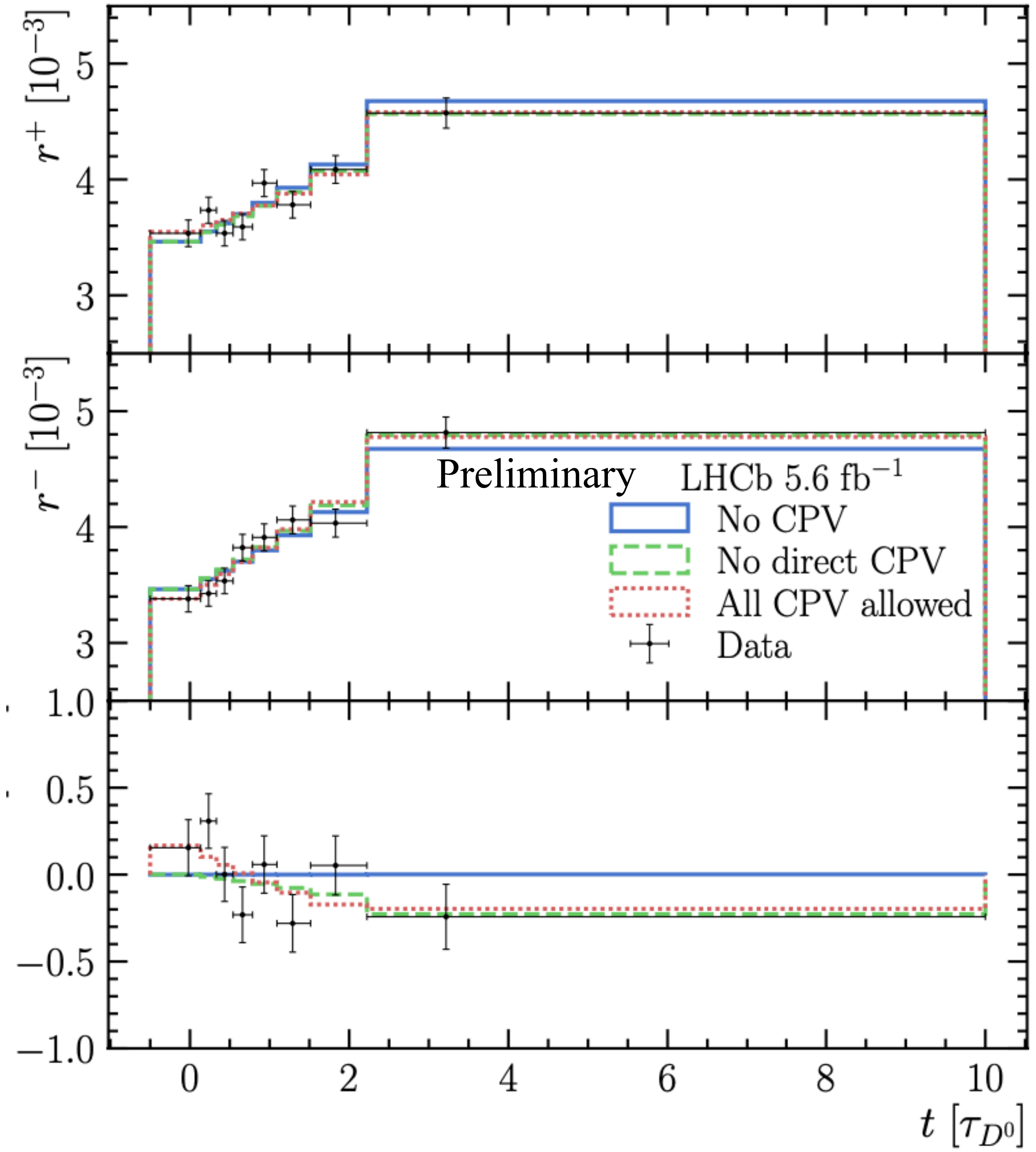
LHCb-PAPER-2024-044 (in preparation)

- Full parametrized fit to the ratio of WS/RS is performed along with different hypothesis on no direct CPV or no CPV in any combination
- Statistically dominated measurement and improvement on systematic uncertainties
- All results compatible with CP symmetry
- Work on-going to report the result with the same parameterizations as prompt analysis

Results of the full parametrized fit with CPV allowed

Parameter		Correlations [%]					
		R_D^+	y'^+	$(x'^+)^2$	R_D^-	y'^-	$(x'^-)^2$
R_D^+	$(3.55 \pm 0.08) \times 10^{-3}$	100.0	-76.8	63.9	-1.5	-0.1	0.0
y'^+	$(3.56 \pm 2.25) \times 10^{-3}$		100.0	-94.0	0.0	0.0	0.0
$(x'^+)^2$	$(10.86 \pm 16.23) \times 10^{-5}$			100.0	0.0	0.0	0.0
R_D^-	$(3.39 \pm 0.08) \times 10^{-3}$				100.0	-76.9	65.3
y'^-	$(8.11 \pm 2.36) \times 10^{-3}$					100.0	-95.0
$(x'^-)^2$	$(-11.29 \pm 18.59) \times 10^{-5}$						100.0





Measurement of CP violation observables in $D^+ \to K^-K^+\pi^+$ decays

- Model independent search with the largest branching fraction Cabibbo suppressed decay
- To eliminate instrumental asymmetries Cabibbo favored decay $D_s^+ \to K^-K^+\pi^+$ with the same final state
- Strong phases can vary across the Dalitz plot → possible enhancement of local asymmetries
- Same transition of $D^0 \to K^-K^+$ where no CPV has been found that led to $> 3\sigma$ effect on $D^0 \to \pi^-\pi^+$

Phys. Rev. Lett. 131, 091802

- Full Run 2 dataset 5.4 fb^{-1}
- Local CP asymmetry parametrized as

$$\Delta A^i_{CP} = A^{i,S}_{raw} - A^{i,C}_{raw} - \Delta A^{global}_{raw}$$

$$\Delta A^{global}_{raw} = \frac{\sum_i^{N_{bins}} \frac{A^{i,S}_{raw} - A^{i,C}_{raw}}{\sigma^2_{A^{i,S}_{raw}} + \sigma^2_{A^{i,C}_{raw}}}}{\sum_i^{N_{bins}} \frac{1}{\sigma^2_{A^{i,S}_{raw}} + \sigma^2_{A^{i,C}_{raw}}}}$$

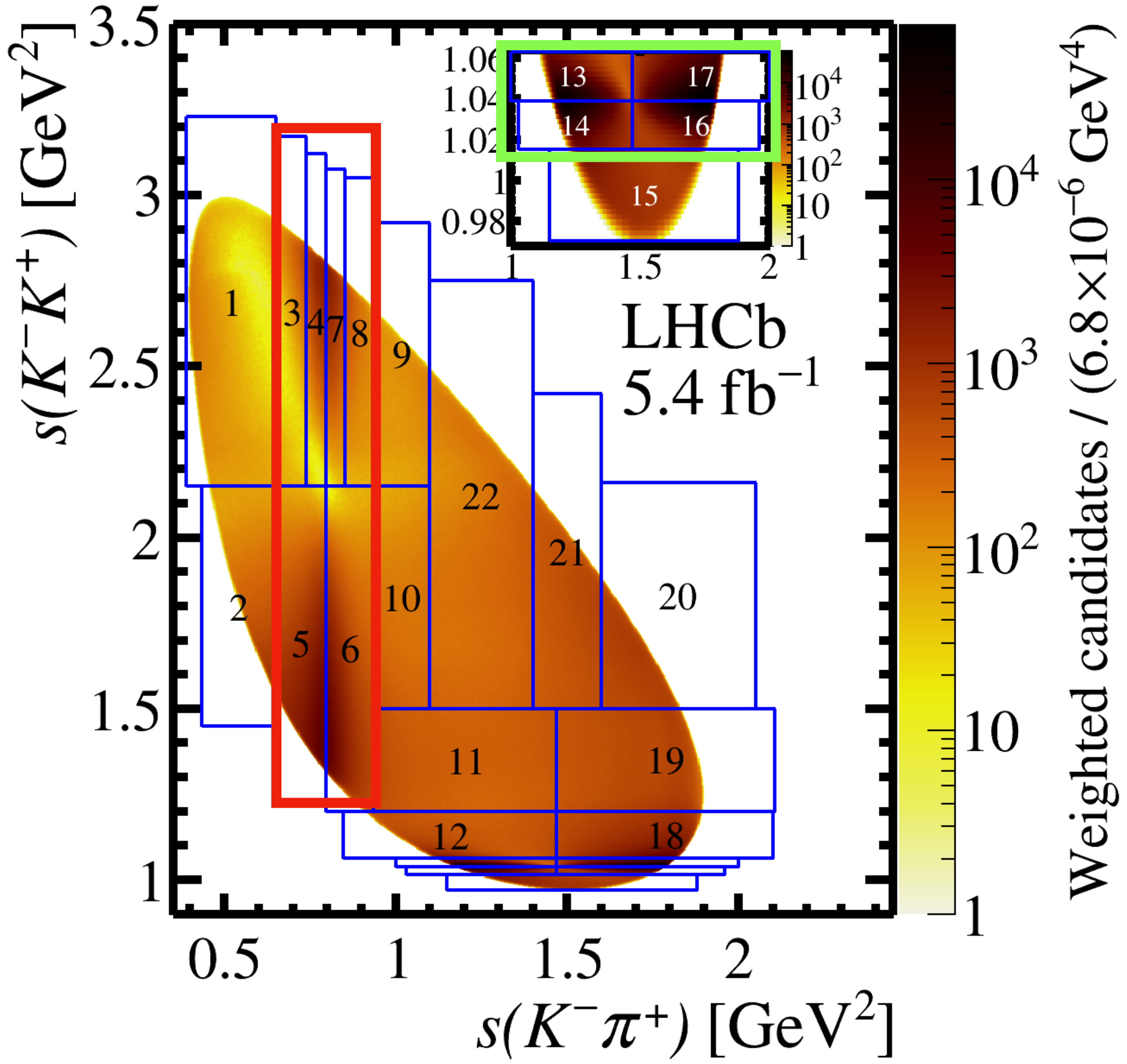
- ΔA^{global}_{raw} accounts for difference in production asymmetries between D^+ and D_s^+

2404.01414

Binning of Dalitz plot

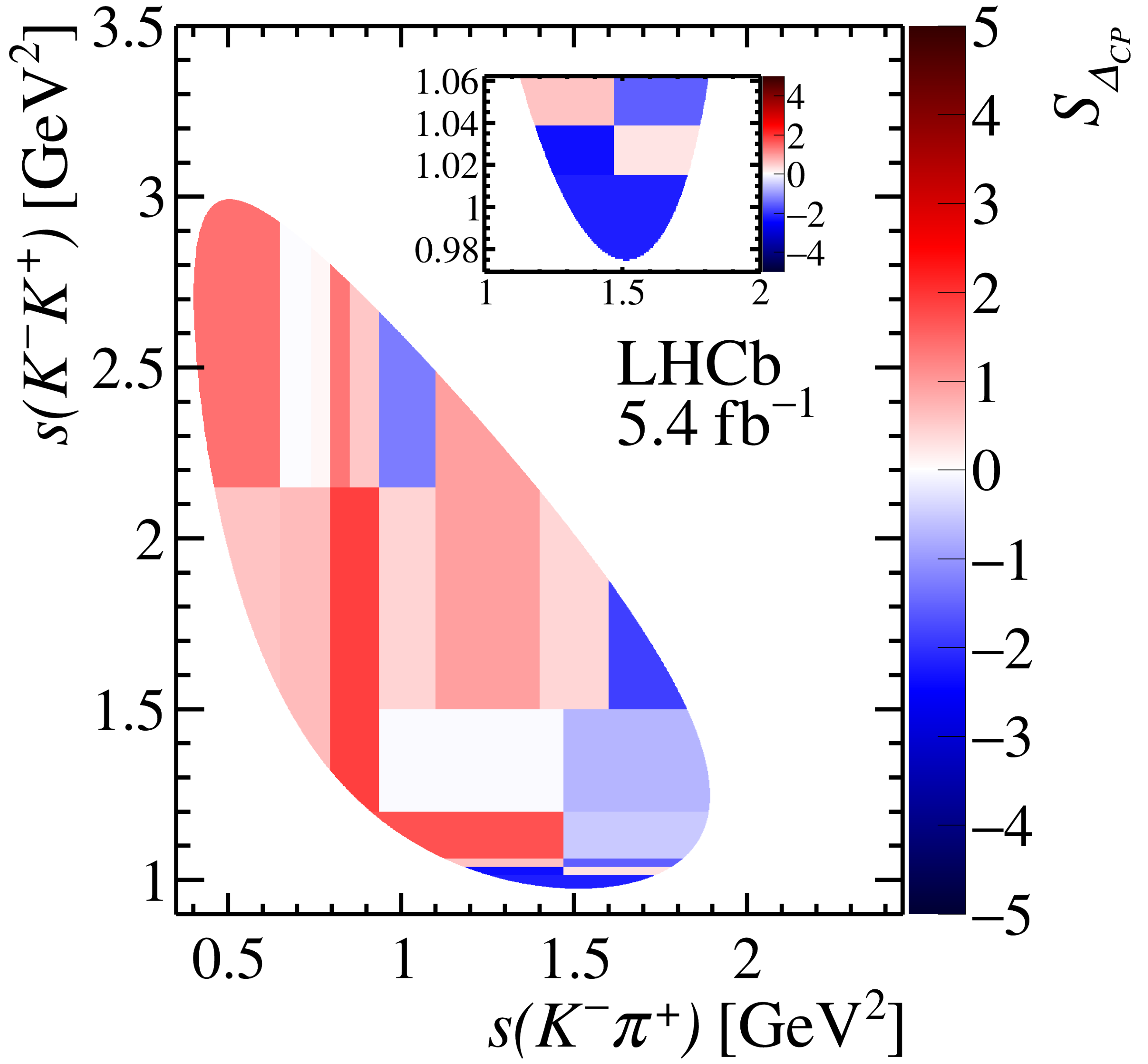
- Hypothesis of no local CP violation tested with

$$\chi^2(\mathcal{S}_{\Delta_{CP}}) = \sum_i^{N_{bins}} (\mathcal{S}^i_{\Delta_{CP}})^2 \text{ with } \mathcal{S}^i_{\Delta_{CP}} = \frac{\Delta A^i_{CP}}{\sigma^2_{\Delta A^i_{CP}}}$$



- For $D^+ \to K^{*0}K^+$ and $D^+ \to \phi\pi^+$ the CP asymmetry is expected to change sign crossing the resonance vertically and horizontally
- Around these resonances CP asymmetry is measured as

$$A_{CP|S} = \frac{1}{2}\left[\left(\Delta A_{raw}^{\text{top-left}} + \Delta A_{raw}^{\text{bottom-right}}\right) - \left(\Delta A_{raw}^{\text{top-right}} + \Delta A_{raw}^{\text{bottom-left}}\right)\right]$$



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Results

- No localized CP violation in $D^+ \to K^-K^+\pi^+$ found

$$\chi^2/n_{d.o.f.} = 31.8/22 \to p\text{-}value = 8.1\,\%$$

- Measurement of CP asymmetries around resonances compatible with hypothesis of CP symmetry

$$A_{CP|S}^{\phi\pi^+} = \left(0.95 \pm 0.43_{(\text{stat})} \pm 0.26_{(\text{syst})}\right) \times 10^{-3}$$

$$A_{CP|S}^{K^{*0}K^+} = \left(-0.26 \pm 0.56_{(\text{stat})} \pm 0.18_{(\text{syst})}\right) \times 10^{-3}$$

- On-going effort from LHCb to also search for CP violation in $D^+ \to \pi^-\pi^+\pi^+$

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Search for CPV in $D^+_{(s)} \to K^0_s K^- \pi^+ \pi^+$ decays

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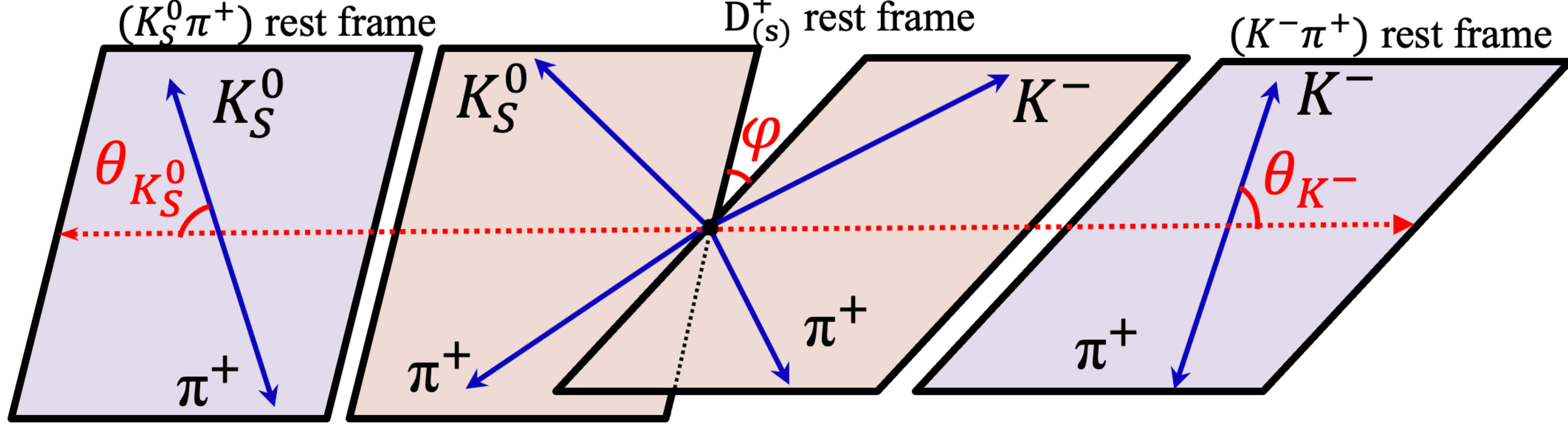
Analysis Strategy



- Model independent search with full Belle+BelleII dataset
- Analysis performed with 6 different kinematic observables
- Measure $a_{CP} = \frac{1}{2}(A_X - \overline{A}_X)$ with A_X asymmetry in kinematic observable X
- a_{CP} unaffected by production and reconstruction asymmetry
- Divide the sample in regions of X

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$$N(D^+_{(s)}, X > 0) = \frac{N^+}{2}(1 + A_X) \quad N(D^+_{(s)}, X < 0) = \frac{N^+}{2}(1 - A_X)$$

$$N(D^-_{(s)}, \overline{X} > 0) = \frac{N^-}{2}(1 + A_X - 2a_{CP}) \quad N(D^-_{(s)}, \overline{X} < 0) = \frac{N^-}{2}(1 - A_X + 2a_{CP})$$

- Kinematic observables: C_{TP}, C_{QP}, $C_{TP} \cdot C_{QP}$, $\cos\theta_{K_S^0} \cdot \cos\theta_{K^-}$, $C_{TP} \cdot \cos\theta_{K_S^0} \cdot \cos\theta_{K^-}$ and $C_{QP} \cdot \cos\theta_{K_S^0} \cdot \cos\theta_{K^-}$

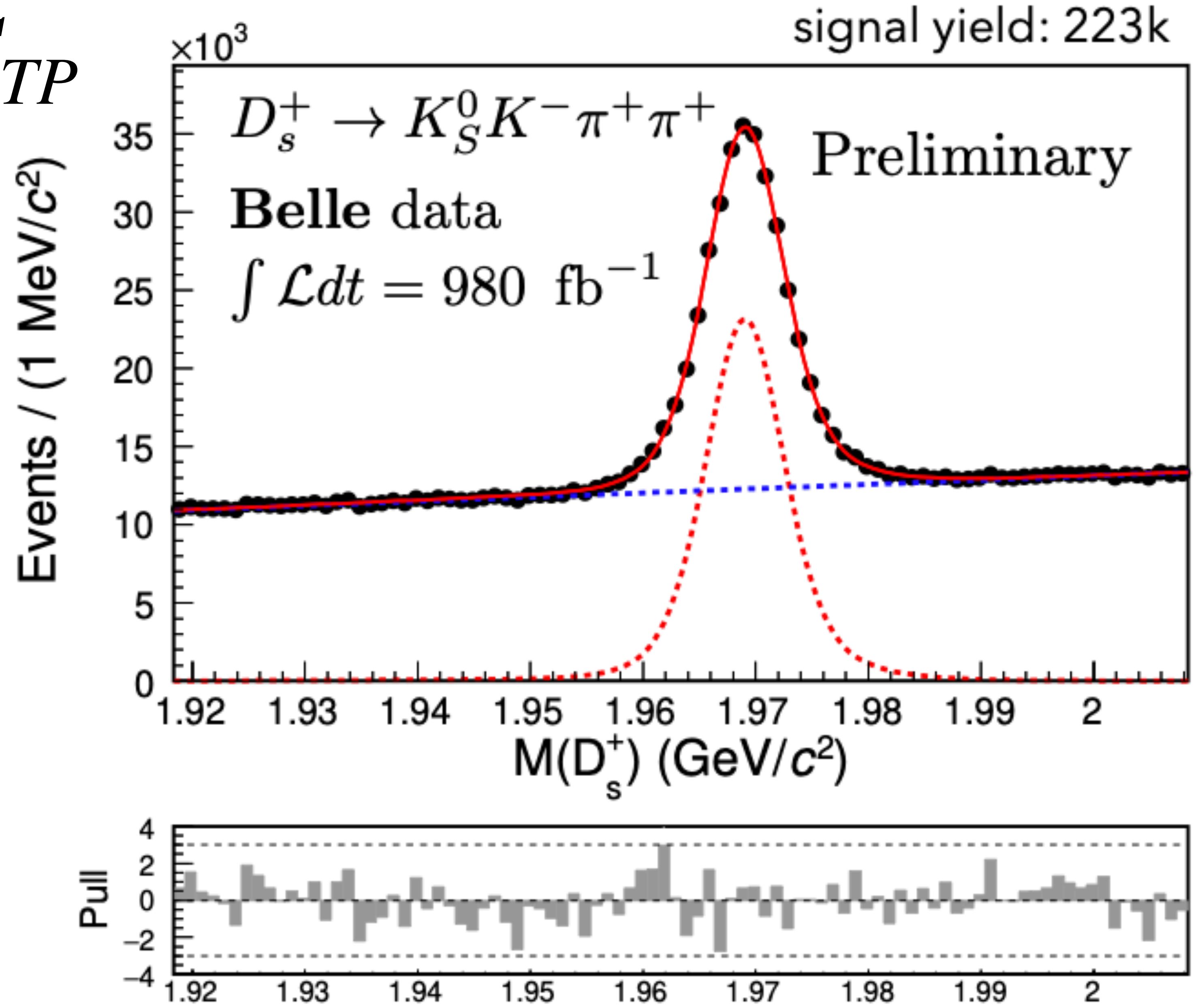
$$C_{TP} = \left(\vec{p}_{K^-} \times \vec{p}_{\pi_h^+}\right) \cdot \vec{p}_{K_S^0} \qquad C_{QP} = \left(\vec{p}_{K^-} \times \vec{p}_{\pi_h^+}\right) \cdot \left(\vec{p}_{K_S^0} \times \vec{p}_{\pi_l^+}\right)$$

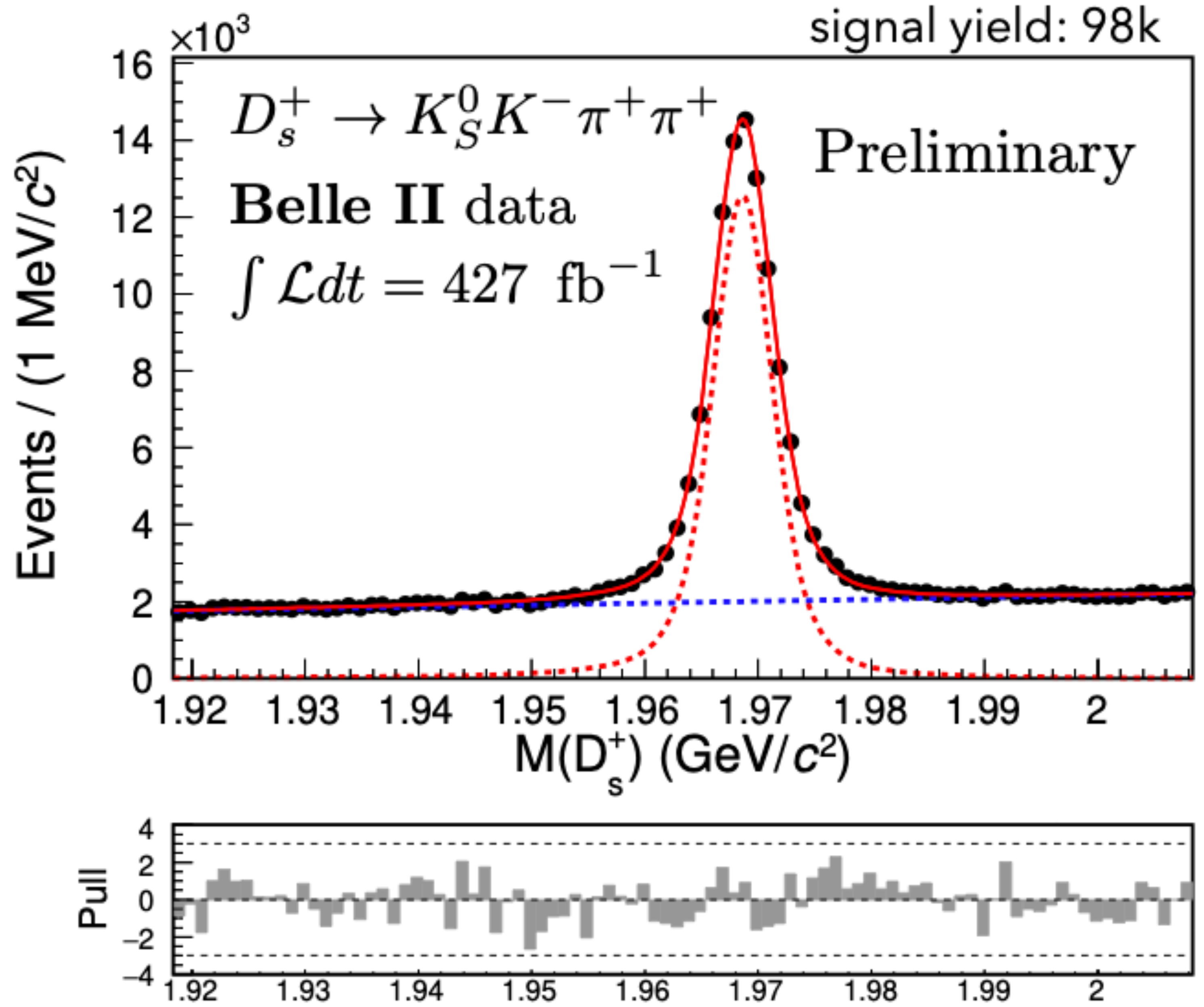
Results

- No evidence of direct CP violation
- Measurement among world's best precision results in this decay

	X	$\mathcal{A}_{CP}^{X}$ Belle $[10^{-3}]$	$\mathcal{A}_{CP}^{X}$ Belle II $[10^{-3}]$	Combined $\mathcal{A}_{CP}^{X}$ $[10^{-3}]$	Significance
D^+	$C_{\rm TP}$	$-4.0 \pm 5.9 \pm 3.0$	$-0.2 \pm 7.0 \pm 1.8$	$-2.3 \pm 4.5 \pm 1.5$	0.5σ
	$C_{\rm QP}$	$-1.0 \pm 5.9 \pm 2.5$	$-0.4 \pm 7.0 \pm 2.4$	$-0.7 \pm 4.5 \pm 1.7$	0.2σ
	$C_{\rm TP}\, C_{\rm QP}$	$+6.4 \pm 5.9 \pm 2.2$	$+0.6 \pm 7.0 \pm 1.3$	$+3.9 \pm 4.5 \pm 1.1$	0.8σ
	$\cos\theta_{K_S^0} \cos\theta_{K^-}$	$-4.7 \pm 5.9 \pm 3.0$	$-0.6 \pm 6.9 \pm 3.0$	$-2.9 \pm 4.5 \pm 2.1$	0.6σ
	$C_{\rm TP} \cos\theta_{K_S^0} \cos\theta_{K^-}$	$+1.9 \pm 5.9 \pm 2.0$	$-0.2 \pm 7.0 \pm 1.9$	$+1.0 \pm 4.5 \pm 1.4$	0.2σ
	$C_{\rm QP} \cos\theta_{K_S^0} \cos\theta_{K^-}$	$+14.9 \pm 5.9 \pm 1.4$	$+7.0 \pm 7.0 \pm 1.6$	$+11.6 \pm 4.5 \pm 1.1$	2.5σ
D_s^+	$C_{\rm TP}$	$-0.3 \pm 3.1 \pm 1.3$	$+1.0 \pm 3.9 \pm 1.1$	$+0.2 \pm 2.4 \pm 0.8$	0.1σ
	$C_{\rm QP}$	$+0.6 \pm 3.1 \pm 1.2$	$+2.0 \pm 3.9 \pm 1.4$	$+1.1 \pm 2.4 \pm 0.9$	0.4σ
	$C_{\rm TP}\, C_{\rm QP}$	$+1.5 \pm 3.2 \pm 1.4$	$-2.7 \pm 3.9 \pm 1.7$	$-0.2 \pm 2.5 \pm 1.1$	0.1σ
	$\cos\theta_{K_S^0} \cos\theta_{K^-}$	$-3.7 \pm 3.1 \pm 1.1$	$-6.3 \pm 3.9 \pm 1.2$	$-4.7 \pm 2.4 \pm 0.8$	1.8σ
	$C_{\rm TP} \cos\theta_{K_S^0} \cos\theta_{K^-}$	$-4.4 \pm 3.2 \pm 1.4$	$+0.8 \pm 3.9 \pm 1.4$	$-2.2 \pm 2.5 \pm 1.0$	0.8σ
	$C_{\rm QP} \cos\theta_{K_S^0} \cos\theta_{K^-}$	$-1.6 \pm 3.1 \pm 1.3$	$-0.0 \pm 3.9 \pm 1.7$	$-1.0 \pm 2.4 \pm 1.0$	0.4σ

Fits for C_{TP}





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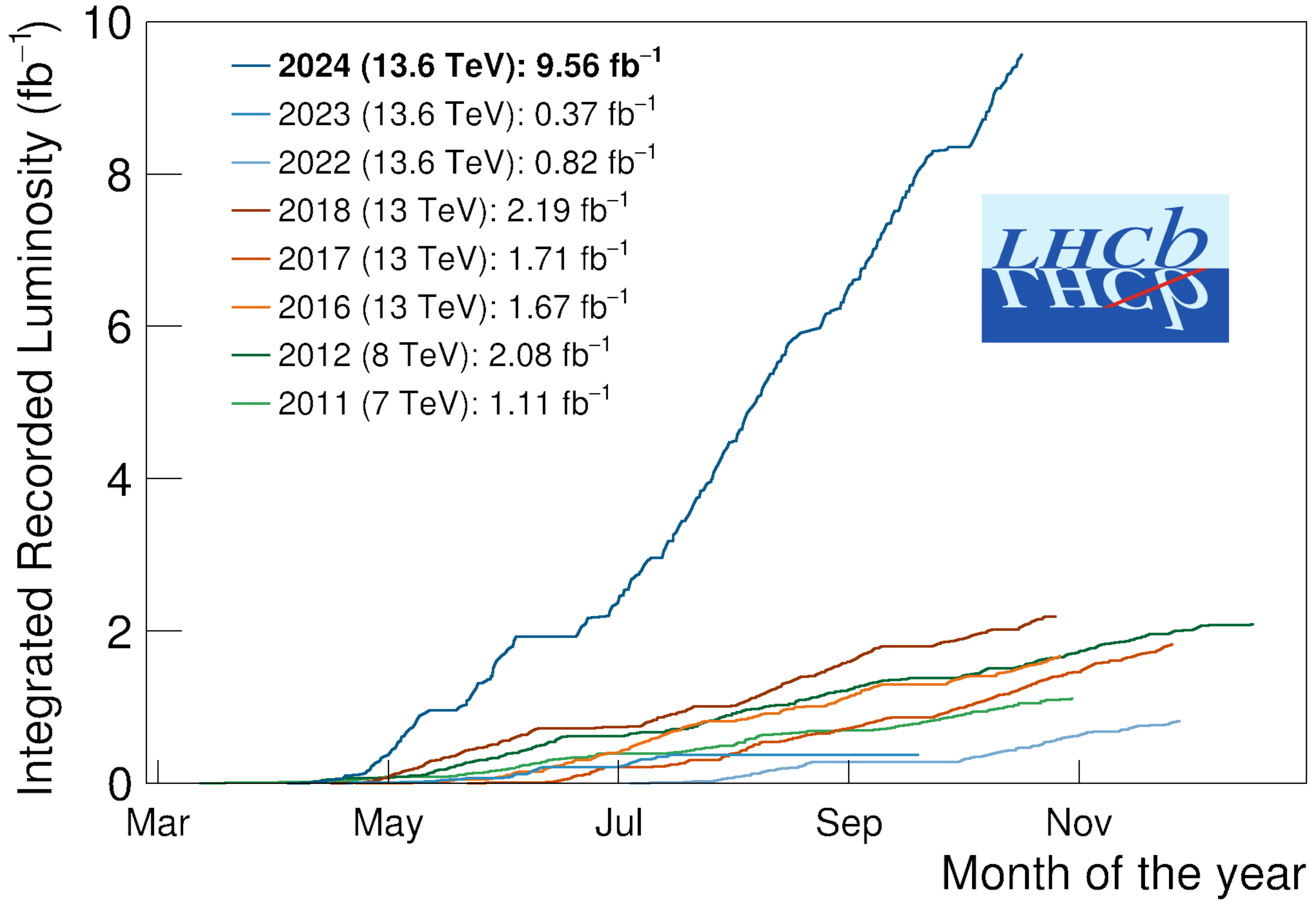
Conclusions and Outlooks

- Charm physics is a unique probe for new physics
- Many new measurement in the charm physics field with many different observables
- No evidence of CP violation in analyses presented today
- Increasing precision on many charm physics parameters

- Great prospects from LHCb with Run 3 dataset, larger than Run1+2
- New precision measurement will be possible
- Record luminosity of $> 9.5\ \mathrm{fb}^{-1}$



Thank you for your attention