LHCb overview

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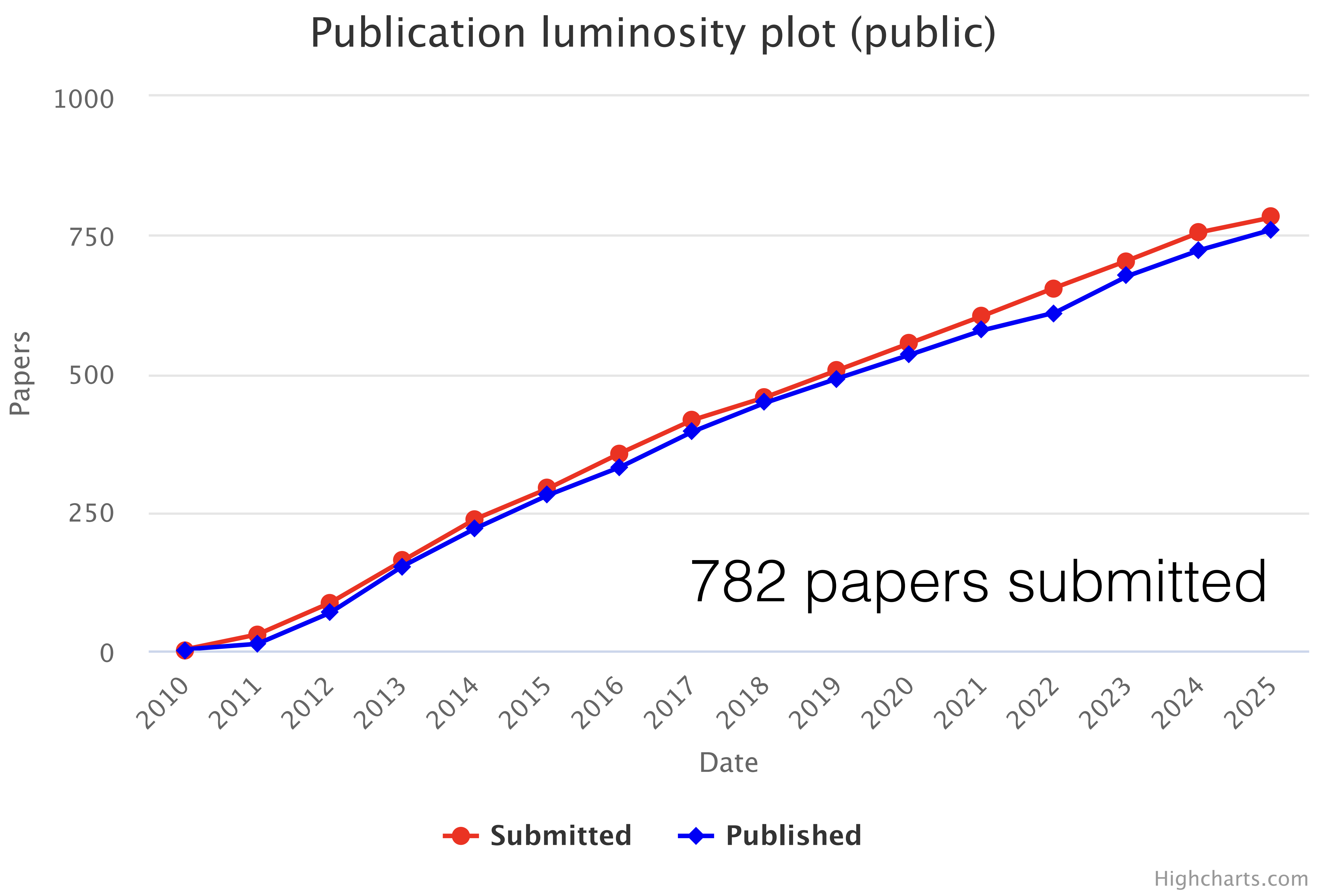
Outline

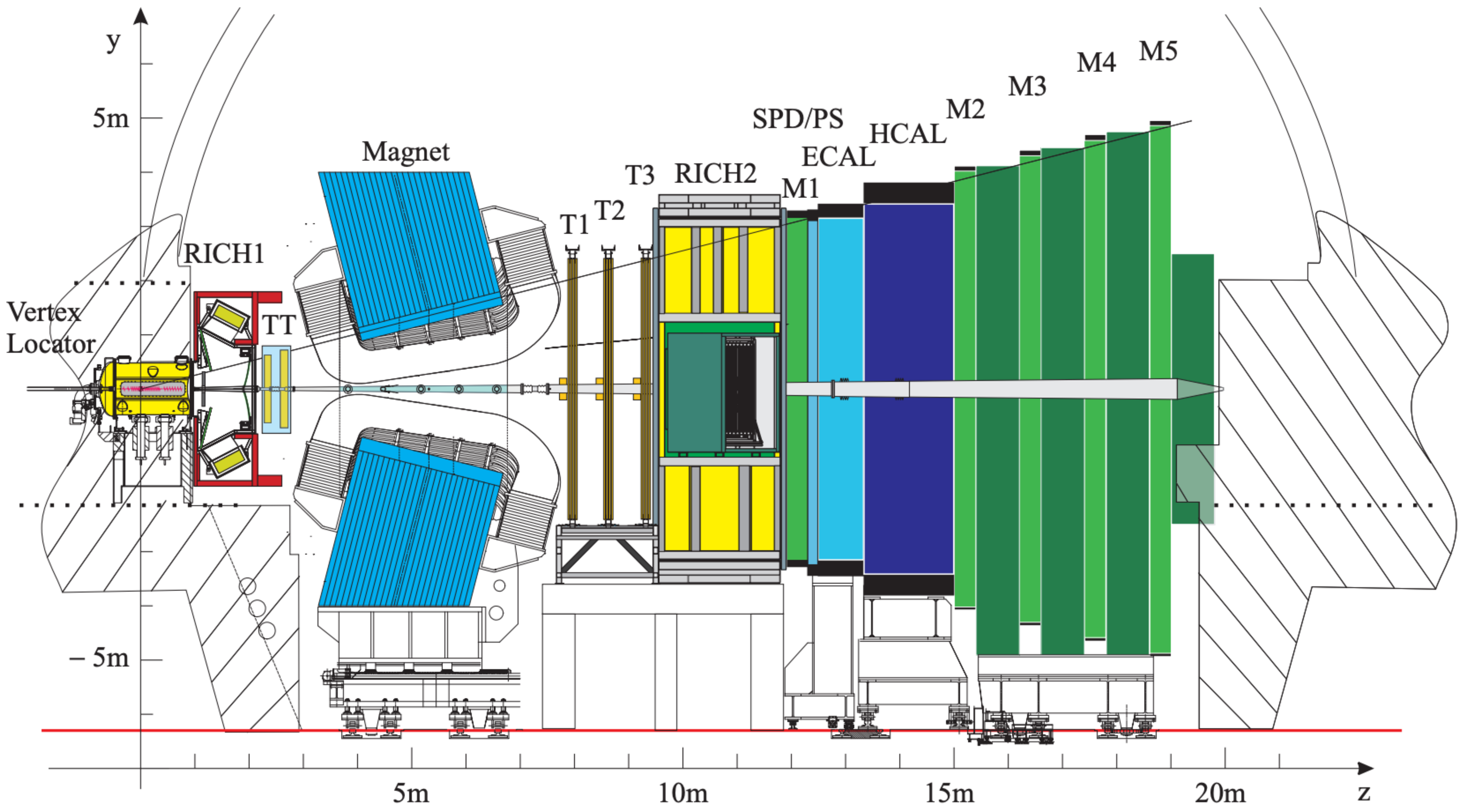
- Introduction
- Recent results
- Run 3 performance
- Prospects

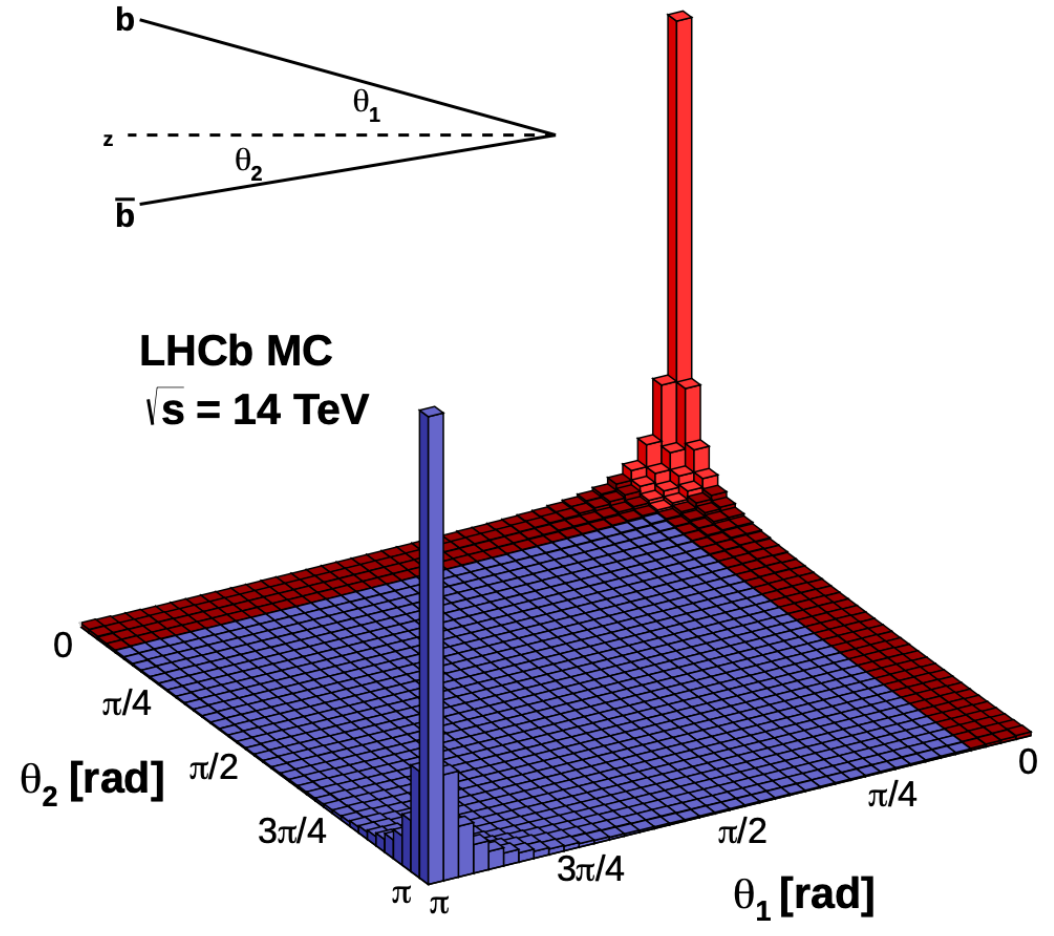


Disclaimer: this talk cannot cover all the recent results; you can refer to the publication page for a full list of LHCb publications

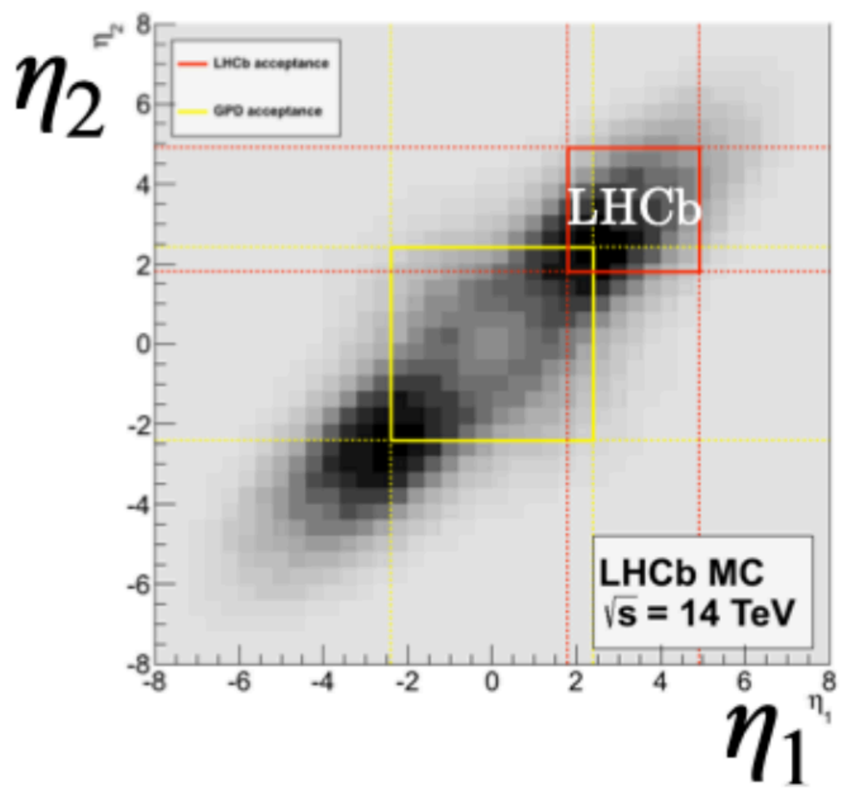
LHCb detector

General purpose detector specialised in beauty and charm hadrons





$2 < \eta < 5$

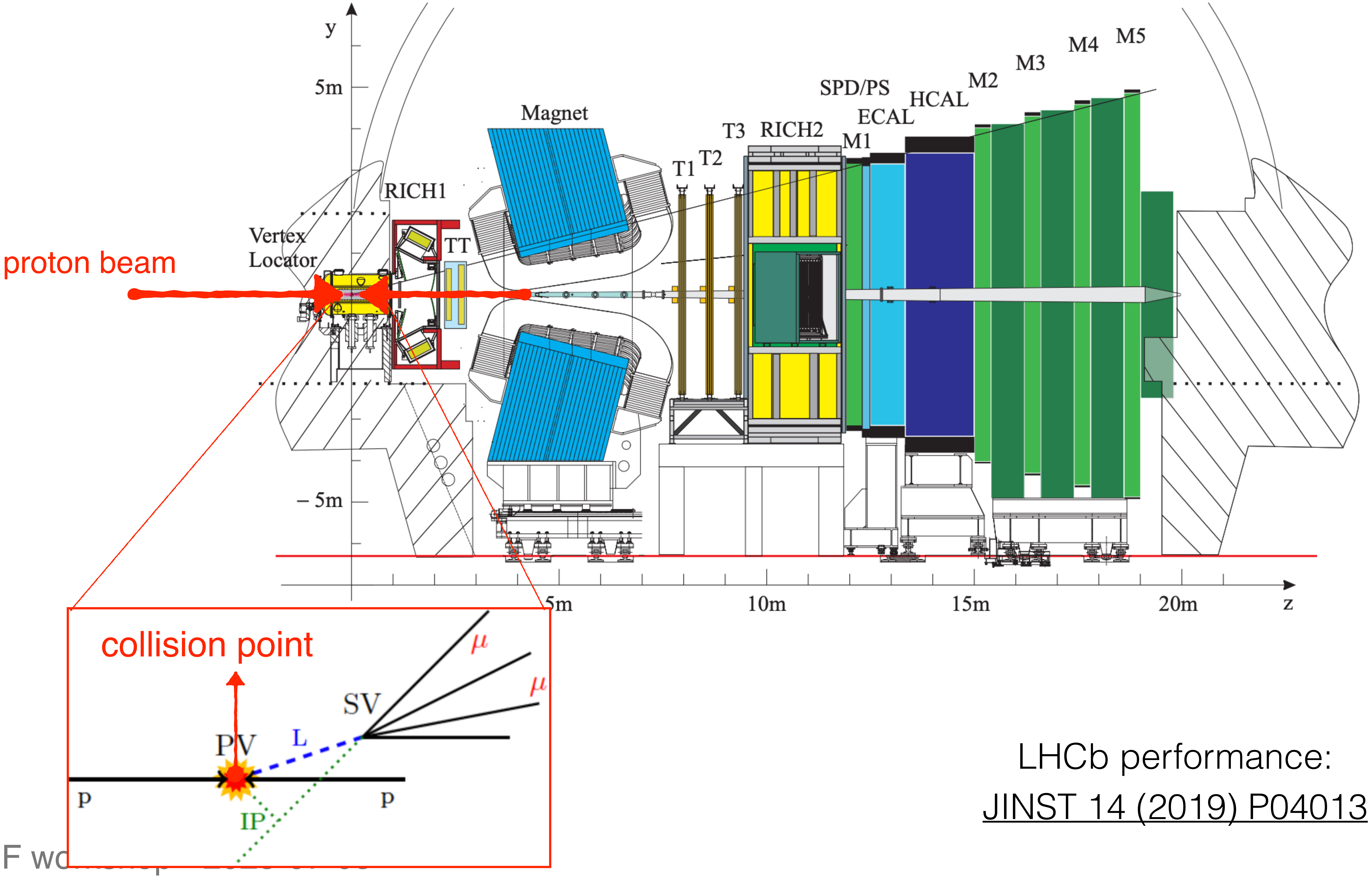


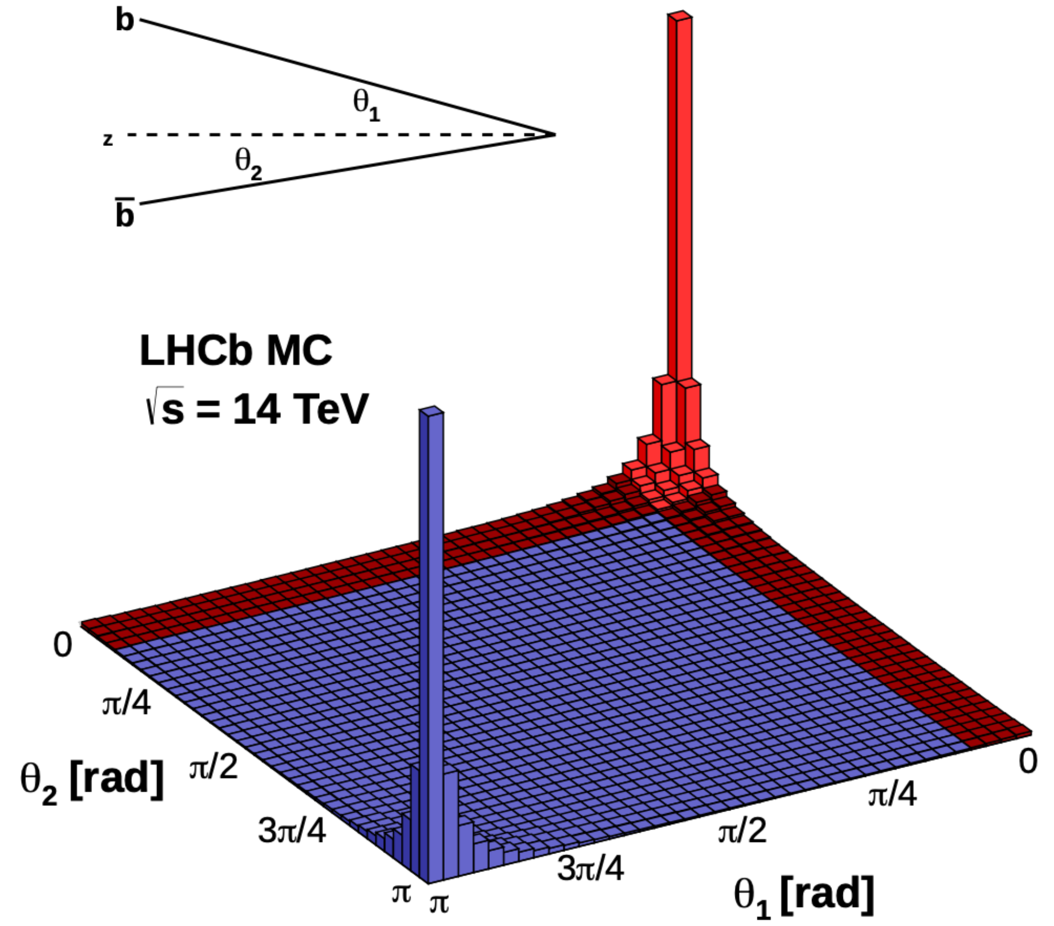
LHCb performance:
JINST 14 (2019) P04013

LHCb detector

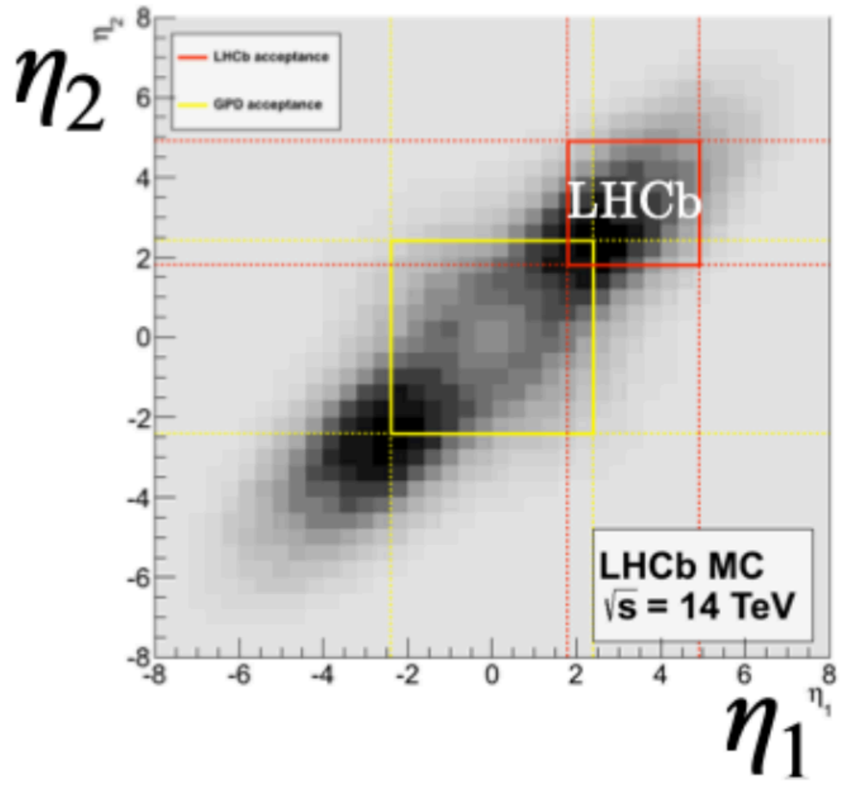
General purpose detector specialised in beauty and charm hadrons

- Daughters of b & c hadron decays: $p_T \sim \mathcal{O}(1\ \mathrm{GeV}/c)$, flight distance $L \sim 1\ \mathrm{mm}$





$2 < \eta < 5$



LHCb performance:
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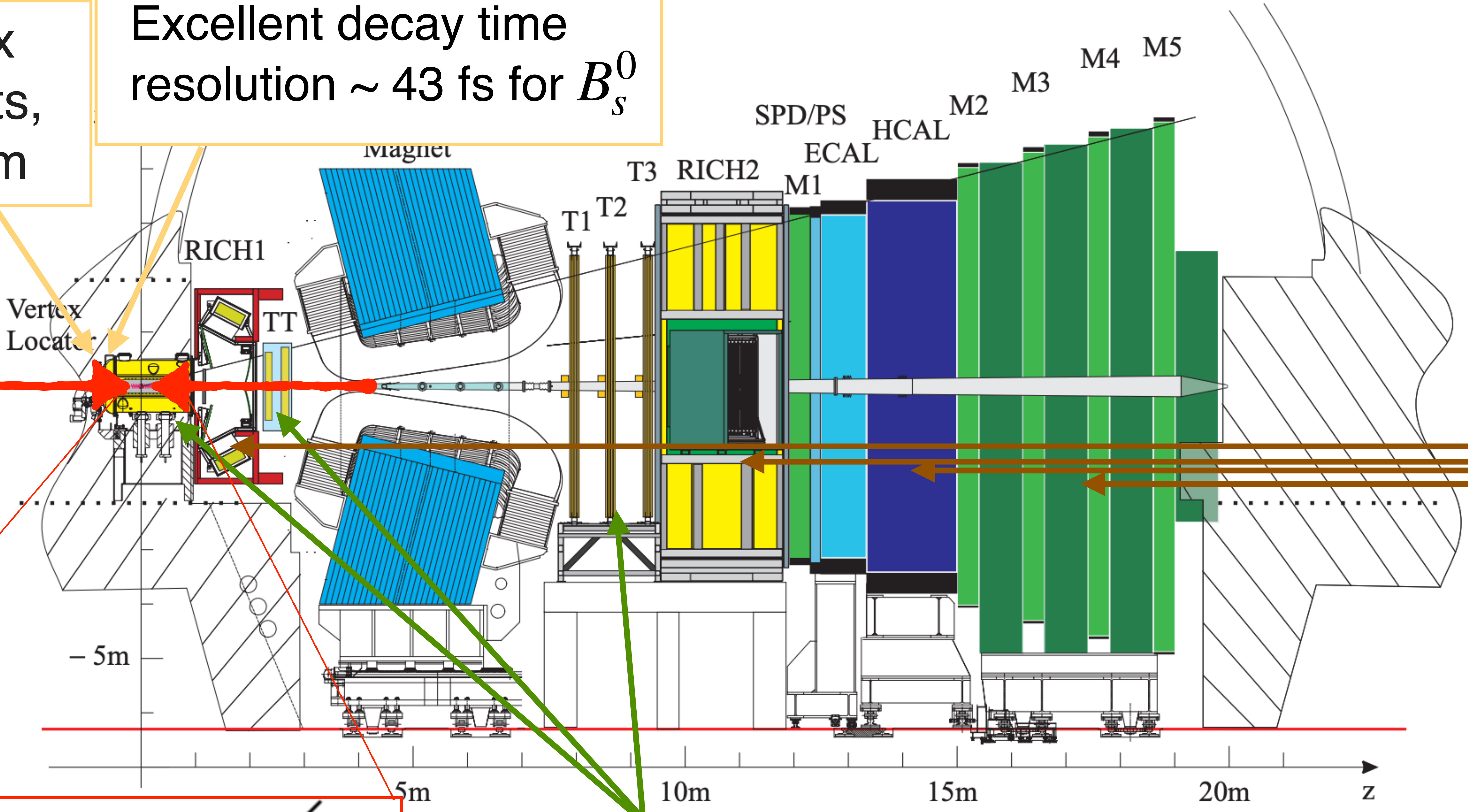
LHCb detector

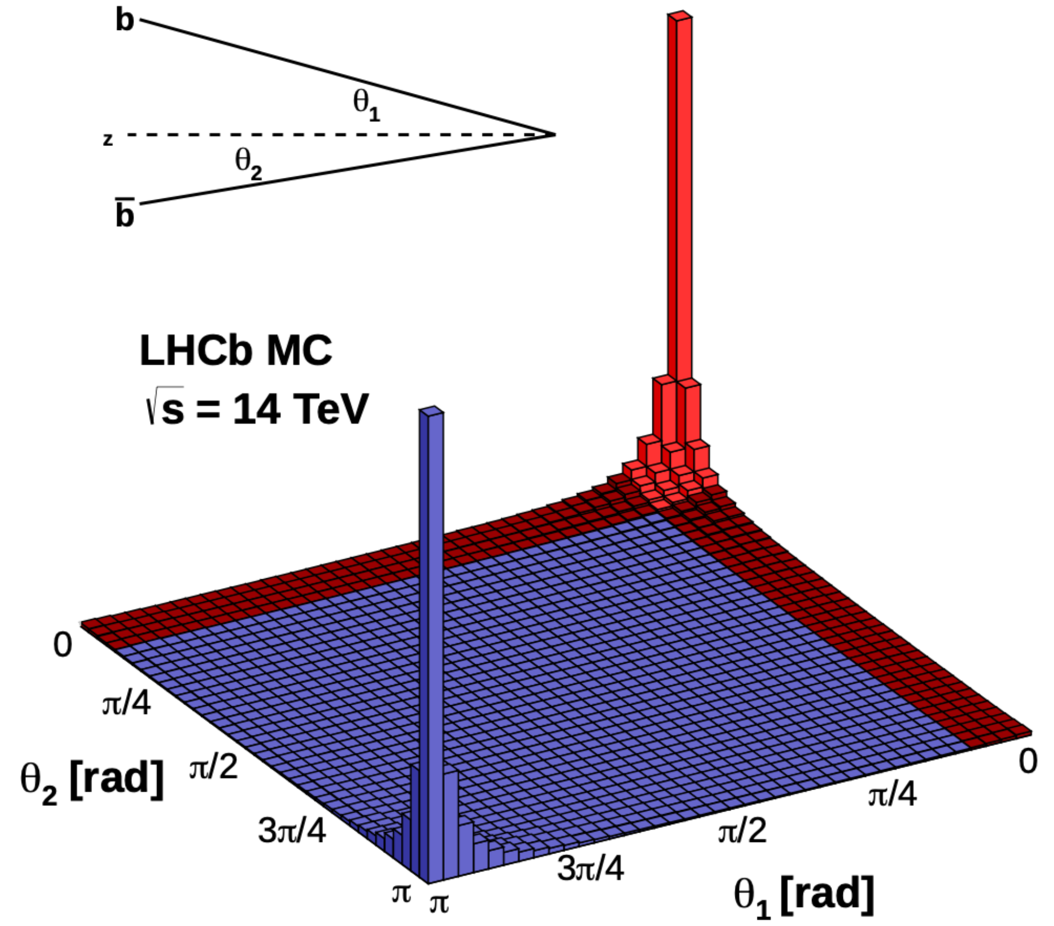
General purpose detector specialised in beauty and charm hadrons

- Daughters of b & c hadron decays: $p_T \sim \mathcal{O}(1\ \mathrm{GeV}/c)$, flight distance $L \sim 1\ \mathrm{mm}$

Precise vertex measurements, $\sigma(IP_x)$~ 35 μm

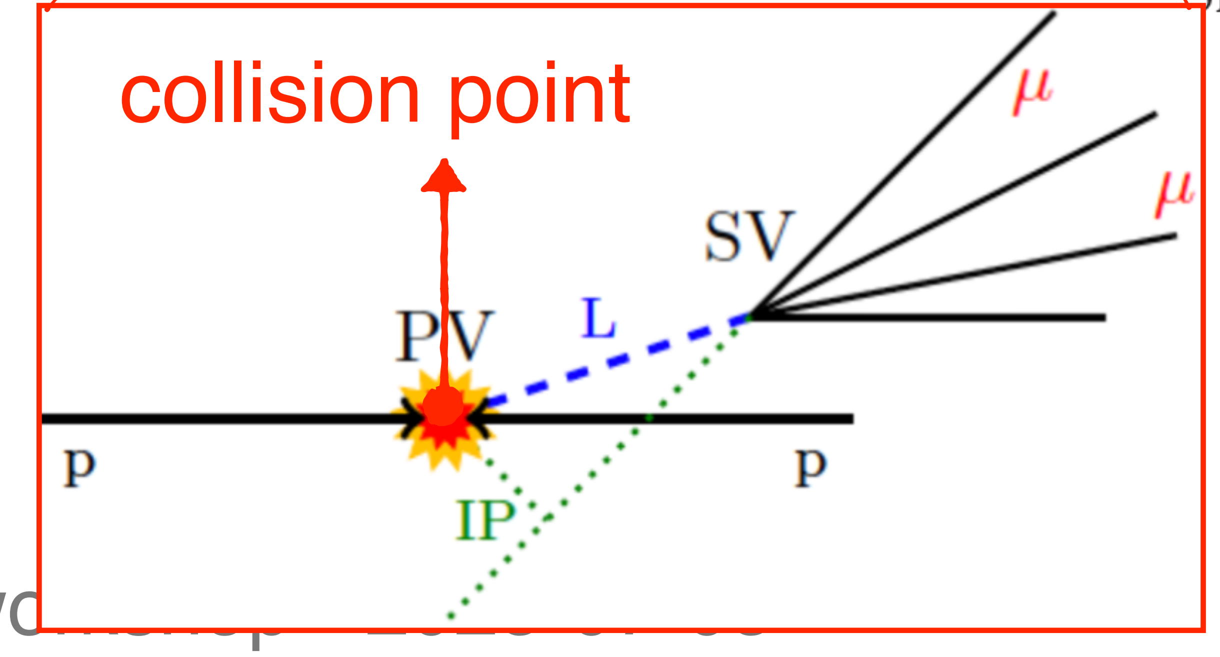
Excellent decay time resolution ~ 43 fs for B_s^0





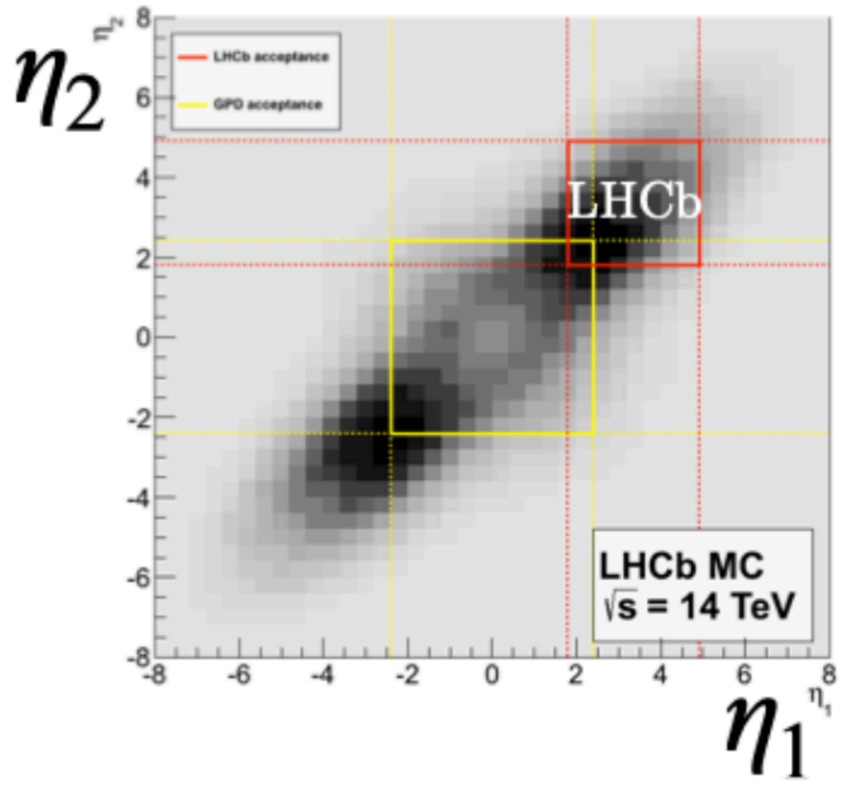
$2 < \eta < 5$

Excellent particle identification
$\epsilon(K) \approx 95\ \%$
misID $p(\pi \rightarrow K) \approx 5\ \%$
$\epsilon(\mu) \approx 97\ \%$



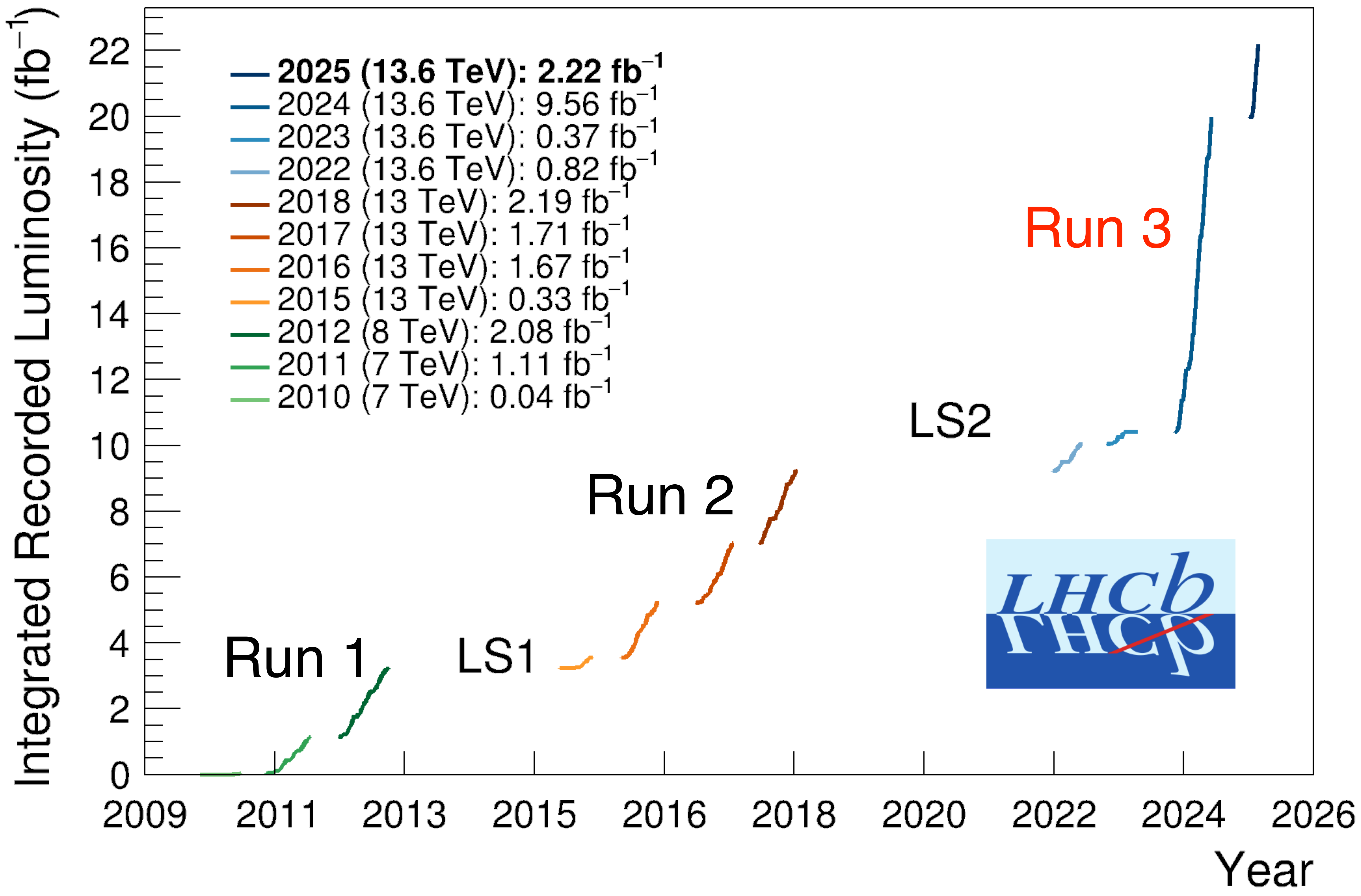
Excellent momentum resolution ~ 0.5%

LHCb performance:
JINST 14 (2019) P04013



Luminosity

- Run 1: 2011+2012, 7, 8 TeV
- Run 2: 2015-2018, 13 TeV
- Run 3: 2022-2026, 13.6 TeV



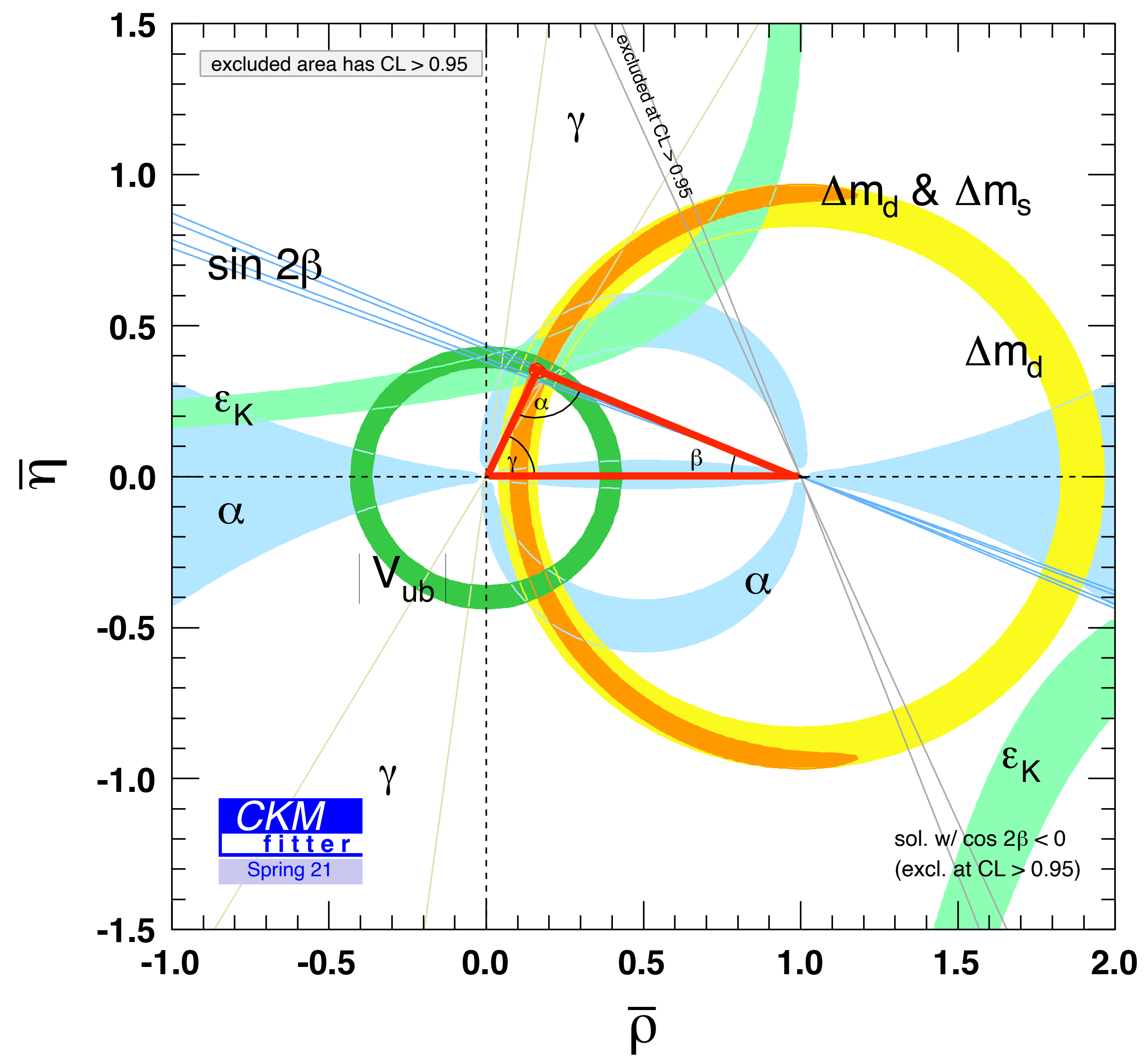
- Runs 1+2 : 9 fb^{-1}
- Run 3 : 23 fb^{-1} (expected)
- Large number of beauty and charm hadrons:

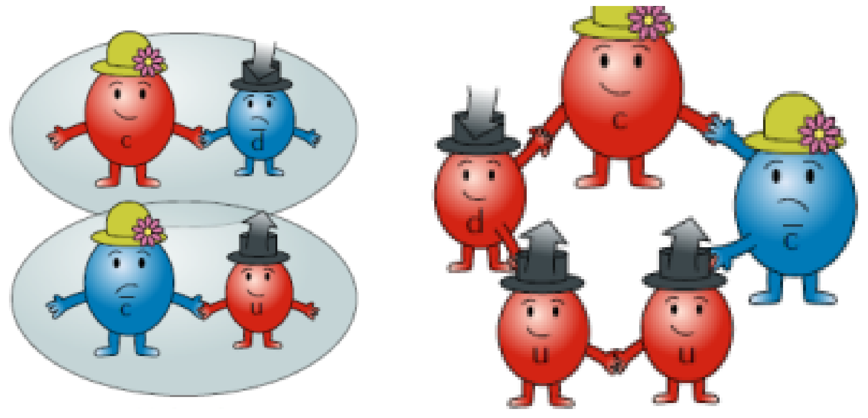
$\sigma(b\bar{b})(13\ \text{TeV}) = (144 \pm 1 \pm 21)\ \mu\text{b}$ in $2 < y < 4.5$ [PRL118(2017)052002]

$\sigma(pp \to c\bar{c}X)(13\ \text{TeV}) = (2369 \pm 192)\ \mu\text{b}$ in $1 < p_T < 8$ GeV/c & $2 < y < 4.5$

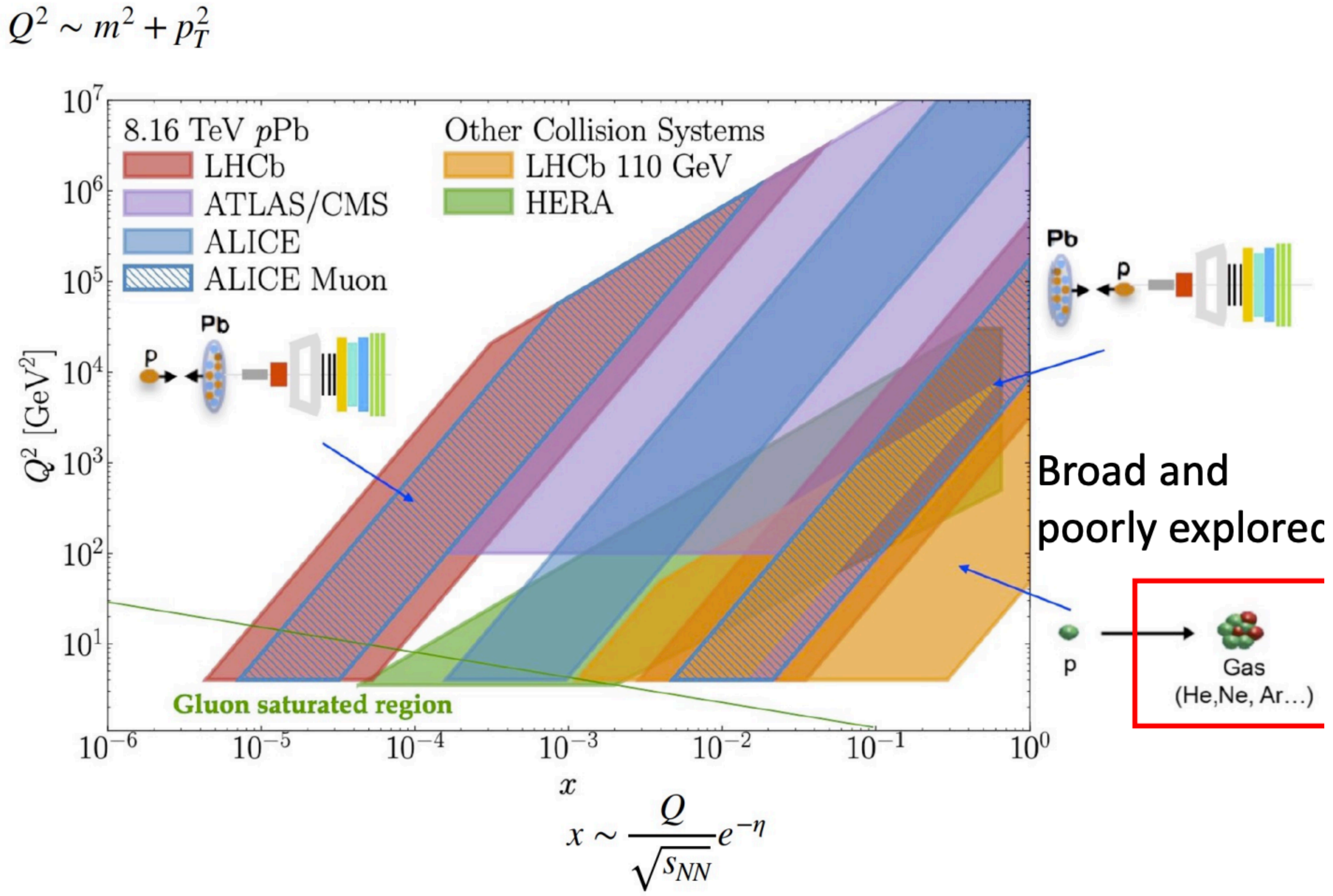
LHCb physics

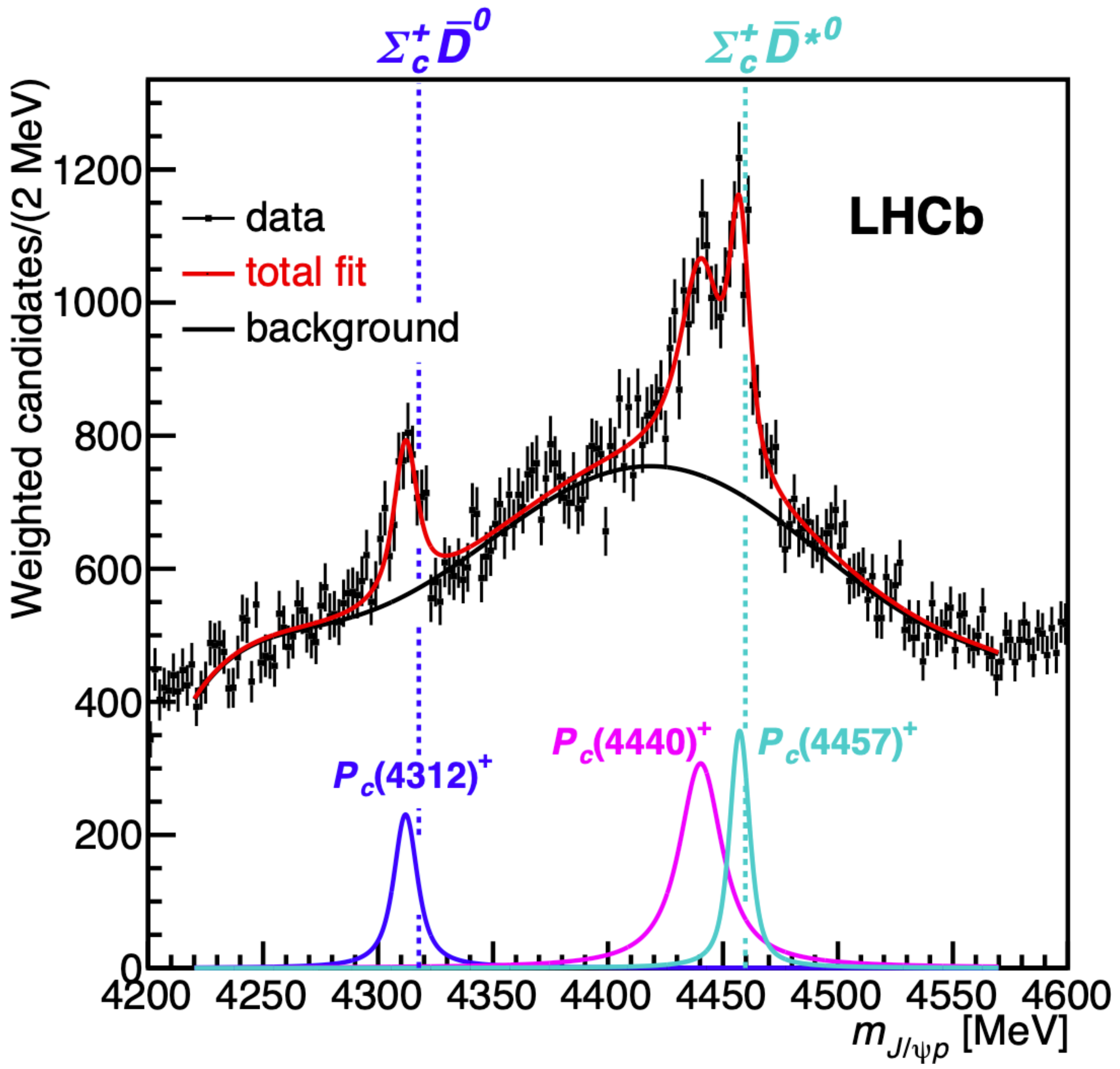
- Precise measurements of flavour observables of **CKM matrix**
- Probe new physics through **rare decays, FCNC, CP violation** etc
- **Hadron physics** to understand the QCD
- Heavy ions & EW physics





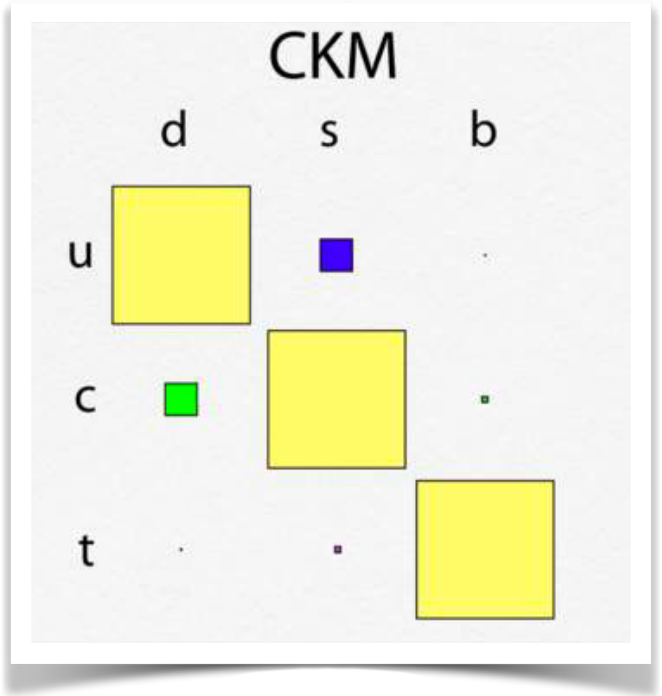
exotic states





CKM matrix

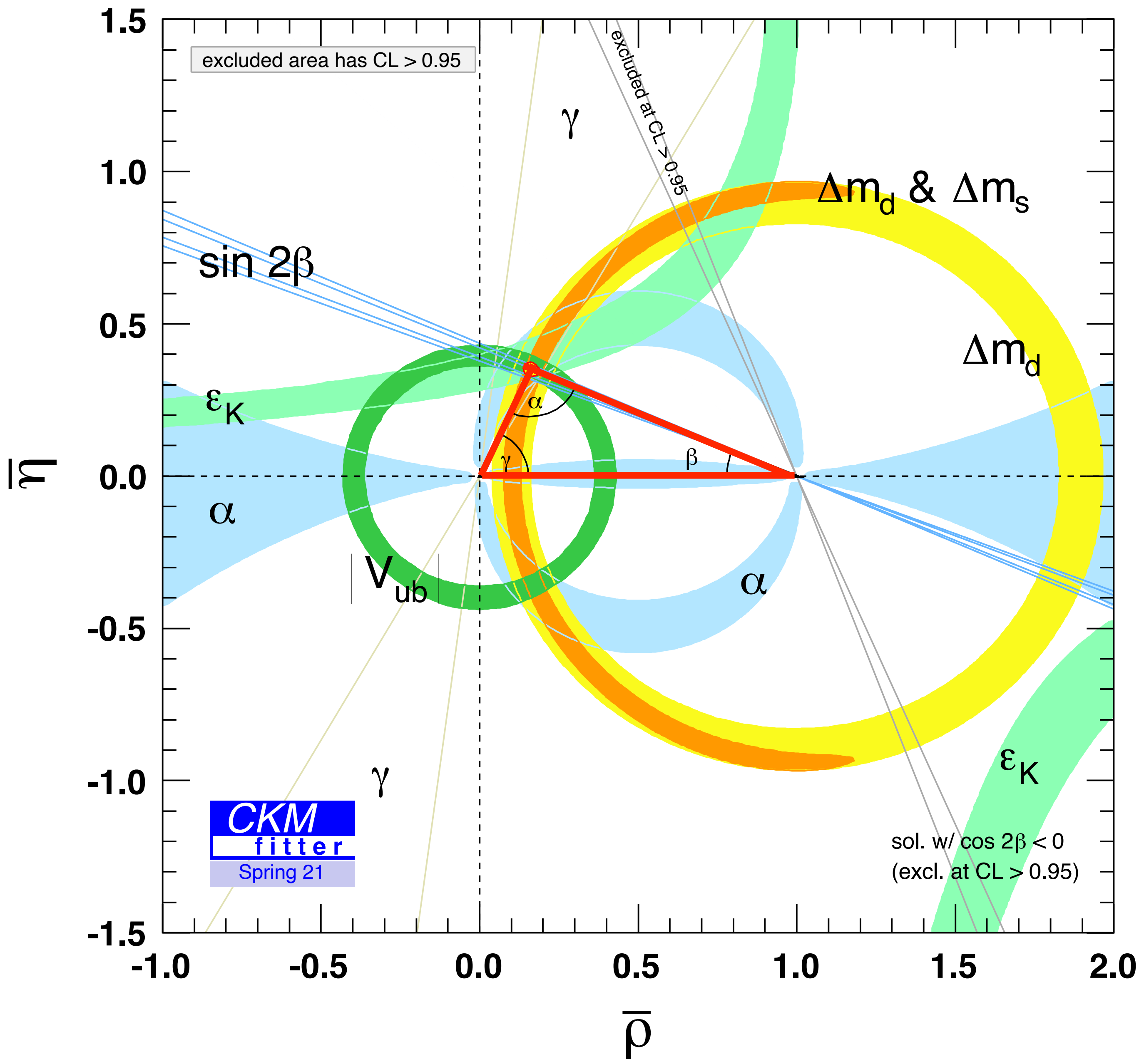
$$V_{\mathrm{CKM}} \equiv V_L^u V_L^{d\dagger} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



CKM matrix

$$V_{CKM} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} + \mathcal{O}(\lambda^5) \sim \begin{pmatrix} 1 & 0.2 & 0.004 \\ 0.2 & 1 & 0.04 \\ 0.008 & 0.04 & 1 \end{pmatrix}$$

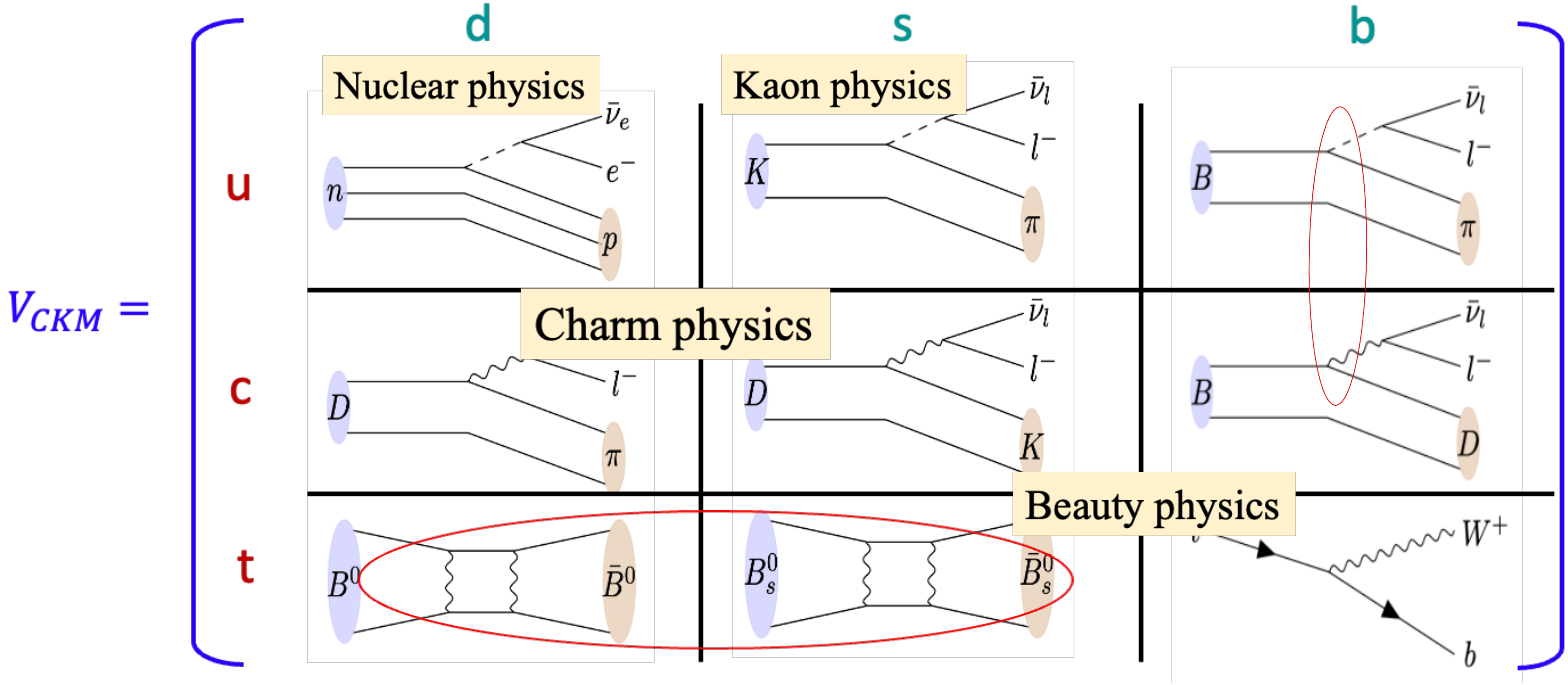
- Key test of the SM: Verify unitarity of CKM matrix
  - Magnitudes: branching fractions or mixing frequencies
  - Phases: CP violation measurement
- Sensitive probe for new physics



$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

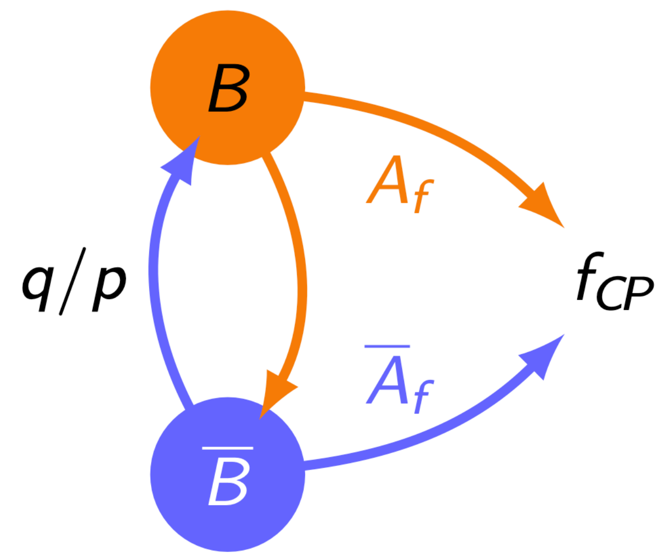
$$\alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right), \beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$

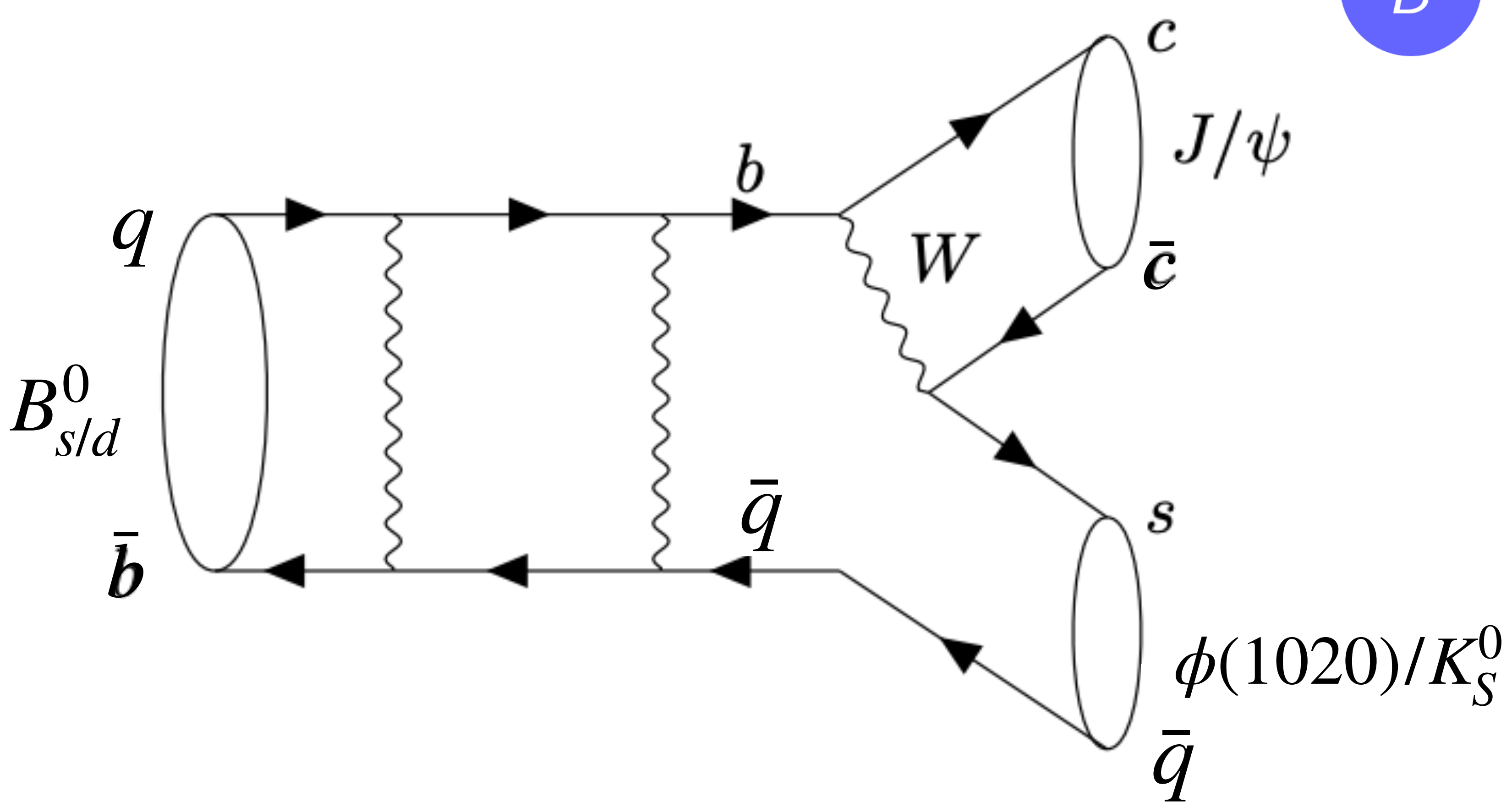
Measurement of CKM matrix

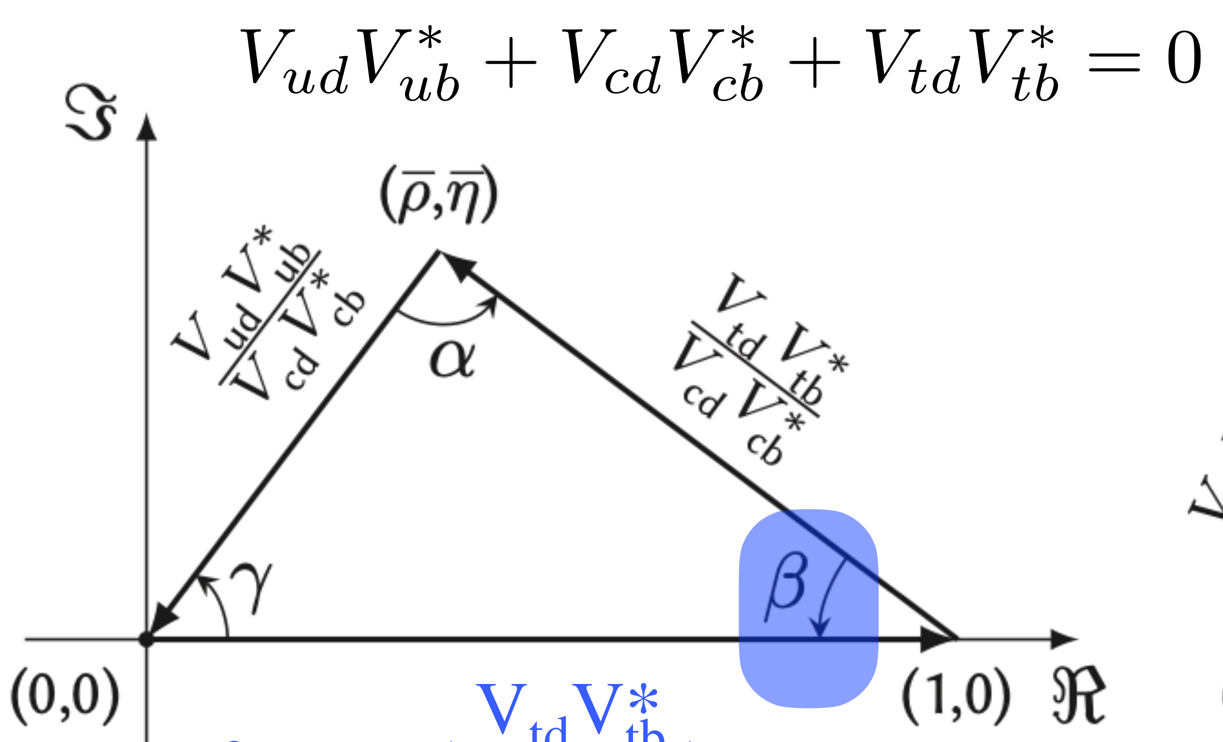


Complementarity between beauty and charm factories

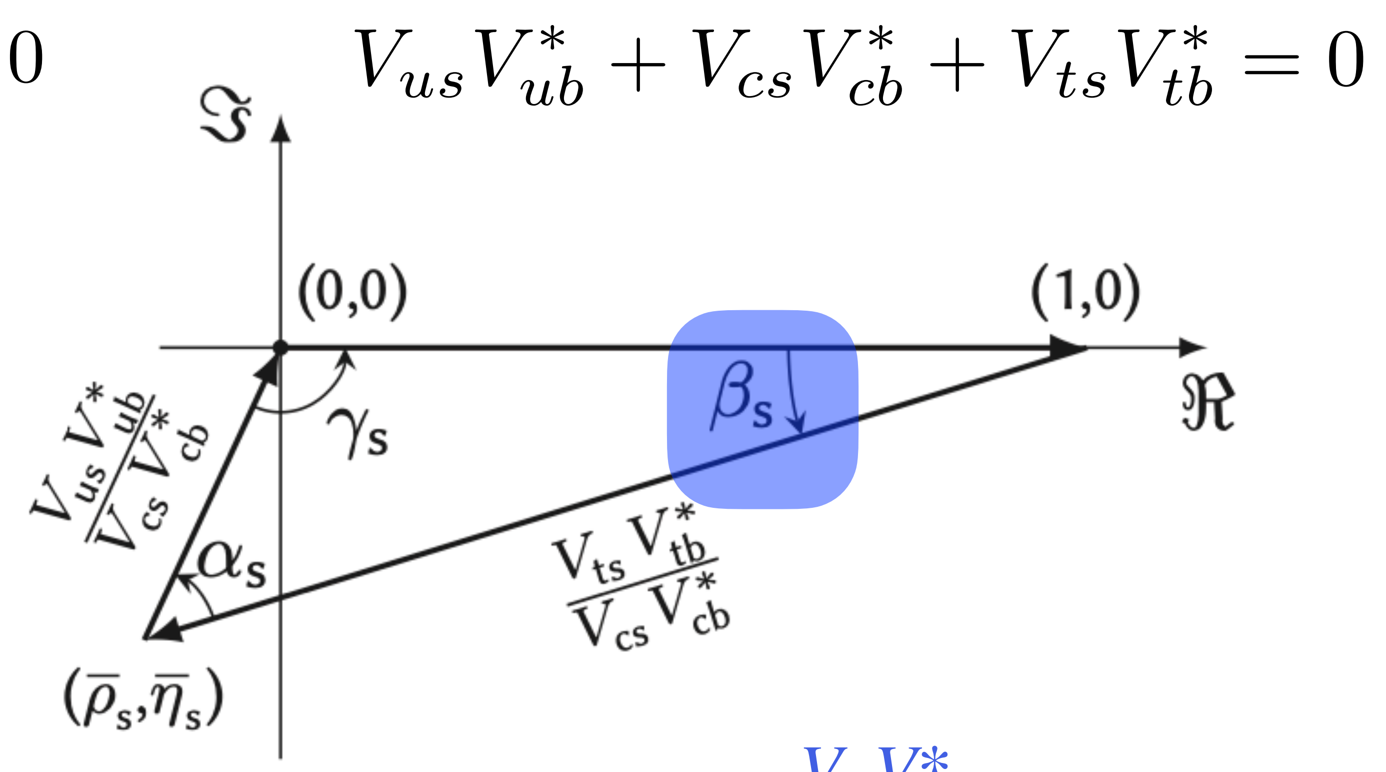
CKM angle $\beta_{(s)}$







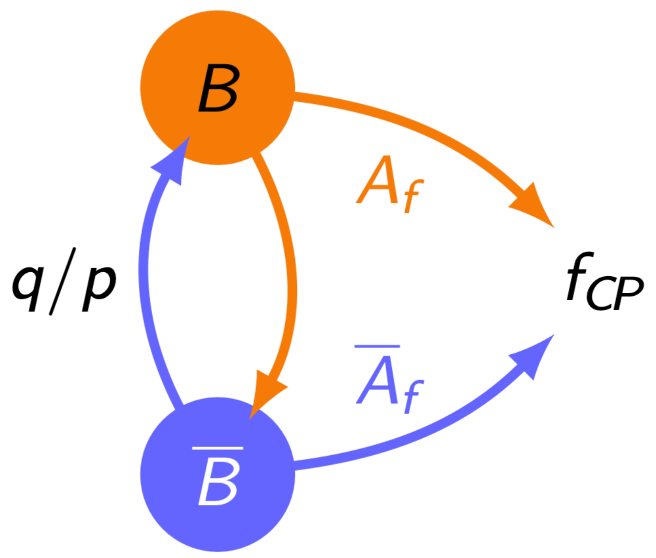
$\beta = \arg(\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*})$

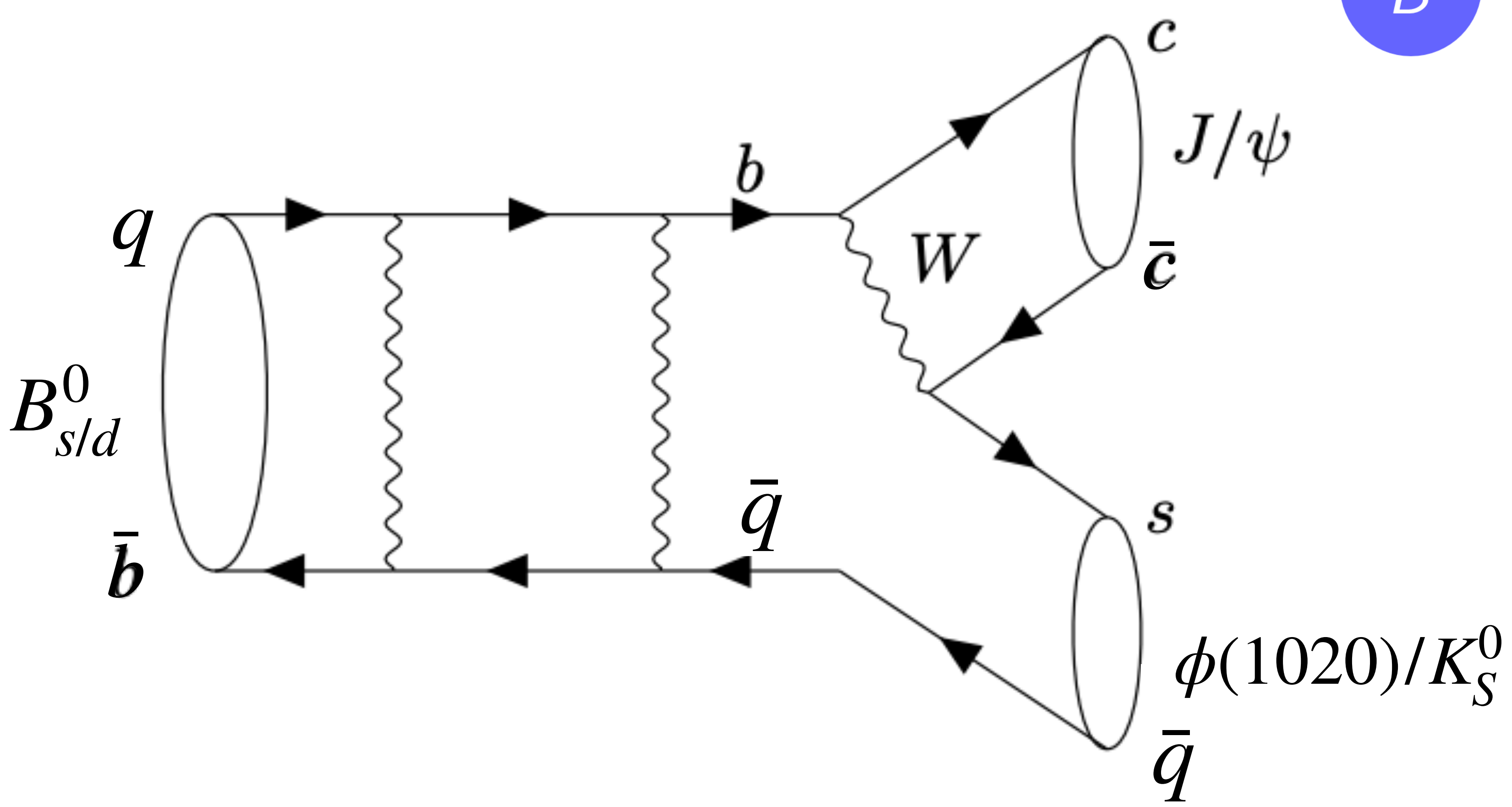


$\beta_s = arg(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*})$

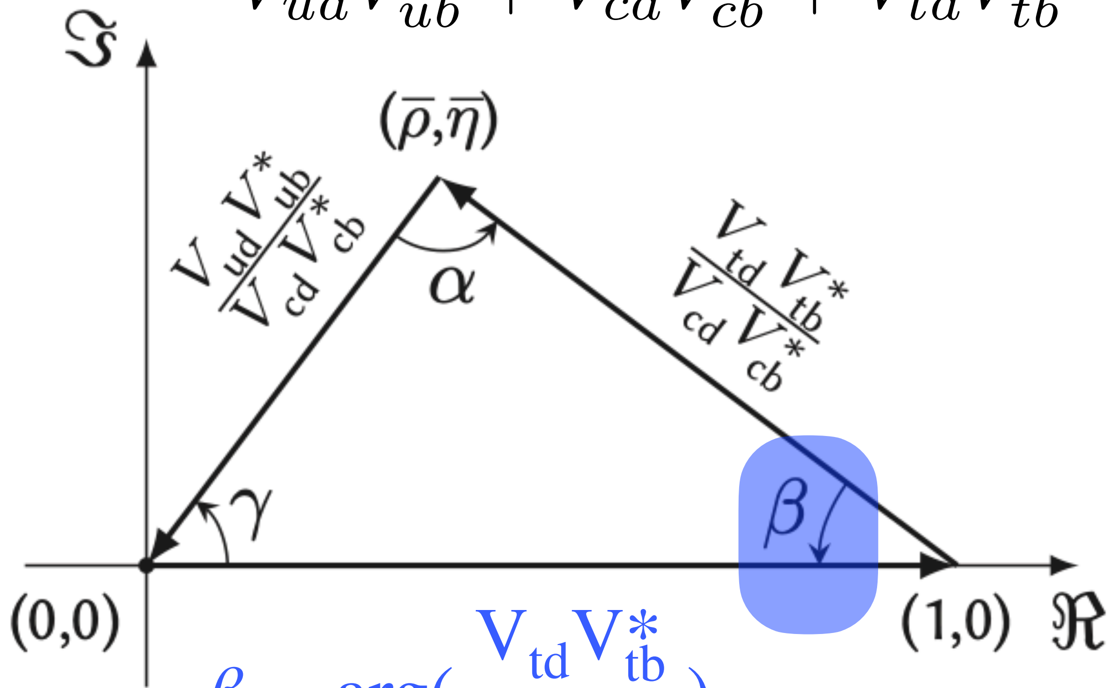
$$A_{CP}(t) = \frac{\Gamma_{\bar{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\bar{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} \propto -\eta_f \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$$

CKM angle $\beta_{(s)}$



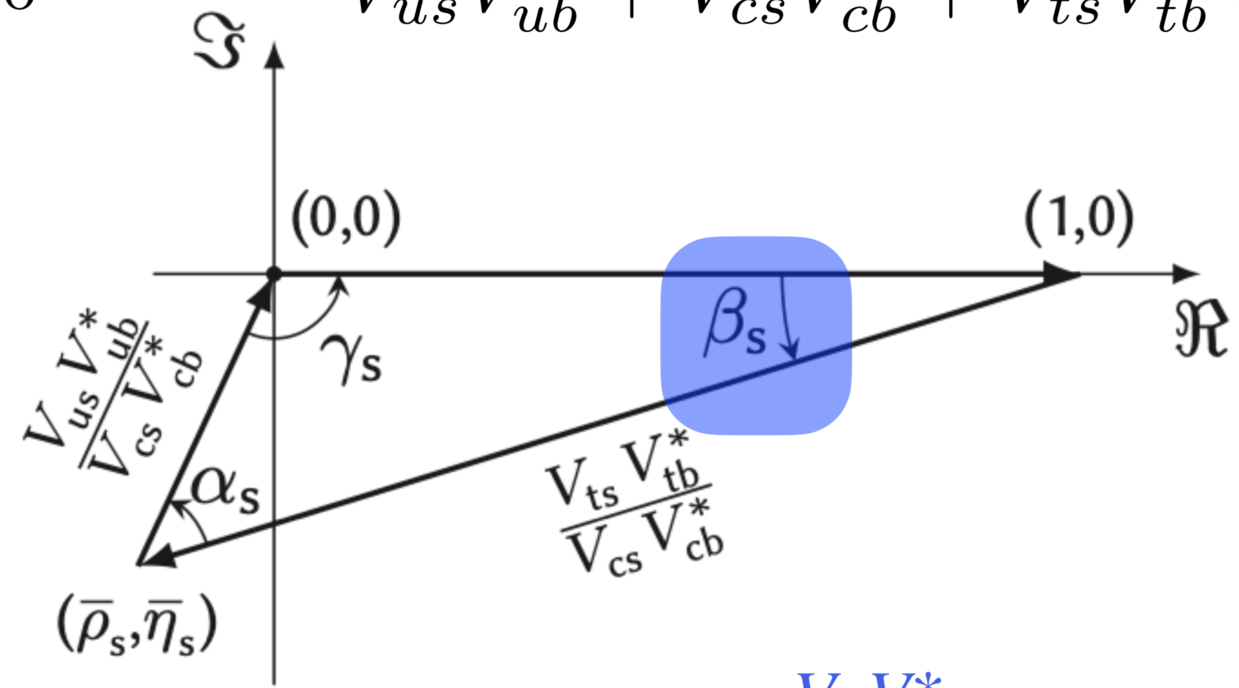


$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



$$\beta = \arg\left(\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right)$$

$$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

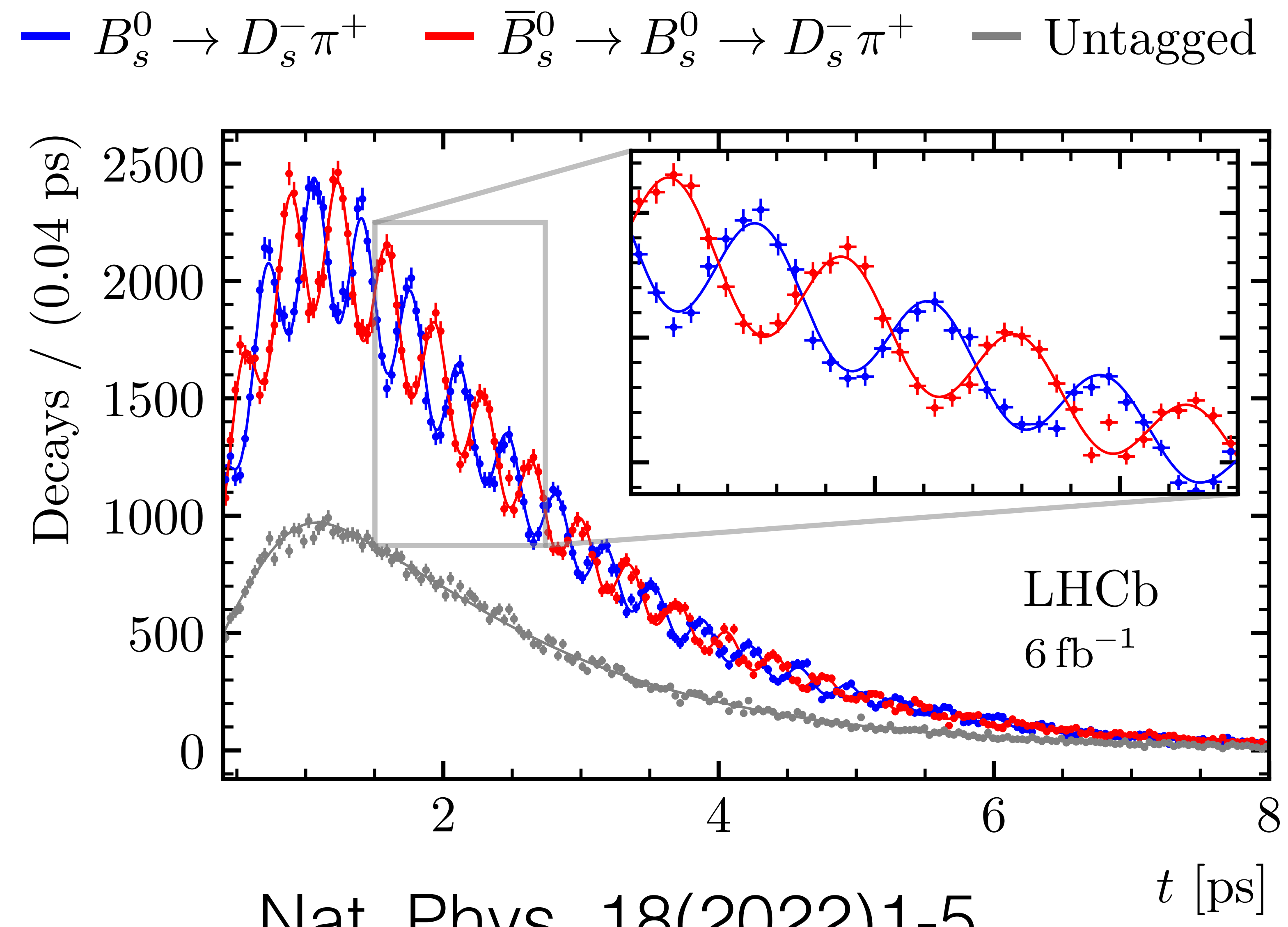


$$\beta_s = \arg\left(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}\right)$$

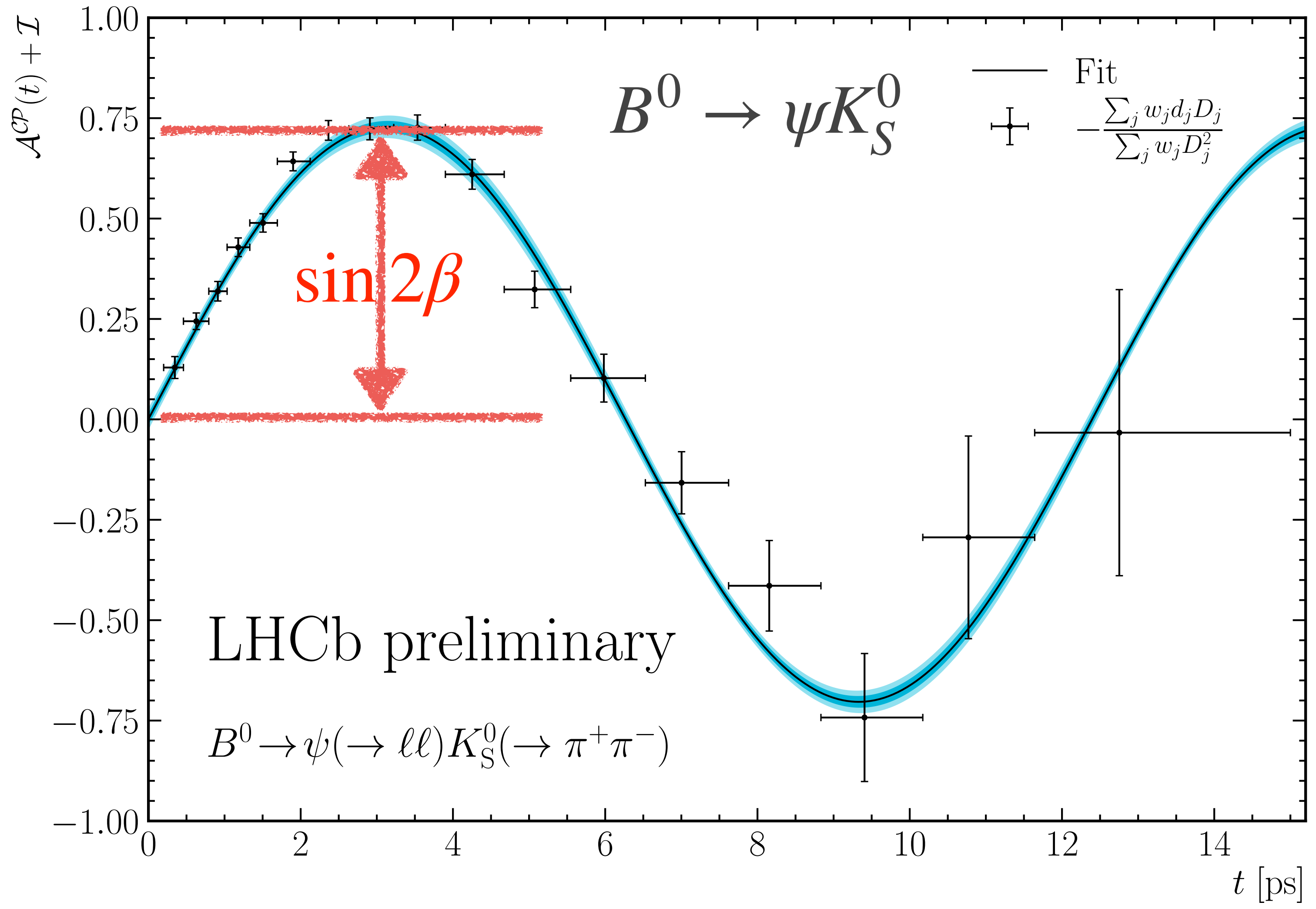
$$A_{CP}(t) = \frac{\Gamma_{\bar{B}^0_{(s)}\to f}(t) - \Gamma_{B^0_{(s)}\to f}(t)}{\Gamma_{\bar{B}^0_{(s)}\to f}(t) + \Gamma_{B^0_{(s)}\to f}(t)} \propto -\eta_f \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$$

$$S_{\psi K^0_S}^{\text{Run 2}} = 0.716 \pm 0.013 \pm 0.008$$

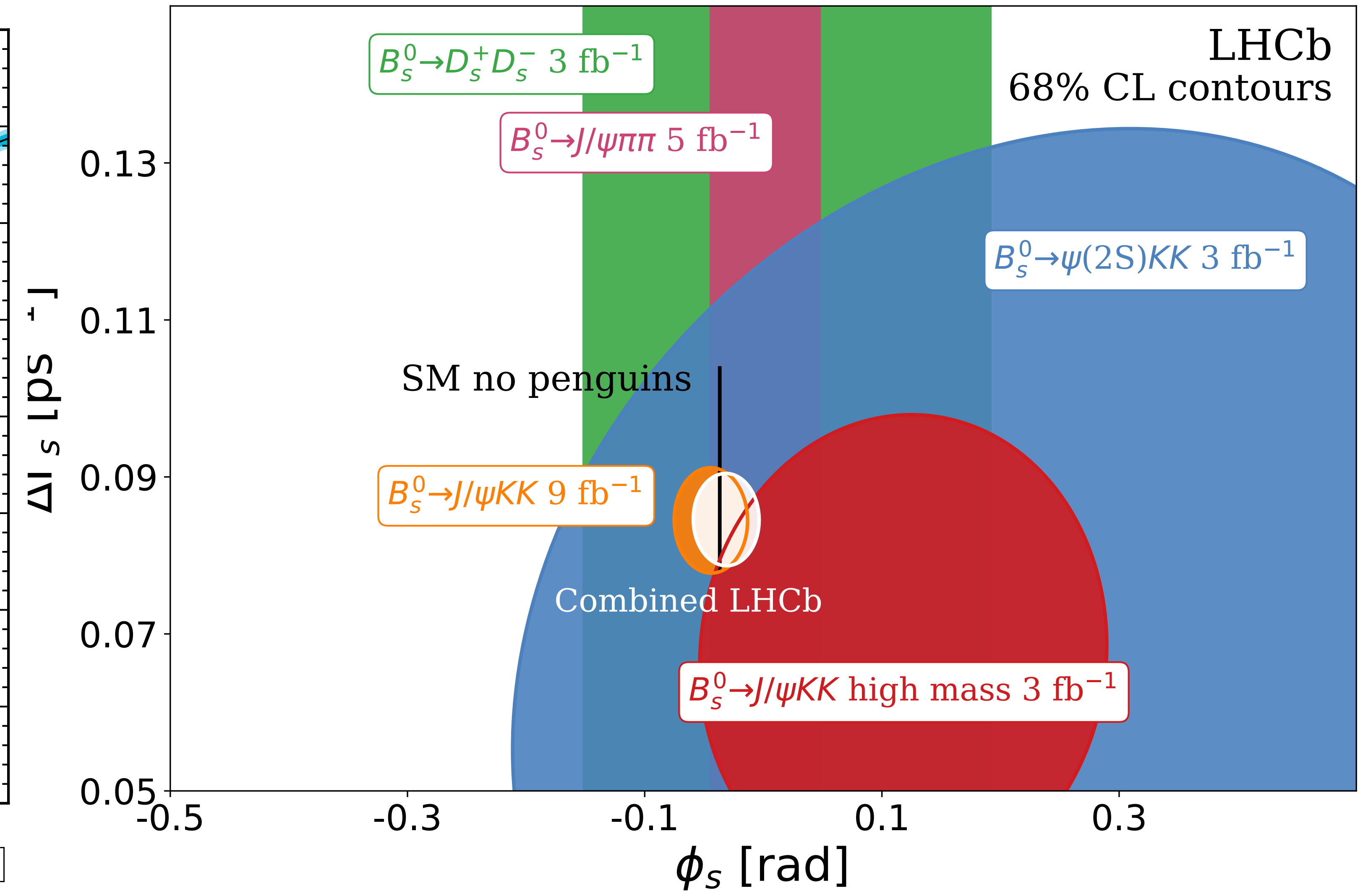
$$\phi_s^{c\bar{c}s} = -0.031 \pm 0.018 \text{ rad}$$



Nat. Phys. 18(2022)1-5



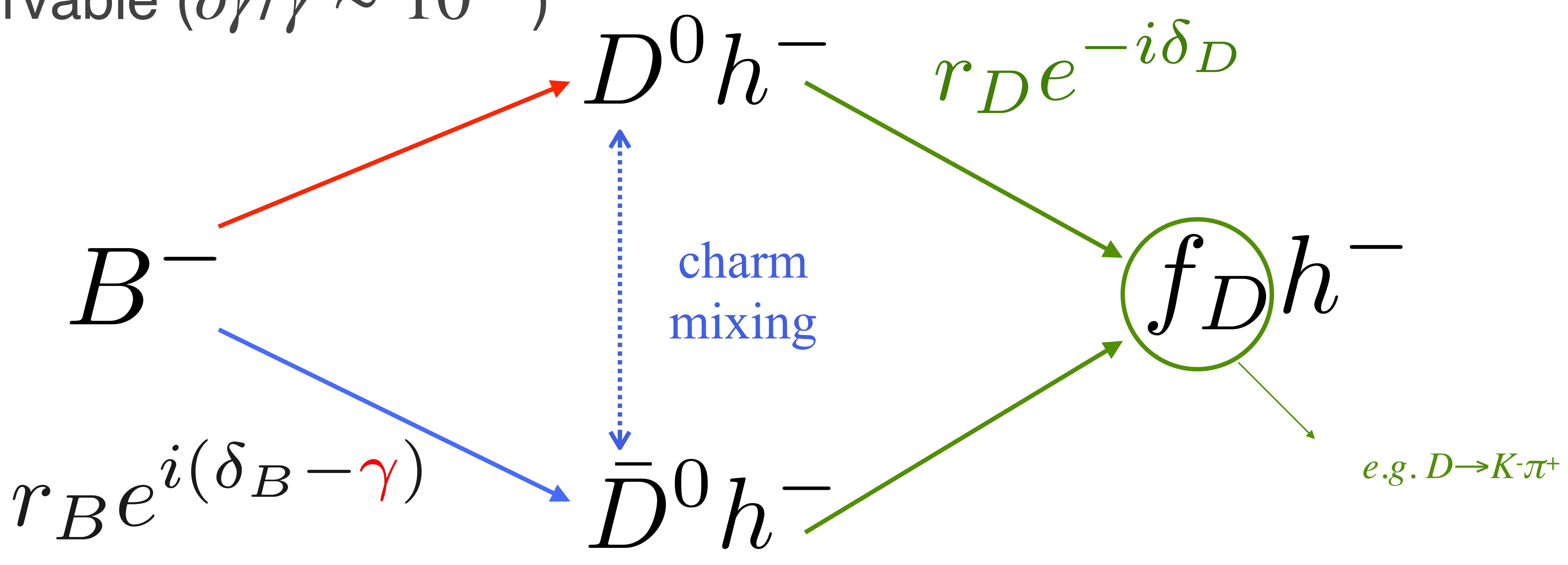
Phys. Rev. Lett. 132 (2024) 021801

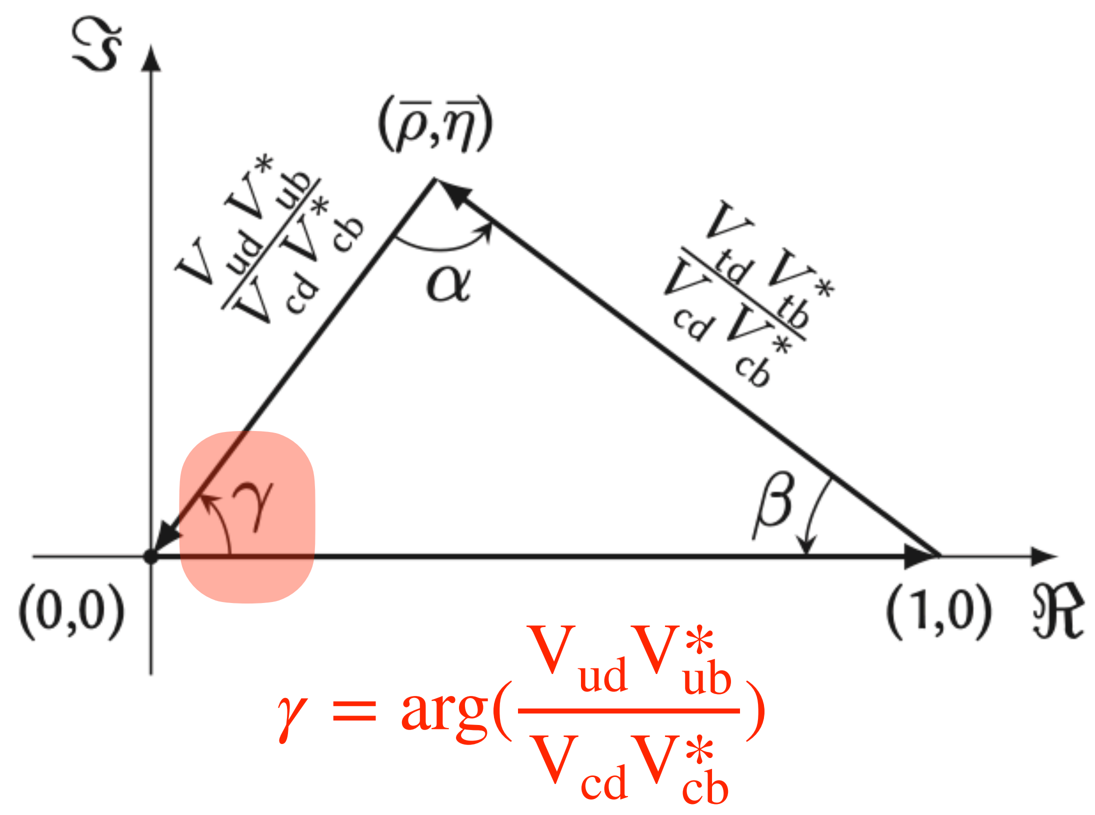


Phys. Rev. Lett. 132 (2024) 051802

CKM angle γ

- Weak phase in interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$, theoretically clean observable ($\delta\gamma/\gamma \sim 10^{-7}$)





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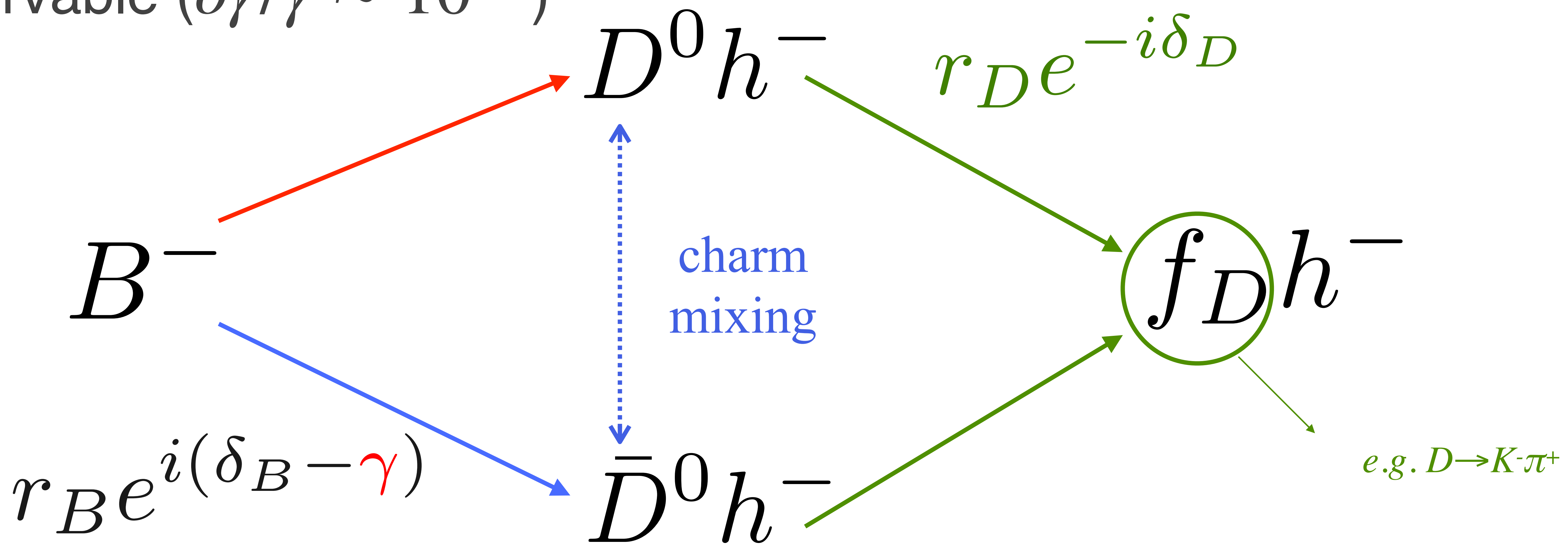

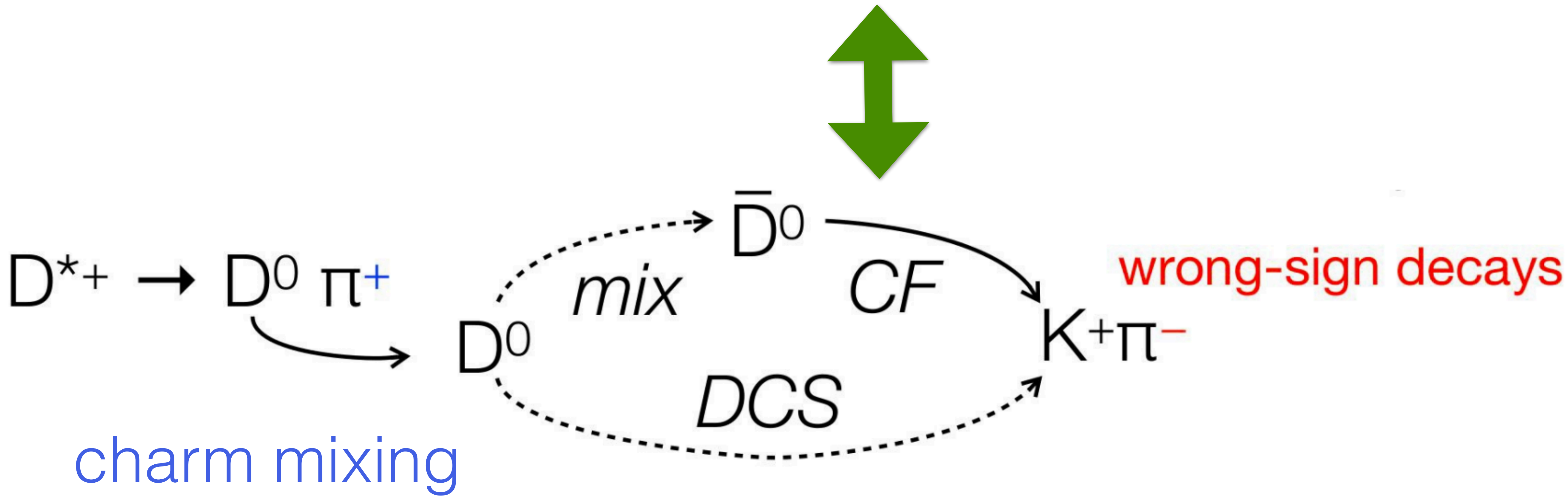

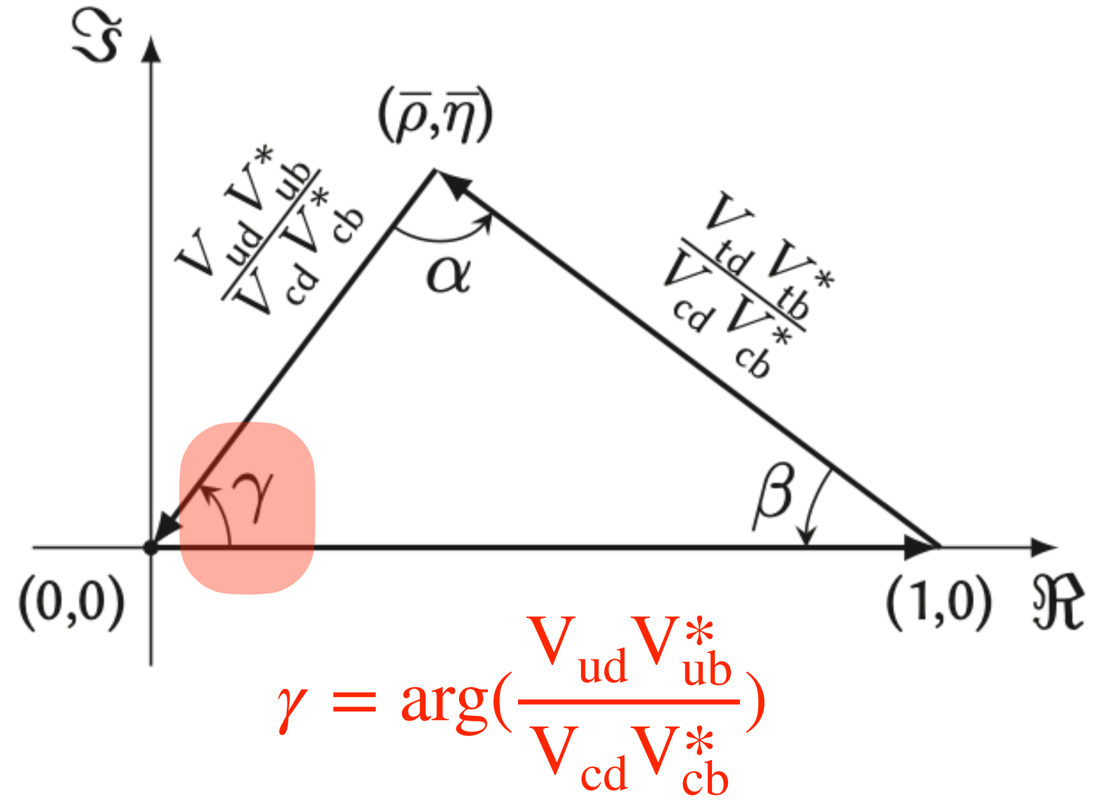

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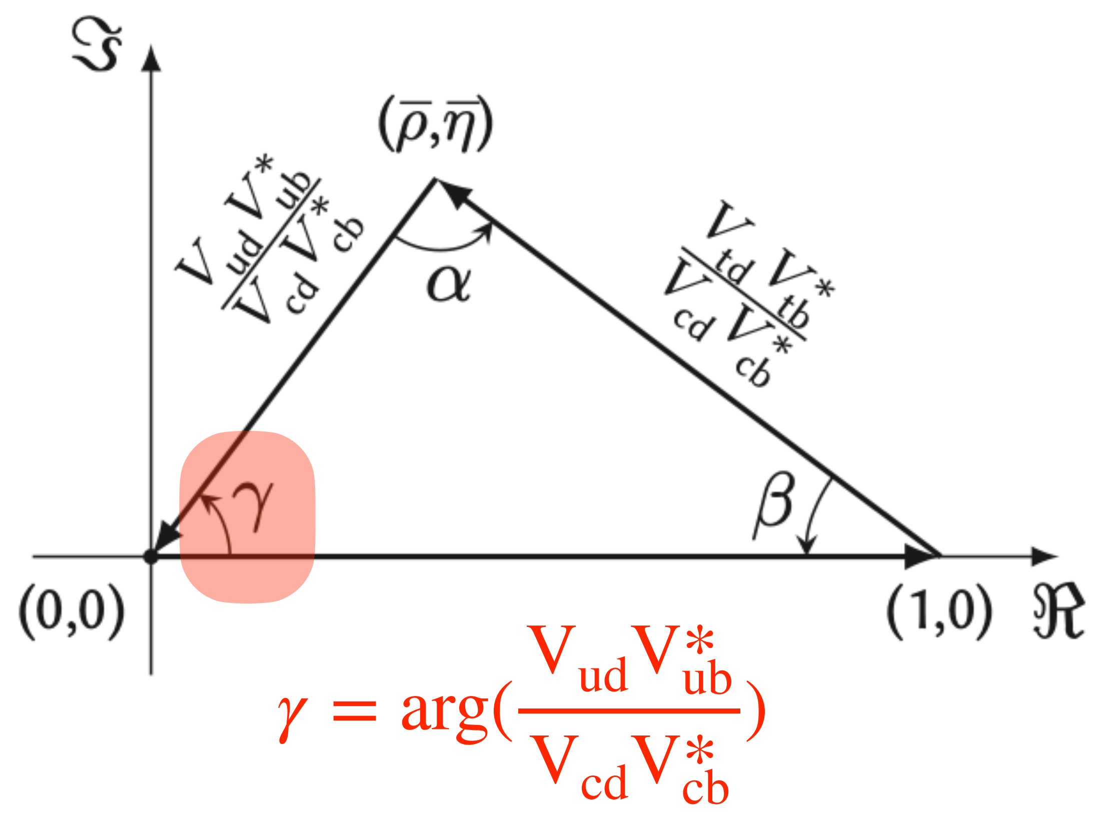
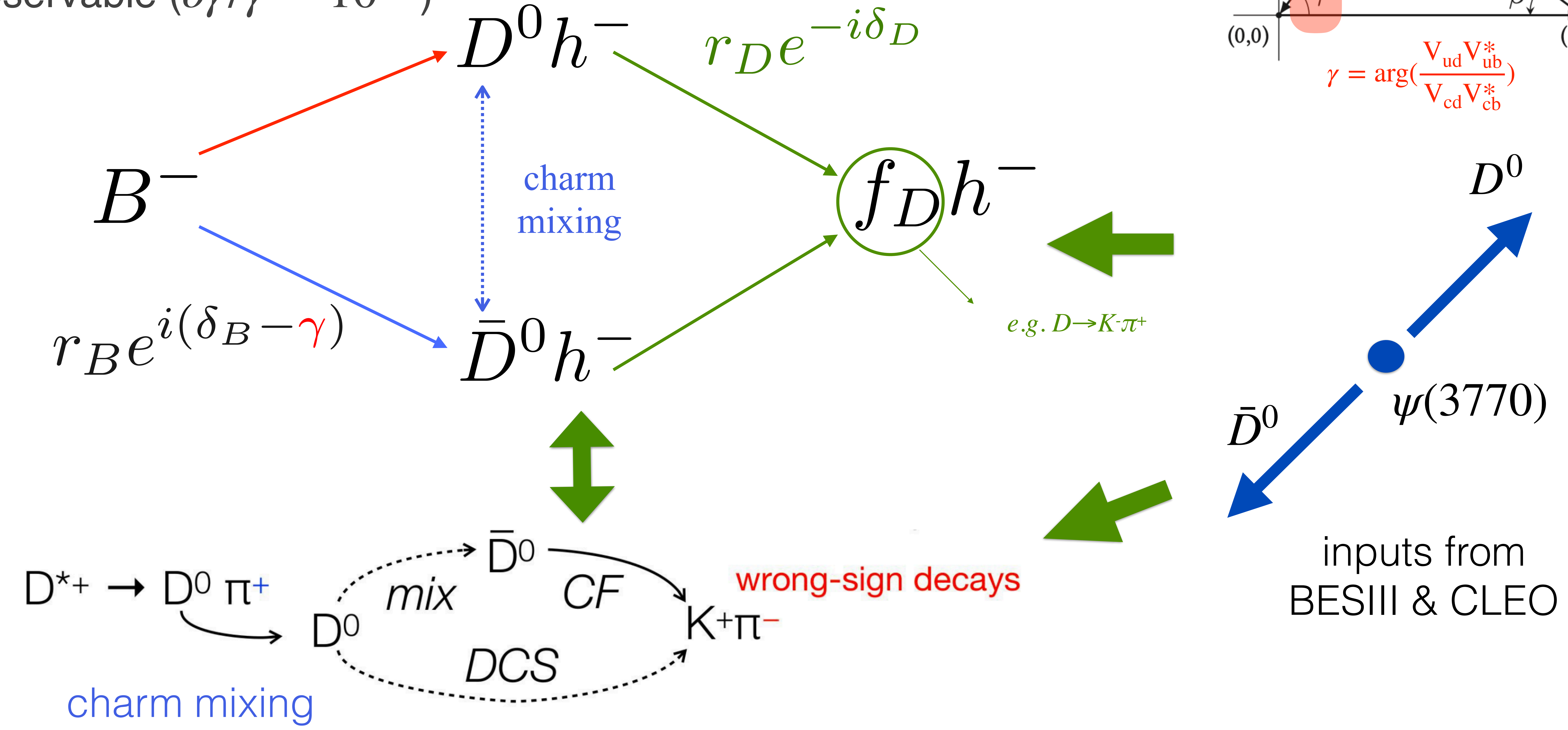
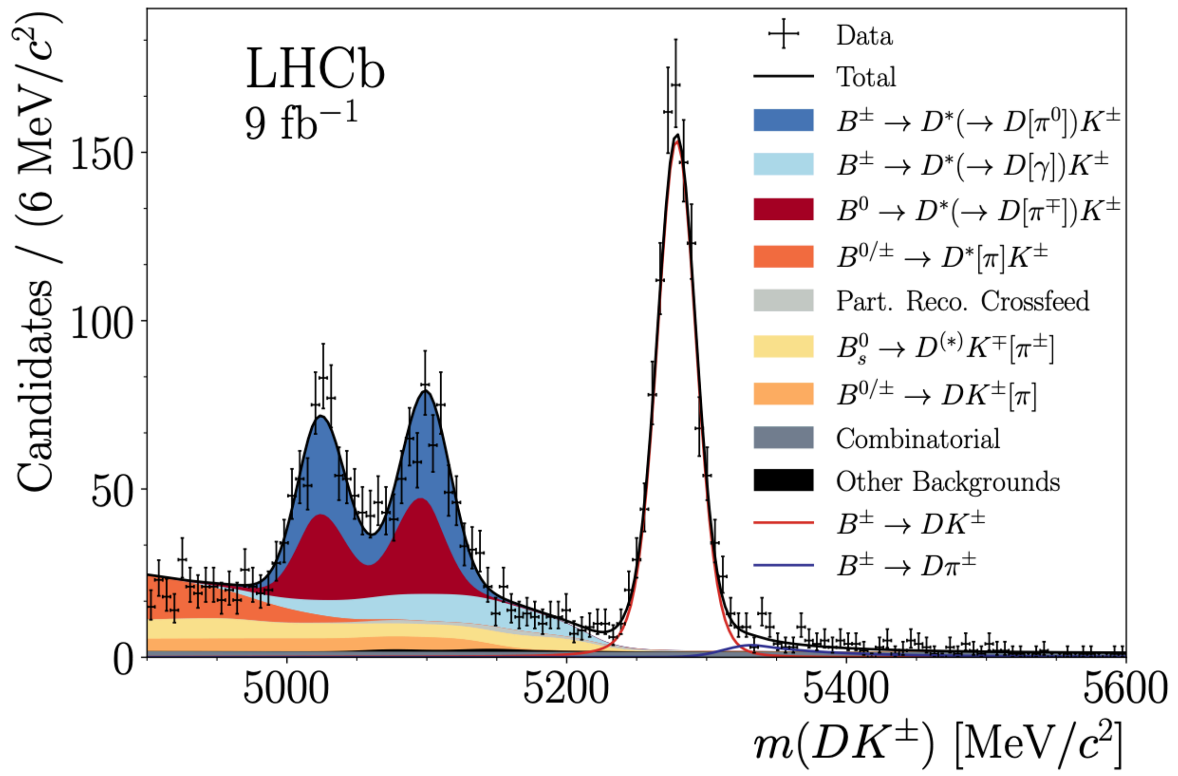




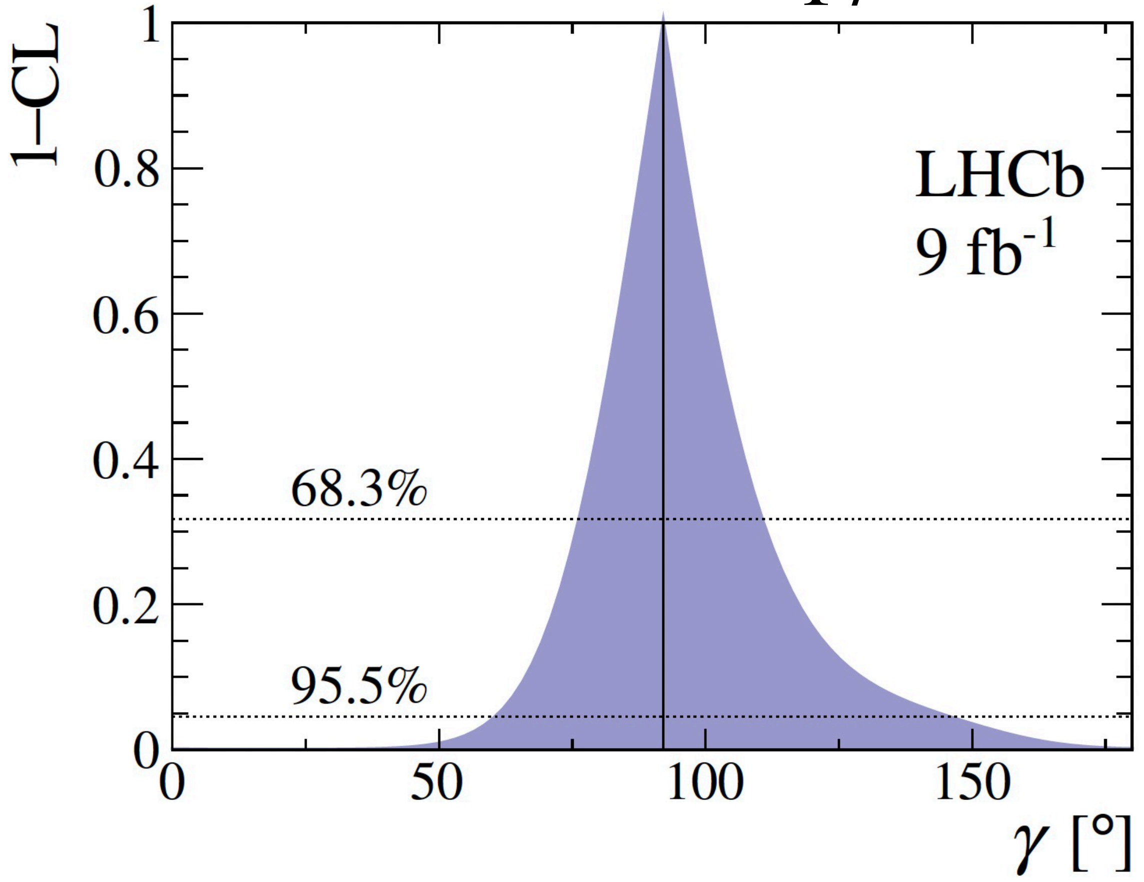
$$\Gamma(B^\pm \to Dh^\pm) \propto |r_D e^{-i\delta_D} + r_B e^{i(\delta_B \pm \gamma)}|^2 \Rightarrow r_D^2 + r_B^2 + 2\kappa_D\kappa_B r_D r_B \cos(\delta_B + \delta_D \pm \gamma)$$

γ measurements

JHEP02(2024)118

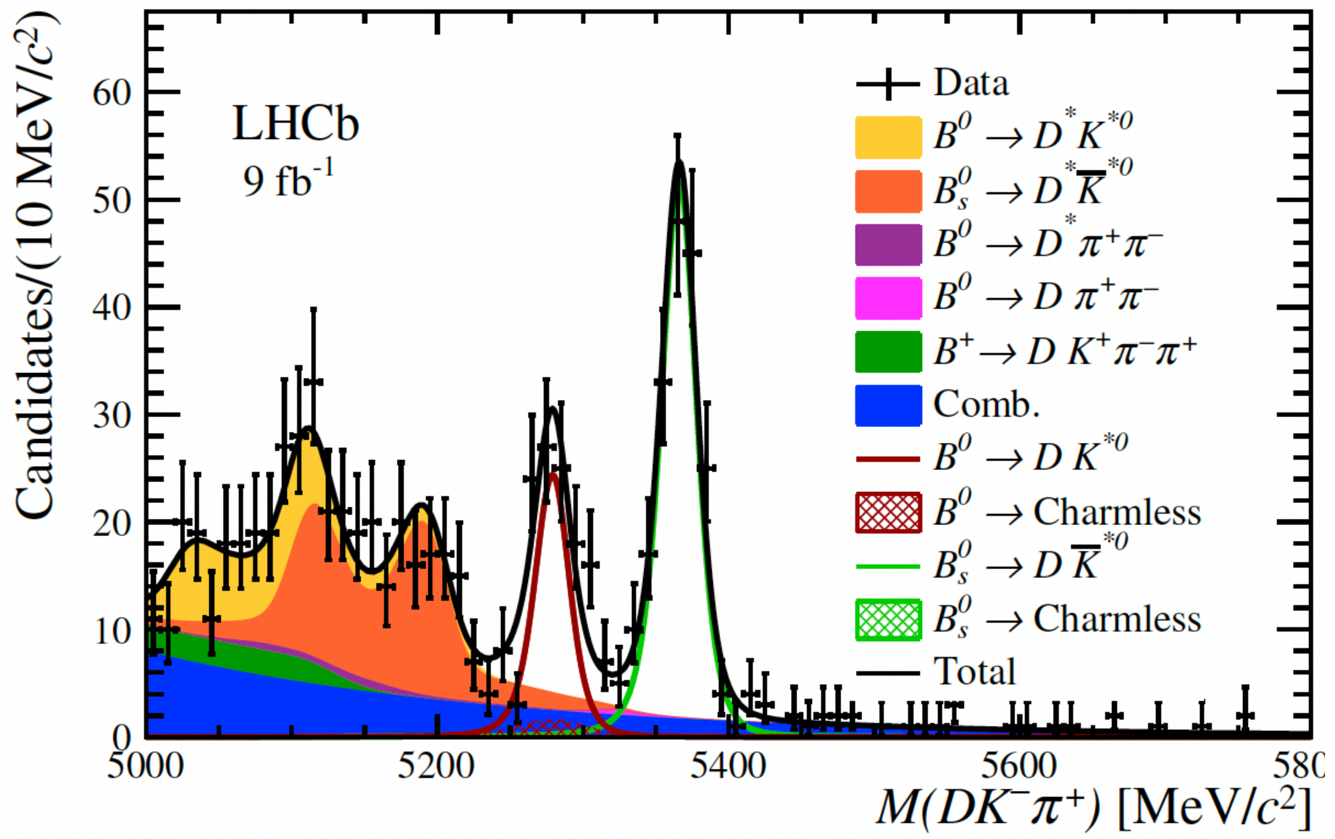


$\gamma = (92^{+21}_{-17})^{\circ}$

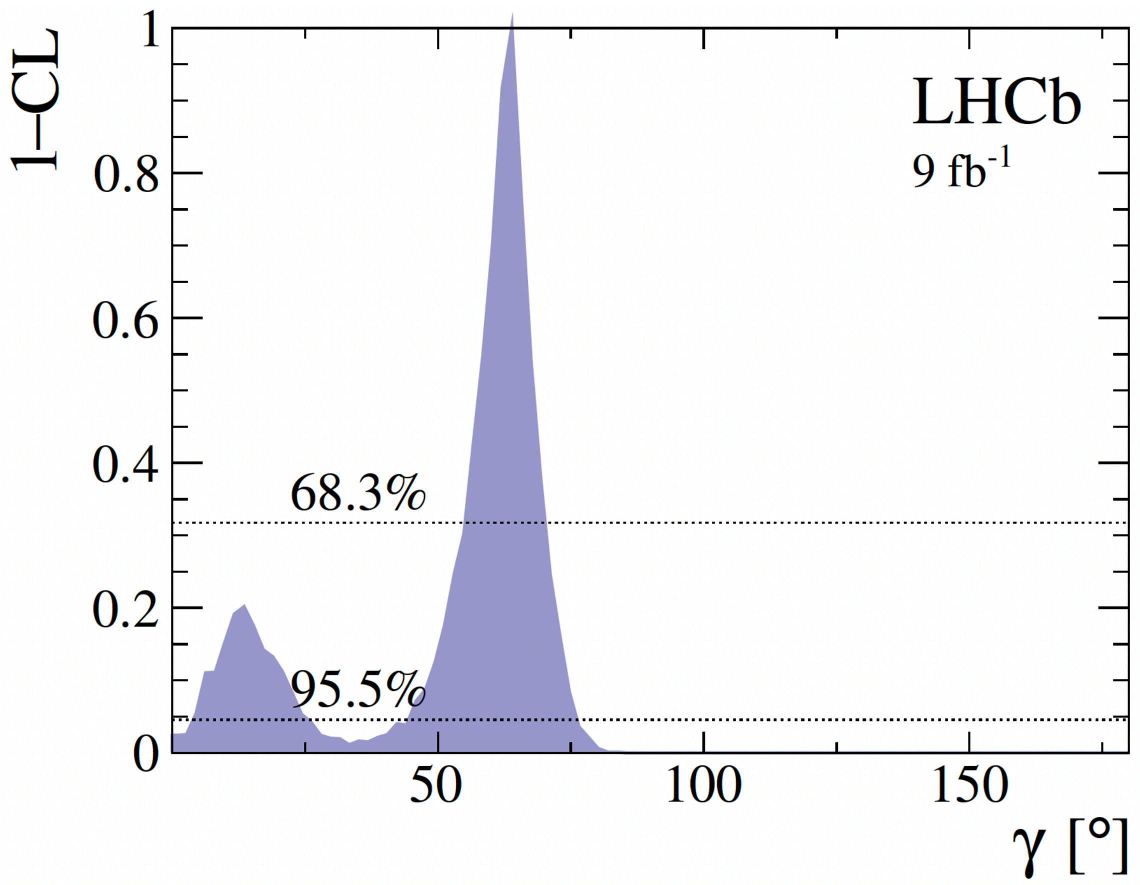


Partial reco. $B^{\pm} \to D^{*0} h^{\pm}$ with $D^{*0} \to D(\to K^0_S hh)\gamma/\pi^0$

JHEP05(2024)025

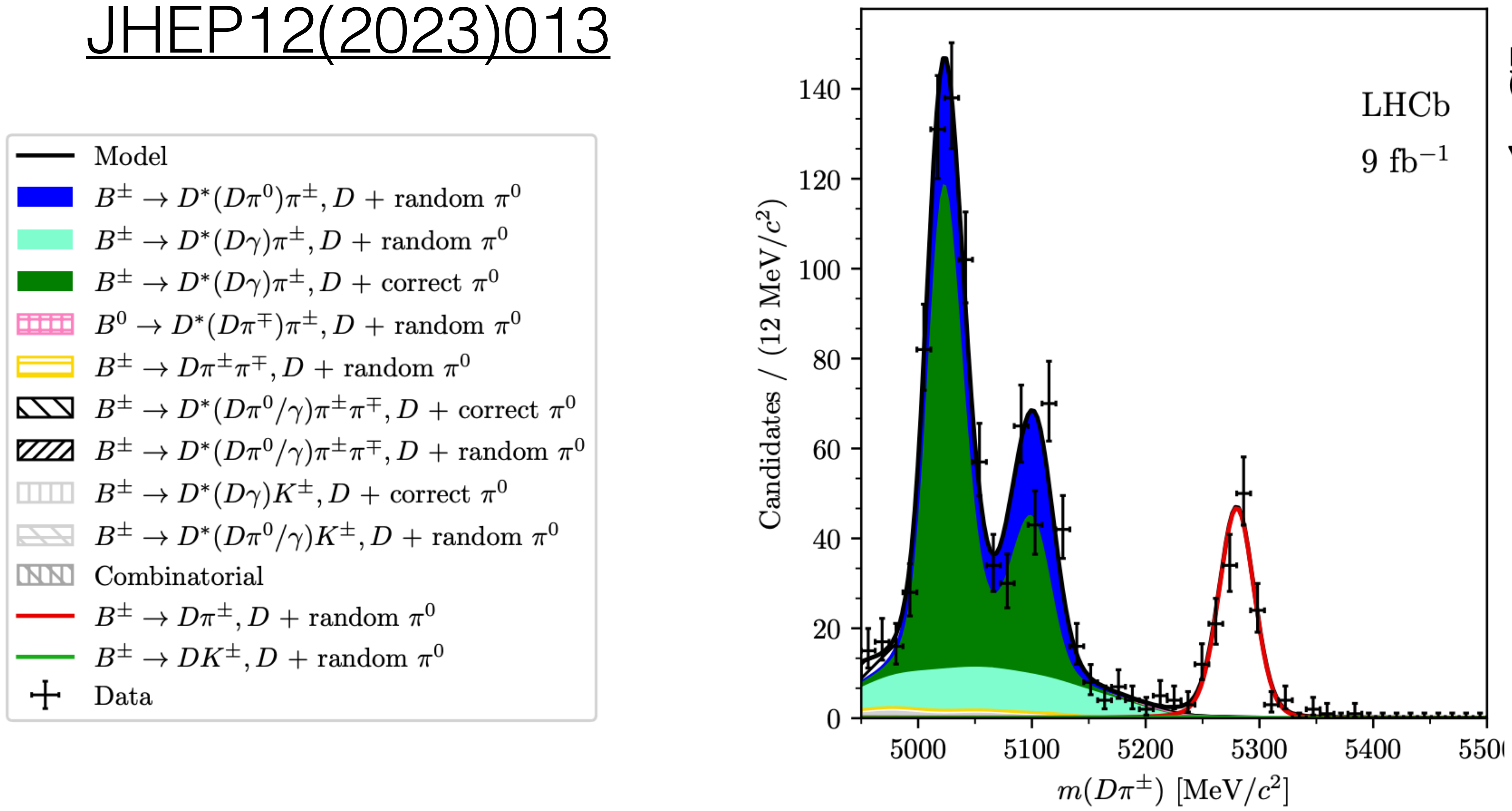


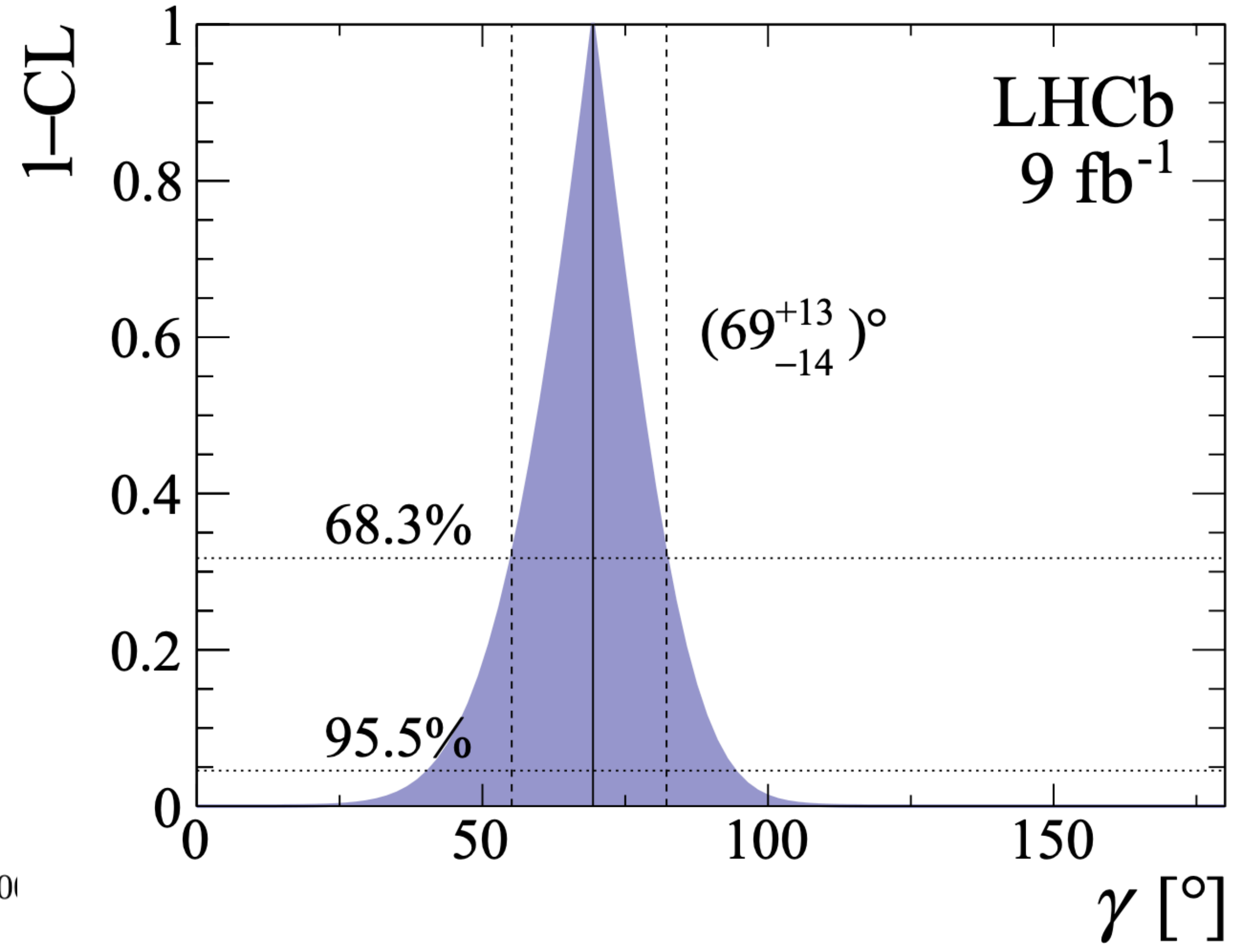
$\gamma = (63.2^{+6.9}_{-8.1})^{\circ}$



$B^0 \to D^0 K^*(892)^0$ with $D \to hh$ & $4h$ & $K^0_S hh$

JHEP12(2023)013





Full reconstruction of $B^{\pm} \to D^{*0} K^{\pm}$ with $D^{*0} \to D(\to K^0_S hh)\gamma/\pi^0$

$\gamma = (69^{+13}_{-14})^{\circ}$

Latest γ combination

LHCb-CONF-2024-004

B decay	D decay	Ref.	Dataset	Status since Ref. [14]
$B^{\pm} \to Dh^{\pm}$	$D \to h^{\pm}h'^{\mp}$	[35]	Run 1&2	*As before*
$B^{\pm} \to Dh^{\pm}$	$D \to h^{+}h^{-}\pi^{+}\pi^{-}$	[19]	Run 1&2	**New**
$B^{\pm} \to Dh^{\pm}$	$D \to K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$	[36]	Run 1&2	*As before*
$B^{\pm} \to Dh^{\pm}$	$D \to h^{\pm}h'^{\mp}\pi^{0}$	[37]	Run 1&2	*As before*
$B^{\pm} \to Dh^{\pm}$	$D \to K^0_S h^{+}h^{-}$	[38]	Run 1&2	*As before*
$B^{\pm} \to Dh^{\pm}$	$D \to K^0_S K^{\pm}\pi^{\mp}$	[39]	Run 1&2	*As before*
$B^{\pm} \to D^{*}h^{\pm}$	$D \to h^{\pm}h'^{\mp}$ (PR)	[35]	Run 1&2	*As before*
$B^{\pm} \to D^{*}h^{\pm}$	$D \to K^0_S h^{+}h^{-}$ (PR)	[20]	Run 1&2	**New**
$B^{\pm} \to D^{*}h^{\pm}$	$D \to K^0_S h^{+}h^{-}$ (FR)	[21]	Run 1&2	**New**
$B^{\pm} \to DK^{*\pm}$	$D \to h^{\pm}h'^{\mp}$	[22]†	Run 1&2	**Updated**
$B^{\pm} \to DK^{*\pm}$	$D \to h^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$	[22]†	Run 1&2	**Updated**
$B^{\pm} \to DK^{*\pm}$	$D \to K^0_S h^{+}h^{-}$	[22]†	Run 1&2	**New**
$B^{\pm} \to Dh^{\pm}\pi^{+}\pi^{-}$	$D \to h^{\pm}h'^{\mp}$	[40]	Run 1	*As before*
$B^{0} \to DK^{*0}$	$D \to h^{\pm}h'^{\mp}$	[23]	Run 1&2	**Updated**
$B^{0} \to DK^{*0}$	$D \to h^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$	[23]	Run 1&2	**Updated**
$B^{0} \to DK^{*0}$	$D \to K^0_S h^{+}h^{-}$	[24]	Run 1&2	**Updated**
$B^{0} \to D^{\mp}\pi^{\pm}$	$D^{+} \to K^{-}\pi^{+}\pi^{+}$	[41]	Run 1	*As before*
$B^0_s \to D_s^{\mp}K^{\pm}$	$D_s^{+} \to h^{+}h^{-}\pi^{+}$	[25, 42]†	Run 1&2	**Updated**
$B^0_s \to D_s^{\mp}K^{\pm}\pi^{+}\pi^{-}$	$D_s^{+} \to h^{+}h^{-}\pi^{+}$	[43]	Run 1&2	*As before*

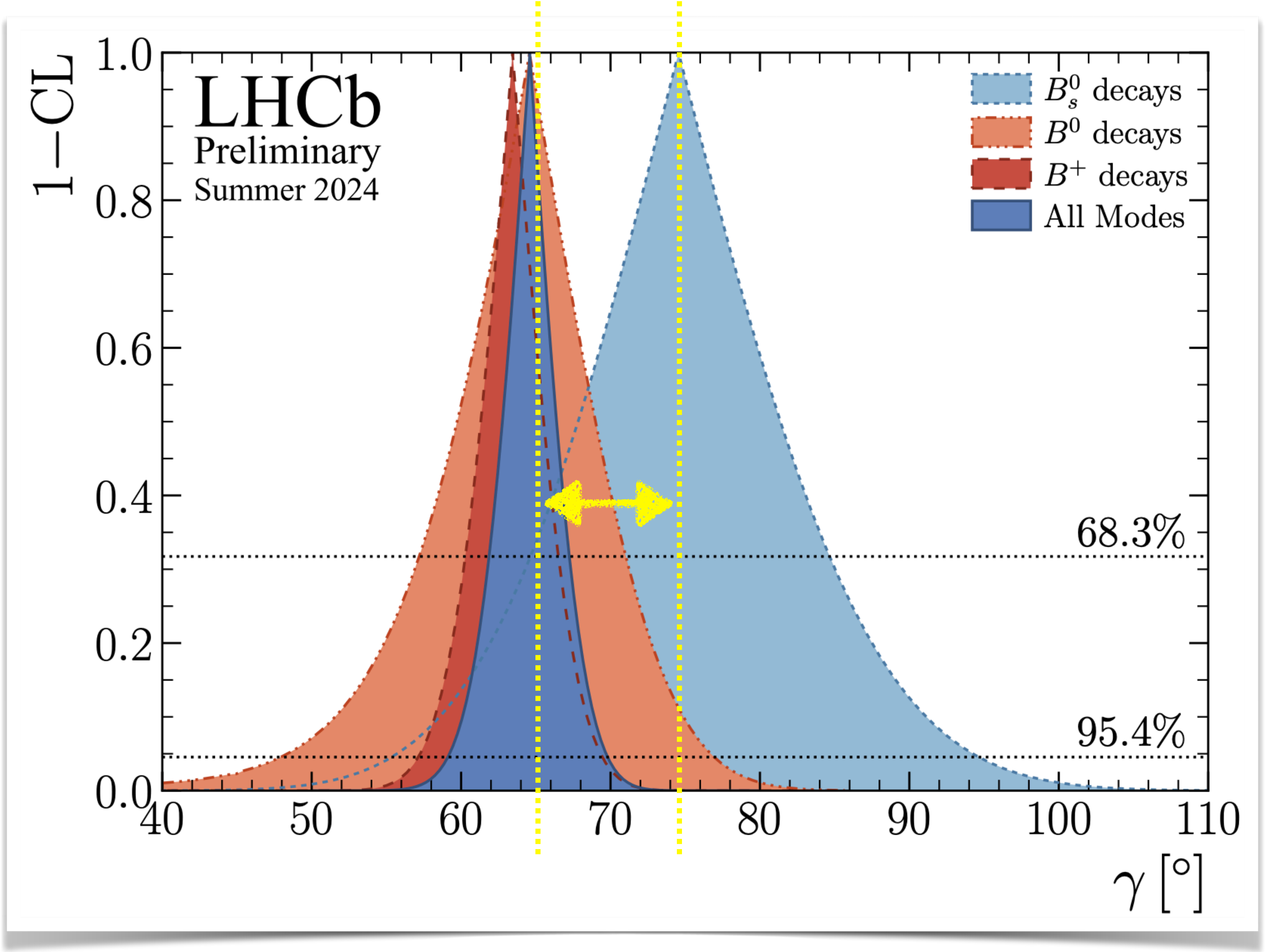
D decay	Observable(s)	Ref.	Dataset	Status since Ref. [14]
$D^0 \to h^{+}h^{-}$	ΔA_{CP}	[44–46]	Run 1&2	*As before*
$D^0 \to K^{+}K^{-}$	$A_{CP}(K^{+}K^{-})$	[46–48]	Run 2	*As before*
$D^0 \to h^{+}h^{-}$	$y_{CP} - y_{CP}^{K^-\pi^+}$	[49, 50]	Run 1&2	*As before*
$D^0 \to h^{+}h^{-}$	ΔY	[51–54]	Run 1&2	*As before*
$D^0 \to K^{+}\pi^{-}$ (double tag)	$R^{\pm}$, $(x'^{\pm})^2$, $y'^{\pm}$	[55]	Run 1	*As before*
$D^0 \to K^{+}\pi^{-}$ (single tag)	$R_{K\pi}$, $A_{K\pi}$, $c_{K\pi}^{(\prime)}$, $\Delta c_{K\pi}^{(\prime)}$	[27, 56]	Run 1&2	**Updated**
$D^0 \to K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$	$(x^2 + y^2)/4$	[57]	Run 1	*As before*
$D^0 \to K^0_S\pi^{+}\pi^{-}$	x, y	[58]	Run 1	*As before*
$D^0 \to K^0_S\pi^{+}\pi^{-}$	x_{CP}, y_{CP}, Δx, Δy	[59]	Run 1	*As before*
$D^0 \to K^0_S\pi^{+}\pi^{-}$	x_{CP}, y_{CP}, Δx, Δy	[60, 61]	Run 2	*As before*
$D^0 \to \pi^{+}\pi^{-}\pi^{0}$	$\Delta Y^{\rm eff}$	[26]	Run 2	**New**

Decay	Parameters	Source	Ref.	Status since Ref. [14]
$B^{\pm} \to DK^{*\pm}$	$\kappa_{B^\pm}^{DK^{*\pm}}$	LHCb	[62]	*As before*
$B^{0} \to DK^{*0}$	$\kappa_{B^0}^{DK^{*0}}$	LHCb	[63]	*As before*
$B^{0} \to D^{\mp}\pi^{\pm}$	β	HFLAV	[13]	**Updated**
$B^0_s \to D_s^{\mp}K^{\pm}(\pi\pi)$	ϕ_s	LHCb	[64]	**Updated**
$D \to K^{+}\pi^{-}$	$\cos\delta_D^{K\pi}$, $\sin\delta_D^{K\pi}$, $(r_D^{K\pi})^2$, x^2, y	CLEO-c	[65]	*As before*
$D \to K^{+}\pi^{-}$	$A_{K\pi}$, $A_{K\pi}^{\pi\pi\pi^0}$, $r_D^{K\pi}\cos\delta_D^{K\pi}$, $r_D^{K\pi}\sin\delta_D^{K\pi}$	BESIII	[66]	*As before*
$D \to h^{+}h^{-}\pi^{0}$	$F^{+}_{\pi\pi\pi^0}$, $F^{+}_{KK\pi^0}$	CLEO-c	[67]	*As before*
$D \to \pi^{+}\pi^{-}\pi^{+}\pi^{-}$	$F^{+}_{4\pi}$	CLEO-c+BESIII	[67, 68]	*As before*
$D \to K^{+}K^{-}\pi^{+}\pi^{-}$	$F^{+}_{KK\pi\pi}$	BESIII	[69]	**New**
$D \to K^{+}\pi^{-}\pi^{0}$	$r_D^{K\pi\pi^0}$, $\delta_D^{K\pi\pi^0}$, $\kappa_D^{K\pi\pi^0}$	CLEO-c+LHCb+BESIII	[70–72]	*As before*
$D \to K^{\pm}\pi^{\mp}\pi^{+}\pi^{-}$	$r_D^{K3\pi}$, $\delta_D^{K3\pi}$, $\kappa_D^{K3\pi}$	CLEO-c+LHCb+BESIII	[57, 70–72]	*As before*
$D \to K^0_S K^{\pm}\pi^{\mp}$	$r_D^{K^0_S K\pi}$, $\delta_D^{K^0_S K\pi}$, $\kappa_D^{K^0_S K\pi}$	CLEO-c	[73]	*As before*
$D \to K^0_S K^{\pm}\pi^{\mp}$	$r_D^{K^0_S K\pi}$	LHCb	[74]	*As before*

Latest γ combination

LHCb-CONF-2024-004

- **19** LHCb B decay measurements + **11** D decay measurements + 27 external inputs
- **29** physics parameters of interest + additional nuisance parameters



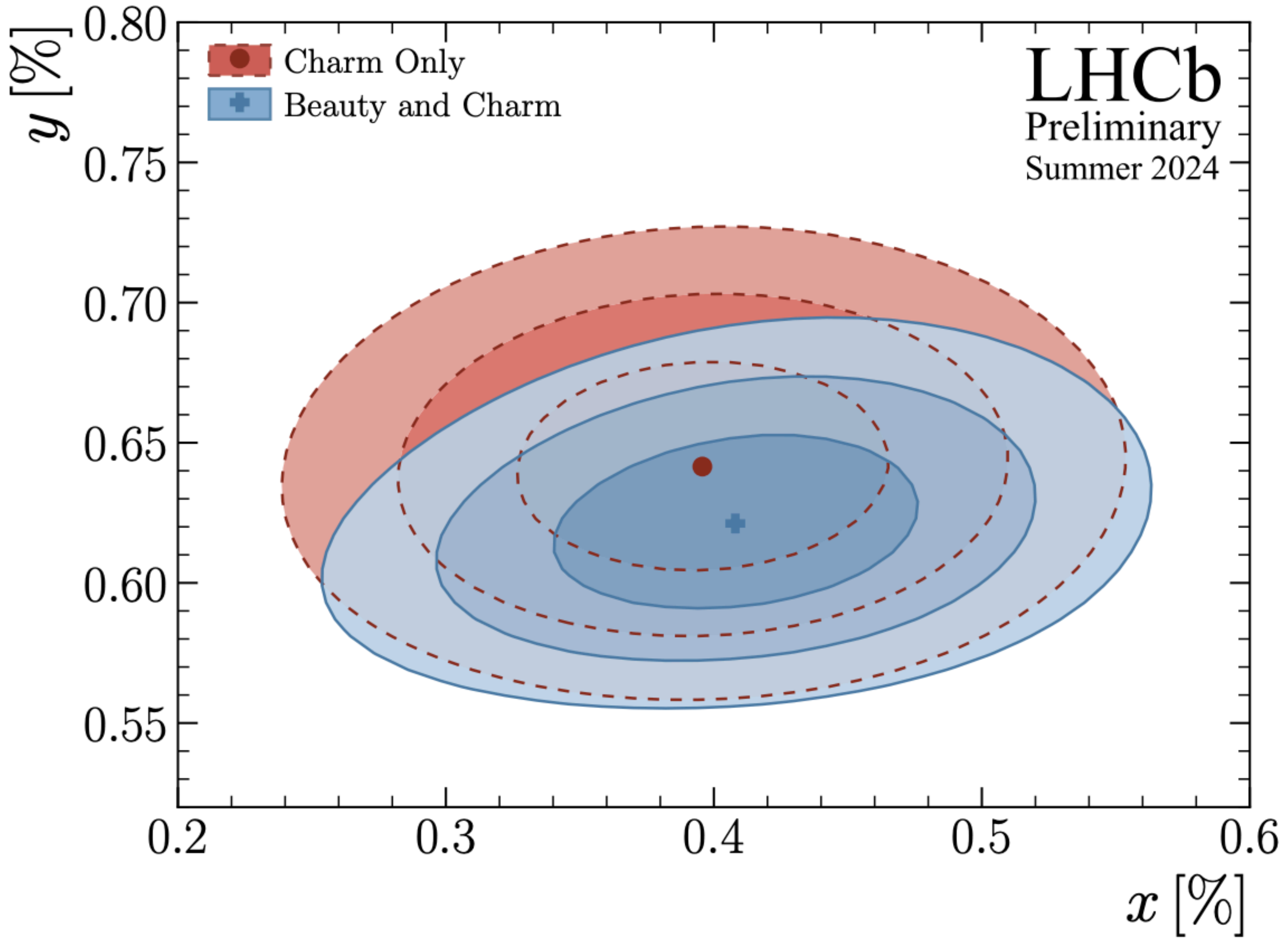
$\gamma = (64.6 \pm 2.8)^\circ$

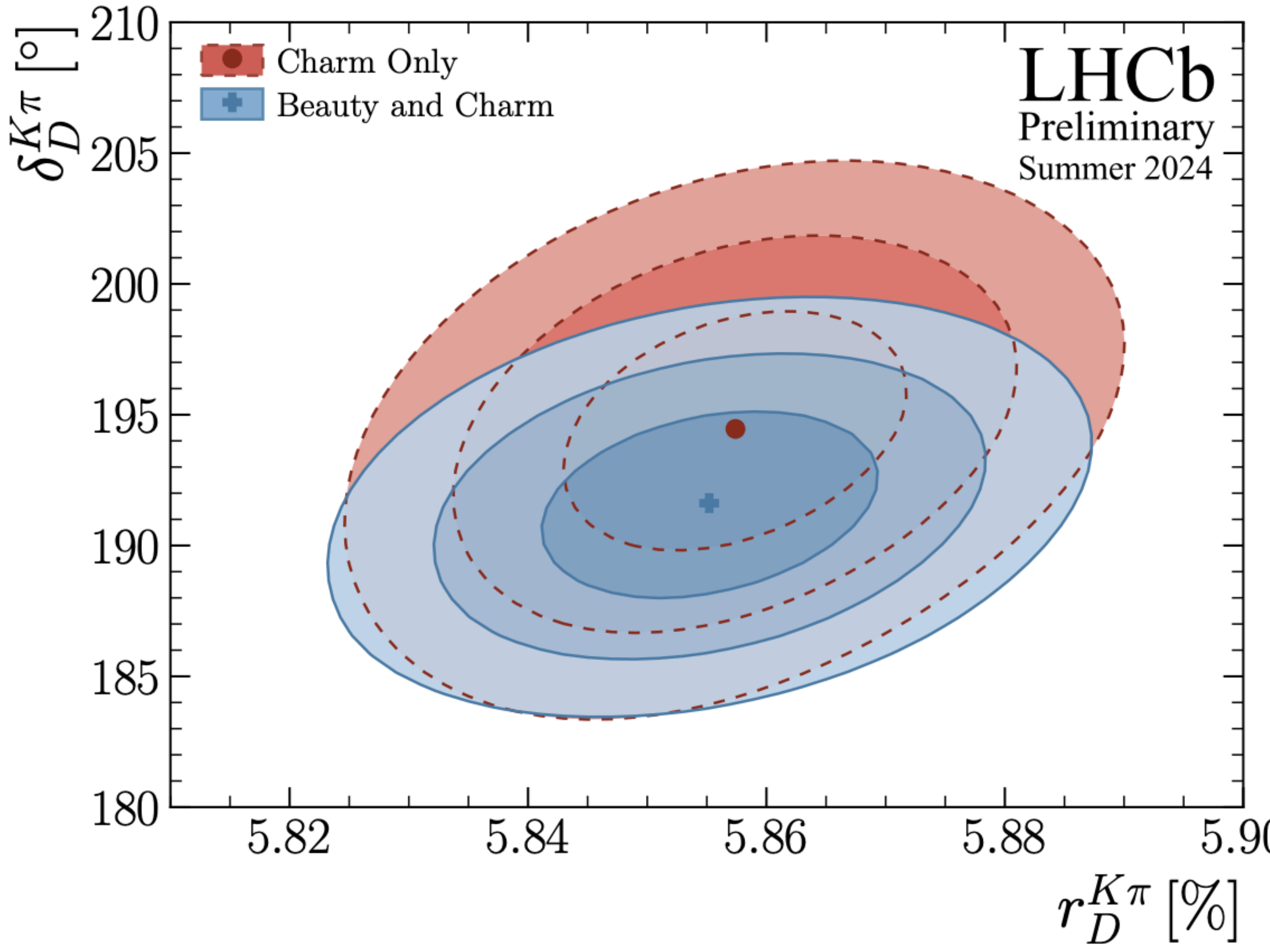
$x = (0.41 \pm 0.05)\,\%$

$y = (0.621^{+0.022}_{-0.021})\,\%$

$|q/p| = 0.989 \pm 0.015$

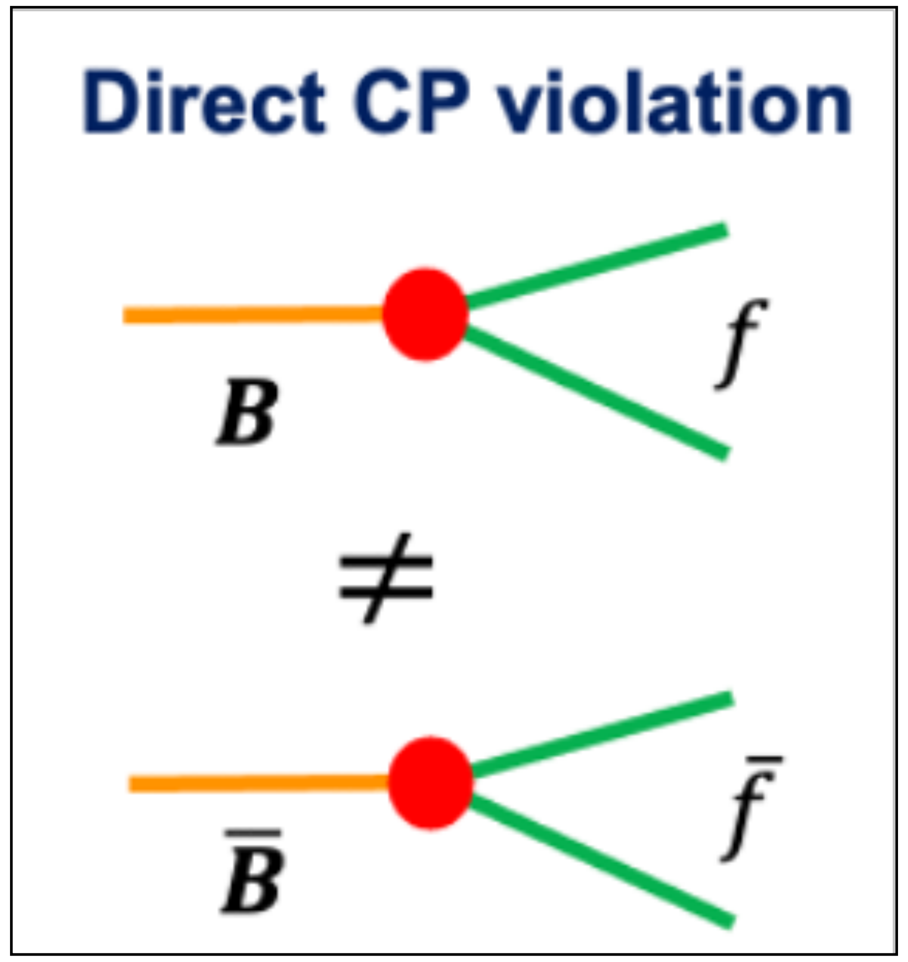
$\delta_D^{K\pi} = (191.6^{+2.5}_{-.4})^\circ$

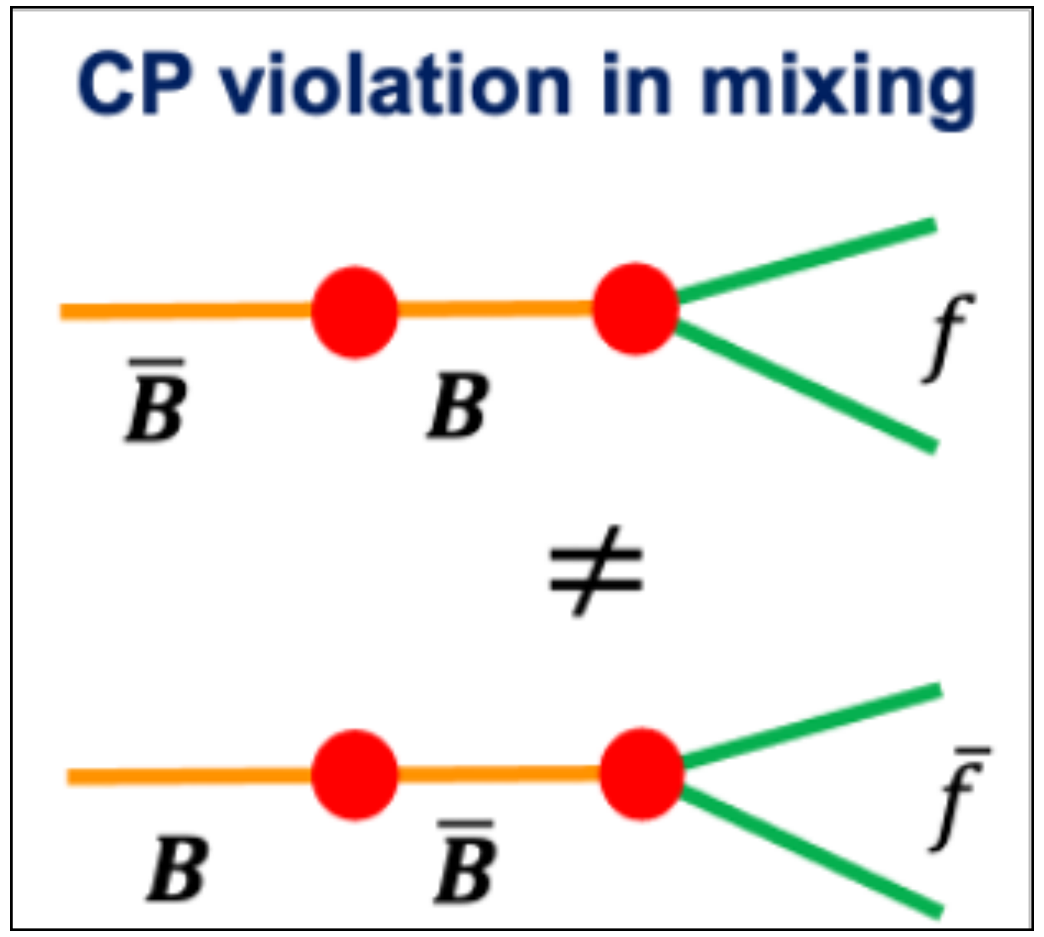


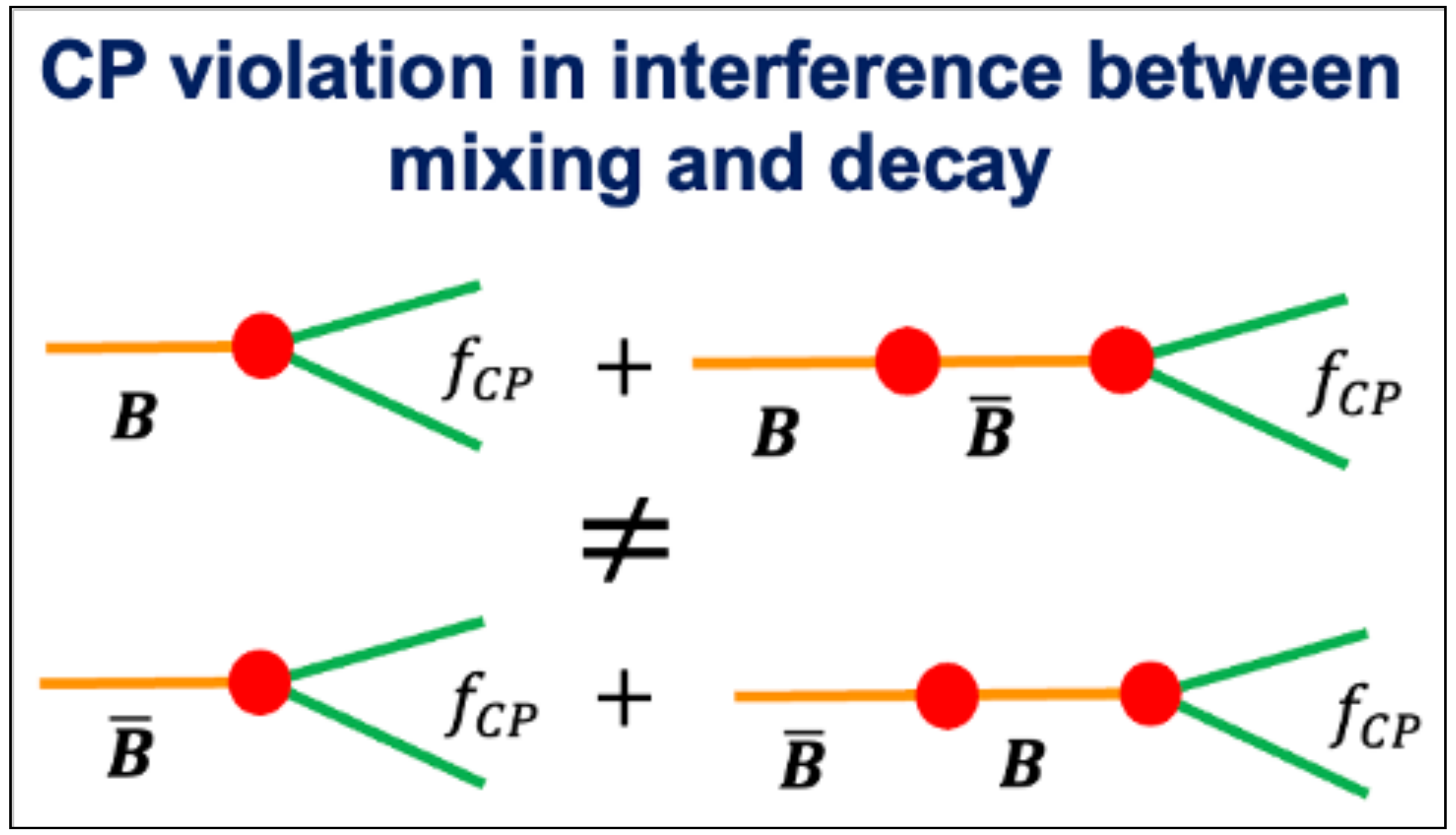


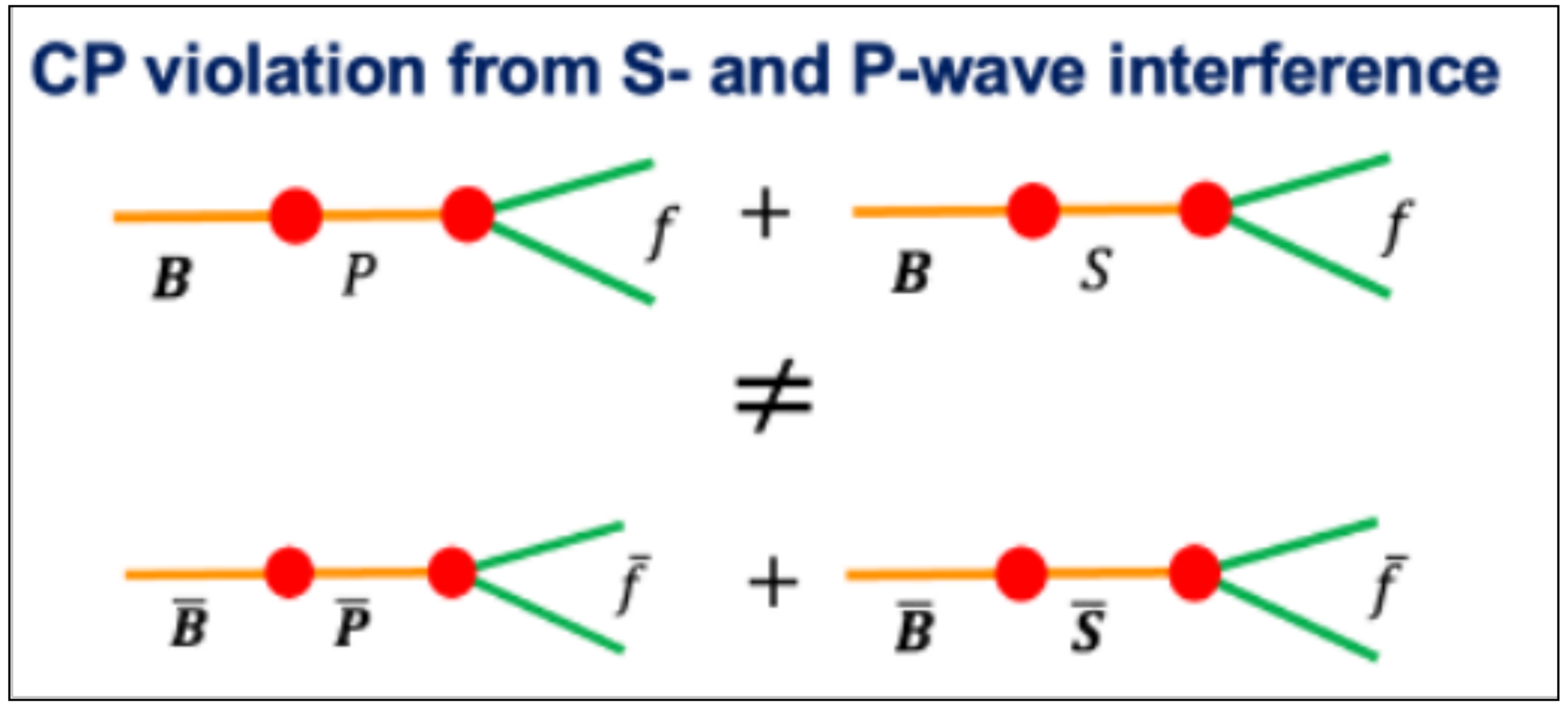
- Surpass LHCb design: 4°
- Consistent with SM predictions $(65.5^{+0.09}_{-2.65})^\circ$

CP violation







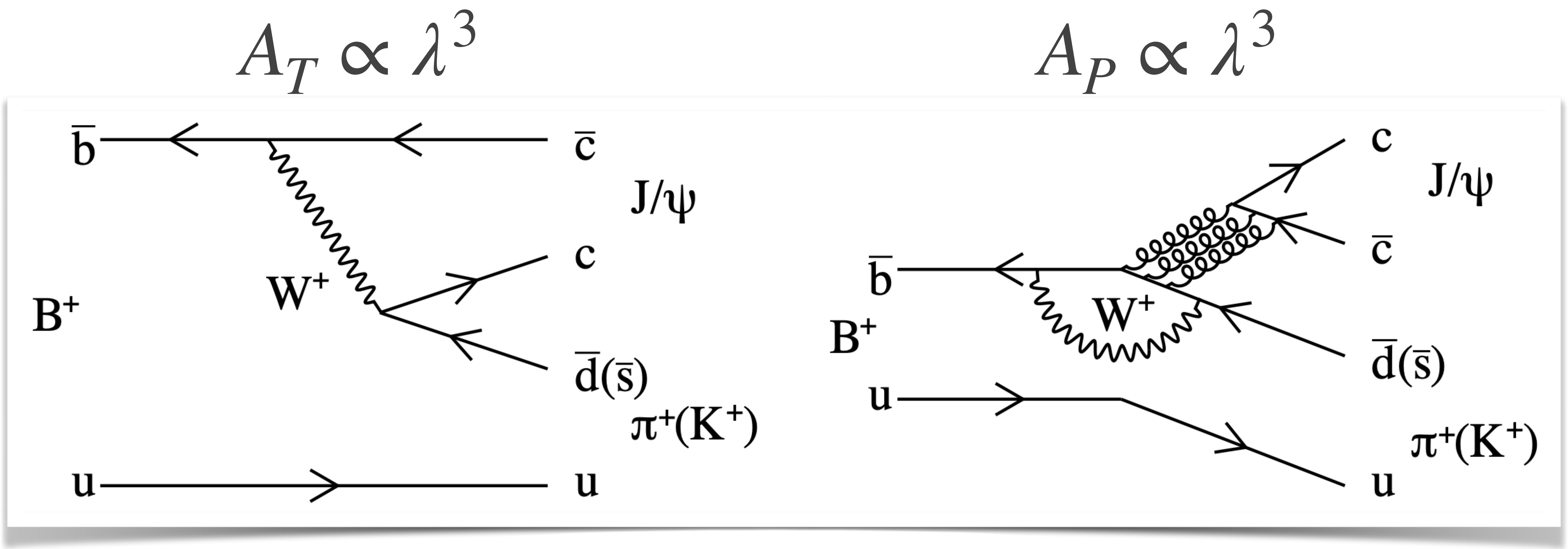


Direct CPV in $B^+ \to J/\psi\pi^+$

arXiv: 2411.12178

- O(1%) direct CP violation expected in $B^+ \to J/\psi\pi^+$ [PRD 49 (1994) 5904, PRD 52 (1995) 242]
- Important control channel to understand penguin effects in $\sin 2\beta$ measurement

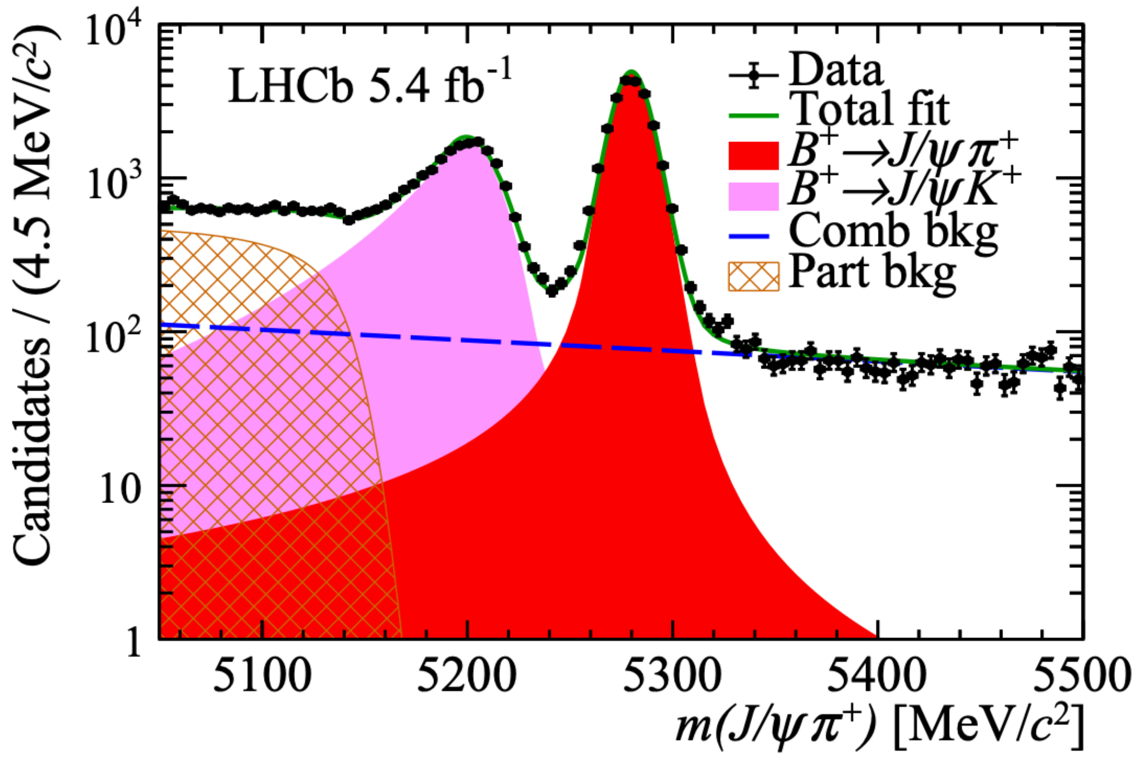
[PRD 79 (2009) 014030, JHEP 03 (2015) 145]

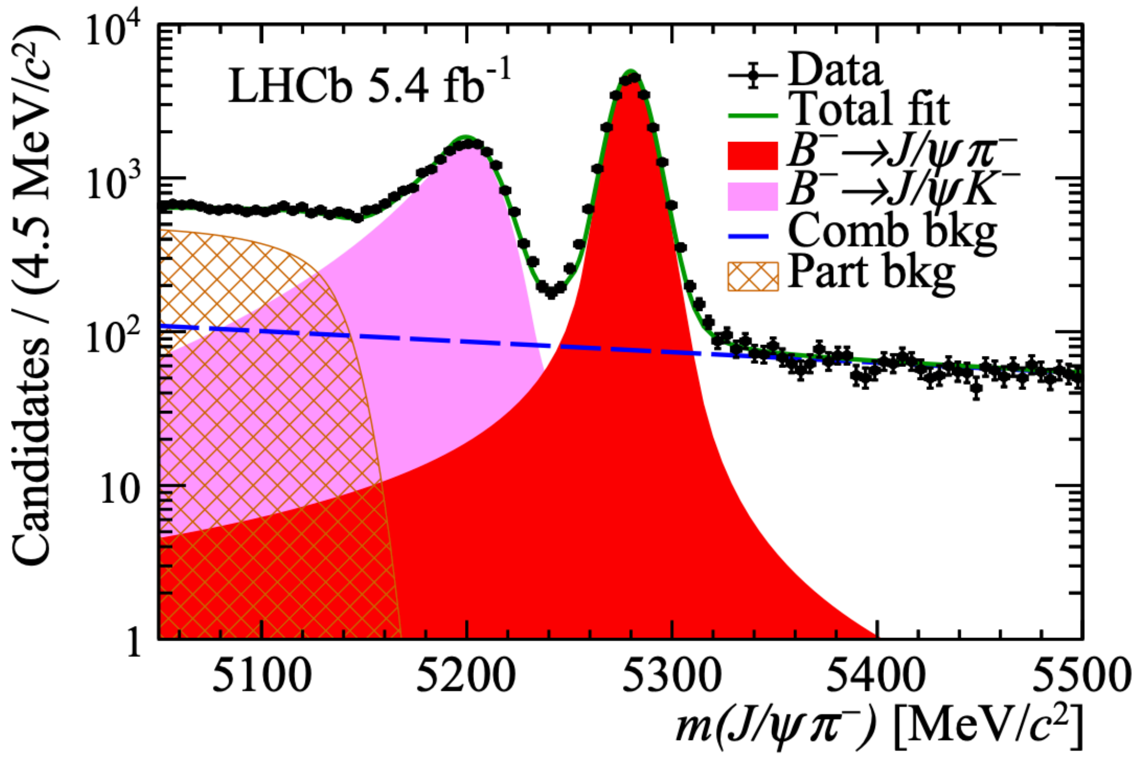


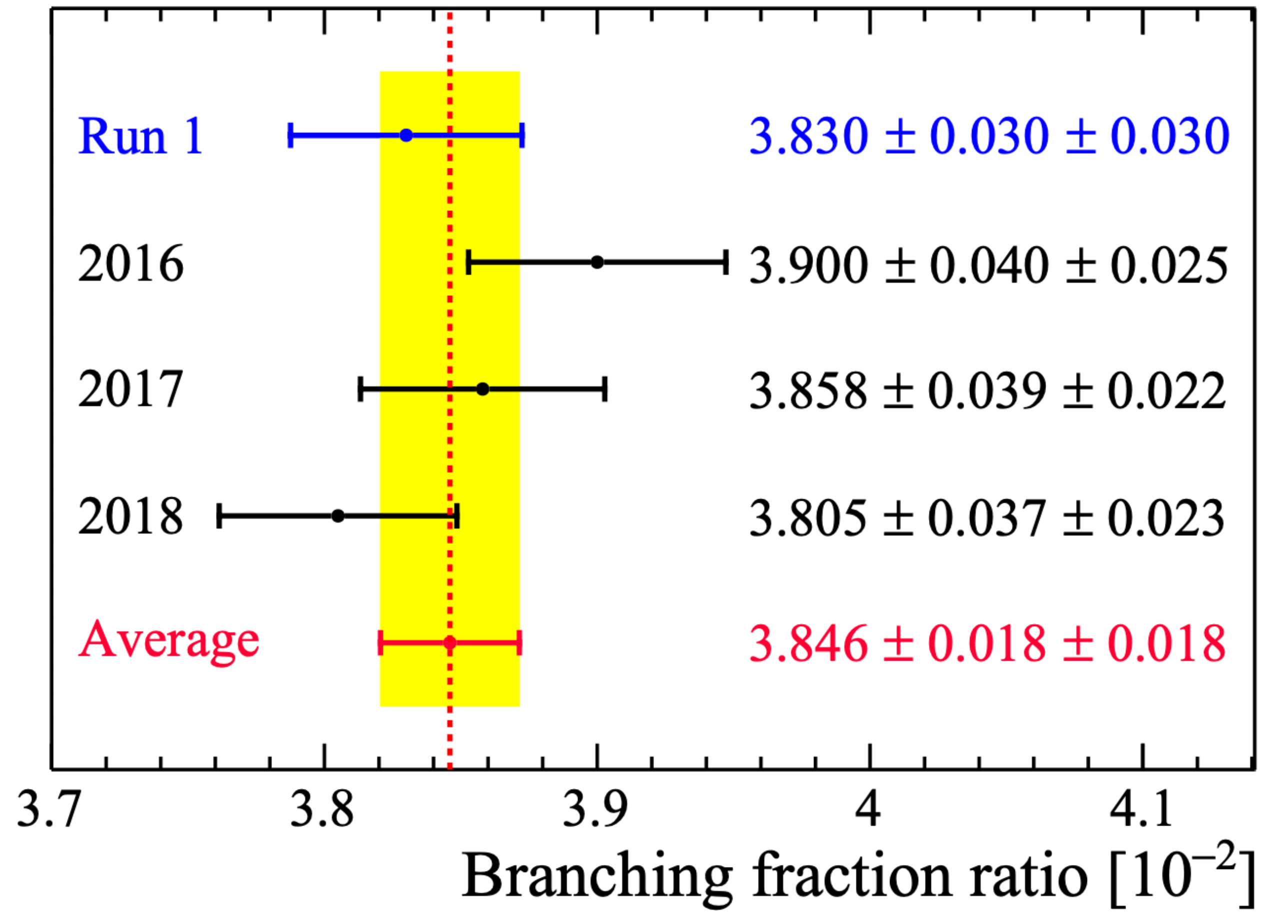
$$\mathscr{R}_{\pi/K} \equiv \frac{B(B^+ \to J/\psi\pi^+)}{B(B^+ \to J/\psi K^+)} = \frac{N_\pi}{N_K} \times \frac{\epsilon_K}{\epsilon_\pi}$$

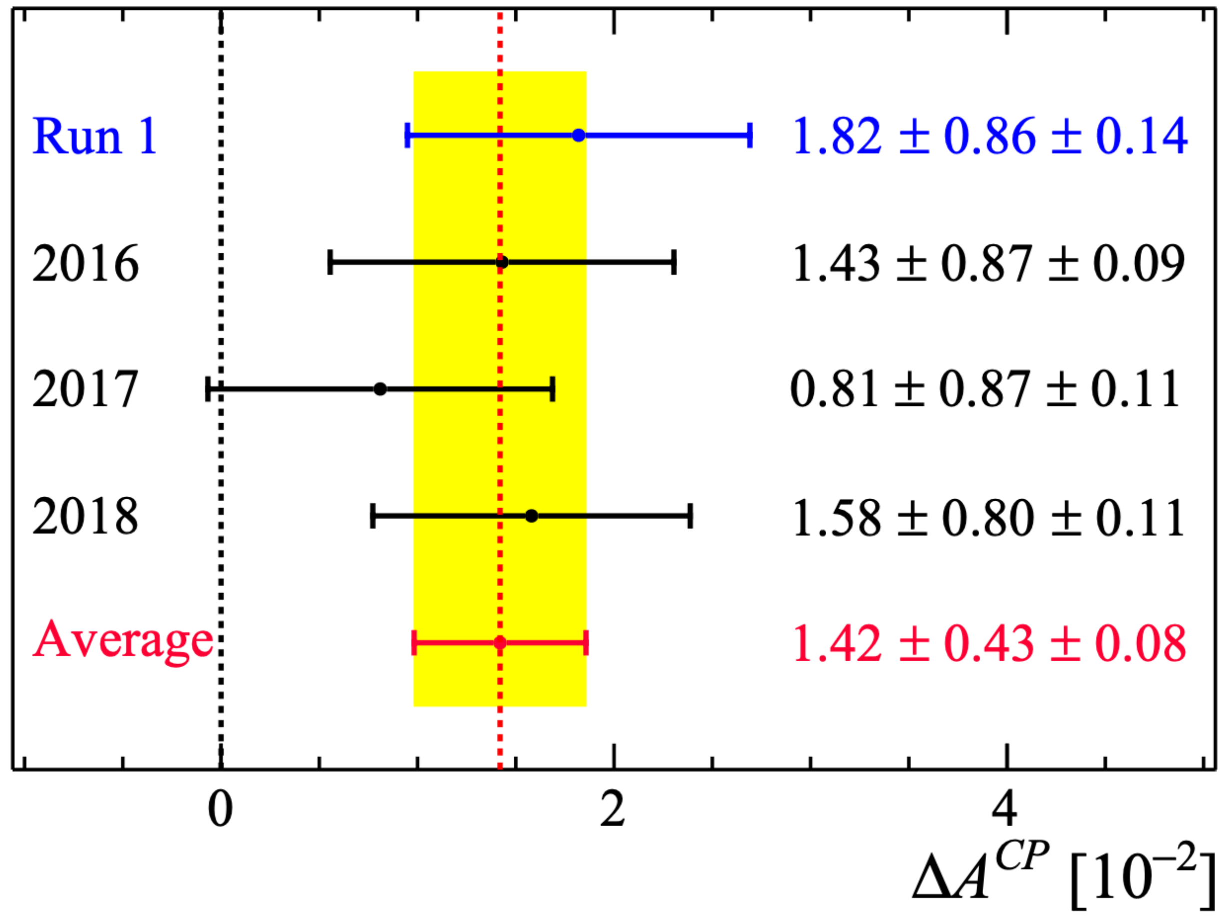
$$\Delta A^{CP} \equiv A^{CP}(B^+ \to J/\psi\pi^+) - A^{CP}(B^+ \to J/\psi K^+)$$
$$= \Delta A_{raw} - \Delta A_D^{K/\pi} - \Delta A_{PID}^{K/\pi}$$

First evidence for direct CP violation in beauty decays to charmonium final states (3.2 σ)

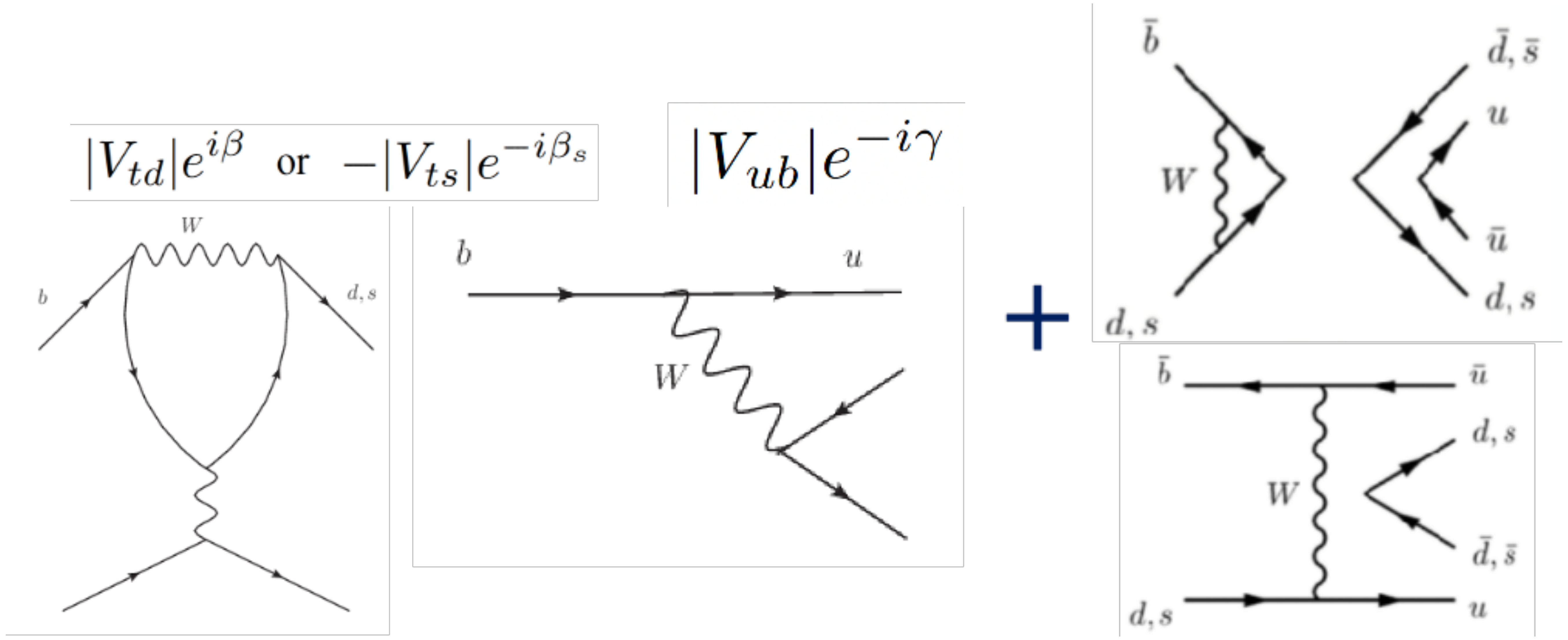


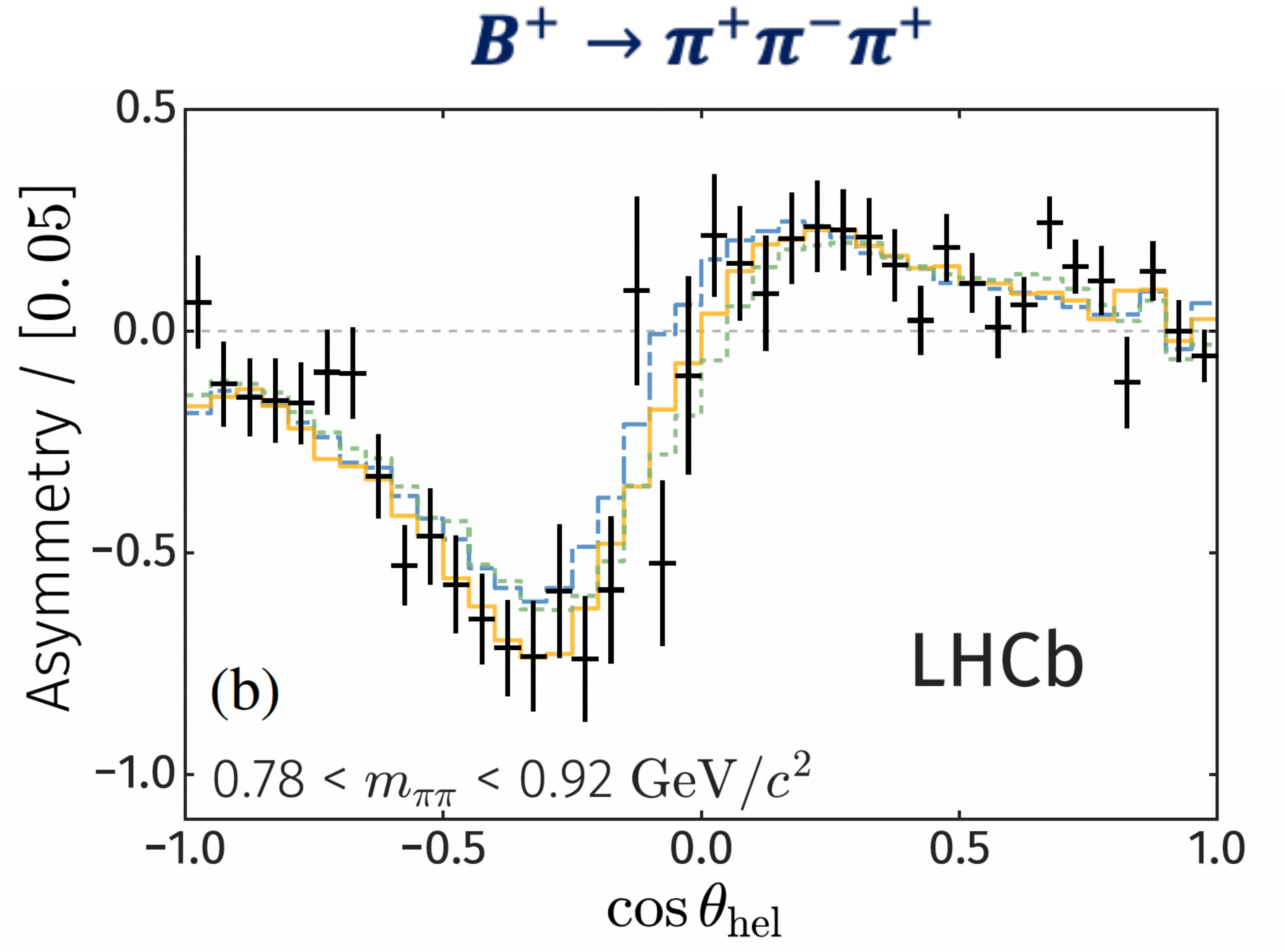






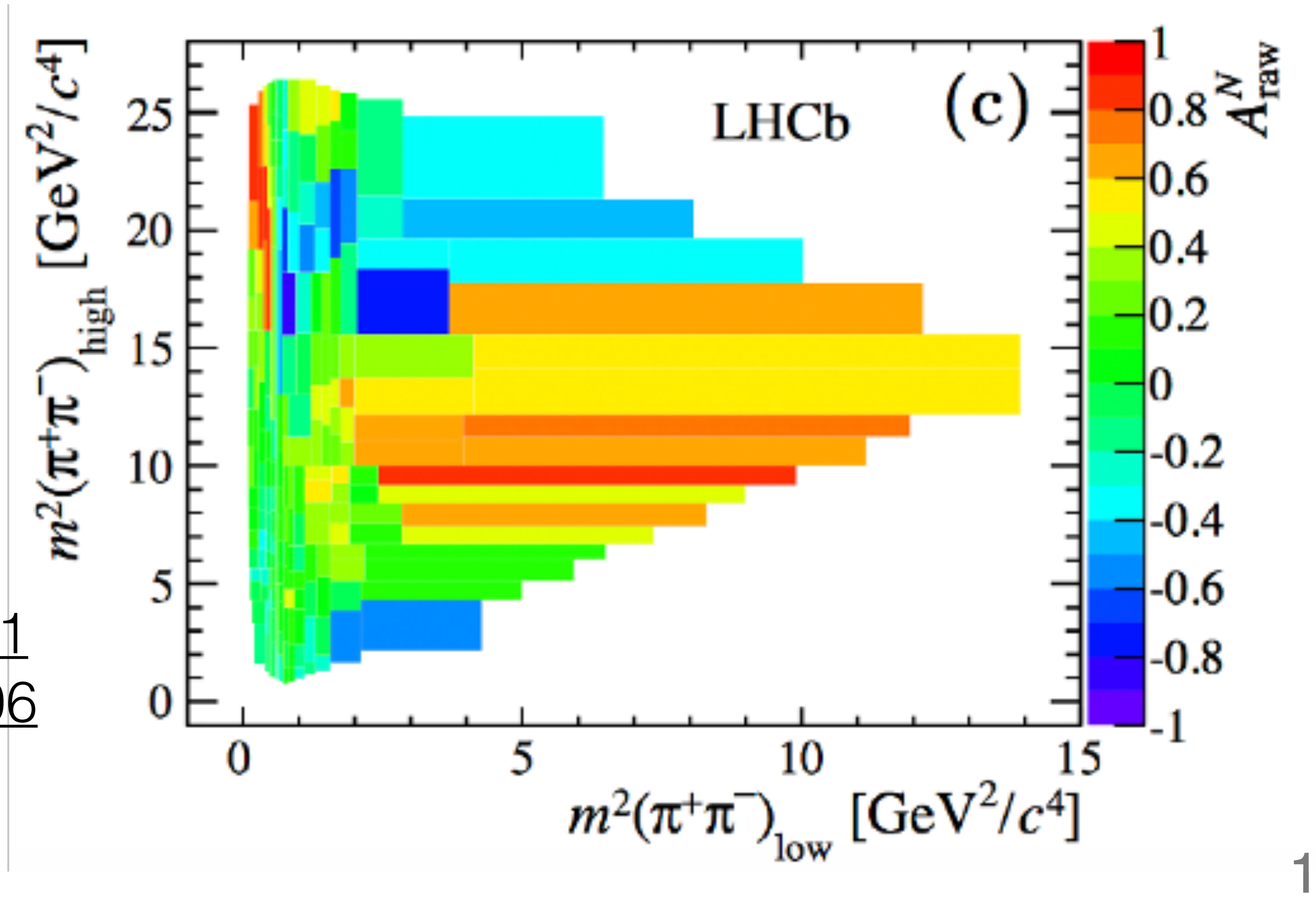
Charmless three-body b decays





- Complex CP violation pattern in multi-body B decays, as large as 80%
- Interesting to search for CP violation in Λ_b^0 decays

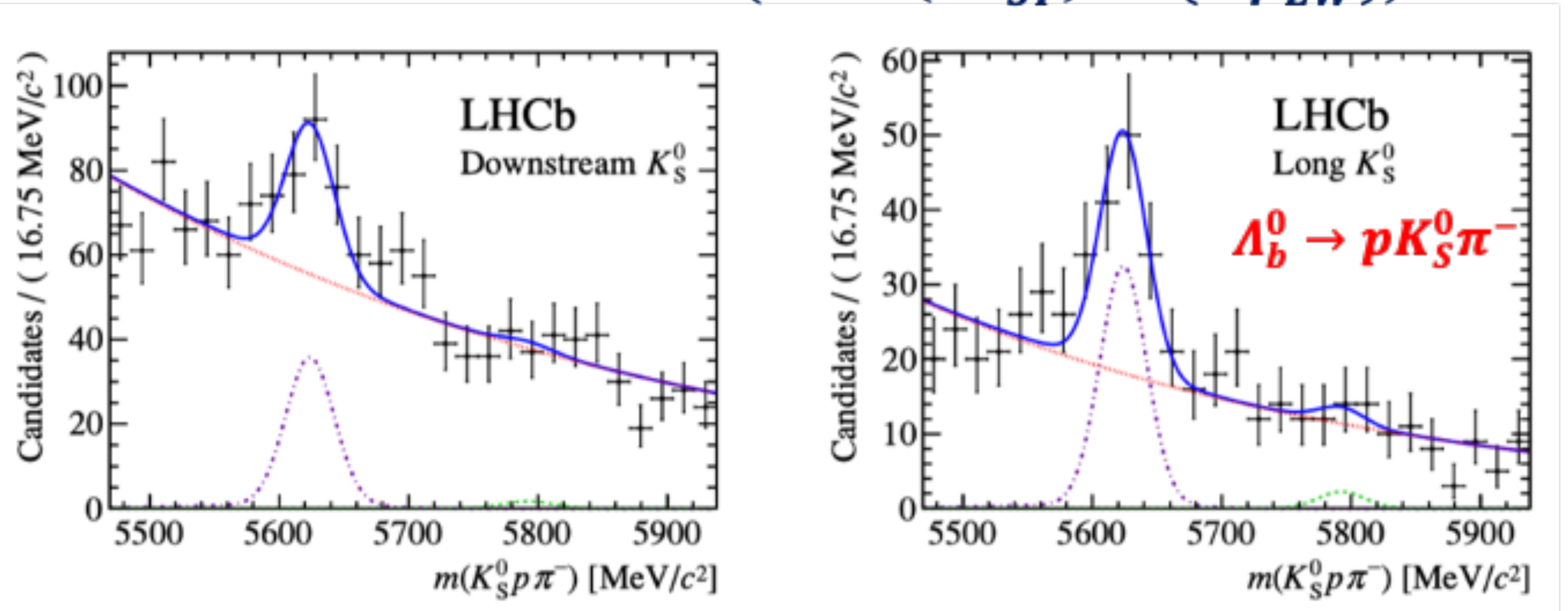
PRL124 (2020) 031801
PRD101 (2020) 012006



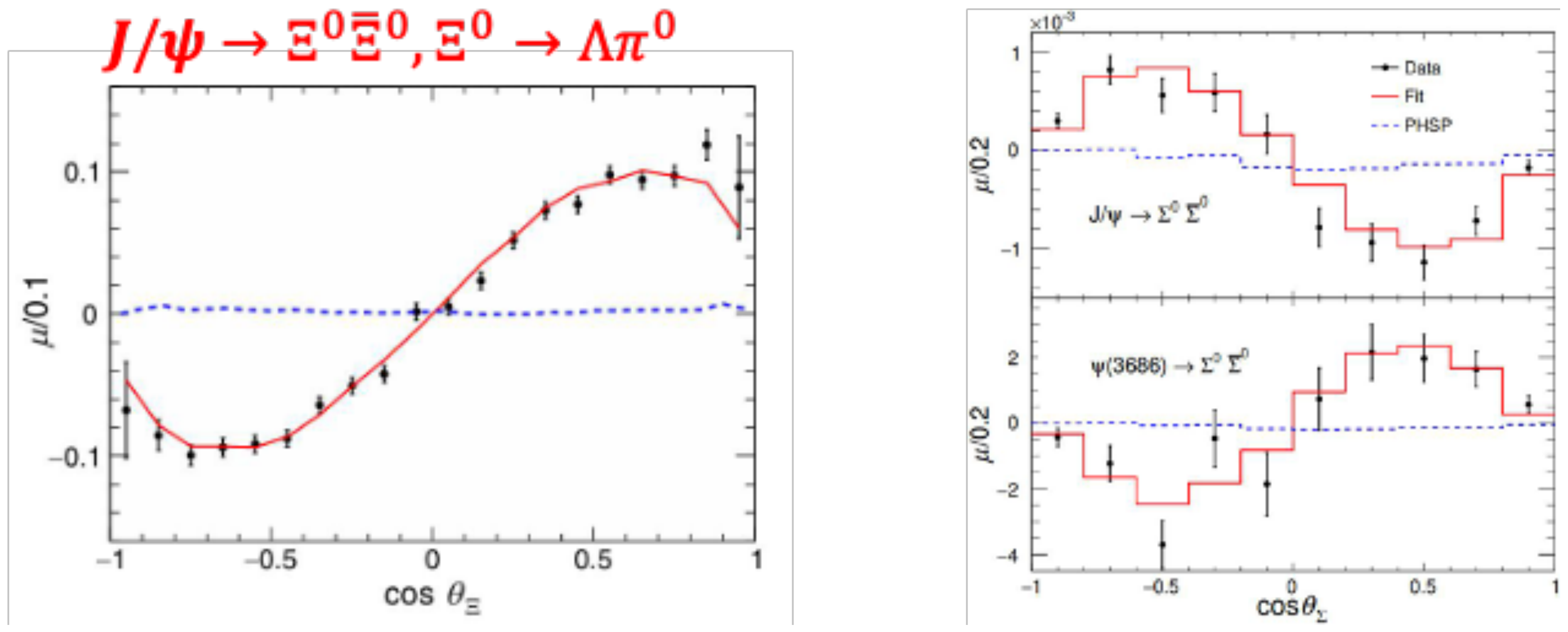
CP Violation in baryonic decays

- Baryons crucial for asymmetries in Universe, no CP violation in baryons observed yet
- CPV: b baryons $\mathcal{O}(1-10\%)$, c baryons $\mathcal{O}(0.1\%)$, hyperon $\mathcal{O}(0.001-0.01\%)$

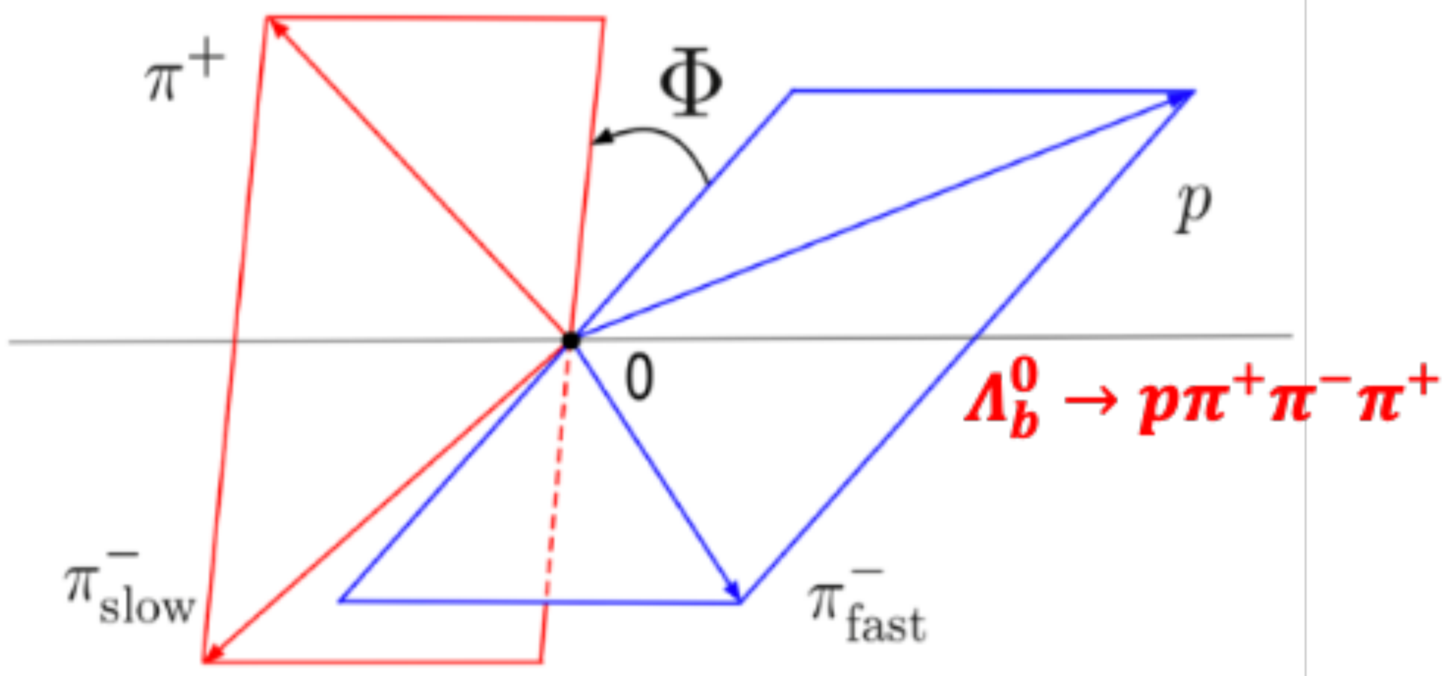
Direct CP violation ($\propto \sin(\Delta\delta_{ST})\sin(\Delta\phi_{EW})$)



Decay parameters asymmetry



Triple-product asymmetry ($\propto \cos(\Delta\delta_{ST})\sin(\Delta\phi_{EW})$)



- Puzzling situation: similar Λ^0_b production as B^+, huge significance of CPV in B^+, none in Λ^0_b?

arXiv:2411.18323

A long list of searches in b baryons at LHCb

Decay	Methods	Data	Reference
$\Lambda_b^0 \to p K_S^0 \pi^-$	A_{CP}	1 fb^{-1}	JHEP 04 (2014) 087
$\Lambda_b^0 \to \Lambda h h'$	A_{CP}	3 fb^{-1}	JHEP 05 (2016) 081
$\Lambda_b^0 \to p \pi^- \pi^+ \pi^-$	TPA, energy test	3 fb^{-1} 6.6 fb^{-1}	Nature Physics 13 (2017) 391 PRD 102 (2020) 051101
$\Lambda_b^0 \to p K^- \mu^+ \mu^-$	A_{CP}	3 fb^{-1}	JHEP 06 (2017) 108
$\Lambda_c^+ \to p h^- h^+$	A_{CP}	3 fb^{-1}	JHEP 03 (2018) 182
$\Lambda_b^0 \to p K^- / p \pi^-$	A_{CP}	3 fb^{-1}	PLB 787 (2018) 124
$\Lambda_b^0 \to p h^- h^+ h^-$	TPA	3 fb^{-1}	JHEP 08 (2018) 039
$\Lambda_b^0 \to p h^- h^+ h^-$	A_{CP}	3 fb^{-1}	EPJC 79 (2019) 745
$\Xi_b^- \to p K^- K^-$	Amplitude	5 fb^{-1}	PRD 104 (2020) 052010
$\Xi_c^+ \to p K^- \pi^+$	kNN	3 fb^{-1}	EPJC 80 (2020) 986
$\Lambda_b^0 \to p D^0 K^-$	Miranda S_{CP}^i	9 fb^{-1}	PRD104 (2021) 112008
$\Lambda_b^0 \to \Lambda \gamma$	photon polarization	3 fb^{-1}	PRD105 (2022) L051104
$\Lambda_b^0 \to p h^-$	A_{CP}	9 fb^{-1}	arXiv:2412.13958, submitted to PRD
$\Lambda_b^0 \to \Lambda_c^+ h^-$	Decay parameter	9 fb^{-1}	PRL 133 (2024) 261804
$\Lambda_b^0 \to \Lambda h h'$	A_{CP}	9 fb^{-1}	PRL 134 (205) 101802
$\Lambda_b^0 \to p K^- \pi^+ \pi^-$	A_{CP}	9 fb^{-1}	arXiv:2503.16954, submitted to Nature

credit: Yanxi Zhang

Evidence of CP violation in baryonic decays

arXiv: 2411.15441

Signal channel

$A^{S}_{CP} = A^{S}_{\mathrm{Raw}} - A^{\Lambda^0_b}_{\mathrm{P}} - A^{S}_{\mathrm{D}}$

Control channel

$A^{C}_{CP} = A^{C}_{\mathrm{Raw}} - A^{\Lambda^0_b}_{\mathrm{P}} - A^{C}_{\mathrm{D}}$

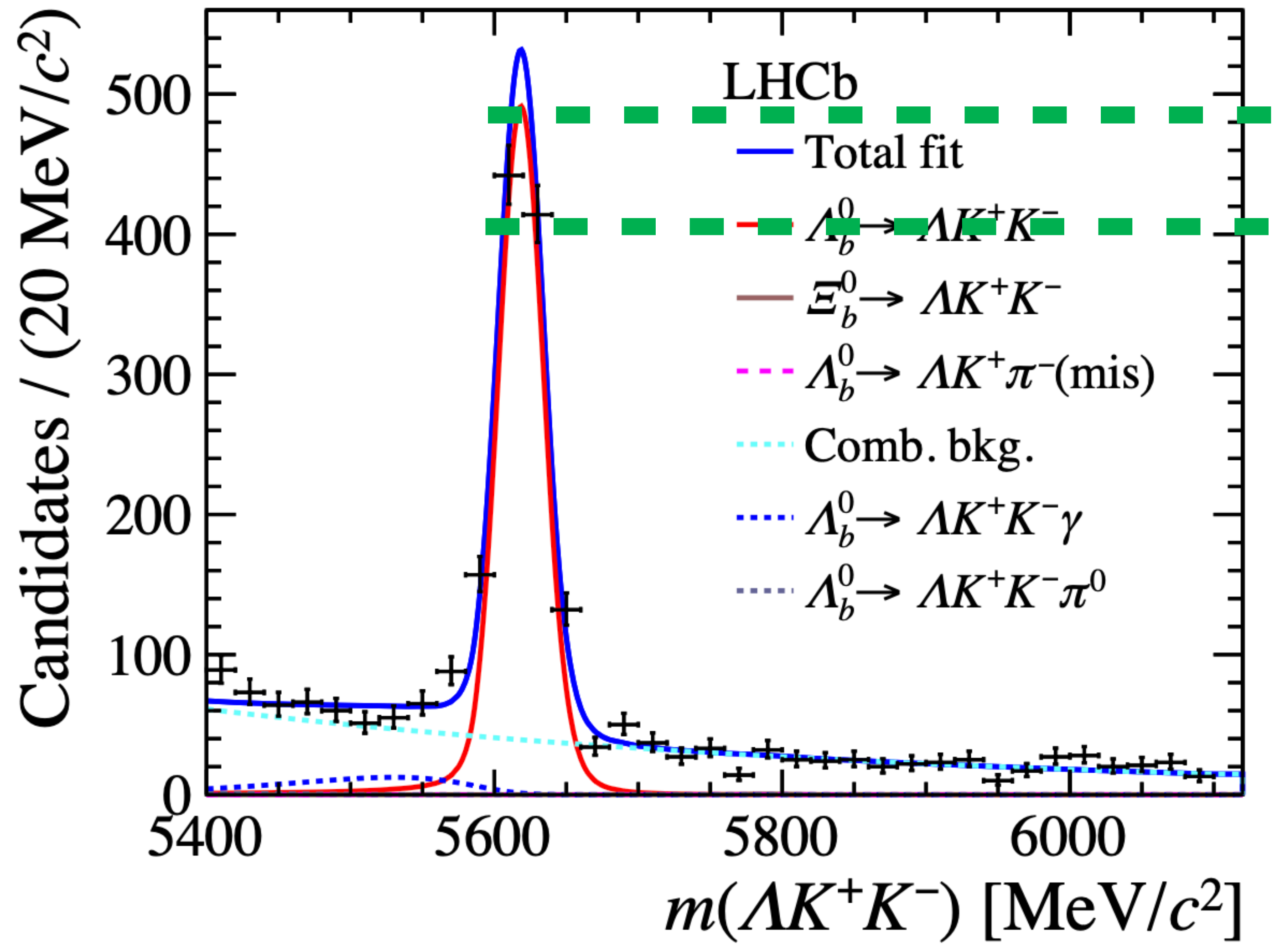
$\Lambda^0_b \to \Lambda^+_c(\to \Lambda\pi^+)\pi^-$

$A_{CP}\sim 0$

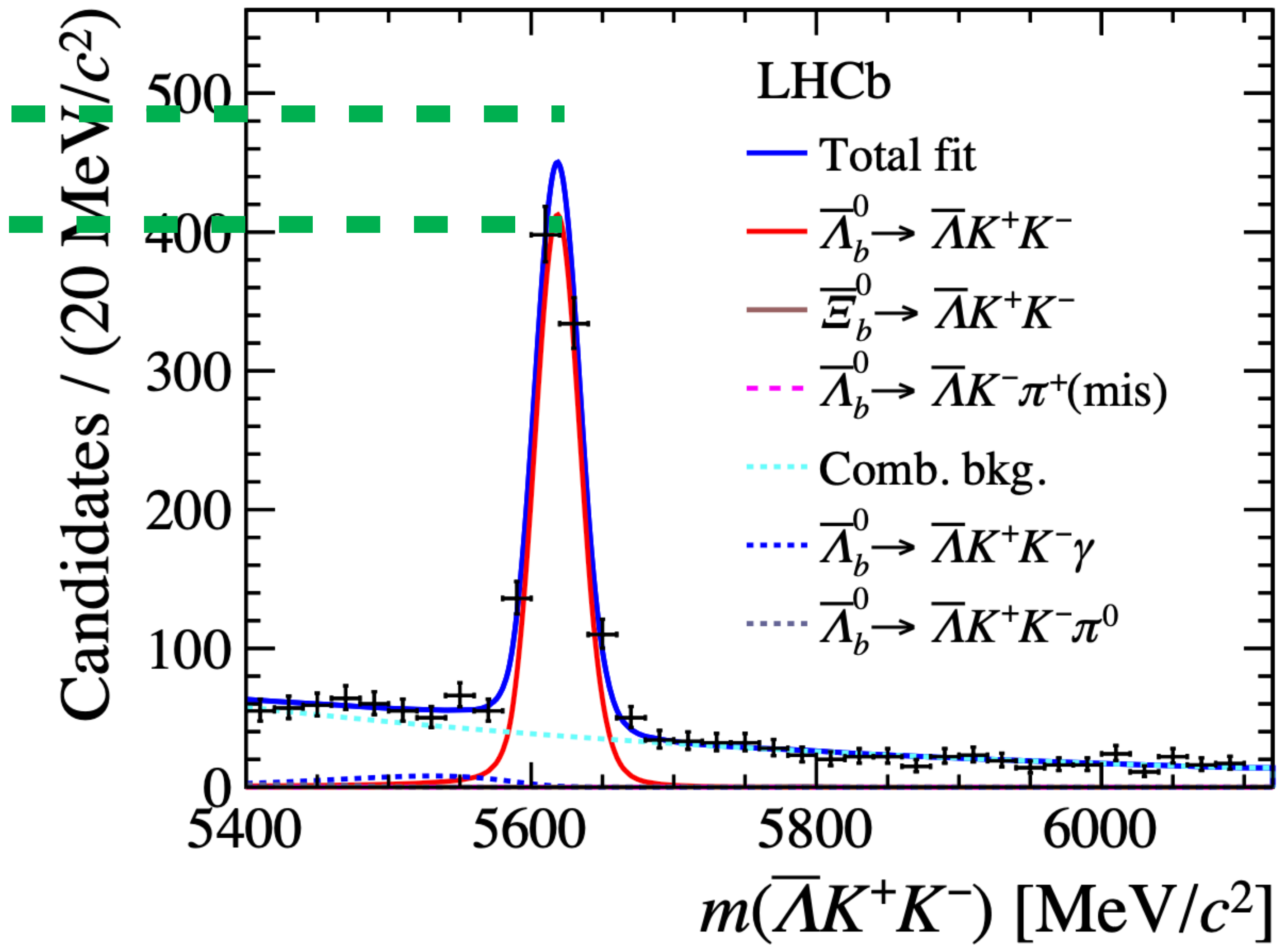
$\Delta A_{CP} = \Delta A_{\mathrm{Raw}} - \Delta A^{\Lambda^0_b}_{\mathrm{P}} - \Delta A_{\mathrm{D}}$

$$\mathcal{A}^{CP}(\Lambda^0_b/\Xi^0_b \to f) \equiv \frac{\Gamma(\Lambda^0_b/\Xi^0_b \to f) - \Gamma(\bar{\Lambda}^0_b/\bar{\Xi}^0_b \to \bar{f})}{\Gamma(\Lambda^0_b/\Xi^0_b \to f) + \Gamma(\bar{\Lambda}^0_b/\bar{\Xi}^0_b \to \bar{f})}$$

Preliminary



$\Lambda^0_b \to \Lambda K^+K^-$

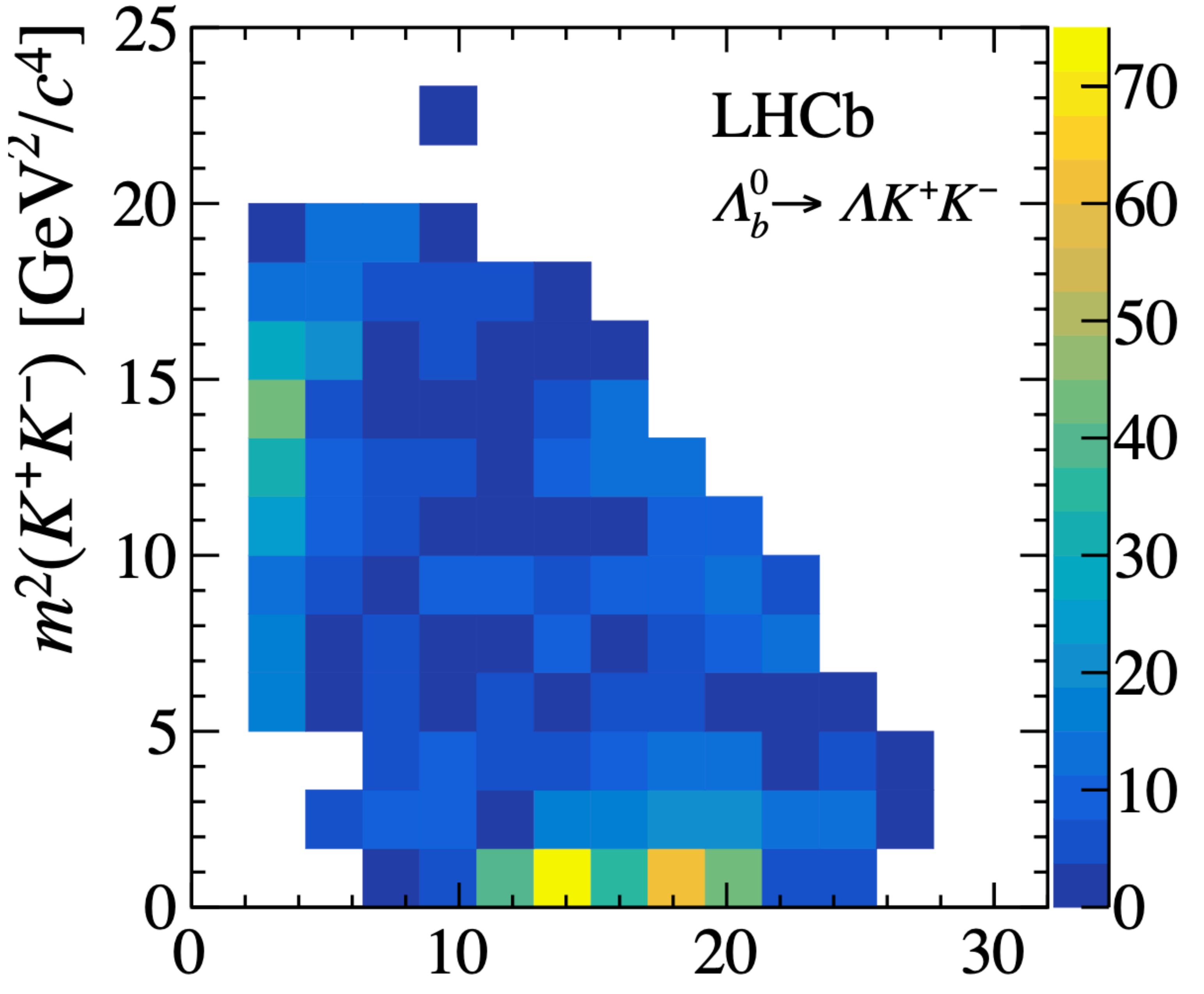


$\bar{\Lambda}^0_b \to \bar{\Lambda} K^+K^-$

$$\Delta A_{CP} = 0.083 \pm 0.023 \pm 0.016$$

First evidence for CP violation, 3.1σ

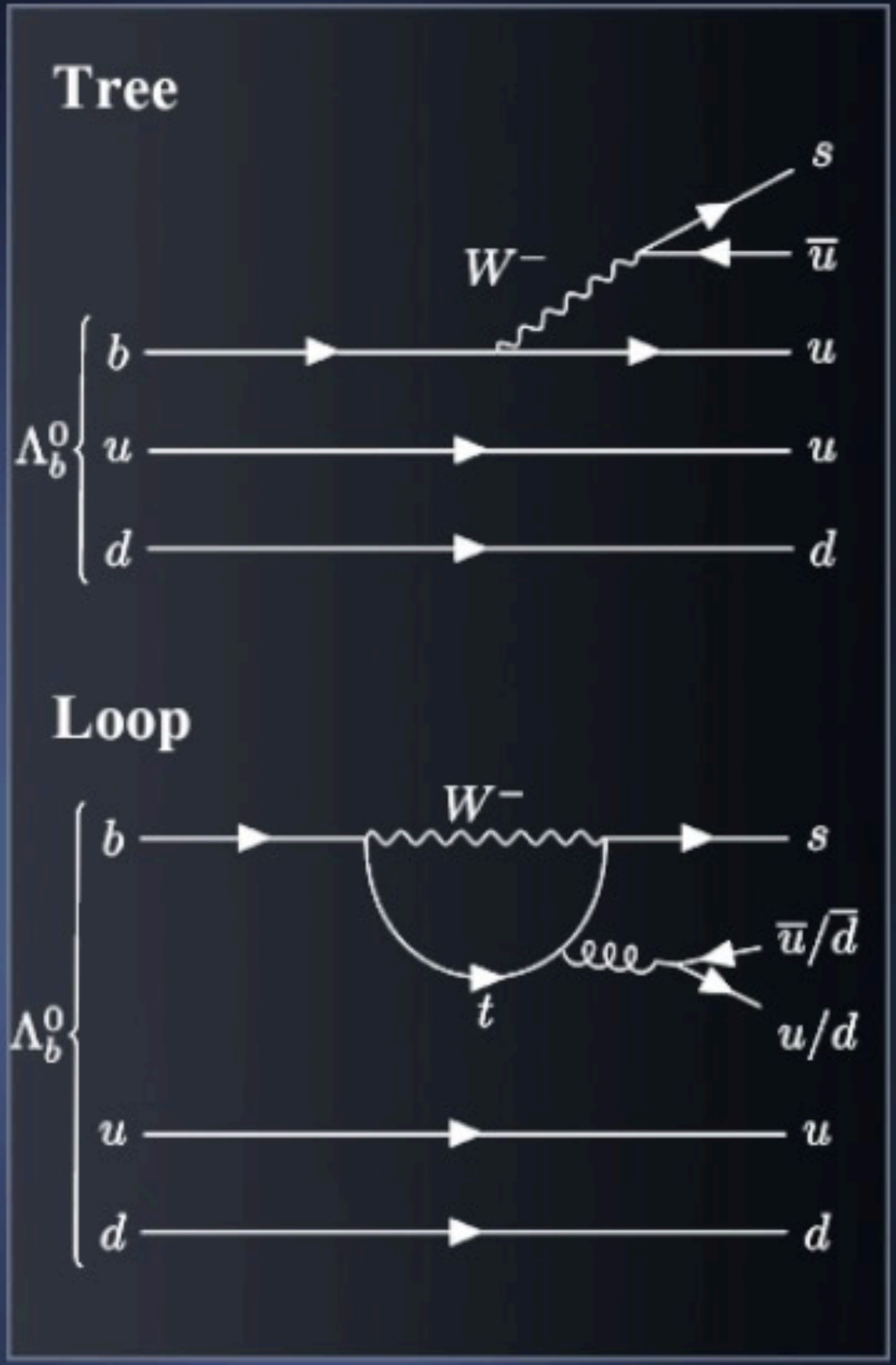
$\Lambda^0_b \to \Lambda K^+K^-$ yields

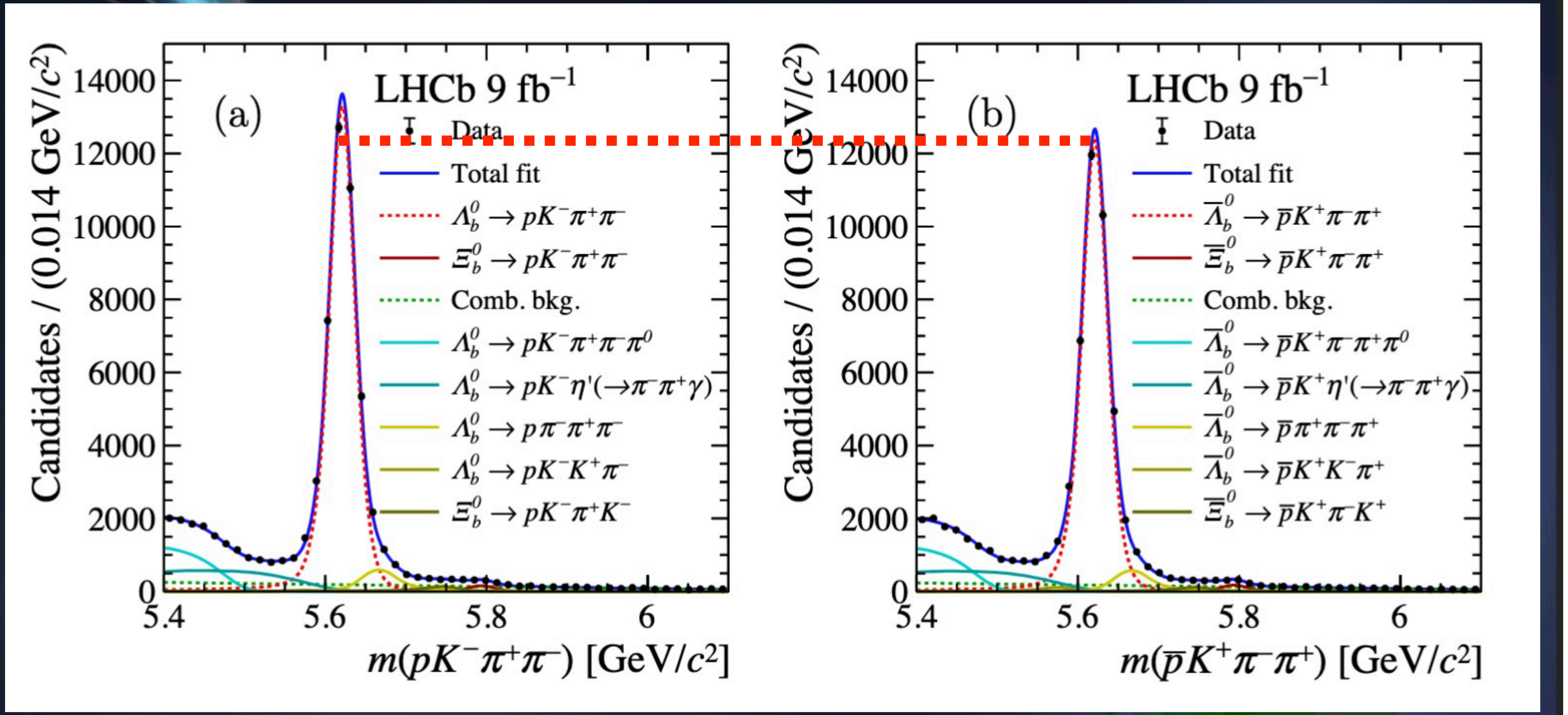


Preliminary

First observation of CP violation in baryon

arXiv:2503.14954
Accepted by Nature

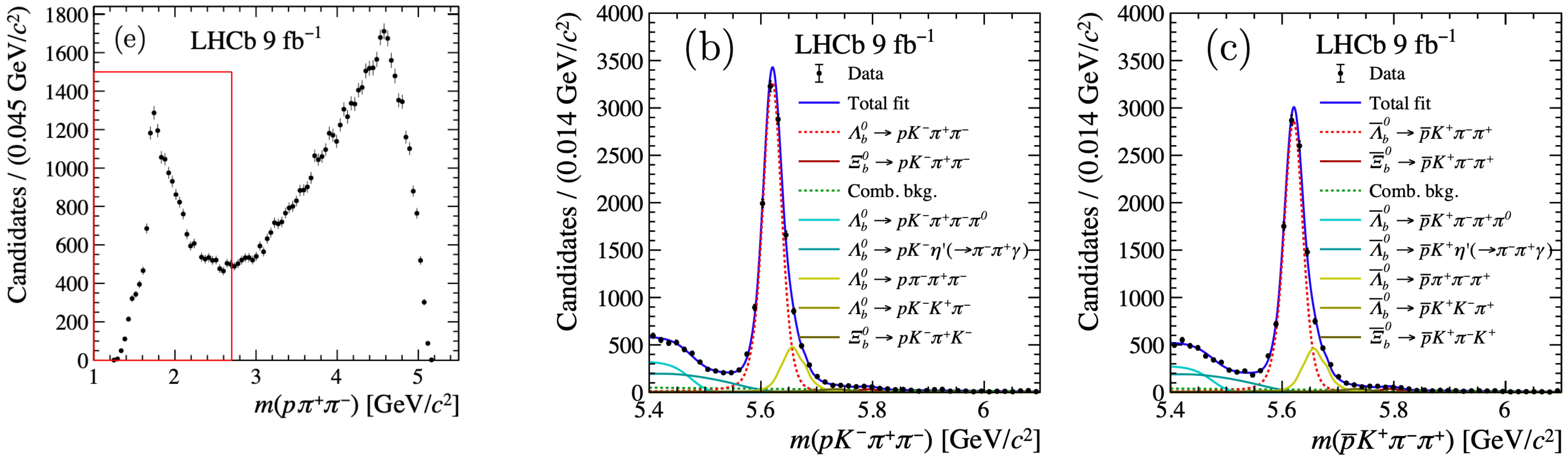




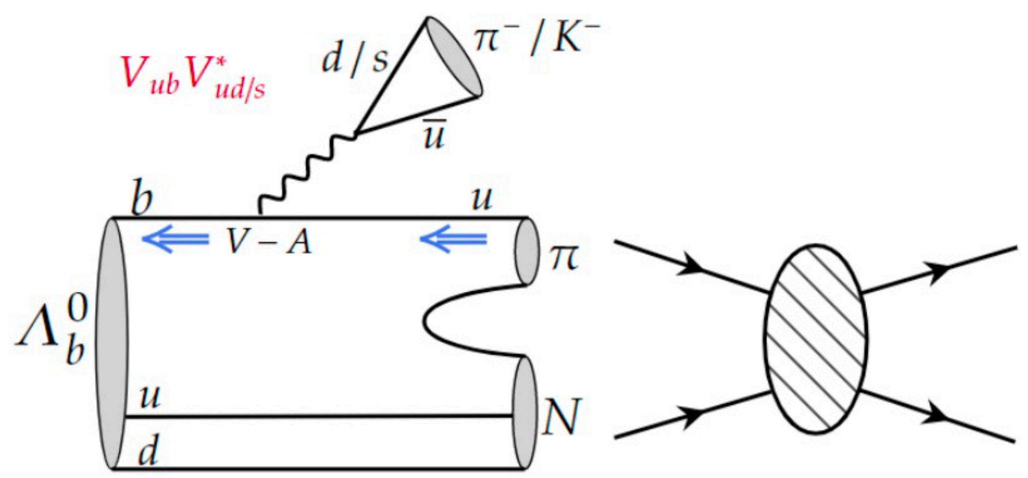
$$\mathcal{A}_{CP} \equiv \frac{\Gamma(\Lambda_b^0 \to pK^-\pi^+\pi^-) - \Gamma(\bar{\Lambda}_b^0 \to \bar{p}K^+\pi^-\pi^+)}{\Gamma(\Lambda_b^0 \to pK^-\pi^+\pi^-) + \Gamma(\bar{\Lambda}_b^0 \to \bar{p}K^+\pi^-\pi^+)} = (2.45 \pm 0.46 \pm 0.10)\%$$

First observation of CP violation in baryon

arXiv:2503.14954
Accepted by Nature



Decay topology	Mass region (GeV/c^2)	$\mathcal{A}_{CP}$
$\Lambda_b^0 \to R(pK^-)R(\pi^+\pi^-)$	$m_{pK^-} < 2.2$ $m_{\pi^+\pi^-} < 1.1$	$(5.3 \pm 1.3 \pm 0.2)\%$
$\Lambda_b^0 \to R(p\pi^-)R(K^-\pi^+)$	$m_{p\pi^-} < 1.7$ $0.8 < m_{\pi^+K^-} < 1.0$ or $1.1 < m_{\pi^+K^-} < 1.6$	$(2.7 \pm 0.8 \pm 0.1)\%$
$\Lambda_b^0 \to R(p\pi^+\pi^-)K^-$	$m_{p\pi^+\pi^-} < 2.7$	$(5.4 \pm 0.9 \pm 0.1)\%$
$\Lambda_b^0 \to R(K^-\pi^+\pi^-)p$	$m_{K^-\pi^+\pi^-} < 2.0$	$(2.0 \pm 1.2 \pm 0.3)\%$

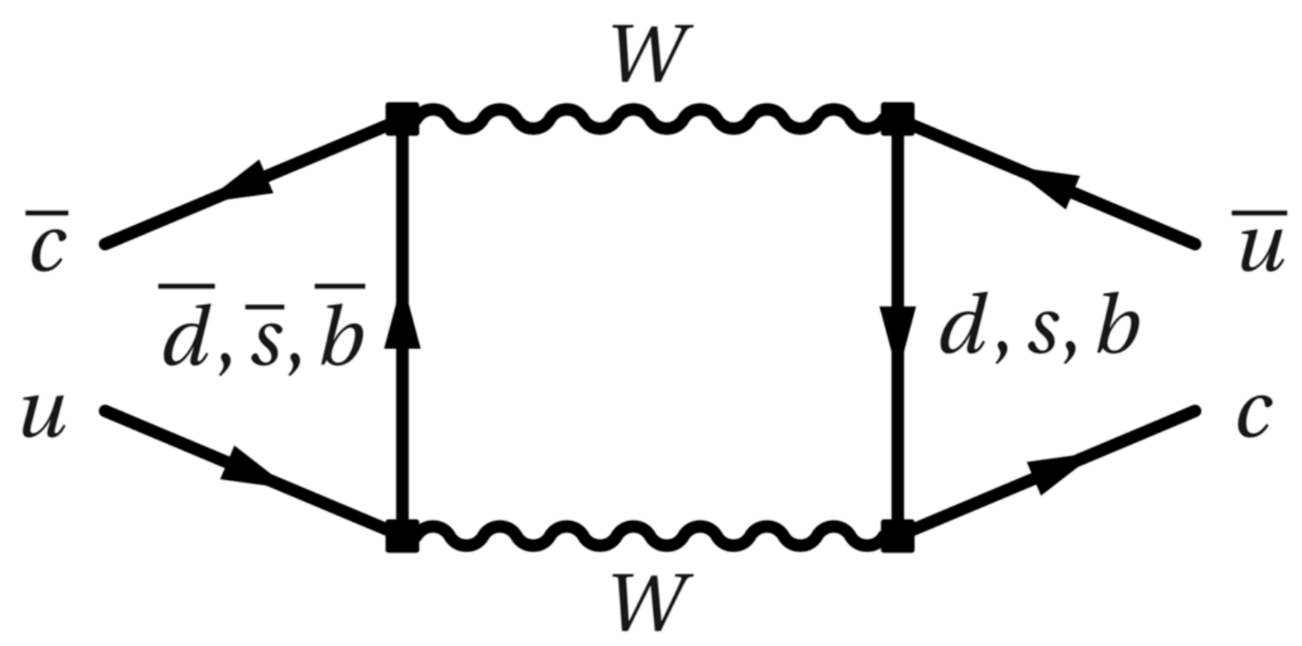


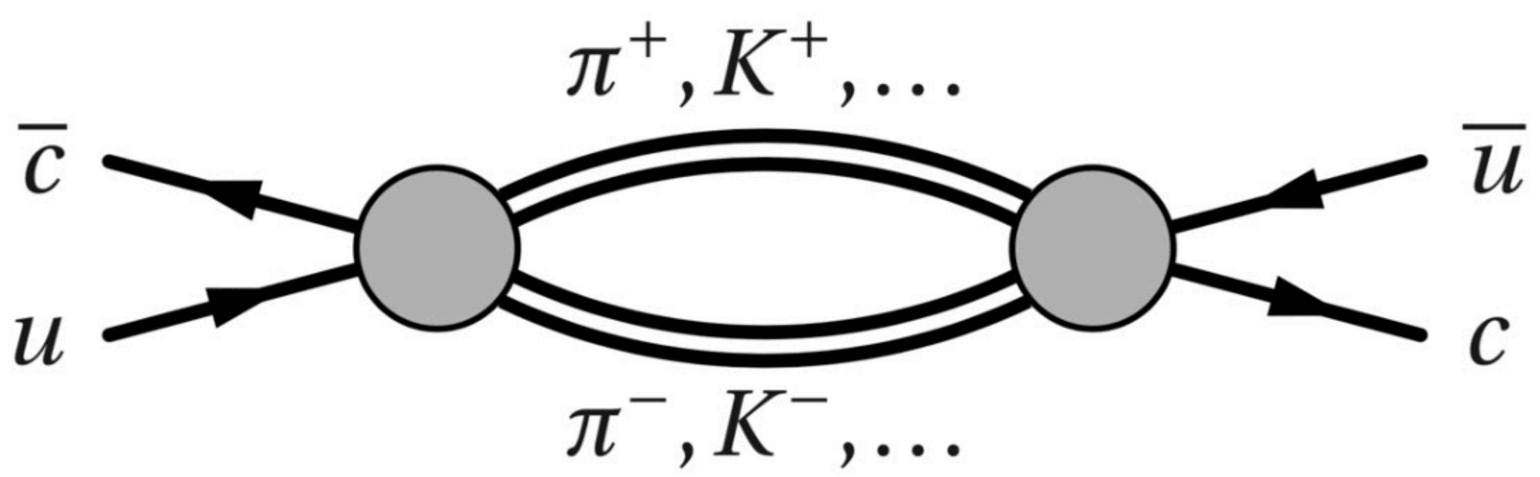
[J.P. Wang, F.S. Yu, CPC 48 (2024) 101002]

- CP violation unexpectedly small for baryons
- Is it SM or new physics? Likely SM, but more studies needed to quantify

CP violation in charm sector

- GIM mechanism very effective for charm decays, SM loops highly suppressed
- Tiny weak phases in first two generations of CKM matrix (< λ_b~ 0.1%)
- Oscillation and CPV ($\leq 10^{-3}$)
- Long distance contribution comparable/larger than short distance





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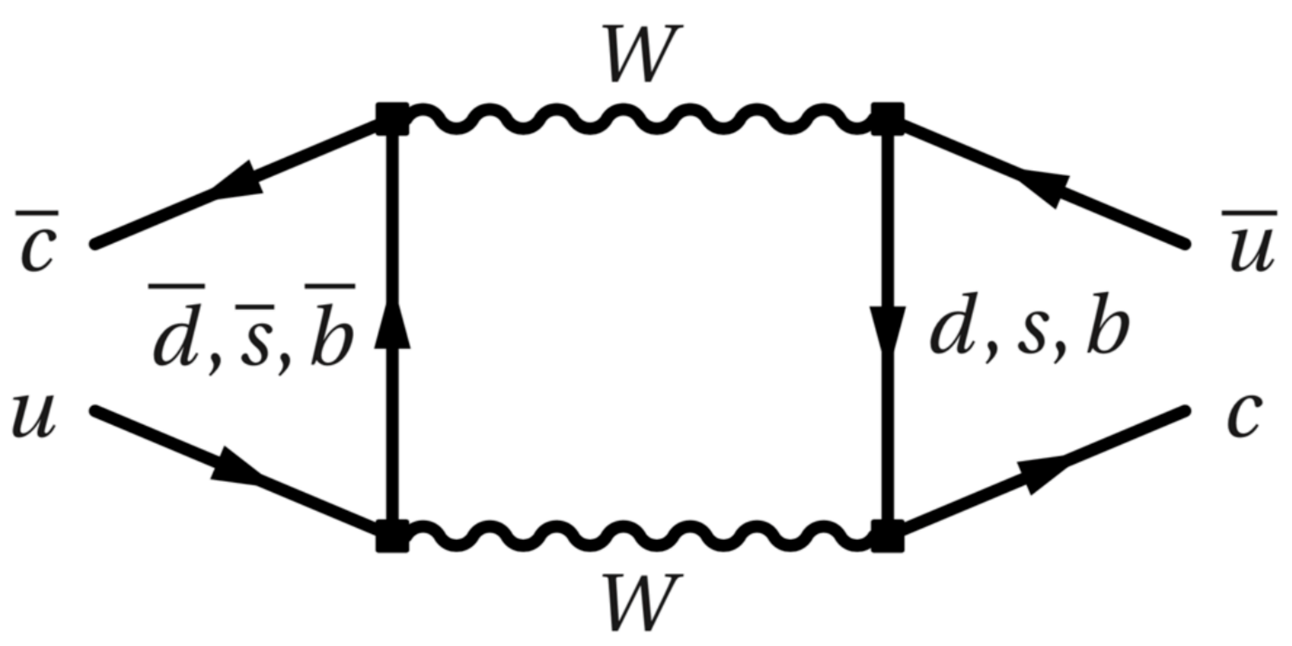
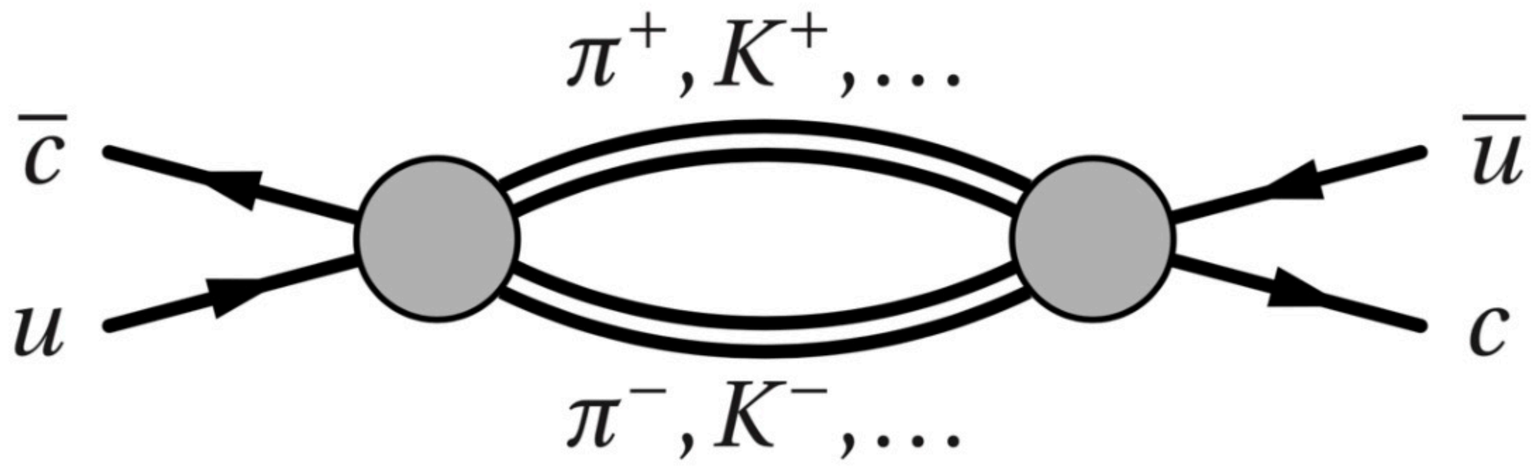




Breakthroughs by LHCb thanks to huge statistics:

First observation of CPV in $D^0 \to h^+h^-$ decays

$\Delta A_{CP} = A_{CP}(K^+K^-) - A_{CP}(\pi^+\pi^-) = (-15.4 \pm 2.9)\times 10^{-4}$ [PRL(2019)211803]

Evidence of CPV in $D^0 \to \pi^+\pi^-$ decay

$A_{CP}(\pi^+\pi^-) = (23.2 \pm 6.1)\times 10^{-4}$ (3.8σ) [PRL(2023)211803]

Direct CP violation in $D^+ \to K^+K^-\pi^+$

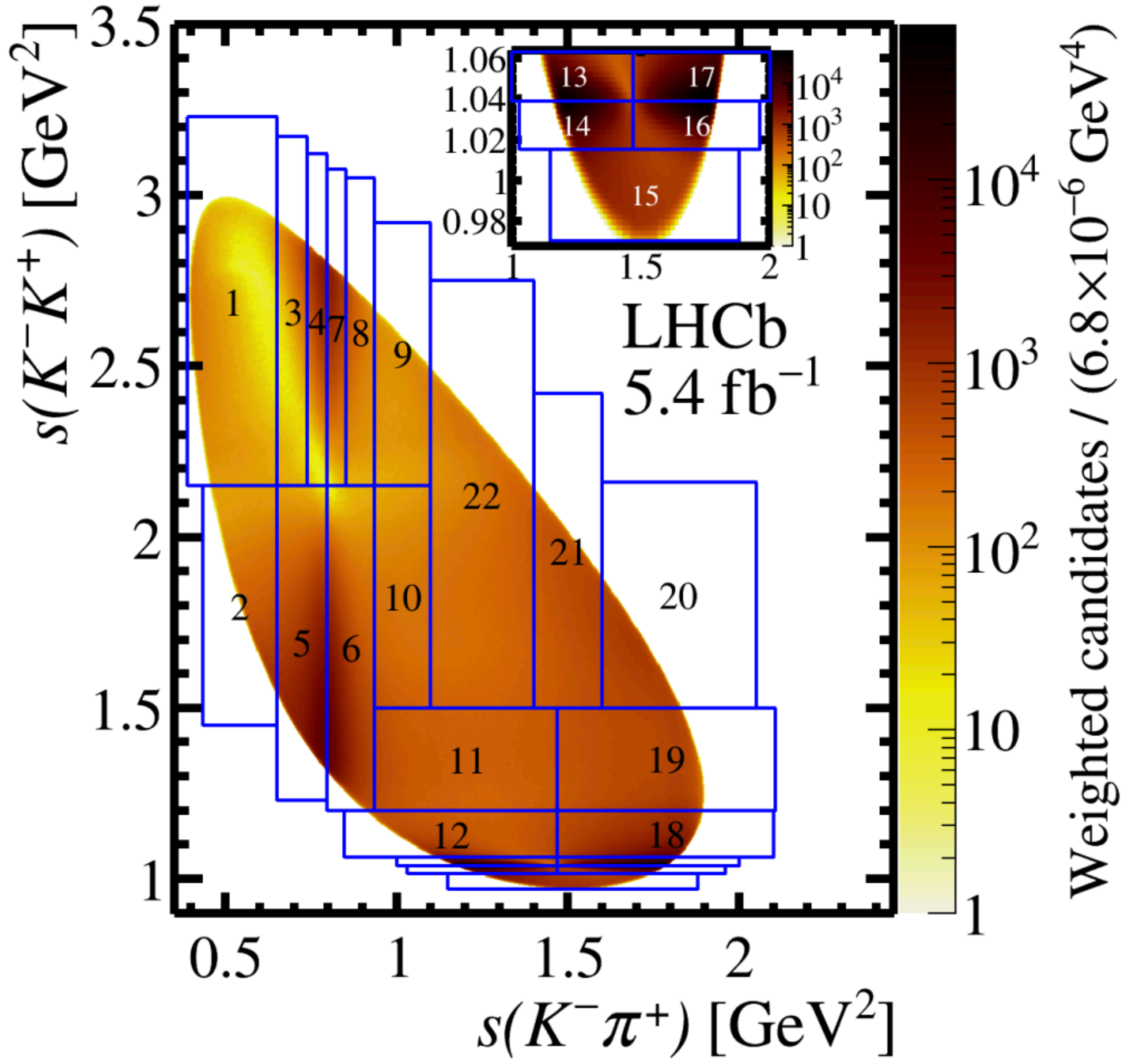
PRL134(2025)081901

- Search for localised CP violation in the phase space of $D^+ \to K^+K^-\pi^+$ (S) decay
- Control channel $D_s^+ \to K^+K^-\pi^+$ (C) to subtract nuisance asymmetries

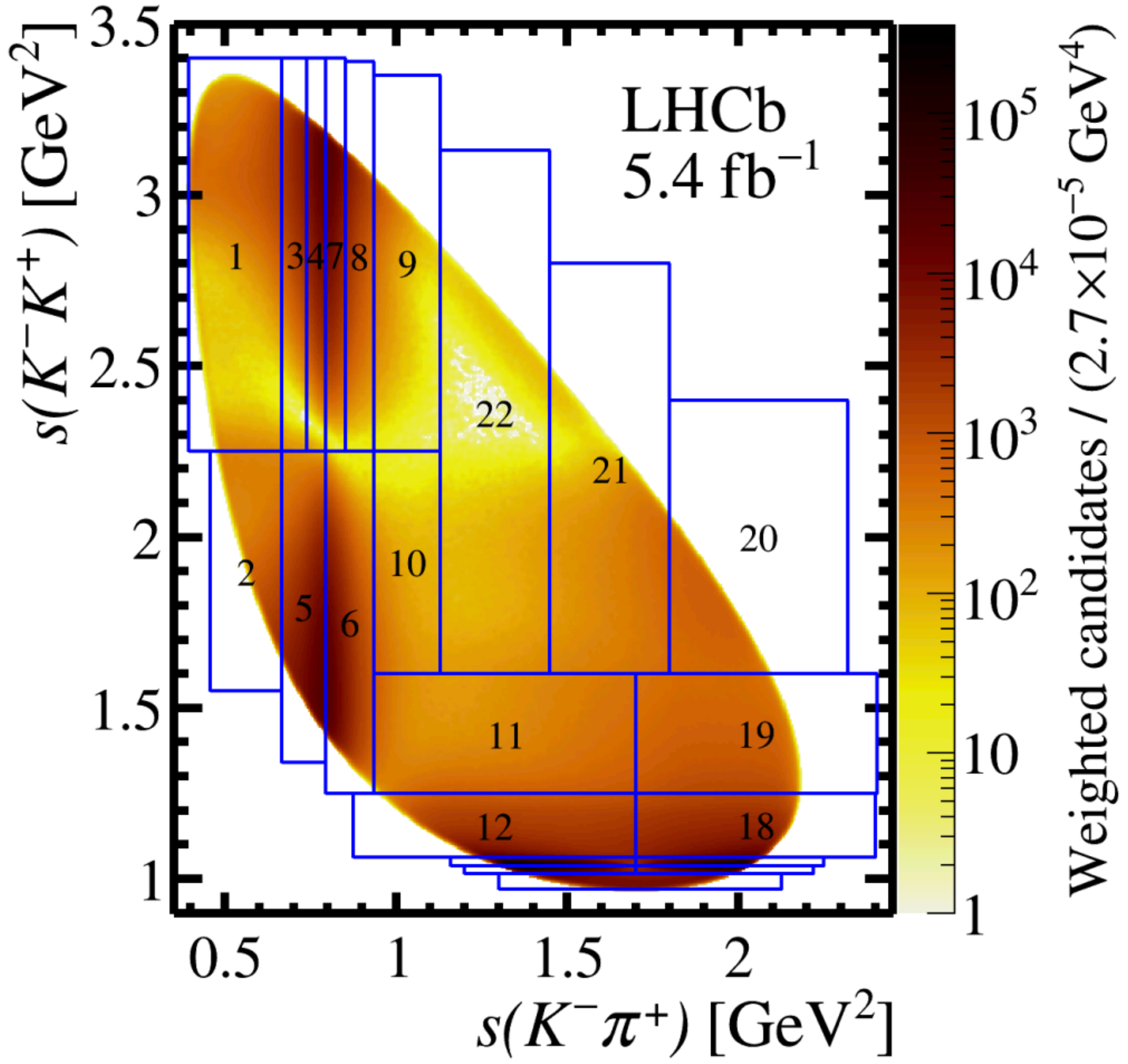
$$\Delta A^i_{CP} = A^{i,S}_{\rm raw} - A^{i,C}_{\rm raw} - \Delta A^{\rm global}_{\rm raw}$$

- Extract a p-value for the hypothesis of no localised CP violation

$$\chi^2(\mathcal{S}_{\Delta_{CP}}) = \sum_i^{N_{\rm bins}} (\mathcal{S}^i_{\Delta_{CP}})^2, \qquad \mathcal{S}^i_{\Delta_{CP}} = \frac{\Delta A^i_{CP}}{\sigma_{\Delta A^i_{CP}}}$$



$D^+ \to K^+K^-\pi^+$ (S)



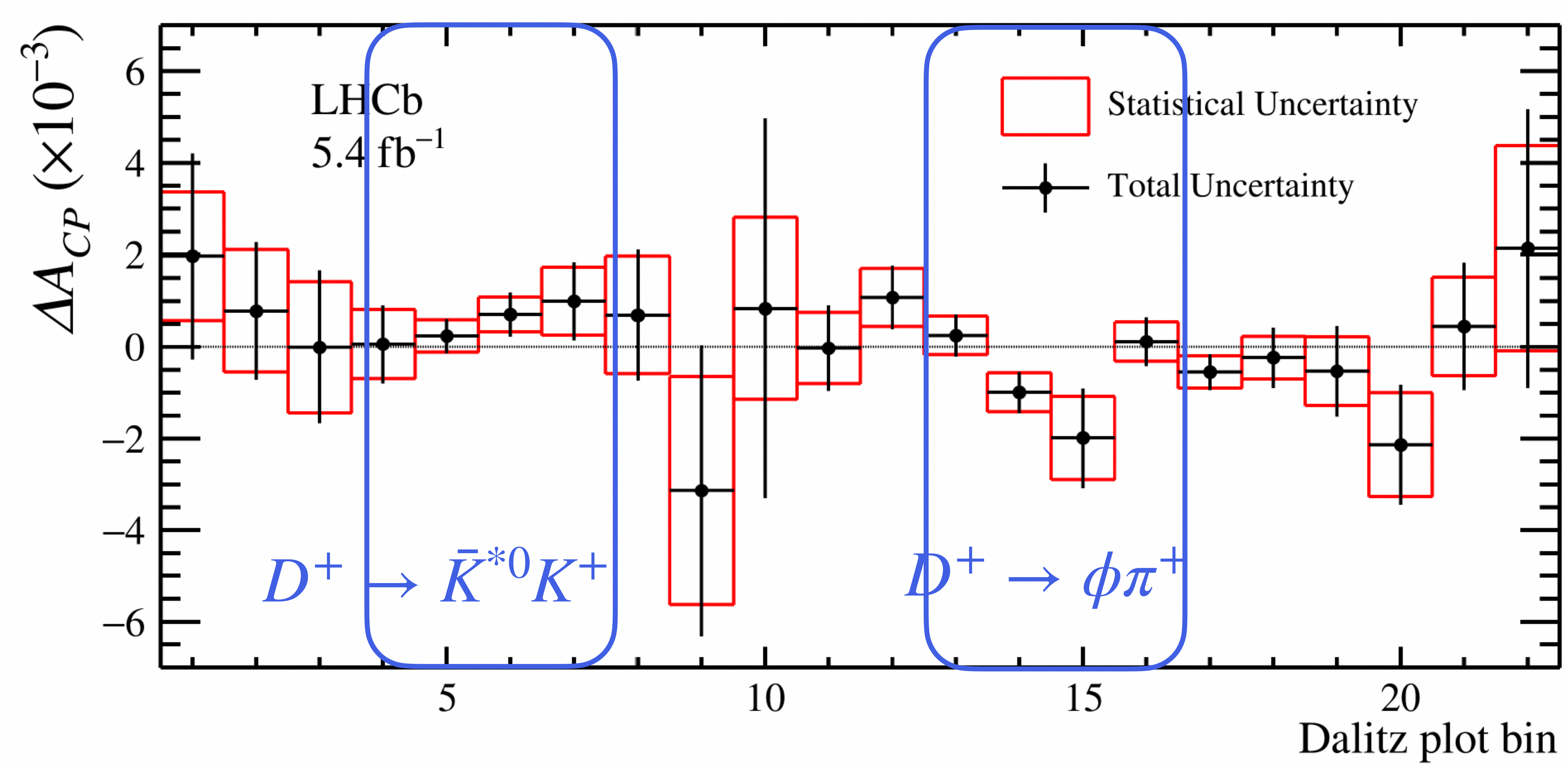
$D_s^+ \to K^+K^-\pi^+$ (C)

Direct CP violation in $D^+ \to K^+K^-\pi^+$

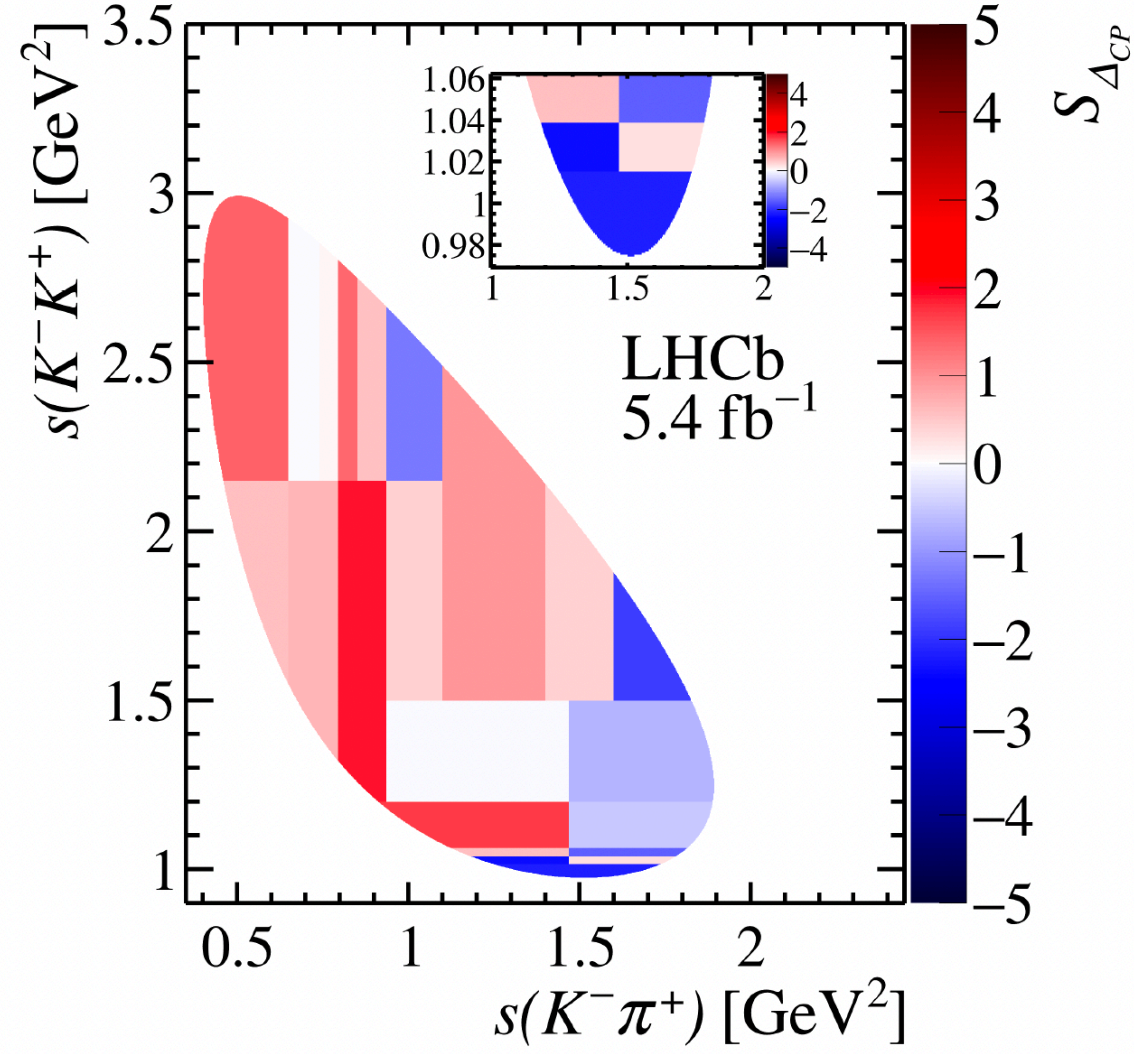
PRL134(2025)081901

- ΔA^i_{CP} precision up to 10^{-3}

$$A^{\phi\pi^+}_{CP|S} = (0.95 \pm 0.43 \pm 0.26) \times 10^{-3}$$
$$A^{\bar{K}^{*0}K^+}_{CP|S} = (-0.26 \pm 0.56 \pm 0.18) \times 10^{-3}$$



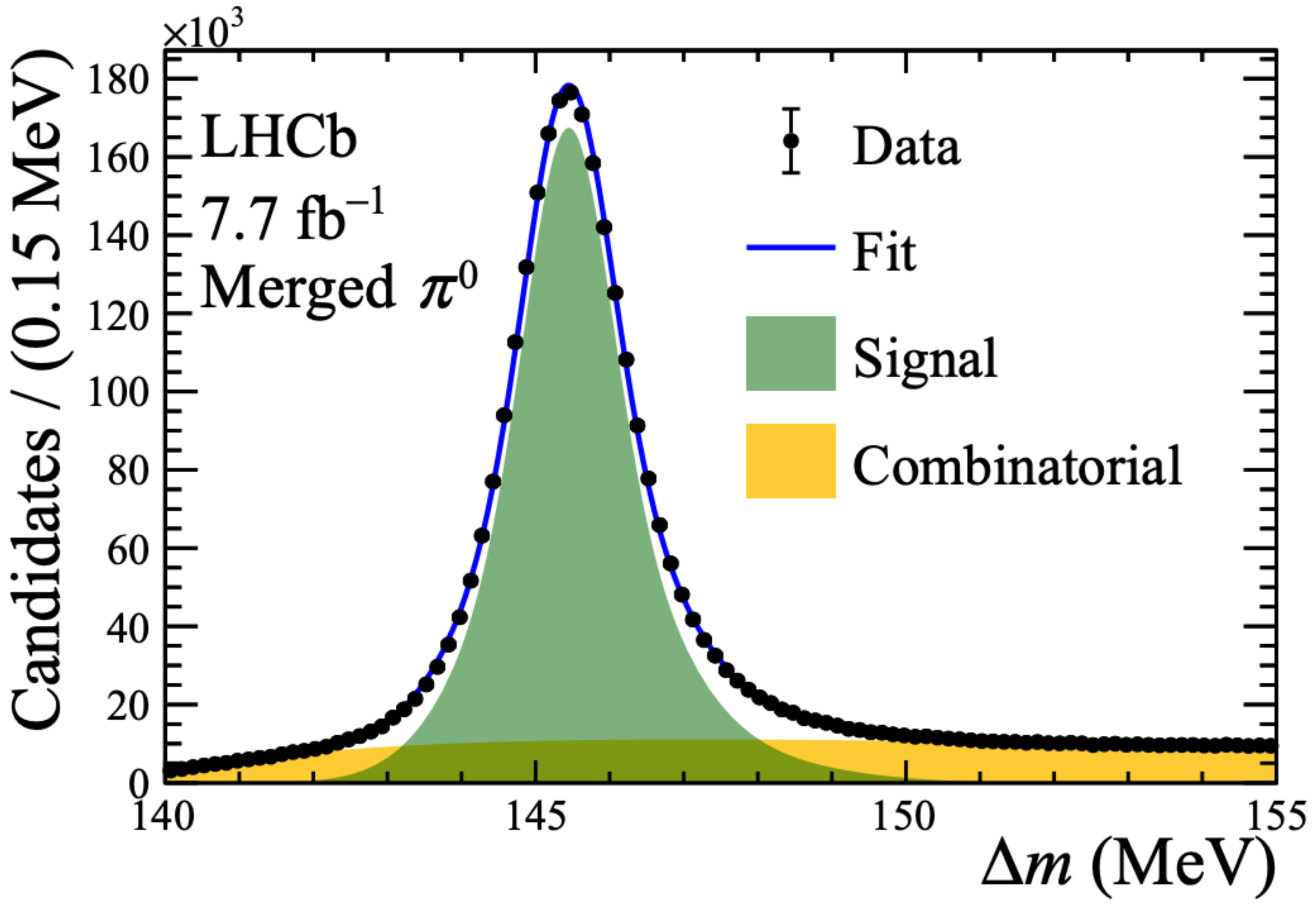
- p-values (2.3-14.1%) compatible with absence of localised CP violation in Dalitz plot

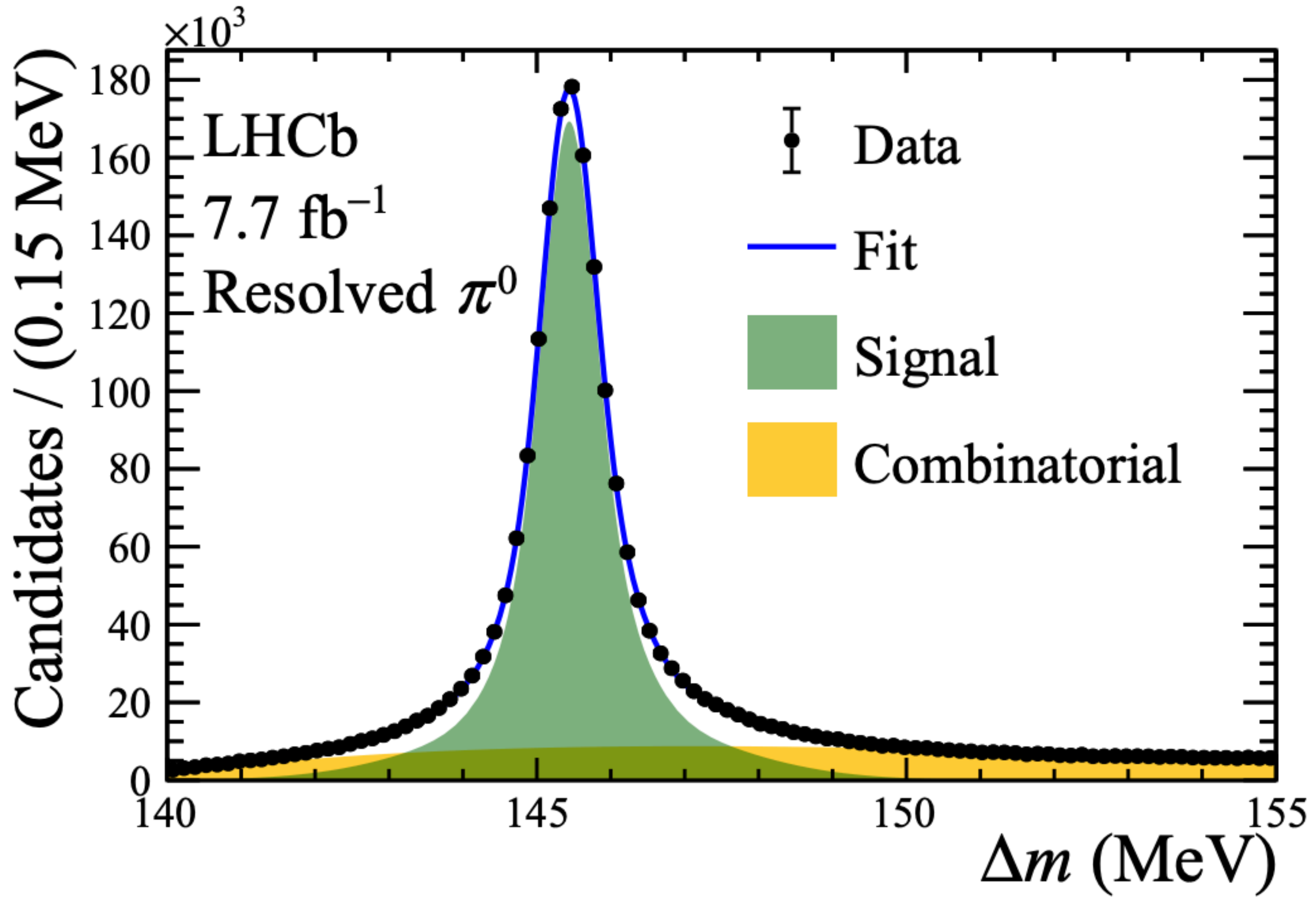


Time-dependent CP violation in $D^0 \to \pi^+\pi^-\pi^0$

Phys. Rev. Lett. 133 (2024) 101803

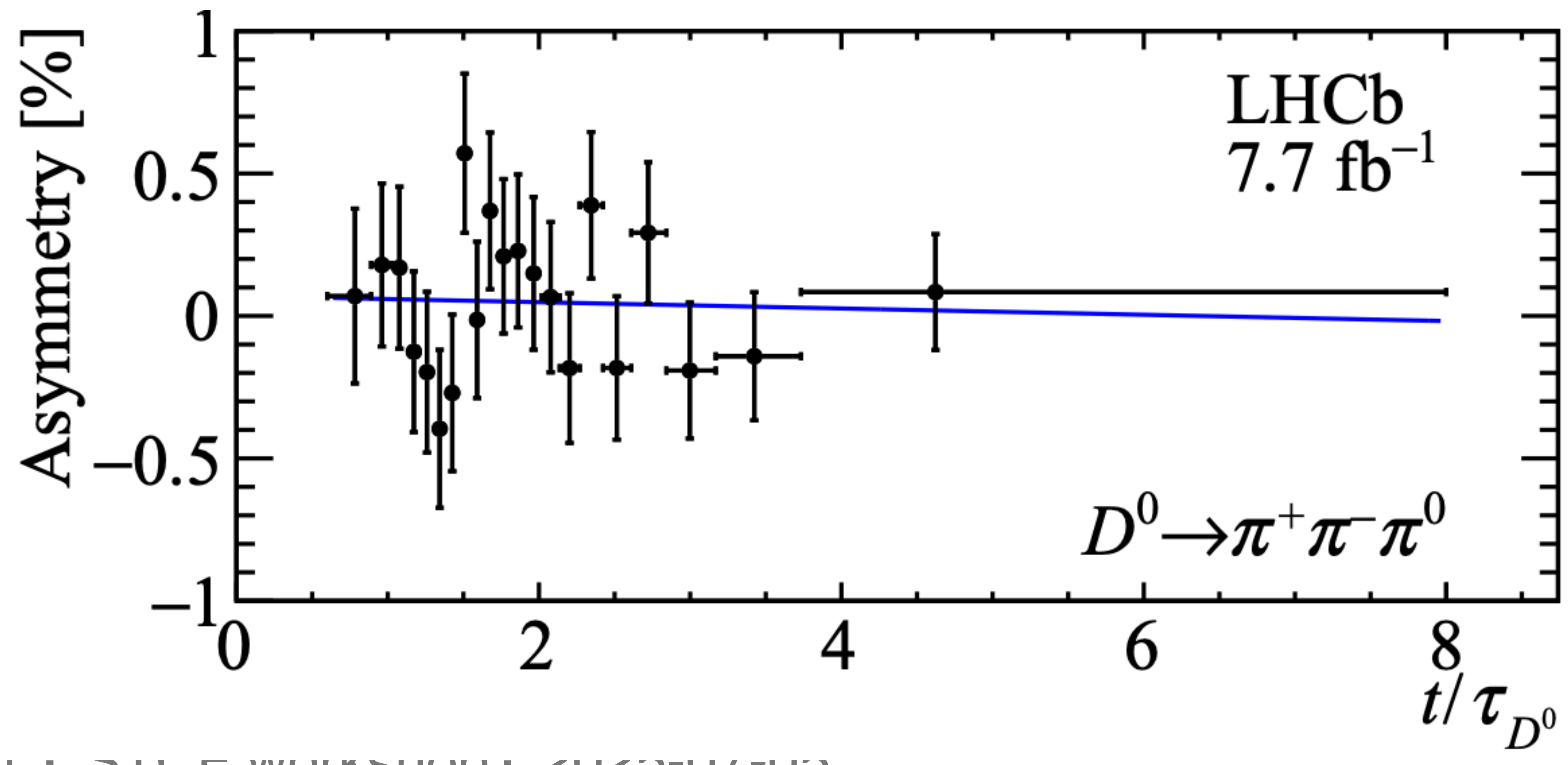
- First measurement of time-dependent CP violation in SCS mode





$$A_{CP}(f_{CP},t) \equiv \frac{\Gamma_{D^0\to f_{CP}}(t) - \Gamma_{\bar{D}^0\to f_{CP}}(t)}{\Gamma_{D^0\to f_{CP}}(t) + \Gamma_{\bar{D}^0\to f_{CP}}(t)} \approx a^{\mathrm{dir}}_{f_{CP}} + \Delta Y_{f_{CP}} \frac{t}{\tau_{D^0}}.$$

$$A_{\mathrm{meas}}(\langle t/\tau_{D^0}\rangle_i) \equiv \frac{N^i_{D^0} - N^i_{\bar{D}^0}}{N^i_{D^0} + N^i_{\bar{D}^0}}$$

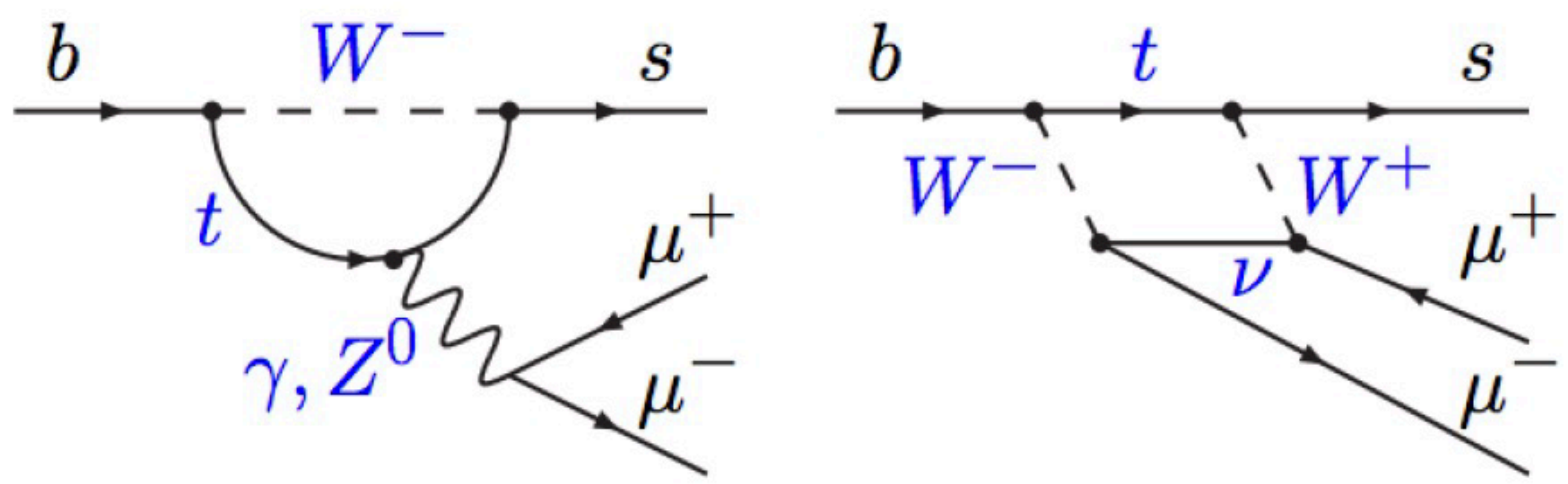


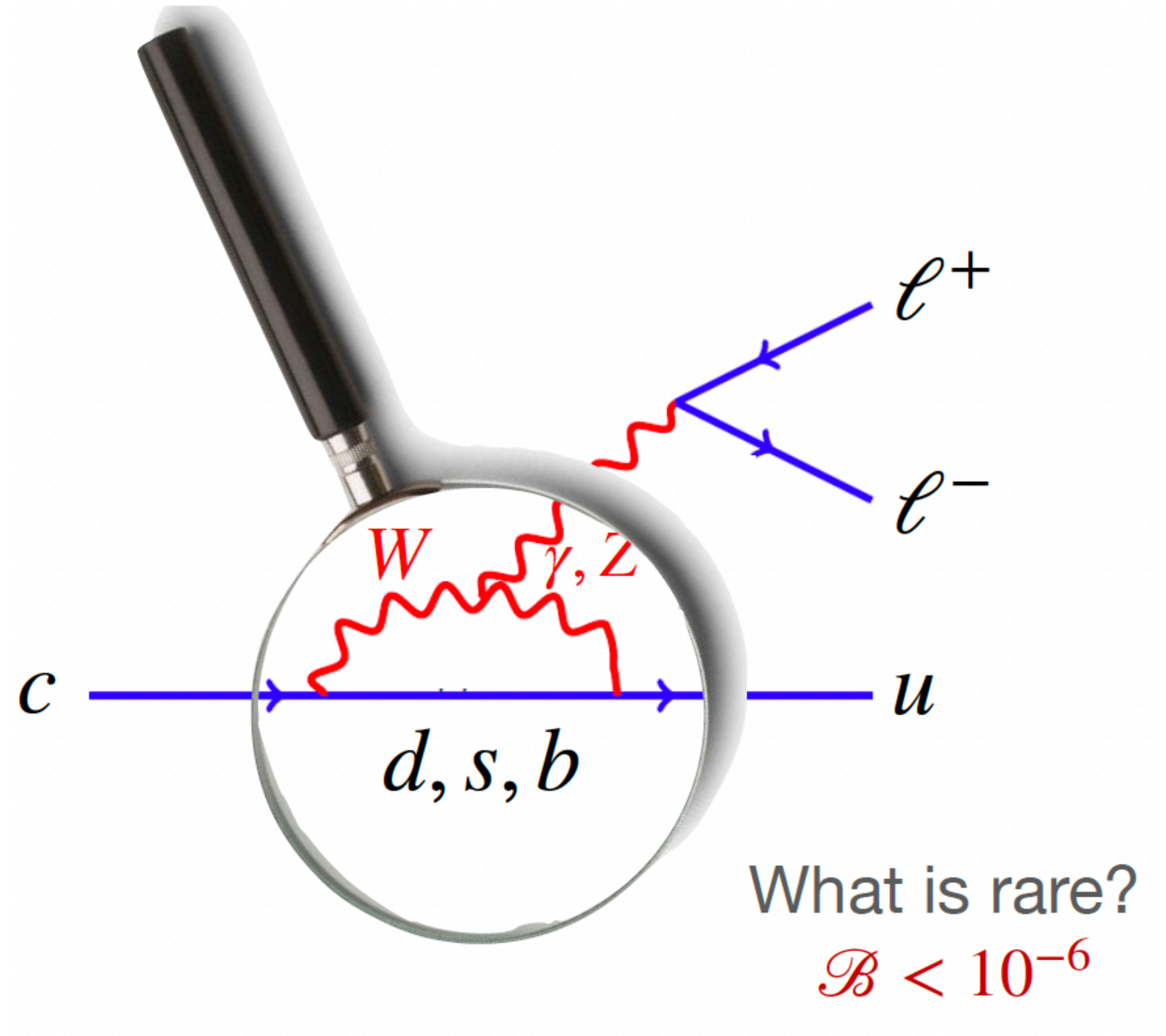
$$\Delta Y_{f_{CP}} \approx \frac{\eta_{f_{CP}}}{2}\left[\left(\left|\frac{q}{p}\right| + \left|\frac{p}{q}\right|\right) x\sin\phi - \left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) y\cos\phi\right]$$

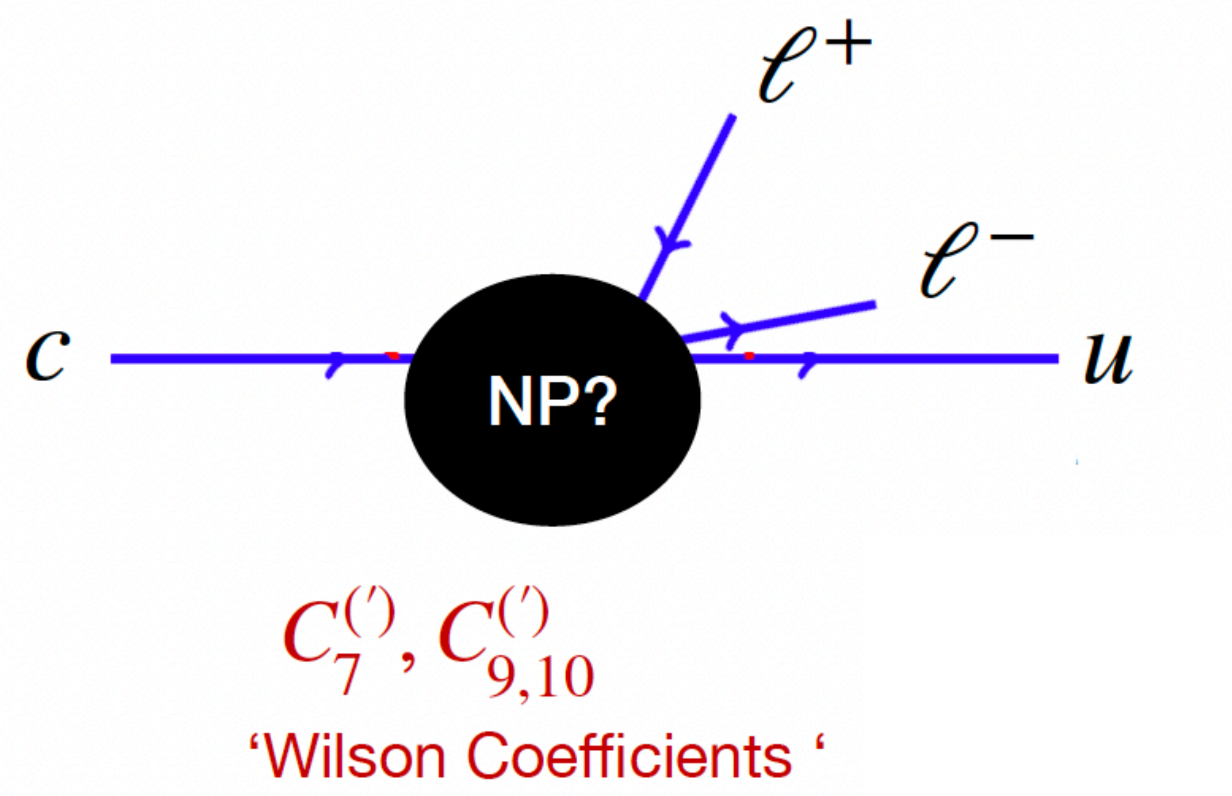
- No evidence for time-dependent CP violation, constant with world average

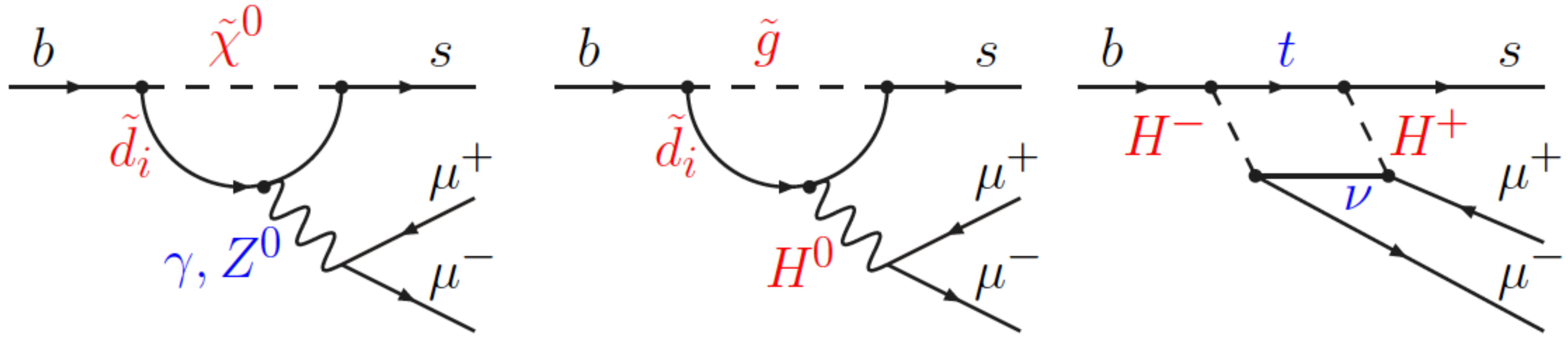
$$\Delta Y \equiv \eta_{CP}\Delta Y_{f_{CP}} = (-1.3 \pm 6.3 \pm 2.4)\times 10^{-4}$$

Rare decays









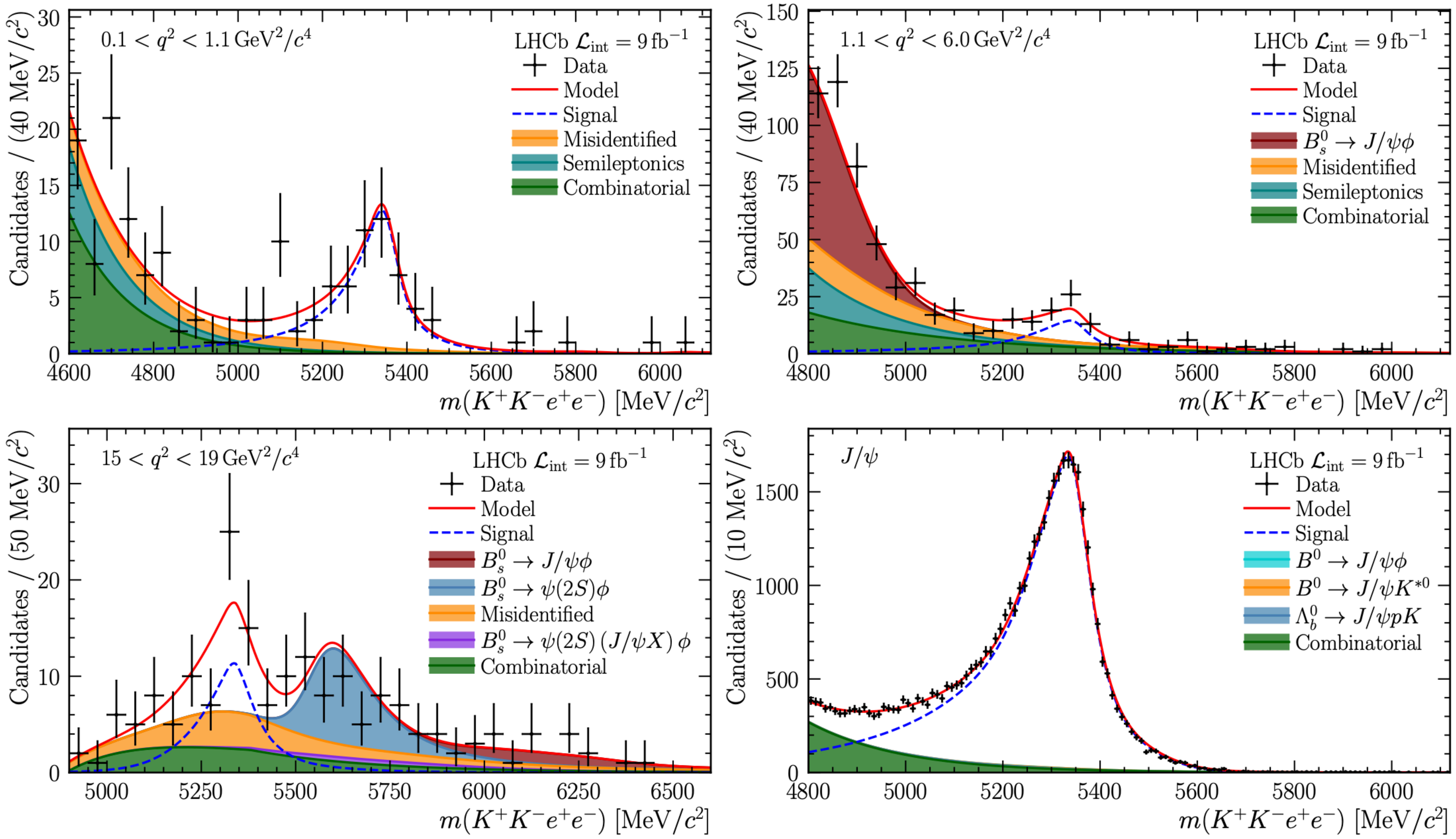
- Sensitive to tiny contributions of heavy BSM (>multi TeV) particles
- Testing different couplings than b and s quark systems

Test of lepton flavour universality

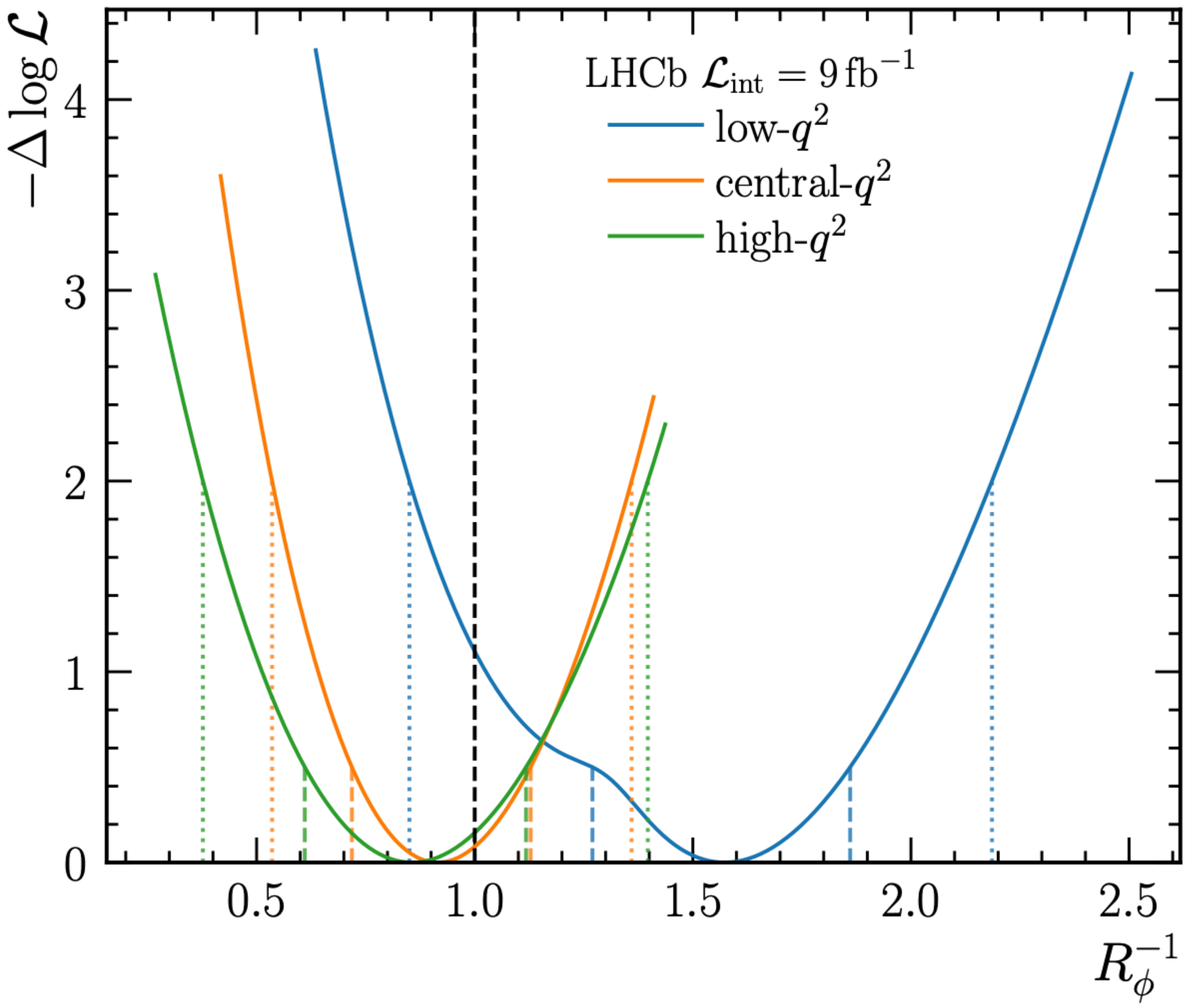
PRL134(2025)121803

q^2 $[\mathrm{GeV}^2/c^4]$	R_ϕ^{-1}	$\mathrm{d}\mathcal{B}(B_s^0\to\phi e^+e^-)/\mathrm{d}q^2$ $[10^{-7}\,\mathrm{GeV}^{-2}c^4]$
$0.1 < q^2 < 1.1$	$1.57\,^{+0.28}_{-0.25} \pm 0.05$	$1.38\,^{+0.25}_{-0.22} \pm 0.04 \pm 0.19 \pm 0.06$
$1.1 < q^2 < 6.0$	$0.91\,^{+0.20}_{-0.19} \pm 0.05$	$0.26 \pm 0.06 \pm 0.01 \pm 0.01 \pm 0.01$
$15.0 < q^2 < 19.0$	$0.85\,^{+0.24}_{-0.23} \pm 0.10$	$0.39 \pm 0.11 \pm 0.04 \pm 0.02 \pm 0.02$

$$B_s^0 \to \phi\ell^+\ell^-$$

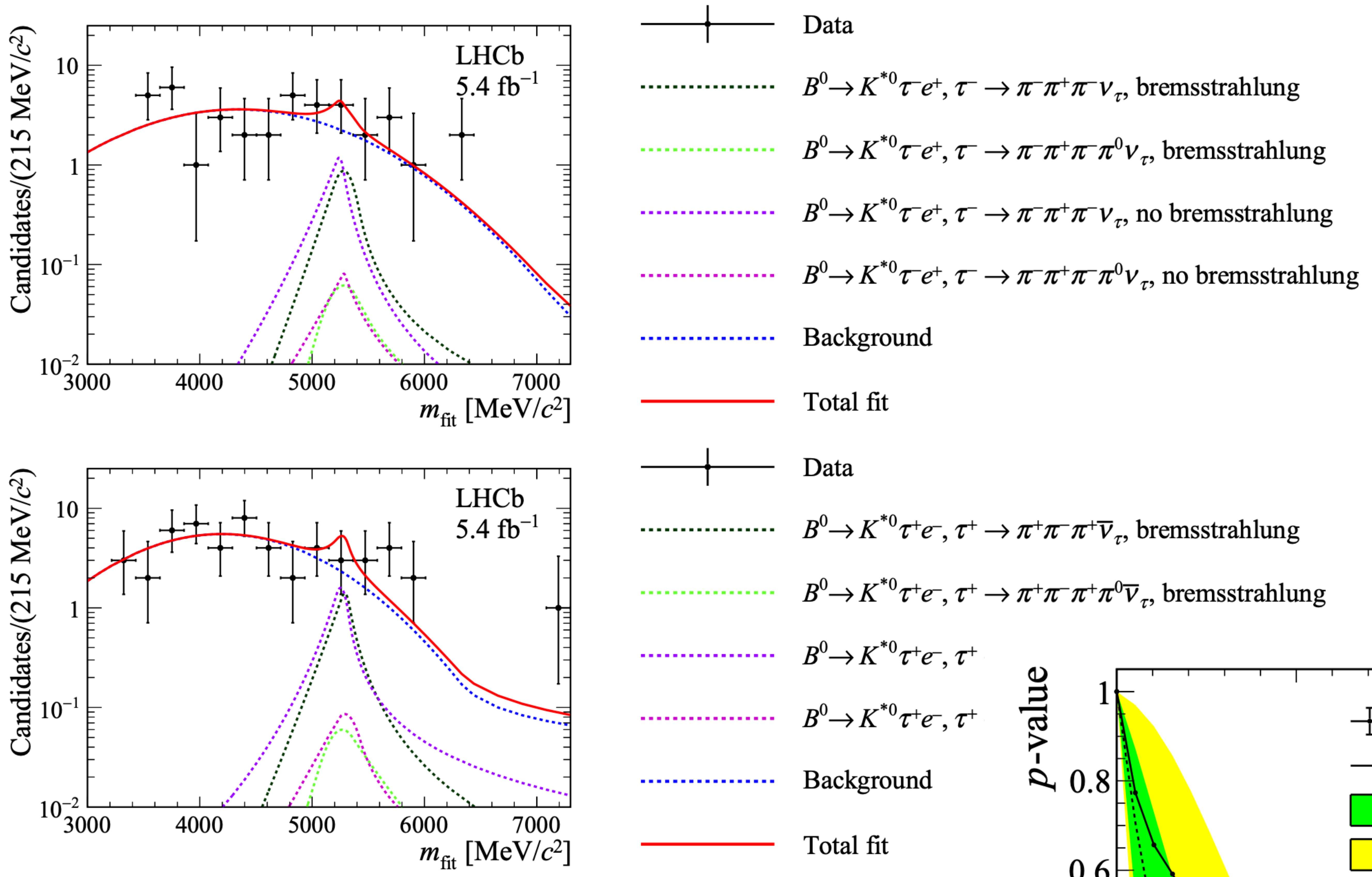


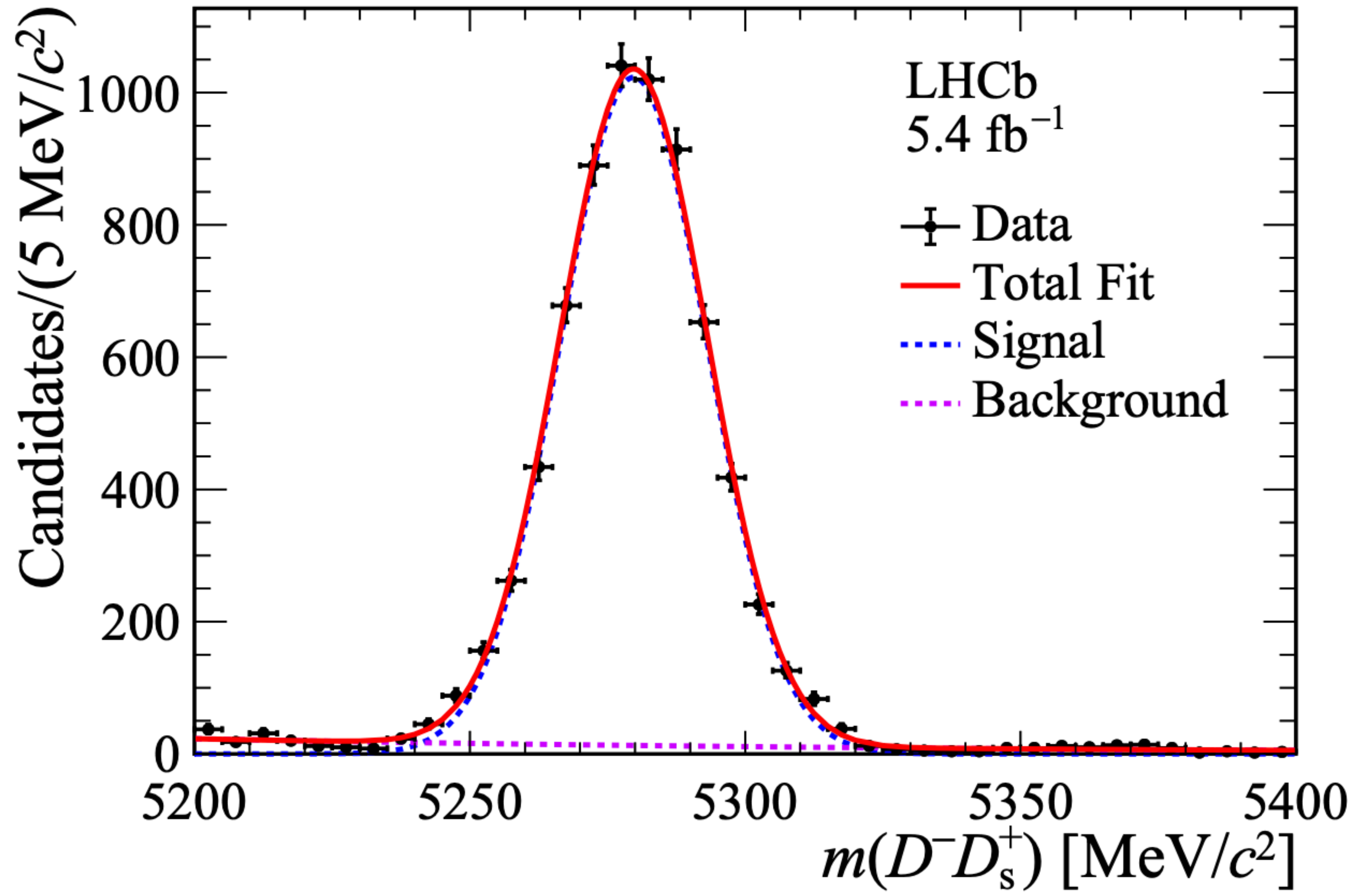
Agree with the Standard Model expectation of lepton flavour universality



Search for $B^0 \to K^{*0}\tau e$

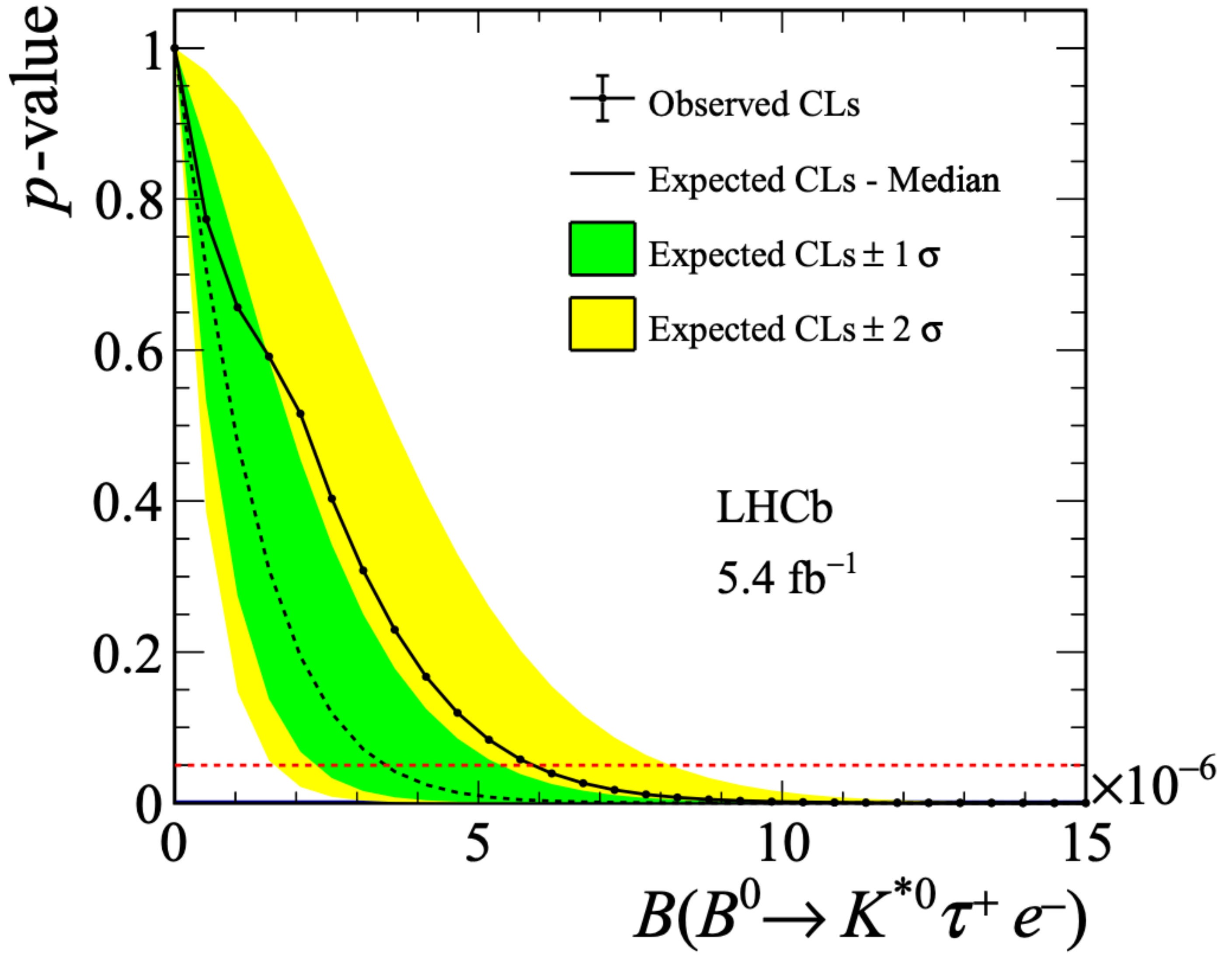
arXiv:2506.15347

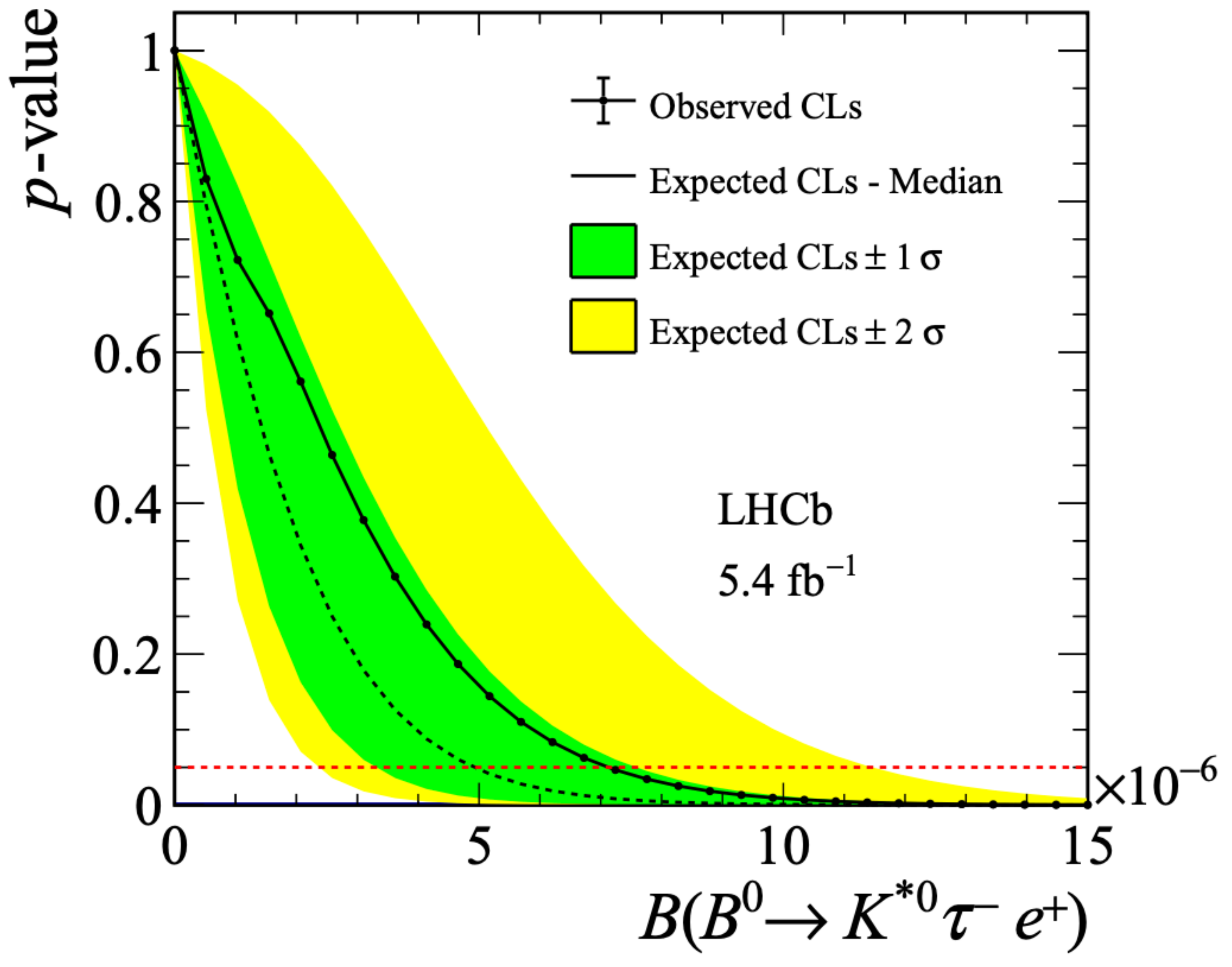




$\mathcal{B}(B^0 \to K^{*0}\tau^- e^+) < 5.9\ (7.1) \times 10^{-6}$

$\mathcal{B}(B^0 \to K^{*0}\tau^+ e^-) < 4.9\ (5.9) \times 10^{-6}$



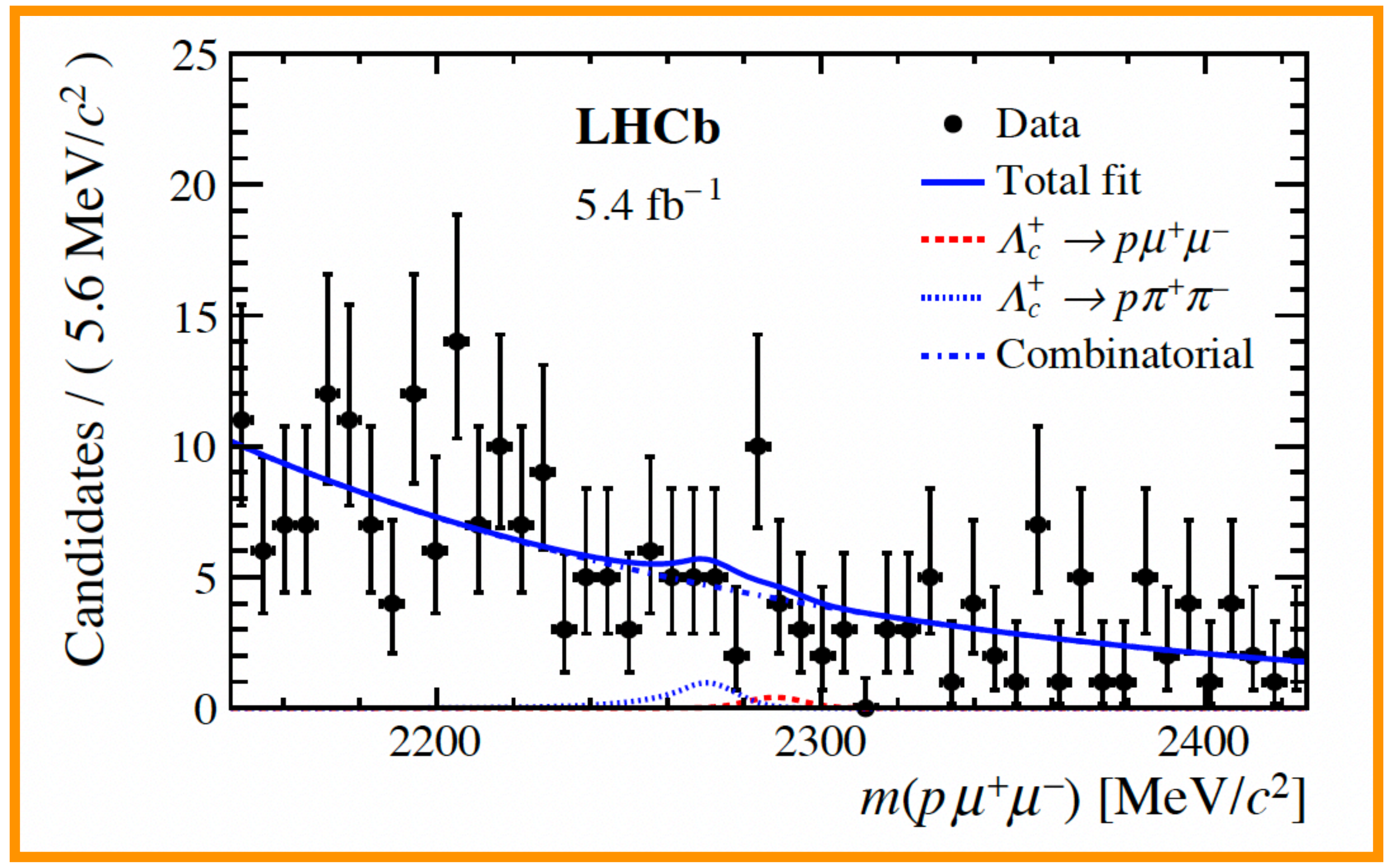


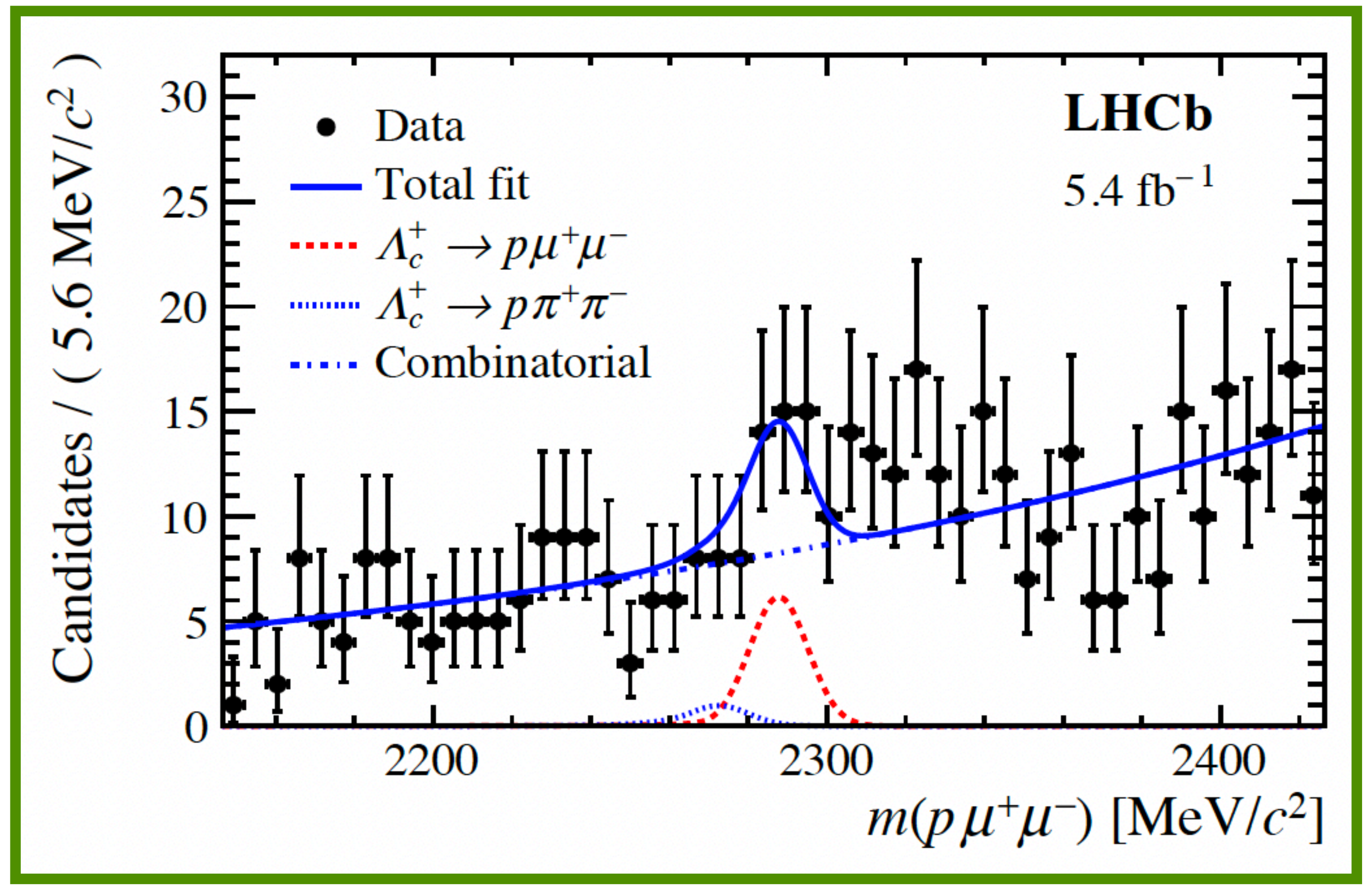
Search for $\Lambda_c^+ \to p\mu^+\mu^-$

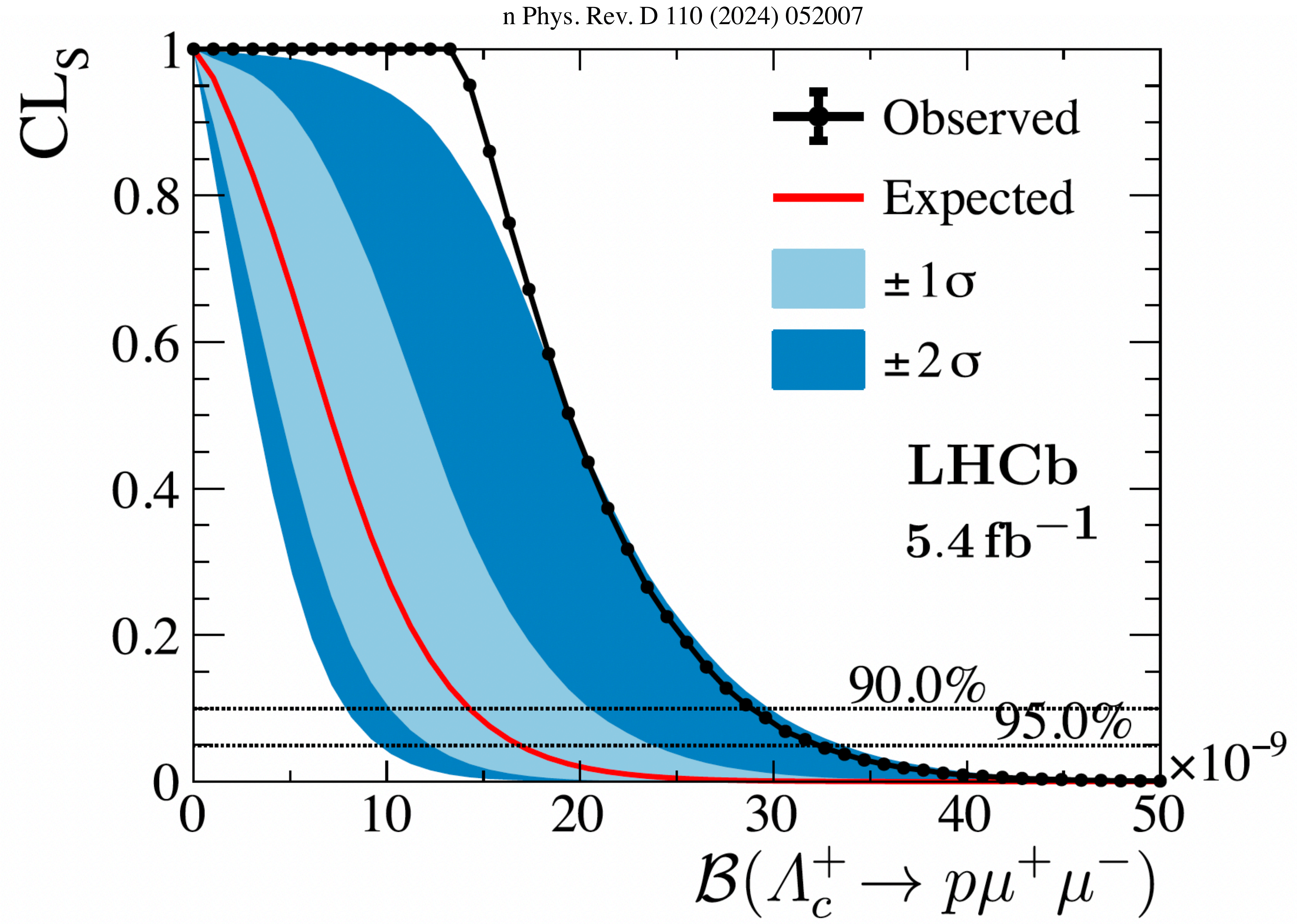
PRD110(2024)052007

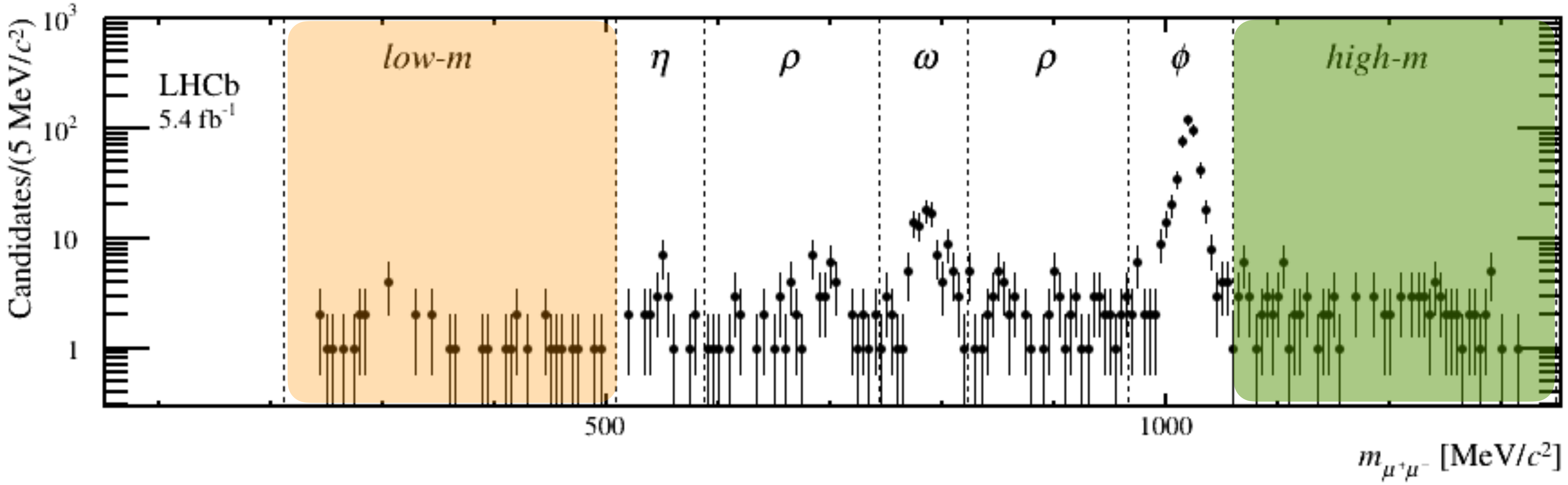
$$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 0.93\ (1.1) \times 10^{-8} \quad \text{at} \quad 90\%\ (95\%)\ \text{CL}\ (low\text{-}m)$$

$$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 3.0\ (3.3) \times 10^{-8} \quad \text{at} \quad 90\%\ (95\%)\ \text{CL}\ (high\text{-}m)$$









$$\frac{\mathcal{B}(\Lambda_c^+ \to p\omega(\to \mu^+\mu^-))}{\mathcal{B}(\Lambda_c^+ \to p\phi(\to \mu^+\mu^-))} = 0.240 \pm 0.030\ (\text{stat.}) \pm 0.018\ (\text{syst.})$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to p\rho(\to \mu^+\mu^-))}{\mathcal{B}(\Lambda_c^+ \to p\phi(\to \mu^+\mu^-))} = 0.229 \pm 0.051\ (\text{stat.}) \pm 0.022\ (\text{syst.})$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to p\eta(\to \mu^+\mu^-))}{\mathcal{B}(\Lambda_c^+ \to p\phi(\to \mu^+\mu^-))} = 0.032 \pm 0.013\ (\text{stat.}) \pm 0.004\ (\text{syst.})$$

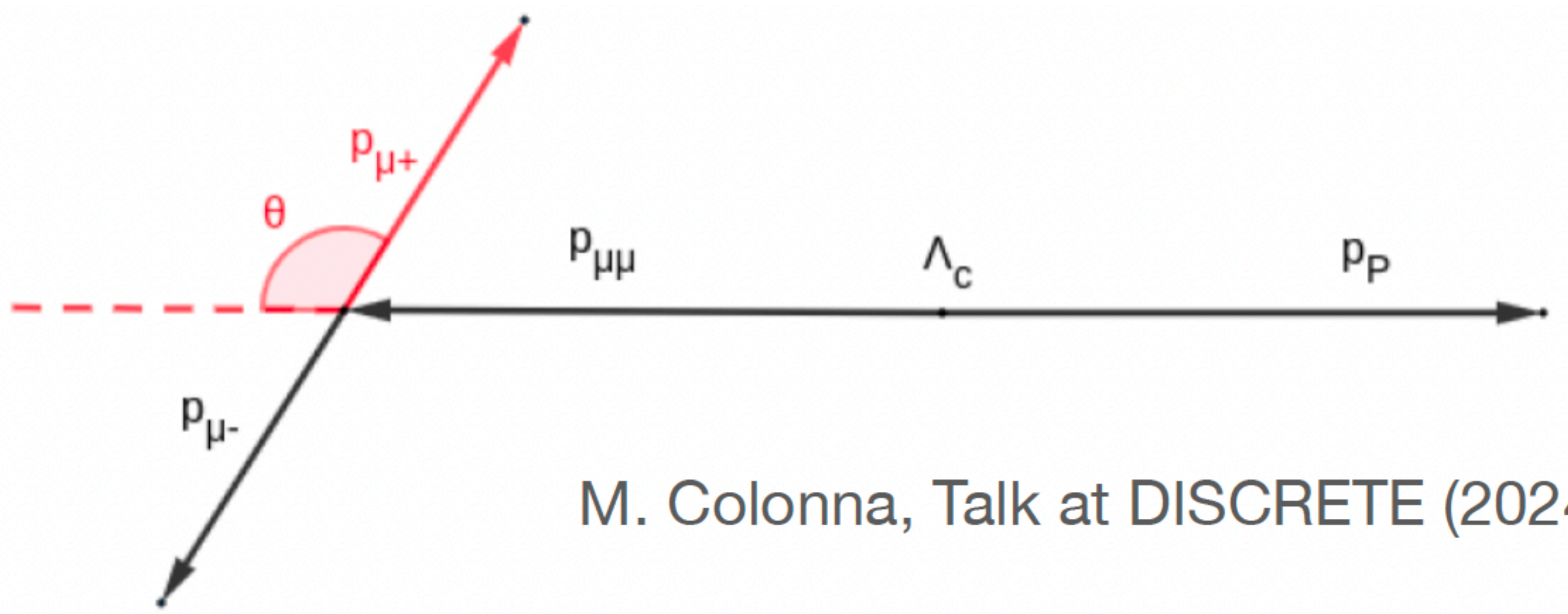
Angular and CP asymmetries of $\Lambda_c^+ \to p\mu^+\mu^-$

RD111(2-25)L091102

$$\frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} = \frac{3}{2}\left(K_{1ss}\sin^2\theta_\ell + K_{1cc}\cos^2\theta_\ell + K_{1c}\cos\theta_\ell\right)$$

K_{1c}~C_{10} (Null test!)

$$A_{FB}(\propto K_{1c}) = \frac{1}{\Gamma}\left[\int_0^1 d\cos\theta_\mu - \int_{-1}^0 d\cos\theta_\mu\right]\frac{d\Gamma}{d\cos\theta_\mu}$$



M. Colonna, Talk at DISCRETE (2024)

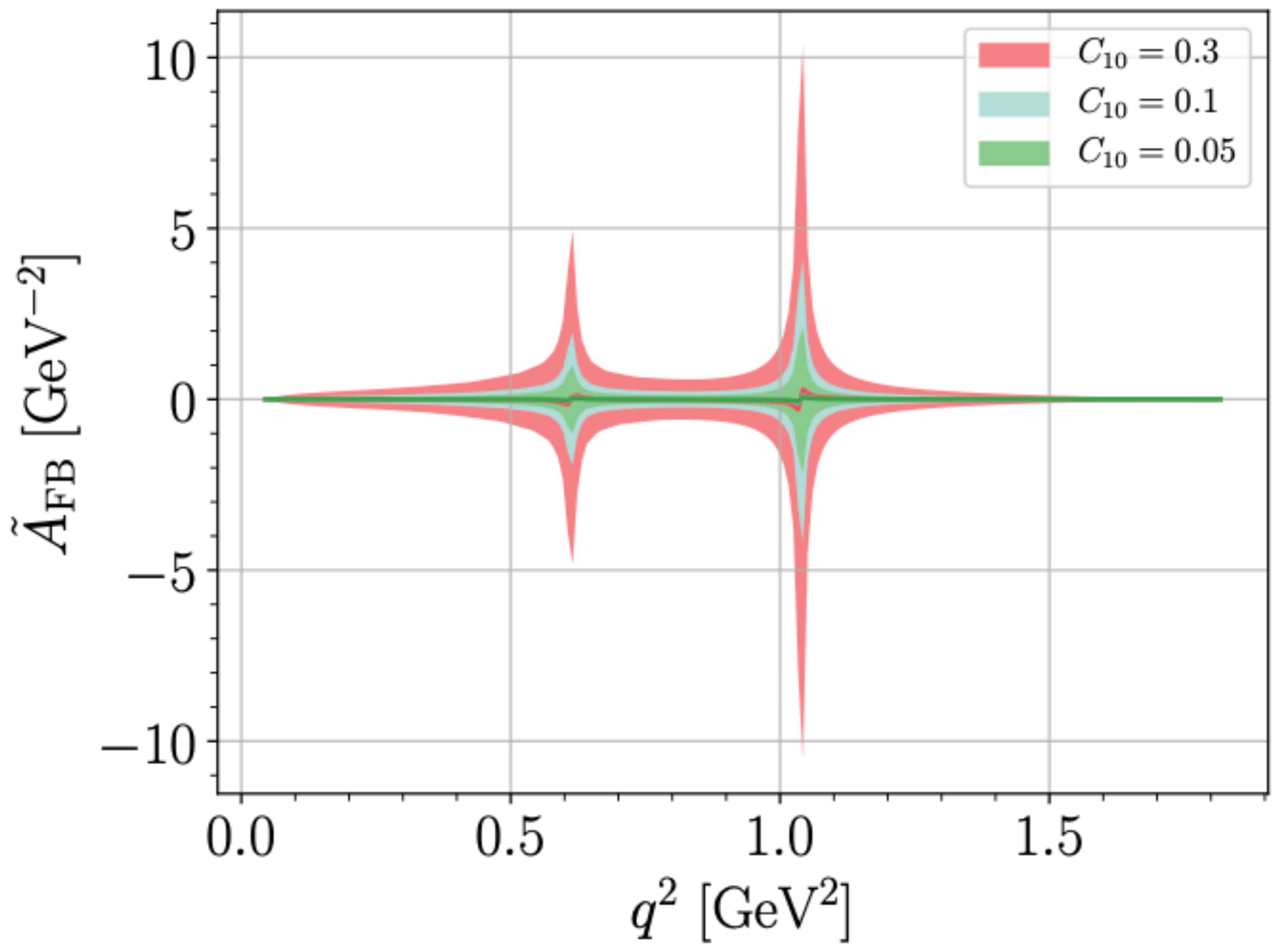
- First study of angular & CP asymmetry in rare baryonic charm decay

Search for resonance-enhanced effects

$$A_{FB} = \frac{\Gamma(\cos\theta_\mu > 0) - \Gamma(\cos\theta_\mu < 0)}{\Gamma(\cos\theta_\mu > 0) + \Gamma(\cos\theta_\mu < 0)}$$

$$A_{CP} = \frac{\Gamma(\Lambda_c^+ \to p\mu^+\mu^-) - \Gamma(\Lambda_c^- \to \bar{p}\mu^+\mu^-)}{\Gamma(\Lambda_c^+ \to p\mu^+\mu^-) + \Gamma(\Lambda_c^- \to \bar{p}\mu^+\mu^-)}$$

Null tests!



Angular and CP asymmetries of $\Lambda_c^+ \to p\mu^+\mu^-$

$$\frac{d^2\Gamma}{dq^2 d\cos\theta_\ell} = \frac{3}{2}\left(K_{1ss}\sin^2\theta_\ell + K_{1cc}\cos^2\theta_\ell + K_{1c}\cos\theta_\ell\right)$$

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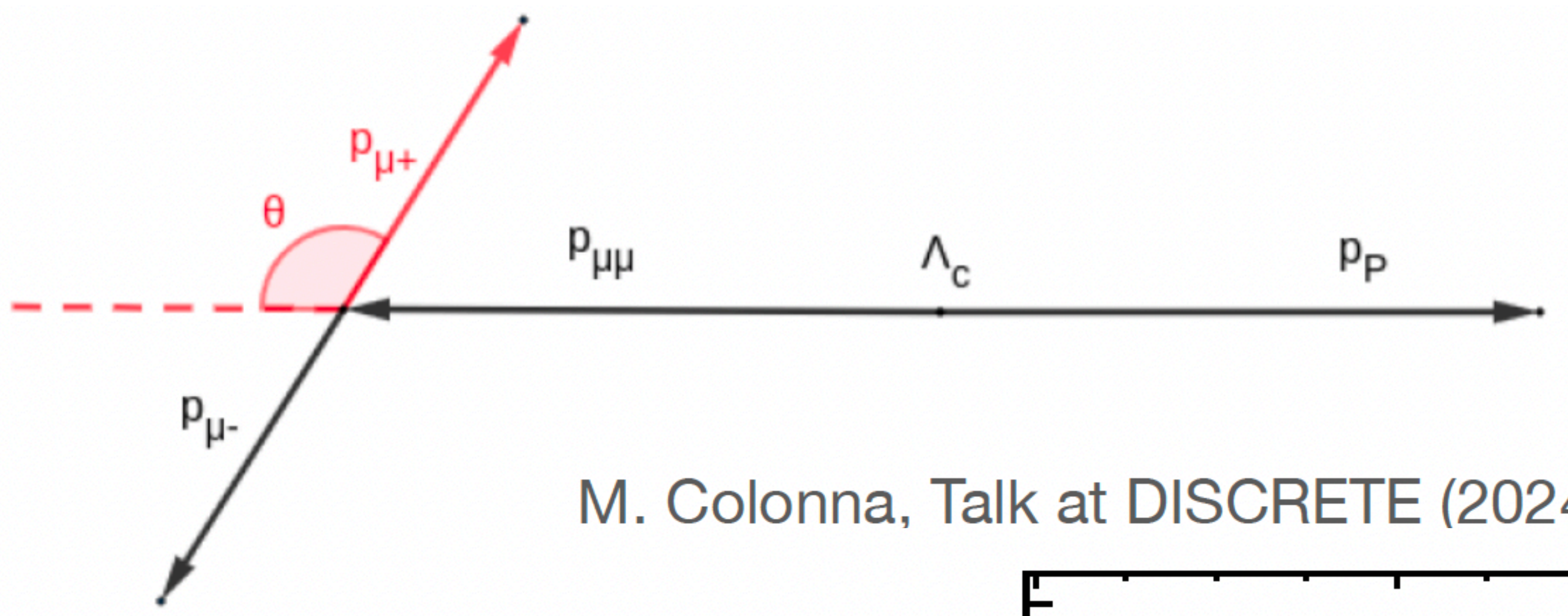

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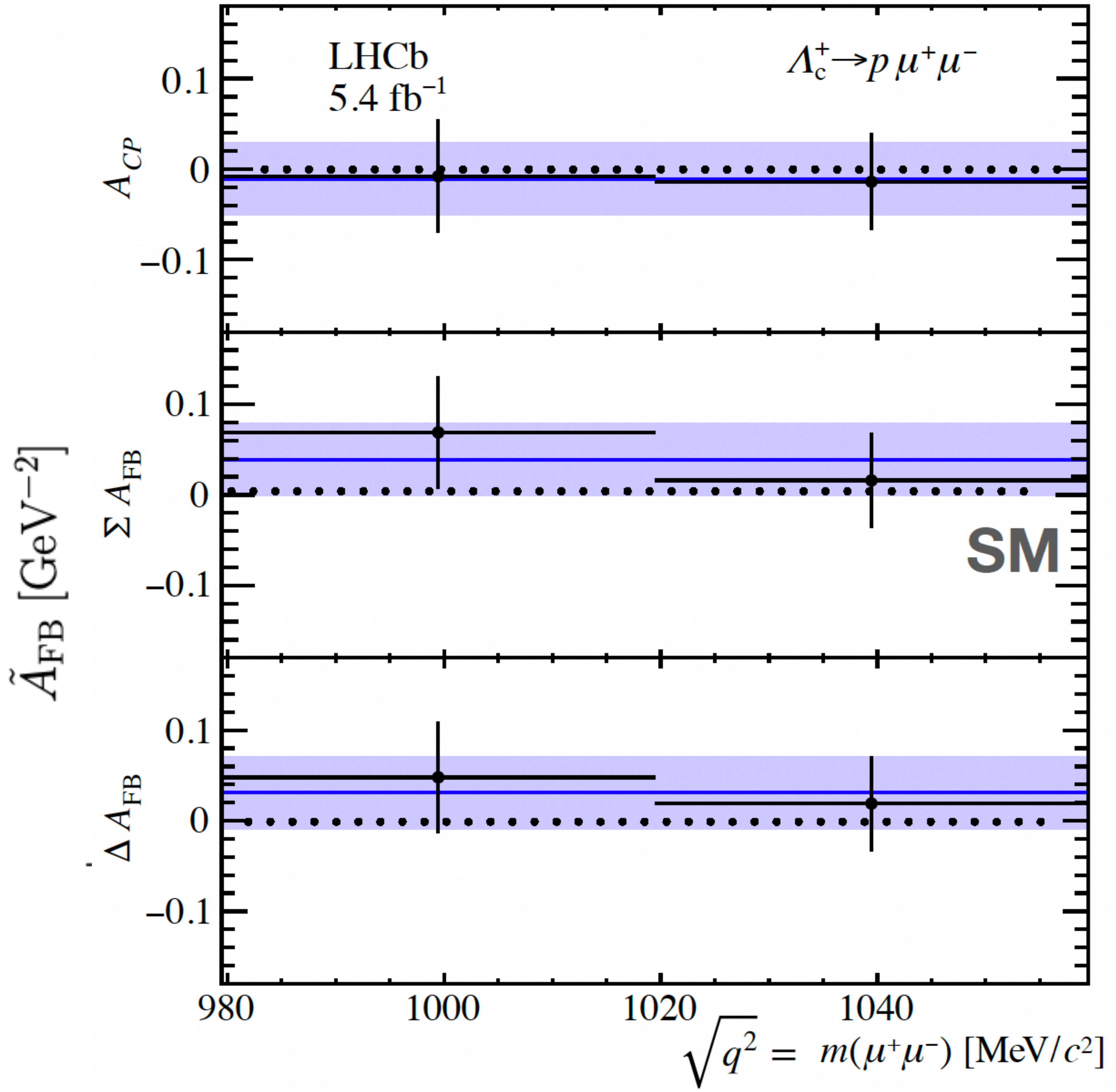
Null tests!

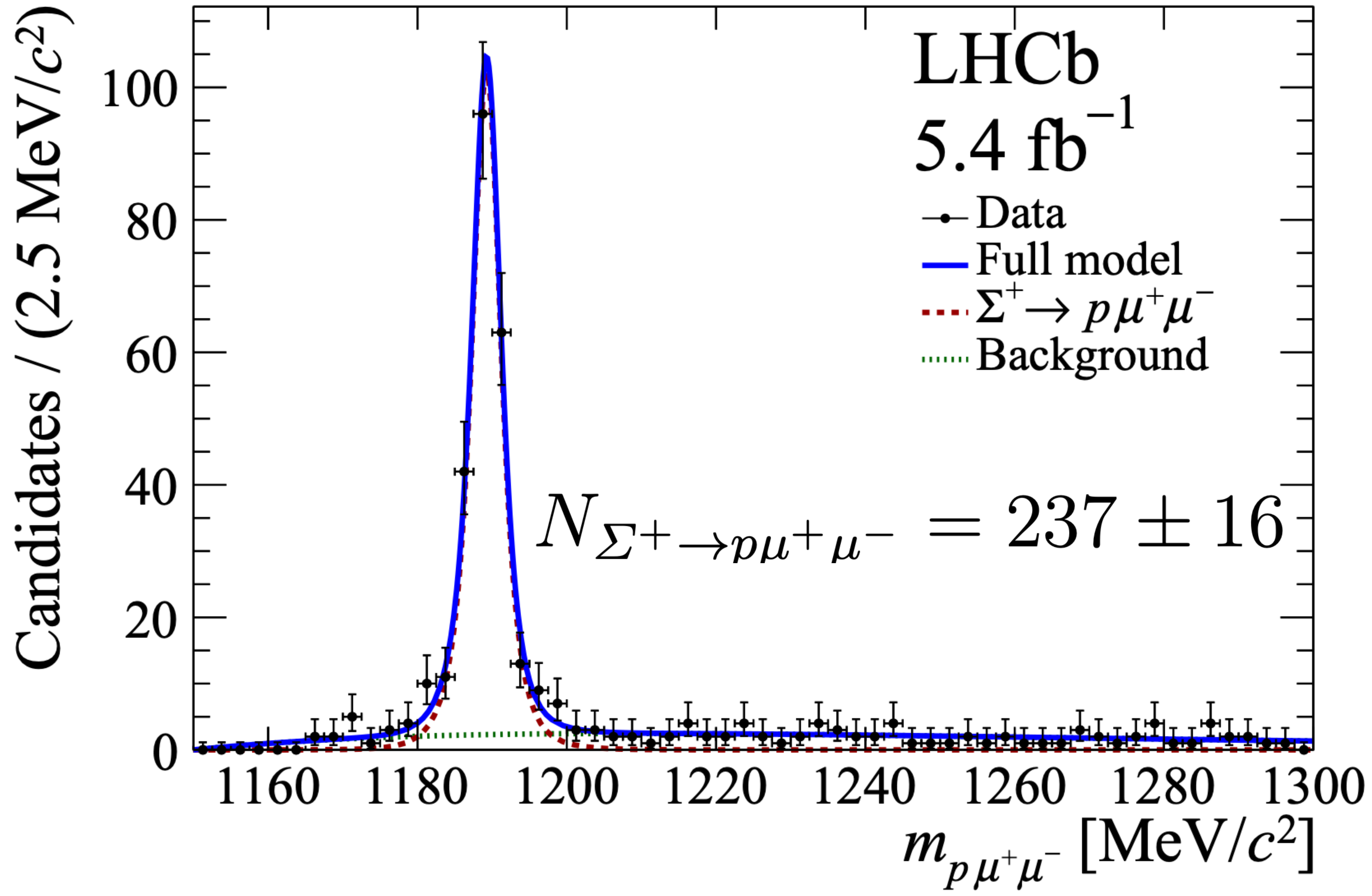


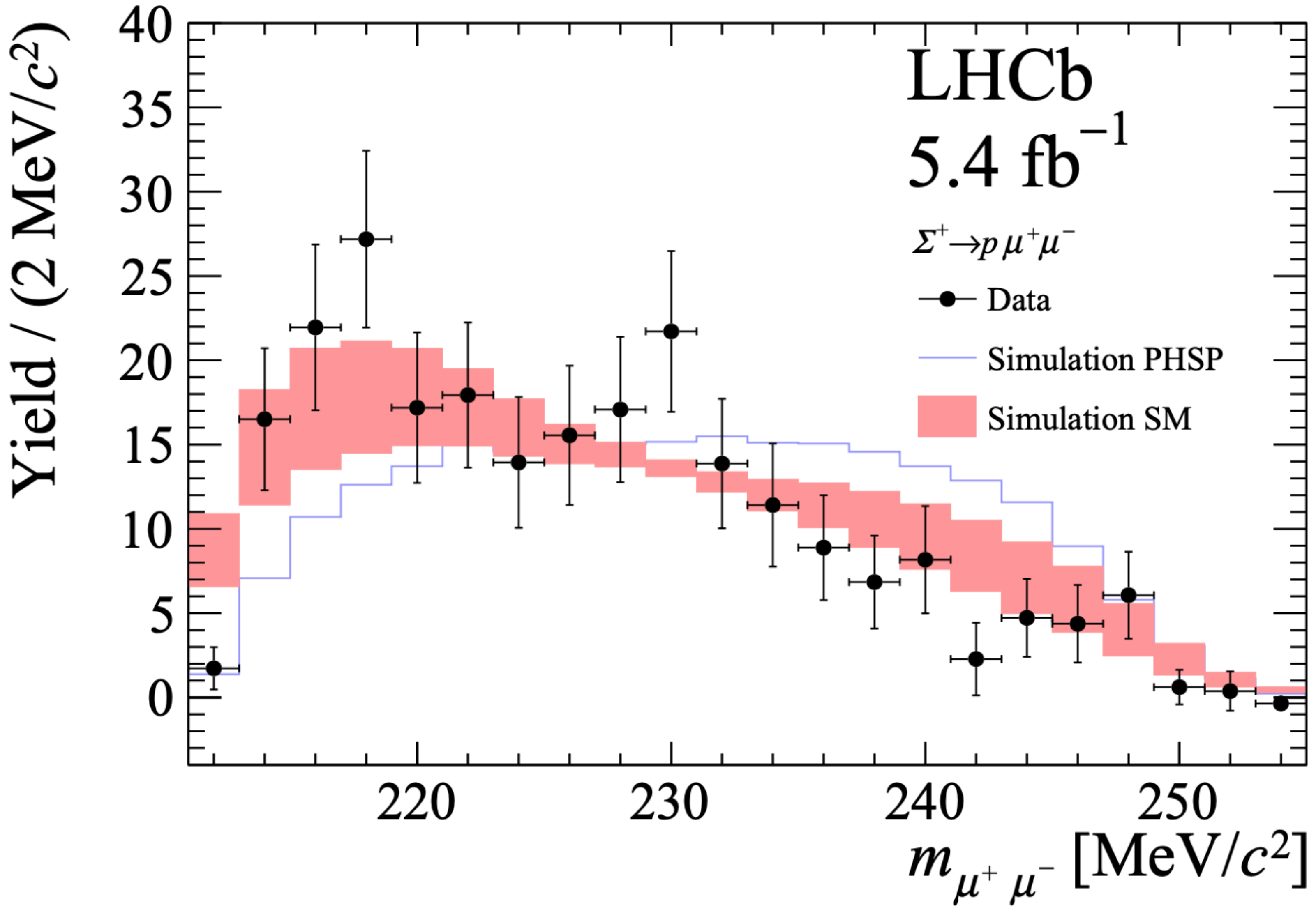
Observation of $\Sigma^+ \to p\mu^+\mu^-$

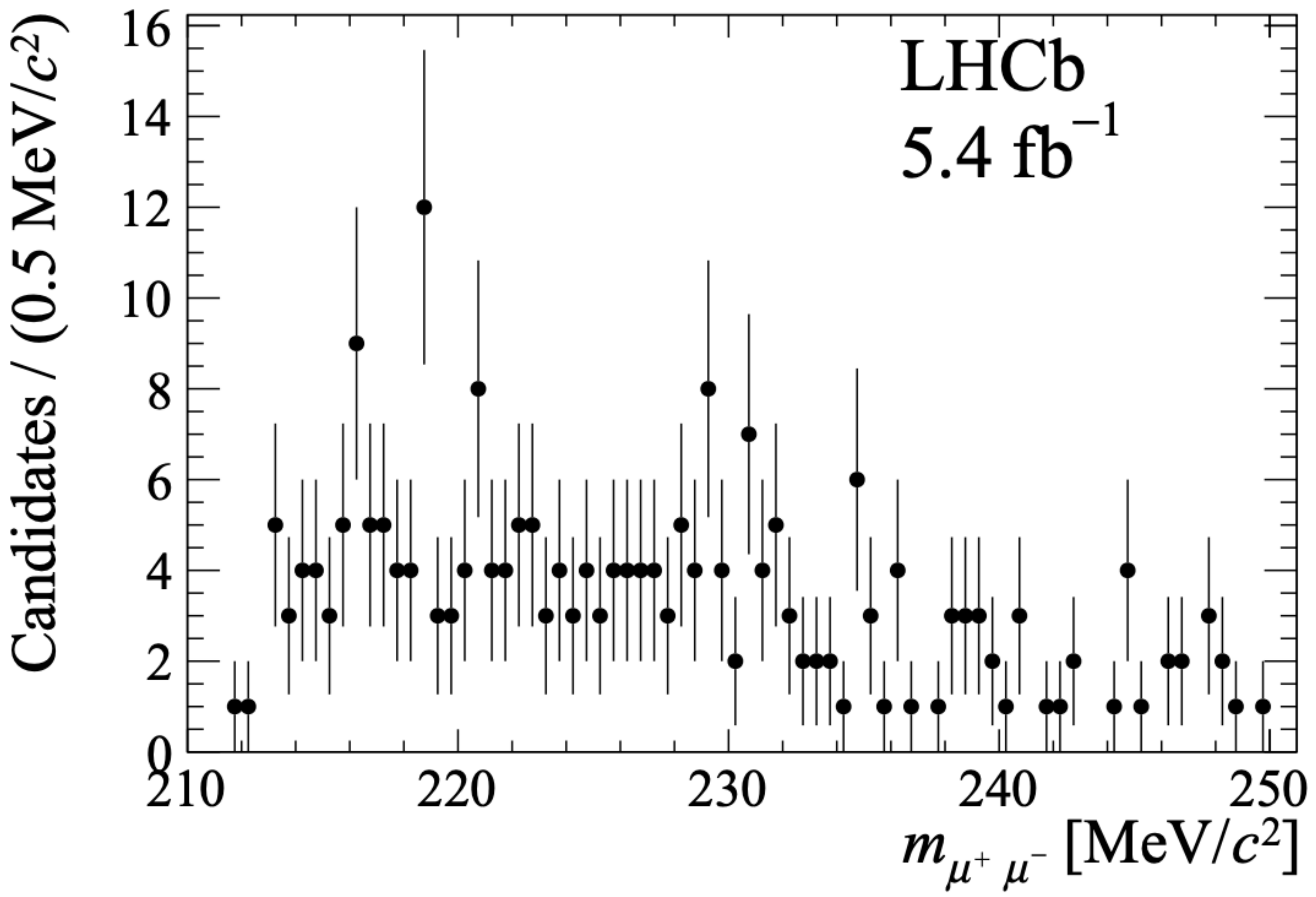
arXiv:2504.06096

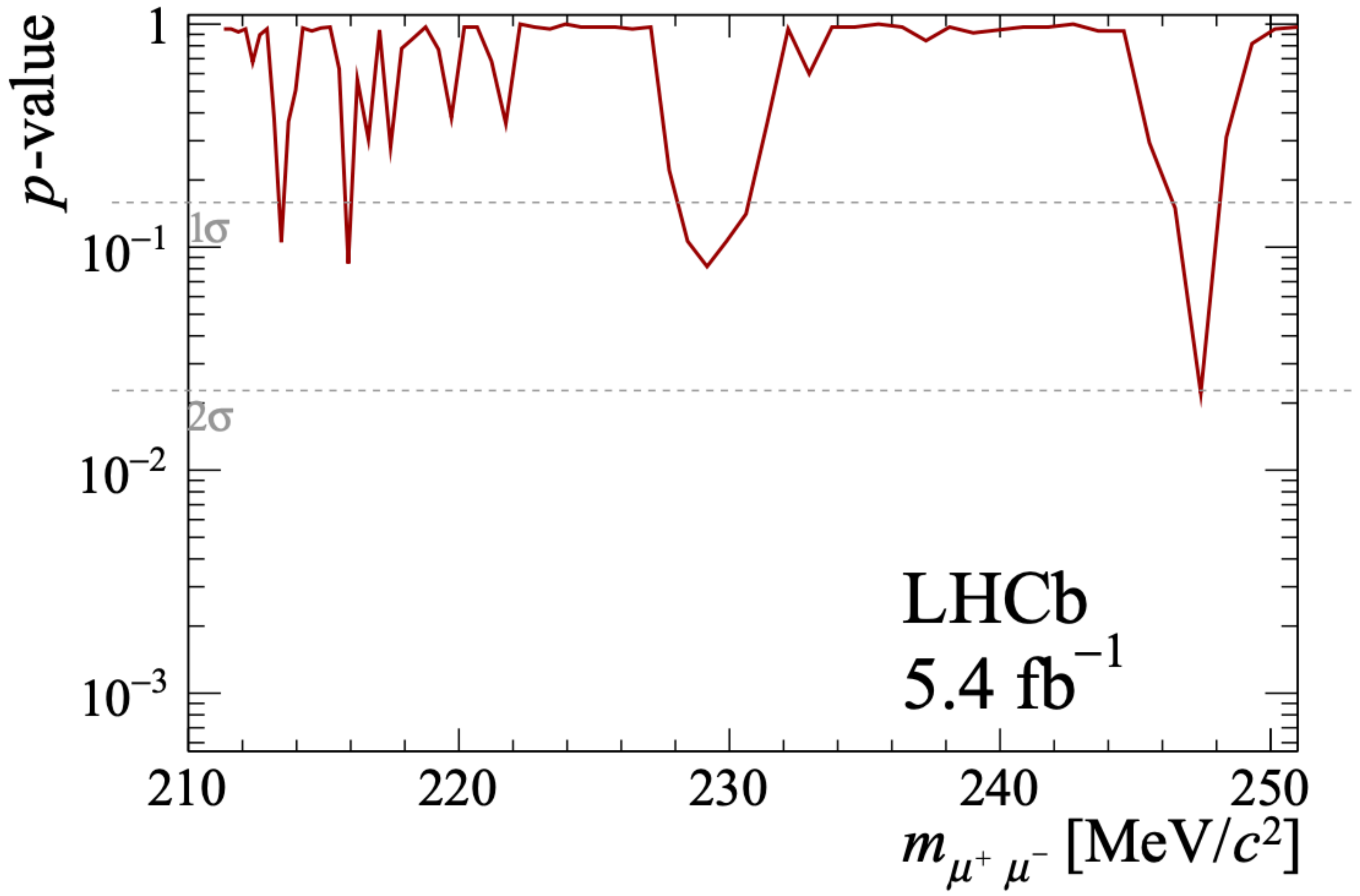
$$\mathcal{B}(\Sigma^+ \to p\mu^+\mu^-) = (1.09 \pm 0.17) \times 10^{-8}$$

- No structure is seen in the dimuon invariant-mass distribution
- Compatible with expectations from the SM

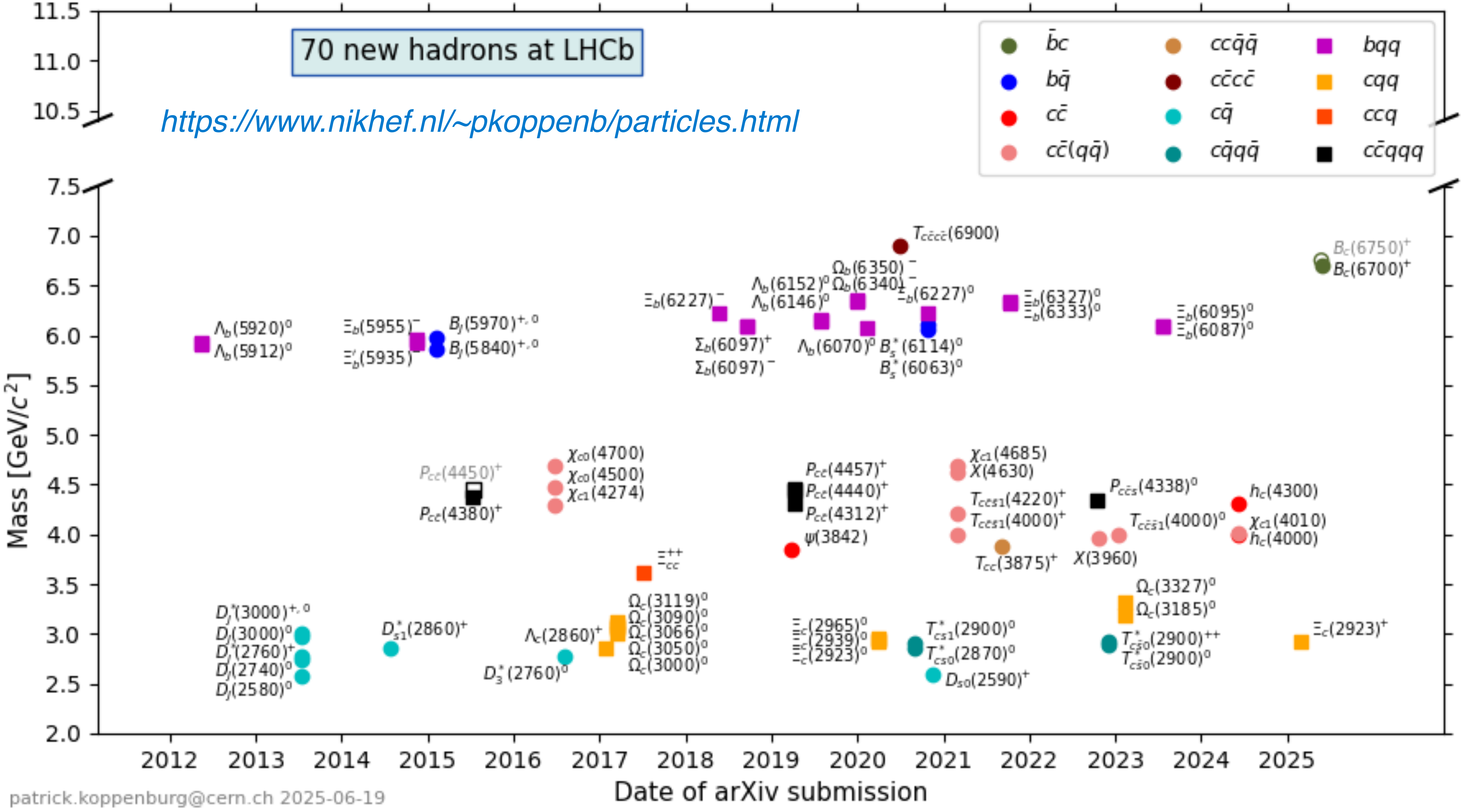




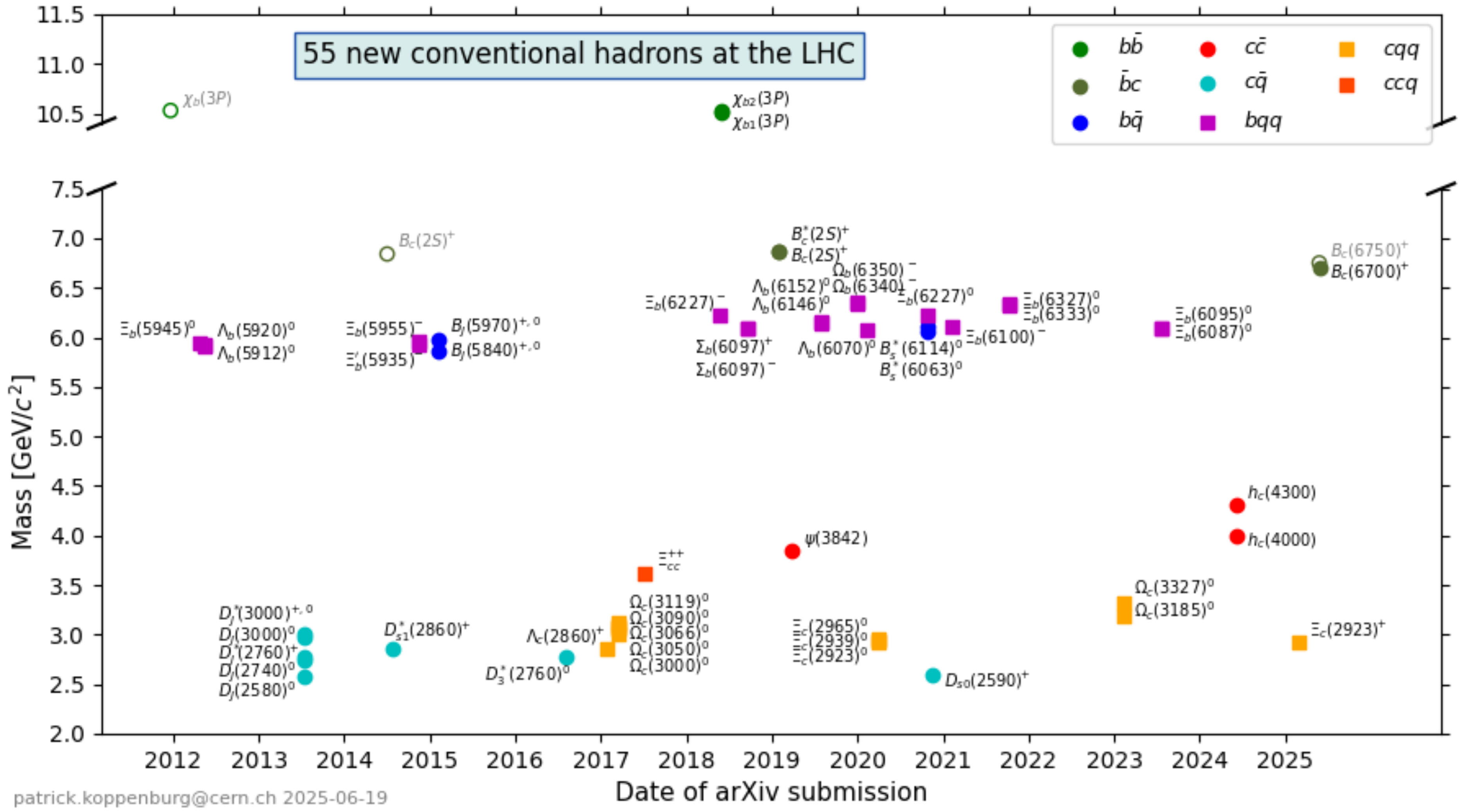




QCD: Hadron spectroscopy



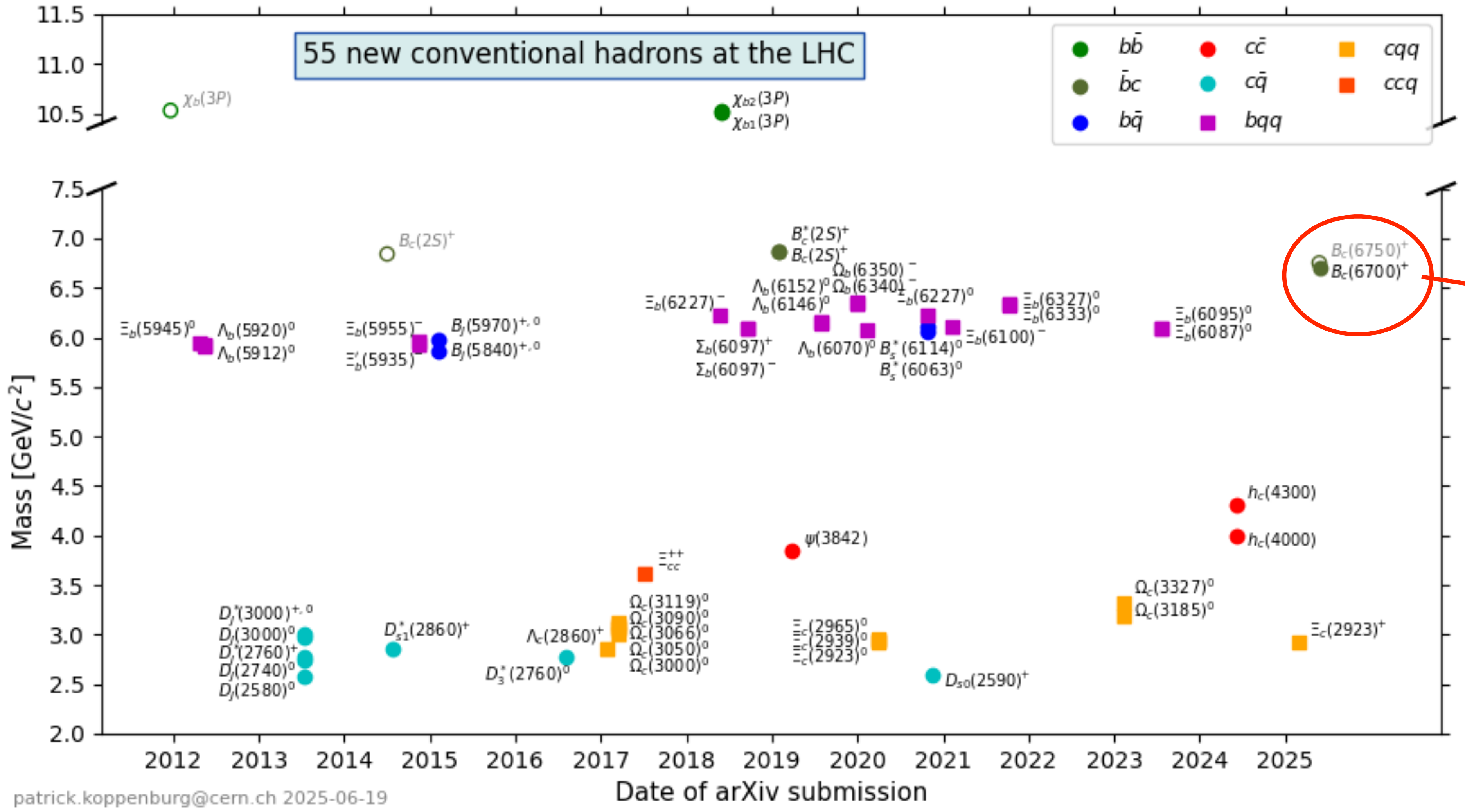
Conventional hadrons



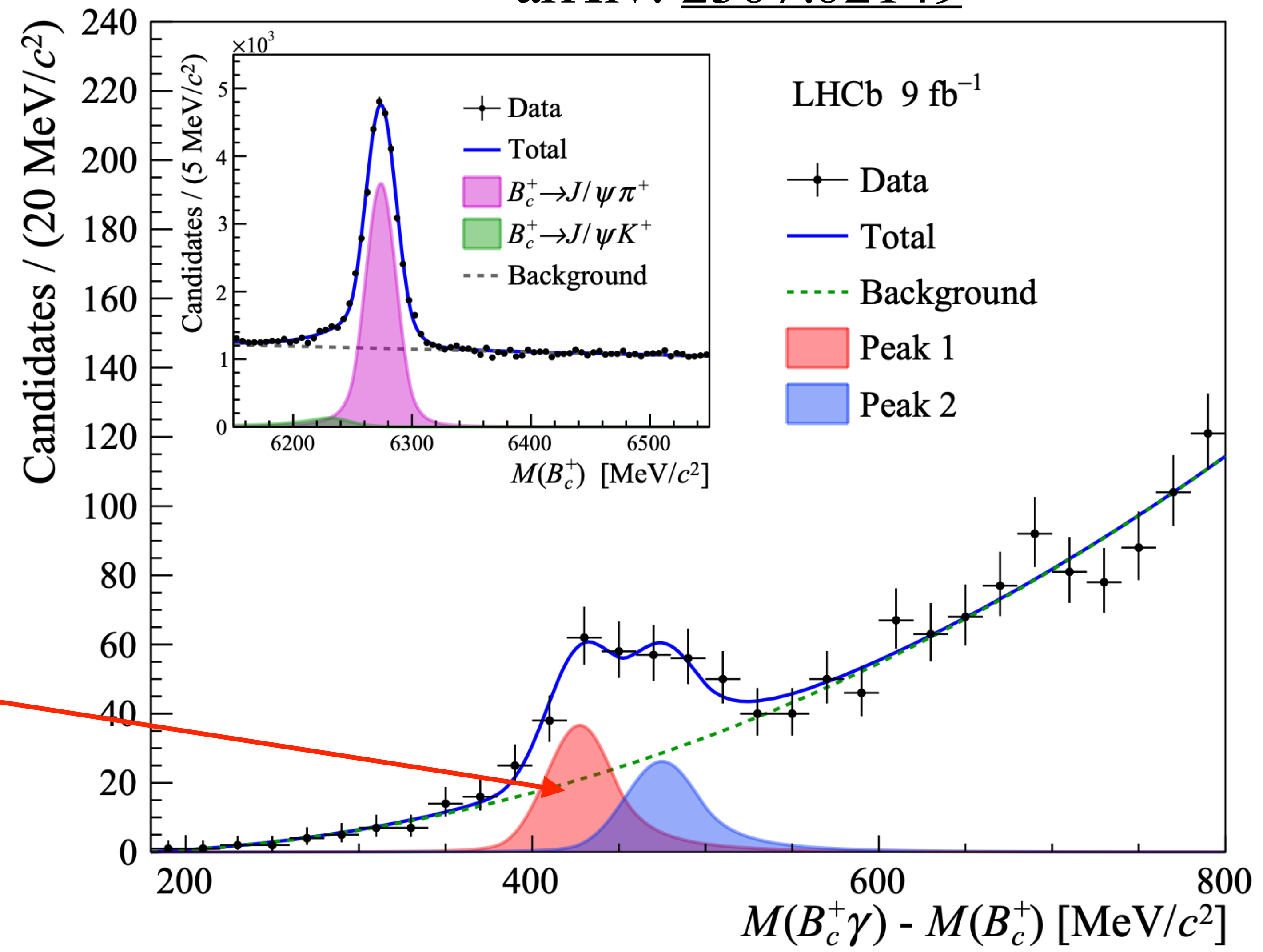
arXiv:2502.18987

$$Q = m_{\Xi_b \pi\pi} - m_{\Xi_b} - 2m_\pi$$

Conventional hadrons



LHCb-PAPER-2025-014
arXiv: 2507.02149



arXiv:2502.18987

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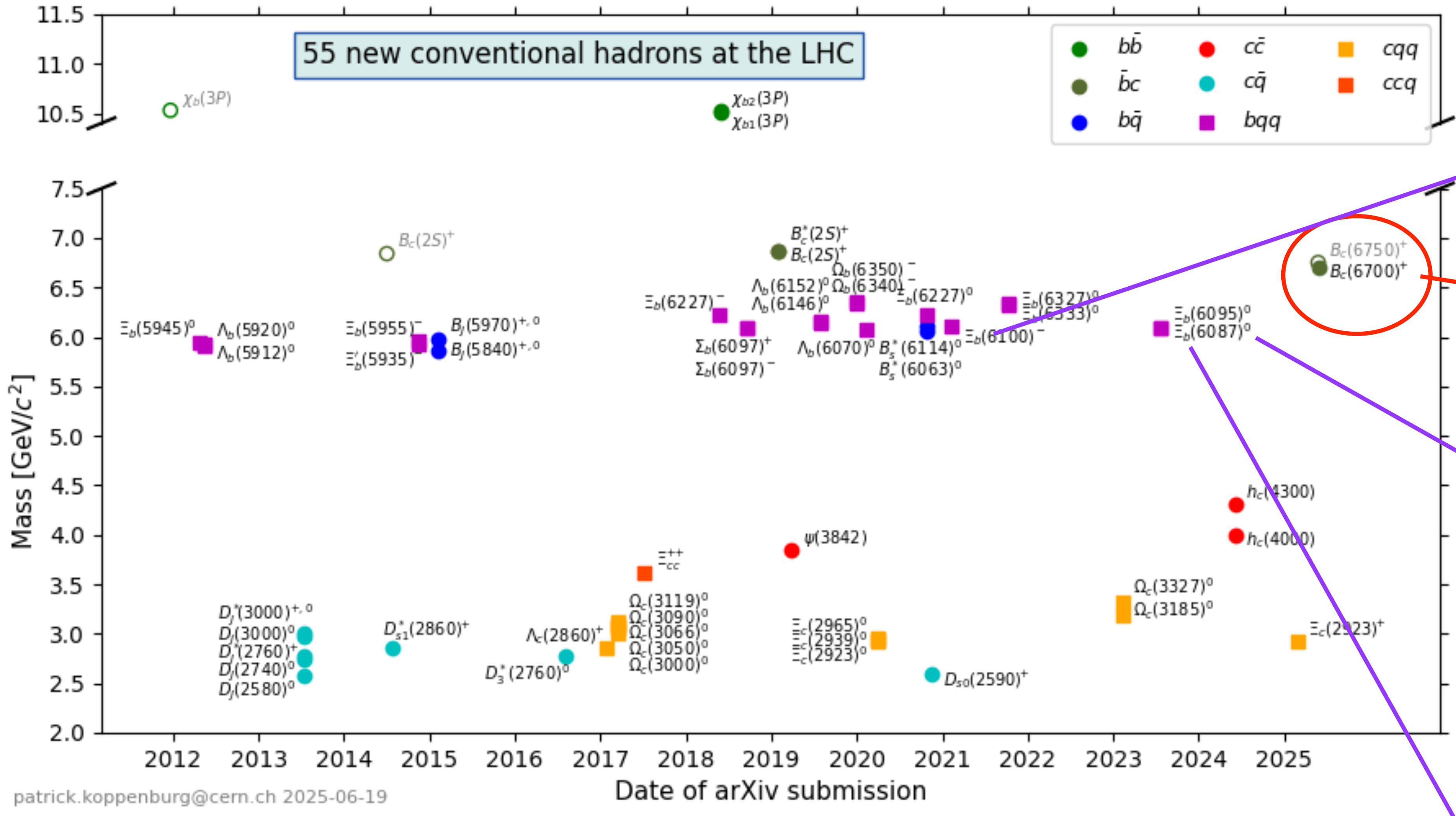
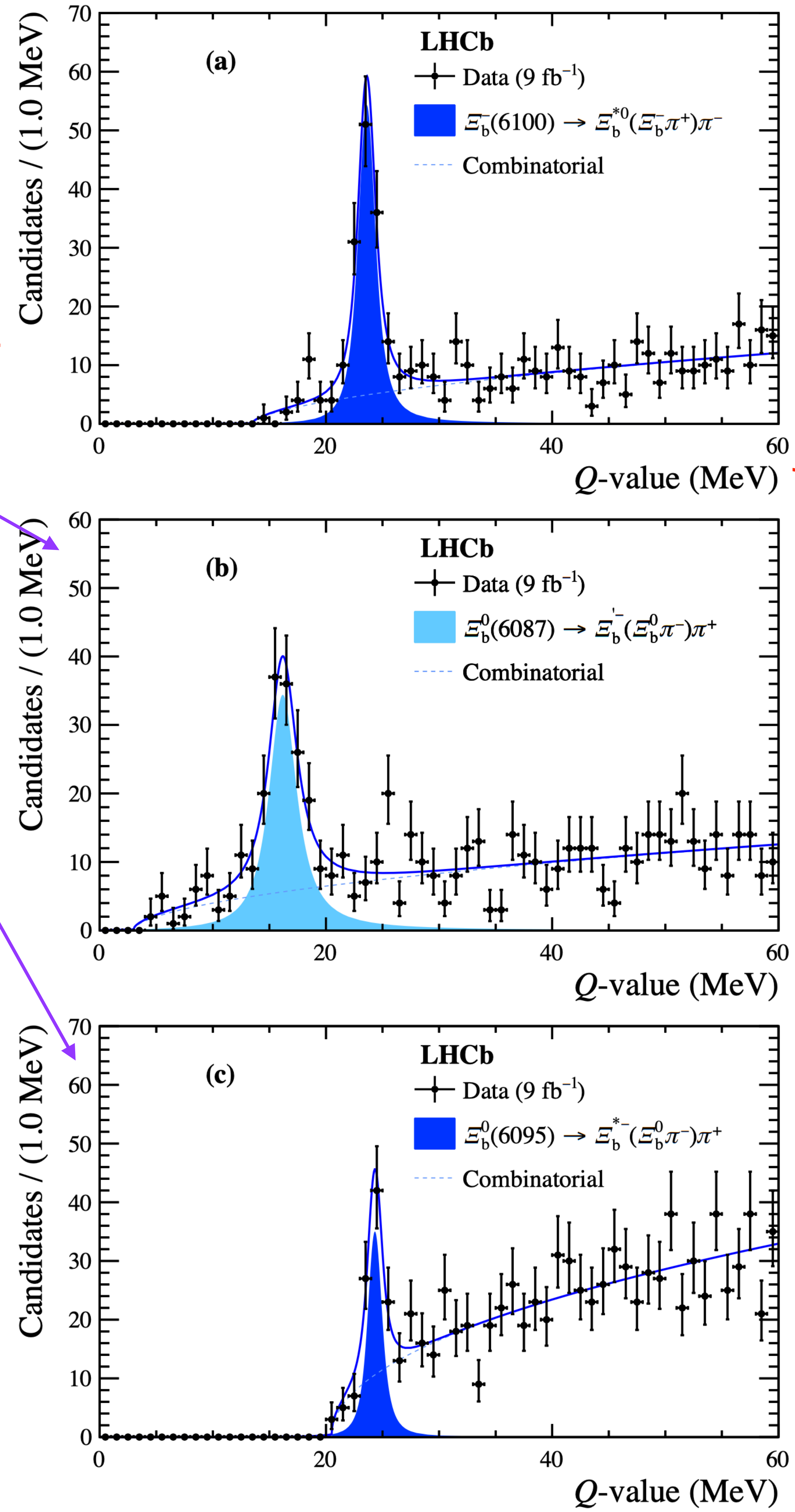


Phys. Rev. Lett. 131 (2023) 171901



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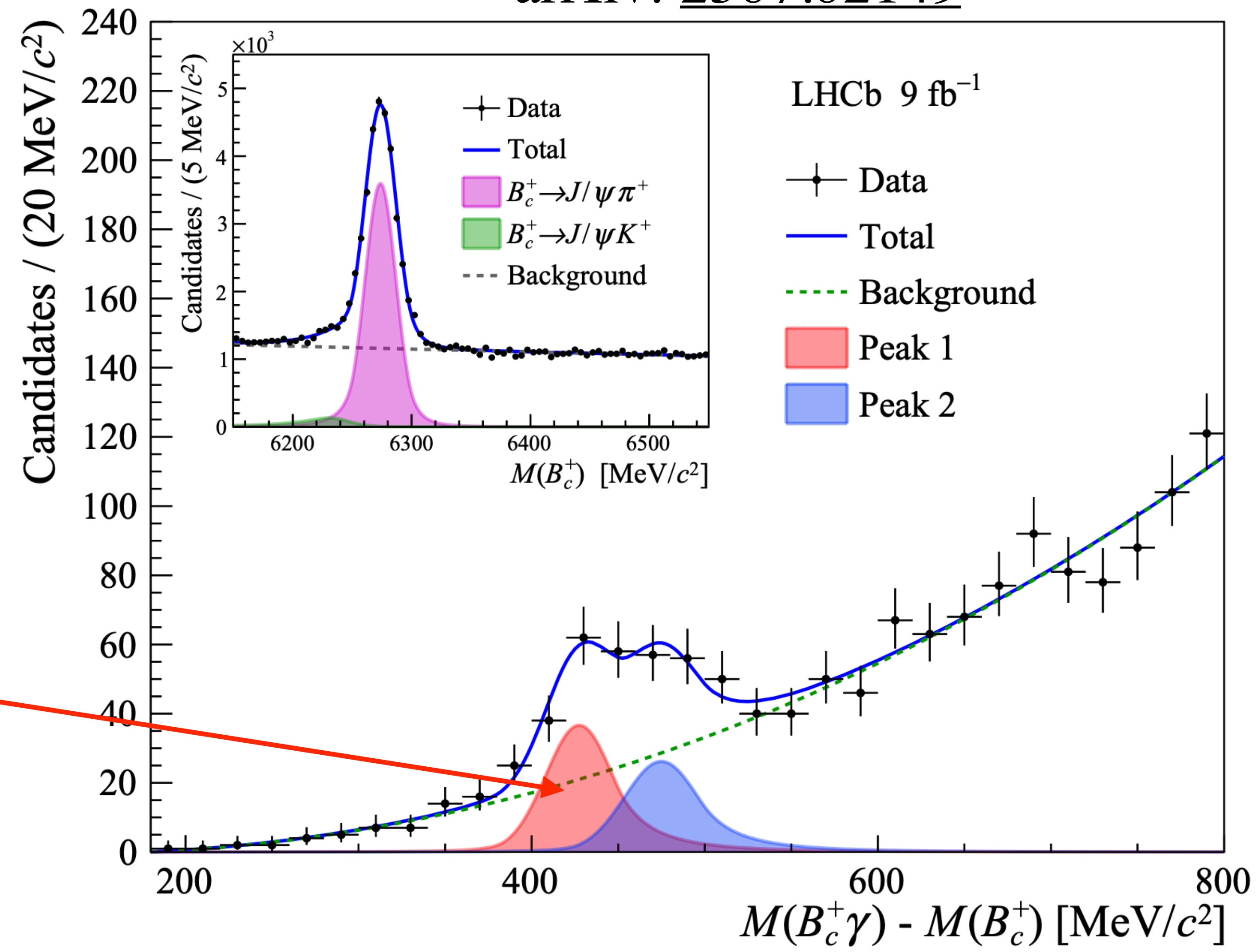
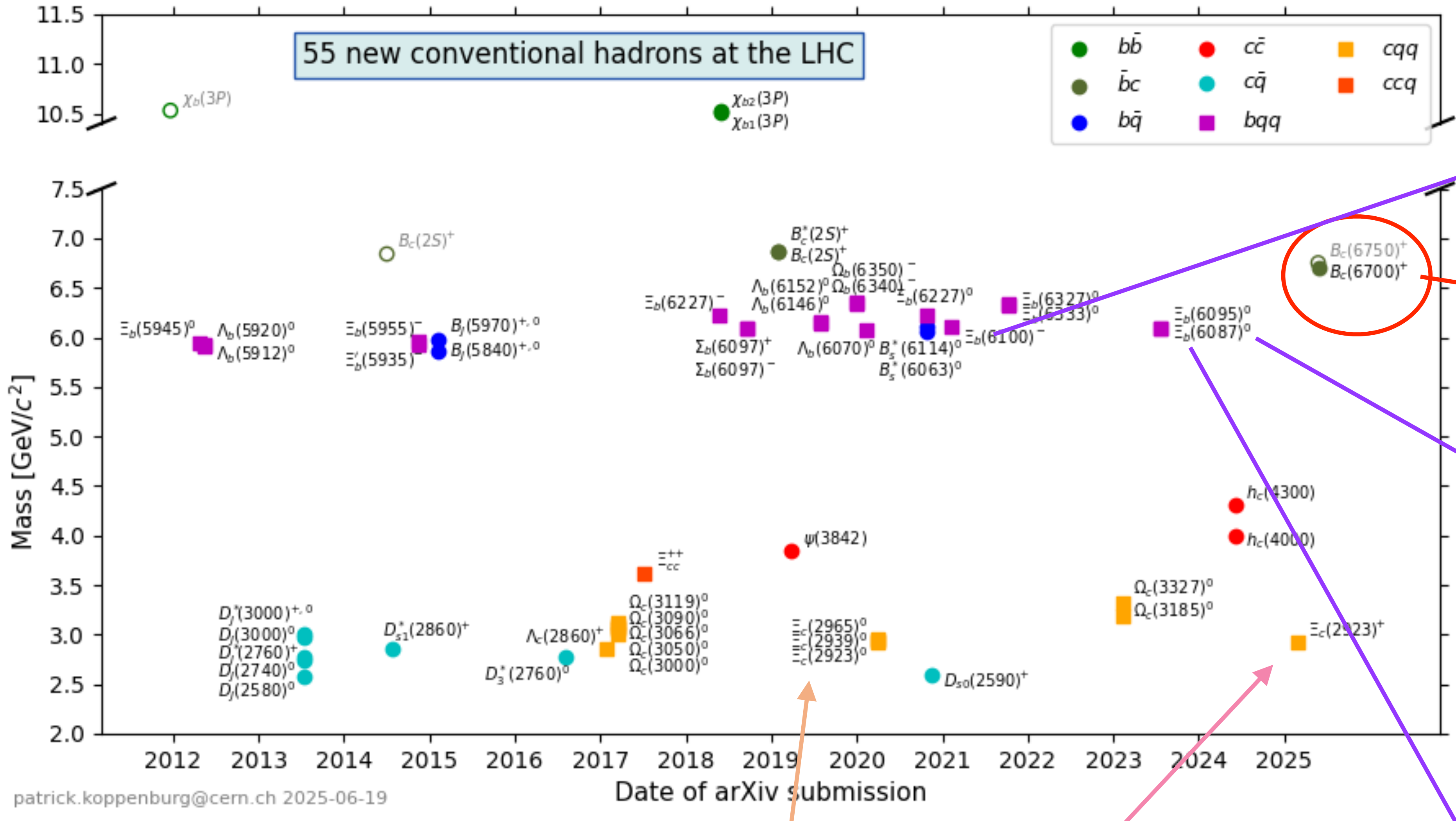
LHCb-PAPER-2025-014
arXiv: 2507.02149

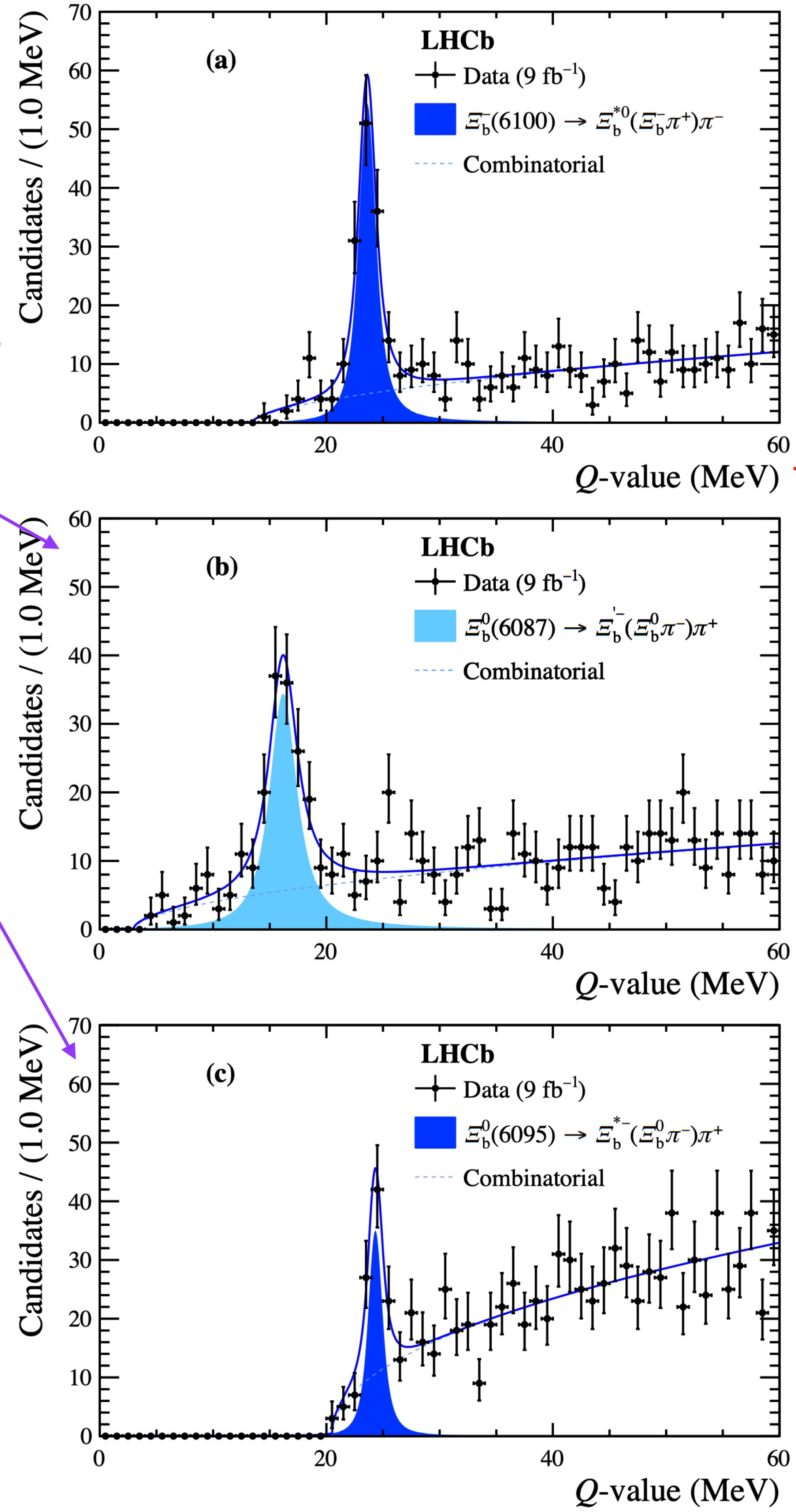


arXiv:2502.18987

Conventional hadrons



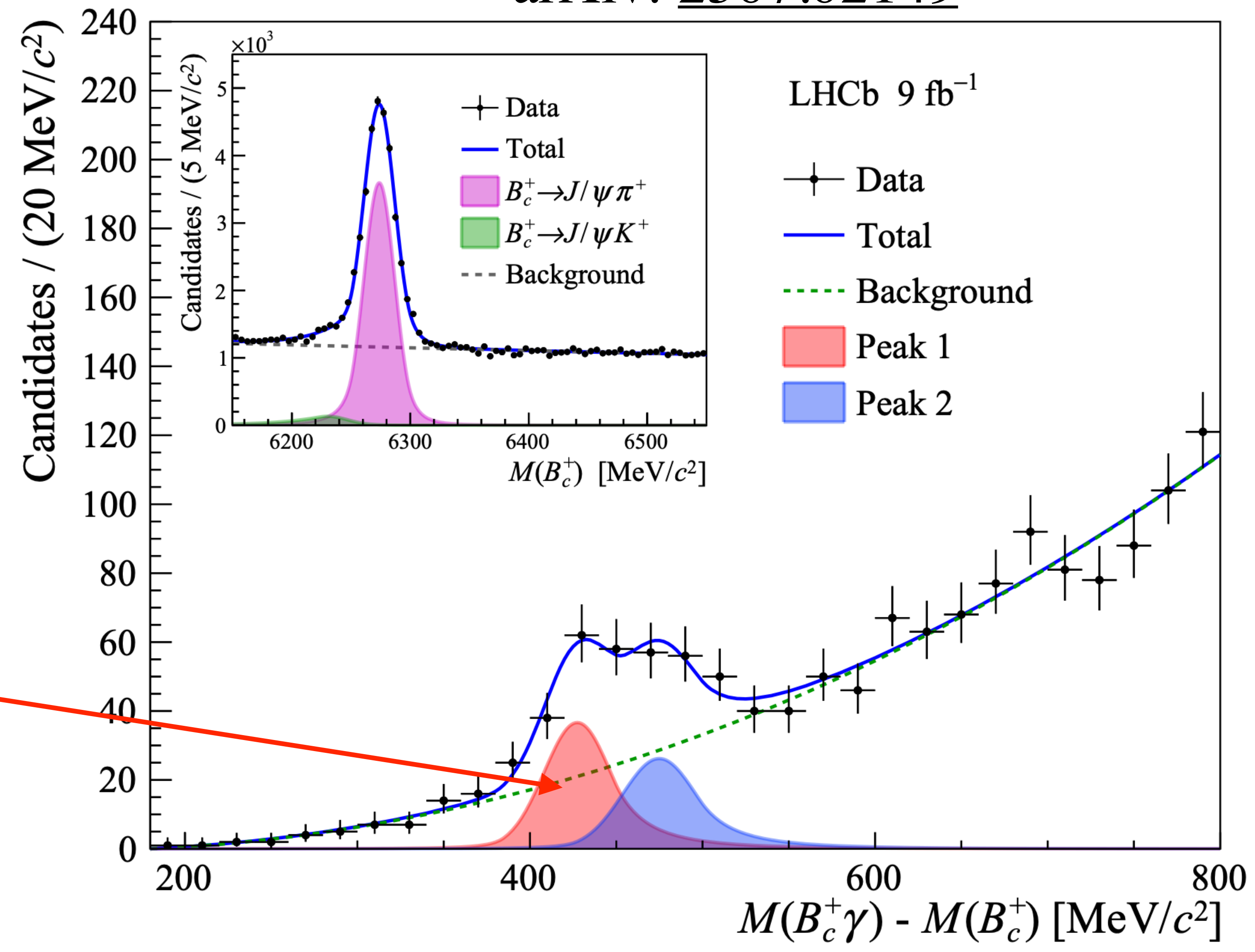
Phys. Rev. Lett. 131 (2023) 171901



$Q = m_{\Xi_b\pi\pi} - m_{\Xi_b} - 2m_\pi$

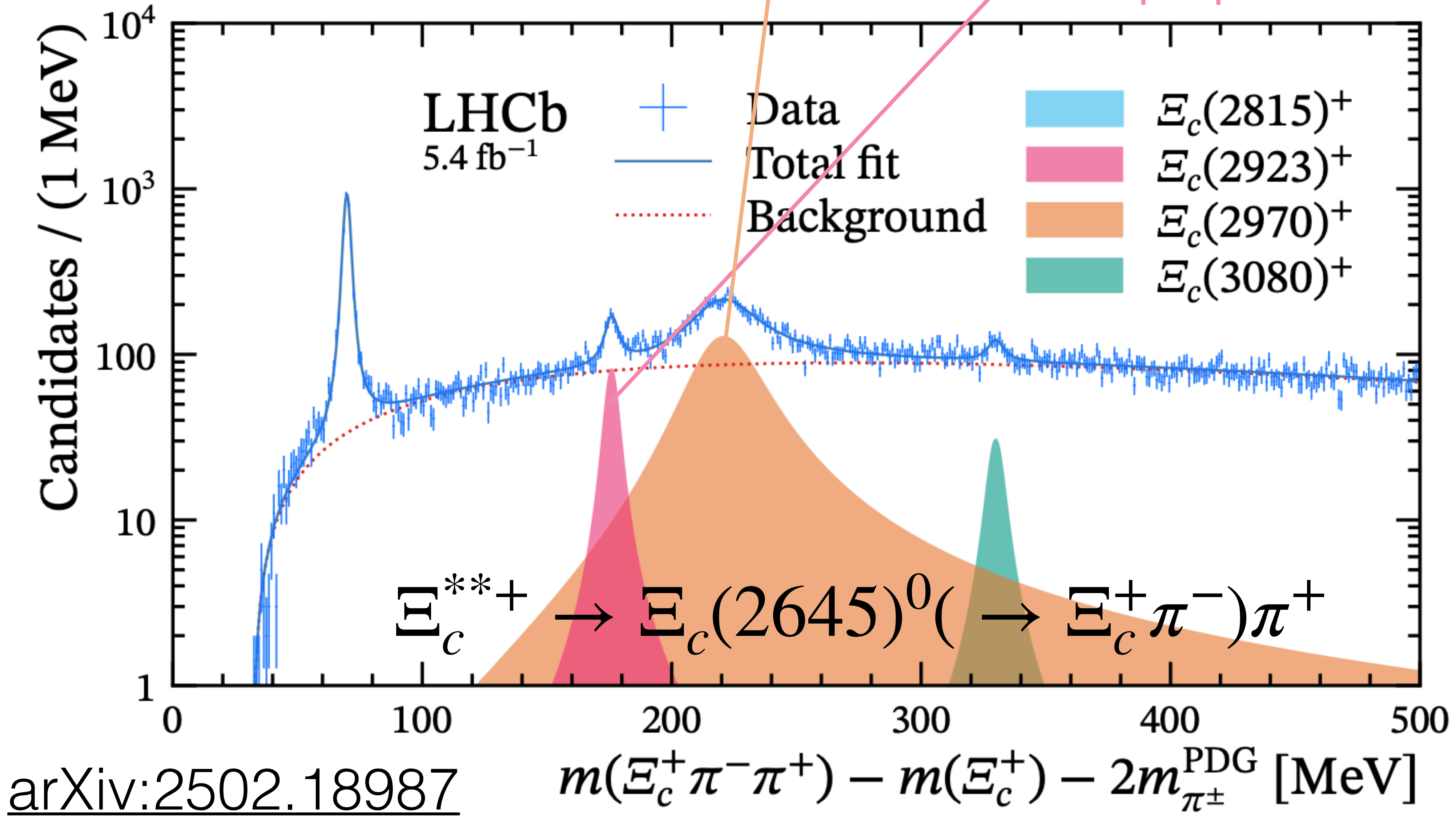
LHCb-PAPER-2025-014

arXiv: 2507.02149



$\Xi_c(2965)^0$?

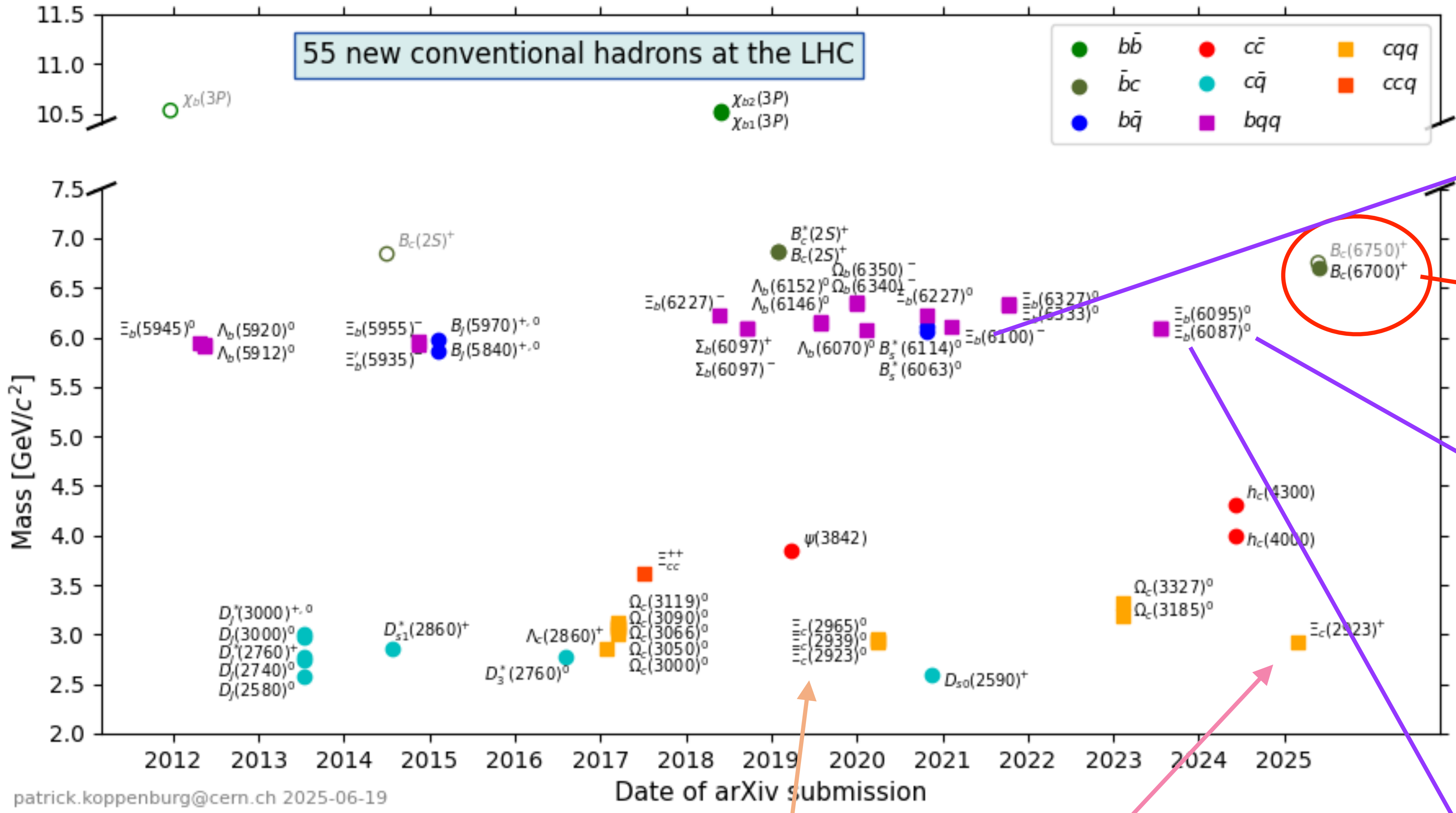
$\Xi_c(2932)^0$ isospin partner

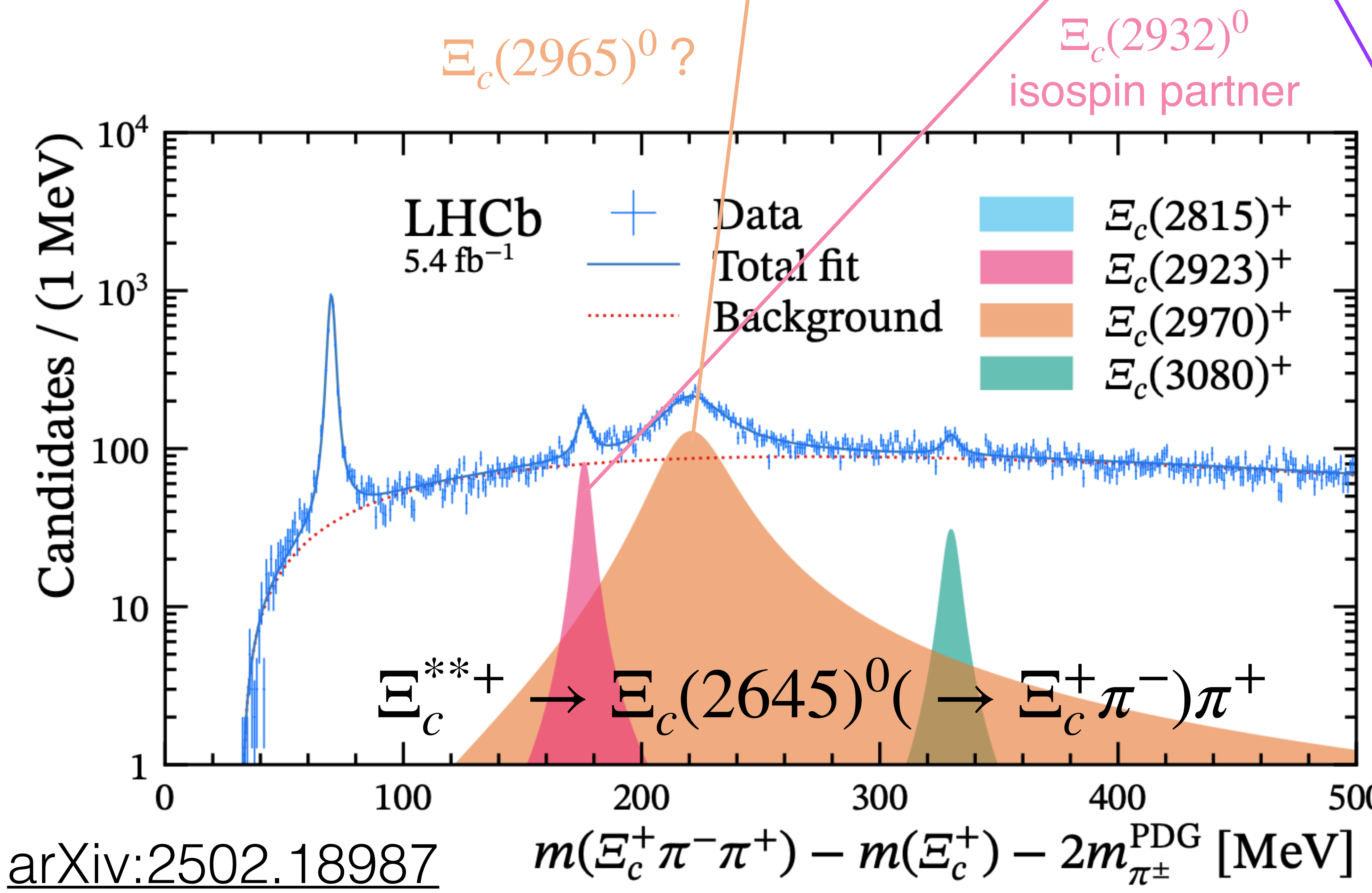


$\Xi_c^{**+} \to \Xi_c(2645)^0(\to \Xi_c^+\pi^-)\pi^+$

arXiv:2502.18987

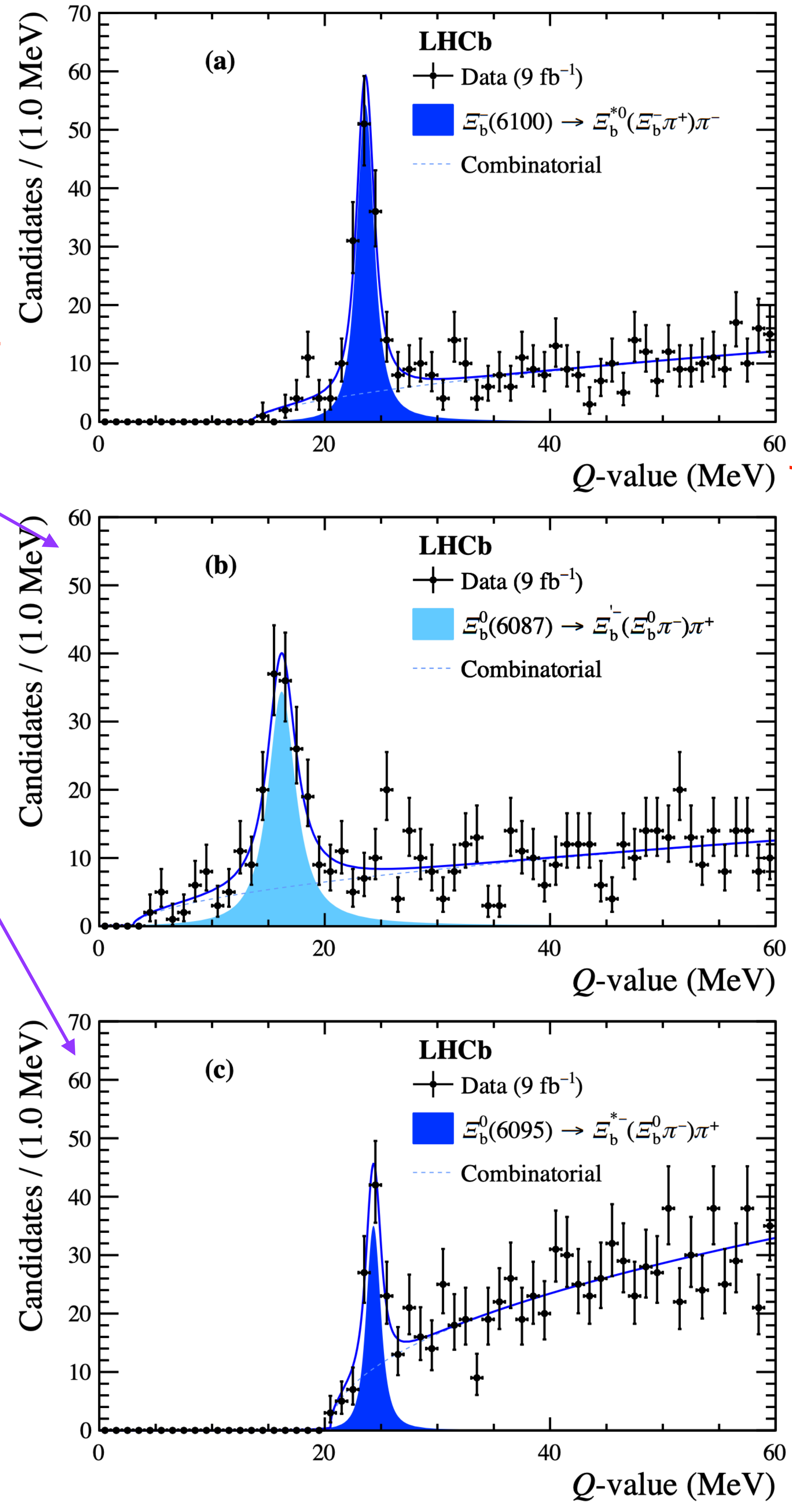
Conventional hadrons





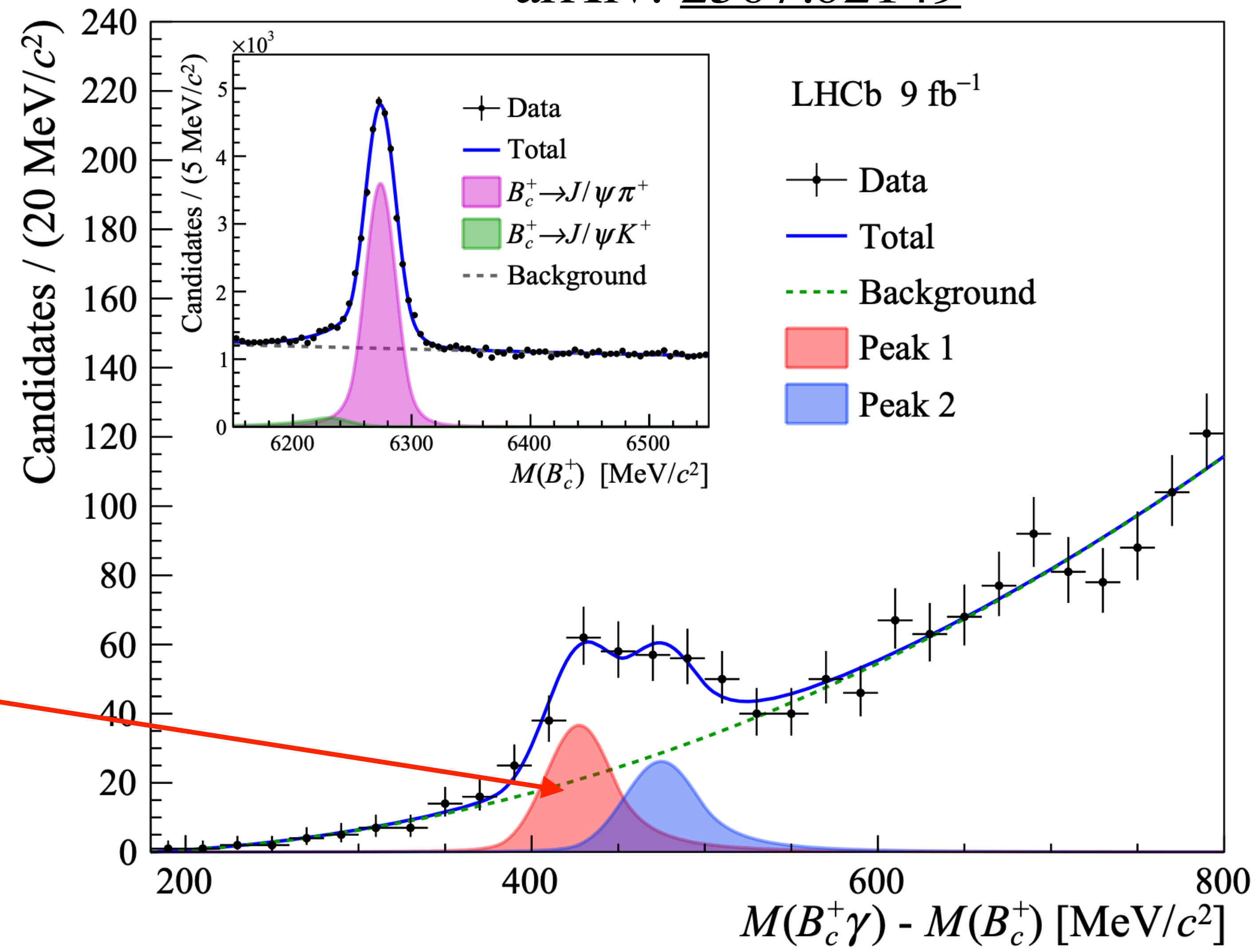
arXiv:2502.18987

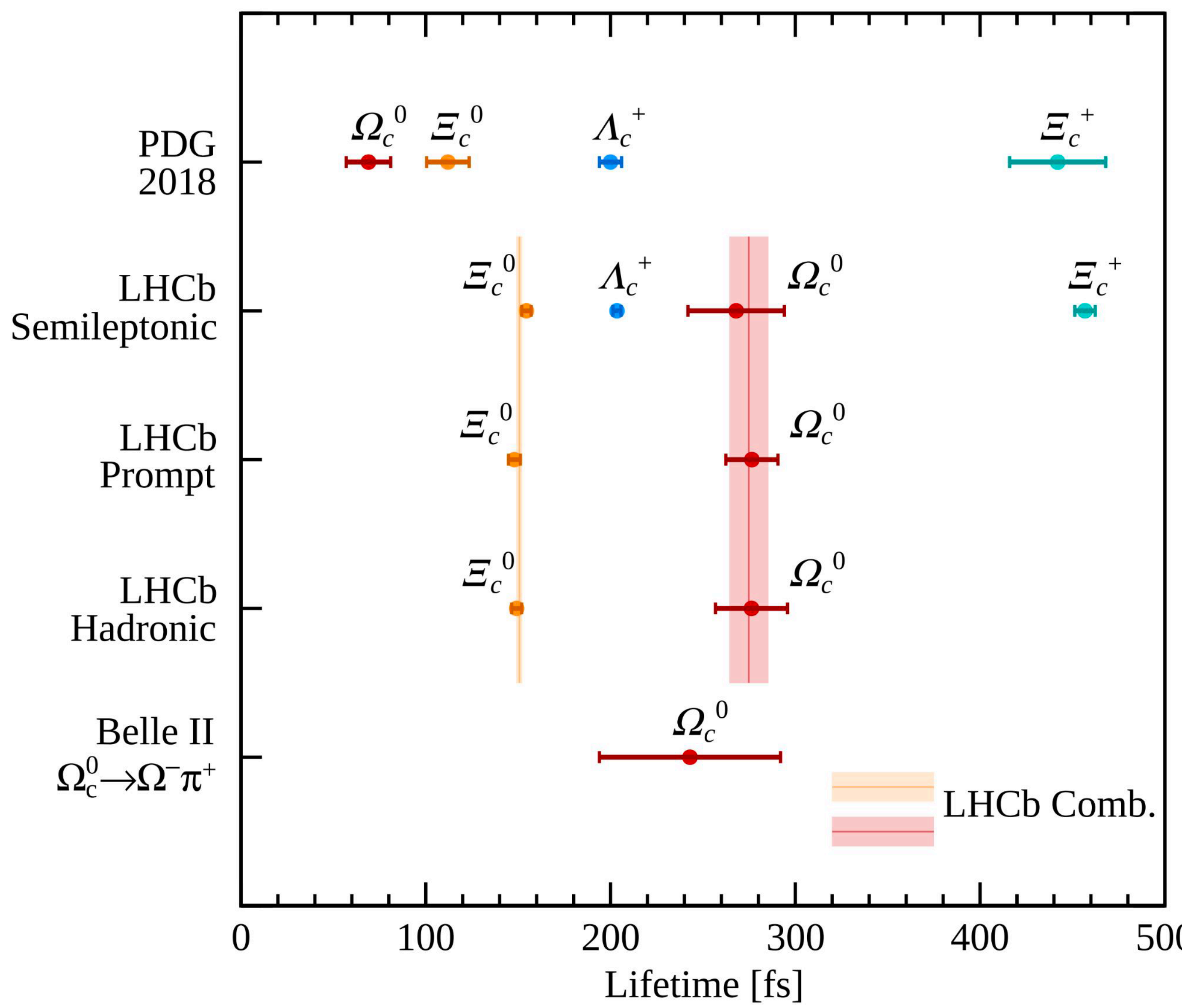
Phys. Rev. Lett. 131 (2023) 171901



$$Q = m_{\Xi_b\pi\pi} - m_{\Xi_b} - 2m_\pi$$

LHCb-PAPER-2025-014
arXiv: 2507.02149



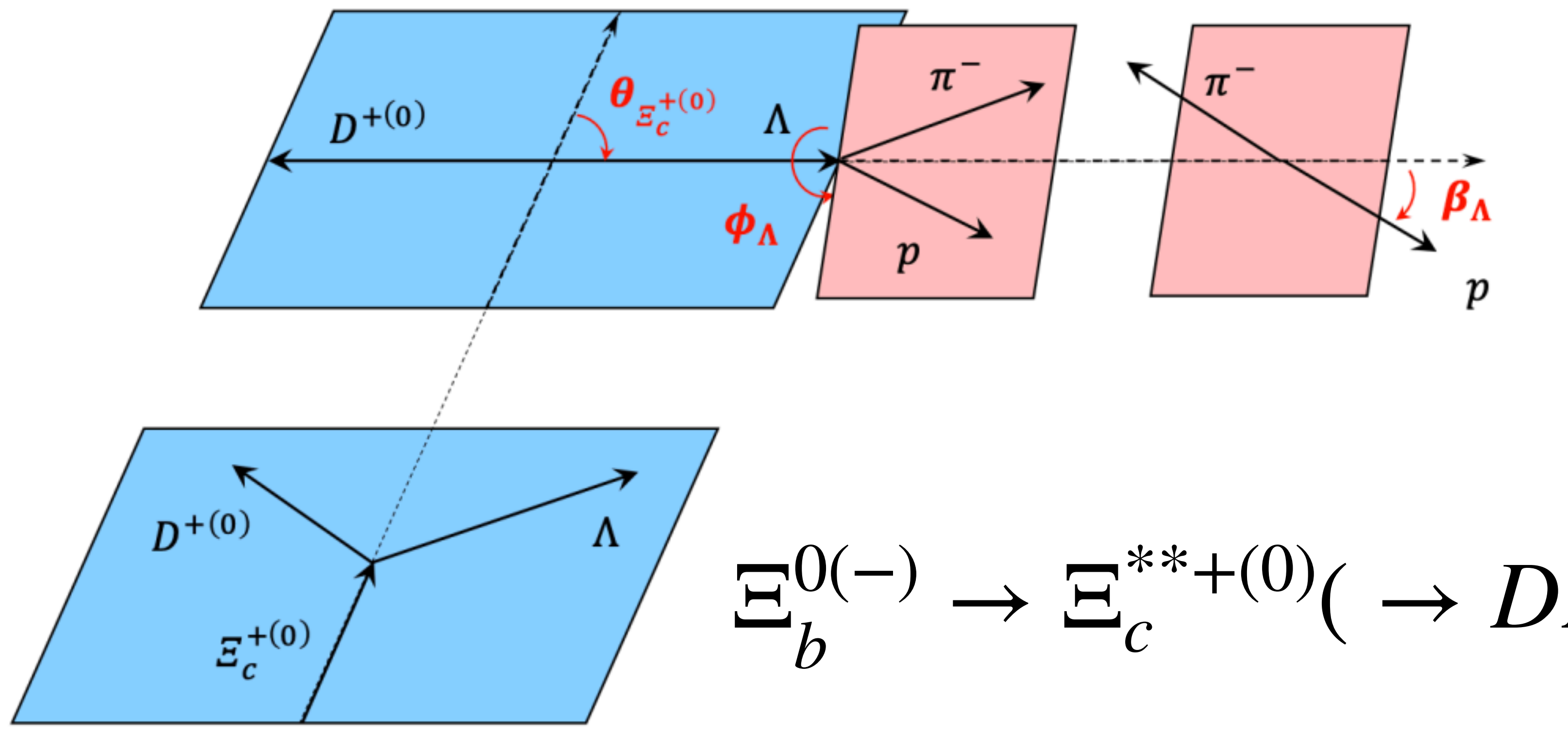


arXiv: 2506.13334

Spin parity of $\Xi_c(3055)^{+(0)}$

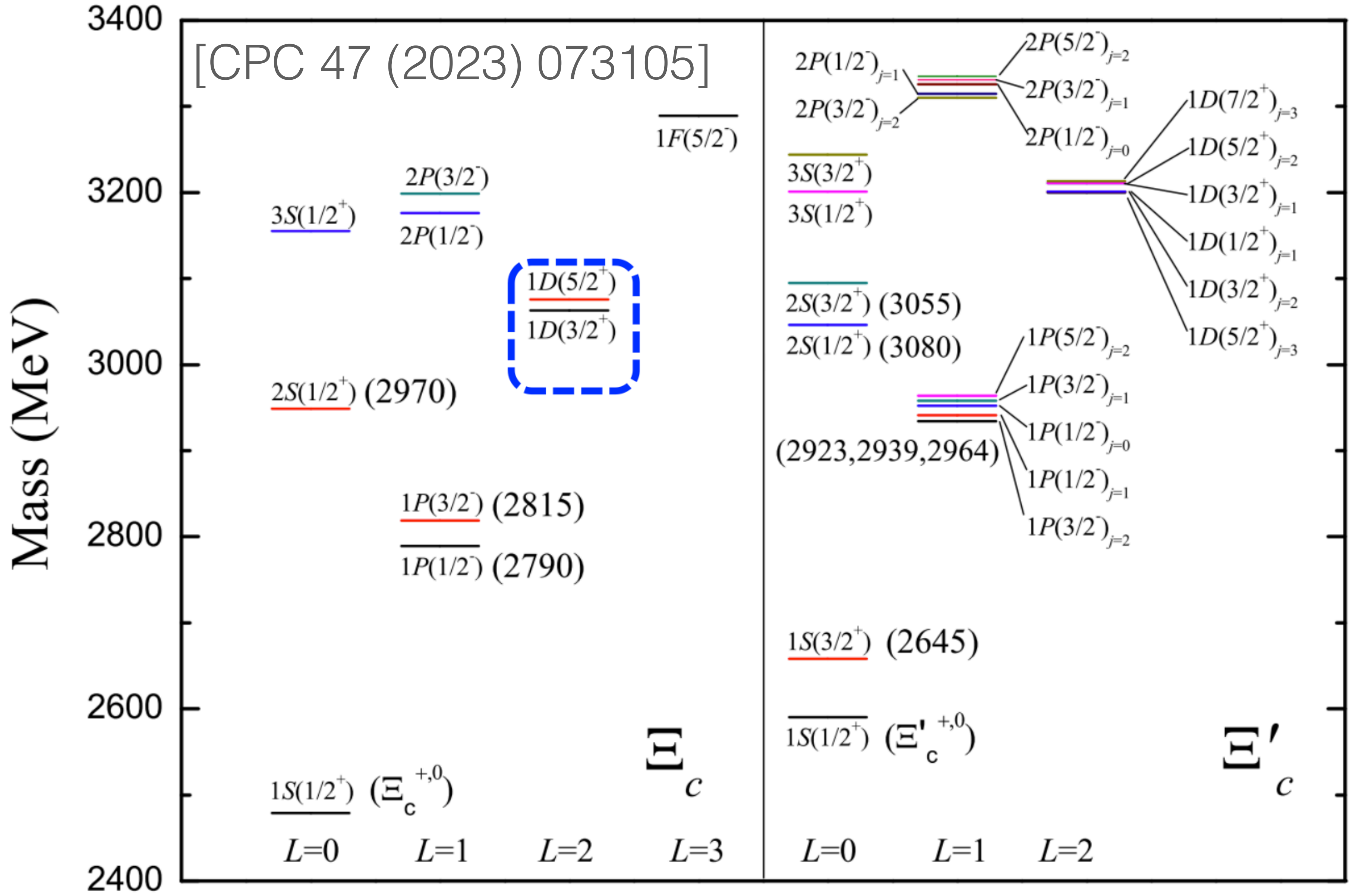
PRL134(2025)081901

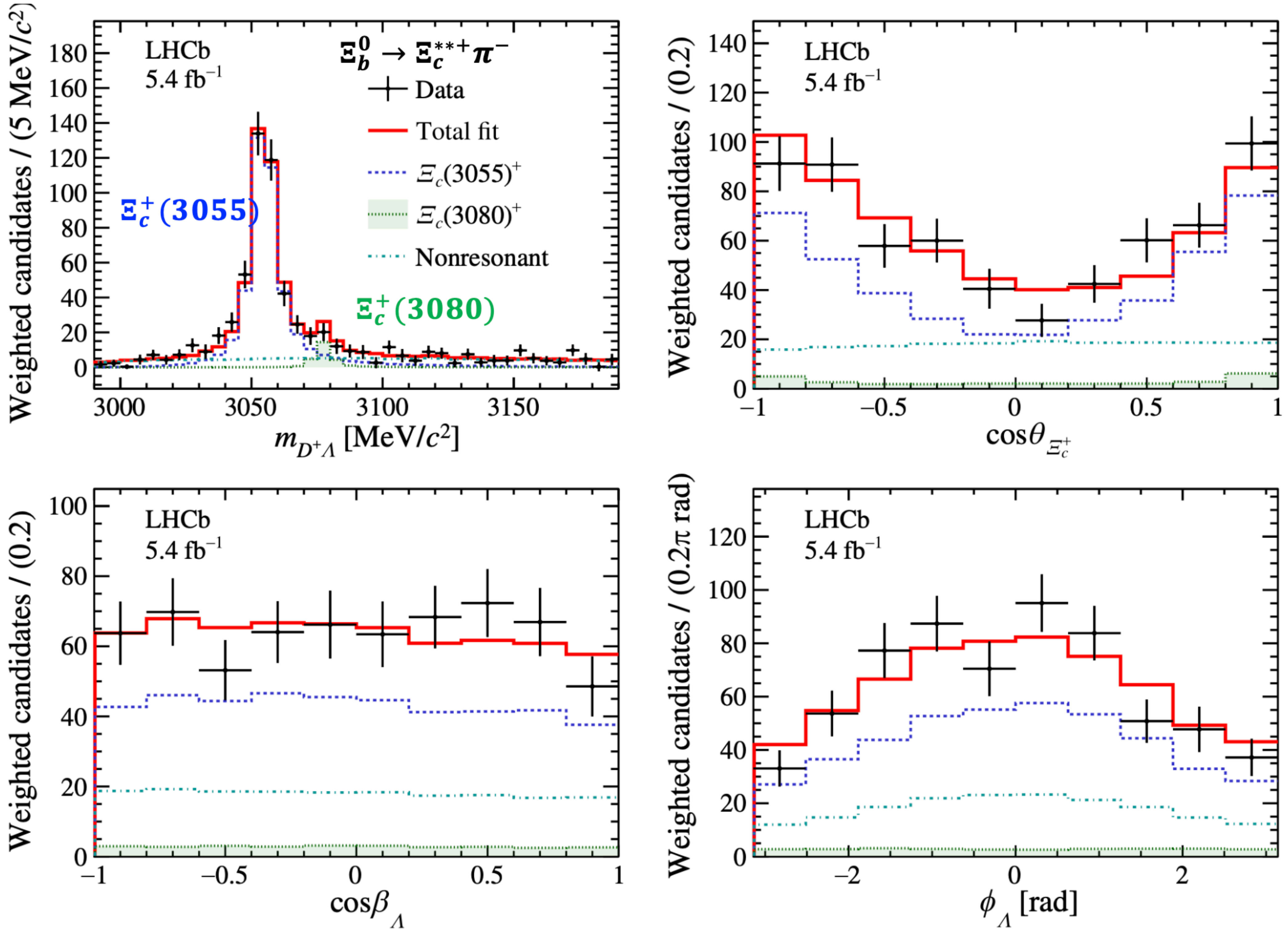
- $J^P(\Xi_b(3055))$ determined to be $3/2^+$ (6.5 σ), $\Xi_c(3080)$ favoured as $5/2^+$ but not significant
- Favors $\Xi_c(3055)^{+(0)}$ as a 1D λ-mode excitation of flavor antitriplet



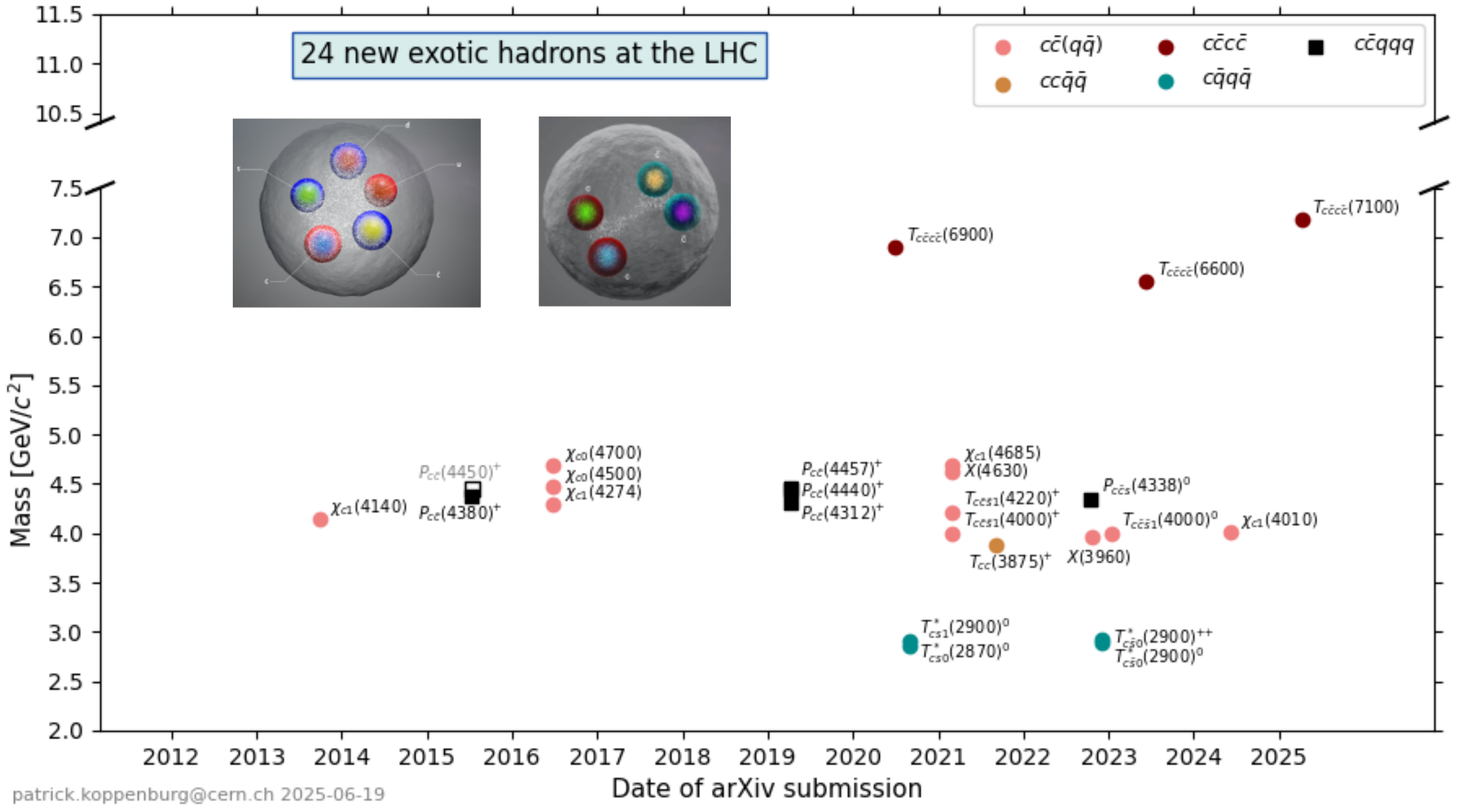
$$\Xi_b^{0(-)} \to \Xi_c^{**+(0)}(\to D\Lambda)\pi^-$$

Quantity	$\Xi_c(3055)^+$	$\Xi_c(3055)^0$
m [MeV/c^2]	$3054.52 \pm 0.36 \pm 0.17$	$3061.00 \pm 0.80 \pm 0.23$
Γ [MeV/c^2]	$8.01 \pm 0.76 \pm 0.34$	$12.4 \pm 2.0 \pm 1.1$
α	$-0.92 \pm 0.10 \pm 0.05$	$-0.92 \pm 0.16 \pm 0.22$
$R_{\mathcal{B}}$	$0.045 \pm 0.023 \pm 0.006$	$0.14 \pm 0.06 \pm 0.04$

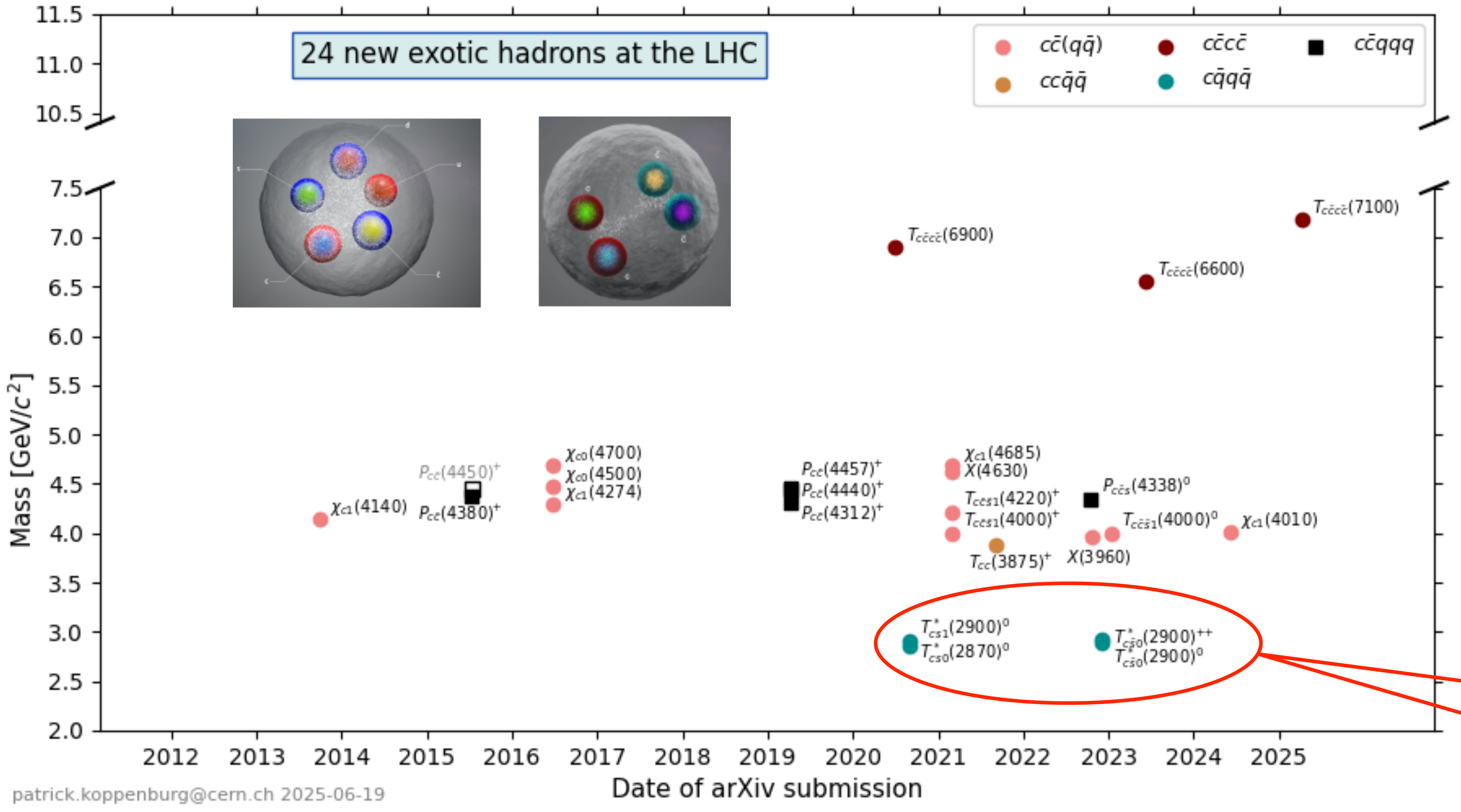




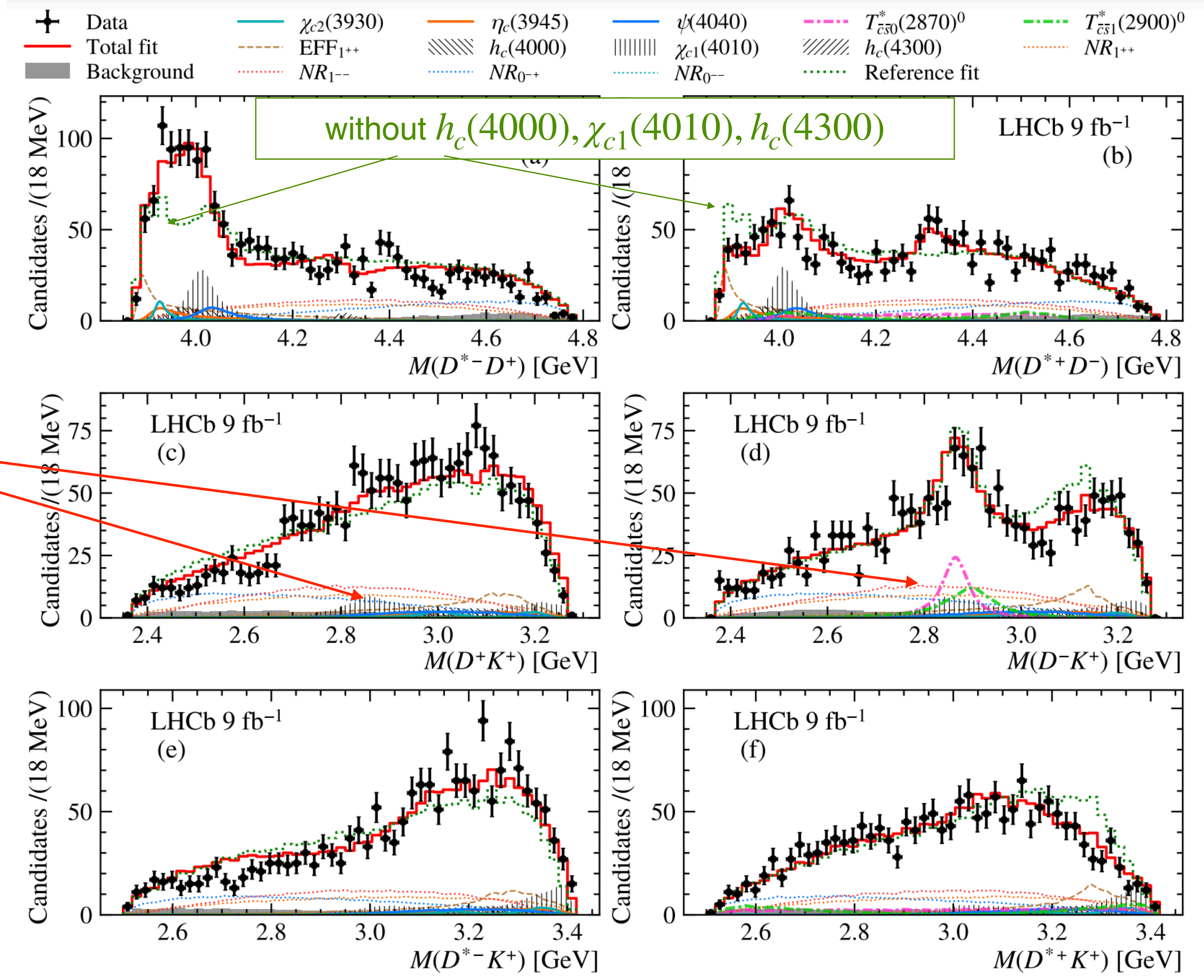
Exotic hadrons



Exotic hadrons

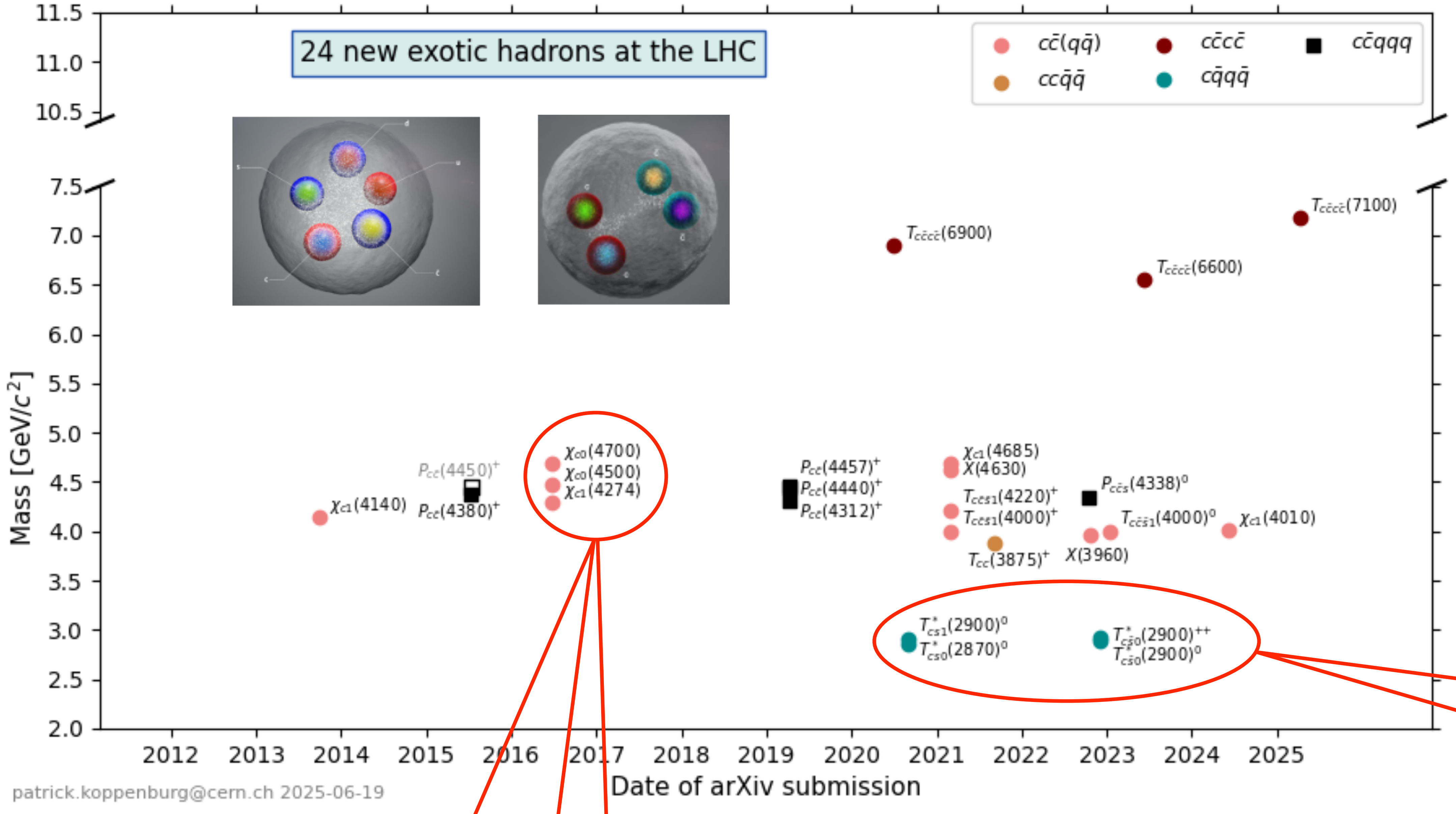


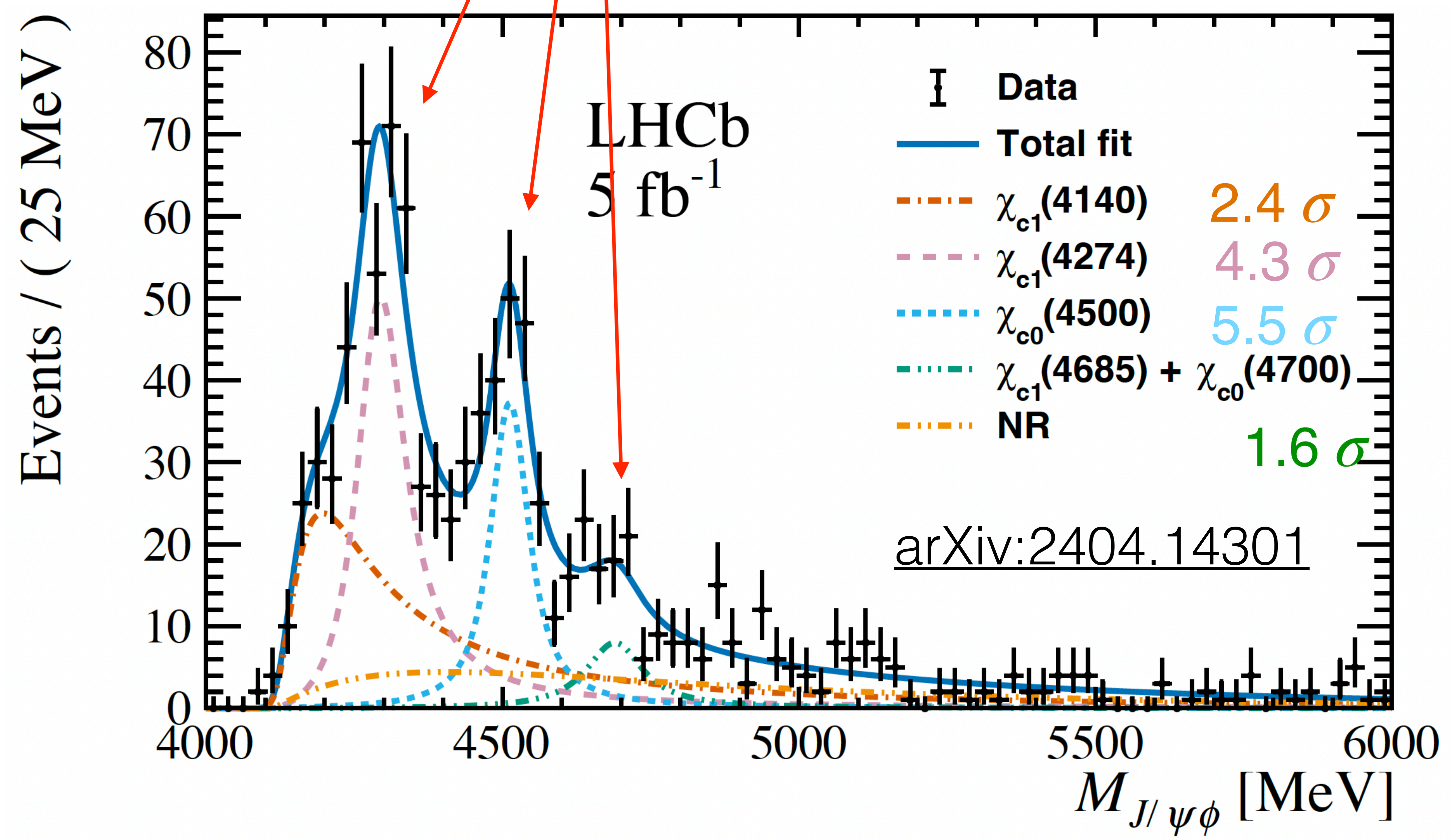
arXiv:2406.03156



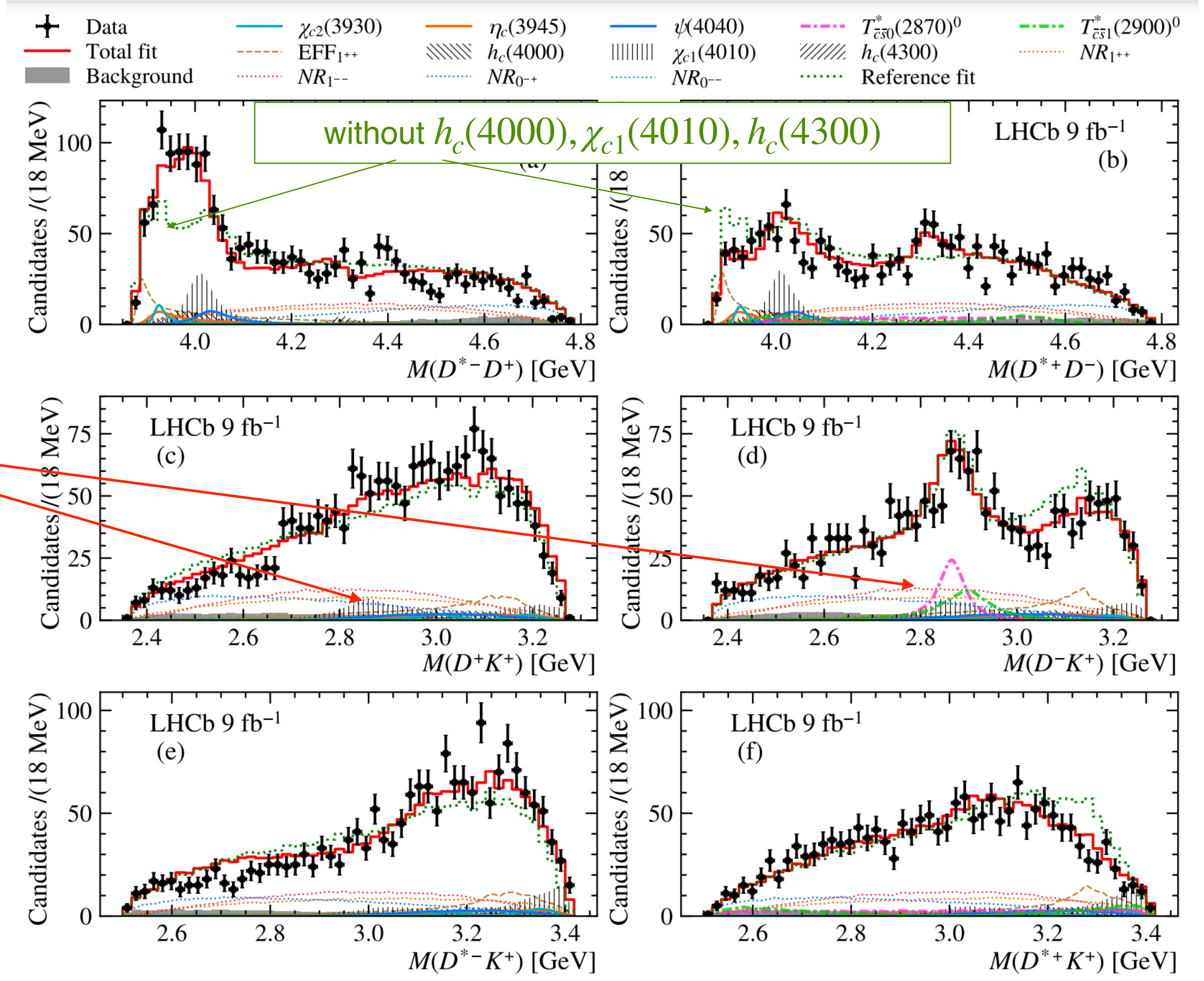
$$B^+ \to D^{*\pm}D^{\mp}K^+$$

Exotic hadrons



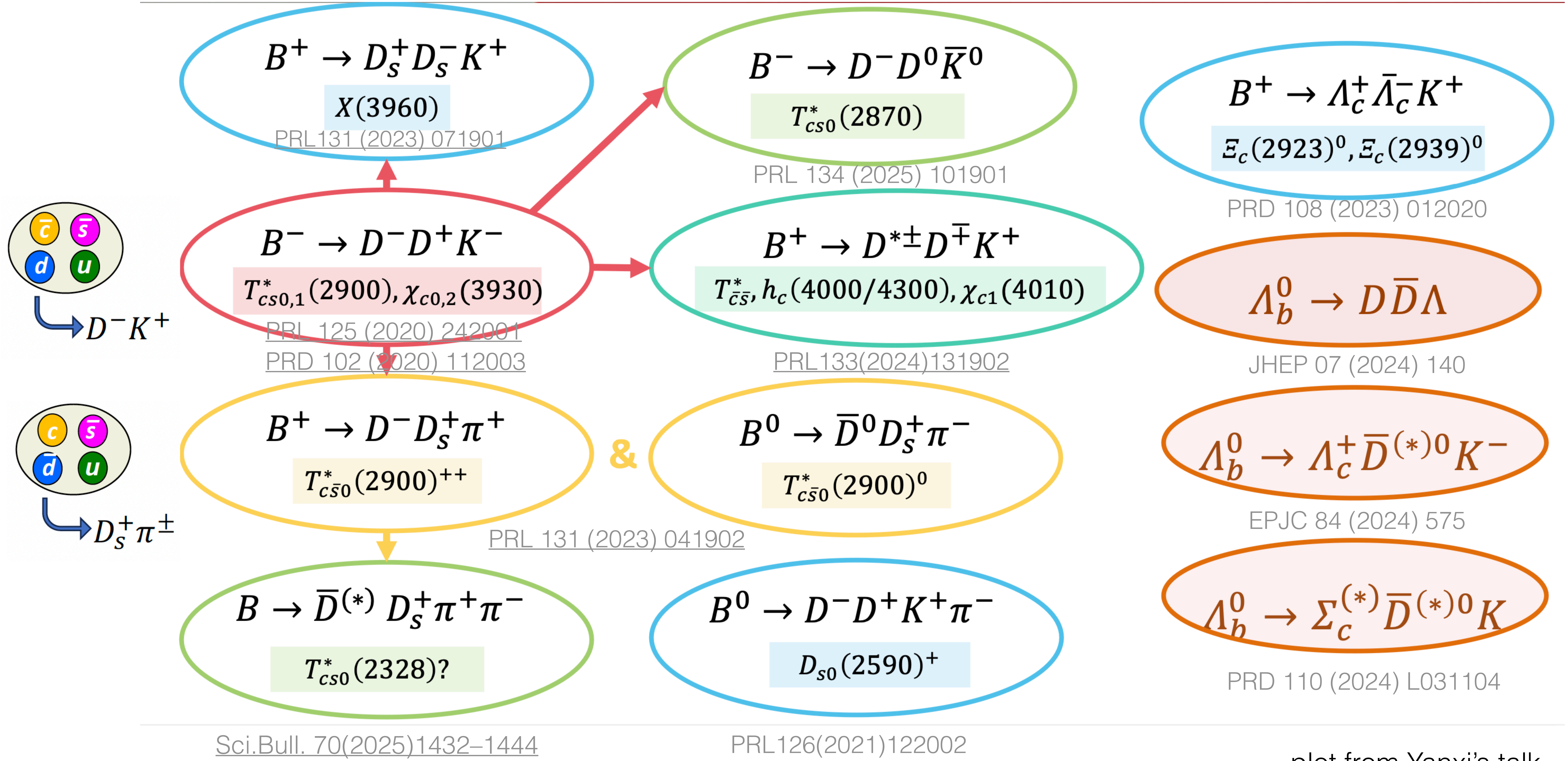


arXiv:2406.03156



$B^+ \to D^{*\pm} D^{\mp} K^+$

Study of $B \to D^{(*)}\bar{D}h(h)$

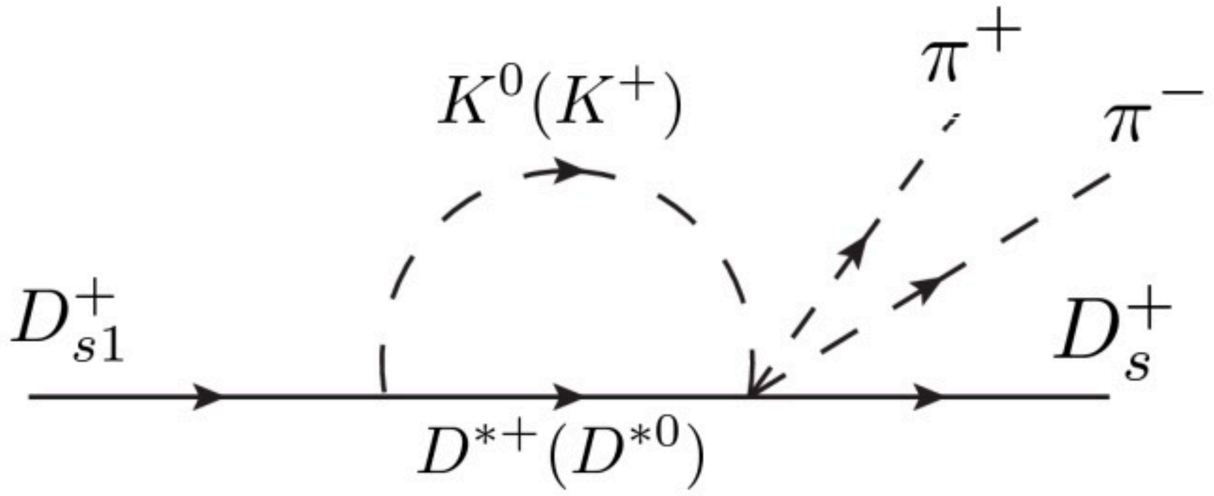


plot from Yanxi's talk

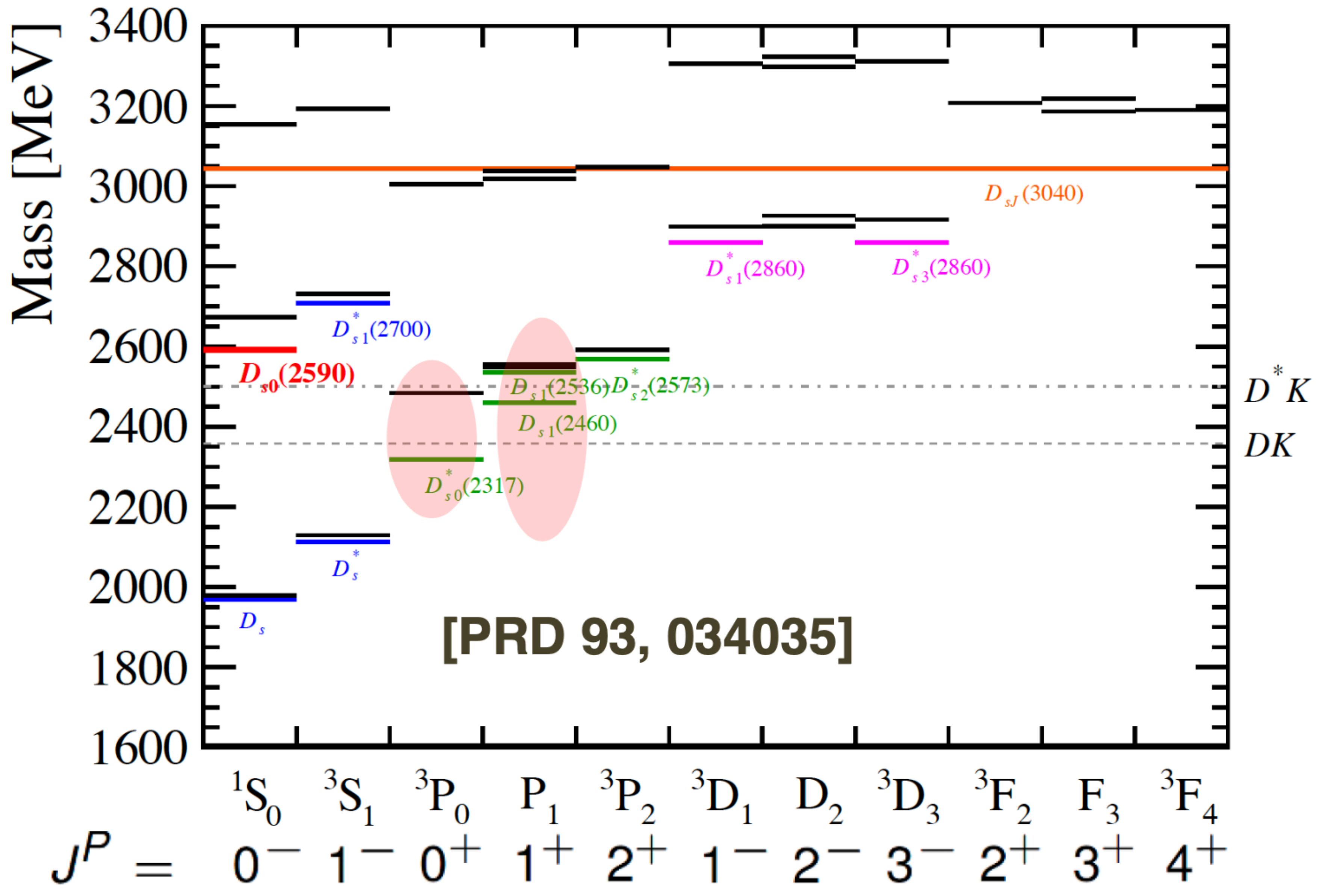
Study of $D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-$

Sci.Bull. 70(2025)1432–1444

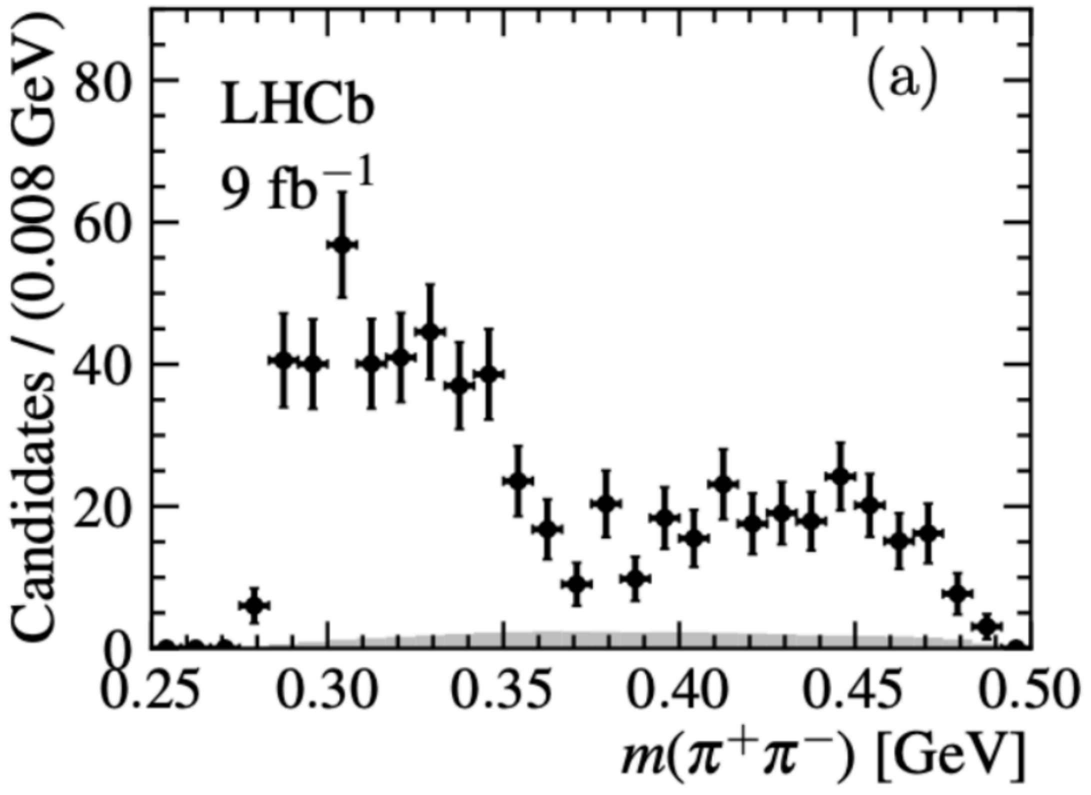
- Unexpected properties for $D_{s0}^*(2317)^+$ and $D_{s1}(2460)^+$
  - Masses ~100 MeV below predictions
  - Isospin-violating decay $D_s^{(*)+}\pi^0$
- Double-bump line shape $m(\pi\pi)$ if $D_{s1}(2460)^+$ is a D^*K molecule

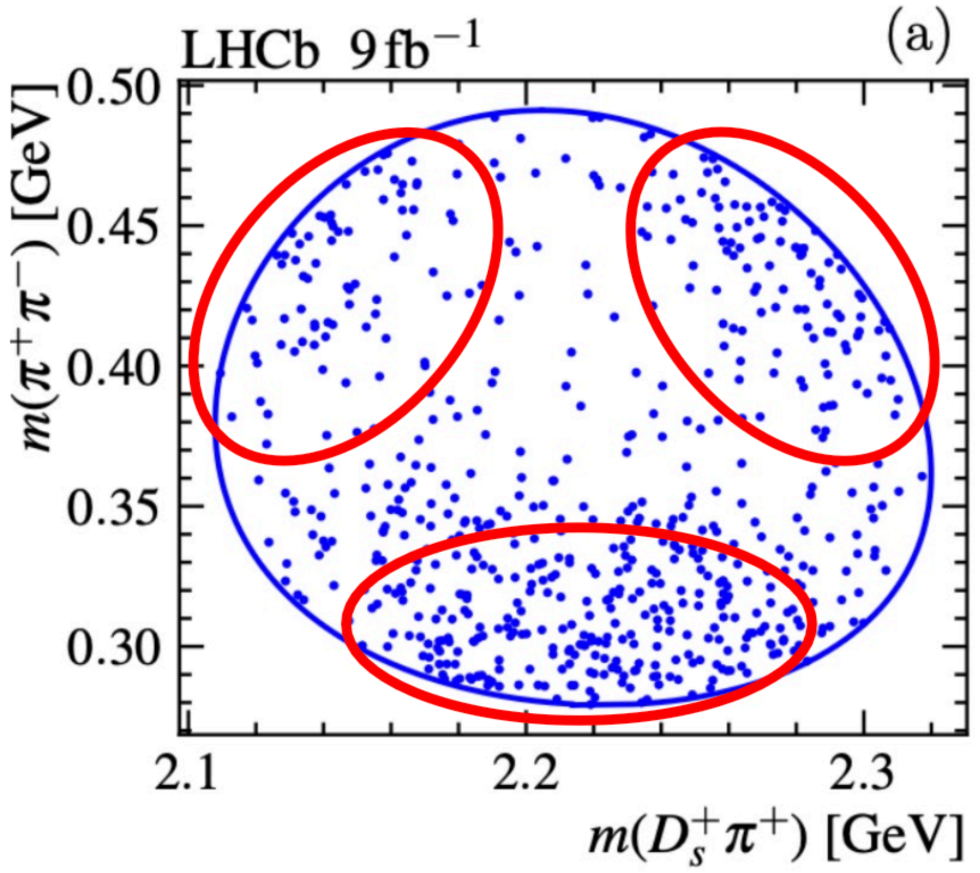


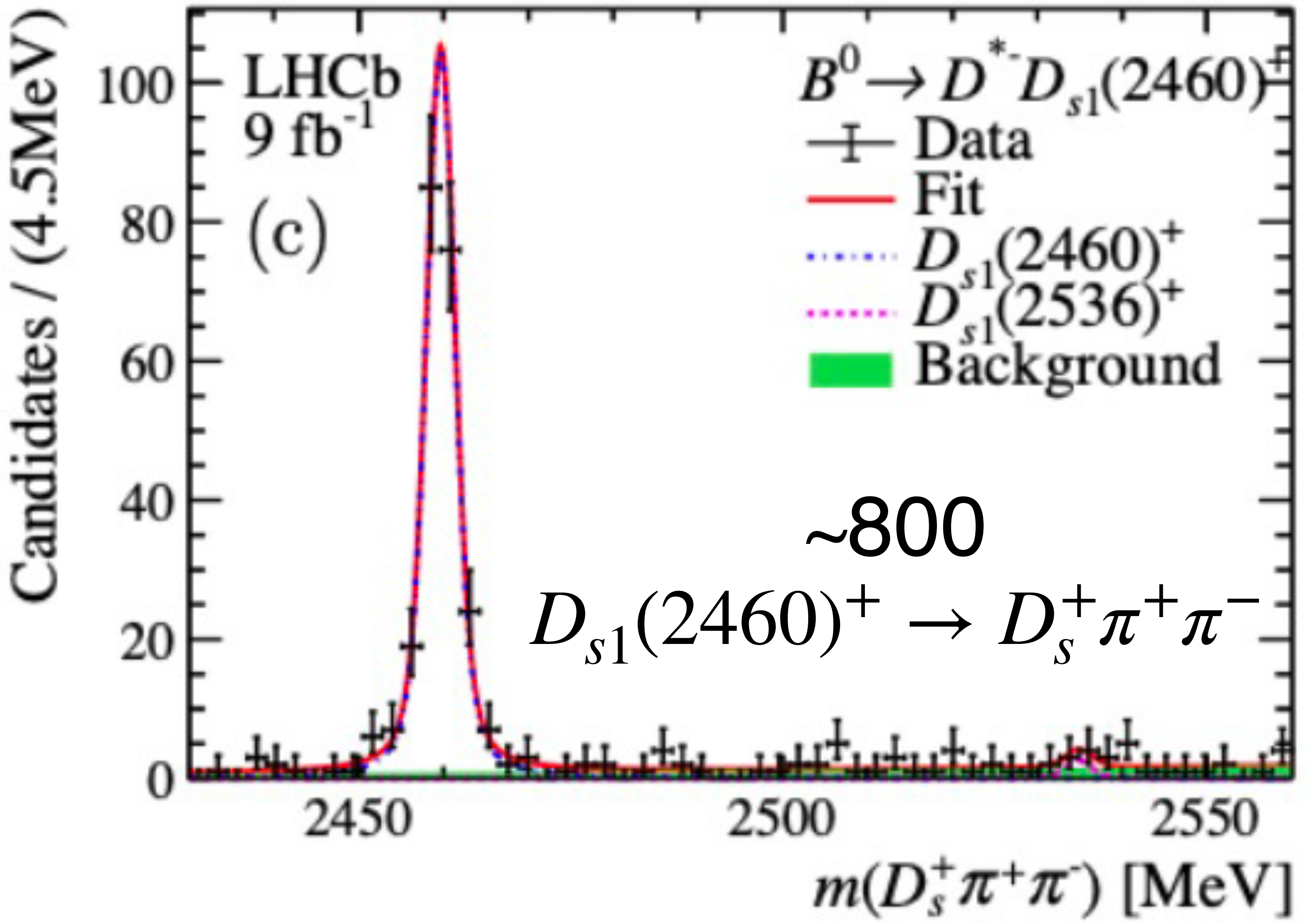
[Commun. Theor. Phys. 75 055203]



- $D_{s0}(2317)^+$ as tetraquark: isospin partners proposed inspired by $T_{c\bar{s}}(2900)^{++/0} \to D_s^+\pi^{+/0}$ [PRD 110, 034014]







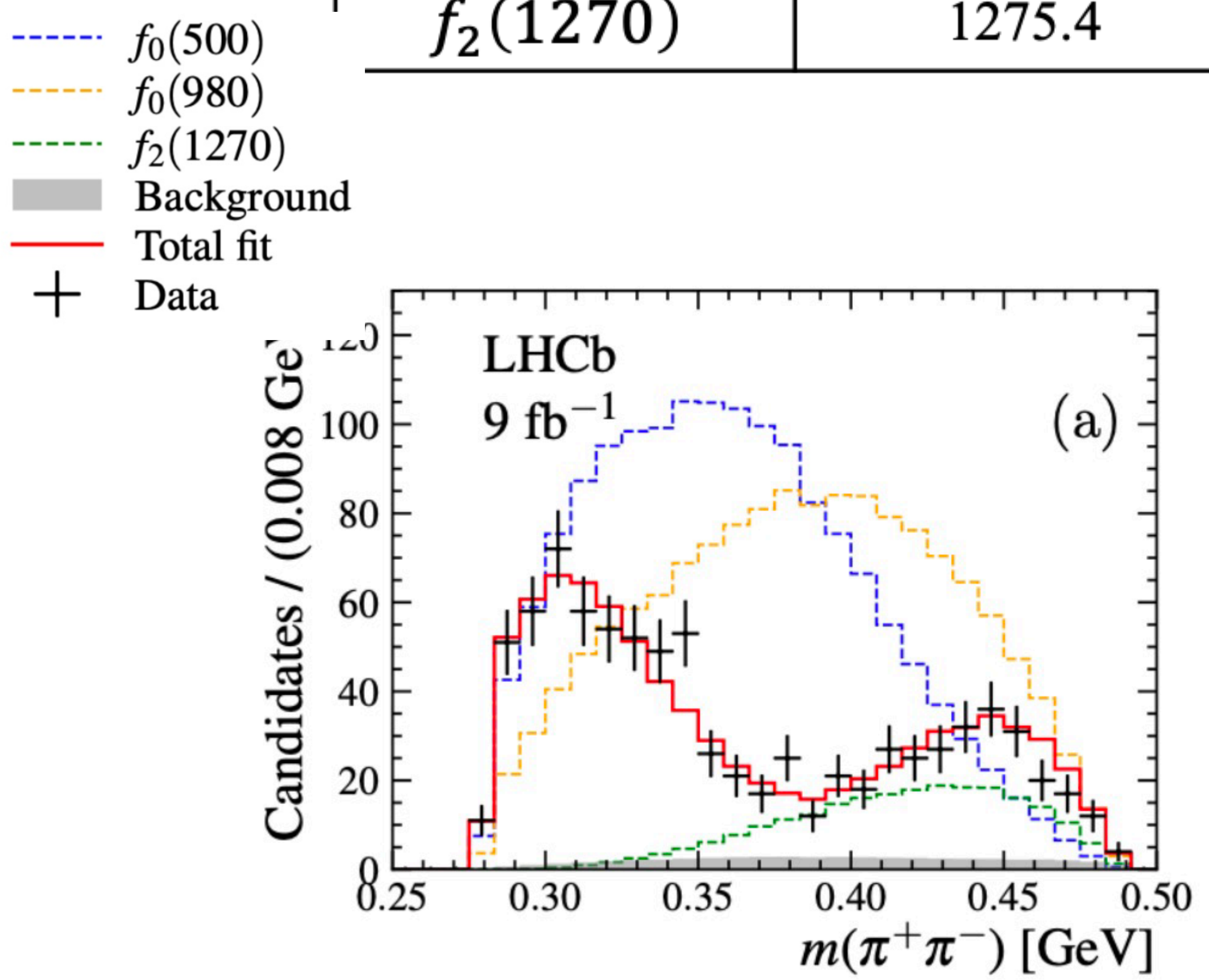
Study of $D_{s1}(2460)^+ \to D_s^+\pi^+\pi^-$

Sci.Bull. 70(2025)1432–1444

Two model describe data equally well!

- $f_0(500) + f_0(980) + f_2(1270)$
  - Large contribution from $f_0(980)$ and $f_2(1270)$ despite beyond phase space limit
  - Can't be rejected, but implausible

Resonance	Mass (MeV)	Width (MeV)	FF (%)
$f_0(500)$	$376 \pm 9 \pm 16$	$175 \pm 23 \pm 16$	$197 \pm 35 \pm 23$
$f_0(980)$	945.5	167	$187 \pm 38 \pm 43$
$f_2(1270)$	1275.4	186.6	$29 \pm 2 \pm 1$



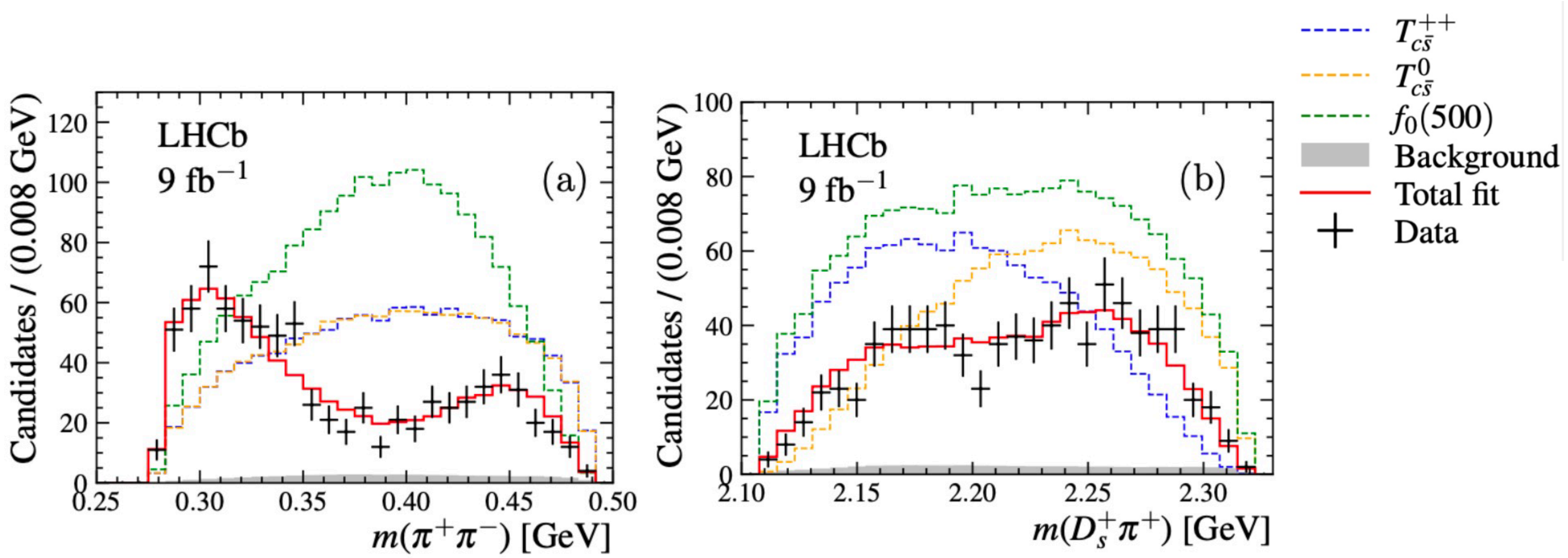
- $f_0(500) + T_{c\bar{s}}^{++} + T_{c\bar{s}}^{0}$ (new exotics)

$T_{c\bar{s}}^{++} \to D_s^+\pi^+$, $T_{c\bar{s}}^{0} \to D_s^+\pi^-$

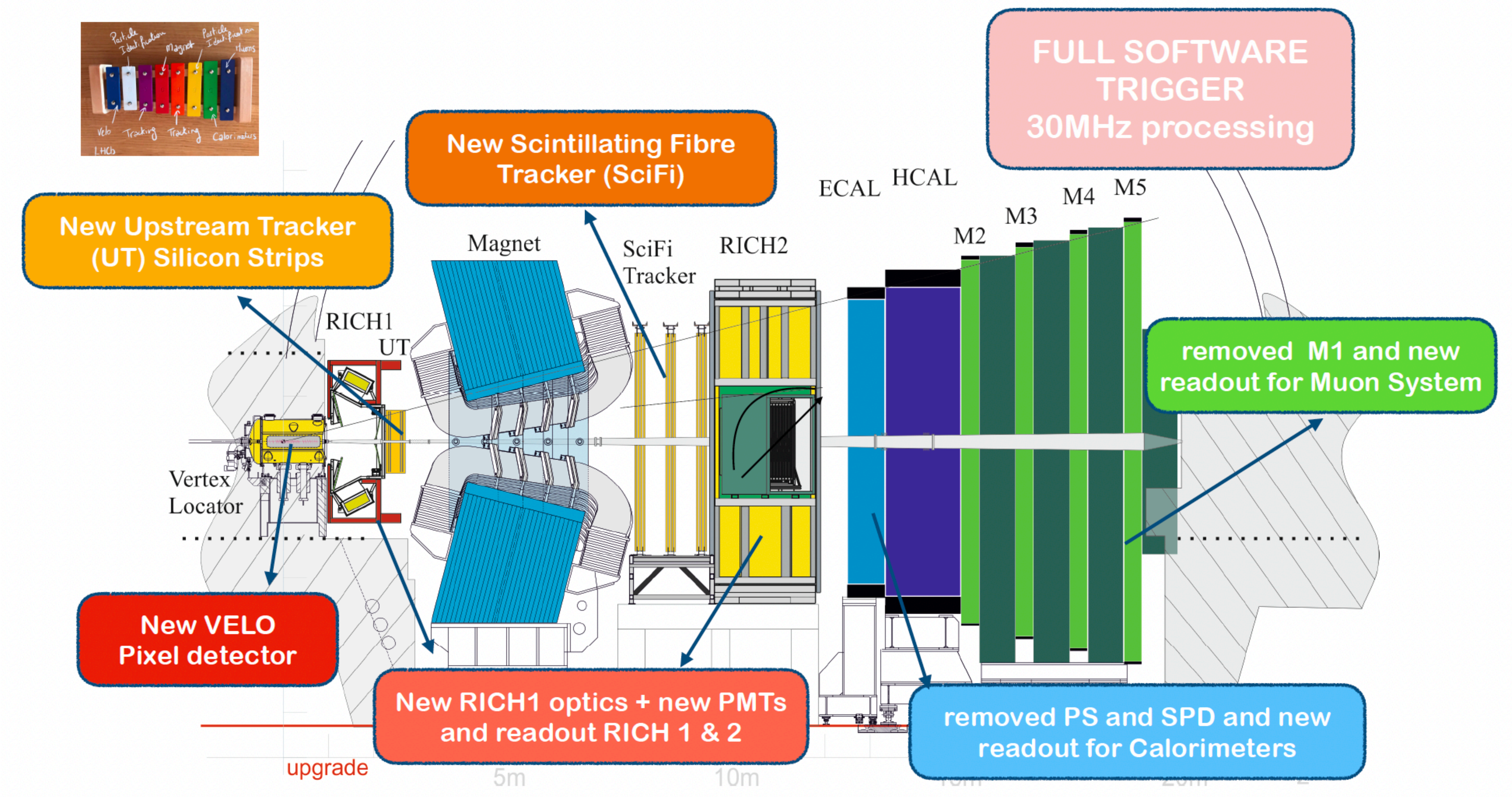
Consistent with isospin symmetry

$T_{c\bar{s}}$ masses ~ $D_{s0}^*(2317)^+$, but different widths

Resonance	Mass (MeV)	Width (MeV)	FF (%)
$f_0(500)$	$472 \pm 32 \pm 19$	$226 \pm 24 \pm 18$	$237^{+51}_{-43} \pm 42$
$T_{c\bar{s}}$	$2328 \pm 12 \pm 12$	$96 \pm 16^{+170}_{-23}$	$151^{+31}_{-33} \pm 25$



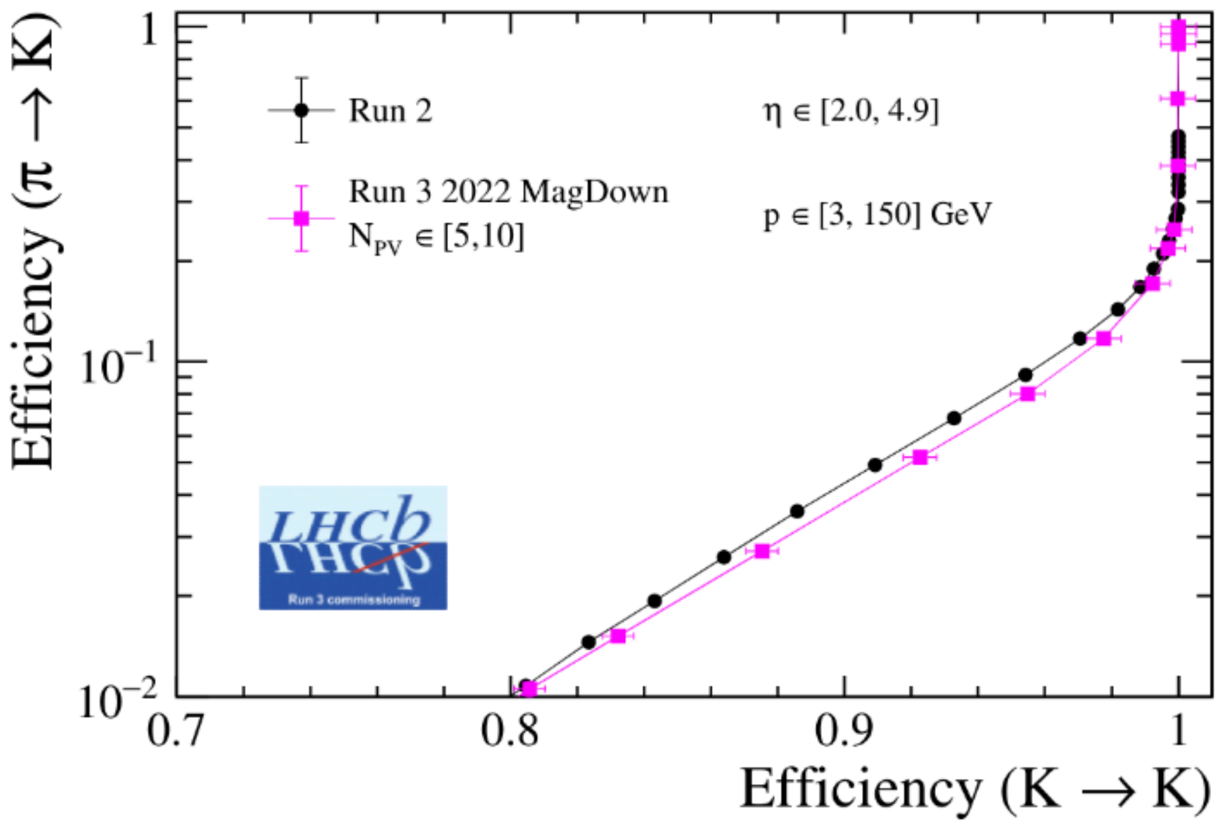
Run 3 in data taking

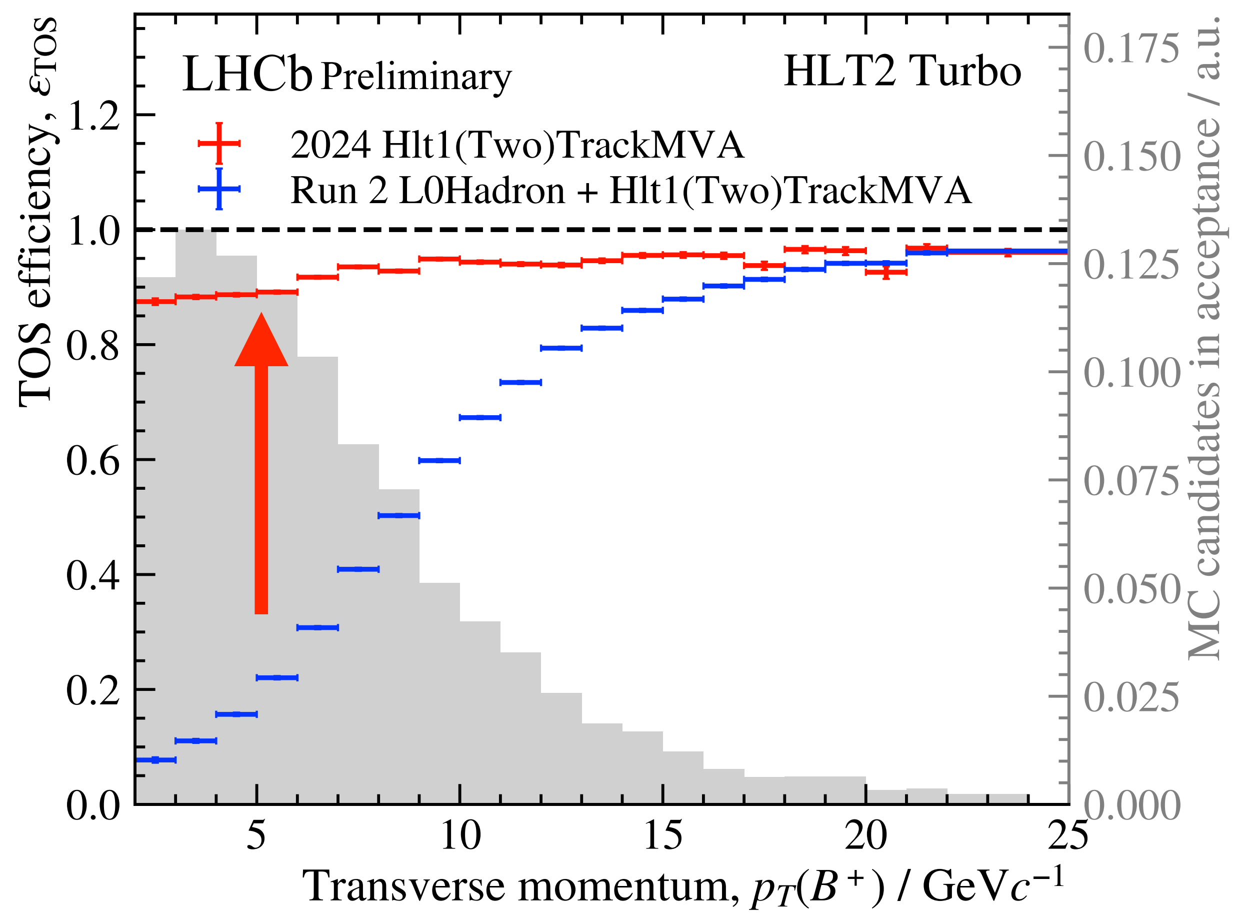


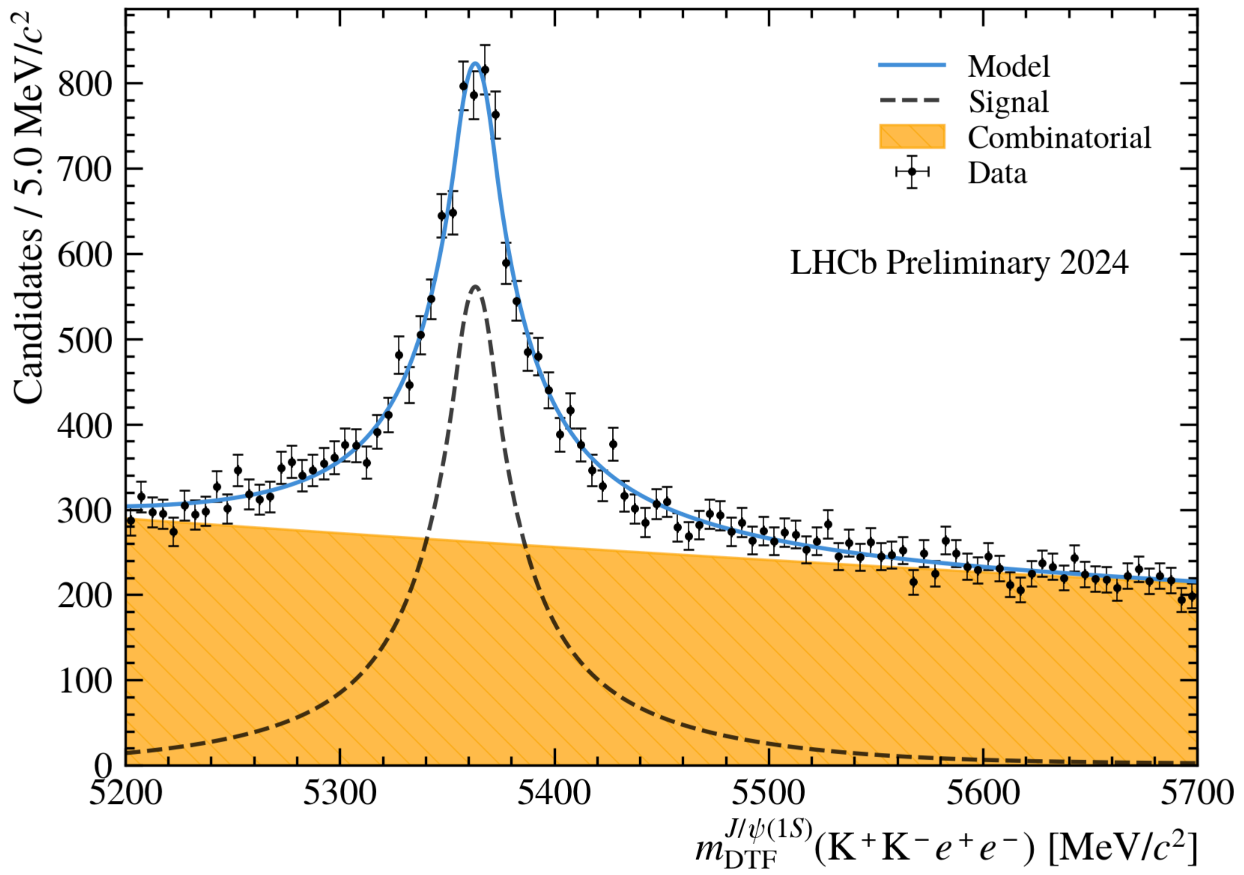
Major upgrade of all sub-detectors and readout

12

The LHCb Upgrade I arXiv:2305.10515



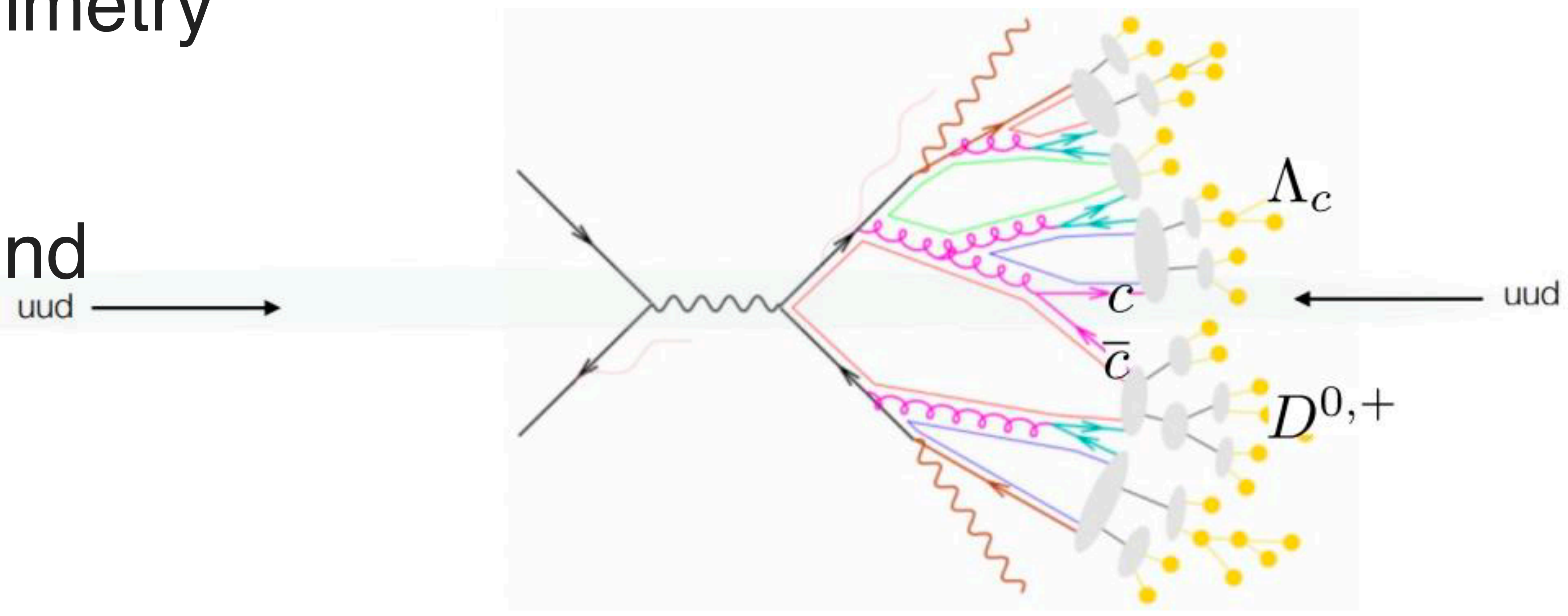




Production asymmetry of charm hadrons in Run 3

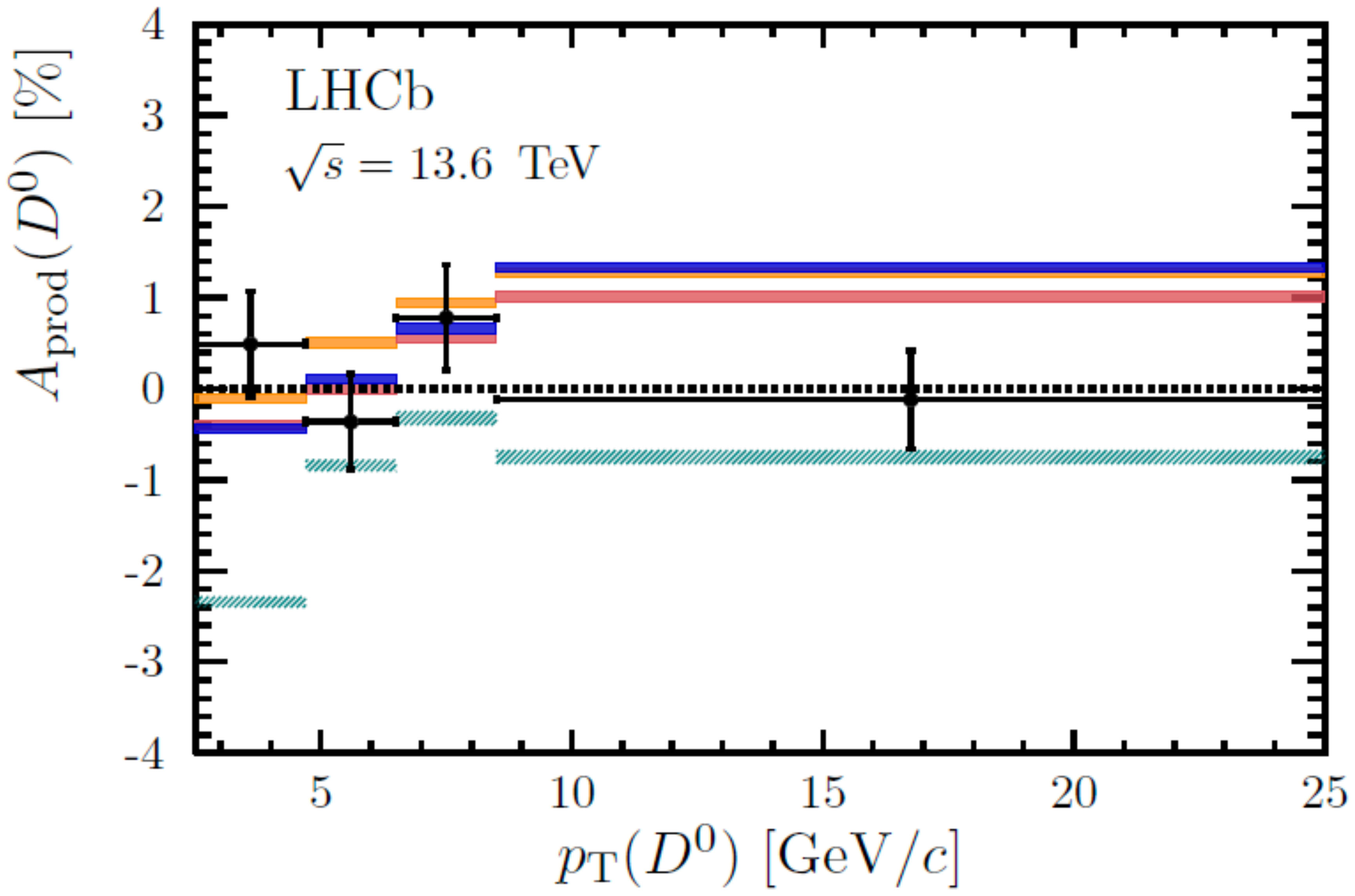
arXiv:2505.14494

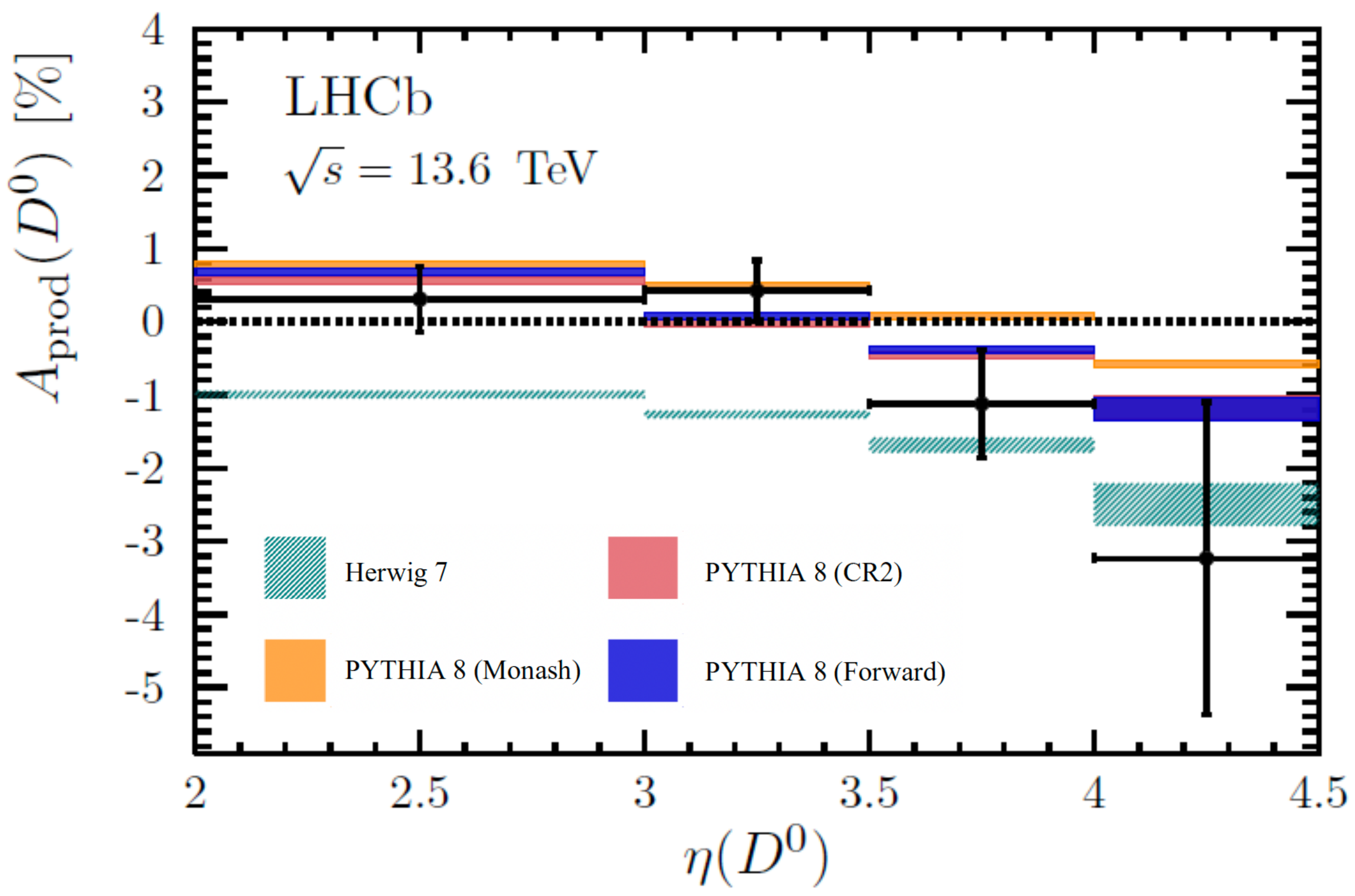
- In pp collisions, c and $\bar{c}$ produced in pairs BUT the symmetry disrupted in the hadronisation.
- Test hadronisation models to tune event generators (Lund string model, cluster hadronisation model…)



$$A_{\text{prod}}(X_c) = \frac{\sigma(X_c) - \sigma(\bar{X}_c)}{\sigma(X_c) + \sigma(\bar{X}_c)} = f_{X_c}(\sqrt{s}, p_T, \eta)$$

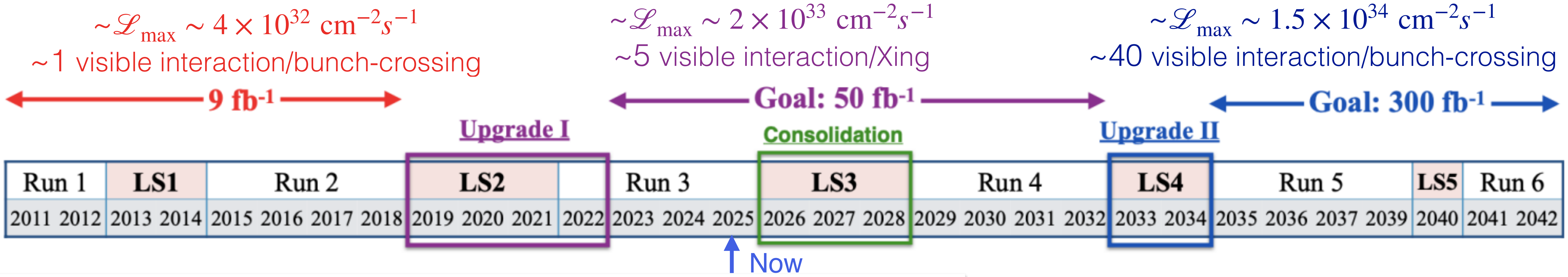
First result using Run 3 data!





- No significant asymmetry observed
- Comparable statistical uncertainty as Run 1 with ~1/15 integrated luminosity

Looking at Run 3 and beyond



Observable	Current LHCb	LHCb 2025	Belle II	Upgrade II	ATLAS & CMS
EW Penguins					
R_K $(1<q^2<6\,\mathrm{GeV}^2c^4)$	0.1 [274]	0.025	0.036	0.007	–
R_{K^*} $(1<q^2<6\,\mathrm{GeV}^2c^4)$	0.1 [275]	0.031	0.032	0.008	–
R_ϕ, R_{pK}, R_π	–	0.08, 0.06, 0.18	–	0.02, 0.02, 0.05	–
CKM tests					
γ, with $B_s^0\to D_s^+K^-$	$(^{+17}_{-22})^\circ$ [136]	4°	–	1°	–
γ, all modes	$(^{+5.0}_{-5.8})^\circ$ [167]	1.5°	1.5°	0.35°	–
$\sin 2\beta$, with $B^0\to J/\psi K_S^0$	0.04 [609]	0.011	0.005	0.003	–
ϕ_s, with $B_s^0\to J/\psi\phi$	49 mrad [44]	14 mrad	–	4 mrad	22 mrad [610]
ϕ_s, with $B_s^0\to D_s^+D_s^-$	170 mrad [49]	35 mrad	–	9 mrad	–
$\phi_s^{s\bar{s}s}$, with $B_s^0\to\phi\phi$	154 mrad [94]	39 mrad	–	11 mrad	Under study [611]
a_{sl}^s	33×10^{-4} [211]	10×10^{-4}	–	3×10^{-4}	–
$\lvert V_{ub}\rvert/\lvert V_{cb}\rvert$	6% [201]	3%	1%	1%	–
$B_s^0, B^0\to\mu^+\mu^-$					
$\mathcal{B}(B^0\to\mu^+\mu^-)/\mathcal{B}(B_s^0\to\mu^+\mu^-)$	90% [264]	34%	–	10%	21% [612]
$\tau_{B_s^0\to\mu^+\mu^-}$	22% [264]	8%	–	2%	–
$S_{\mu\mu}$	–	–	–	0.2	–
$b\to c\ell^-\bar{\nu}_l$ **LUV studies**					
$R(D^*)$	0.026 [215, 217]	0.0072	0.005	0.002	–
$R(J/\psi)$	0.24 [220]	0.071	–	0.02	–
Charm					
$\Delta A_{CP}(KK-\pi\pi)$	8.5×10^{-4} [613]	1.7×10^{-4}	5.4×10^{-4}	3.0×10^{-5}	–
A_Γ $(\approx x\sin\phi)$	2.8×10^{-4} [240]	4.3×10^{-5}	3.5×10^{-4}	1.0×10^{-5}	–
$x\sin\phi$ from $D^0\to K^+\pi^-$	13×10^{-4} [228]	3.2×10^{-4}	4.6×10^{-4}	8.0×10^{-5}	–
$x\sin\phi$ from multibody decays	–	$(K3\pi)$ 4.0×10^{-5}	$(K_S^0\pi\pi)$ 1.2×10^{-4}	$(K3\pi)$ 8.0×10^{-6}	–

LHCb-PUB-2018-009

Great opportunities for many new discoveries and NP searches

Uncertainty reduced by factor ~10

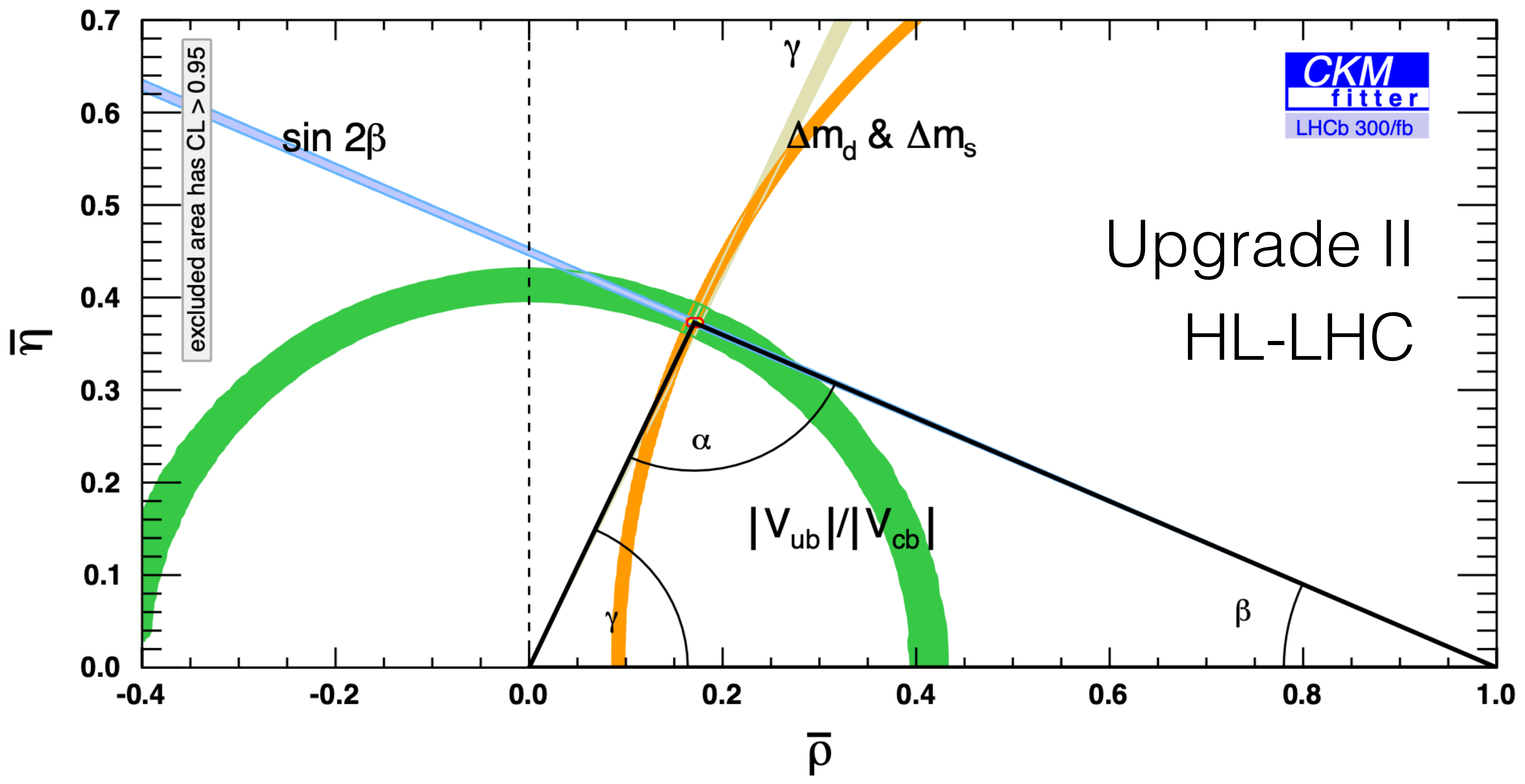
1% level precision for CKM elements

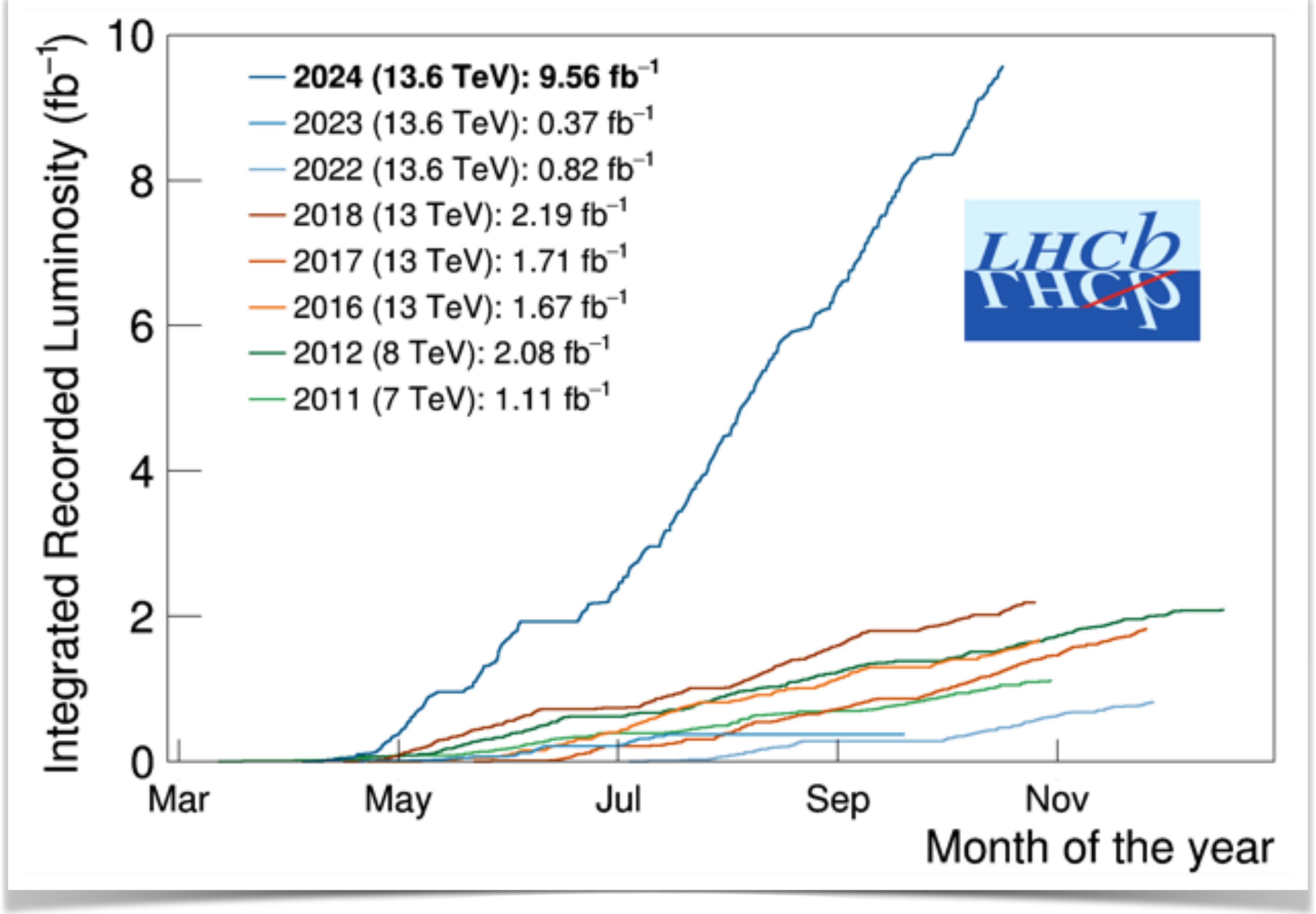
High precision in charm physics, up to 10^{-5}

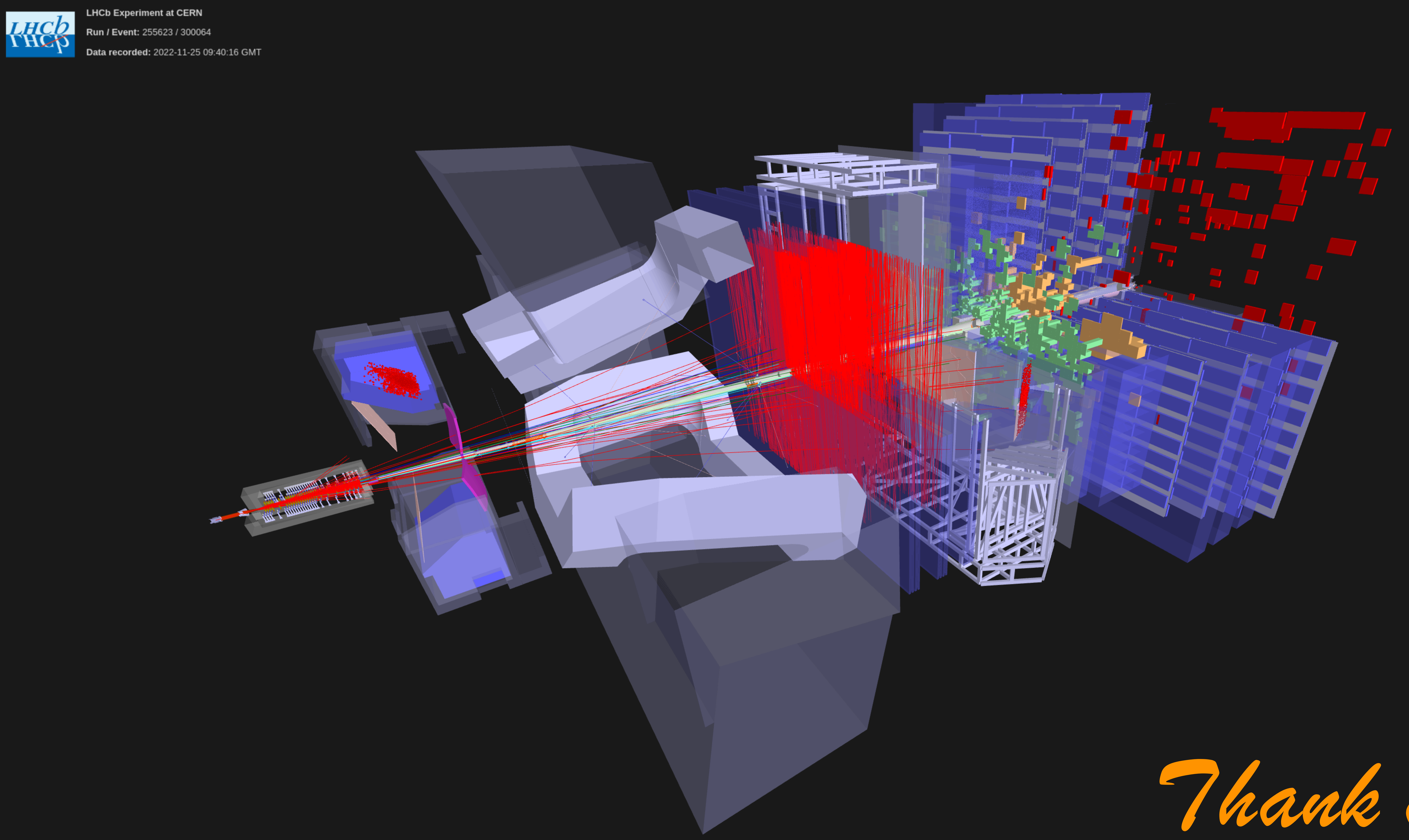
Summary

- ✓ LHCb pushes flavour physics to new frontier
- ✓ World-leading precision measurements of CKM matrix: $\beta_{(s)}$, γ, $|V_{qb}|$
- ✓ Rich hadron spectroscopies to understand QCD
- ✓ New physics searches in rare decays

Run 3 is running, a lot of new results to coming!






LHCb Experiment at CERN
Run / Event: 255623 / 300064
Data recorded: 2022-11-25 09:40:16 GMT

Thank you

Back up slides

$\mathscr{L}$, $\sigma_{c\bar{c}}$, acceptance, trigger efficiencies

↓

		√s	Yield $D^0 \to KK$	Coverage	Flight distance	σ_t
Charm factory (e^+e^-)	BESIII	3.7 - 4.6 GeV	3fb^{-1}: 0.06M @20 fb^{-1}: 0.5M*	Almost full	/	/
B factory (e^+e^-)	Belle	10.6 GeV	0.25 M	Almost full	~200 μm	~200 fs
	Belle II	10.6 GeV	@50 ab^{-1}: 25M*	Almost full	~200 μm	70-90 fs
Hadron (pp)	LHCb	Run3: 13 TeV Run2: 13 TeV Run1: 7,8 TeV	@23 fb^{-1}: 500M* Run2: 60M Run1: 8M	4% of solid angle; catching ~40% of $\sigma_{Q\bar{Q}}$	0.4 -1 cm	50 fs

*extrapolations

Charm factory

- Background-free
- Lowest statistics
- No boost
- Quantum coherence ★
- Inclusive charm, neutrals and neutrinos
- Absolute branching fractions

B factory

- Low background
- Low statistics
- Low boost
- Good for neutrals and neutrinos ★
- (Some) absolute branching fractions

Hadron collider

- High background
- High statistics ★
- High boost
- Challenging for neutrals and neutrinos
- Complex and biasing triggers

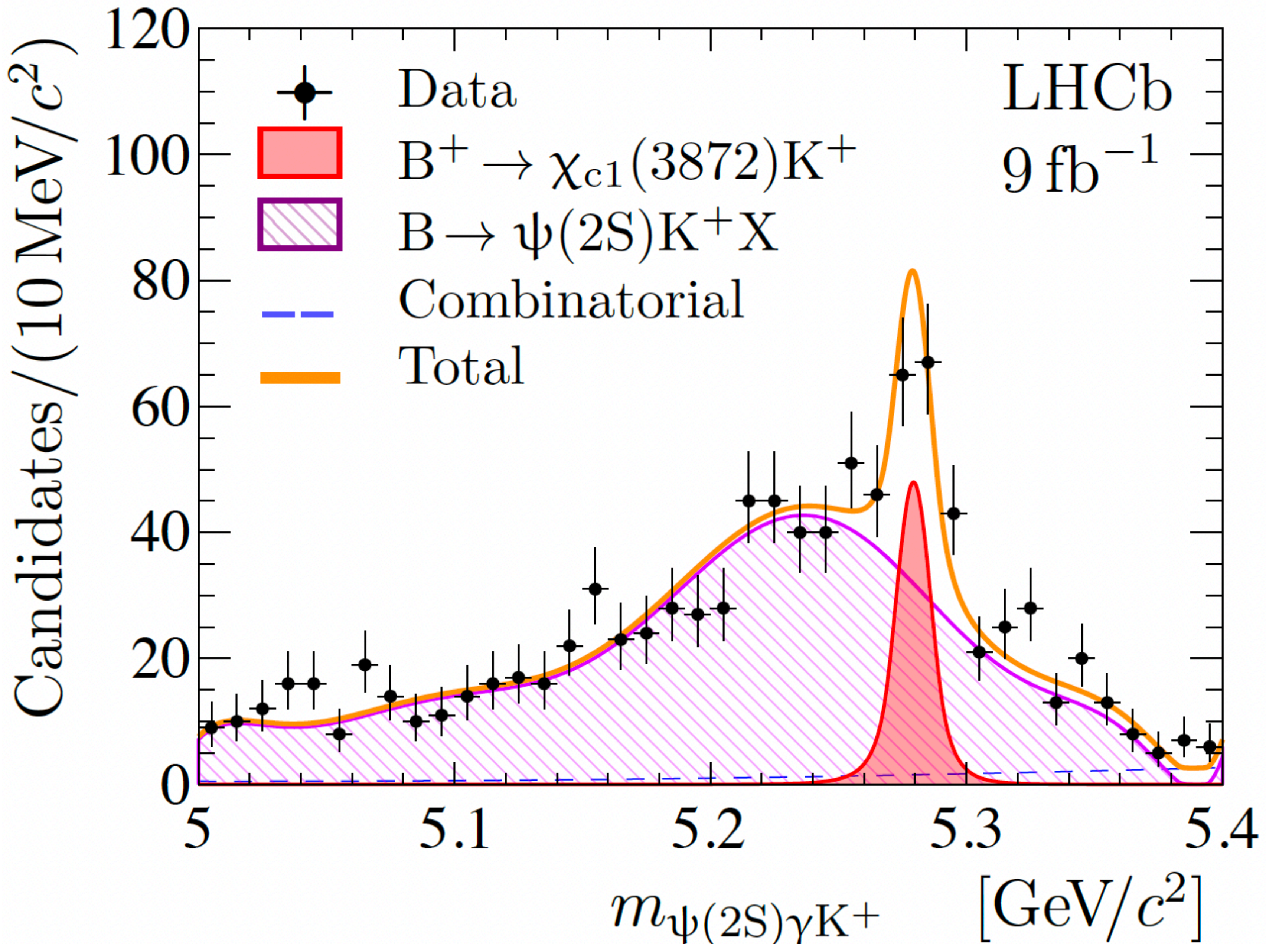
credit: Tara Nanut

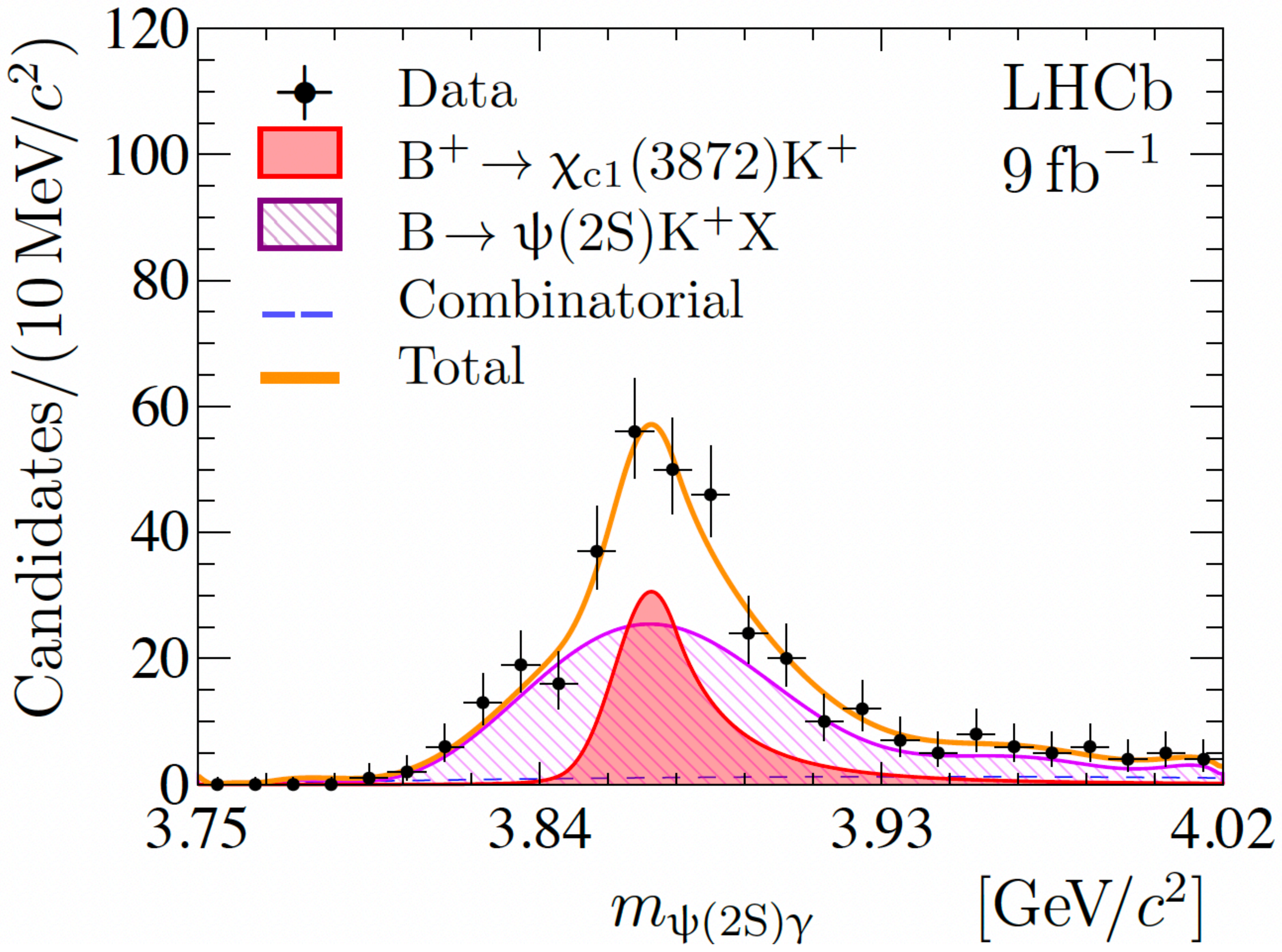
Observation of $\chi_{c1}(3872) \to \gamma\psi(2S)$

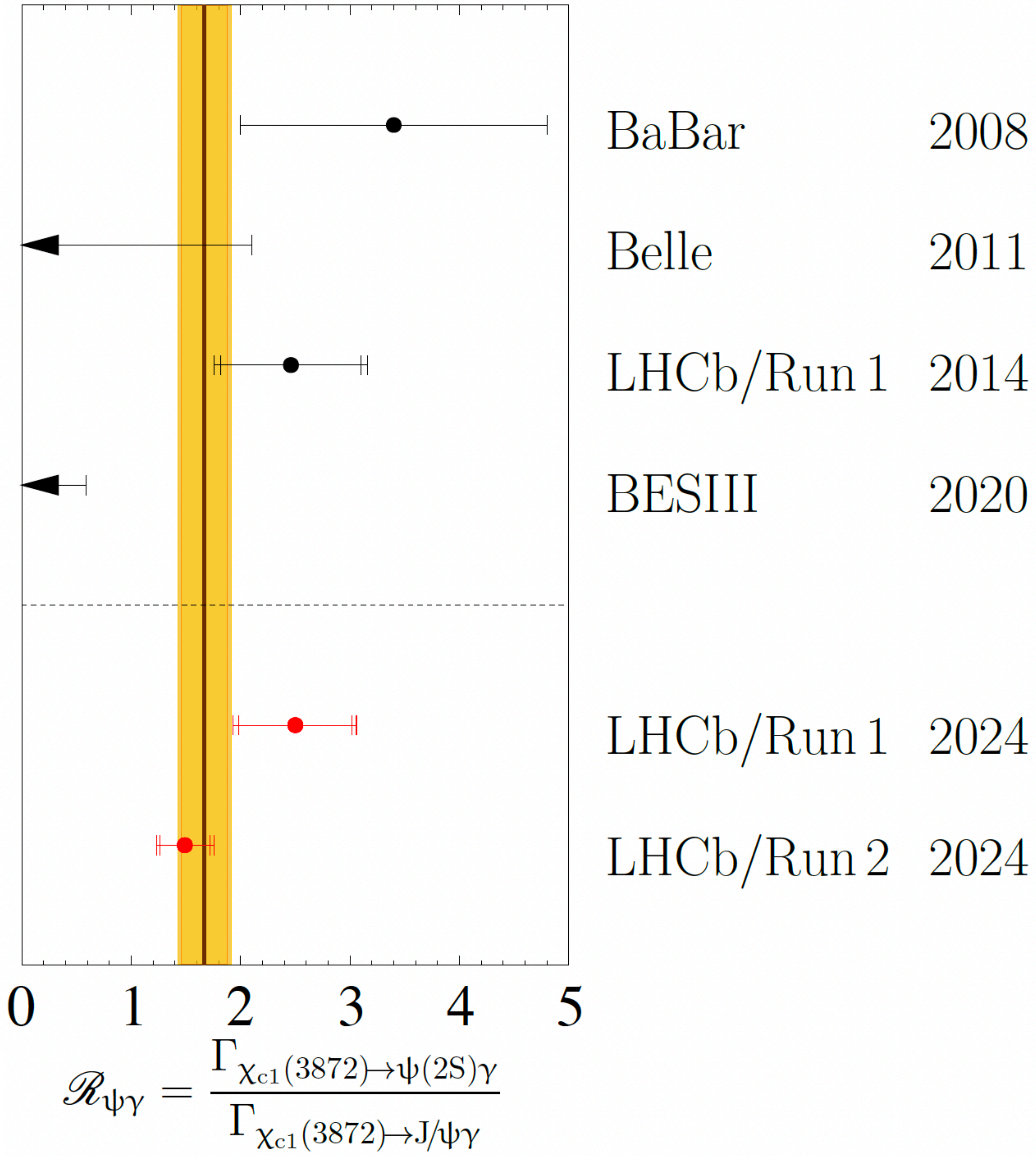
arXiv:2406.17006

- $\chi_{c1}(3872) \to \gamma\psi(2S)$ observed in $B^+ \to \chi_{c1}(3872)K^+$ with 9 fb^{-1} pp collision data
- In tension with the upper limit set by BESIII
- Inconsistent with pure $D\bar{D}^*$ molecular hypothesis for $\chi_{c1}(3872)$ but agree with many others

$$\frac{\Gamma_{\chi_{c1}(3872)\to\psi(2S)\gamma}}{\Gamma_{\chi_{c1}(3872)\to J/\psi\gamma}} = 1.67 \pm 0.21 \pm 0.12 \pm 0.04$$







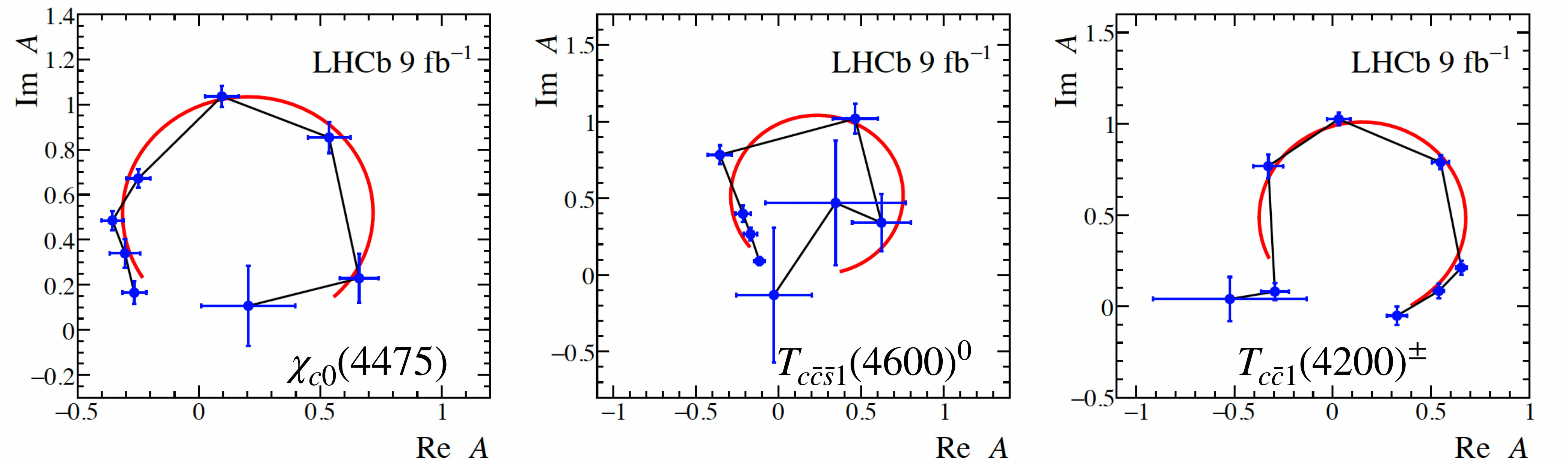
Amplitude analysis of $B^+ \to \psi(2S)K^+\pi^+\pi^-$

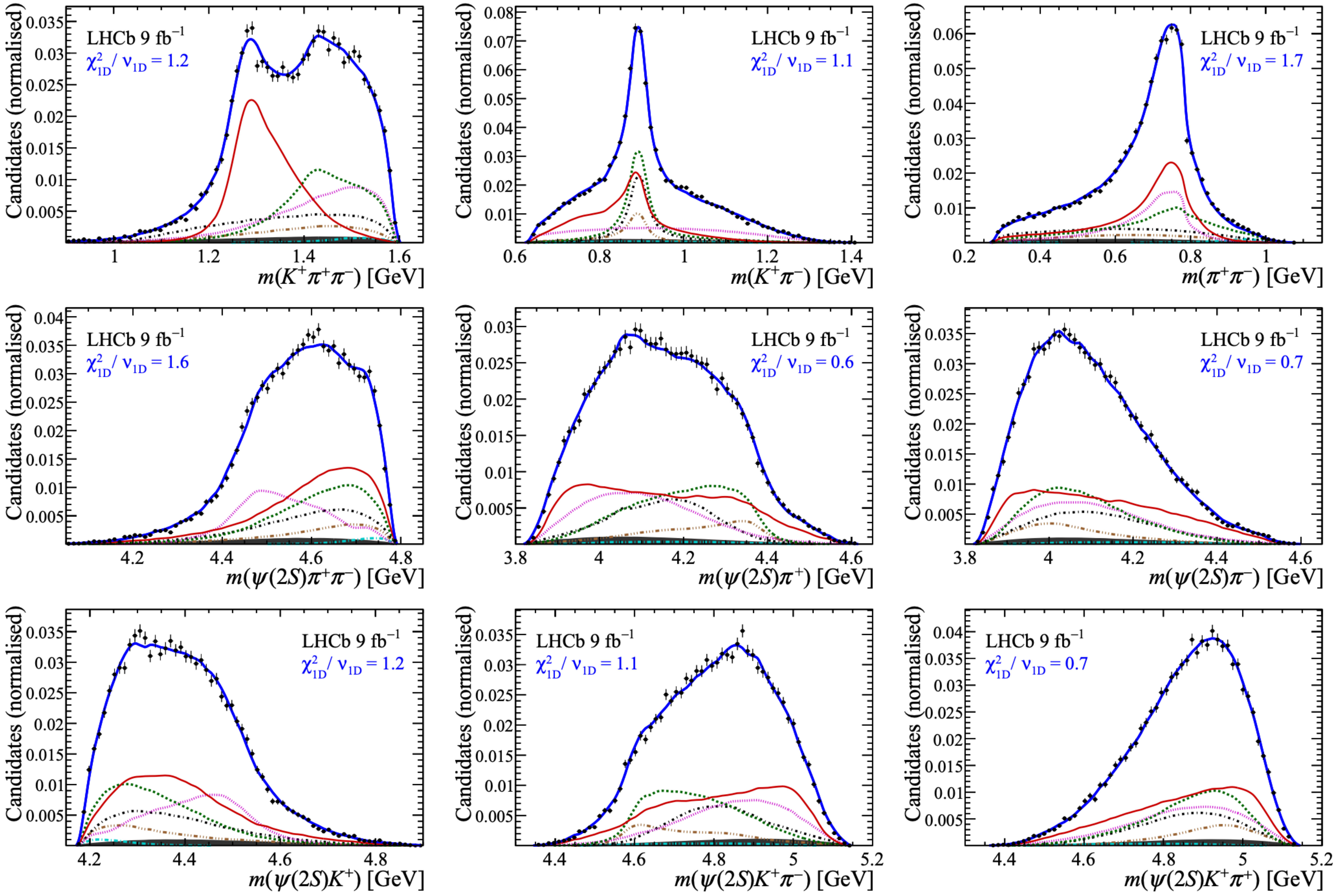
arXiv:2407.12475

- First full 7D amplitude analysis of $B^+ \to \psi(2S)K^+\pi^+\pi^-$ with 9 fb^{-1} pp collision data
- $T_{c\bar{c}1}(4430)^{\pm}$ resonance confirmed, $J^P(T_{c\bar{c}1}(4200)^{\pm}) = 1^+$ with a significance > 5σ
- Hidden-charm exotic states to $\psi(2S)K^+\pi^-$ final sates observed for the first time
- Four $X^0 \to \psi(2S)\pi^+\pi^-$ states identified and shows similarities to $X(J/\psi\phi)$

$\chi_{c0}(4475) \to \rho(770)^0\psi(2S)$	99.04± 0.49± 1.66
$\chi_{c0}(4475) \to T_{c\bar{c}1}(4200)^-\pi^+$	0.50± 0.25± 0.39
$\chi_{c0}(4475) \to T_{c\bar{c}1}(4200)^+\pi^-$	0.50± 0.25± 0.39
Sum $\chi_{c0}(4475)$	100.03± 0.02± 1.42

$T_{c\bar{c}\bar{s}1}(4600)^0 \to \psi(2S)\ K^*(892)^0$	50.87± 7.79±11.55
$T_{c\bar{c}\bar{s}1}(4600)^0 \to T_{c\bar{c}1}(4200)^-K^+$	16.53± 3.79±12.75
$T_{c\bar{c}\bar{s}1}(4600)^0 \to T_{c\bar{c}\bar{s}1}(4000)^+\pi^-$	9.84± 3.28± 5.34
Sum $T_{c\bar{c}\bar{s}1}(4600)^0$	77.23± 5.22±17.80
$T^*_{c\bar{c}\bar{s}1}(5200)^0 \to \psi(2S)\ [K^+\pi^-]_S$	66.28±15.03±17.35
$T^*_{c\bar{c}\bar{s}1}(5200)^0 \to T_{c\bar{c}\bar{s}1}(4000)^+\pi^-$	9.37±14.12±13.23
Sum $T^*_{c\bar{c}\bar{s}1}(5200)^0$	75.65± 9.18±13.39
$T_{c\bar{c}\bar{s}1}(4900)^0 \to \psi(2S)\ K^*(892)^0$	100





Amplitude analysis of $B^+ \to \psi(2S)K^+\pi^+\pi^-$

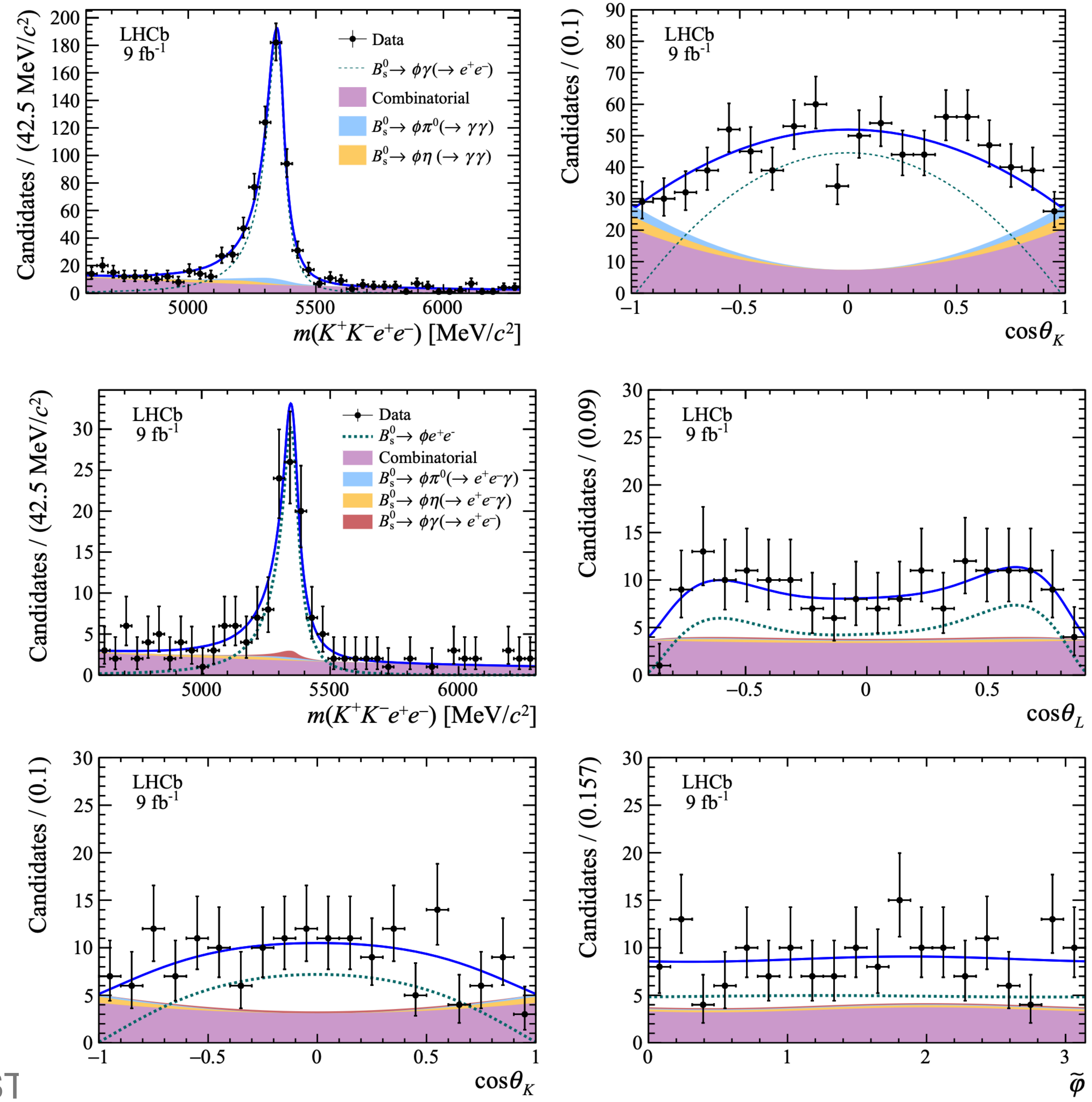
arXiv:2407.12475

- First full 7D amplitude analysis of $B^+ \to \psi(2S)K^+\pi^+\pi^-$ with $9\ \mathrm{fb}^{-1}$ pp collision data
- $T_{c\bar{c}1}(4430)^\pm$ resonance confirmed, $J^P(T_{c\bar{c}1}(4200)^\pm) = 1^+$ with a significance $> 5\sigma$
- Hidden-charm exotic states to $\psi(2S)K^+\pi^-$ final sates observed for the first time
- Four $X^0 \to \psi(2S)\pi^+\pi^-$ states identified and shows similarities to $X(J/\psi\phi)$

Resonance	J^P	m_0 [MeV]	Γ_0 [MeV]	Sign. [σ]	Res. PDG	m_0 [MeV]	Γ_0 [MeV]
$\chi_{c0}(4475)$	0^+	$4475\pm 7\pm 12$	$231\pm 19\pm 32$	> 20 (19)	$\chi_{c0}(4500)$	4474 ± 4	77^{+12}_{-10}
$\chi_{c1}(4650)$	1^+	$4653\pm 14\pm 27$	$227\pm 26\pm 22$	15 (13)	$\chi_{c1}(4685)$	4684^{+15}_{-17}	126 ± 40
$\chi_{c0}(4710)$	0^+	$4710\pm 4\pm 5$	$64\pm 9\pm 10$	14 (10)	$\chi_{c0}(4700)$	4694^{+16}_{-5}	87^{+18}_{-10}
$\eta_{c1}(4800)$	1^-	$4785\pm 37\pm 119$	$457\pm 93\pm 157$	17 (12)	$X(4630)$	4626^{+24}_{-110}	174^{+140}_{-80}
$T^*_{c\bar{c}1}(4055)^+$	1^-	4054 (fixed)	45 (fixed)	8 (7)	$T_{c\bar{c}}(4055)^+$	4054 ± 3.2	45 ± 13
$T_{c\bar{c}1}(4200)^+$	1^+	$4257\pm 11\pm 17$	$308\pm 20\pm 32$	> 20 (> 20	$T_{c\bar{c}1}(4200)^+$	4196^{+35}_{-32}	370^{+100}_{-150}
$T_{c\bar{c}1}(4430)^+$	1^+	$4468\pm 21\pm 80$	$251\pm 42\pm 82$	15 (8)	$T_{c\bar{c}1}(4430)^+$	4478^{+15}_{-18}	181 ± 31
$T_{c\bar{c}\bar{s}1}(4600)^0$	1^+	$4578\pm 10\pm 18$	$133\pm 28\pm 69$	15 (12)			
$T_{c\bar{c}\bar{s}1}(4900)^0$	1^+	$4925\pm 22\pm 47$	$255\pm 55\pm 127$	12 (8)			
$T^*_{c\bar{c}\bar{s}1}(5200)^0$	1^-	$5225\pm 86\pm 181$	$226\pm 76\pm 374$	10 (8)			
$T_{c\bar{c}\bar{s}1}(4000)^+$	1^+	4003 (fixed)	131 (fixed)	> 20 (14)	$T_{c\bar{c}\bar{s}1}(4000)^+$	4003^{+7}_{-15}	131 ± 30

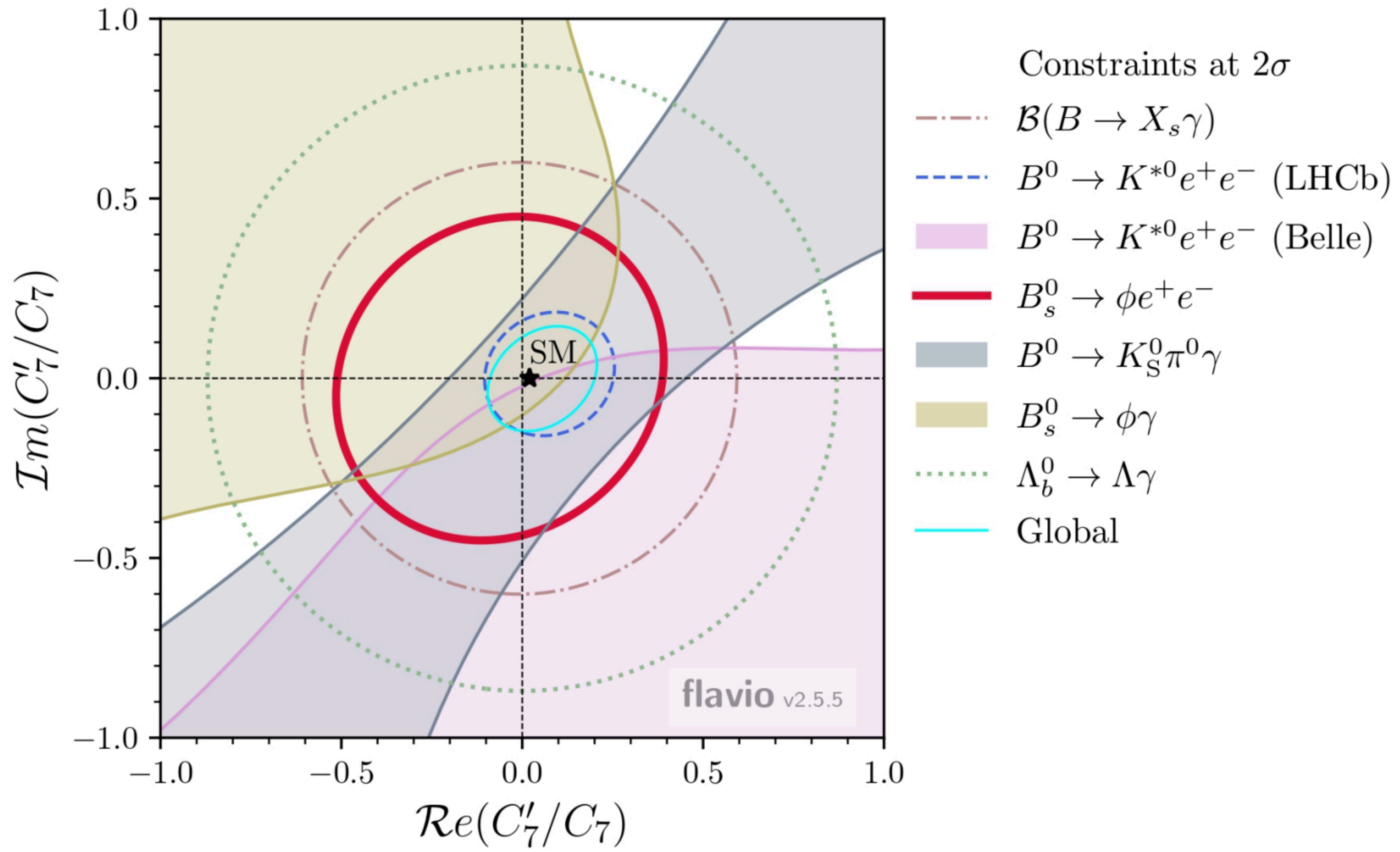
Angular analysis in $B_s^0 \to \phi e^+ e^-$

JHEP 03 (2025) 047



- FCNC process involving $b \to s$ transition

$$
\begin{aligned}
A_{\mathrm{T}}^{(2)} &= -0.045 \pm 0.235 \pm 0.014\,, \\
A_{\mathrm{T}}^{\mathcal{I}mCP} &= \quad 0.002 \pm 0.247 \pm 0.016\,, \\
A_{\mathrm{T}}^{\mathcal{R}eCP} &= \quad 0.116 \pm 0.155 \pm 0.006\,, \\
F_{\mathrm{L}} &= \quad (0.4 \pm 5.6 \pm 1.2)\%\,,
\end{aligned}
$$

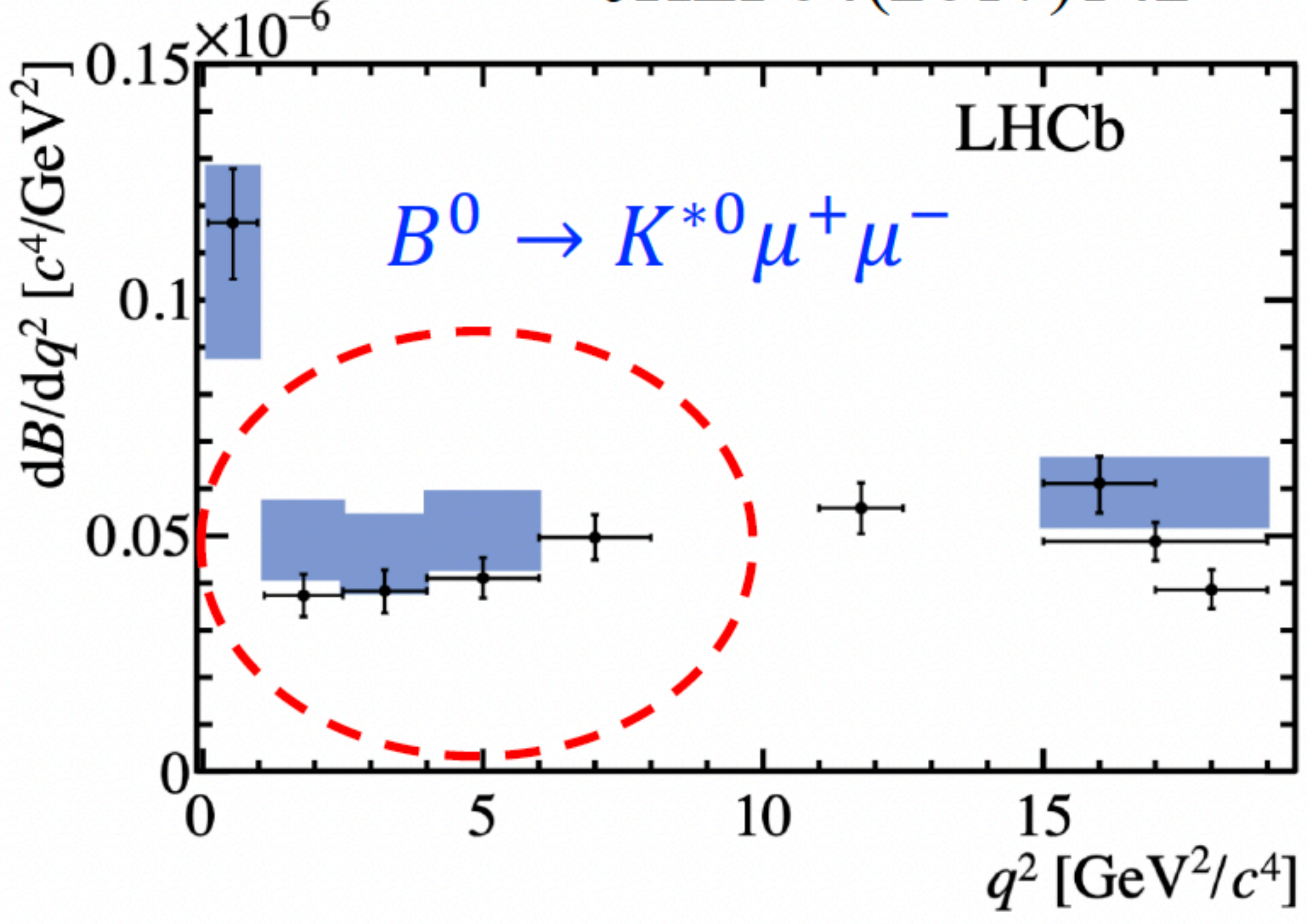


$b \to s\ell^+\ell^-$ decays

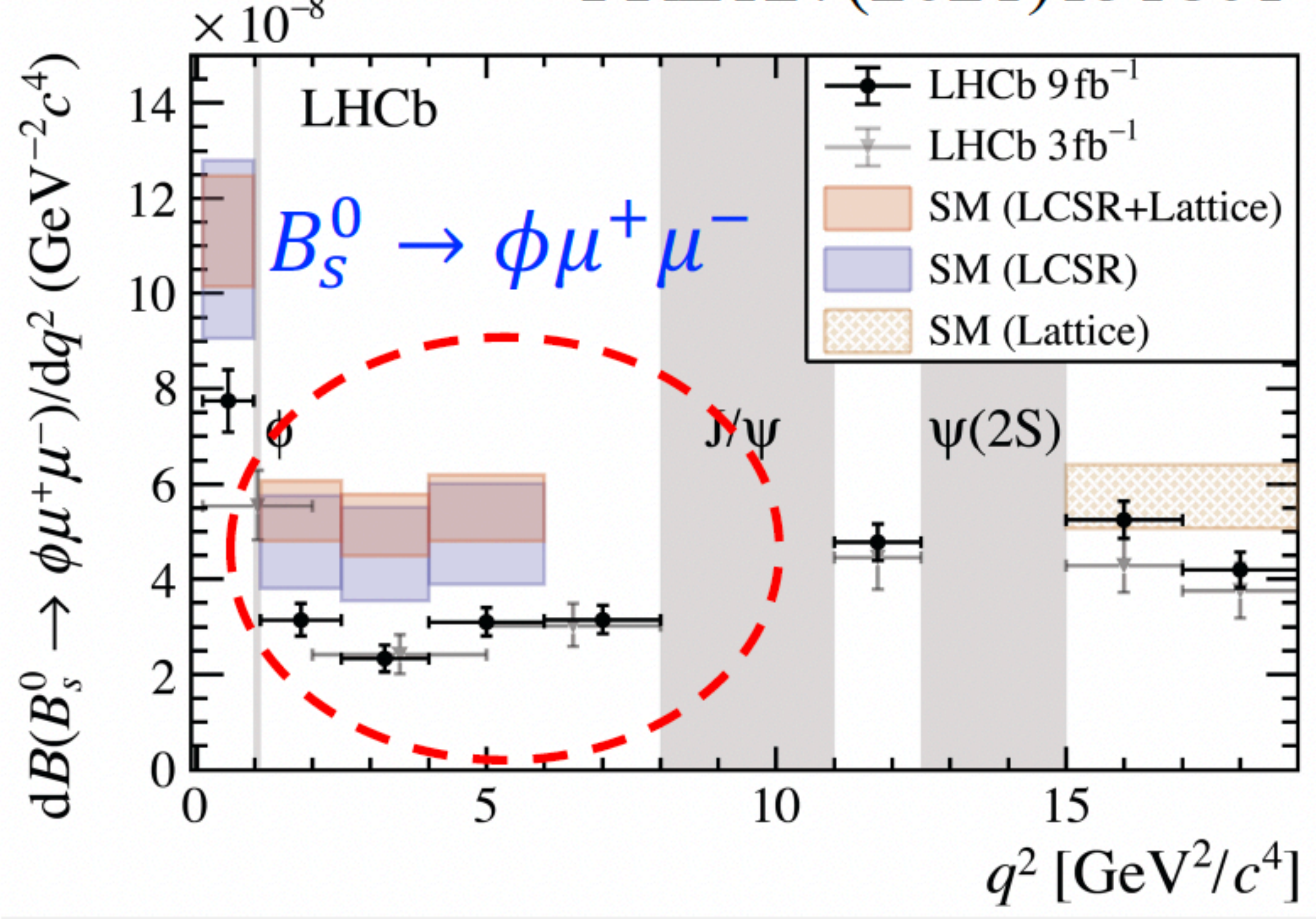
- Anomalous tensions with SM in differential rate

Are these anomalies new physics?

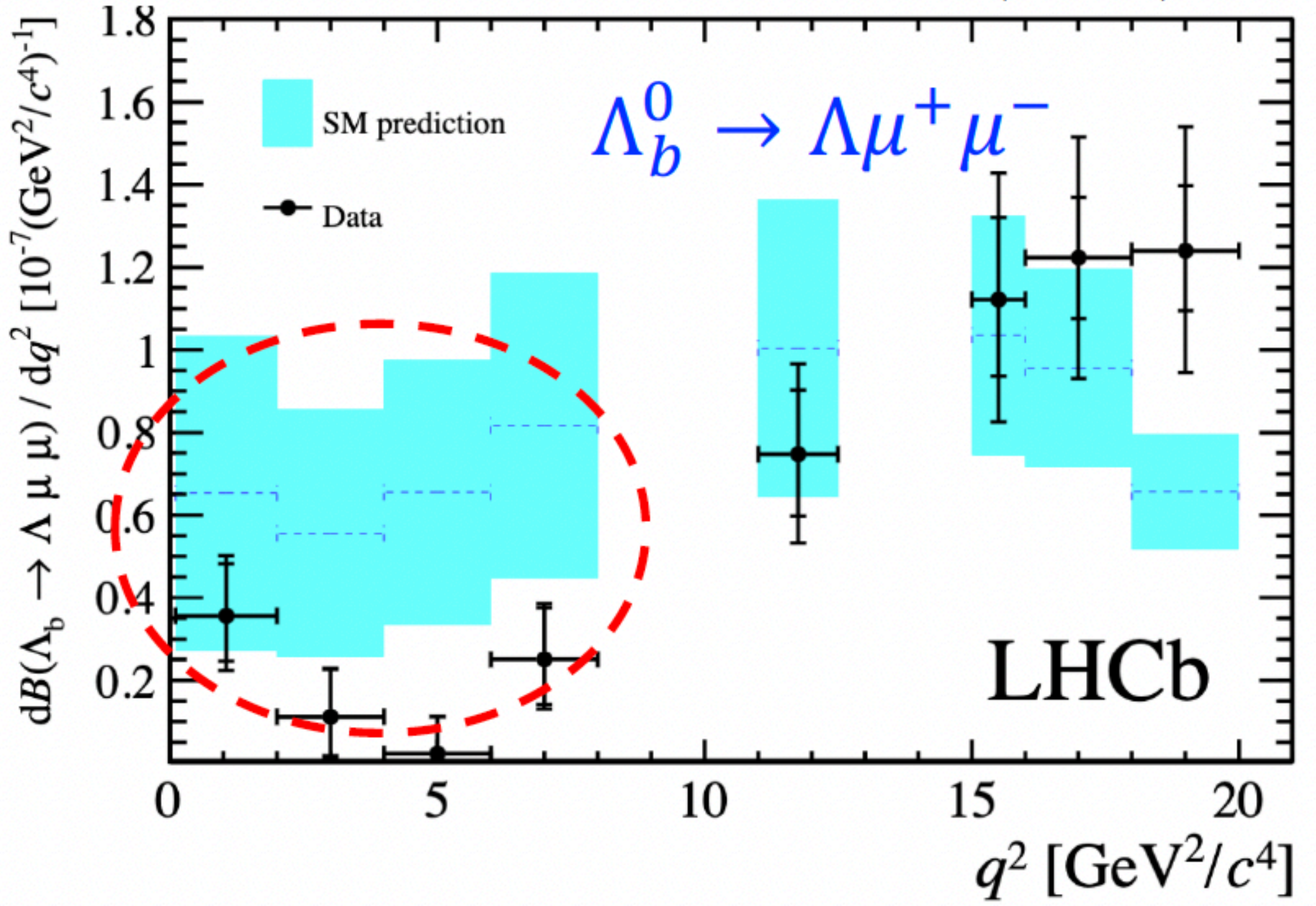
JHEP04(2017)142



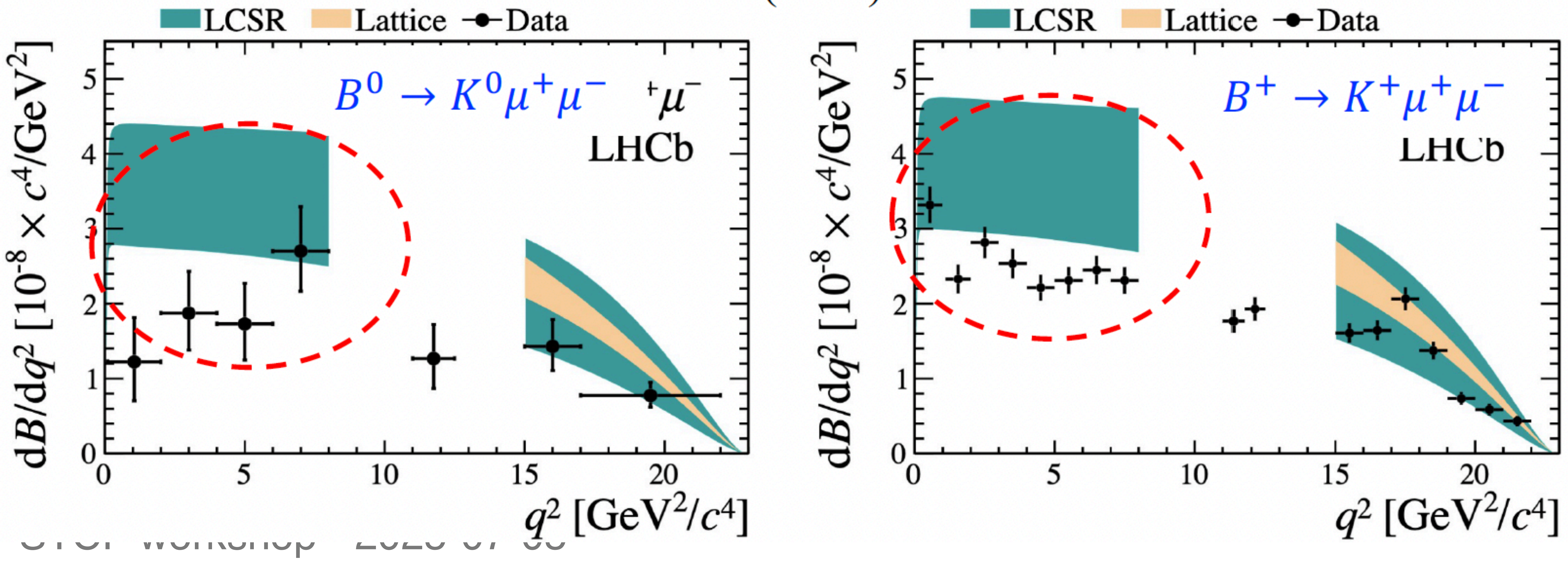
PRL127(2021)151801



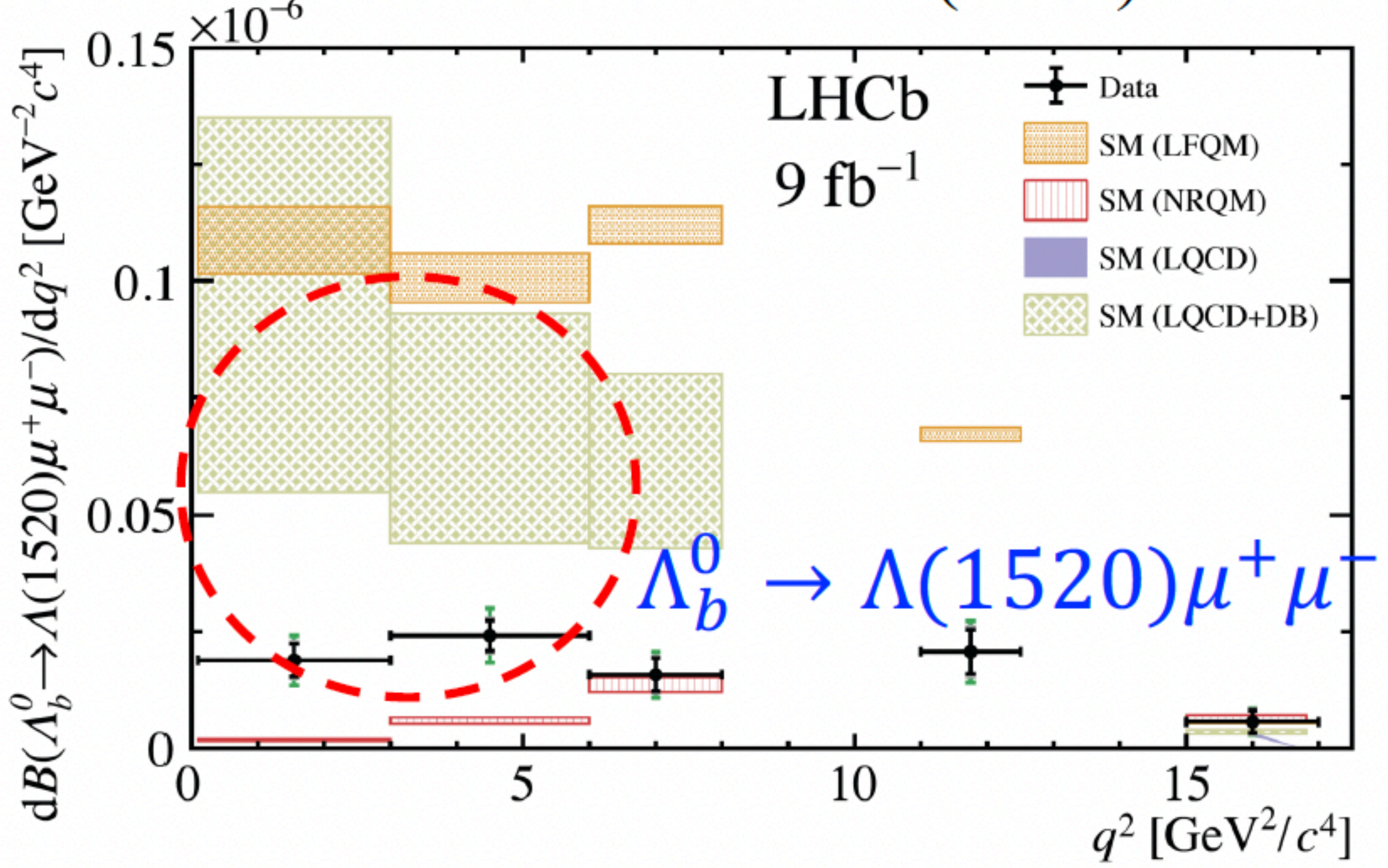
JHEP06(2015)115



JHEP06(2014)133



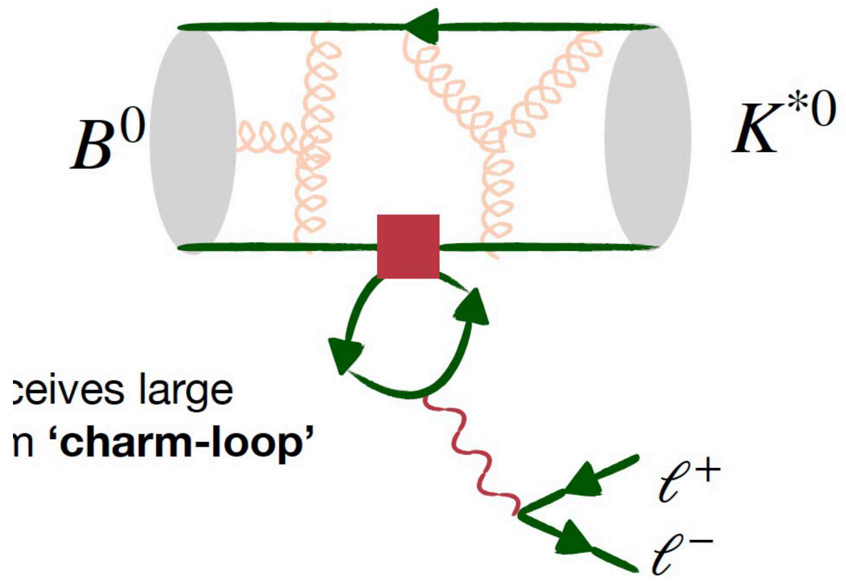
PRL131(2023)151801



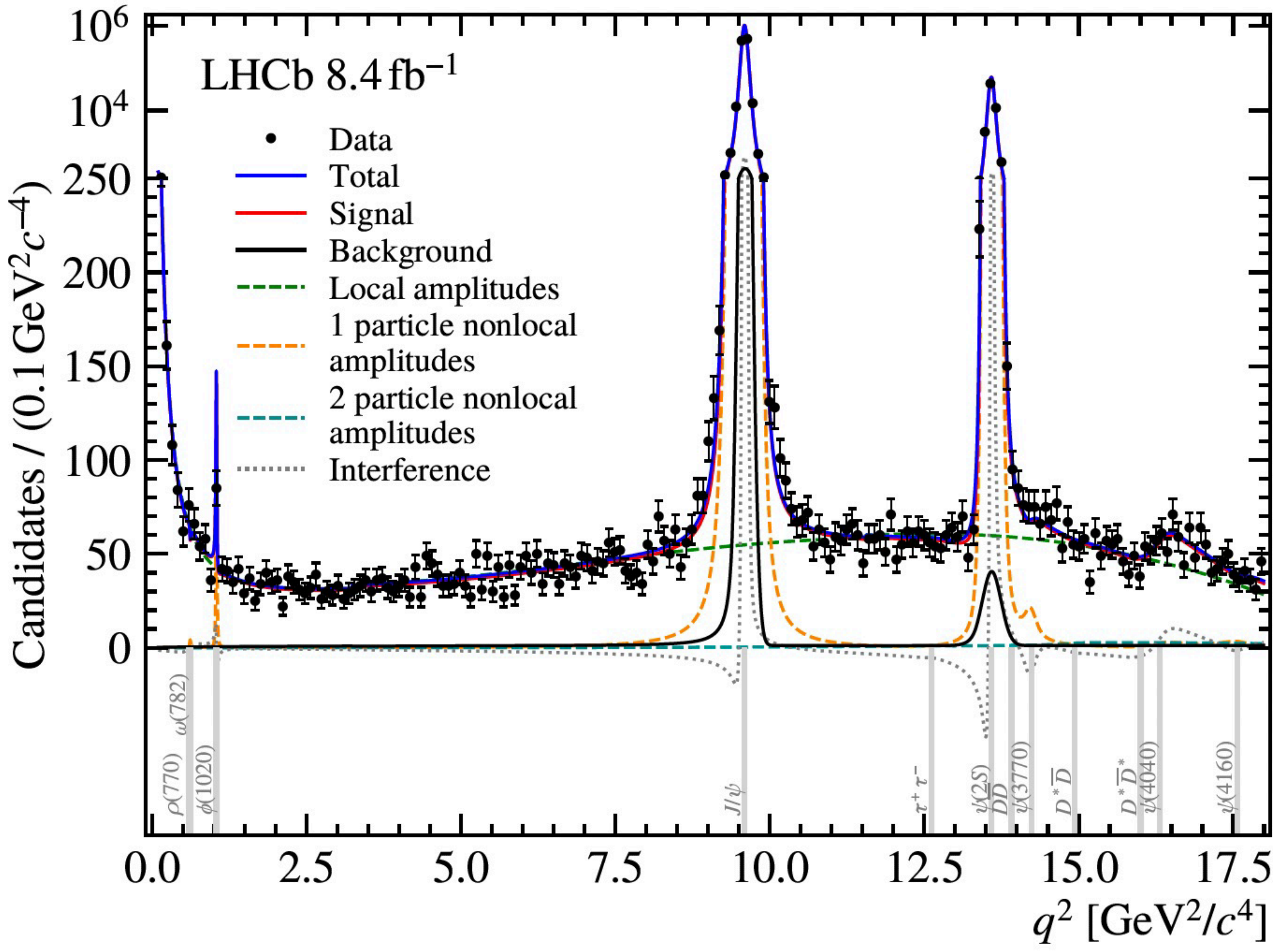
Understanding non-local contributions

arXiv:2405.17347

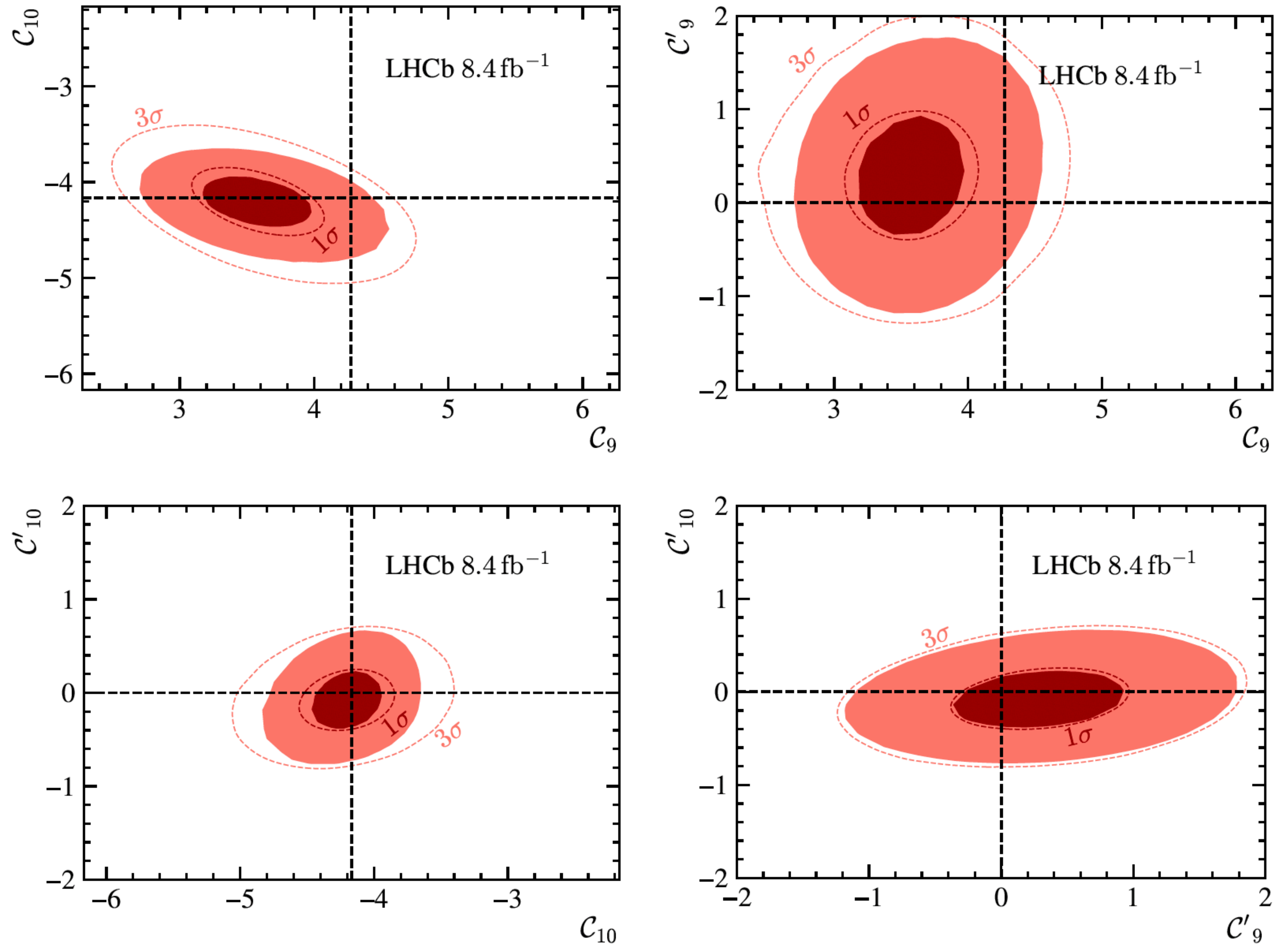
- A model combines the local and nonlocal amplitudes ($\omega, \rho, \phi, \psi, D\bar{D}, \tau\tau$) across whole q^2 spectrum (0.1-18.0 GeV²/c⁴) in $B^0 \to K^{*0}\mu^+\mu^-$
  - Simultaneously determine the nonlocal contributions and Wilson coefficients



$$\frac{\mathrm{d}^5 \overset{(-)}{\Gamma}(B^0 \to K^+\pi^-\mu^+\mu^-)}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}\,\mathrm{d}m^2_{K\pi}} = \frac{9}{32\pi}\sum_i \overset{(-)}{J}_i(q^2) f_i(\cos\theta_\ell, \cos\theta_K, \phi) g_i(m^2_{K\pi})$$



𝒞9: 2.1σ deviation from SM, a slight dependence on local form factor constraint

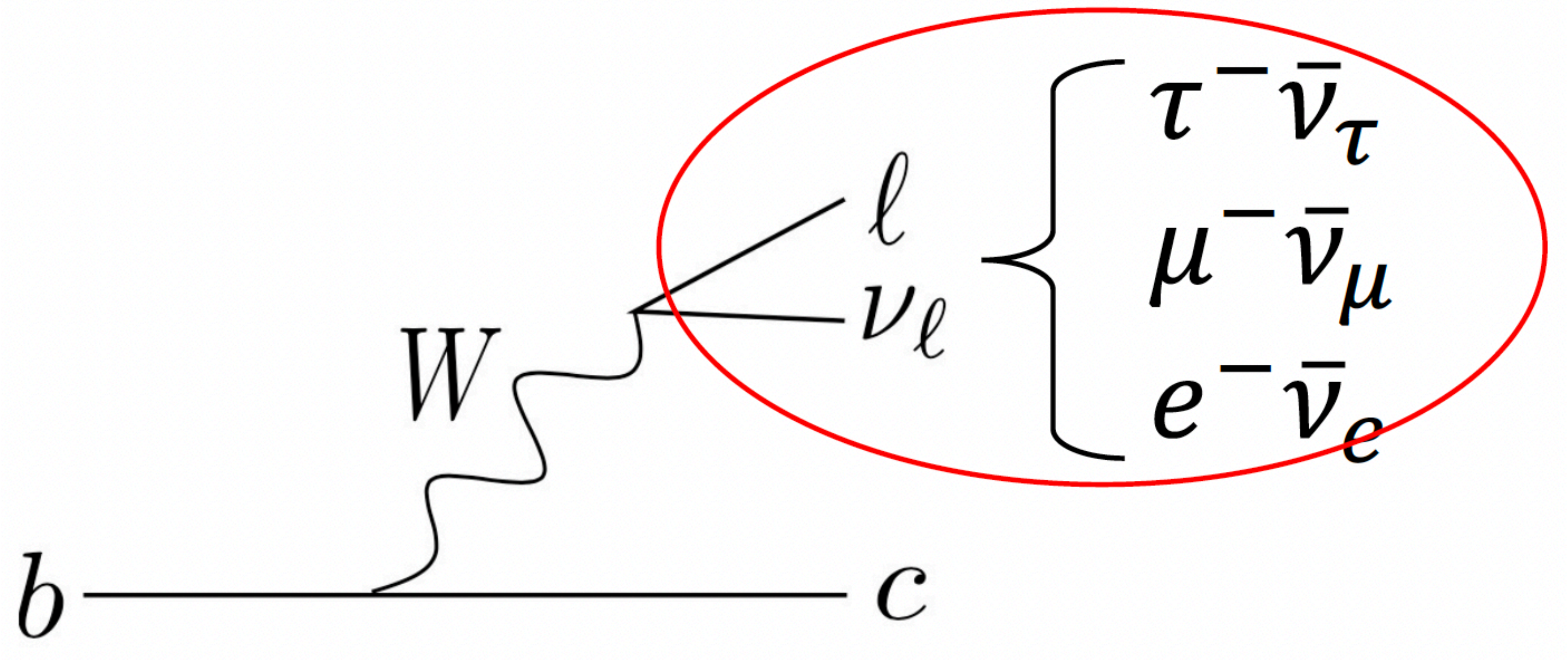


Wilson Coefficient results	
$\mathcal{C}_9$	$3.56 \pm 0.28 \pm 0.18$
$\mathcal{C}_{10}$	$-4.02 \pm 0.18 \pm 0.16$
$\mathcal{C}'_9$	$0.28 \pm 0.41 \pm 0.12$
$\mathcal{C}'_{10}$	$-0.09 \pm 0.21 \pm 0.06$
$\mathcal{C}_{9\tau}$	$(-1.0 \pm 2.6 \pm 1.0) \times 10^2$

- Interference with nonlocal contributions has a minor impact on the Wilson Coefficients

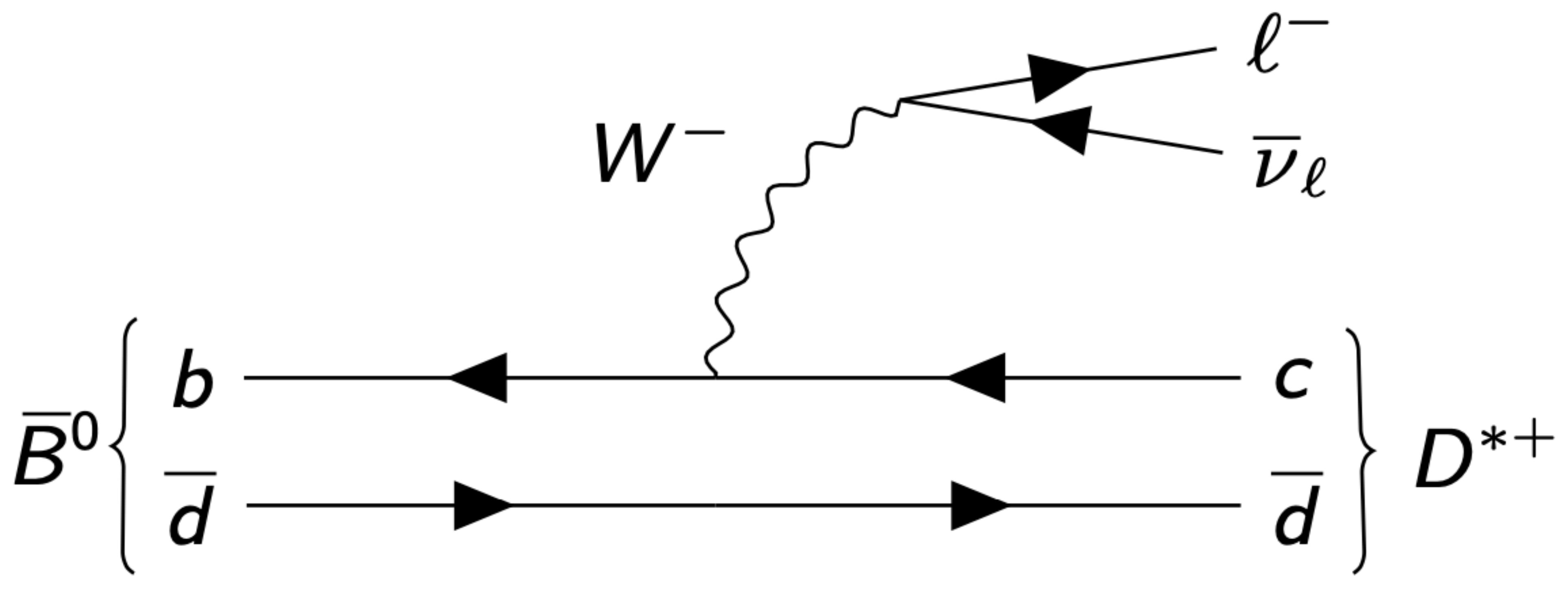
Lepton flavour anomalies in charged current

- $W^{\pm}$ couples equally to three generations of leptons, tested through $R(H_c)$ measurements



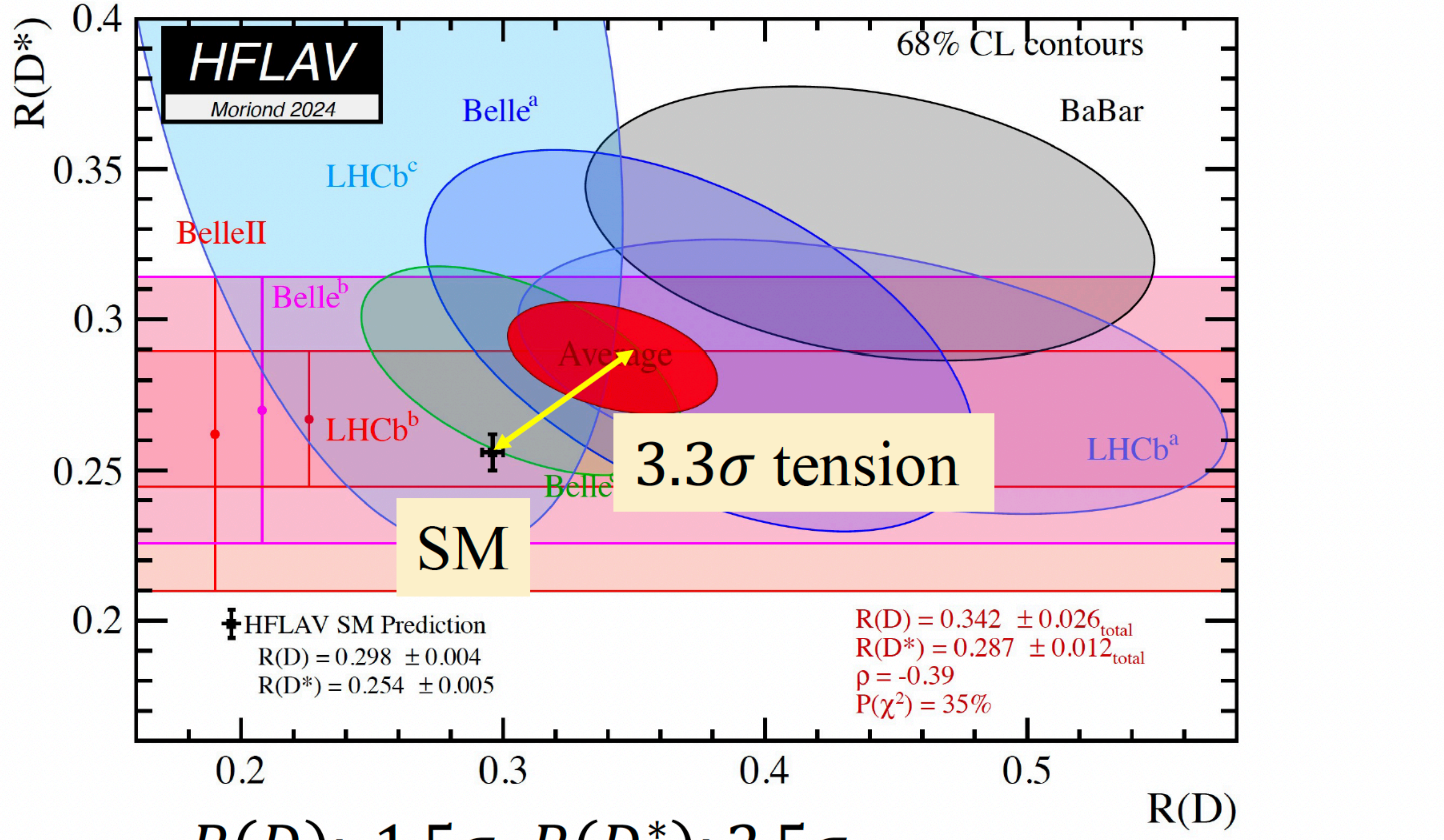
$$R(H_c) = \frac{\mathcal{B}(H_b \to H_c \tau^+ \nu_\tau)}{\mathcal{B}(H_b \to H_c \mu^+ \nu_\mu)}$$

$H_c = D^{(*)+}, D^0, D_s^+, \Lambda_c^+, J/\psi \ldots$



$R(D^{(*)})$ with $\tau \to \mu\nu\nu, \tau \to 3\pi\nu$

PRL131(2023)111802
PRD108(2023) 012018
arXiv:2406.03387



$R(D)$: 1.5σ, $R(D^*)$: 2.5σ