Recent CP violation results from LHCb

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2026轻强子专题研讨会

Outline of the talk

- Introduction
- Precise measurement of the CKM angle γ with a novel approach
- CP violation studies in $B^+ \to K^+\pi^+\pi^-$ decays
- Prospects and conclusion

Disclaimer: results are selected based on personal taste

Why CP violation

- SM model very successful;
- Still an effective theory, many unexplained phenomena;
- One standing-out quest: understanding matter and antimatter asymmetry in the Universe

$$\frac{N_B - N_{\bar{B}}}{N_B + N_{\bar{B}}} \sim 10^{-10} \ll 10^{-17}$$ predicted by CKM mechanism

- Extra sources of CP violation needed
  - Higgs sector? $\mathcal{H}_{f\bar{f}h} = y_f \bar{f} h \left(\kappa_f + i\tilde{\kappa}_f \gamma^5\right) f$
  - Neutrino sector? PMNS matrix
  - Quark sector?
  - Other places?

All requires New physics

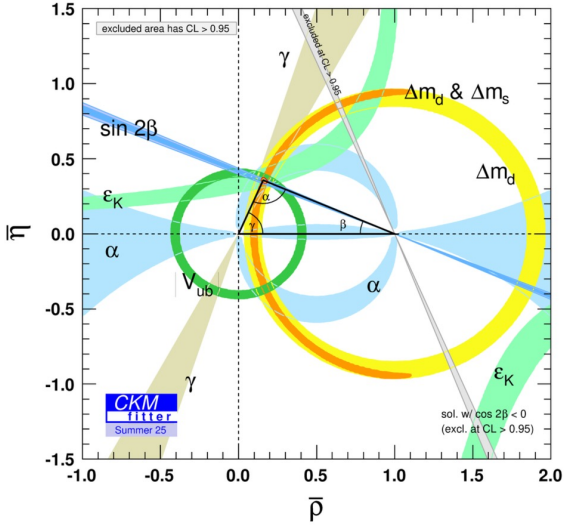
Precision measurements

- **Precision essential to find the footprint of NP**

$$\mathcal{A}(\psi_i \to \psi_j + X) = \mathcal{A}_0 \left(\frac{c_{\rm SM}}{v^2} + \frac{c_{\rm NP}}{\Lambda^2} \right)$$

NP scale: Λ

Energy scale for SM: $v \sim 100$ GeV



- **Unitarity test: precision driven!**

Is current precision enough? No

$$V_{ud}V_{ud}^* + V_{us}V_{us}^* + \overset{10^{-5}}{V_{ub}V_{ub}^*} - 1$$

$$= [0.00012, -0.00295]\ (3\sigma)$$

Cabbibo anomaly?

Disaster for new physics searches if CKM elements not precise

Changing $|V_{cb}|$: $39 \cdot 10^{-3} \Rightarrow 42 \cdot 10^{-3}$

changes $|V_{cb}|^2$: by 16% $(B_{s,d} \to \mu^+\mu^-,\ \Delta M_{s,d})$

$|V_{cb}|^3$: by 25% $(K^+ \to \pi^+\nu\bar{\nu}, \varepsilon_K)$

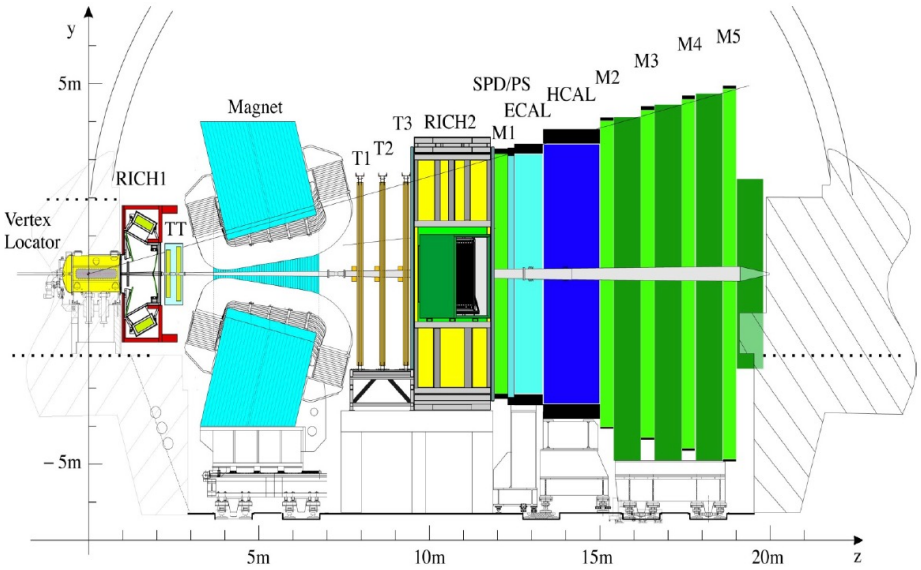
$|V_{cb}|^4$: by 35% $(K_L \to \pi^0\nu\bar{\nu}, K_S \to \mu^+\mu^-)$

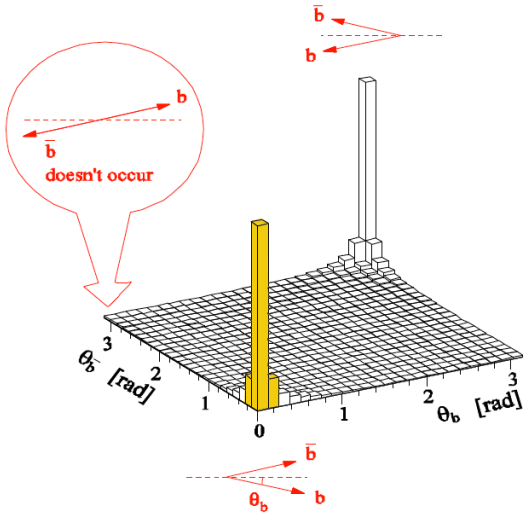
From A. Buras

- **Precise measurements in NP sensitive decays**

The LHCb detector (Run 1+2)

2008 JINST 3 S08005





Excellent vertex and IP, decay time resolution:

- $\sigma(\mathrm{IP}) \approx 20\ \mu\mathrm{m}$ for high-p_{T} tracks
- $\sigma(\tau) \approx 45$ fs for $B_s^0 \to J/\psi\phi$ and $B_s^0 \to D_s^- \pi^+$ decays

Very good momentum resolution:

- $\delta p/p \approx 0.5\% - 1\%$ for $p \in (0,200)$ GeV
- $\sigma(m_B) \approx 24$ MeV for two-body decays

Hadron and Muon identification

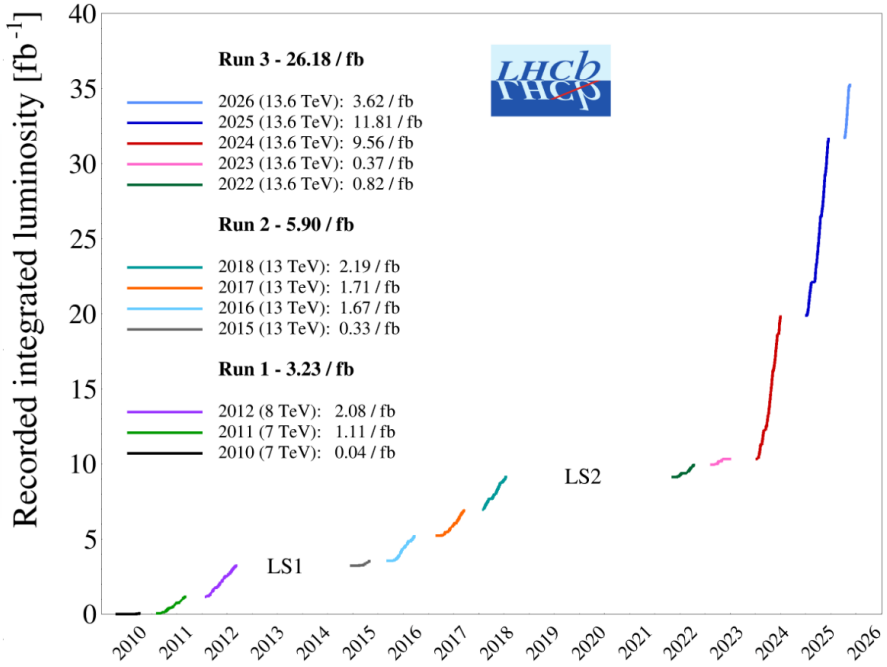
- $\epsilon_{K\to K} \approx 95\%$ for $\epsilon_{\pi\to K} \approx 5\%$ up to 100 GeV
- $\epsilon_{\mu\to\mu} \approx 97\%$ for $\epsilon_{\pi\to\mu} \approx 1-3\%$

Data good for analyses

- $> 99\%$

Designed for CP violation and heavy flavor studies

The LHCb status



- Run 1:
  - 2011 (7 TeV): 1 fb^{-1}
  - 2012 (8 TeV): 2 fb^{-1}
- Run 2:
  - 2015-2018 (13 TeV): 6 fb^{-1}
- **Run 3:**
  - **2024 alone (13.6 TeV): 9.56 fb^{-1}**
  - **2025 (13.6 TeV): 11.81 fb^{-1}**
  - **2026 (13.6 TeV): >3.62 fb^{-1}**

- **A new LHCb detector for Run 3 operates at $\times 5$ higher instantaneous luminosity**
- **Similar performance, while efficiency for hadron final states increased by a factor of 2**

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CKM angle γ

- **Measured through tree-level dominated $b \to c$ and $b \to u$ processes** $\gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$
- **Negligible theoretical uncertainty** [JHEP 01(2014) 051]
- **Less affected by NP entering trough quantum fluctuation ➡️ SM candle**
- **NP search by comparing between direct and indirect measurements**

$\gamma_{\text{ind.}} = (66.16^{+0.78}_{-3.20})^\circ$ [CKMfitter 2025]

$\gamma_{\text{dir.}} = (62.8 \pm 2.6)^\circ$ [LHCb-CONF-2025-003]

- **Currently, single best measurements from $B^\pm \to (K_S^0 h^+ h^-)_D h'^\pm$ decays**

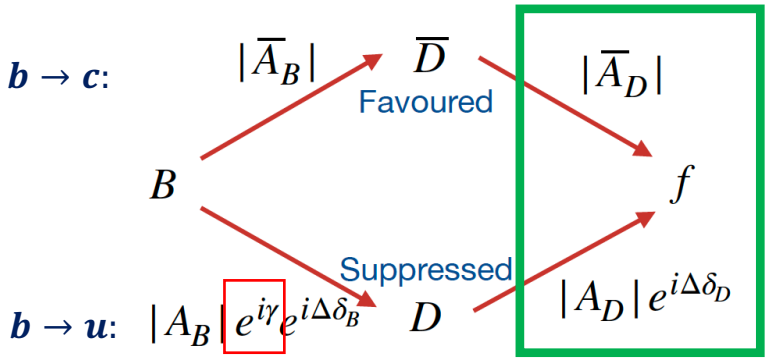
$$\gamma_{\text{GGSZ}} = (68.7^{+5.2}_{-5.1})^\circ$$ [LHCb-PAPER-2020-019]

Statistical uncertainty dominated
Sensitivity loss due to binned approach

→

A novel approach developed using unbinned MI method

Joint measurement between LHCb and BESIII

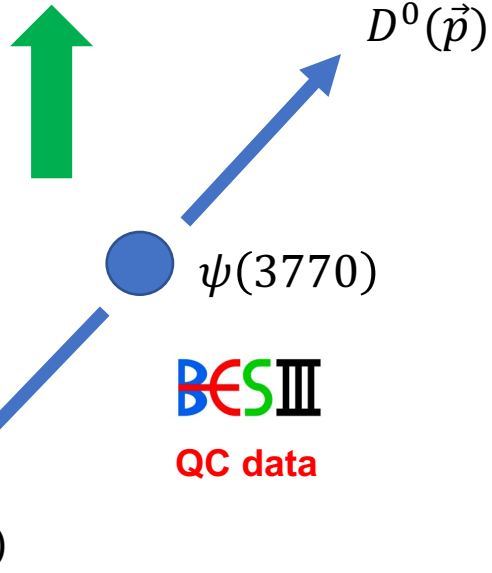


$\bar{A}(D): \bar{D}^0 \to f$

$A(D): D^0 \to f$

$$\gamma \equiv \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

$$r_D e^{i\Delta\delta_D} = \frac{A_D}{\bar{A}_D}$$



γ measurements

First joint analyses between LHCb and BESIII collaborations

QC data

Logic of the new method (1)

$$x_\pm + iy_\pm = r_B e^{i(\delta_B \pm \gamma)}$$

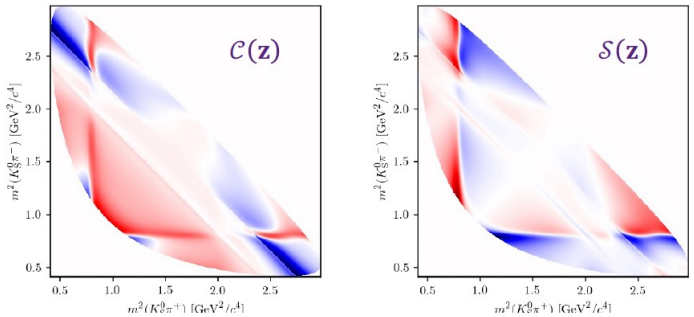
$$B^-: p_B(\mathbf{z}) \propto p_D(\mathbf{z}) + (x_-^2 + y_-^2)\bar{p}_D(\mathbf{z}) + 2[x_-\mathcal{C}(\mathbf{z}) + y_-\mathcal{S}(\mathbf{z})]$$
$$B^+: \bar{p}_B(\mathbf{z}) \propto \bar{p}_D(\mathbf{z}) + (x_+^2 + y_+^2)p_D(\mathbf{z}) + 2[x_+\mathcal{C}(\mathbf{z}) - y_+\mathcal{S}(\mathbf{z})]$$

$D^0/\bar{D}^0 \to K_S^0 h^+ h^-$ decay density

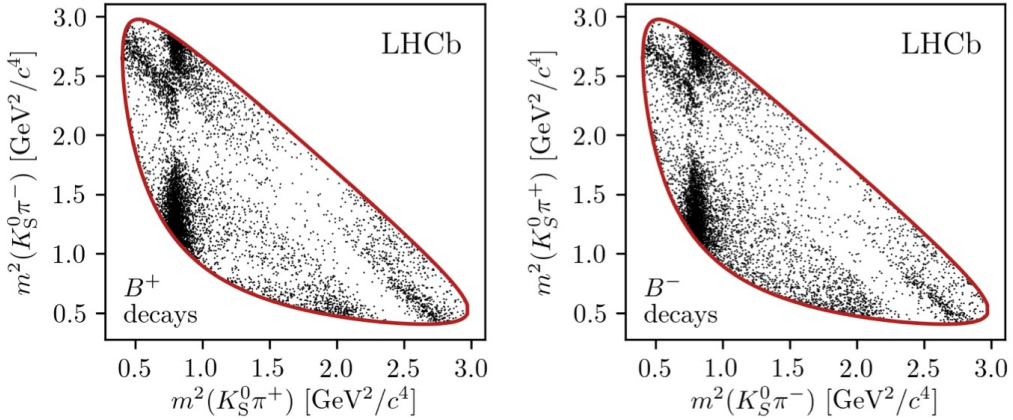
$\{\mathcal{C}, \mathcal{S}\} = \sqrt{p_D \bar{p}_D}\{\cos, \sin\}(\phi)$

Novel approach: fourier transformation

[EPJC78 (2018) 2, 121]

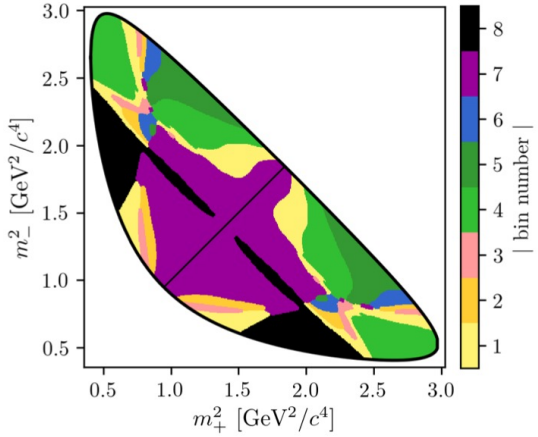


Density difference indicates CP violation



Traditional method: binning

~10% loss of sensitivity



Logic of the new method (2)

$$x_\pm + iy_\pm = r_B e^{i(\delta_B \pm \gamma)}$$

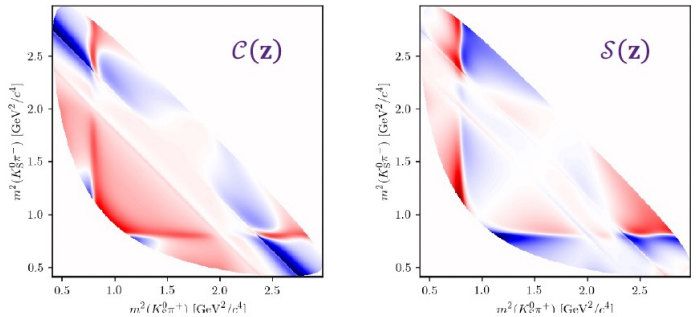
$$B^-: p_B(\mathbf{z}) \propto p_D(\mathbf{z}) + (x_-^2 + y_-^2)\bar{p}_D(\mathbf{z}) + 2[x_- \mathcal{C}(\mathbf{z}) + y_- \mathcal{S}(\mathbf{z})]$$
$$B^+: \bar{p}_B(\mathbf{z}) \propto \bar{p}_D(\mathbf{z}) + (x_+^2 + y_+^2)p_D(\mathbf{z}) + 2[x_+ \mathcal{C}(\mathbf{z}) - y_+ \mathcal{S}(\mathbf{z})]$$

$D^0/\bar{D}^0 \to K_S^0 h^+ h^-$ decay density

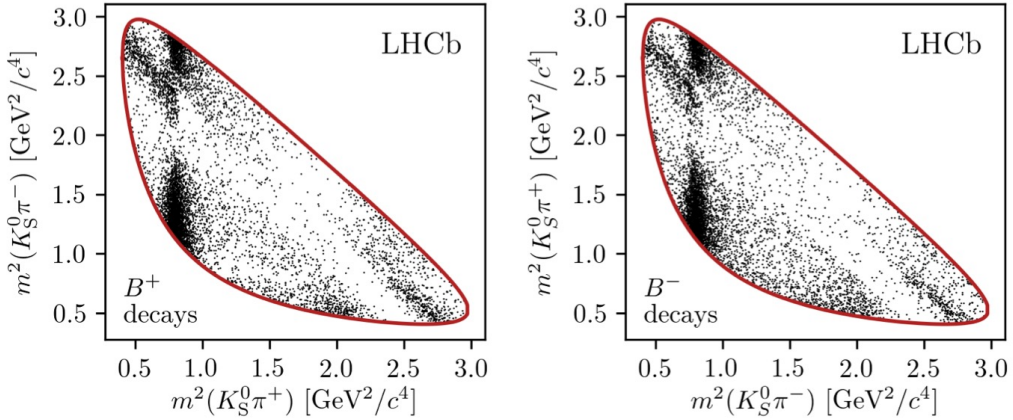
$\{\mathcal{C}, \mathcal{S}\} = \sqrt{p_D \bar{p}_D}\{\cos, \sin\}(\phi)$

Novel approach: fourier transformation

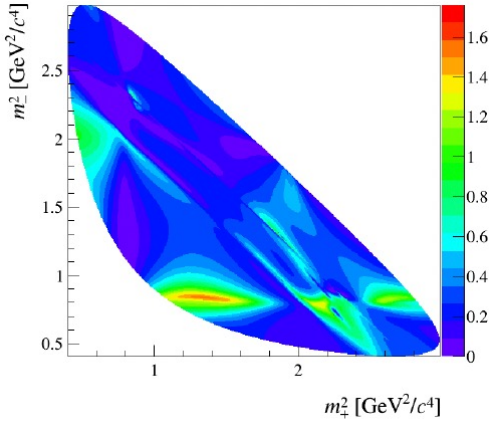
[EPJC78 (2018) 2, 121]



Density difference indicates CP violation



Only considering phase information



A further weight added to take into account amplitude, purity, efficiency information

Weights and BESIII inputs

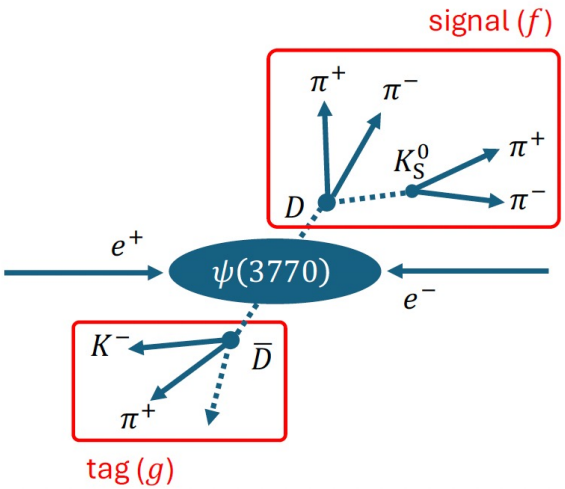
- **Why weights works? Equation holds when multiplying both sides by the same constant**

$$p_B(\mathbf{z}) \propto p_D(\mathbf{z}) + (x_-^2 + y_-^2)\bar{p}_D(\mathbf{z}) + 2[x_-\mathcal{C}(\mathbf{z}) + y_-\mathcal{S}(\mathbf{z})]$$

$$\mathcal{N}_n = h_B\left[P_n^+ + (x_-^2 + y_-^2)P_n^- + 2[x_-C_n + y_-S_n]\right]$$

multipled by $w_n(\mathbf{z})$ and integrated over $\mathbf{z}$

- **BESIII QC data: $\psi(3770) \to D\bar{D}$**



Mode	$K_S^0 h^+ h^-$	$K_L^0 h^+ h^-$
Flavor	$K\pi\pi^0$, $K\pi$, $K\pi\pi\pi$, $Ke\nu$	$K\pi\pi^0$, $K\pi$, $K\pi\pi\pi$
CP even	KK, $\pi\pi$, $K_S^0\pi^0\pi^0$, $K_L^0\pi^0$, $\pi\pi\pi^0$	KK, $\pi\pi$, $K_S^0\pi^0\pi^0$, $\pi\pi\pi^0$
CP odd	$K_S^0\pi^0$, $K_S^0\eta_{\gamma\gamma}$, $K_S^0\eta_{\pi\pi\pi^0}$, $K_S^0\omega$ $K_S^0\eta'_{\gamma\rho}$, $K_S^0\eta'_{\pi\pi\eta}$, $K_L^0\pi^0\pi^0$	$K_S^0\pi^0$, $K_S^0\eta_{\gamma\gamma}$, $K_S^0\eta_{\pi\pi\pi^0}$, $K_S^0\omega$ $K_S^0\eta'_{\gamma\rho}$, $K_S^0\eta'_{\pi\pi\eta}$

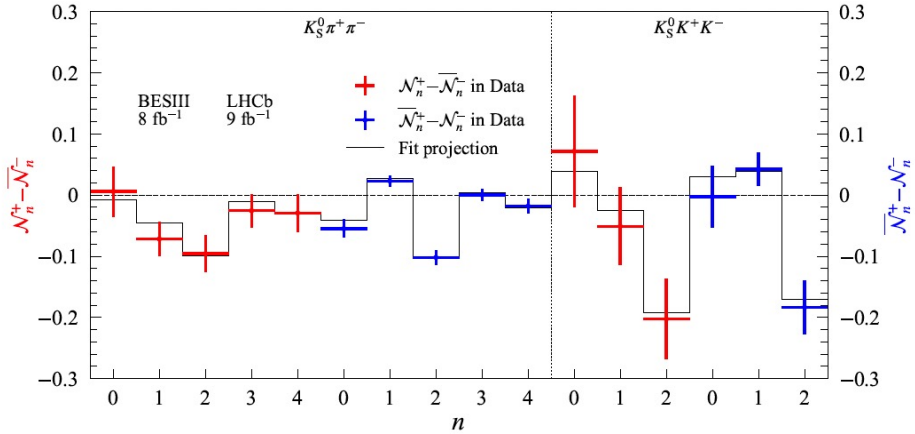
- **Example: CP tagged $K_S^0 h^+ h^-$**

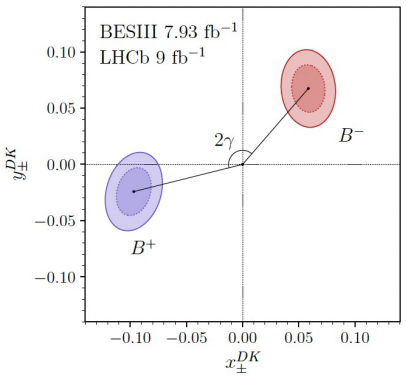
$$\mathcal{N}_n(K_{S/L}^0 h'^+ h'^- | CP) \propto \left[P_n^+ + P_n^- - 2s_K(2F_+ - 1)(-1)^n C_n\right],$$

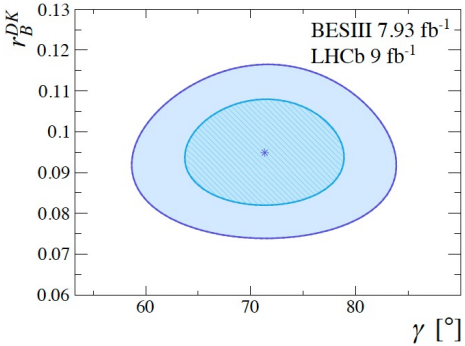
$$\overline{\mathcal{N}}_n(K_{S/L}^0 h'^+ h'^- | CP) \propto \left[P_n^- + P_n^+ - 2s_K(2F_+ - 1)(-1)^n C_n\right],$$

CP observables and results

- **Observables from B decays, indicating CP violation effects**







- **Results on γ and strong parameters**

$$\gamma = (71.3 \pm 5.0)^\circ\,,$$

$$r_B^{DK} = 0.0949^{+0.0086}_{-0.0085}\,, \quad r_B^{D\pi} = 0.0064^{+0.0021}_{-0.0019}\,,$$

$$\delta_B^{DK} = (121.6^{+5.6}_{-5.9})^\circ\,, \quad \delta_B^{D\pi} = (311^{+17}_{-20})^\circ\,.$$

Improved about 5% compared to the binned method

Most precise single measurement to date on γ

Opens new possibilities for γ measurements in other multibody decays

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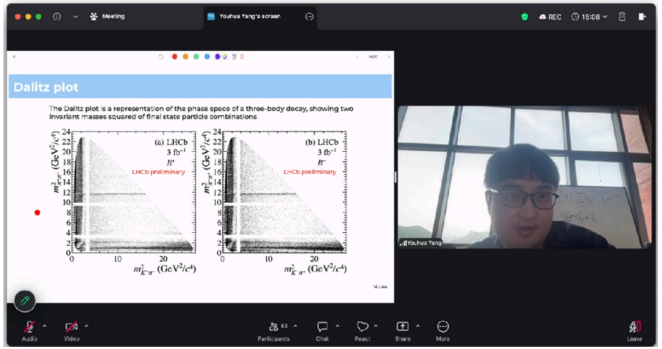
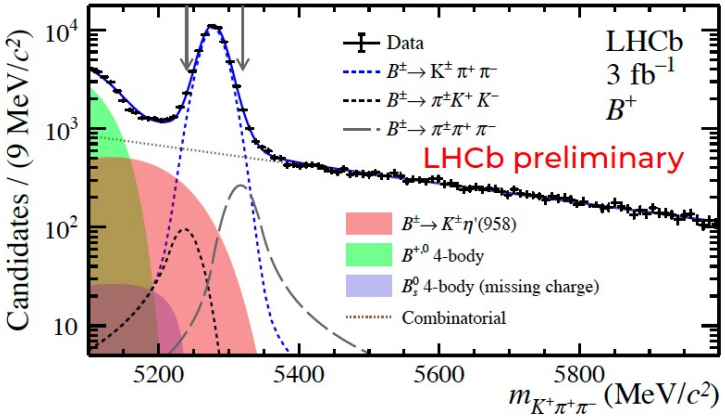
- Precise measurement of the CKM angle γ with a novel approach
- **CP violation studies in $B^+ \to K^+\pi^+\pi^-$ decays**
- Prospects and conclusion

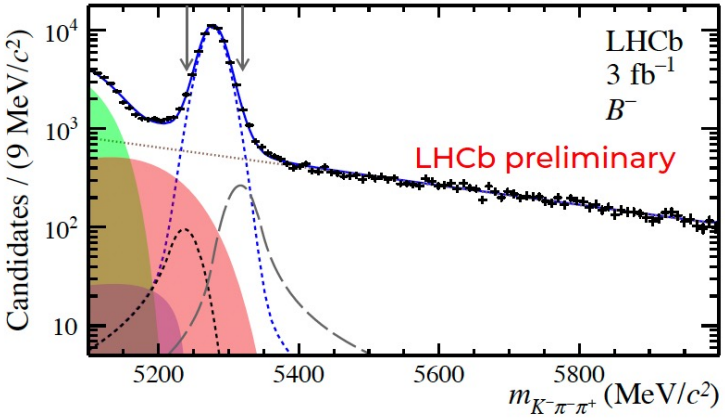


CERN LHC seminar by Youhua Yang

CP violation in $B^+ \to K^+\pi^-\pi^-$ decays

- **Around 40 × data than B-factories using only Run 1 data**



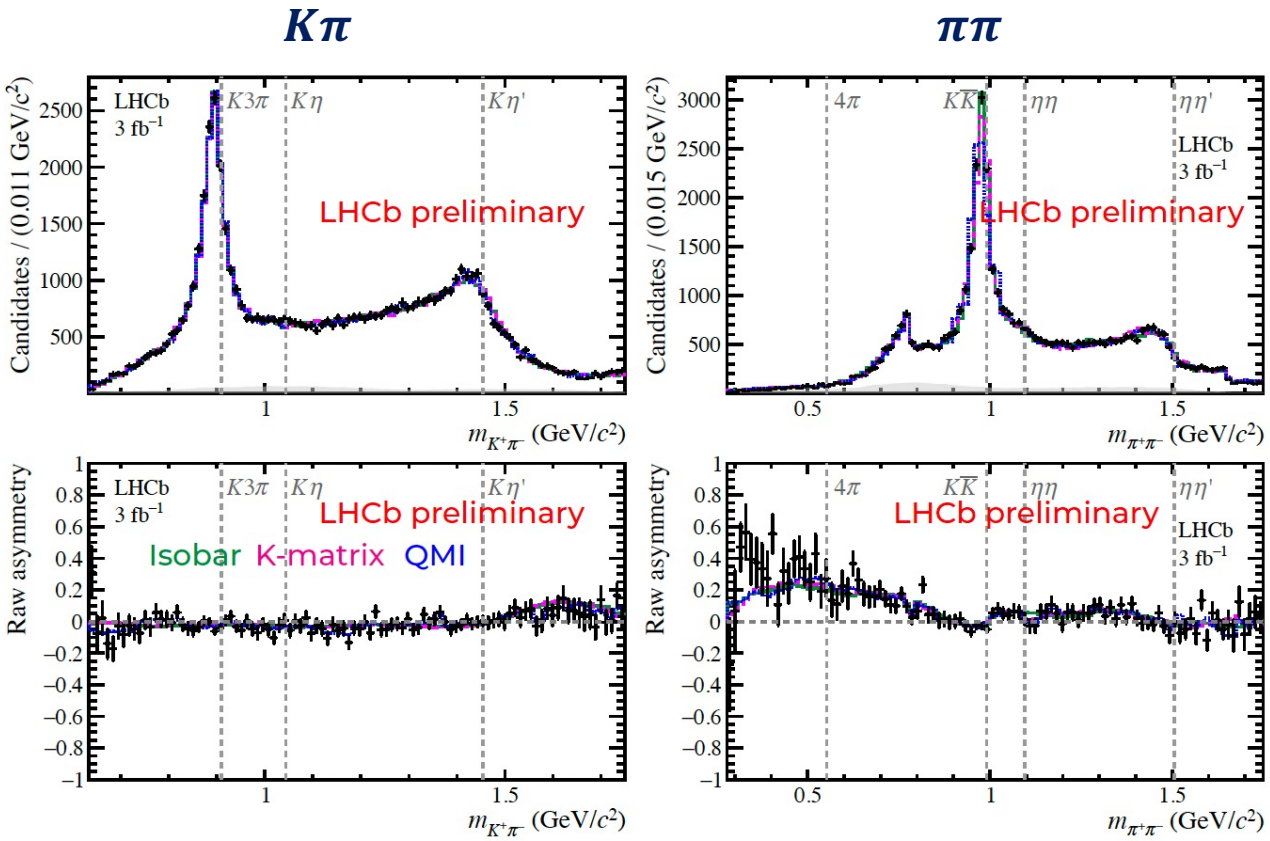


- **Advanced techniques in amplitude analyses:**
  - **Three ways to model S-wave: Isobar, K-Matrix, and MI approach (first MI implementation of $K\pi$ and $\pi\pi$ S-wave together)**
  - **Using GLASS to model $K\pi$ S-wave**
  - **Include also $\pi\pi \to \pi\pi$ (significant contributions found) and $KK \to \pi\pi$ rescattering contributions from dispersive relationship**

A glance of results (1)

Projections

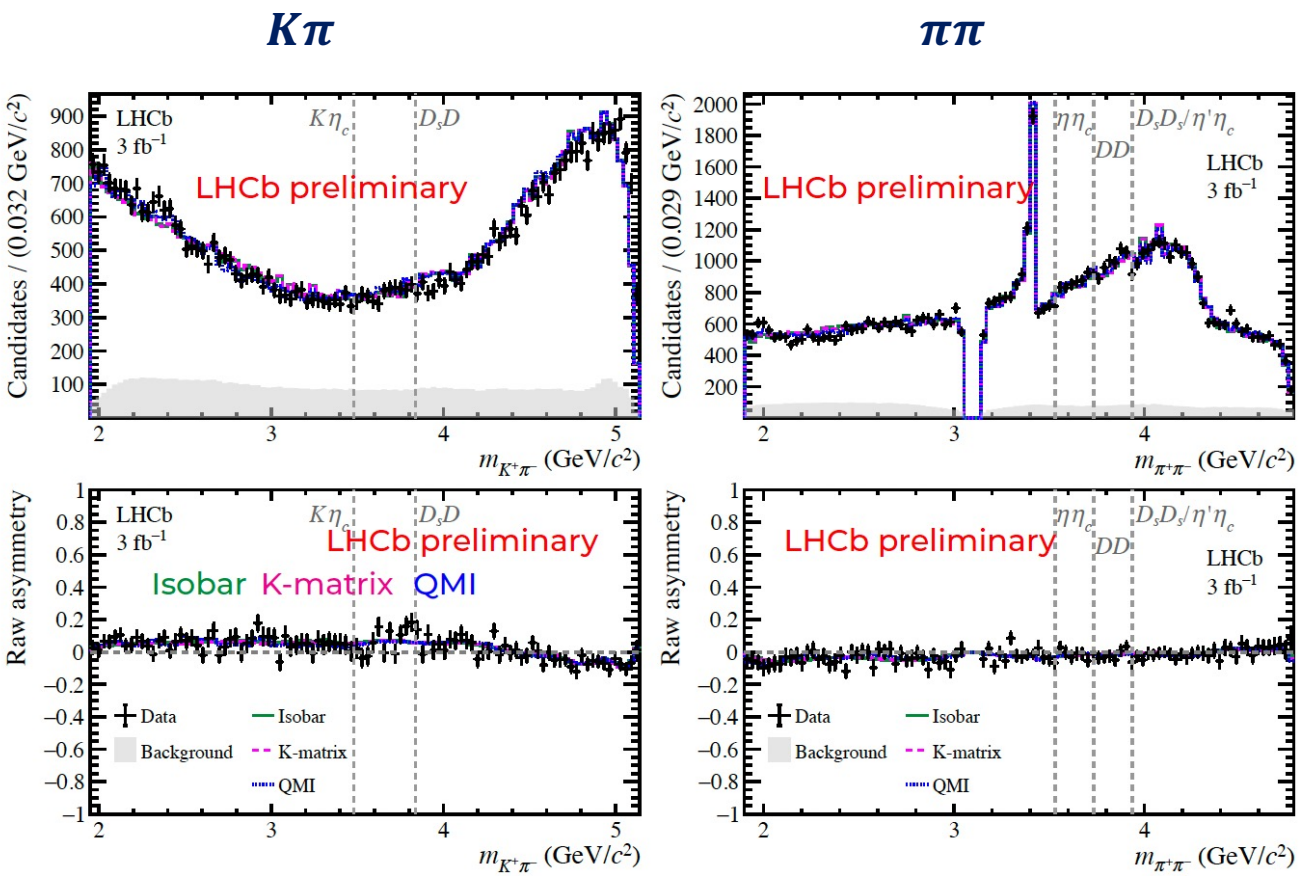
Asymmetry



A glance of results (2)

Projections

Asymmetry

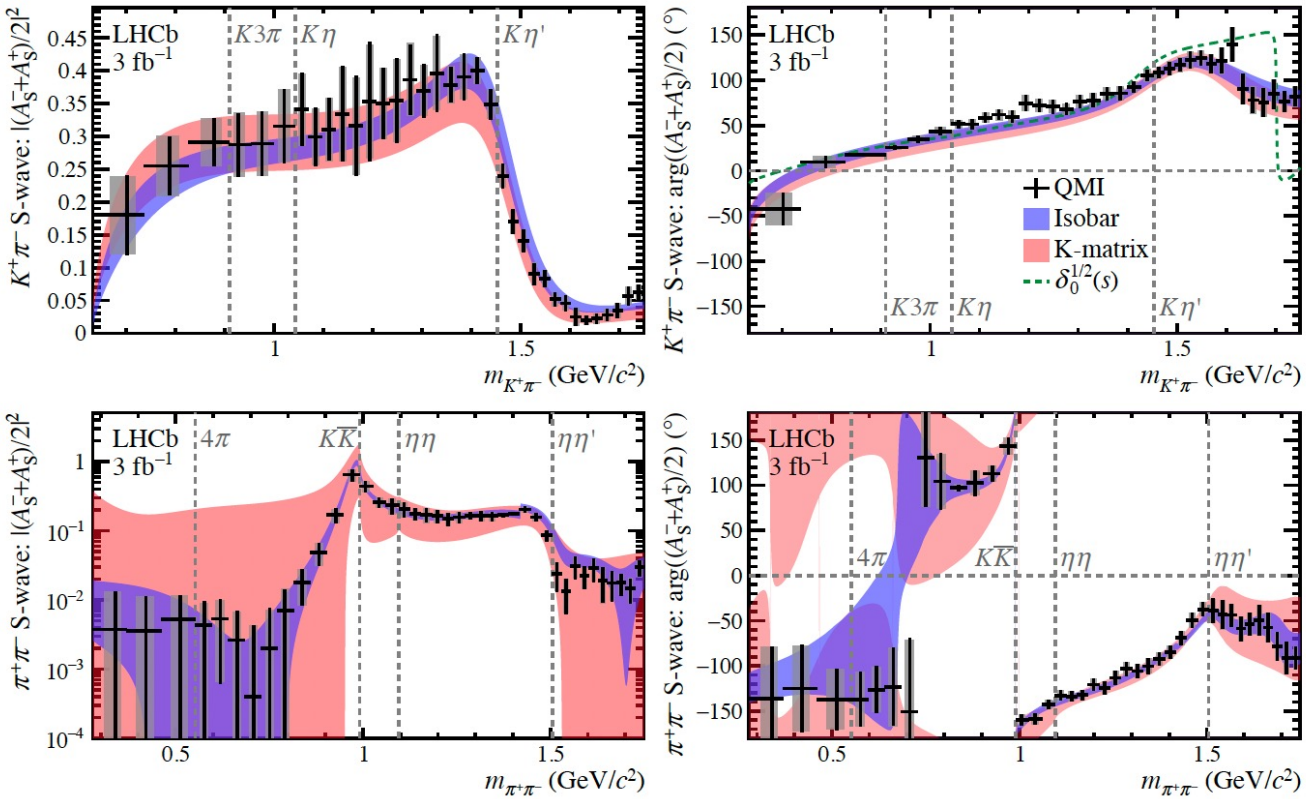


Amplitude and phase of S-wave

Amplitude **Phase**

Kπ

ππ



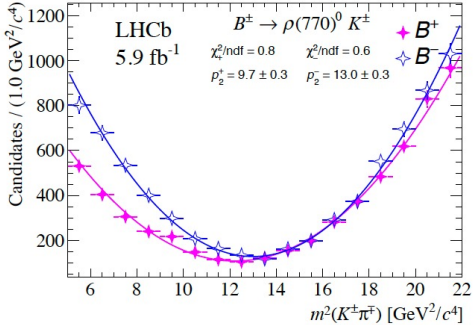
CP violation in $B^+ \to \rho(770)K^+(1)$

- **Measured by BaBar [PRD78 (2008) 012004] and Belle [PRL96 (2006) 251803] using amplitude analysis**

$$0.44 \pm 0.10^{+0.06}_{-0.14} \text{ (BaBar)} \qquad 0.30 \pm 0.11^{+0.11}_{-0.04} \text{ (Belle)}$$

- **However, a model-independent determination of CP violation in $\pi^+\pi^-$ P-wave around $\rho(770)$ by LHCb sees a much smaller CP violation**

$$0.150 \pm 0.022$$



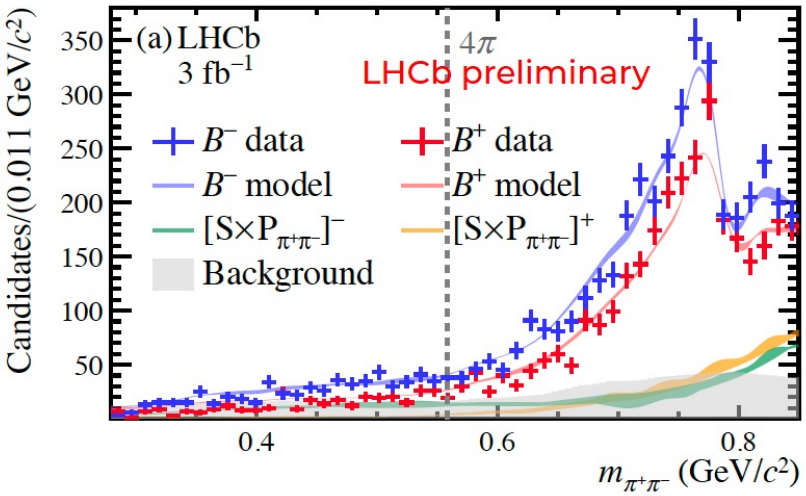
- **Our results from amplitude analysis:**

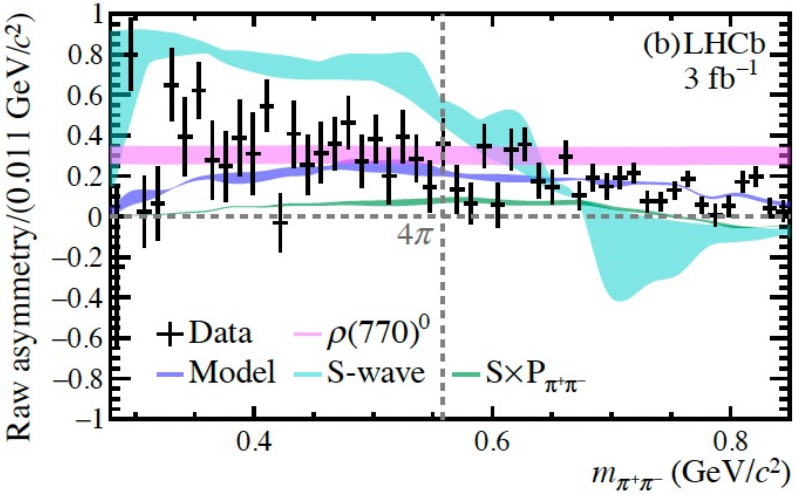
Parameter	Isobar	K-matrix	QMI
$A_{CP}(\rho(770)^0)$	$0.280 \pm 0.022 \pm 0.029$	$0.271 \pm 0.022 \pm 0.014$	$0.359 \pm 0.037 \pm 0.048$
$A_{CP}(\omega(782)^0)$	$0.011 \pm 0.158 \pm 0.064$	$-0.023 \pm 0.131 \pm 0.063$	$-0.004 \pm 0.139 \pm 0.015$

- **Consistent with BaBar and Belle, higher than model-independent which contains dilution from $\omega(782)$ with CP violation consistent with zero**

CP violation in $B^+ \to \rho(770)K^+(2)$

- **CP violation in $\rho(770)$ region clearly visible**





- **Predictions from theory:**

QCDF	pQCD	SCET	FS
31.7% [NPB675 (2003) 333] 45.4%[PRD80 (2009) 114008]	71% [PRD74 (2006) 094020]	16%[PRD78 (2008) 034011]	30.6%[PRD91 (2015) 014011]

CP violation in $B^+ \to \omega(782)K^+$

- **Quite some predictions gave very large CP violation**

QCDF	pQCD	SCET	FS
19.3% [NPB675 (2003) 333] 22.1%[PRD80 (2009) 114008]	32% [PRD74 (2006) 094020]	12.3%[PRD78 (2008) 034011]	1.0%[PRD91 (2015) 014011]

- **Our measured results, consistent with zero, but with large uncertainties**

Parameter	Isobar	K-matrix	QMI
$A_{CP}(\omega(782)^0)$	$0.011 \pm 0.158 \pm 0.064$	$-0.023 \pm 0.131 \pm 0.063$	$-0.004 \pm 0.139 \pm 0.015$

- **Modeling of $\omega(782)$ decay**
  - **$\omega(782) \to \pi^+\pi^-$ directly: RBW**
  - **$\omega(782) \to \rho(770) \to \pi^+\pi^-$: GS×RBW**
  - **Little difference on NLL**

Parameter (Isobar)	Fit fraction (%)	A_{CP}	$\delta^+(°)$	$\delta^-(°)$
$\omega(782)$	0.202 ± 0.030	0.011 ± 0.158	104.3 ± 7.2	82.4 ± 6.5
$\rho(770) - \omega(782)$	0.175 ± 0.026	0.005 ± 0.129	2.1 ± 7.5	-20.0 ± 6.1

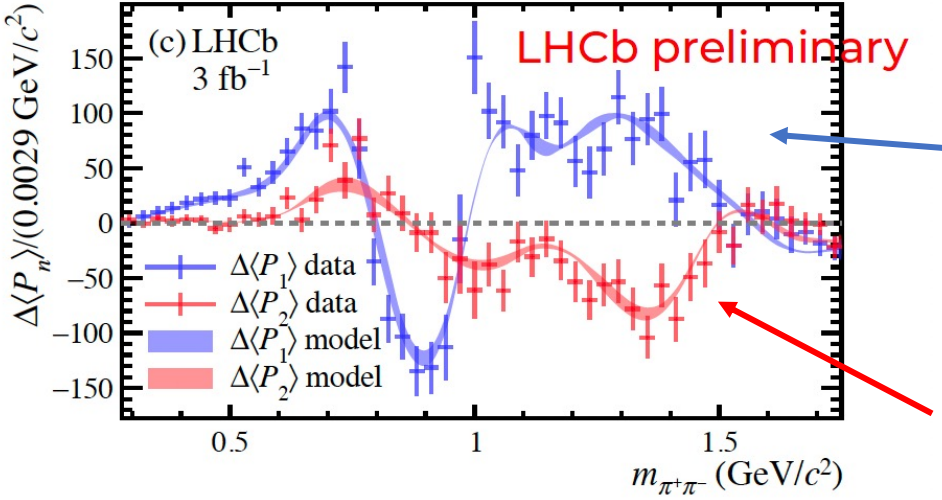
CP violation through interference between different waves

- **Legendre polynomial weighted CP violation**

$$\langle P_1 \rangle \propto SP\cos(\theta_S - \theta_P) + 2\sqrt{\tfrac{2}{5}}PD\cos(\theta_P - \theta_D)$$

$$\langle P_2 \rangle \propto \sqrt{\tfrac{2}{5}}P^2 + \sqrt{\tfrac{10}{7}}D^2 + \sqrt{2}SD\cos(\theta_S - \theta_D)$$

- **CP violation in interference between S-P waves (discovery) and S-D waves (evidence)**



Almost flat vs $m(\pi^+\pi^-)$

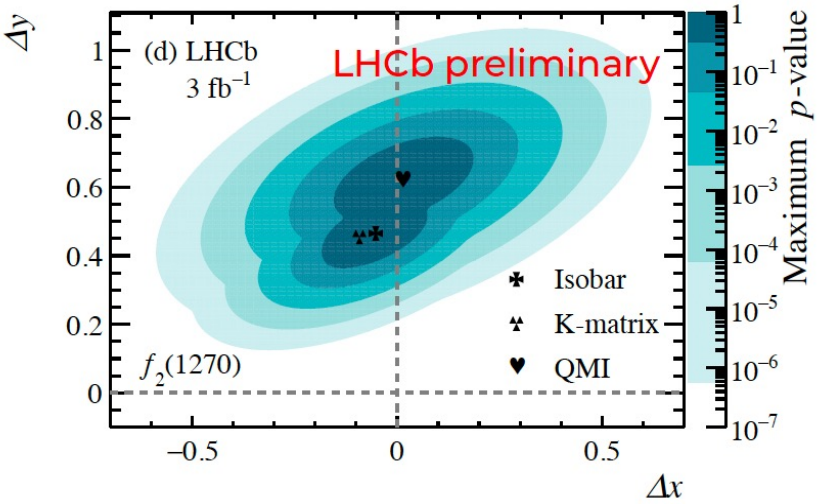
S-P waves $\cos(\theta_S - \theta_P)$

Phase shift of π around $\rho(770)$ pole

P wave + D wave + possible S-D wave interference

More CP violation results

Parameter	Isobar	K-matrix	QMI
$A_{CP}^{S}(m_{\pi^+\pi^-} < m_{4\pi})$	$0.657 \pm 0.033 \pm 0.059$ (9.7σ)	$0.638 \pm 0.008 \pm 0.016$ (35.5σ)	$0.754 \pm 0.115 \pm 0.113$ (4.7σ)
$A_{CP}(f_2(1270))$	$-0.354 \pm 0.047 \pm 0.076$ (4.1σ)	$-0.402 \pm 0.051 \pm 0.041$ (6.1σ)	$-0.279 \pm 0.067 \pm 0.115$ (2.1σ)
$A_{CP}(\rho_3(1690))$	$0.603 \pm 0.090 \pm 0.121$ (4.2σ)	$0.477 \pm 0.100 \pm 0.096$ (3.4σ)	$0.698 \pm 0.135 \pm 0.163$ (3.3σ)



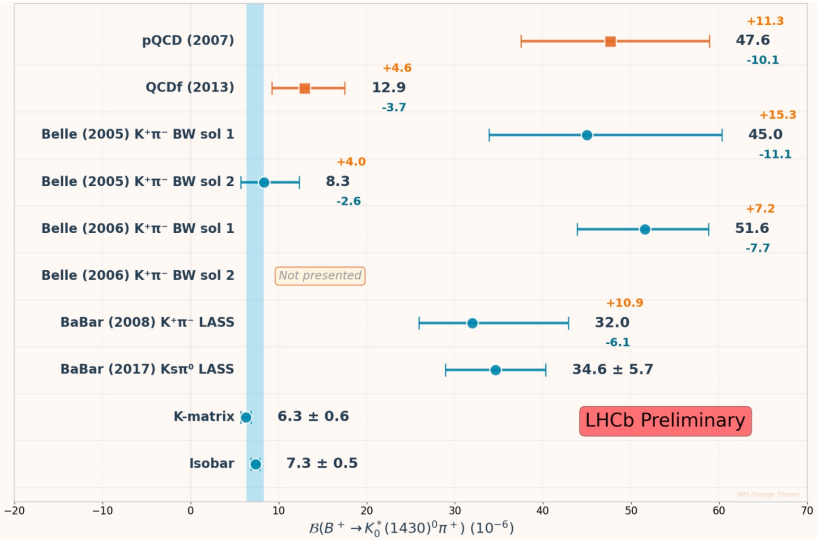
- **Very large CP violation found in S-wave low $m(\pi^+\pi^-)$ mass ($\pi\pi$ rescattering region)**
- **Direct A_{CP} not exceeding 5σ for $f_2(1270)$, however amplitude analysis offer more information**

$$A = \sum c_i F_i, \qquad \bar{A} = \sum \bar{c}_i F_i$$

$$c_i = (x_i + \Delta x_i) + i(y_i + \Delta y_i) \qquad \bar{c}_i = (x_i - \Delta x_i) + i(y_i - \Delta y_i)$$

- **CP established with more than 8.2σ with phase information**
- **Evidence of CP violation in spin-3 final state also seen**

Branching fraction of $B^+ \to K_0^*(1430)\pi^+$



- Different predictions from pQCD[EPJC50 (2007) 877] and QCDf[PRD87 (2013) 114001]
- Two solutions from Belle measurements, one agree with pQCD, other with QCDf; the one with larger branching fraction presented in later Belle paper
- BaBar also favors larger branching fraction (pQCD)
- Predictions with QCDf agree better with $B \to K_0^*(1430)[\eta^{(\prime)}, \rho, \omega, \phi]$

Our results favors QCDf!

$$\delta_{\rm Res}(s) = \phi_{\rm Nonres} + \delta'_{\rm Res}\,,\ \delta_{\rm ER}(s) = \phi_{\rm ER} + \delta'_{\rm ER}$$

Two improvements:

$$A_{\rm GLASS}(s) \equiv a_{\rm GLASS}(\sin\delta_{\rm Res} e^{i\delta_{\rm Res}} e^{2i\delta_{\rm ER}} + a_{\rm ER}\sin\delta_{\rm ER} e^{i\delta_{\rm ER}})$$

- Larger datasets: same model as Belle also favor QCDf
- Model improvements: GLASS instead of LASS

LASS: $a_{ER} = 1, \phi_{\rm nonres} = 0$
$\phi_{ER} = 0$

Separation between SVP and $K^*(892)$

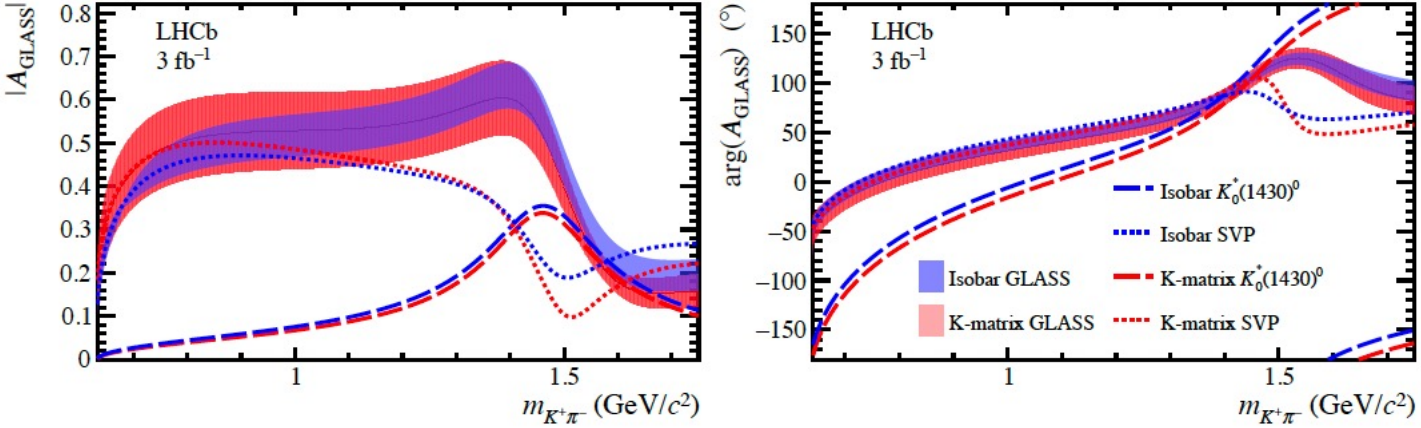
$$A_{\mathrm{GLASS}}(s) \equiv a_{\mathrm{GLASS}}(\sin\delta_{\mathrm{Res}} e^{i\delta_{\mathrm{Res}}} e^{2i\delta_{\mathrm{ER}}} + a_{\mathrm{ER}} \sin\delta_{\mathrm{ER}} e^{i\delta_{\mathrm{ER}}})$$

$$\delta_{\mathrm{Res}}(s) = \phi_{\mathrm{Nonres}} + \delta'_{\mathrm{Res}}\,,\ \delta_{\mathrm{ER}}(s) = \phi_{\mathrm{ER}} + \delta'_{\mathrm{ER}}$$

LASS: $a_{ER} = 1, \phi_{\mathrm{nonres}} = 0$
$\phi_{ER} = 0$

$K^*(892)$ separated following (as close as RBW):

$$A_{K_0^*}(s) \equiv \left[\frac{1}{2}\cos 2\phi_{\mathrm{Nonres}} \sin 2\phi_{K_0^*}(s) + i\cos^2\phi_{\mathrm{Nonres}} \sin^2\phi_{K_0^*}(s)\right] e^{2i\delta_{\mathrm{ER}}}\,,\quad \phi_{K_0^*}(s) \equiv \arctan\left[\frac{m_{K_0^*}\Gamma(s)}{(m_{K_0^*}^2 - s)}\right],$$



Extra benefit: $f_X(1300)$

- **With LASS parameterization, BaBar and Belle also need a scalar $f_X(1300)$**
- **In Belle study[PRD71 (2005) 092003], different spin-parity tried, 1^- gives best NLL while 0^+ consistent with $f_0(1370)$**

J^P	Mass (MeV)	Width (MeV)	NLL
0^+(solution1, L)	1369 ± 26	185 ± 52	-4041.8
0^+(solution2, S)	1400 ± 28	165 ± 48	-4024.4
1^-	1330 ± 19	210 ± 48	-4048.1
2^+	1337 ± 38	85 ± 31	-4013.0

- **In BaBar study[PRD78 (2008) 012004], 0^+ gives a mass consistent with $f_0(1500)$ with $m = 1479 \pm 8$ MeV and $\Gamma = 80 \pm 19$ MeV, while 1^- also fits well with mass consistent with $\rho(1450)$**
- **Fit fraction of $f_X(1300)$ in Belle varies from 3.7% to 6.7%, while in BaBar, it is around 1.3%**
- **Theoretical interpretations: known scalar $f_0(1370)$ or $f_0(1500)$; Artefact from glueball; unknown scalar etc.**

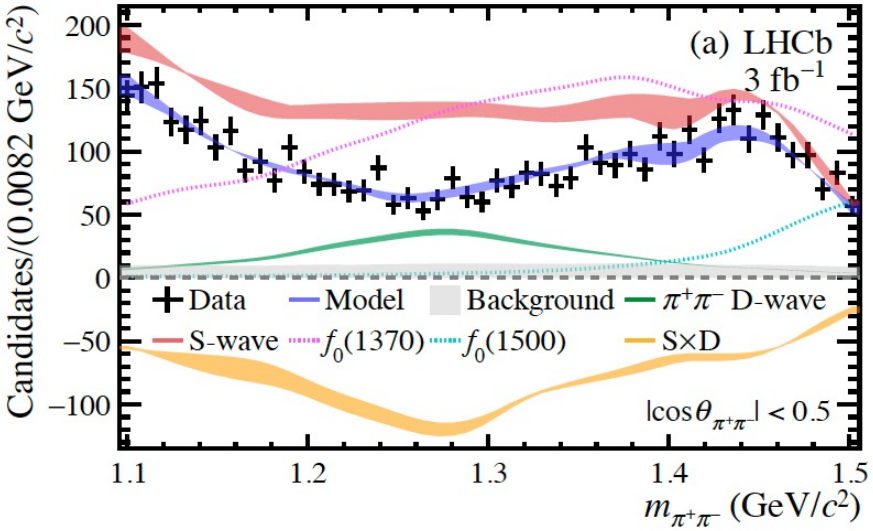
Our results on $f_X(1300)$

- **Our results when using LASS model, also need $f_X(1300)$ with $m = 1454 \pm 2$ MeV and $\Gamma = 120 \pm 5$ MeV**

Model	$\Delta(-2\text{NLL})$
LASS + $f_X(1300)$ (free mass + width)	1521
LASS + $f_0(1370) + f_0(1500)$ (fixed mass + width)	1598

BETTER

- **Our results when using GLASS**
  - **No need to include $f_X(1300)$**
  - $\Delta(-2\text{NLL})$ **more than 1500 better**
  - $\mathbf{FF}(f_0(1370)) = (16.8 \pm 1.0 \pm 0.8)\%$
  - $\mathbf{FF}(f_0(1500)) = (1.9 \pm 0.2 \pm 0.3)\%$



New decays and improved branching fractions

- **Quite some new decays found;**
- **Almost all the branching fractions are improved**

Component	Isobar (%)	
$K_2^*(1430)^0$	$2.253 \pm 0.125 \pm 0.302$	(6.9σ)
$f_2(1270)$	$2.152 \pm 0.110 \pm 0.275$	(7.3σ)
$K_0^*(1430)^0$	$13.076 \pm 0.633 \pm 1.602$	(7.6σ)
$f_0(1370)$	$16.785 \pm 0.951 \pm 0.770$	(13.7σ)
$f_0(1500)$	$1.857 \pm 0.150 \pm 0.255$	(6.3σ)
$K^*(1410)^0$	$0.700 \pm 0.092 \pm 0.158$	(8.5σ)
$\rho(1450)^0$	$1.213 \pm 0.212 \pm 1.024$	(3.9σ)
$\rho_3(1690)^0$	$0.408 \pm 0.047 \pm 0.094$	(7.2σ)
$K_0^*(1950)^0$	$0.793 \pm 0.092 \pm 0.133$	(15.4σ)
$f_0(500)$	$1.833 \pm 0.214 \pm 0.313$	(8.0σ)
$f_0(1710)$	$0.714 \pm 0.094 \pm 0.584$	(5.3σ)
$\pi\pi$-$\pi\pi$	$5.365 \pm 0.833 \pm 1.584$	(8.5σ)

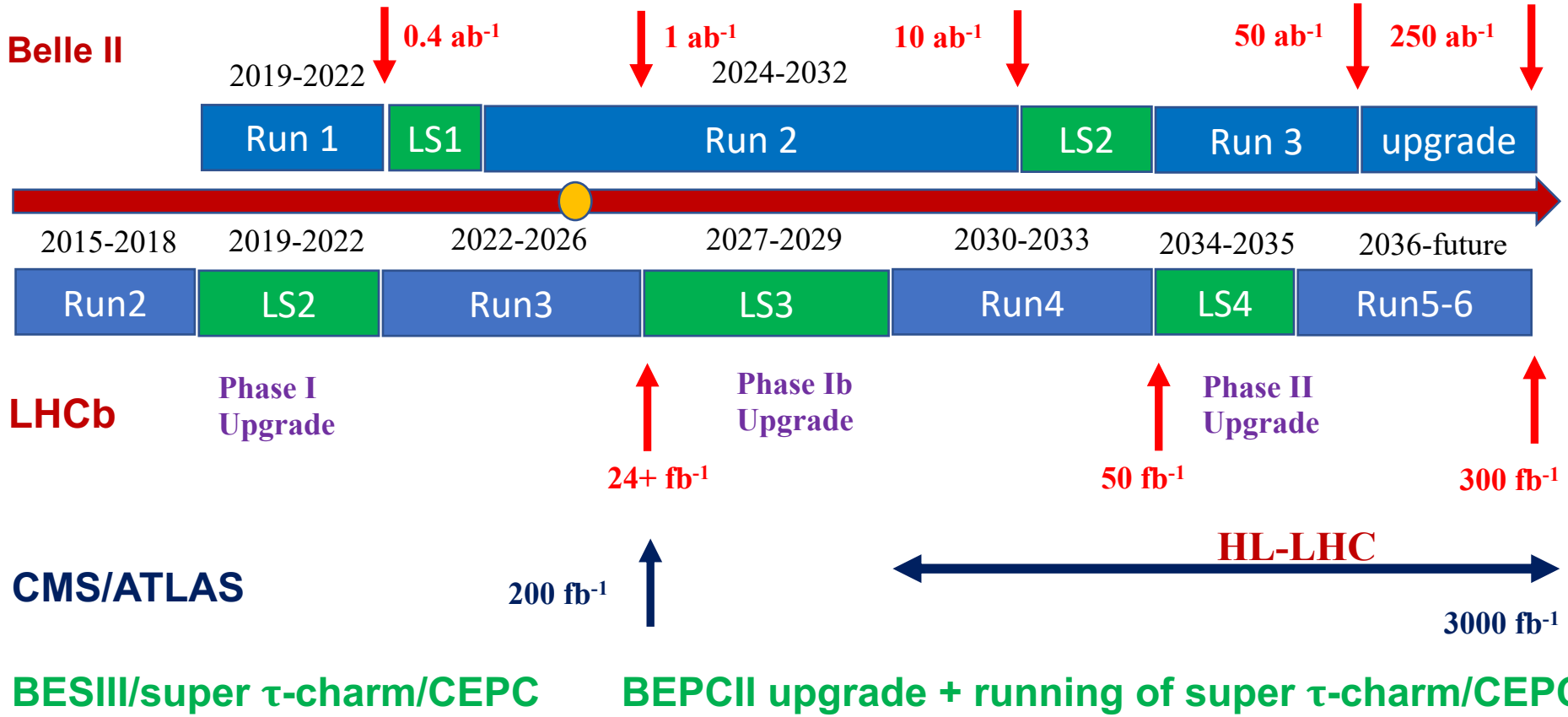
Component	HFLAV (10^{-6})	Branching fraction (10^{-6})	Upper limit at 90% (95%) CL (10^{-6})
$B^+ \to K^*(892)^0\pi^+$	10.4 ± 0.8	$10.54 \pm 0.44 \pm 0.44 \pm 0.26$	—
$B^+ \to K^*(1410)^0\pi^+$	< 45 (90% CL)	$9.17 \pm 2.39 \pm 2.49 \pm 1.82$	—
$B^+ \to K^*(1680)^0\pi^+$	< 12 (90% CL)	$0.49 \pm 0.21 \pm 0.23 \pm 0.03$	< 0.91 (1.02)
$B^+ \to \rho(770)^0K^+$	3.74 ± 0.47	$4.51 \pm 0.39 \pm 0.29 \pm 0.11$	—
$B^+ \to \omega(782)K^+$	6.47 ± 0.4	$7.59 \pm 1.71 \pm 0.73 \pm 0.67$	—
$B^+ \to \rho(1450)^0K^+$ †	< 12 (90% CL)	$0.70 \pm 0.60 \pm 0.40 \pm 0.02$	—
$B^+ \to \rho(1700)^0K^+$ †	LHCb preliminary	$0.20 \pm 0.22 \pm 0.01 \pm 0.00$	< 0.51 (0.59)
$B^+ \to K_2^*(1430)^0\pi^+$	$5.6^{+2.2}_{-1.4}$	$3.90 \pm 0.57 \pm 0.31 \pm 0.13$	—
$B^+ \to f_2(1270)K^+$	1.07 ± 0.31	$2.21 \pm 0.30 \pm 0.30 \pm 0.09$	—
$B^+ \to f_2'(1525)K^+$	< 3.4(90% CL)	$3.90 \pm 3.84 \pm 0.63 \pm 0.51$ LHCb preliminary	< 9.31 (10.68)
$B^+ \to K_3^*(1780)^0\pi^+$	-	$1.02 \pm 0.27 \pm 0.91 \pm 0.06$	< 2.32 (2.65)
$B^+ \to \rho_3(1690)^0K^+$	-	$1.00 \pm 0.26 \pm 0.37 \pm 0.06$	—
$B^+ \to \chi_{c0}(1P)K^+$ ($\times 10^{-2}$)	2.16 ± 0.38	$2.03 \pm 0.12 \pm 0.18 \pm 0.09$	
$B^+ \to K_0^*(1430)^0\pi^+$	46.9 ± 5.0	$7.35 \pm 0.49 \pm 1.09 \pm 0.81$	—
$B^+ \to K_0^*(1950)^0\pi^+$	-	$1.32 \pm 0.27 \pm 0.08 \pm 0.36$	—
$B^+ \to f_0(500)K^+$ †	-	$1.06 \pm 0.22 \pm 0.03$	—
$B^+ \to f_0(980)K^+$ †	$9.4^{+0.84}_{-0.92}$	$9.55 \pm 0.44 \pm 0.23$	—
$B^+ \to f_0(1370)K^+$ †	< 11 (90% CL)	$9.67 \pm 0.70 \pm 0.23$	—
$B^+ \to f_0(1500)K^+$	-	$4.65 \pm 0.74 \pm 0.32$	—
$B^+ \to f_0(1710)K^+$ †	-	$0.41 \pm 0.34 \pm 0.01$	—
$B^+ \to (\pi\pi\text{-}\pi\pi)K^+$ †	-	$3.09 \pm 1.03 \pm 0.08$	—
$B^+ \to (\pi\pi\text{-}K\bar{K})K^+$ †	-	$0.13 \pm 0.09 \pm 0.00$	< 0.26 (0.29)

Outline of the talk

- Introduction
- Precise measurement of the CKM angle γ with a novel approach
- CP violation studies in $B^+ \to K^+\pi^+\pi^-$ decays
- **Prospects and conclusion**

Disclaimer: results are selected based on personal taste

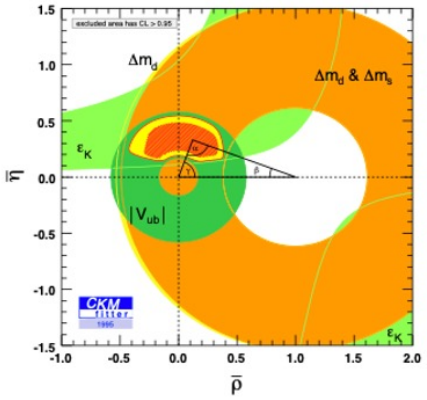
Prospects on flavor physics programs



BESIII/super τ-charm/CEPC

BEPCII upgrade + running of super τ-charm/CEPC

Future of flavor physics



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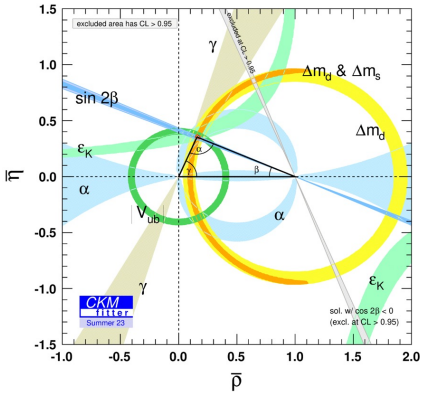
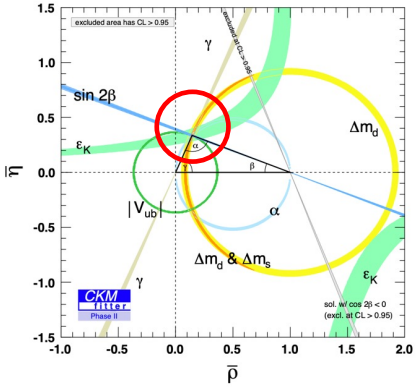
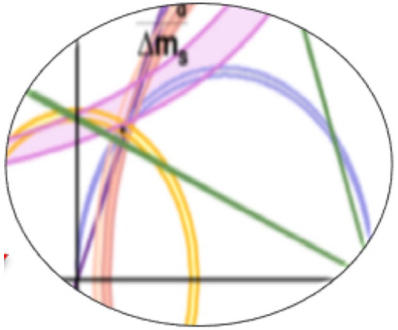


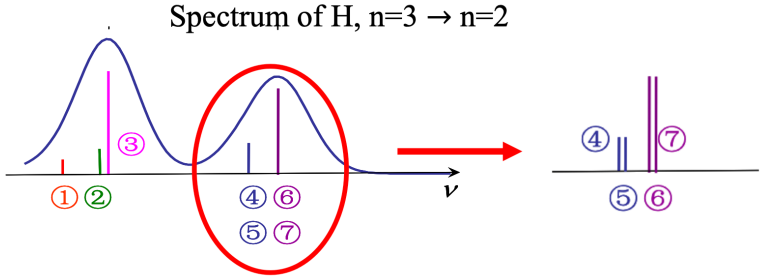
2023



2040?



New physics may probably arrive soon!



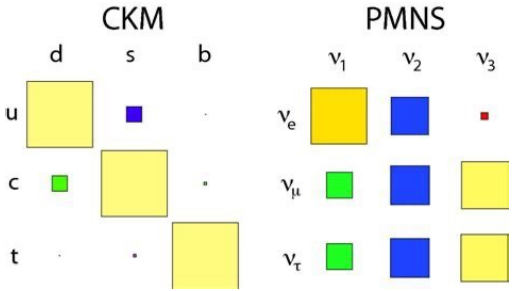
Thank you for your attention!

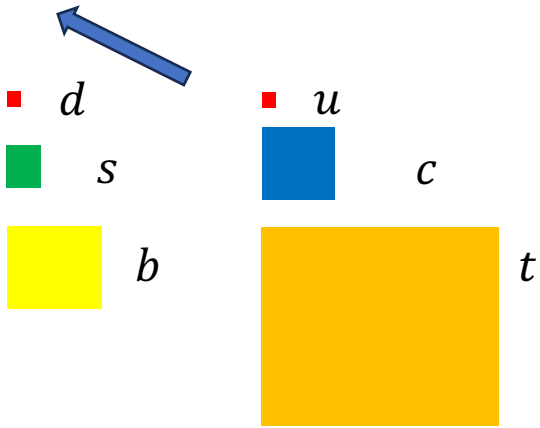
CP violation in SM

- Complex phases in CKM matrix and PMNS matrix
- CKM matrix：unitary matrix connecting interaction and mass eigenstates

$$\begin{pmatrix} d^I \\ s^I \\ b^I \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Interaction eigenstates Mass eigenstates





- Matrix pattern very different？ Why？
- Jarlskog invariant:

$$J_{exp} \sim 3\times10^{-5} < J_{max} = 1/6\sqrt{3} \sim 0.1$$

- Related to mass hierarchy? Relation between Yukawa and CKM?

A new LHCb detector

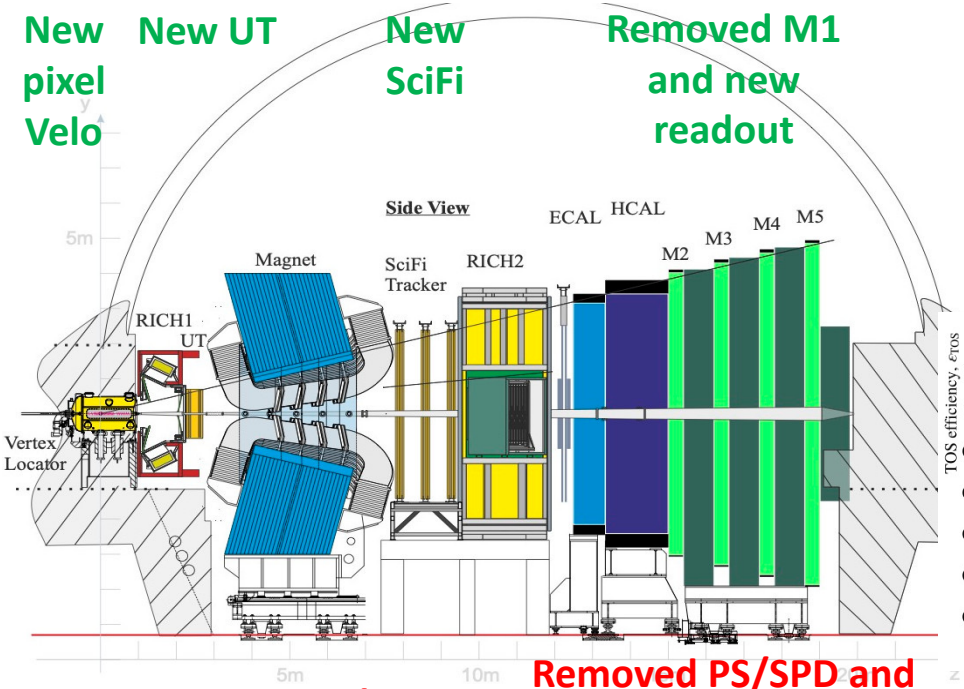
- With our new LHCb detector, already collected more data than Run1+2
- More importantly, full software trigger ➜ better performance on hadronic final states

New pixel Velo

New UT

New SciFi

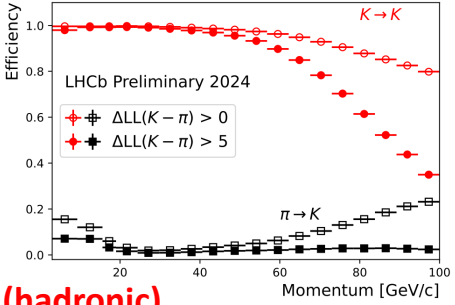
Removed M1 and new readout



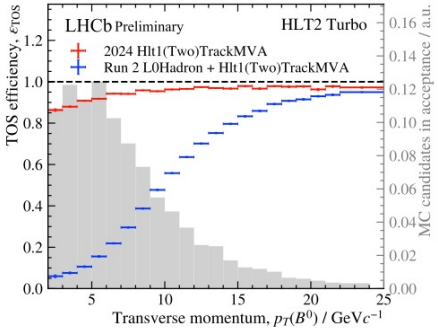
New RICH optics and PMS

Removed PS/SPD and new readout

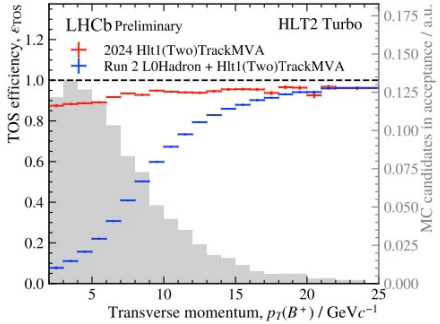
Similar PID performance



Twice trigger efficiencies (hadronic)



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



$B^+ \to \bar{D}^0 \pi^+$

Next LHCb detector from 2030