



# 第十九届重味物理和CP破坏研讨会 暨会议20周年庆典

2022年 12月9日-11日

## 大会总结

于福升 兰州大学

主办：中科院高能所、南京师范大学、北京大学、清华大学、上海交通大学、中国科学院大学、南开大学、复旦大学、兰州大学、烟台大学、华中师范大学、江苏师范大学、内蒙古大学、暨南大学、南京市科协、南京物理学会  
承办：南京师范大学物理科学与技术学院

报告总数：60

理论报告：39

实验报告：21

理论与实验结合

非常抱歉没办法面面俱到讲到每一个报告内容!

# 2002年第一届重味物理和CP破坏研讨会



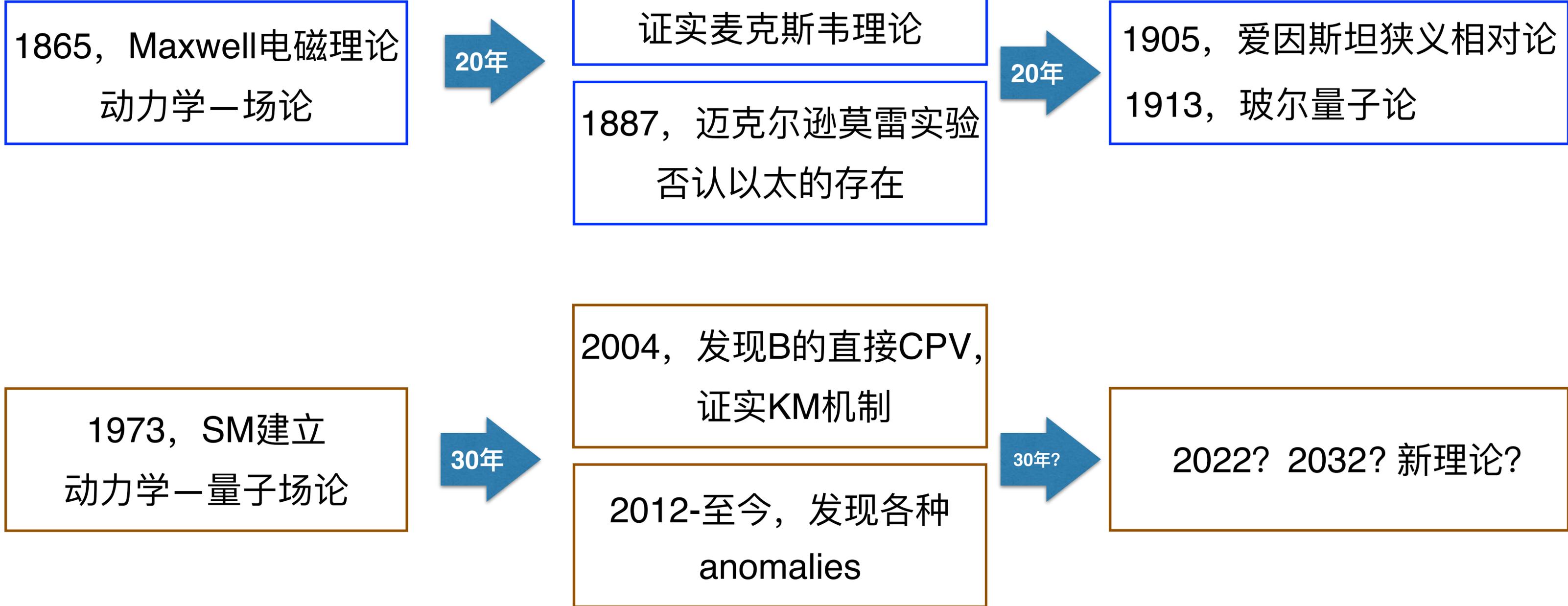
队伍壮大、年轻！  
感谢两三代前辈们的努力！

# 2019年全国重味物理和CP破坏研讨会

2019. 7. 29-8. 1 于呼和浩特



## 二三十年能做什么？



# 高精度：做到极致

引力波的发现：不仅仅是验证了广义相对论，更重要的是提供了新的实验手段，多信使时代，  
如相变引力波等

迈克尔逊-莫雷实验：什么都没有发现，也不见得一定是坏事，它同样可以带来物理学革命

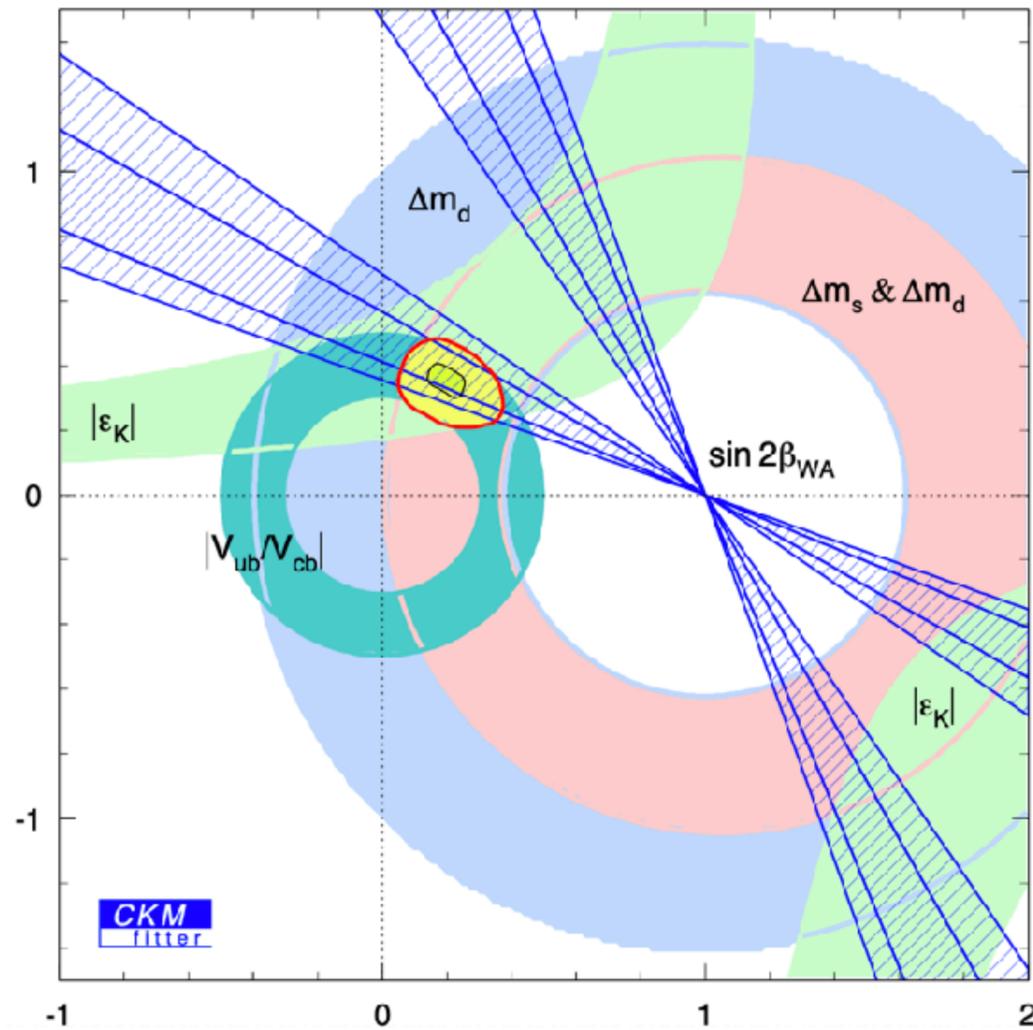
重味物理就是高精度前沿，就是要把各种事情做到极致，以期新的突破和发现！！！！

# 高精度：做到极致

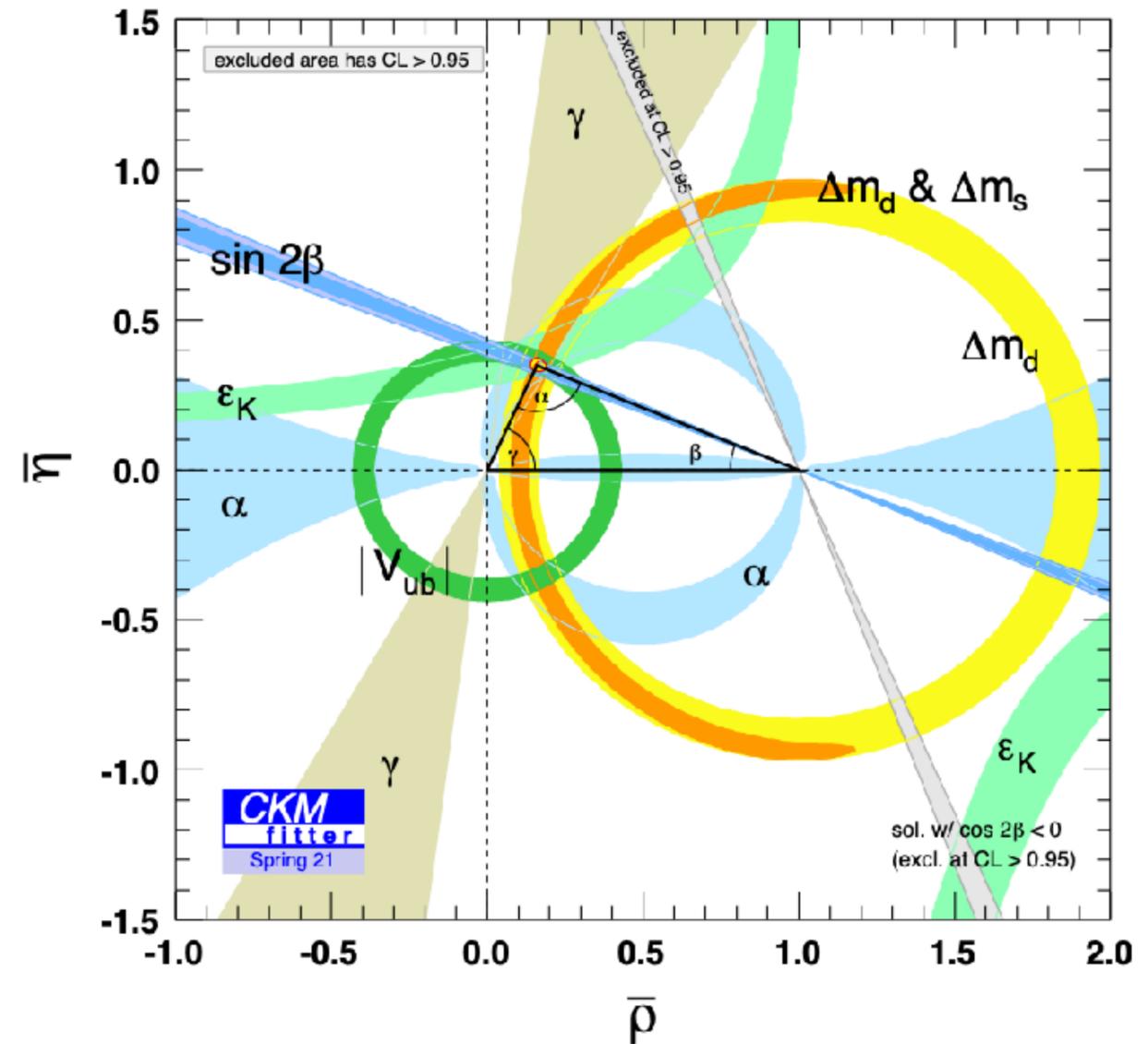
- 1.实验精度的提高
- 2.理论精度的提高
- 3.理论与实验结合

# CKM unitarity

2002



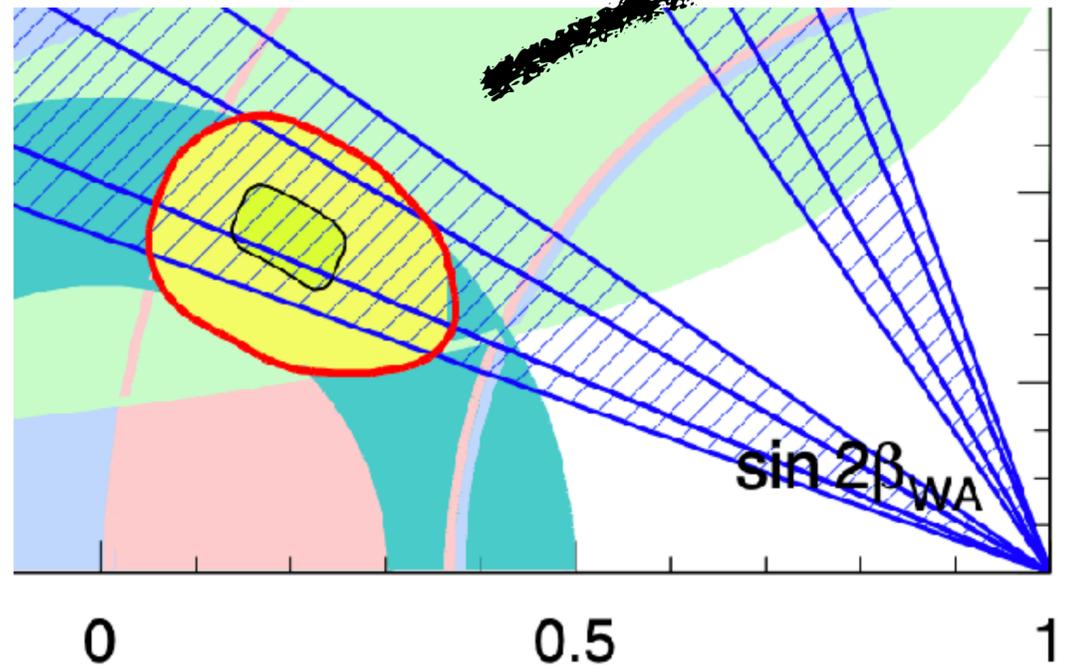
2022



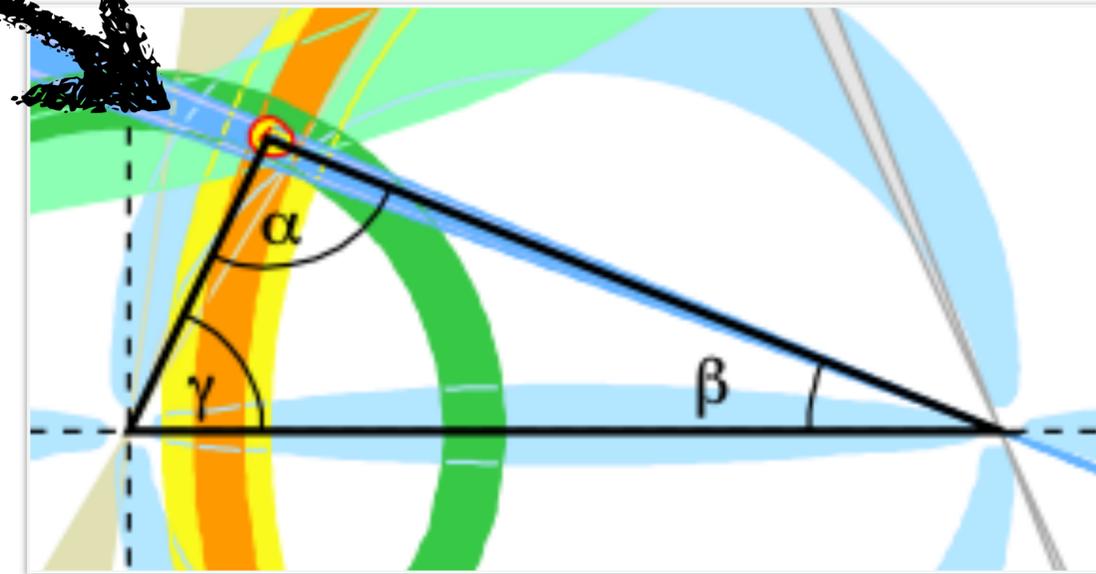
The only phase parameter in the SM

# CKM unitarity

2002

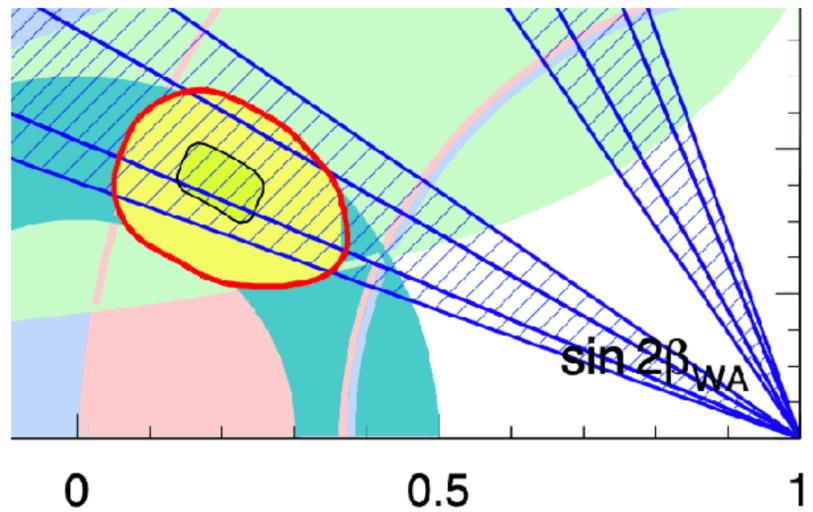


2022



# CKM unitarity

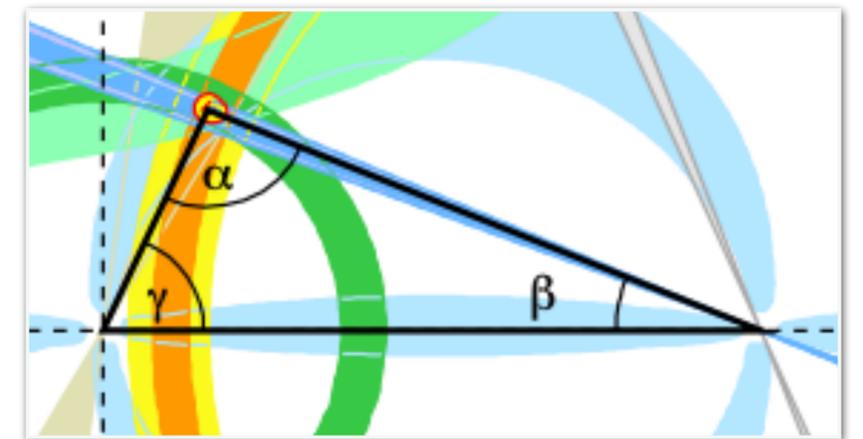
2002



2012

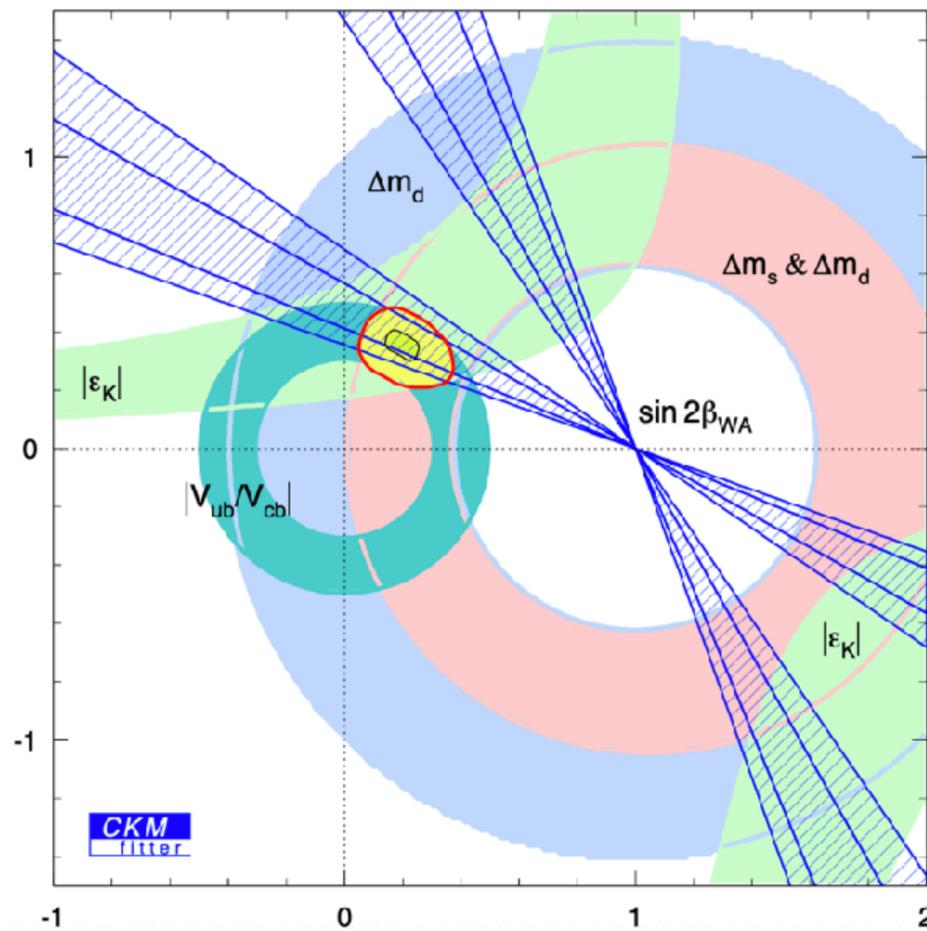
Higgs discovery  
 $B_s^0 \rightarrow \mu^+ \mu^-$ : SM  
 $B \rightarrow D\tau\nu$ : BSM

2022

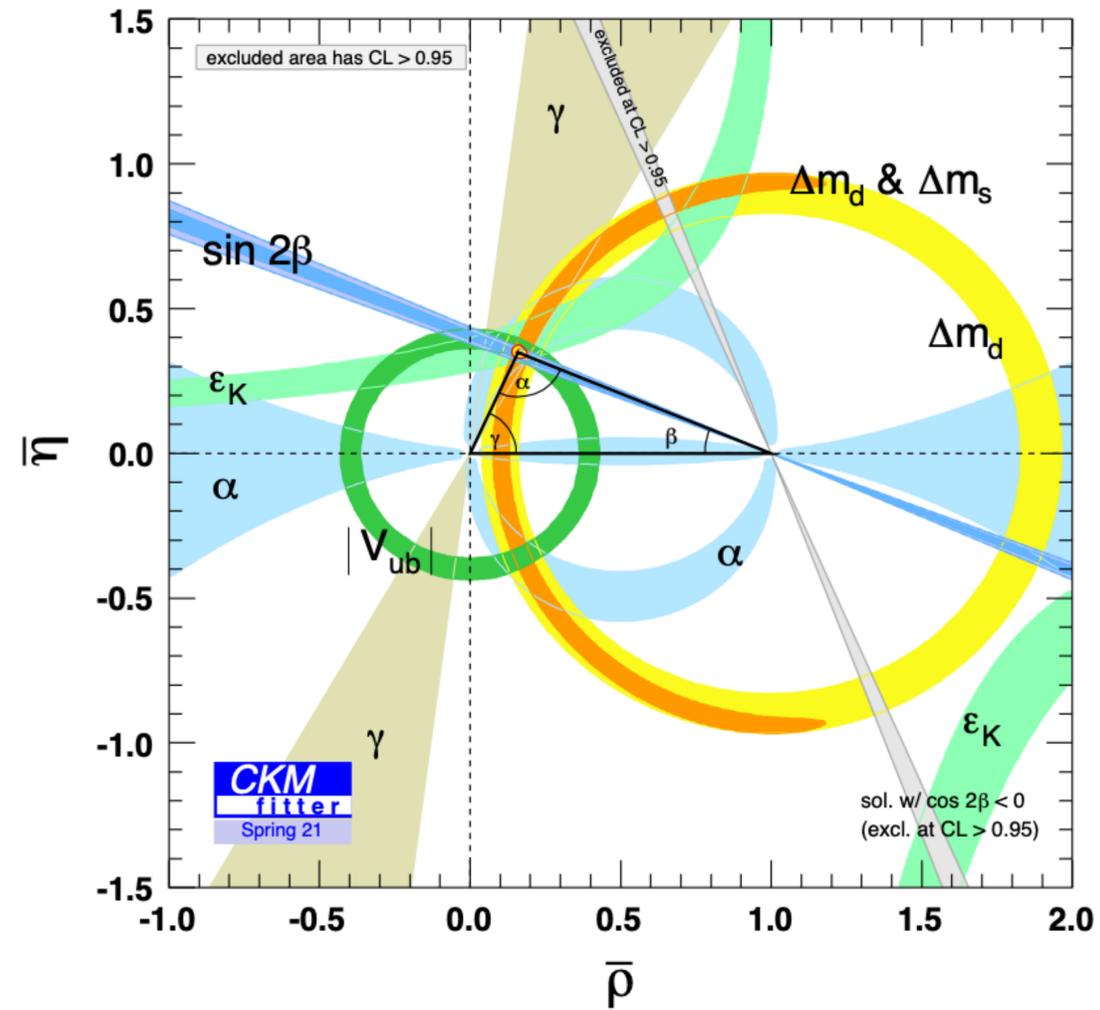


# CKM unitarity

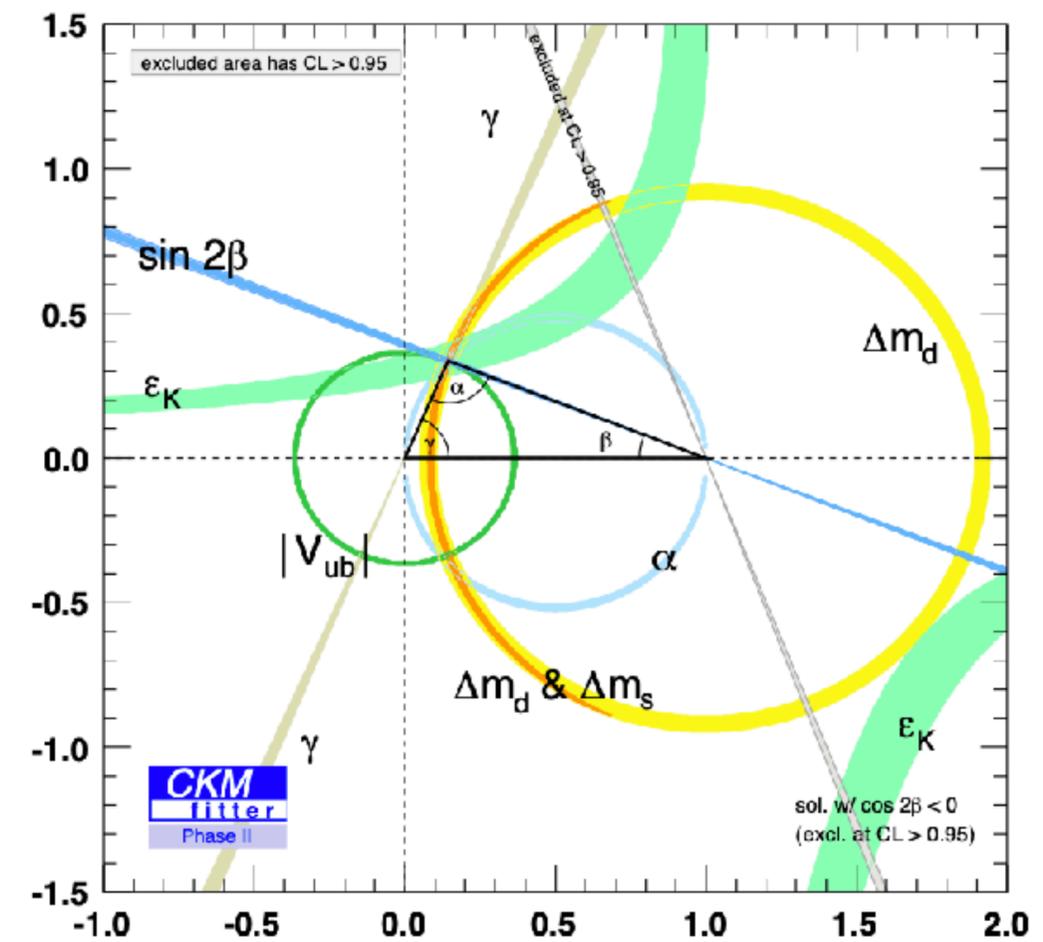
2002

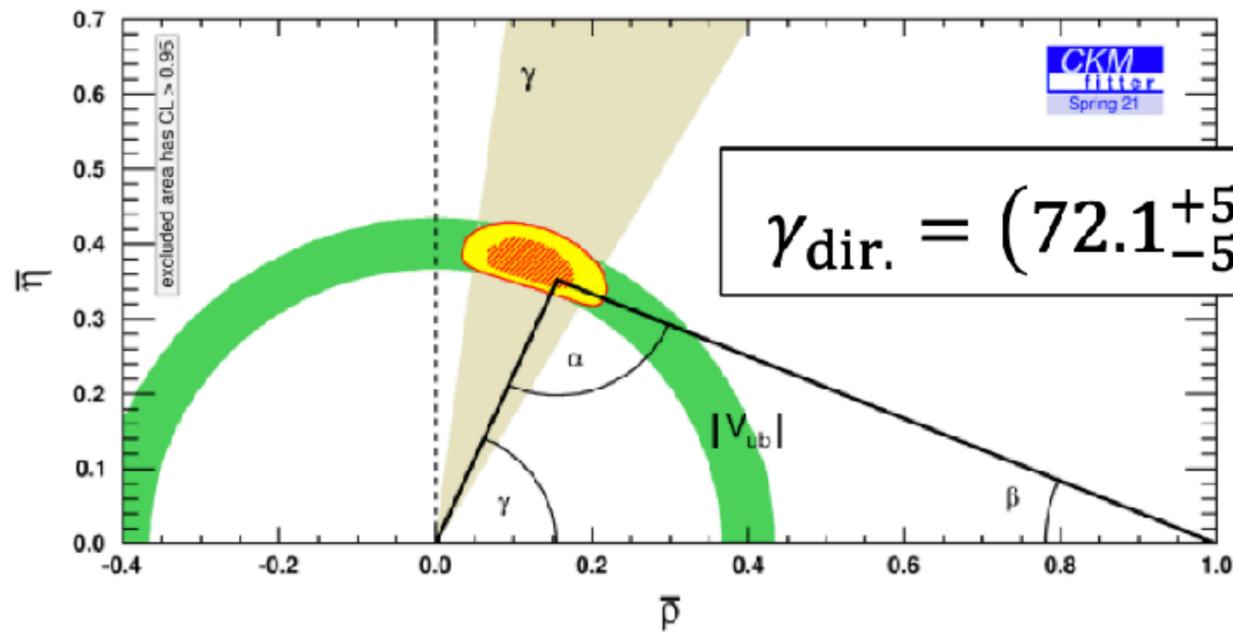


2022



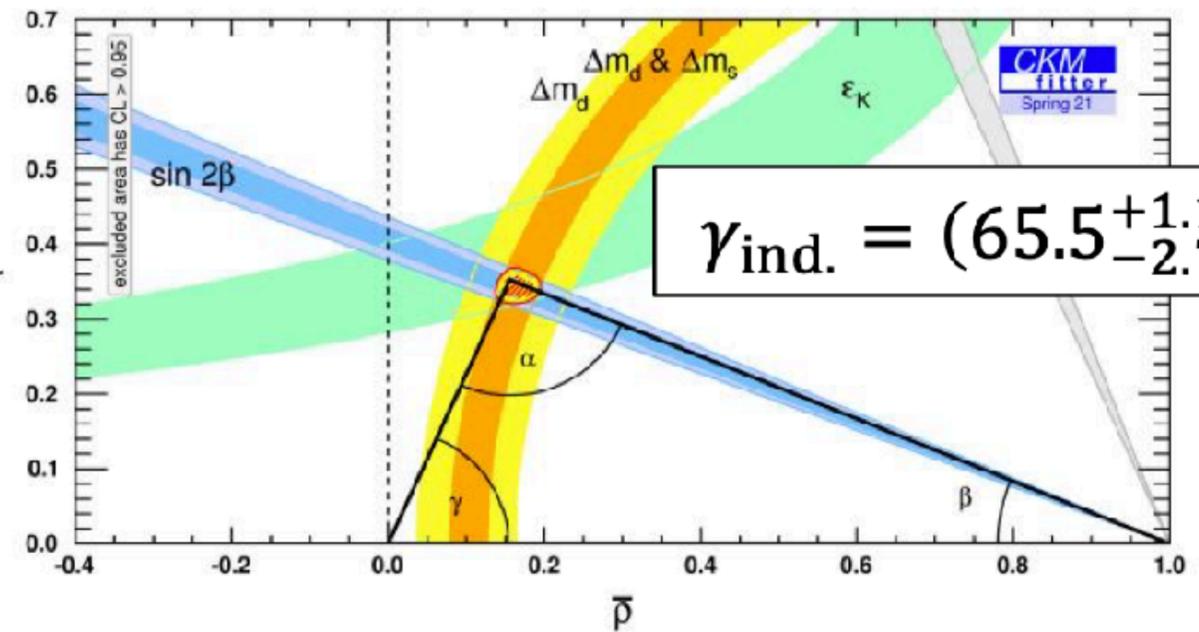
2032 ??



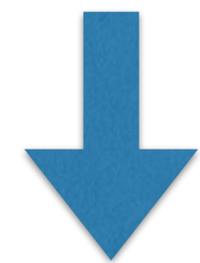


2021

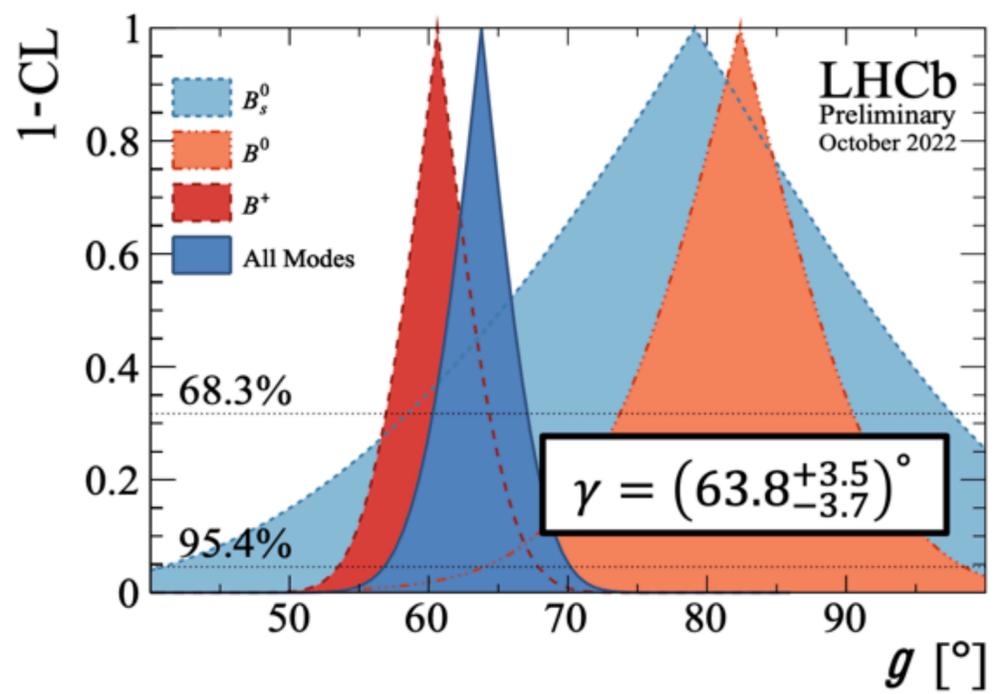
CKMfitter, Preliminary results as of spring 2021



$\gamma$  angle



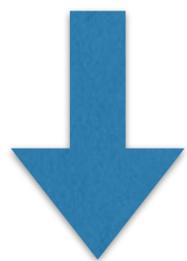
2022



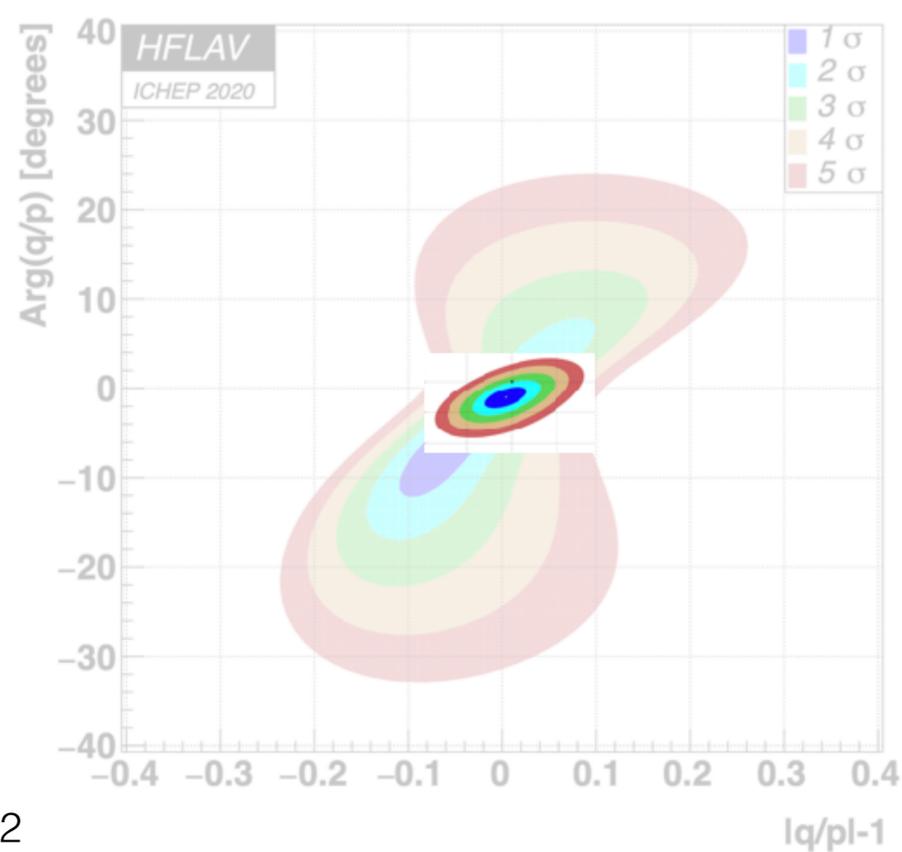
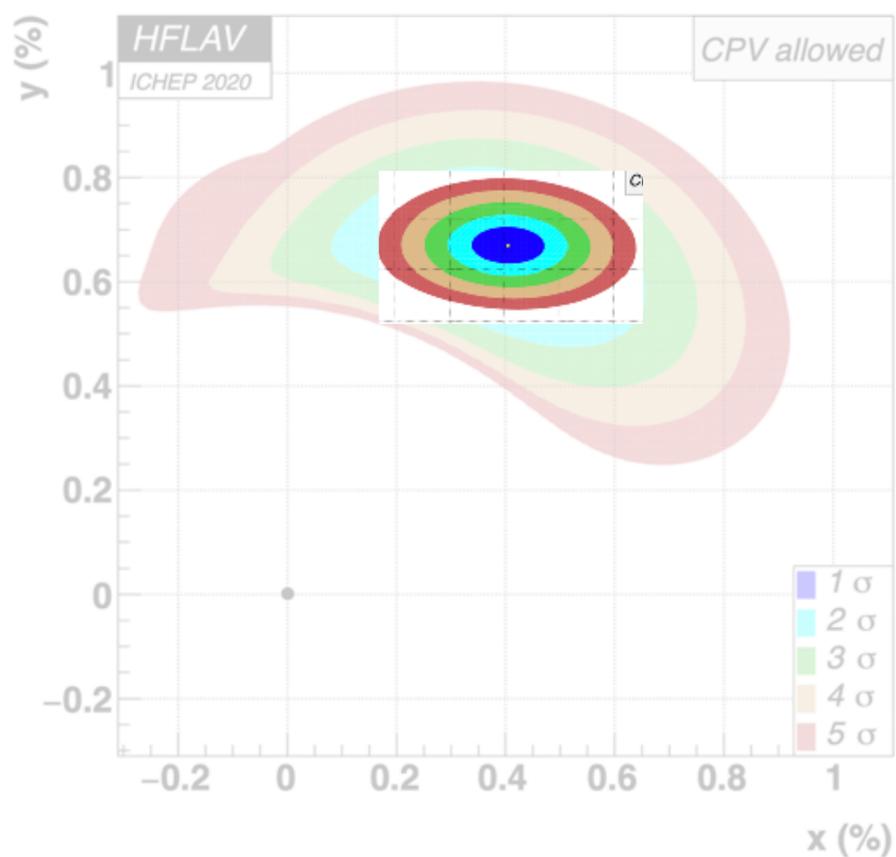
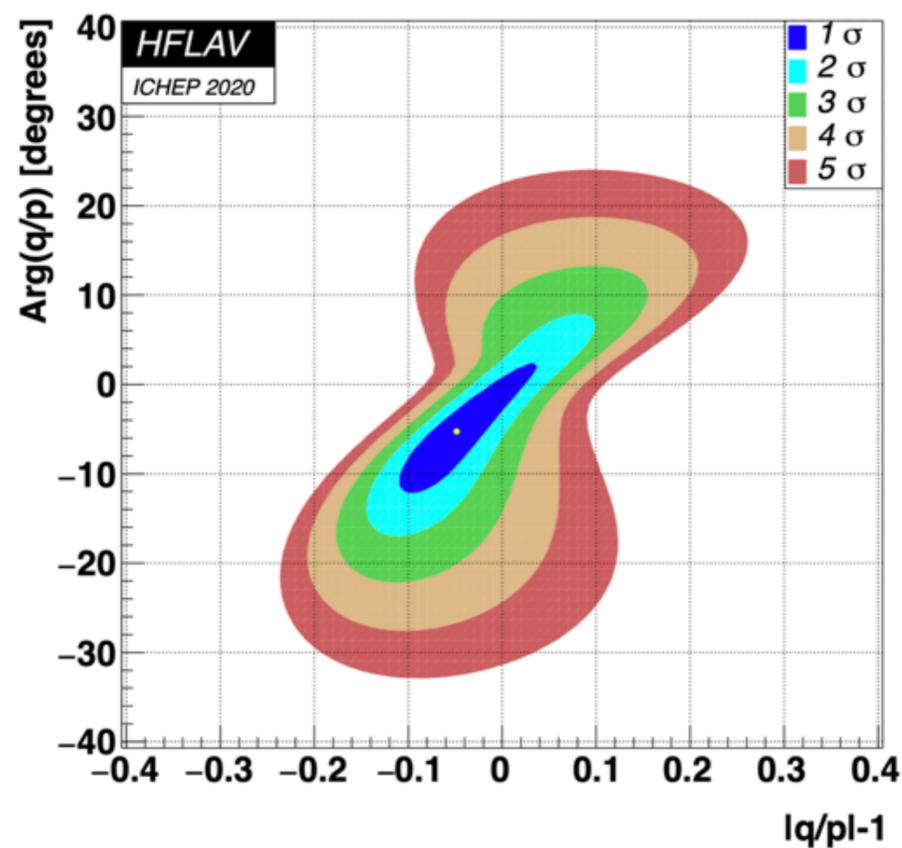
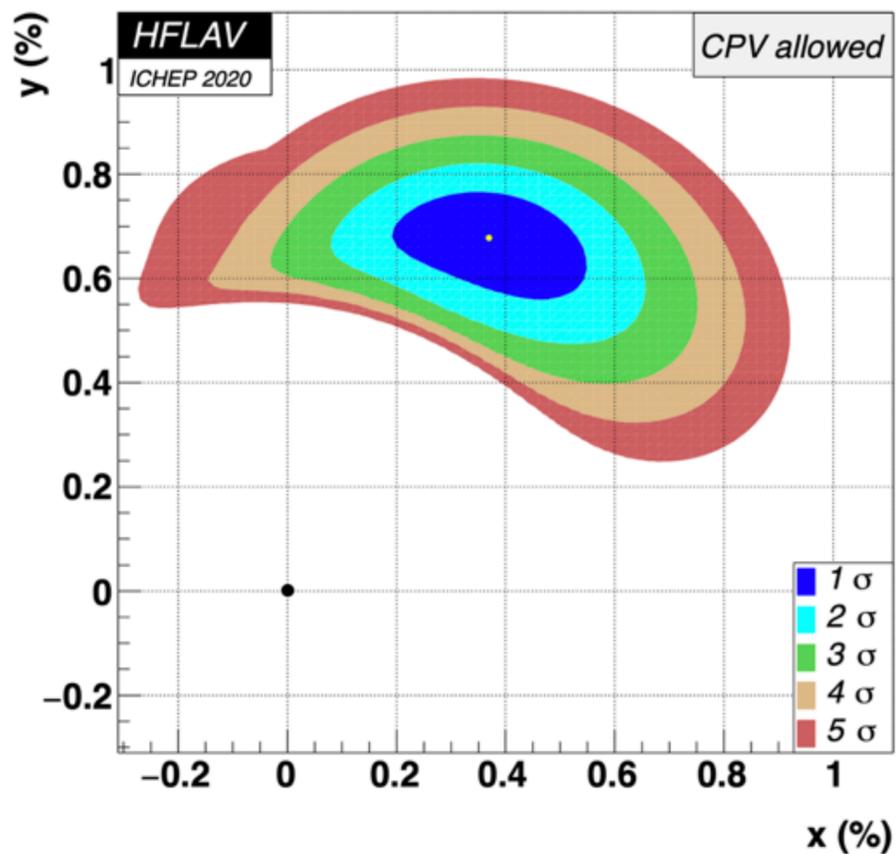
LHCb, see Shunan Zhang's talk

reached  $< 4^\circ$ , got closer to indirect determination  $\gamma_{\text{ind.}} = (65.5^{+1.1}_{-2.7})^\circ$

2020

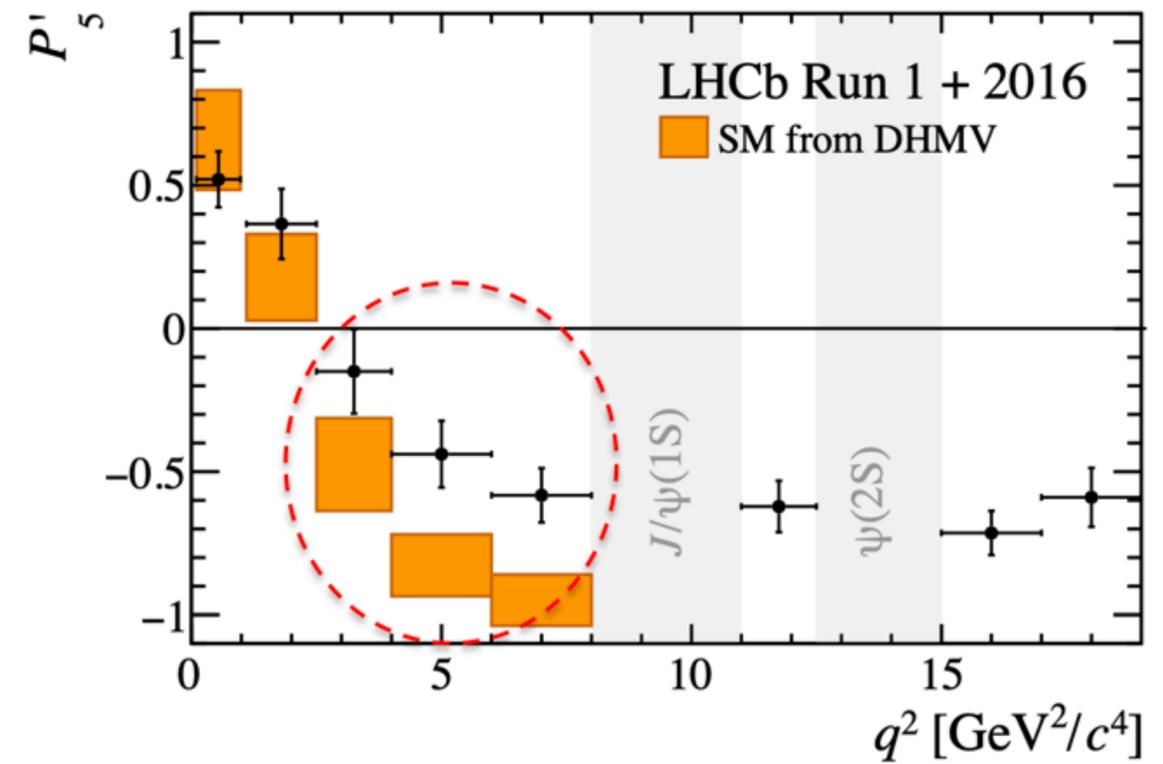
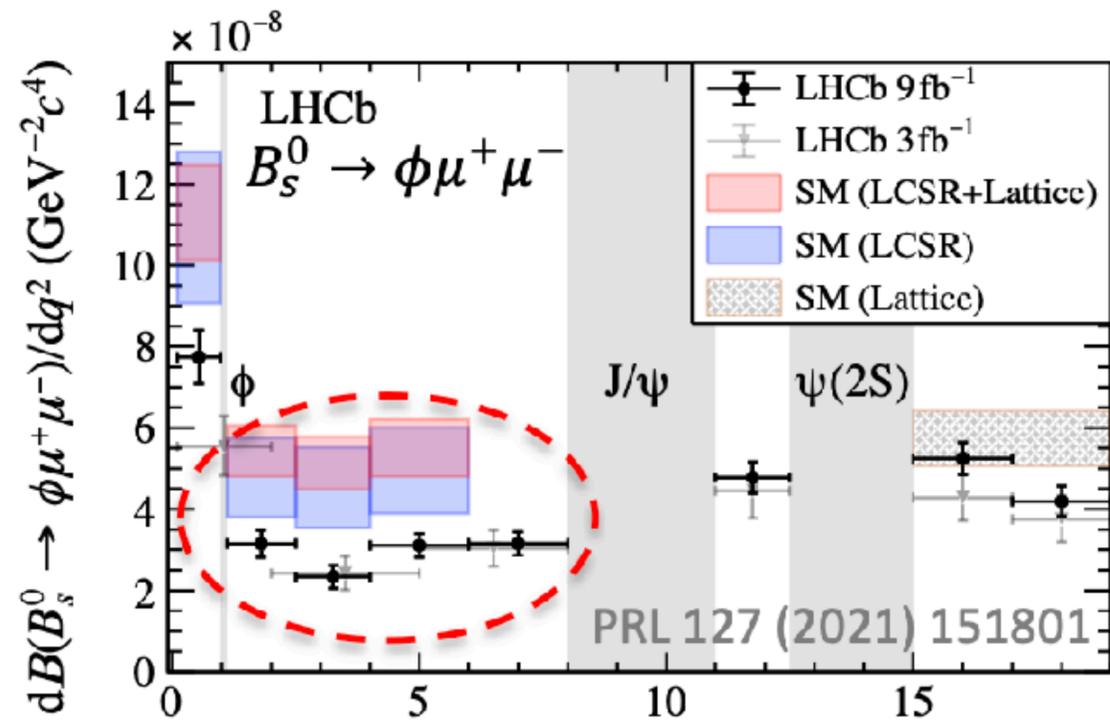


2022



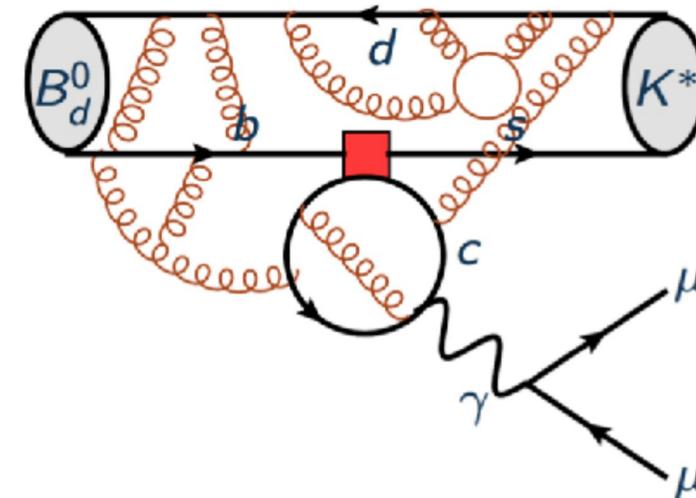
$D^0 - \bar{D}^0$

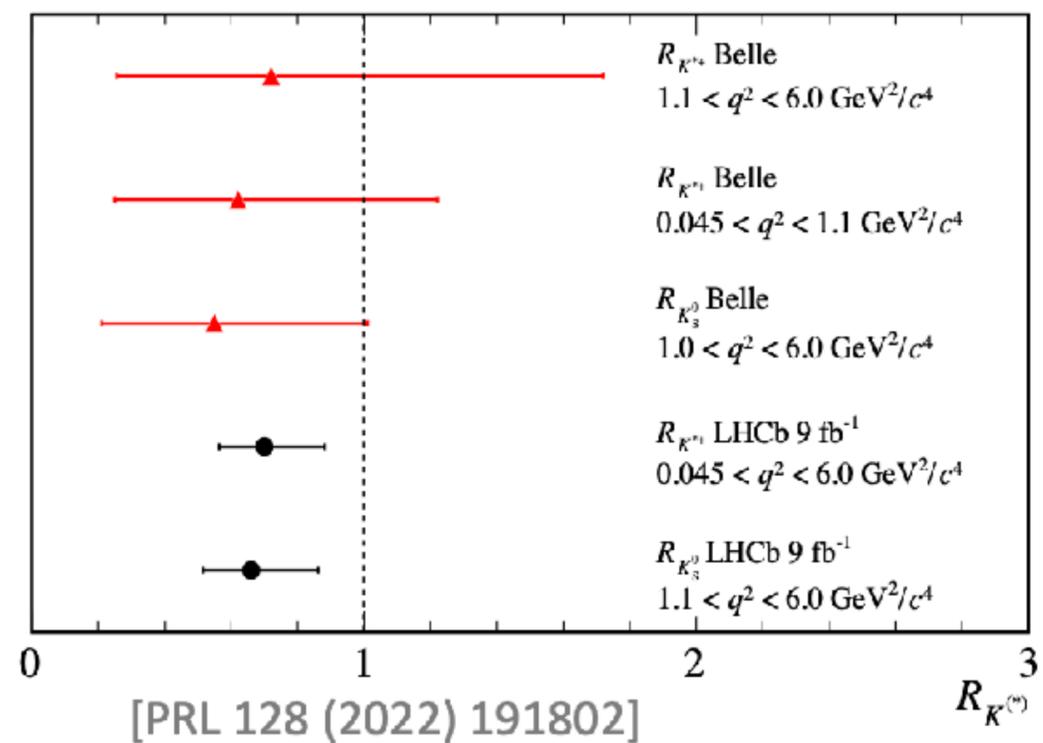
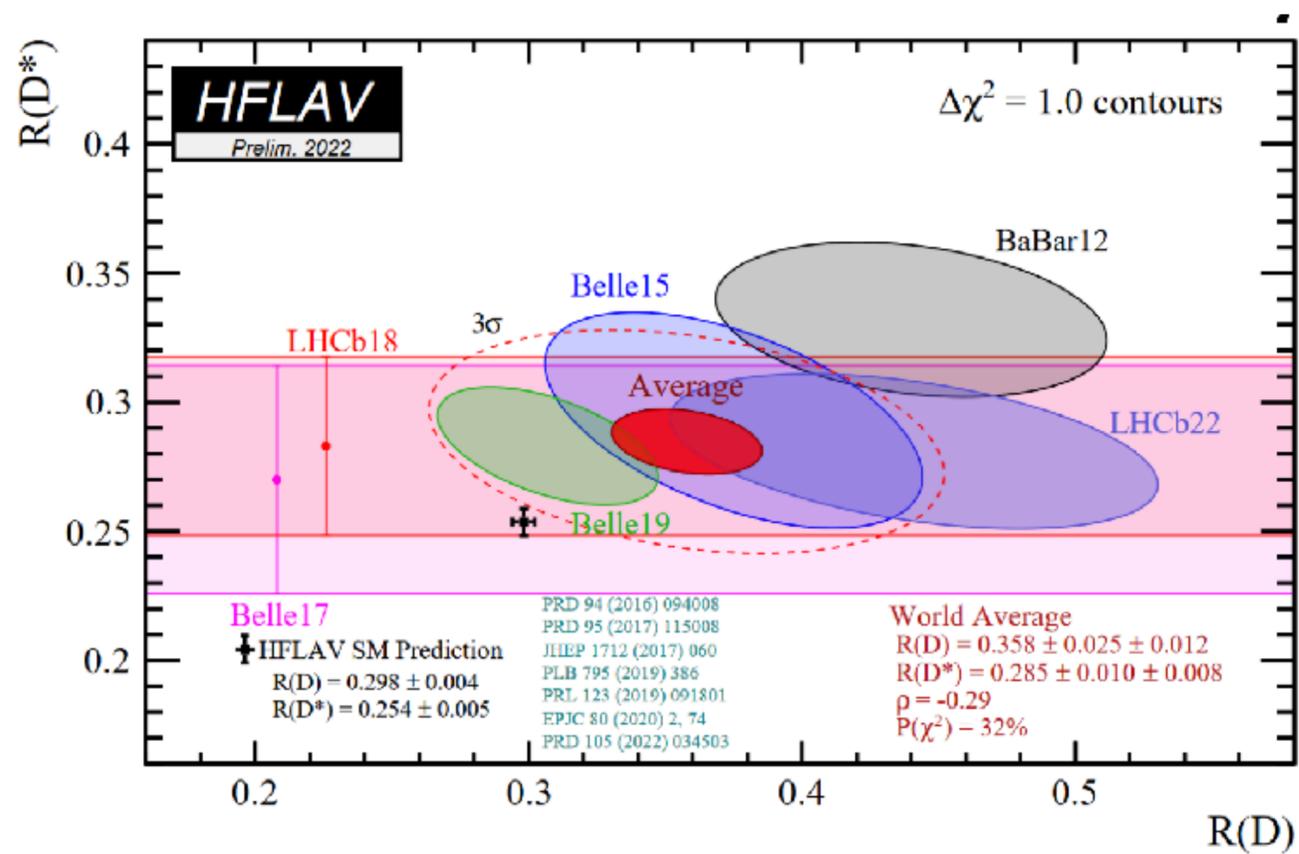
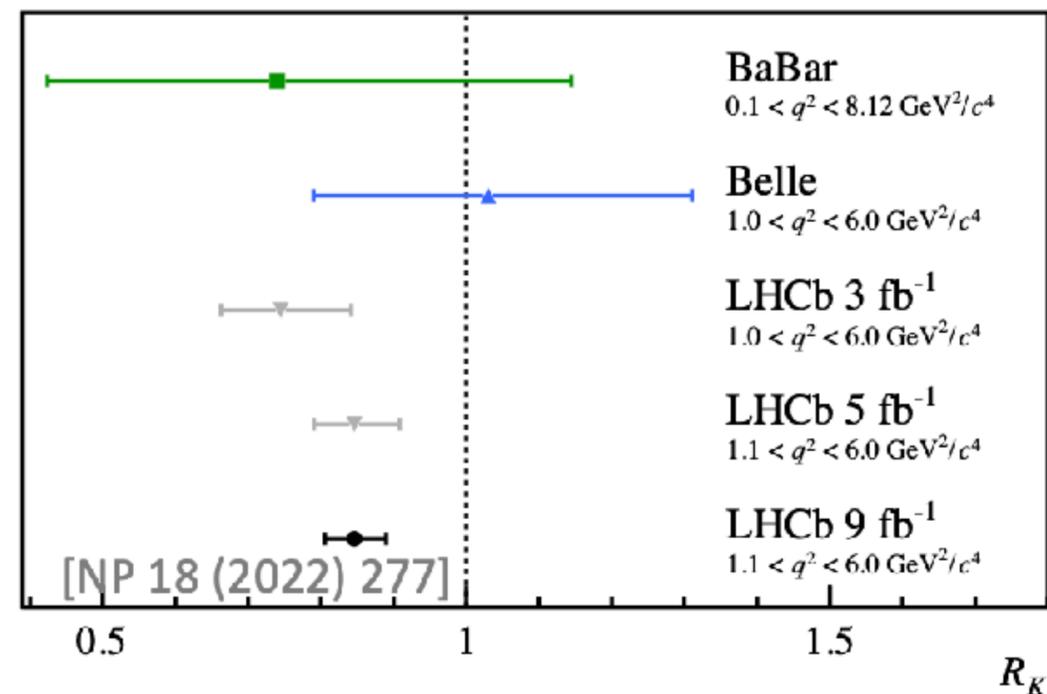
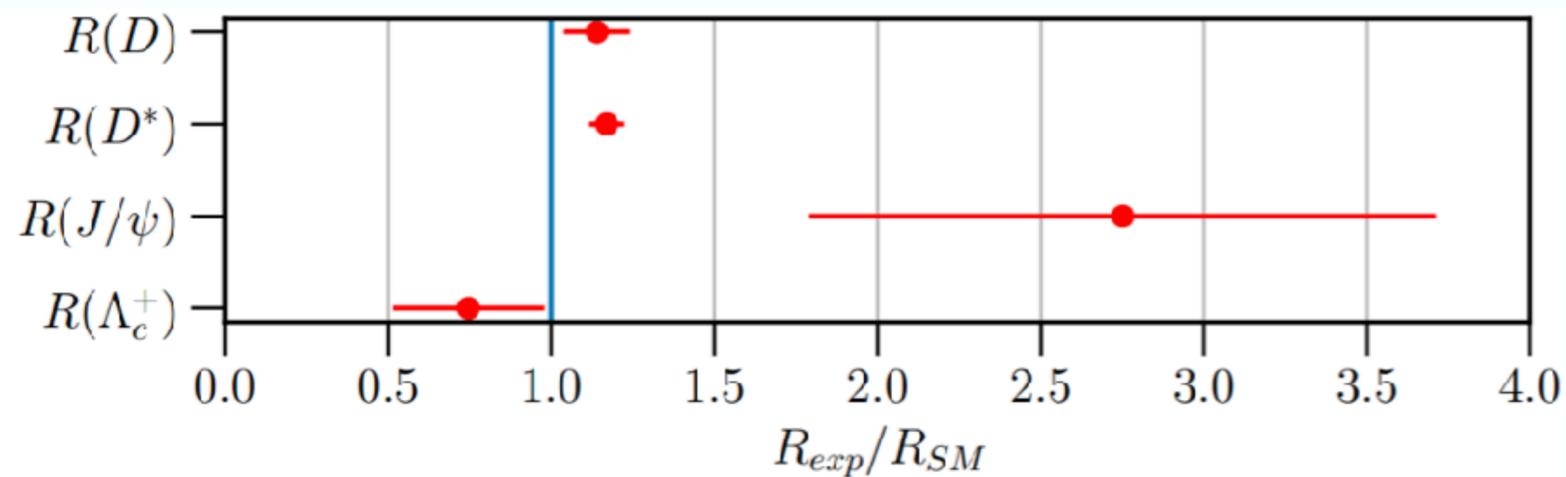
mixing



LHCb, see Jibo He's talk

- Anomalies in partial distributions, angular distributions
- Theoretical precisions required to be improved
- Form factors and long-distance contributions





$R(D^{(*)}): 3\sigma \rightarrow 2\sigma$

LHCb, see Jibo He's talk

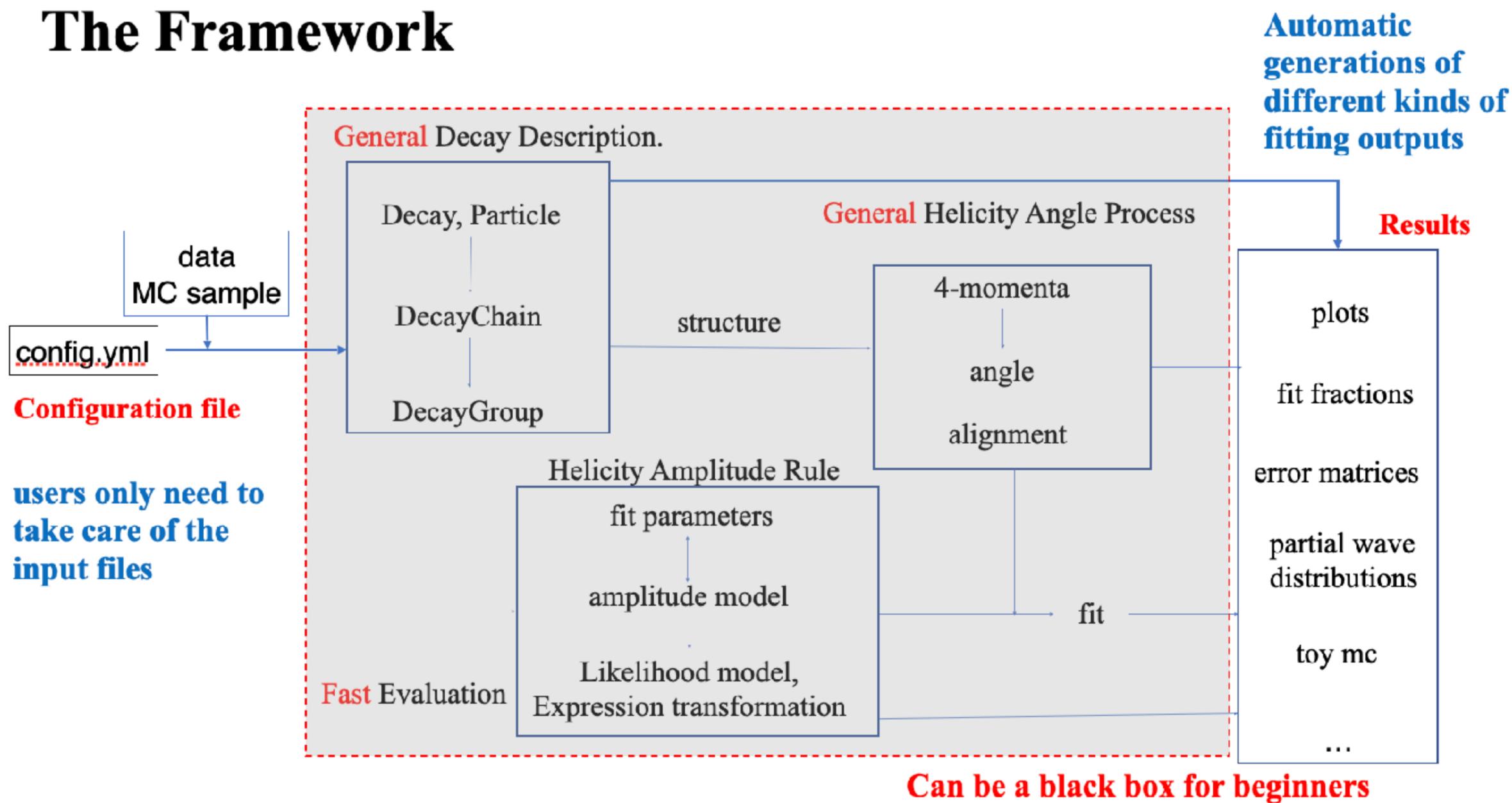
# 极化、角分布和分波分析

现在的统计量到了可以大规模做分布和分波分析的时候了

更多维度、更多信息，这是新的机遇

# 极化、角分布和分波分析

## The Framework



- Fast
- General
- Easy to use
- Open access and well supported

See Yi Jiang's talk

# 极化、角分布和分波分析

[arXiv:2208.03262, accepted by PRD]

## Amplitude analysis of $\Lambda_c^+ \rightarrow pK^-\pi^+$

- 2016 data,  $\mathcal{L} = 0.5\text{fb}^{-1}$ ;  $\sim 400\text{k}$  signals; helicity-based Am.An.

Resonance	$J^P$	Mass (MeV)	Width (MeV)
$\Lambda(1405)$	$1/2^-$	1405.1	50.5
$\Lambda(1520)$	$3/2^-$	1515 – 1523	10 – 20
$\Lambda(1600)$	$1/2^+$	1630	250
$\Lambda(1670)$	$1/2^-$	1670	30
$\Lambda(1690)$	$3/2^-$	1690	70
$\Lambda(2000)$	$1/2^-$	1900 – 2100	20 – 400
<hr/>			
$\Delta(1232)^{++}$	$3/2^+$	1232	117
$\Delta(1600)^{++}$	$3/2^+$	1640	300
$\Delta(1700)^{++}$	$3/2^-$	1690	350
<hr/>			
$K_0^*(700)$	$0^+$	824	478
$K^*(892)$	$1^-$	895.5	47.3
$K_0^*(1430)$	$0^+$	1375	190

$\Lambda_c^+$  from b-hadron decays

Decay orientation angles in the lab system

- All parameters of amplitude model reported
- Mass and width of  $\Lambda(2000)$  determined

$m = 1988 \pm 2 \pm 21 \text{ MeV}$        $\Gamma = 179 \pm 4 \pm 16 \text{ MeV}$

LHCb, see Liang Sun's talk

arXiv 2209.08464 (JHEP accepted).

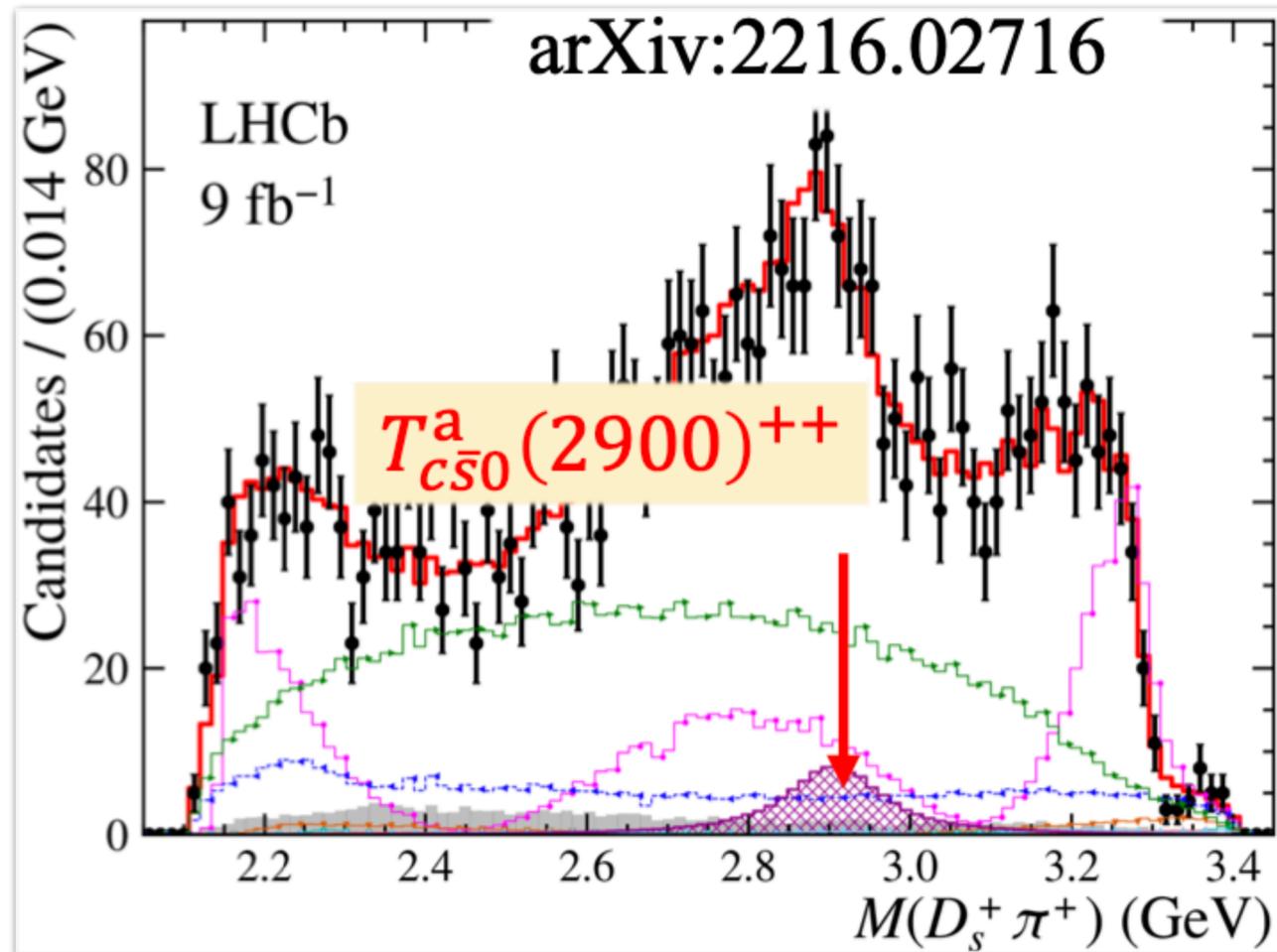
## PWA for $\Lambda_c^+ \rightarrow \Lambda\pi^+\pi^0$

Process	Magnitude	Phase $\phi$ (rad)	FF (%)	Significance
$\Lambda\rho(770)^+$	1.0 (fixed)	0.0 (fixed)	$57.2 \pm 4.2$	$36.9\sigma$
$\Sigma(1385)^+\pi^0$	$0.43 \pm 0.06$	$-0.23 \pm 0.18$	$7.18 \pm 0.60$	$14.8\sigma$
$\Sigma(1385)^0\pi^+$	$0.37 \pm 0.07$	$2.84 \pm 0.23$	$7.92 \pm 0.72$	$16.0\sigma$
$\Sigma(1670)^+\pi^0$	$0.31 \pm 0.08$	$-0.77 \pm 0.23$	$2.90 \pm 0.63$	$5.1\sigma$
$\Sigma(1670)^0\pi^+$	$0.41 \pm 0.07$	$2.77 \pm 0.20$	$2.65 \pm 0.58$	$5.2\sigma$
$\Sigma(1750)^+\pi^0$	$1.75 \pm 0.21$	$-1.73 \pm 0.11$	$16.6 \pm 2.2$	$10.1\sigma$
$\Sigma(1750)^0\pi^+$	$1.83 \pm 0.21$	$1.34 \pm 0.11$	$17.5 \pm 2.3$	$10.2\sigma$
$\Lambda + NR_{1-}$	$4.05 \pm 0.47$	$2.16 \pm 0.13$	$29.7 \pm 4.5$	$10.5\sigma$

- About 10K events survived which purity is larger than 80%.

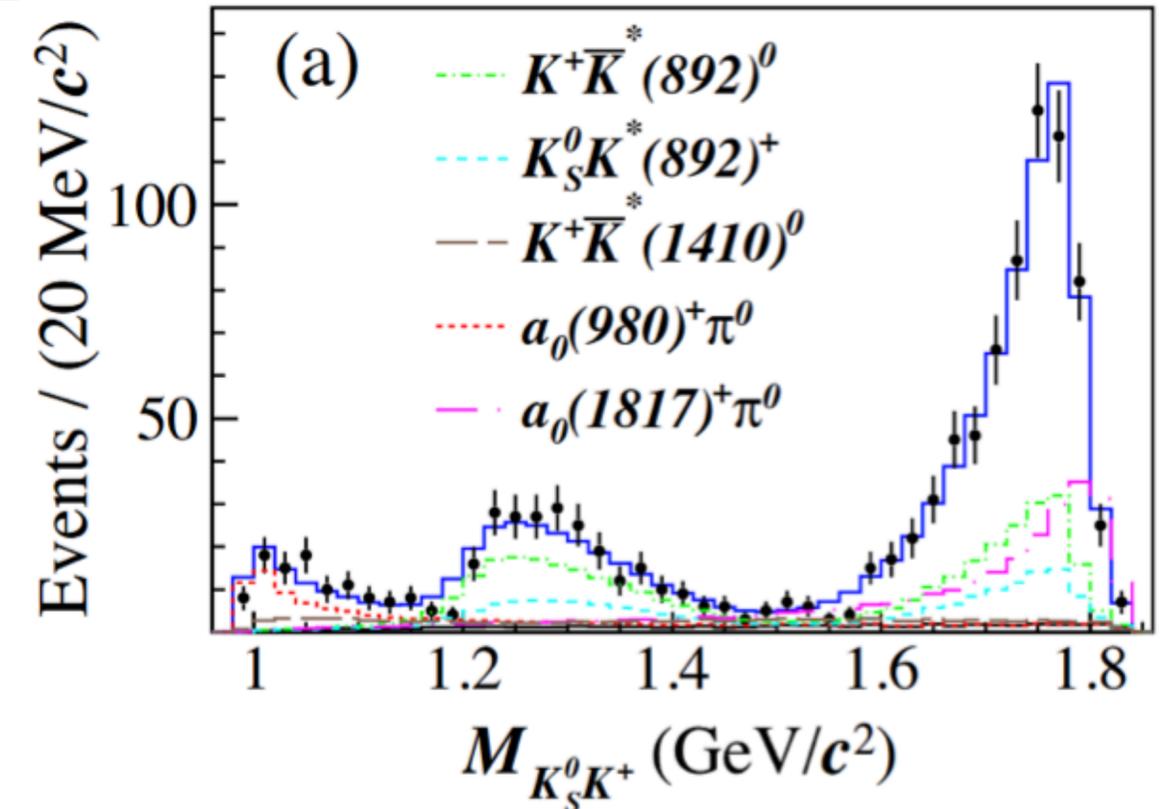
BESIII, see Pei-Rong Li's talk

# 极化、角分布和分波分析



$T_{c\bar{s}}(2900)^{0,++}$  in  $B \rightarrow DD_s\pi$  by LHCb,  
see Yi-Ming Li's talk

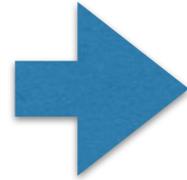
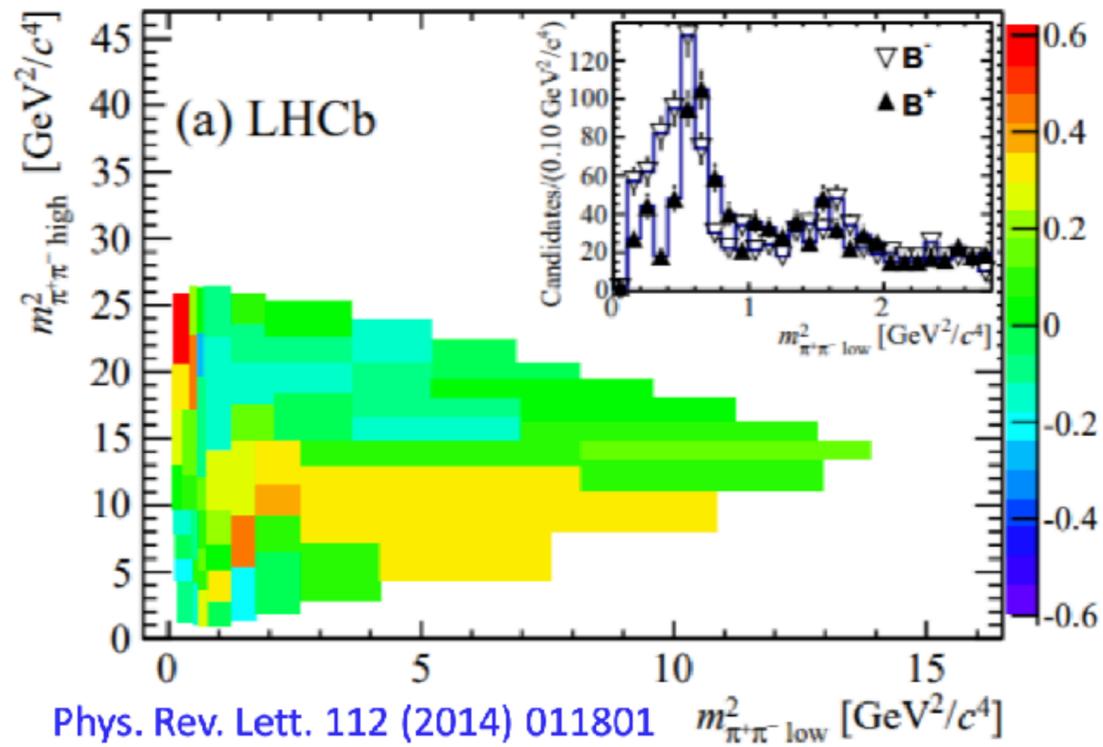
## Phys. Rev. Lett. 129, 182001 (2022)



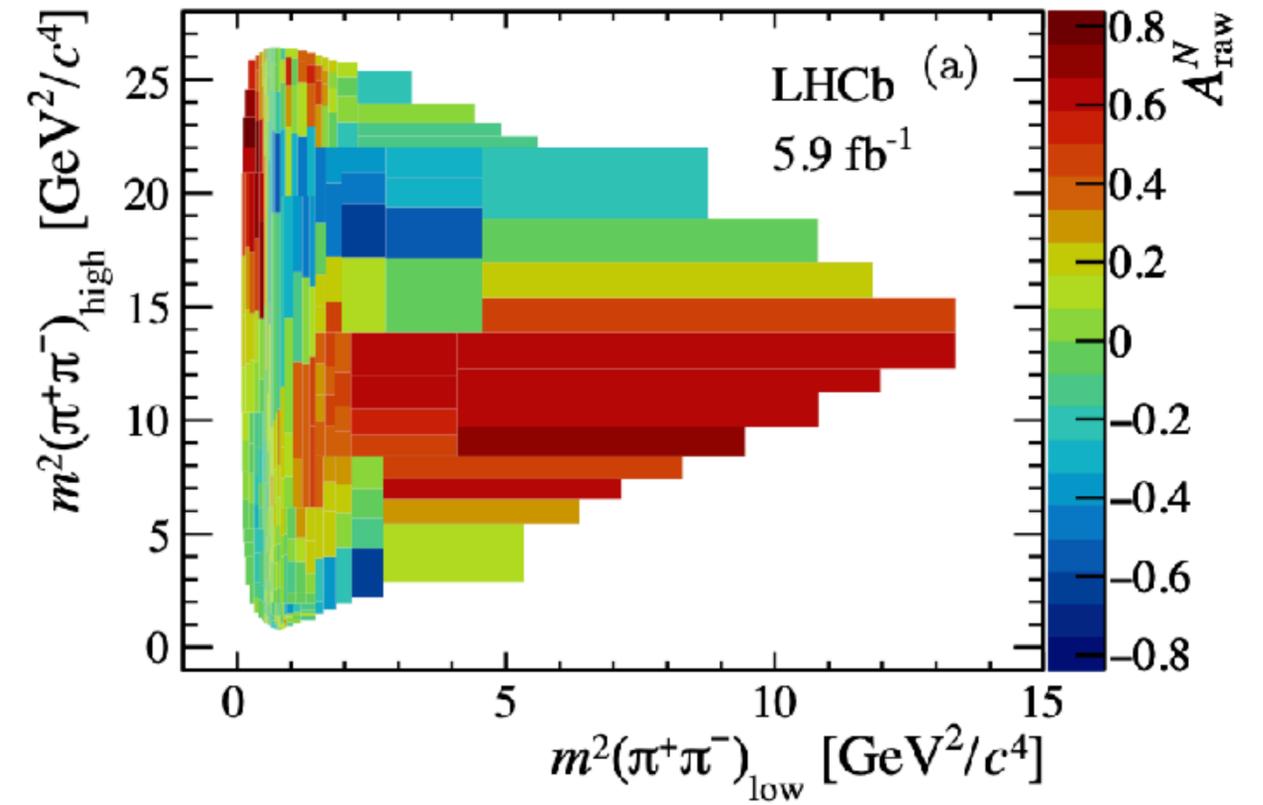
$a_0(1817)$  in  $D_s \rightarrow KK\pi$  by BESIII,  
see Yu Lu's talk

# 极化、角分布和分波分析

2014



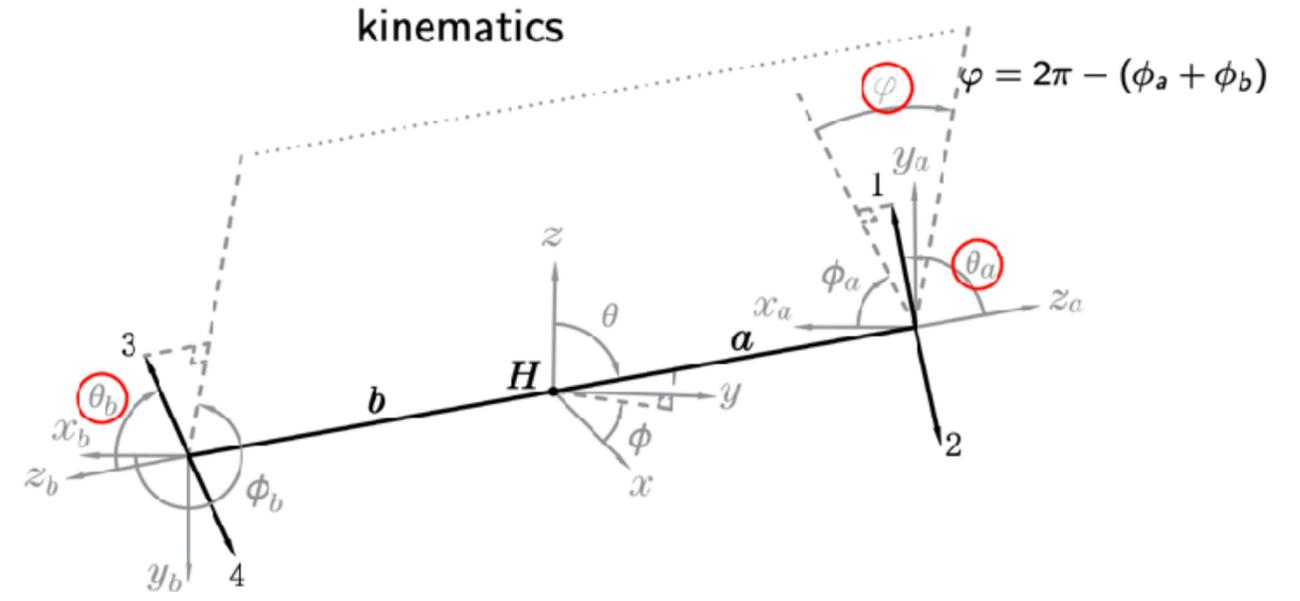
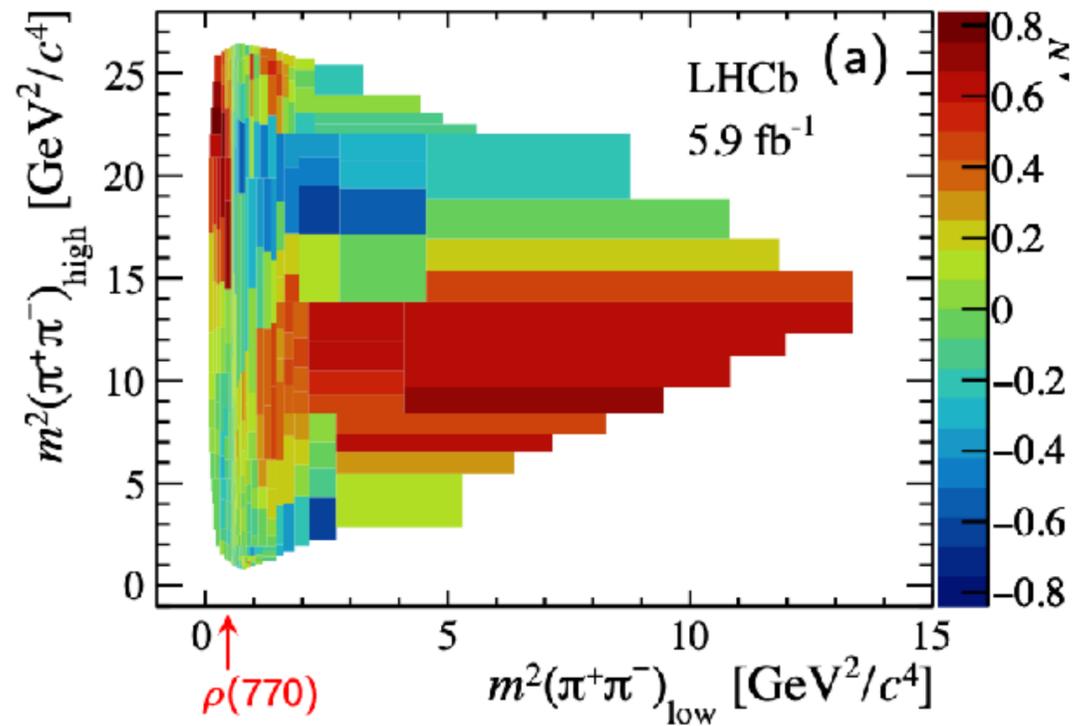
2022



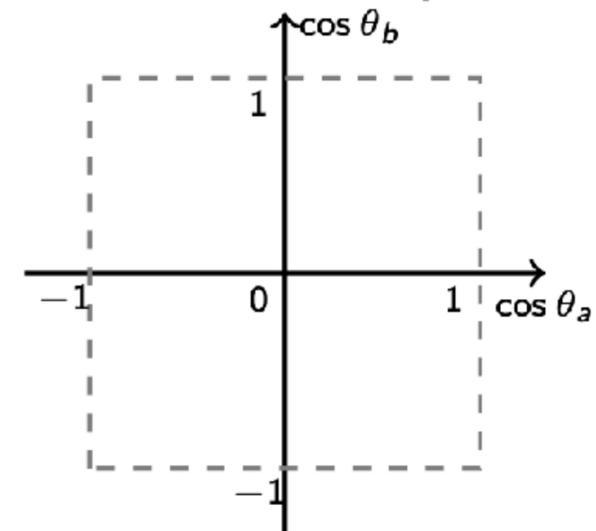
- Regional CPV in multi-body decays

See Jie-Sheng Yu's talk

# 极化、角分布和分波分析



2 Dim Phase Space



$$\int |\overline{\mathcal{A}}|^2 d\varphi \propto \sum_{jl} \Gamma_{jl}(s_{12}, s_{34}) P_j(\cos\theta_a) P_l(\cos\theta_b)$$

- CP violation from interference between resonances
- It can be measured by the angular correlations

See Zhen-Hua Zhang's talk

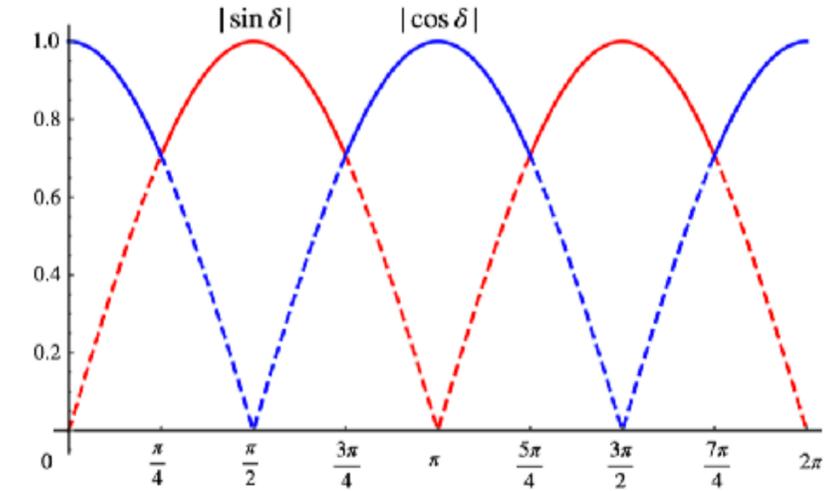
# 极化、角分布和分波分析

- Complementary observables to search for baryon CPV

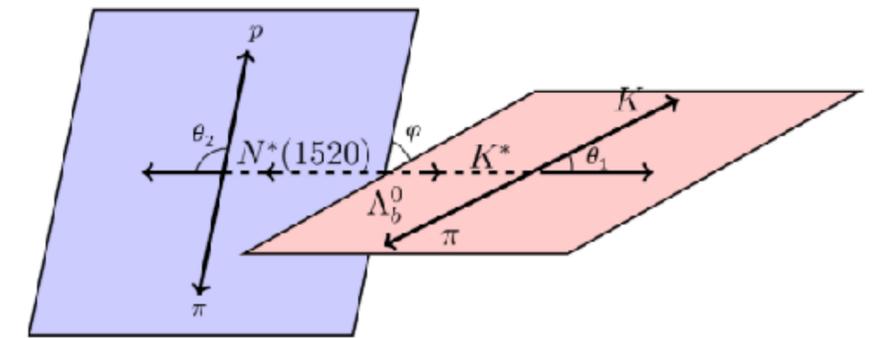
$$a_{CP}^{T\text{-odd}} \propto \sin \phi \cos \delta$$

$$a_{CP}^{T\text{-even}} \propto \sin \phi \sin \delta$$

- Strong phase dependence:  $\sin \delta_s$  vs  $\cos \delta_s$



$$\begin{aligned} \frac{d\Gamma}{dc_1 dc_2 d\varphi} \propto & - \frac{s_1^2 s_2^2}{\sqrt{3}} \text{Im} \left( \mathcal{H}_{+1,+\frac{3}{2}} \mathcal{H}_{-1,-\frac{1}{2}}^* + \mathcal{H}_{+1,+\frac{1}{2}} \mathcal{H}_{-1,-\frac{3}{2}}^* \right) \sin 2\varphi \\ & + \frac{s_1^2 s_2^2}{\sqrt{3}} \text{Re} \left( \mathcal{H}_{+1,+\frac{3}{2}} \mathcal{H}_{-1,-\frac{1}{2}}^* + \mathcal{H}_{+1,+\frac{1}{2}} \mathcal{H}_{-1,-\frac{3}{2}}^* \right) \cos 2\varphi \\ & - \frac{4s_1 c_1 s_2 c_2}{\sqrt{6}} \text{Im} \left( \mathcal{H}_{+1,+\frac{3}{2}} \mathcal{H}_{0,+\frac{1}{2}}^* + \mathcal{H}_{0,-\frac{1}{2}} \mathcal{H}_{-1,-\frac{3}{2}}^* \right) \sin \varphi \\ & + \frac{4s_1 c_1 s_2 c_2}{\sqrt{6}} \text{Re} \left( \mathcal{H}_{+1,+\frac{3}{2}} \mathcal{H}_{0,+\frac{1}{2}}^* + \mathcal{H}_{0,-\frac{1}{2}} \mathcal{H}_{-1,-\frac{3}{2}}^* \right) \cos \varphi \end{aligned}$$



See Qin Qin's and Jian-Peng Wang's talks

# 极化、角分布和分波分析

## T-odd correlation induced CP asymmetry

- T-odd correlation  $Q_-$  induced CPV have cosine dependence on strong phases

$$TQ_- = -Q_-T, \quad A_{CP}^{Q_-} \equiv \frac{\langle Q_- \rangle - \langle \bar{Q}_- \rangle}{\langle Q_- \rangle + \langle \bar{Q}_- \rangle} \propto \cos \delta_s$$

if it satisfies two conditions: (i) for the final-state basis  $\{|\psi_n\rangle, n=1,2,\dots\}$ , there is a unitary transformation  $U$ , s.t.  $UT|\psi_n\rangle = e^{-i\alpha}|\psi_n\rangle$ ; (2)  $UQ_-U^\dagger = Q_-$ .

### Proof:

$$\begin{aligned} \langle f|Q_-|f\rangle &= \langle i|S^\dagger Q_- S|i\rangle \\ &= \sum_{m,n} \langle \psi_i|S^\dagger|\psi_m\rangle \langle \psi_m|Q_-|\psi_n\rangle \langle \psi_n|S|\psi_i\rangle \\ &= \sum_{m,n} A_m^* A_n \langle \psi_m|Q_-|\psi_n\rangle. \end{aligned}$$

$$\begin{aligned} \langle \psi_m|Q_-|\psi_n\rangle &= \langle \psi_m|\mathcal{T}^\dagger \mathcal{T} Q_-|\psi_n\rangle^* \\ &= -\langle \psi_m|\mathcal{T}^\dagger Q_- \mathcal{T}|\psi_n\rangle^* \\ &= -\langle \psi_m|\mathcal{T}^\dagger U^\dagger U Q_- U^\dagger U \mathcal{T}|\psi_n\rangle^* \\ &= -\langle \psi_m|\mathcal{T}^\dagger U^\dagger Q_- U \mathcal{T}|\psi_n\rangle^* \\ &= -\langle \psi_m|Q_-|\psi_n\rangle^*, \end{aligned}$$



$$\langle f|Q_-|f\rangle \ni \text{Im}(A_m^* A_n)$$



$$A_{CP}^{Q_-} \propto \sin \delta_w \cos \delta_s$$

See Qin Qin's and Jian-Peng Wang's talks

# 极化、角分布和分波分析

## TIME-REVERSAL ASYMMETRIES

IN

$$\Lambda_b \rightarrow \Lambda(\rightarrow p\pi^-)\ell^+\ell^-$$

### T-ODD OBSERVABLES

$$\mathcal{J}_+^r = -2\text{Im}(a_+^r \bar{b}_+^r), \quad \mathcal{J}_-^r = 2\text{Im}(a_-^r \bar{b}_-^r),$$

T-ODD  
P-ODD

$$\mathcal{J}^R \equiv \mathcal{J}_-^R - \mathcal{J}_+^L, \quad \mathcal{J}^L \equiv \mathcal{J}_-^L - \mathcal{J}_+^R,$$

$$\alpha_\Lambda(\vec{p}_+ \times \vec{p}_p) \cdot \vec{p}_\Lambda$$

T-ODD  
P-EVEN

$$\alpha_\Lambda = \frac{|H_{\frac{1}{2}}|^2 - |H_{-\frac{1}{2}}|^2}{|H_{\frac{1}{2}}|^2 + |H_{-\frac{1}{2}}|^2} \quad \text{P-ODD}$$

## ANGULAR DISTRIBUTIONS

$$\mathcal{D}(q^2, \vec{\Omega}) = \frac{3}{32\pi^2} \left( (K_1 \sin^2 \theta_l + K_2 \cos^2 \theta_l + K_3 \cos \theta_l) + (K_4 \sin^2 \theta_l + K_5 \cos^2 \theta_l + K_6 \cos \theta_l) \cos \theta_b + \right.$$

$$\left. (K_7 \sin \theta_l \cos \theta_l + K_8 \sin \theta_l) \sin \theta_b \cos(\phi_b + \phi_l) + (K_9 \sin \theta_l \cos \theta_l + K_{10} \sin \theta_l) \sin \theta_b \sin(\phi_b + \phi_l) + \right.$$

$$\left. (K_{11} \sin^2 \theta_l + K_{12} \cos^2 \theta_l + K_{13} \cos \theta_l) \cos \theta + (K_{14} \sin^2 \theta_l + K_{15} \cos^2 \theta_l + K_{16} \cos \theta_l) \cos \theta_b \cos \theta + \right.$$

$$\left. (K_{17} \sin \theta_l \cos \theta_l + K_{18} \sin \theta_l) \sin \theta_b \cos(\phi_b + \phi_l) \cos \theta + (K_{19} \sin \theta_l \cos \theta_l + K_{20} \sin \theta_l) \sin \theta_b \sin(\phi_b + \phi_l) \cos \theta + \right.$$

$$\left. (K_{21} \cos \theta_l \sin \theta_l + K_{22} \sin \theta_l) \sin \phi_l \sin \theta + (K_{23} \cos \theta_l \sin \theta_l + K_{24} \sin \theta_l) \cos \phi_l \sin \theta + \right.$$

$$\left. (K_{25} \cos \theta_l \sin \theta_l + K_{26} \sin \theta_l) \sin \phi_l \cos \theta_b \sin \theta + (K_{27} \cos \theta_l \sin \theta_l + K_{28} \sin \theta_l) \cos \phi_l \cos \theta_b \sin \theta + \right.$$

$$\left. (K_{29} \cos^2 \theta_l + K_{30} \sin^2 \theta_l) \sin \theta_b \sin \phi_b \sin \theta + (K_{31} \cos^2 \theta_l + K_{32} \sin^2 \theta_l) \sin \theta_b \cos \phi_b \sin \theta + \right.$$

$$\left. (K_{33} \sin^2 \theta_l) \sin \theta_b \cos(2\phi_l + \phi_b) \sin \theta + (K_{34} \sin^2 \theta_l) \sin \theta_b \sin(2\phi_l + \phi_b) \sin \theta \right),$$

R.Aaij et al. [LHCb],  
JHEP 09, 146(2018).

Followed  
by  $P_b$

$$K_9 \propto -\alpha(\mathcal{J}^R + \mathcal{J}^L)$$

$$K_{10} \propto \alpha(\mathcal{J}^R - \mathcal{J}^L)$$

$$P_b = 0.06 \pm 0.07$$

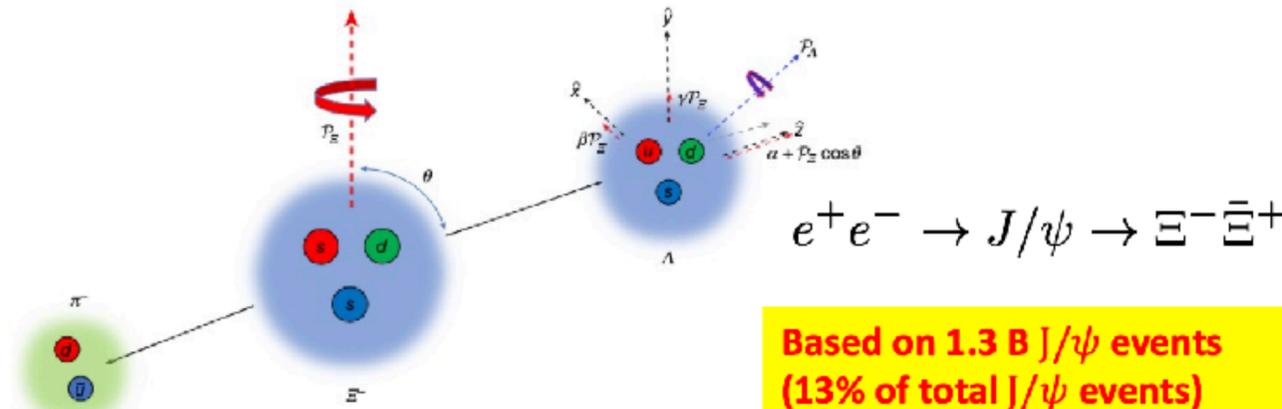
R.Aaij et al. (LHCb), Phys. Lett., B724, 27 (2013).

See Zheng-Yi Wei's talk

# 极化、角分布和分波分析

BES III

Measurements and CP test with  $\Xi^- \rightarrow \Lambda \pi^-$  decay



Based on 1.3 B  $J/\psi$  events  
(13% of total  $J/\psi$  events)  
9-dimensional fit:

- ✓ First measurement of polarization
- ✓ First direct determination of all  $\Xi$  decay parameters
- ✓ First extraction of weak phase difference from baryon weak decays
- ✓ Three CP tests

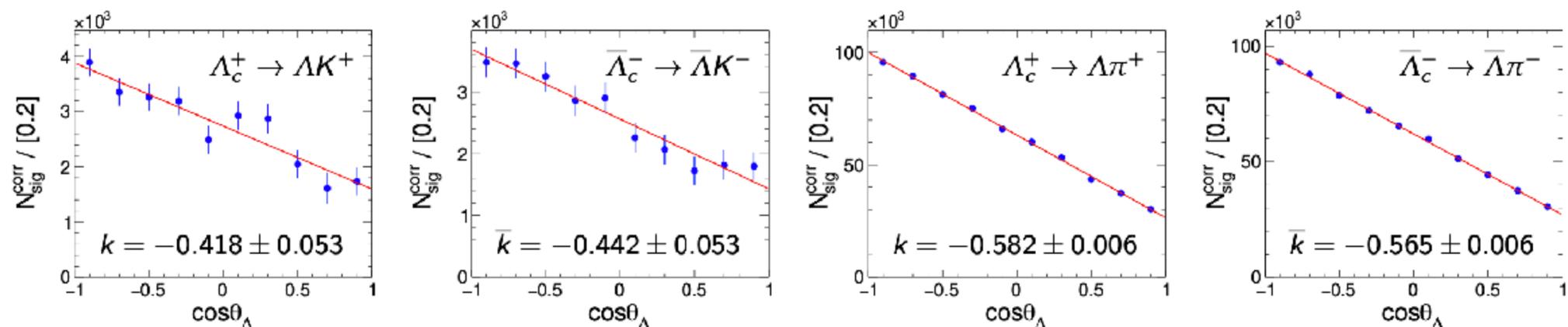
Nature 606, 64 (2022)

Parameter	This work	Previous result
$\alpha_\psi$	$0.586 \pm 0.012 \pm 0.010$	$0.58 \pm 0.04 \pm 0.08$
$\Delta\Phi$	$1.213 \pm 0.046 \pm 0.016 \text{ rad}$	-
$\alpha_\Xi$	$-0.376 \pm 0.007 \pm 0.003$	$-0.401 \pm 0.010$
$\phi_\Xi$	$0.011 \pm 0.019 \pm 0.009 \text{ rad}$	$-0.037 \pm 0.014 \text{ rad}$
$\bar{\alpha}_\Xi$	$0.371 \pm 0.007 \pm 0.002$	-
$\bar{\phi}_\Xi$	$-0.021 \pm 0.019 \pm 0.007 \text{ rad}$	-
$\alpha_\Lambda$	$0.757 \pm 0.011 \pm 0.008$	$0.750 \pm 0.009 \pm 0.004$
$\bar{\alpha}_\Lambda$	$-0.763 \pm 0.011 \pm 0.007$	$-0.758 \pm 0.010 \pm 0.007$
$\xi_p - \xi_s$	$(1.2 \pm 3.4 \pm 0.8) \times 10^{-2} \text{ rad}$	-
$\delta_p - \delta_s$	$(-4.0 \pm 3.3 \pm 1.7) \times 10^{-2} \text{ rad}$	$(10.2 \pm 3.9) \times 10^{-2} \text{ rad}$
$A_{CP}^\Xi$	$(6 \pm 13 \pm 6) \times 10^{-3}$	-
$\Delta\phi_{CP}^\Xi$	$(-5 \pm 14 \pm 3) \times 10^{-3} \text{ rad}$	-
$A_{CP}^\Lambda$	$(-4 \pm 12 \pm 9) \times 10^{-3}$	$(-6 \pm 12 \pm 7) \times 10^{-3}$
$\langle\phi_\Xi\rangle$	$0.016 \pm 0.014 \pm 0.007 \text{ rad}$	

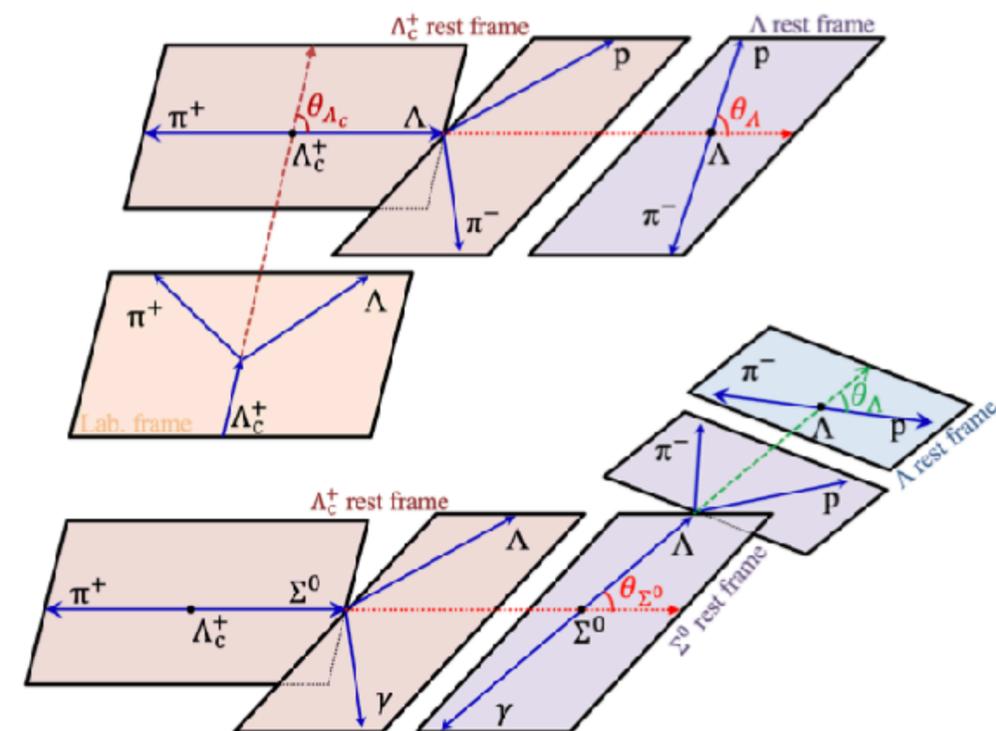
HyperCP(2004):  $\phi_{\Xi, HyperCP} = -0.042 \pm 0.011 \pm 0.011$

the same precision for  $\phi$  as HyperCP with **three orders of magnitude** smaller data sample!

# 极化、角分布和分波分析



Channel	$k = \alpha_{\Lambda_c^+} \alpha_-$	$\bar{k} = \alpha_{\Lambda_c^-} \alpha_+$	$\alpha_{\Lambda_c^+}$	$\alpha_{\Lambda_c^-}$	$A_{CP}^s$	W.A. $A_{CP}^s$	our $A_{CP}^s(\Lambda \rightarrow p\pi^-)$
$\Lambda_c^+ \rightarrow \Lambda K^+$	$-0.418 \pm 0.053$	$-0.442 \pm 0.053$	$-0.566 \pm 0.071 \pm 0.028$	$0.592 \pm 0.070 \pm 0.079$	$-0.023 \pm 0.086 \pm 0.071$	-	-
$\Lambda_c^+ \rightarrow \Lambda \pi^+$	$-0.582 \pm 0.006$	$-0.565 \pm 0.006$	$-0.784 \pm 0.008 \pm 0.006$	$0.754 \pm 0.008 \pm 0.018$	$+0.020 \pm 0.007 \pm 0.013$	$-0.07 \pm 0.22$	$+0.017 \pm 0.007 \pm 0.012$
$\Lambda_c^+ \rightarrow \Sigma^0 K^+$	$-0.43 \pm 0.18$	$-0.37 \pm 0.21$	$-0.58 \pm 0.24 \pm 0.09$	$0.49 \pm 0.28 \pm 0.14$	$+0.08 \pm 0.35 \pm 0.14$	-	-
$\Lambda_c^+ \rightarrow \Sigma^0 \pi^+$	$-0.340 \pm 0.016$	$-0.358 \pm 0.017$	$-0.452 \pm 0.022 \pm 0.023$	$0.473 \pm 0.023 \pm 0.035$	$-0.023 \pm 0.034 \pm 0.030$	-	$-0.026 \pm 0.034 \pm 0.030$
							combined: $+0.013 \pm 0.007 \pm 0.011$



Charmed baryons at Belle

Channel	Comments
$\Lambda_c^+ \rightarrow pK_S^0 K_S^0$ $\Omega_c^0 \rightarrow \Xi^- \pi^+$	First observation
$\Lambda_c^+ \rightarrow pK_S^0 \eta$ $\Xi_c^0 \rightarrow \Lambda_c^+ \pi^-$ $\Omega_c^0 \rightarrow \Omega^- l^+ \nu$	Improved precision
$\Lambda_c^+ \rightarrow \Sigma^+ \gamma, \Xi_c^0 \rightarrow \Xi^0 \gamma$ $\Omega_c^0 \rightarrow \Xi^- K^+, \Omega_c^0 \rightarrow \Omega^- K^+$	Most stringent constraints
$M_{pK}$ in $\Lambda_c^+ \rightarrow pK^- \pi^+$ decay	A threshold cusp effect is preferred
$\bar{B}^0 \rightarrow \Lambda_c(2910)^+ \bar{p}$	A new $\Lambda_c(2910) \rightarrow \Sigma_c(2455)\pi$ state is evident

See Longke Li's and Yubo Li's talks

# 高精度计算：理论新机制

理论深度挖掘，做到极致，往往带来新的机制和新的理论

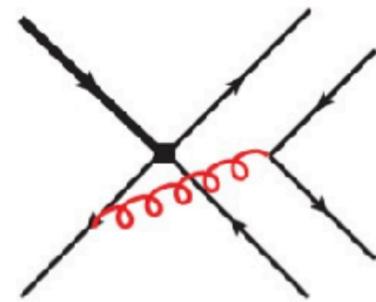
# 高精度计算：理论新机制

See Qin Qin's talks

## Annihilation amplitude

- The fact: **no divergence here!** The power counting **Soft**  $k \sim \Lambda_{\text{QCD}} \rightarrow 0$  is wrong.

- The key: **pick up the missing piece!**



Hard gluon contribution  
 $(p_1 + q_2)^2 \sim m_b^2$

~

The missing piece  
**Hard-collinear gluon contribution**  
 $(p_1 + q_2)^2 \sim m_b \Lambda_{\text{QCD}}$

Both leading power!

- The complete formulation (keep  $p_1 \cdot k$ ):

$$\int_0^\infty d\omega \phi_B^+(\omega) \int_0^1 dx \phi_{M_2}(x) \int_0^1 dy \phi_{M_1}(y) \frac{1}{\bar{x}y(\bar{x} - \omega/m_B + i\epsilon)} \approx 18 \left[ \left( \ln(m_B/\lambda_B) + \gamma_E + 2 \right) - i\pi \right]$$

From hard-collinear gluon exchange

- The annihilation diagram is **calculable, finite**, and contains **strong phase!**

[Lu, Shen, Wang, Wang, 2202.08073]

# 高精度计算：理论新机制

leading logs:

$$e^+e^-, ep: \alpha_s^n \ln^n \left( \frac{Q}{Q_0} \right)$$

$$pp: \dots + \alpha_s^3 (i\pi)^2 \ln^3 \left( \frac{Q}{Q_0} \right) \times \alpha_s^n \ln^{2n} \left( \frac{Q}{Q_0} \right)$$

- Super-leading logs starts at 4 loops
- All-order structure: different

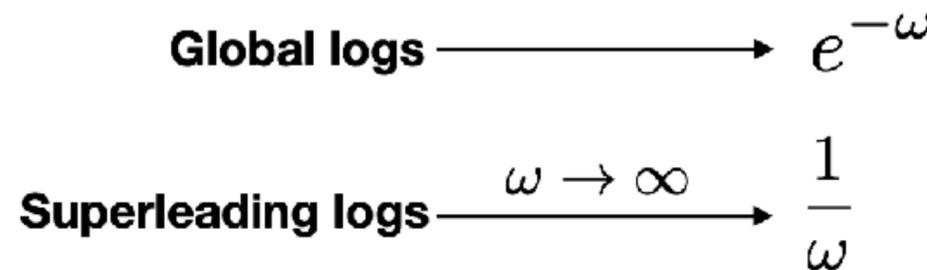
All-order structure: Kampé de Fériet function (a two-variable generalization of the generalized hypergeometric series, the general sextic equation can be solved in terms of it)

$$\Sigma(v, w) = \sum_{m=0}^{\infty} \sum_{r=0}^{\infty} \frac{(1)_{m+r} (1)_m \left(\frac{1}{2}\right)_r}{(2)_{m+r} \left(\frac{5}{2}\right)_{m+r}} \frac{(-w)^m (-vw)^r}{m! r!}$$

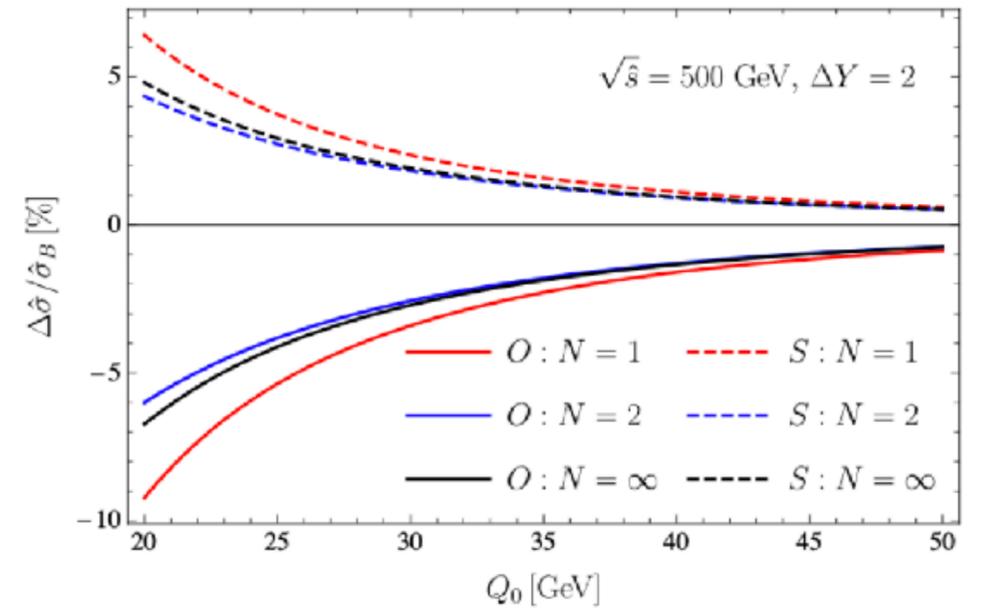
$$= {}^{1+1}F_{2+0} \left( \begin{matrix} 1 : 1, \frac{1}{2} \\ 2, \frac{5}{2} \end{matrix} ; -w, -vw \right)$$

$$w = \frac{N_c \alpha_s(\bar{\mu})}{\pi} \ln^2 \left( \frac{\mu_h}{\mu_s} \right)$$

Sudakov suppression of the superleading logarithms is weaker than the one present for global observables



Numerical results



Red: Four loop    Blue: Five loop    Black: all order

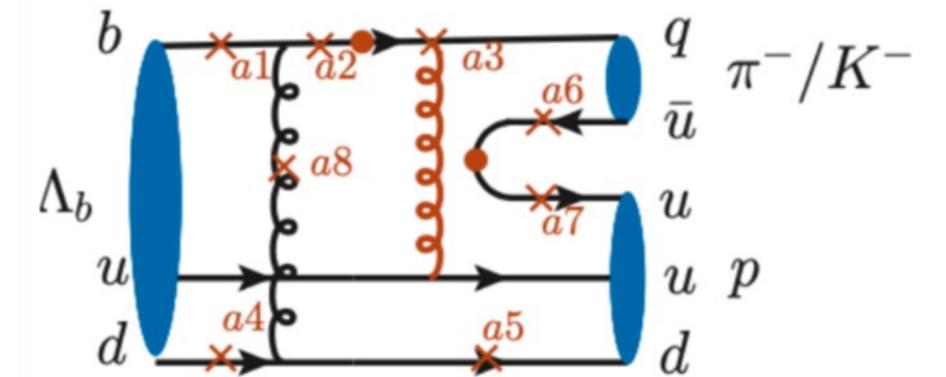
See Ding-Yu Shao's talk

# 高精度计算：理论新机制

	PQCD(this work)		Experiment
$\mathcal{B}r(\Lambda_b \rightarrow p\pi)$	$(27.3_{-18.5}^{+26.2}) \times 10^{-6}$		$(4.5 \pm 0.8) \times 10^{-6}$
$\mathcal{B}r(\Lambda_b \rightarrow pK)$	$(29.4_{-19.6}^{+34.3}) \times 10^{-6}$		$(5.4 \pm 1.0) \times 10^{-6}$
$R_{\pi K}(\Lambda_b)$	$0.93_{-0.20}^{+0.02}$		$0.82 \pm 0.12$
$A_{CP}^{dir}(\Lambda_b \rightarrow p\pi)$	$(-3.63_{-0.07}^{+3.41})\%$		$(-2.5 \pm 2.9)\%$
$A_{CP}^{dir}(\Lambda_b \rightarrow pK)$	$(8.26_{-7.78}^{+0.32})\%$		$(-2.5 \pm 2.2)\%$

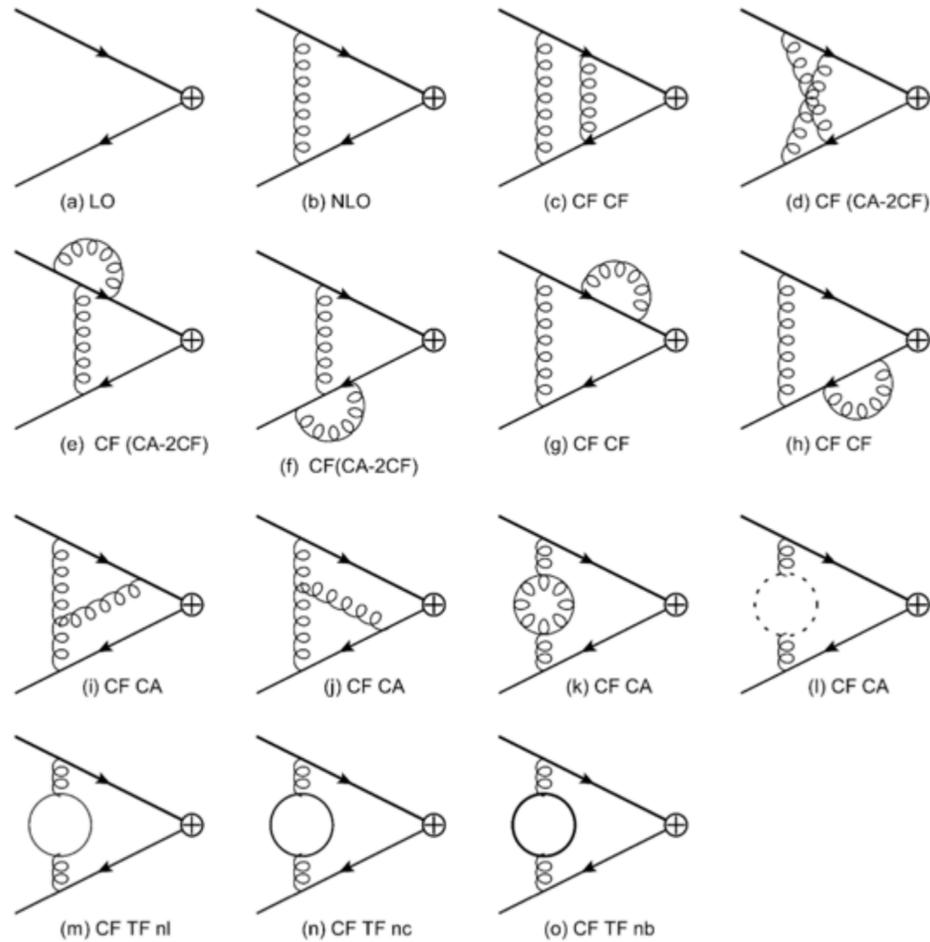
	twist-3	twist-4	twist-5	twist-6
$\Lambda_b \rightarrow p\pi$				
twist-2	6.9(9.6)	-0.51(0.72)	-4.6(-0.64)	-0.02(0.03)
twist-3 <sup>+-</sup>	-0.48(0.68)	22.3(31.2)	0.14(-0.21)	-0.25(-0.37)
twist-3 <sup>-+</sup>	-0.80(1.1)	10.1(14.3)	-0.24(0.33)	0.59(0.84)
twist-4	72.1(99.7)	37.5(-52.4)	<u>1254(1770)</u>	0.003(-0.005)
$\Lambda_b \rightarrow pK$				
twist-2	8.77(12.4)	-0.67(0.95)	-5.72(-8.11)	-0.03(0.05)
twist-3 <sup>+-</sup>	-0.57(0.82)	28.4(41.2)	0.20(-0.29)	-0.34(-0.49)
twist-3 <sup>-+</sup>	-0.99(1.36)	14.3(19.2)	-0.28(0.42)	0.75(1.10)
twist-4	91.1(123)	45.8(-65.8)	<u>1570(2214)</u>	0.04(-0.05)



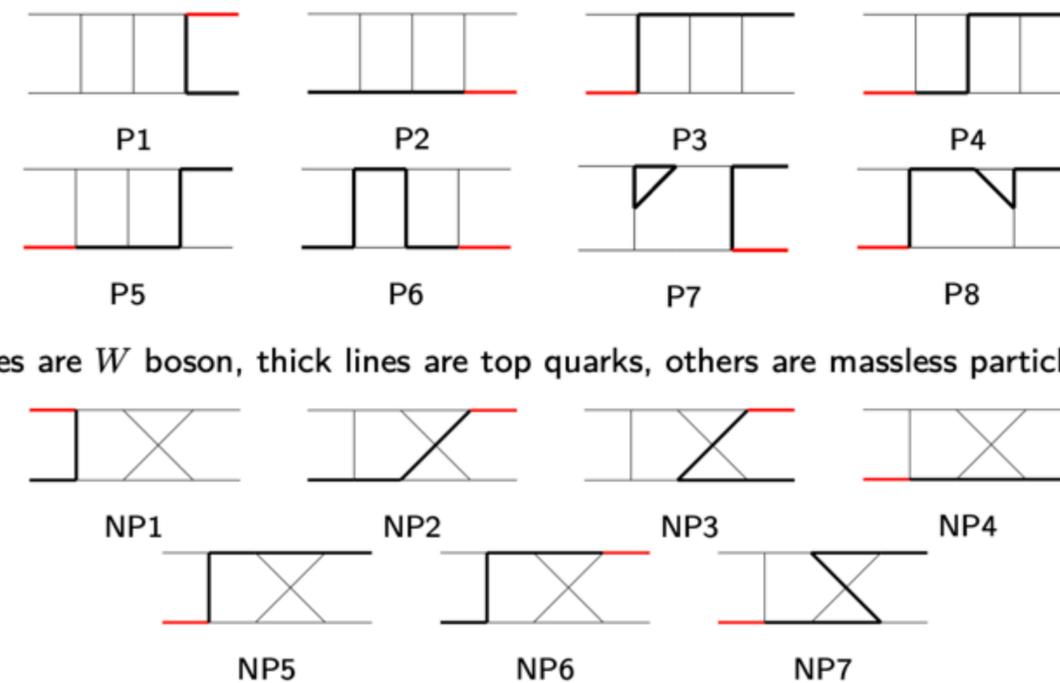
See Jia-Jie Han's and Chao-Qi Zhang's talks

- High twists LCDAs dominate baryon decays.
- Development of PQCD of baryon decays.
- It is the time to investigate the baryonic CPV both in experiment and in theory

# 理论高精度计算



After IBP reduction of FIRE [Smirnov, Chuharev 2019],  $\mathcal{A}^{(2)} = \sum_{\text{spins}} |\mathcal{M}^{(0)*} \mathcal{M}^{(2)}|$  can be reduced to several families of master integrals.



- Two loops of  $B_c^{(*)}$  decay constants

See Wei Tao's talk

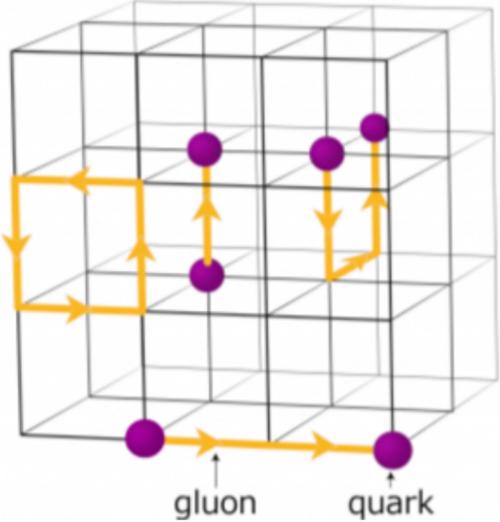
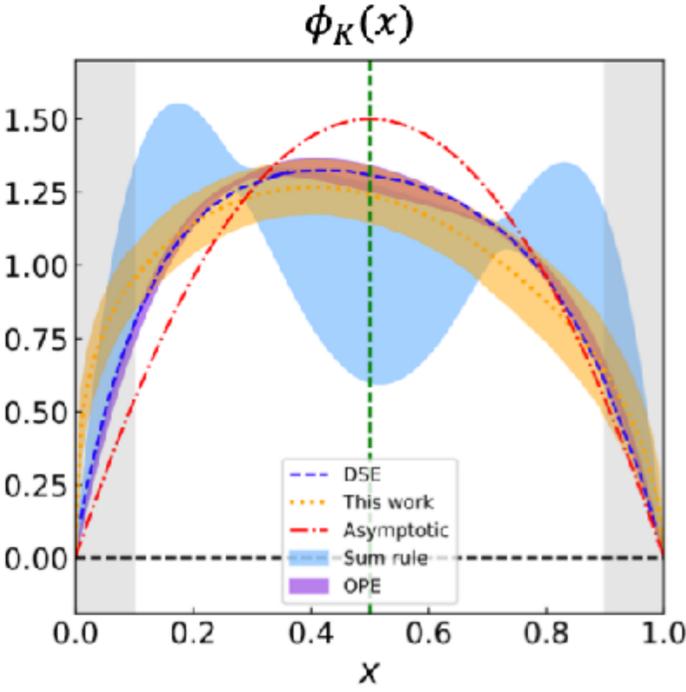
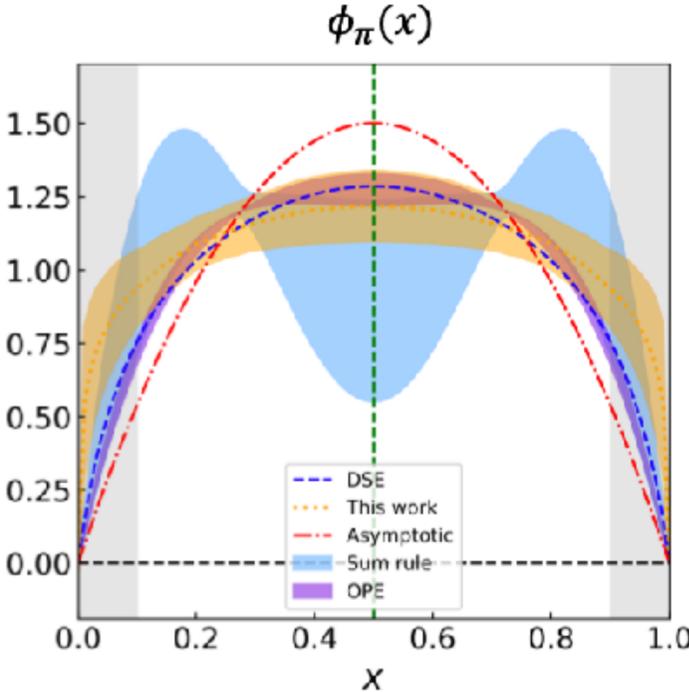
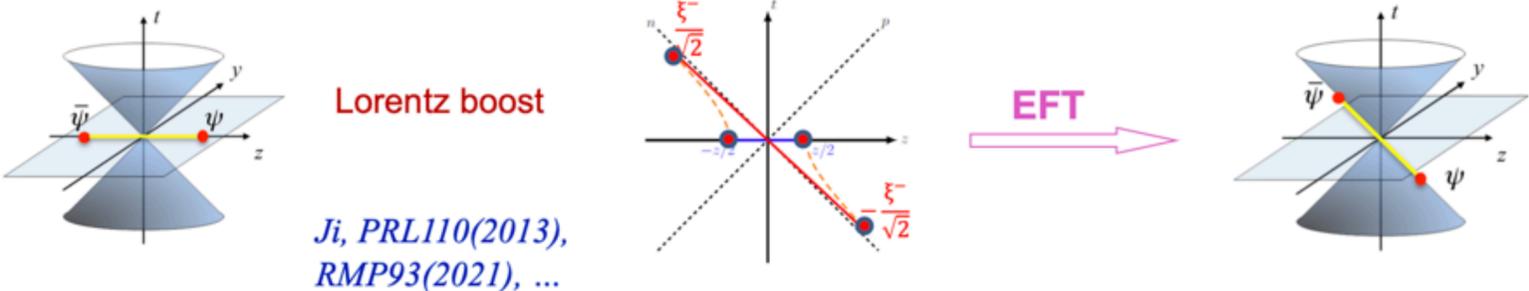
- Two loops of  $tW$  production

See Ye-Fan Wang's talk

# 格点计算光锥分布振幅

✓ Large-momentum effective theory:

connecting Euclidean lattice and physical observables



See Qi-An Zhang's and Jun Hua's talks

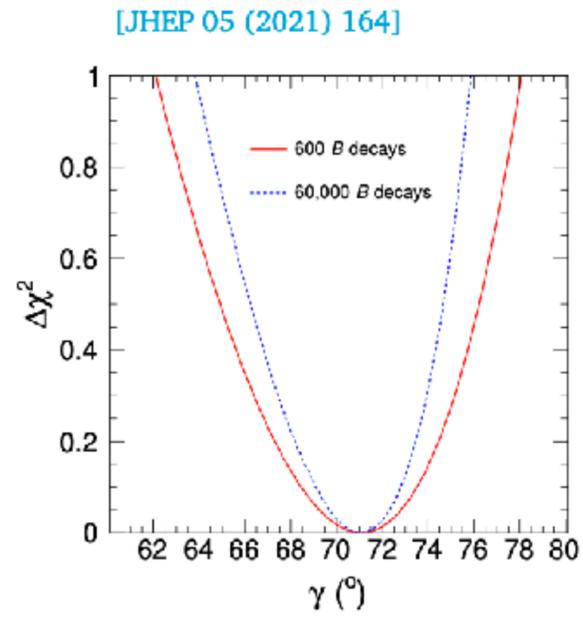
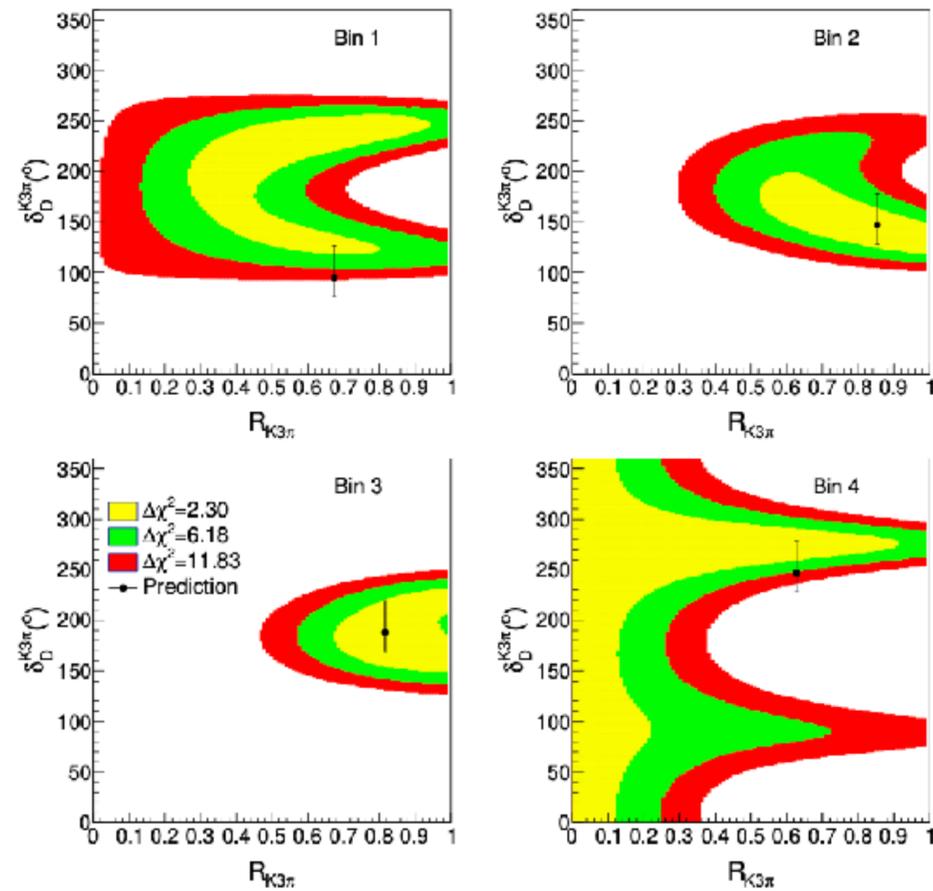
# 理论与实验相结合

群策群力，有组织的科研，联合攻关，机会更多

前面的介绍中很多地方都能体现理论与实验的结合

# 不同实验相结合

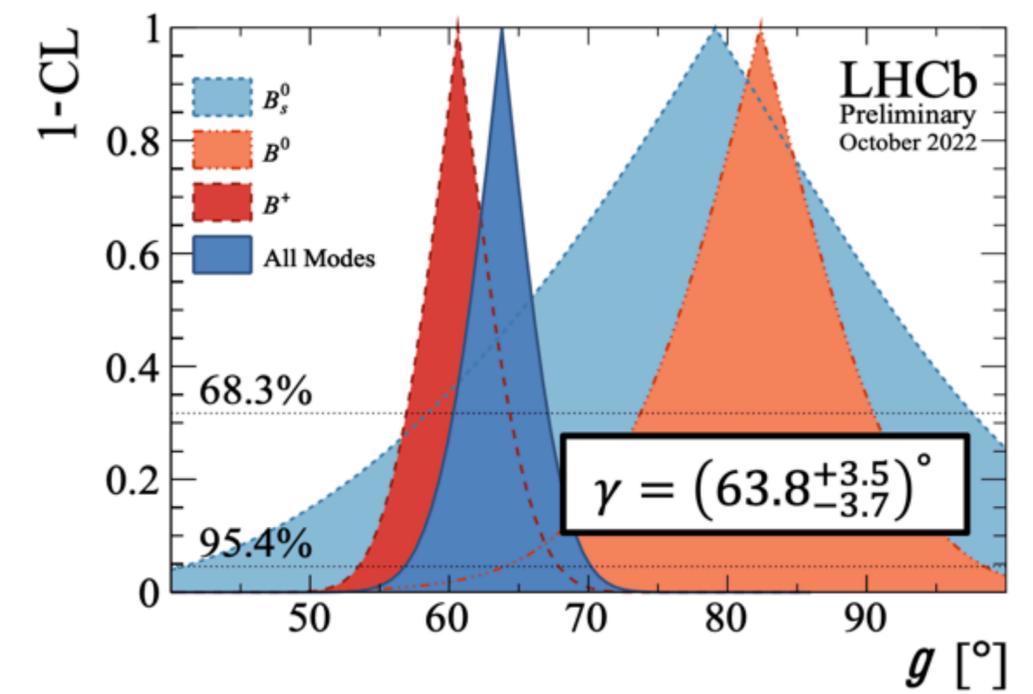
Results of binned  $\delta_D^{K3\pi}$  and  $R_{K3\pi}$



▶  $\sim 6^\circ$  comes from BESIII

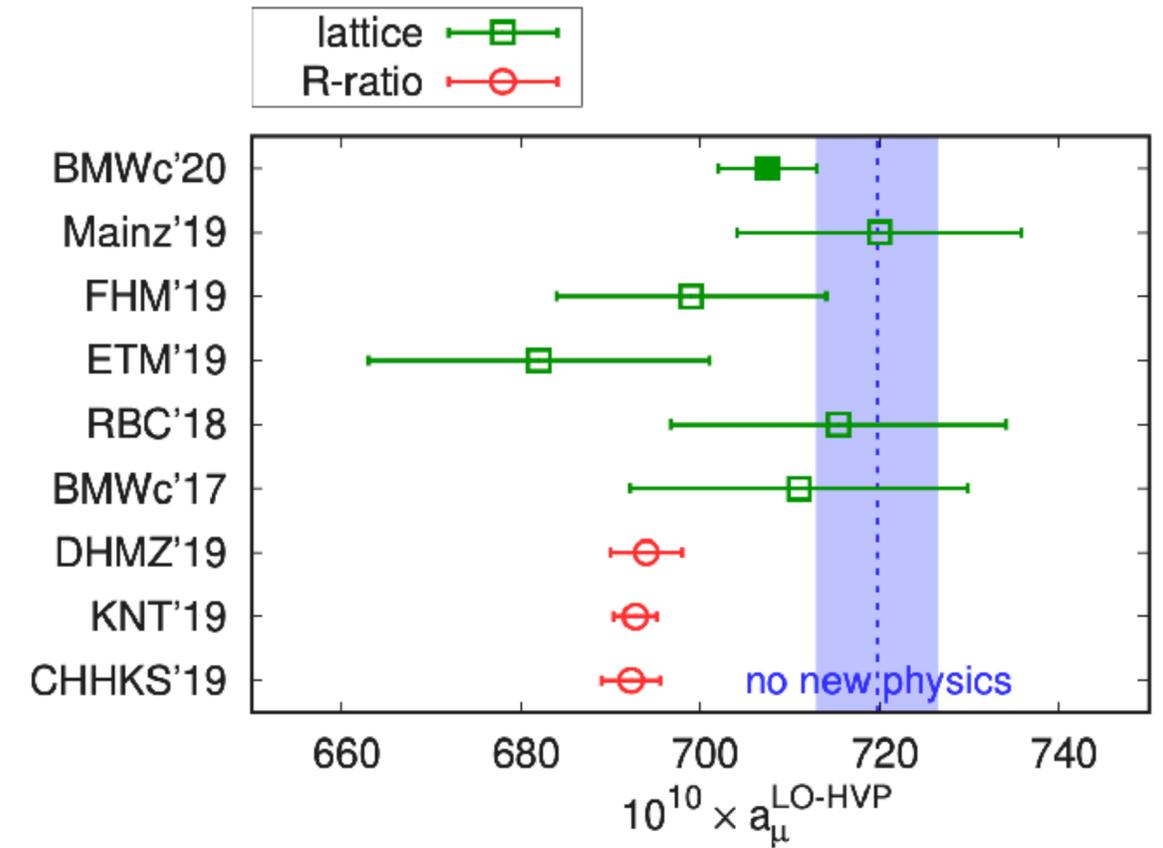
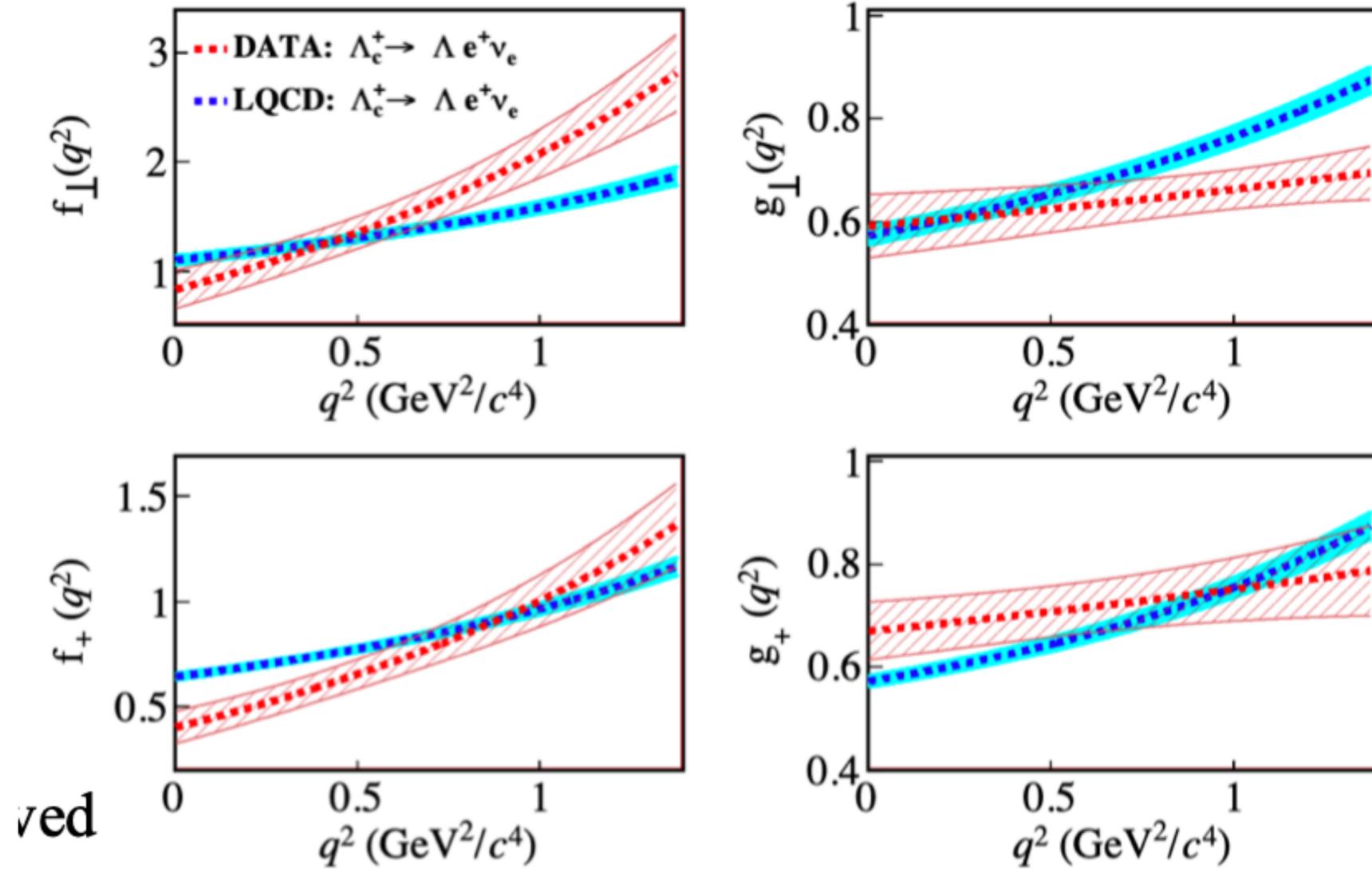
▶ Second-leading  $\gamma = (54.8^{+6.0+0.6+6.7}_{-5.8-0.6-4.3})^\circ$  [LHCb; arXiv:2209.03692]

- BESIII + LHCb
- strong phases  $\rightarrow \gamma$  angle



See Yu Zhang's talk

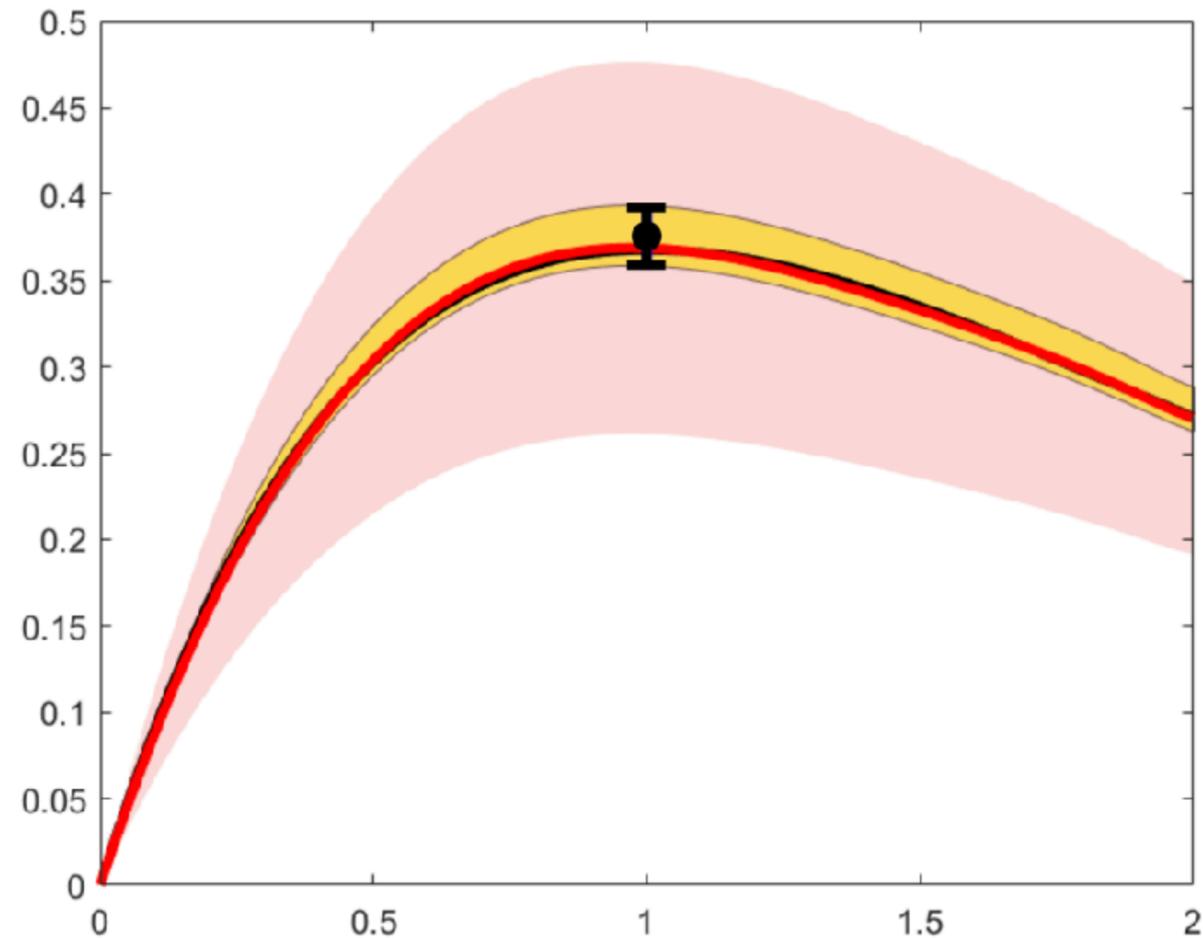
# 实验与格点结合



muon g-2

See Pei-Rong Li's talk

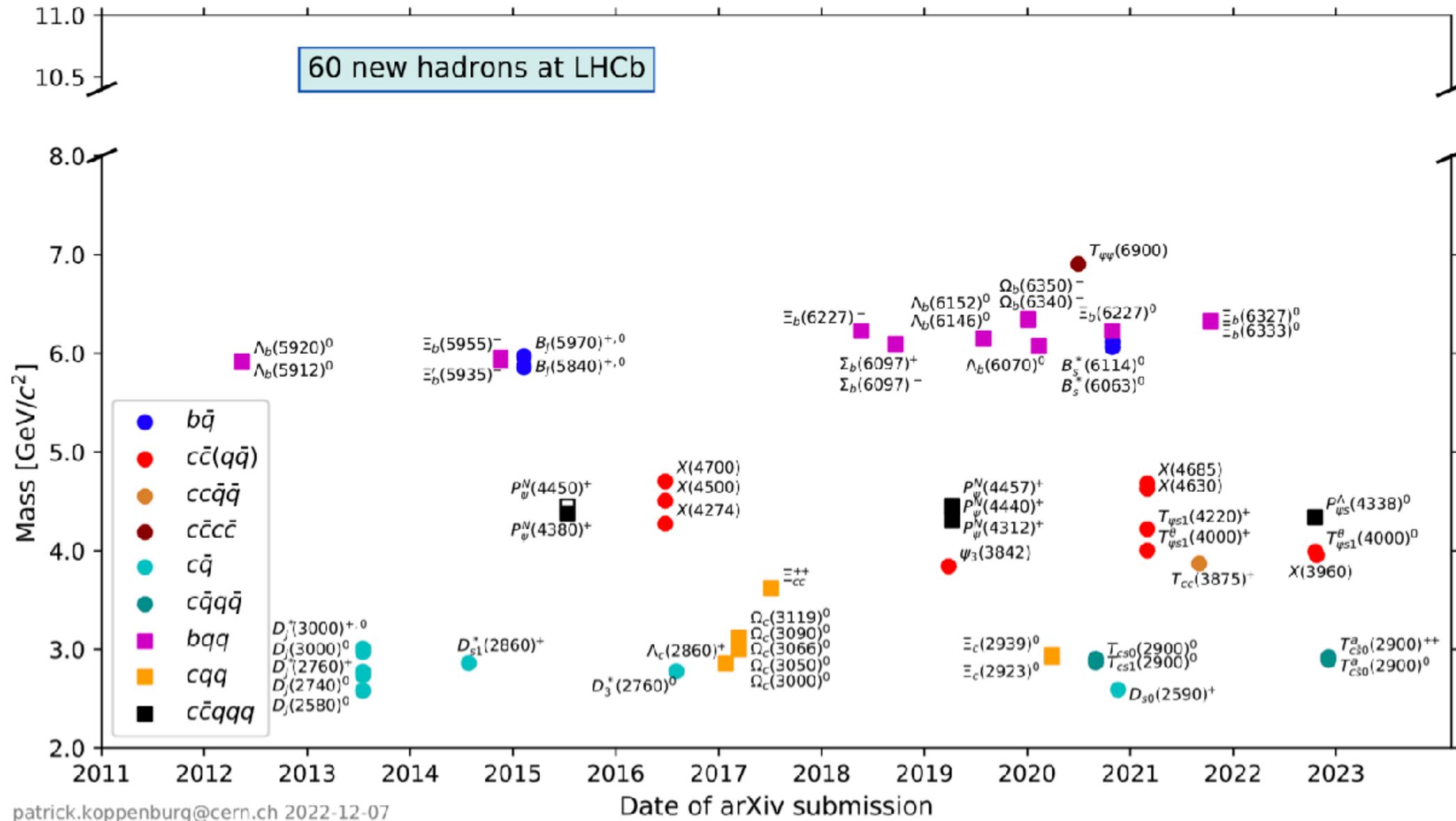
# 反问题方法与实验、格点结合



- If there is an experimental data or lattice data with much smaller uncertainty than the original solutions, we can use it to constrain the solution to be more precise.
- Therefore, this method can combine with experiments and Lattice QCD to improve the precision of predictions

Ao-Sheng Xiong, Ting Wei, FSU, [arXiv:2211.13753](https://arxiv.org/abs/2211.13753)

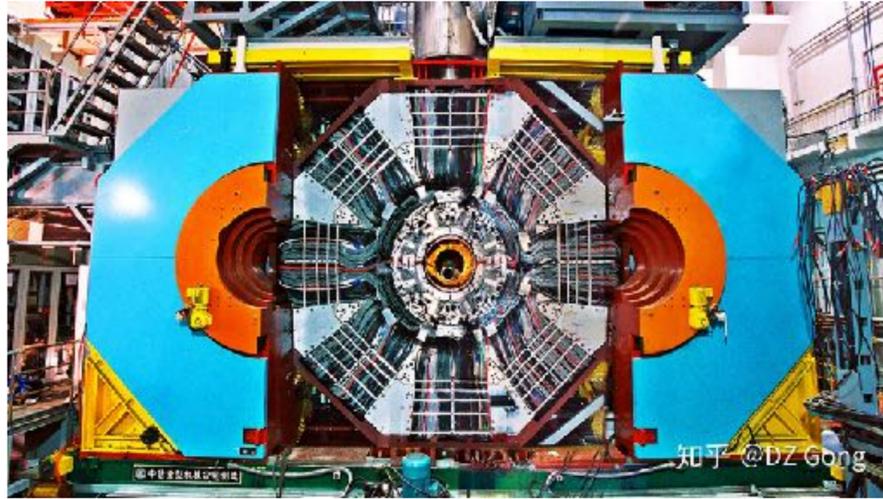
# Particle Zoo 2.0



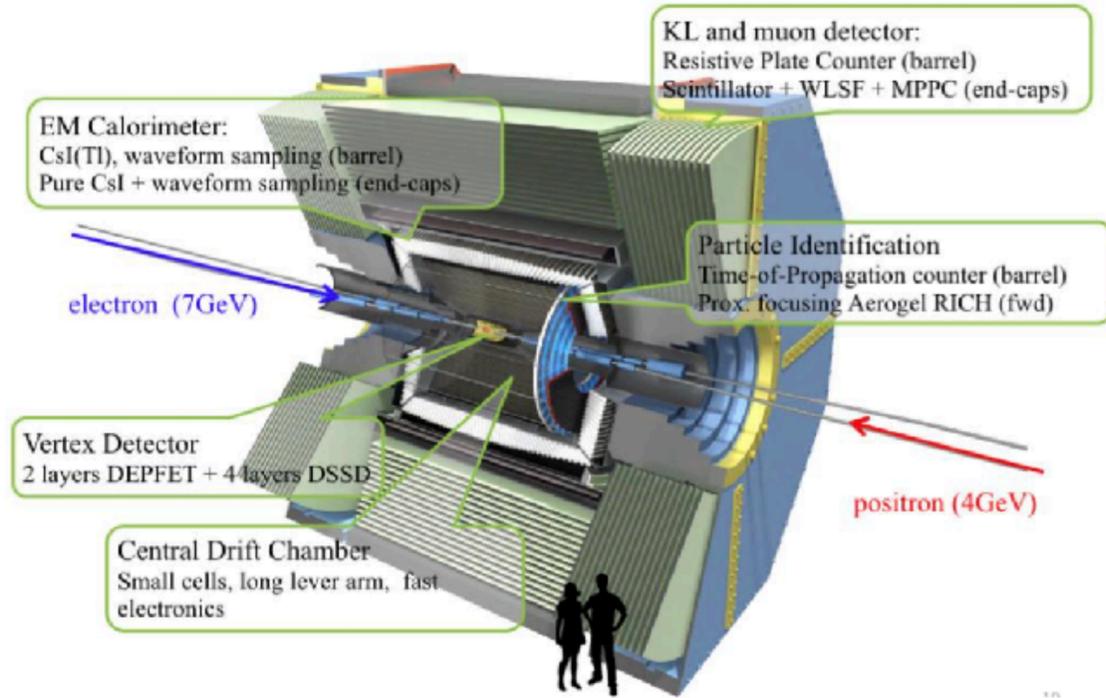
- And many hadrons observed by BESIII and Belle
- Many of them observed in heavy hadron decays
- Particle zoo in 1950s and 1960s leads to the quark model and Standard Model
- What can we expect for the particle zoo 2.0 now?

See Yanxi Zhang's and Yiming Li's talks

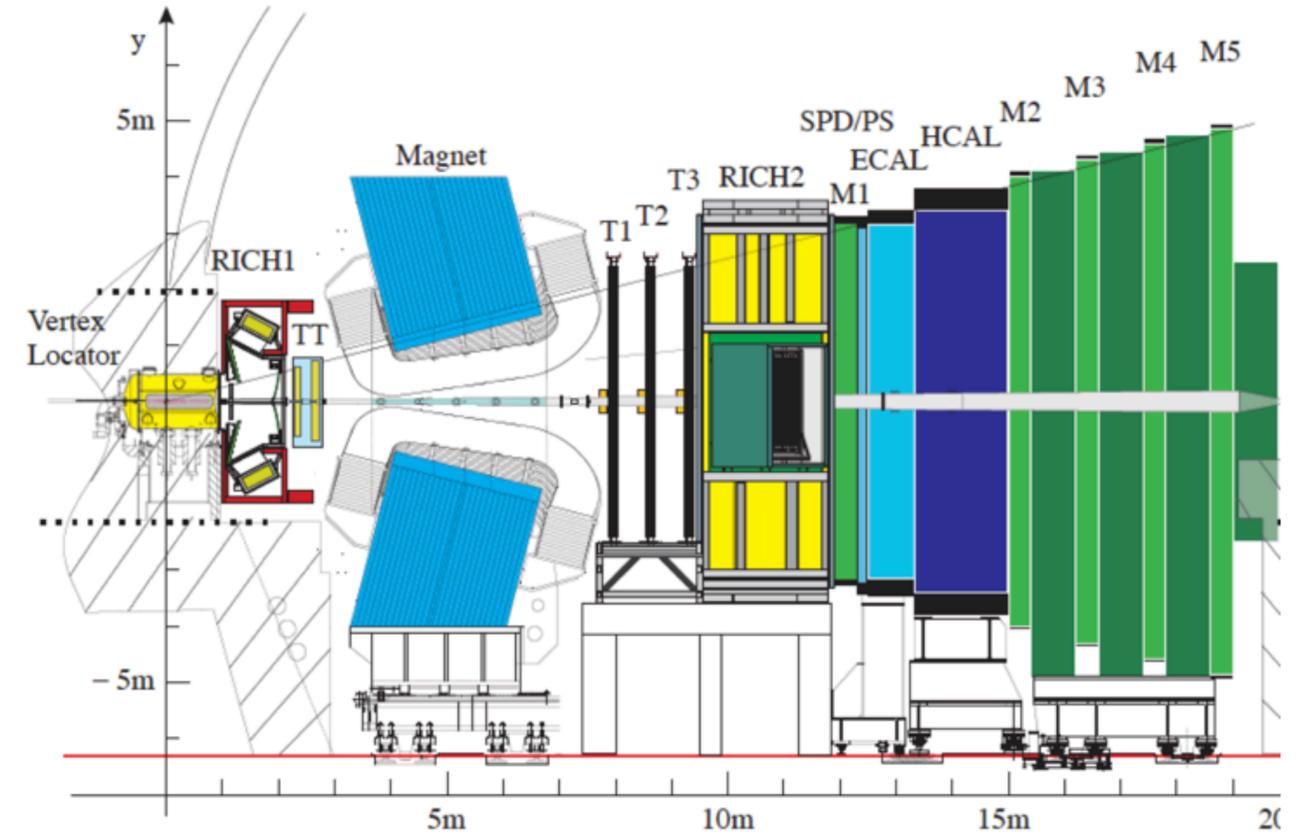
# 展 望



**BESIII**



**Belle and Belle II**

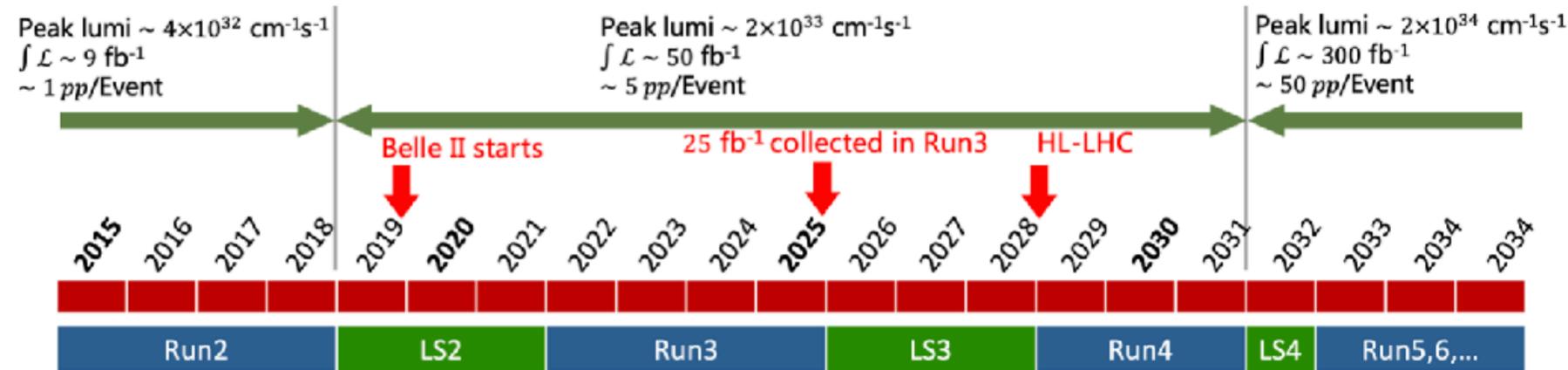


**LHCb**

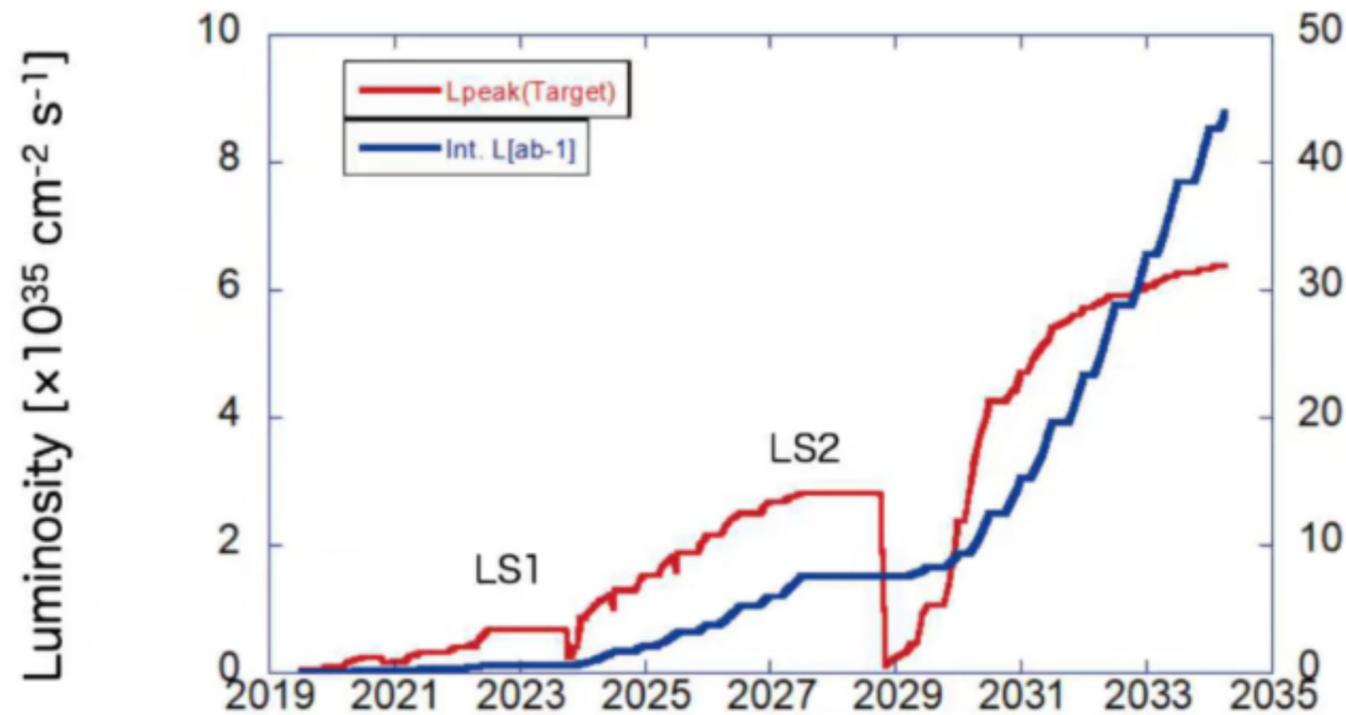
# Long term plan beyond 2035



**LHCb**



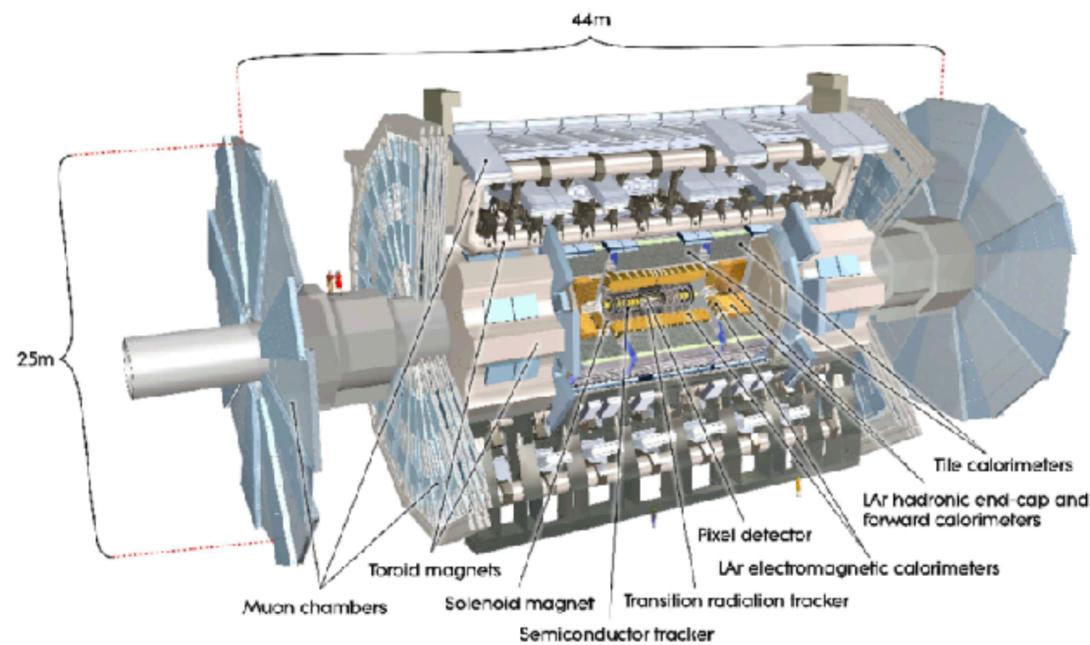
**Belle II**



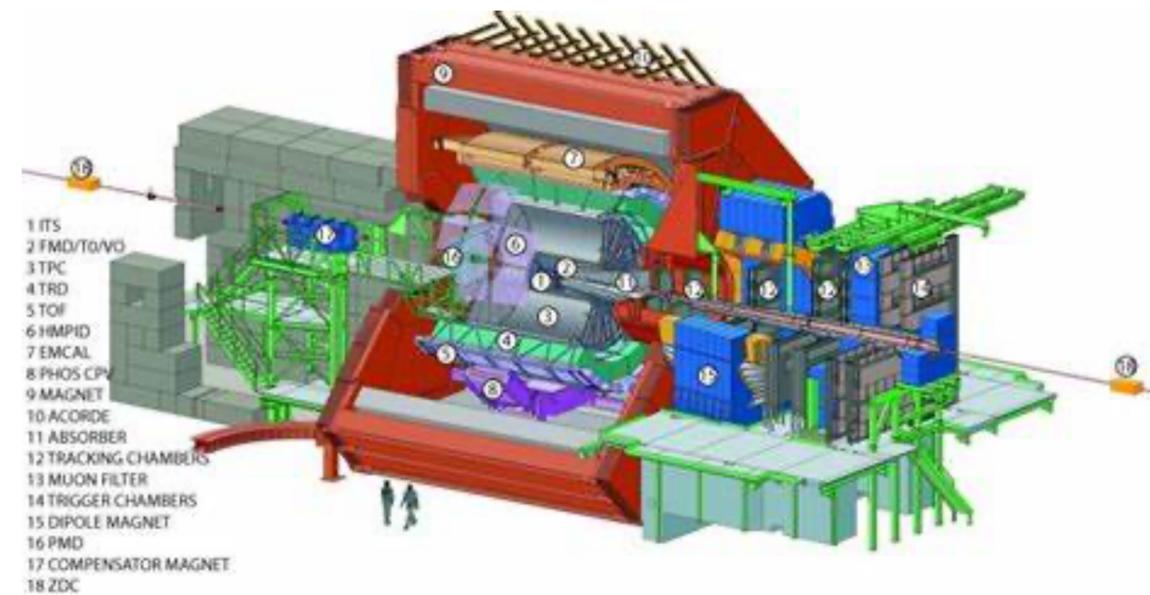
**Game of more than 10 years**

**BESIII**

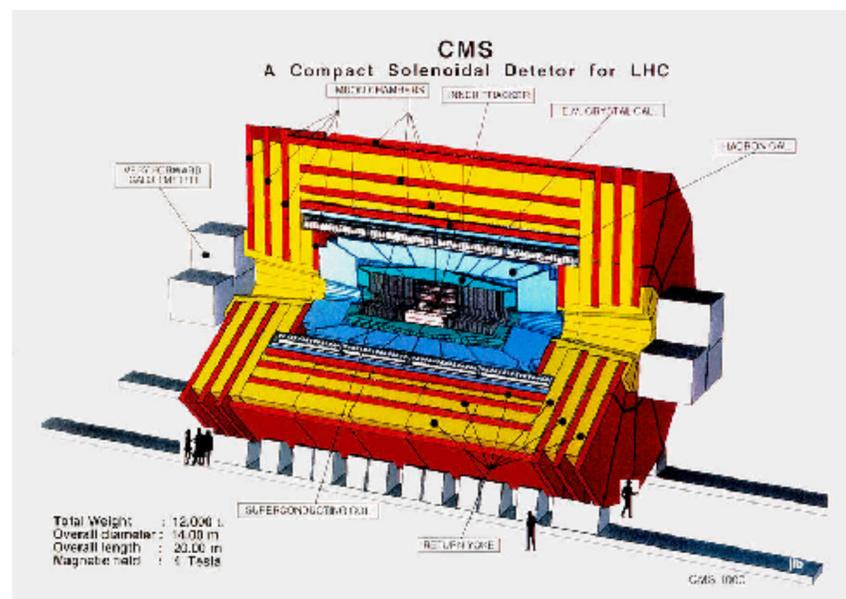
upgrade of BEPCII:  $\times 3$  luminosity + energy to 5.6 GeV



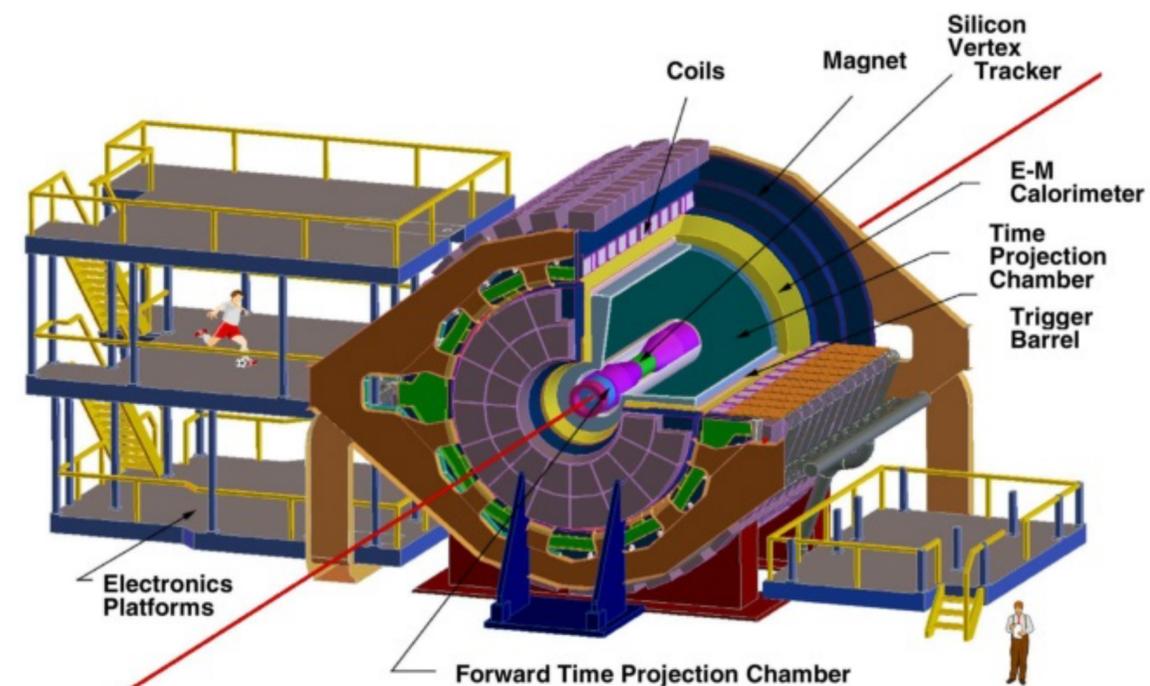
**ATLAS**



**ALICE**

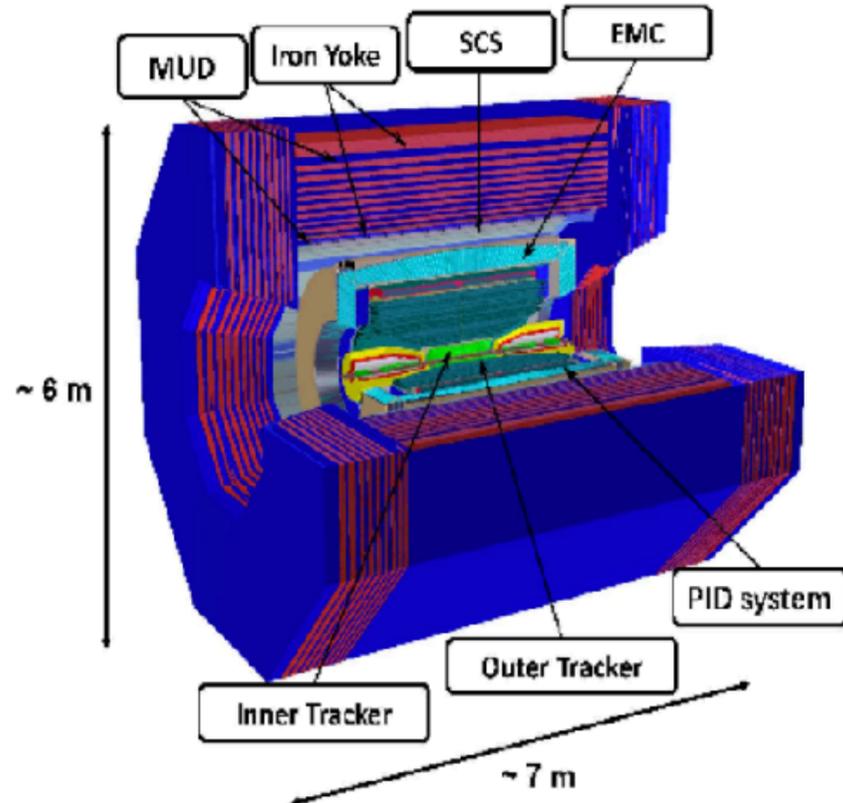


**CMS**



**STAR**

# Super tau-charm facility



	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032-2042	2043-2046
Form collaboration	█	█	█	█												
Conception design CDR	█	█	█	█												
R&D (TDR)	█	█	█	█	█	█	█	█								
Construction								█	█	█	█	█	█	█		
Operation															█	
Upgrade																█

See Yang-Heng Zheng's talk

# Tera Z+ factories

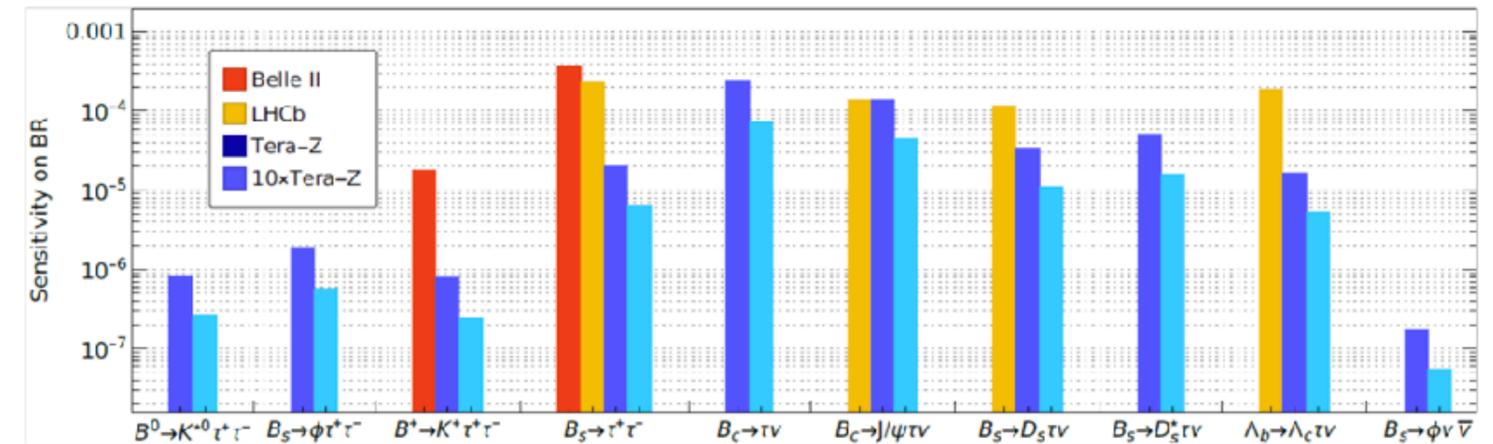
See also

[Y. Amhis, M. Hartmann, C. Hulsens, D. Hill, O. Sumensari 2105.13330](#)

[T. Zheng, J. Xu, L. Cao, D. Yu, W. Wang et al., 2007.08234](#)

[M. Ho, T.H. Kwok, X. Jiang, LL, Tao Liu, 2212.02433](#)

- Anomalies indicating lepton flavor universality violation
- Potential for  $|V_{cb}|$  &  $|V_{ub}|$  extraction
- Current focus: (Semi)leptonic modes



See Lingfeng Li's talk

# Personal Attitudes of Perspectives

**Phenomenologies:** collaboration between theory and experiment

1. Baryon CPV
2. Polarizations, angular distributions and partial wave analysis

## Theories:

Multi-scale in heavy flavor physics.

Interplay of perturbative and non-perturbative QCD

Do your best to the extreme!!

# 重味物理

过去20年，成绩辉煌

未来20年，前景可期