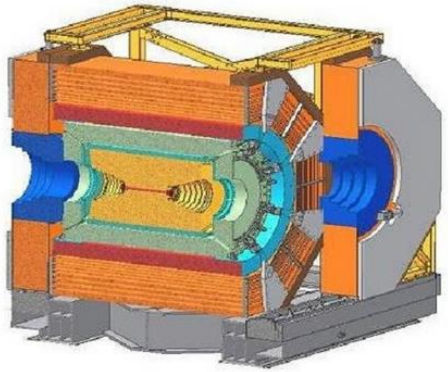


国家自然科学基金委重大项目-研究进展
《北京谱仪BESIII实验上粲夸克衰变中标准模型的精确检验》之课题一

阈值处中性粲介子量子关联性研究

高扬，彭海平

中国科学技术大学

承担单位：中国科学技术大学

合作单位：南华大学

成都，2026/10/17

内容提要

- 总体目标和研究内容按计划执行情况；
- 多体自共轭过程的CP本征态成分比例；
- 三体自共轭过程强相位差参数测量；
- 四体自共轭过程强相位差参数测量；
- 粲味道过程关联因子和强相位差参数测量；

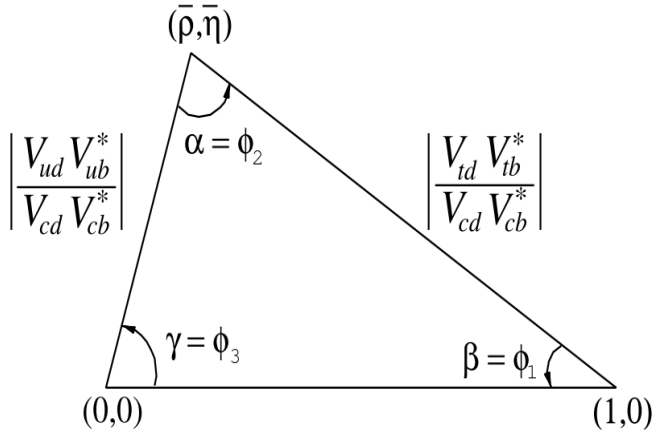
CKM矩阵幺正性

CKM矩阵的幺正性是检验电弱统一理论的重要途径

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

CKM矩阵在复平面上的几何描述：

$$V^{\dagger}V = 1 \Rightarrow \boxed{V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0}$$

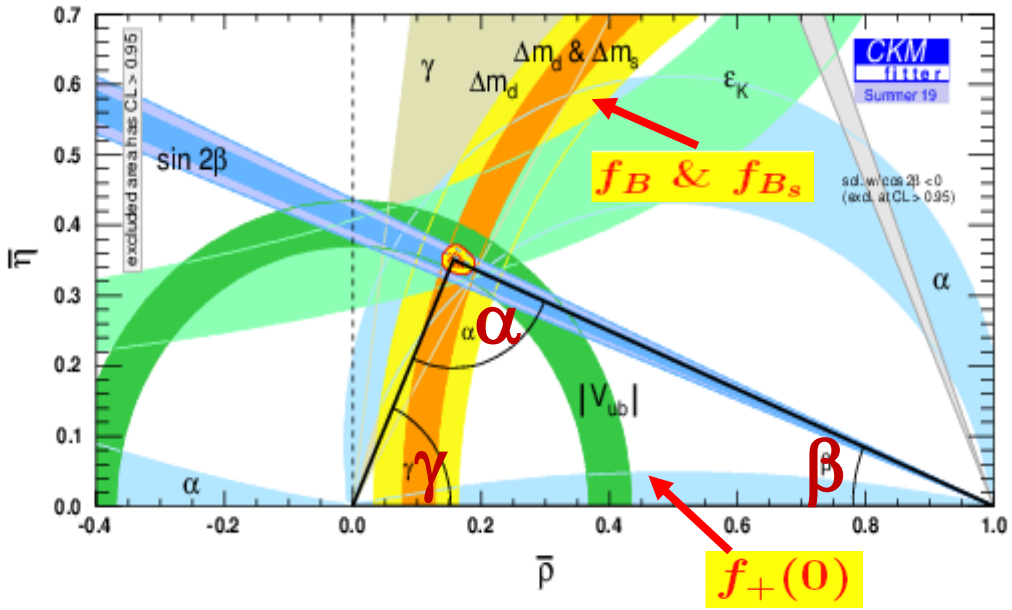


B介子衰变CKM矩阵CP相角 α, β, γ

实验上独立测量三个CP相角，检验三角形的闭合性，是对电弱统一理论的强有力检验

相角γ的挑战

2025



相角的**直接测量**结果：

$$\alpha = \left(86.0^{+3.9}_{-3.2}\right)^{\circ}$$

$$\beta = \left(22.60^{+0.45}_{-0.44}\right)^{\circ}$$

$$\gamma = \left(66.4^{+2.7}_{-2.8}\right)^{\circ}$$

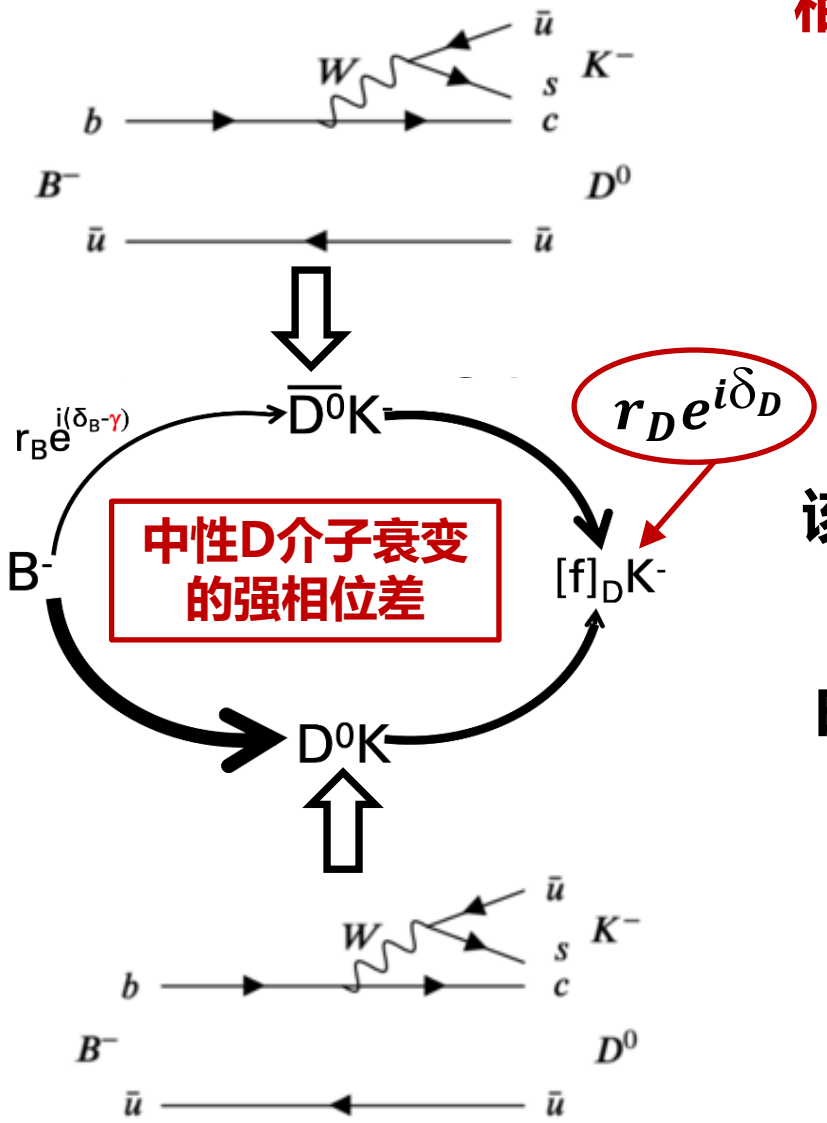
γ测量误差很大

- 实验对γ角开展大量**直接**测量：
  $\gamma = \left(66.4^{+2.7}_{-2.8}\right)^{\circ}$
- CKMFitter 全局拟合**间接**测量：
  $\gamma = \left(66.2^{+0.7}_{-1.4}\right)^{\circ}$

⇨ **直接测量的精度远低于全局拟合**

相角γ的精度挑战CKM幺正性的检验，是粒子物理领域研究重点

相角ϕ_3/γ测量



相角ϕ_3/γ可通过$B \to DK$过程测量，是唯一可在树阶测量的相角

$$\Gamma(B^- \to [f]_D K^-) \propto 1 + r_B^2 r_D^2 + 2R_f r_D r_B \cos(\delta_B - \gamma - \delta_D)$$

$D^0 \to f$ 和 $\bar{D}^0 \to f$ 衰变参数：

$$\left(r_D^f\right)^2 = \int |\bar{A}_f|^2 d\Phi / \int |A_f|^2 d\Phi,$$

$$R_f e^{-i\delta_D^f} = \frac{\int A_f^* \bar{A}_f d\Phi}{\sqrt{\int |A_f|^2 d\Phi \int |\bar{A}_f|^2 d\Phi}}$$

该测量由理论引起的误差可忽略，而中性粲介子衰变的强相位差等参数是关键输入

由ψ(3770)衰变的粲介子的无模型依赖的测量是最佳测量途径

不同方法测量γ相角：

- **GLW方法：** $D \to CP$**本征态** ← F_+
- **ADS方法：** $D \to CF/DCS$**态** ← R_f, δ_D^f
- **GGSZ方法：** $D \to$ **自共轭多体衰变** ← c_i, s_i

BESIII与B工厂的协同研究

LHCb-PUB-2016-025
October 11, 2016

LHCb和BESIII实验经过多次研讨

Synergy of BESIII and LHCb physics programmes

- BESIII目前的结果对γ相角的误差贡献为1°

Abstract

There is potential for BESIII open-charm measurements to have a significant impact on the LHCb physics programme. Despite the general purpose design of the LHCb detector there are certain inputs that can be better determined in other environments or in production mechanisms not accessible at the LHC. With the unprecedented amount of LHCb data that will become available over the one-to-two decades it is necessary to consider where additional inputs are essential, to avoid the situation where the uncertainty on a measurement is dominated by the lack of knowledge of an external input. This document considers the capabilities of the BESIII experiment to provide vital inputs into key LHCb measurements. A number of different potential measurements that could be pursued are discussed.

LHCb-PUB-2016-025
11/10/2016

1 Executive summary

There are at least two vital sets of inputs to the LHCb physics programmes that are most easily accessed using the open-charm data accumulated at BESIII. The first is composed of strong-phase related measurements of neutral D mesons, whose knowledge is vital for a high precision measurement of the CKM angle γ. The use of existing CLEO-c measurements has allowed LHCb to include a wide range of D modes in its determination of the CKM angle γ using $B \to DK$ decays, which together have made possible the currently achieved precision on this fundamental parameter of 8° [1]. These CLEO-c measurements themselves contribute an uncertainty of approximately 2° which, while small compared to the current statistical uncertainties, will soon become dominant as the LHCb rate of data collection increases.

The $\Psi(3770)$ data already accumulated by the BESIII experiment are sufficient to bring the contribution from strong-phase uncertainties to approximately 1°. The goal of the LHCb phase-1 upgrade, due to start collecting data in 2021, is to measure γ with a precision of 1°, which will approximately match the uncertainty on this parameter from indirect constraints from other measurements. Therefore it would be most desirable to have strong-phase measurements from an even larger dataset so that the uncertainty from external inputs does not become dominant. For this reason the existing plan to take another 15-20 fb^{-1} at this resonance would be very important and is highly encouraged. With this amount of data, the strong-phase contribution to the uncertainty on γ will remain sub-dominant throughout the physics programme of the approved LHCb phase-1 upgrade. Plans are also being formulated for a second, phase-2 upgrade, which would accumulate a much larger data set. In this case the input from a 15-20 fb^{-1} $\Psi(3770)$ sample would be essential.

- LHCb实验在Phase-I升级后，对γ相角测量的目标精度为1°
- 强烈需要BESIII实验基于20fb^{-1}数据的强相位差的结果

内容提要

- 总体目标和研究内容按计划执行情况；
- 多体自共轭过程的CP本征态成分比例；
- 三体自共轭过程强相位差参数测量；
- 四体自共轭过程强相位差参数测量；
- 粲味道过程关联因子和强相位差参数测量；

研究目标

开展中性粲介子量子关联效应研究，以国际最高精度测量偶CP成分比例、关联因子及强相差等关键参数，满足未来十年以上年B物理实验精确测量相角γ的输入参数需求

- 全面系统地精密测量自共轭过程的CP本征态偶CP成分比例，提高CP本征态标记道产额
- 精密测量自共轭过程强相位差参数c_i/s_i，使其对γ相角测量的误差贡献控制在0.5°(最好)的水平
- 高精度地测量关联因子和平均强相位差等参数

不同标记方法的研究

实验测量巧妙地利用特殊标记道来简化测量，控制系统误差：

- 通过粲味标记道直接测量D^0衰变区间分宽度K_i，为测量c_i/s_i奠定基础
- 通过CP标记道测量c_i：

$$N(cp,i)=N_{cp,ST}\left(K_i+K_{-i}-2\sqrt{K_iK_{-i}}c_i\eta_{CP}\right)/\left(2N_{flavor,ST}\right)$$

- 通过自共轭道(已测的$K_S\pi^+\pi^-$, $K_L\pi^+\pi^-$等)测量c_i/s_i

$$N(i,j)=N_{D^0\overline{D}^0}\left(K_iK_{-j}+K_{-i}K_j\mp2\sqrt{K_iK_{-j}K_{-i}K_j}\left(c_ic_j+s_is_j\right)\right)/\left(2N_{flavor,ST}N'_{flavor,ST}\right)$$

类型	标记道
粲味标记道	$K^\pm\pi^\mp$,$K^\pm\pi^\mp\pi^0$,$K^\pm\pi^\mp\pi^\pm\pi^\mp$,$K^\pm e^\mp\nu$
偶 CP 标记道	K^+K^-,$\pi^+\pi^-$,$K^0_S\pi^0\pi^0$,$K^0_L\pi^0$,$K^0_L\omega$,$\pi^+\pi^-\pi^0$
奇 CP 标记道	$K^0_S\pi^0$,$K^0_S\eta(\gamma\gamma,\pi^+\pi^-\pi^0)$,$K^0_S\eta'(\rho\gamma,\pi^+\pi^-\eta(\gamma\gamma))$,$K^0_S\omega$,$K^0_L\pi^0\pi^0$
自共轭道	$K^0_S\pi^+\pi^-$, $K^0_L\pi^+\pi^-$

完成不同类型标记道的开发，为后续的研究奠定基础

研究执行情况

□ 多体自共轭过程的CP本征态成分比例

衰变道	进展	
$\pi^+\pi^-\pi^0$ $K^+K^-\pi^0$	MI: BAM1153, PRD 111, 012007(2025)	8fb^{-1}
$\pi^+\pi^-\pi^+\pi^-$	MI: BAM544, PRD 106, 092004(2022)	3fb^{-1}
$K^0_S\pi^+\pi^-\pi^0$	MI: BAM609, PRD 108,032003(2023)	3fb^{-1}
$K^+K^-\pi^+\pi^-$	MI: BAM606, PRD 107,032009(2023) MI: BAM754, PRD 112,012015(2025)	3fb^{-1} 20fb^{-1}
$\pi^+\pi^-\pi^0\pi^0$	MD: BAM628, CPC 48,no.8,083001(2024)	3fb^{-1}
$\eta\pi^+\pi^-$	MI: BAM1001	20fb^{-1}

□ 关联因子和平均强相位差参数的精确测量

衰变道	进展	
$K^-\pi^+$	BAM567, EPJC 82,1009 (2022) BAM900, PRL 135, 171901 (2025) DDX Report	3fb^{-1} 20fb^{-1}
$K^-\pi^+\pi^0/K^-\pi^+\pi^+\pi^-$	BAM431, JHEP 05, 164 (2021) BAM899, JHEP 08, 038 (2026) Report	3fb^{-1} 8fb^{-1} 20fb^{-1}
$K^0_S K^\mp\pi^\pm$	BAM1173	20fb^{-1}

□ 自共轭过程强相位差参数

衰变道	进展	
$K^0_{S/L}\pi^+\pi^-$	MI: BAM364, PRL 124, 241802(2020) MI: BAM827, JHEP 06, 086 (2025) UB: BAM827, arXiv:2604.05712 (PRL) MI: Report UB: Report (Fourier Expan) UB: Report (Polynominal Expan)	3fb^{-1} 8fb^{-1} 8fb^{-1} 20fb^{-1} 20 fb^{-1} 20 fb^{-1}
$K^0_{S/L}K^+K^-$	MI: BAM410, PRD 102,052008 (2020) UB: BAM827, arXiv:2604.05712 (PRL) MI: Report	3fb^{-1} 8fb^{-1} 20fb^{-1}
$\pi^+\pi^-\pi^+\pi^-$	MI: BAM544, PRD 110,112008(2024) MI: BAM1162	3fb^{-1} 20fb^{-1}
$K^0_S\pi^+\pi^-\pi^0$	MI: BAM1163	20fb^{-1}
$K^0_L\pi^+\pi^-\pi^0$	MI: Ongoing	20fb^{-1}
$K^+K^-\pi^+\pi^-$	MI: BAM754, PRD 112,012015(2025)	20fb^{-1}
$\pi^+\pi^-\pi^0$	MI: Report/Report	20fb^{-1}
$K^+K^-\pi^0$	MI: Report	20fb^{-1}

BESIII与LHCb协同研究

衰变道	观测量	统计量（2.9 fb^{-1}）	统计量（8 fb^{-1}）	统计量（20 fb^{-1}）
$K_S^0\pi^+\pi^-$	c_i, s_i	PRL 124, 241802 (2020)	JHEP 06, 086 (2025) UB: arXiv:2604.05712	MI: Report UB: Report (Fourier) UB: Report (Polynominal)
$K_S^0K^+K^-$	c_i, s_i	PRD 102, 052008 (2020)	UB: arXiv:2604.05712	MI: Report
$K^-\pi^+\pi^0$	R, δ	JHEP 05, 164 (2021)	JHEP 08, 038 (2026)	Report
$K^-\pi^+\pi^+\pi^-$				
$K_S^0K^\pm\pi^\mp$	R, δ	— —	— —	BAM1173
$K^-\pi^+$	δ	EPJC 82, 1009 (2022)	— —	Report
$K_S^0\pi^+\pi^-\pi^0$	F_+	PRD 108, 032003 (2023)	— —	BAM1163
	c_i, s_i	— —	— —	
$\pi^+\pi^-\pi^+\pi^-$	F_+	PRD 106, 092004 (2022)	— —	BAM1162
	c_i, s_i	PRD 110,112008 (2024)		
$K^+K^-\pi^+\pi^-$	F_+	PRD 107,032009 (2023)	— —	PRD 112,012015(2025)
	c_i, s_i	— —	— —	
$\pi^+\pi^-\pi^0/K^+K^-\pi^0$	F_+	— —	PRD 111, 012007(2025)	Report/Report/Report
	c_i, s_i	— —	— —	

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- **多体自共轭过程的CP本征态成分比例；**
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多体自共轭过程的CP本征态成分比例

衰变道	进展	BESIII	CLEO
$\pi^+\pi^-\pi^0$ $K^+K^-\pi^0$	MI: BAM764, PRD 111, 012007 (2025) 8fb^{-1}	0.9406+-0.0055+-0.0033 0.631+-0.014+-0.011	0.973+-0.017 (MI) 0.732+-0.055 (MI)
$\pi^+\pi^-\pi^+\pi^-$	MI: BAM544, PRD 106, 092004(2022) 3fb^{-1} MD: BAM628, CPC 48, 083001(2024) 3fb^{-1}	0.735+-0.015+-0.005 0.752+-0.011+-0.015	0.737+-0.028 (MI Global) 0.769+-0.021+-0.010 (MI Binned) 0.729+-0.009+-0.018 (MD)
$K^0_S\pi^+\pi^-\pi^0$	MI: BAM609, PRD 108,032003(2023) 3fb^{-1}	0.235+-0.010+-0.002	0.238+-0.012+-0.012 (MI)
$K^+K^-\pi^+\pi^-$	MI: BAM606, PRD 107,032009(2023) 3fb^{-1} MI: BAM754, PRD 112,012015(2025) 20fb^{-1}	0.730+-0.037+-0.021 0.754+-0.010+-0.008	0.753+-0.018+-0.039 (MD)
$\pi^+\pi^-\pi^0\pi^0$	MD: BAM628, CPC 48,no.8,083001(2024) 3fb^{-1}	0.689+-0.015+-0.024	-

- 利用3~20 fb^{-1}的数据测量了多体自共轭过程CP本征态成分比例
- 测量结果相对于之前的实验结果精度提升
- 该结果对利用GLW方法测量相角γ和测量$D^0\bar{D}^0$CP破坏提供了重要输入

内容提要

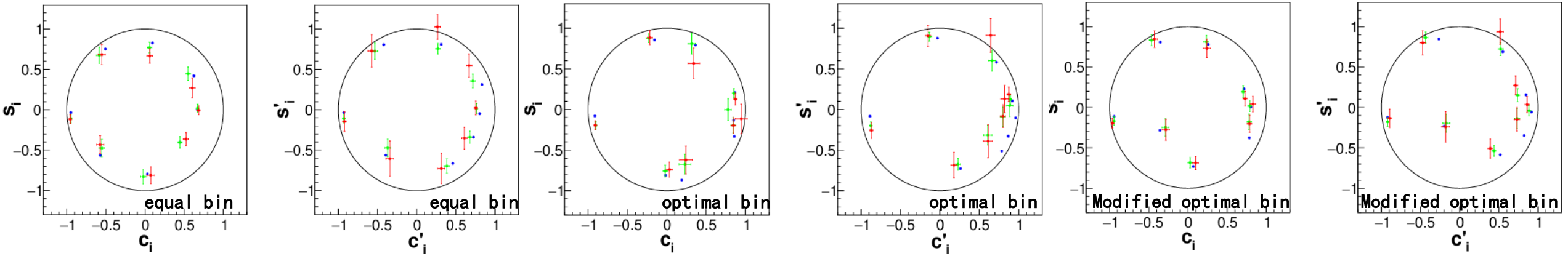
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$D^0 \to K_{S/L}\pi^+\pi^-$强相位差测量

- 利用8fb^{-1}的$D^0\bar{D}^0$阈值产生数据**精确测量了相空间分区的相位差参数c_i/s_i**
- γ测量中相位差的参数贡献的误差:

误差贡献	BESIII 8fb-1 (un)constrain	BESIII 3fb-1 constrain	CLEO
Equal bin	0.7°(0.9°)	0.7°	2.0°
Optimal bin	0.9°(1.5°)	1.2°	3.9°
Modified optimal bin	0.8°(1.1°)	0.8°	2.1°

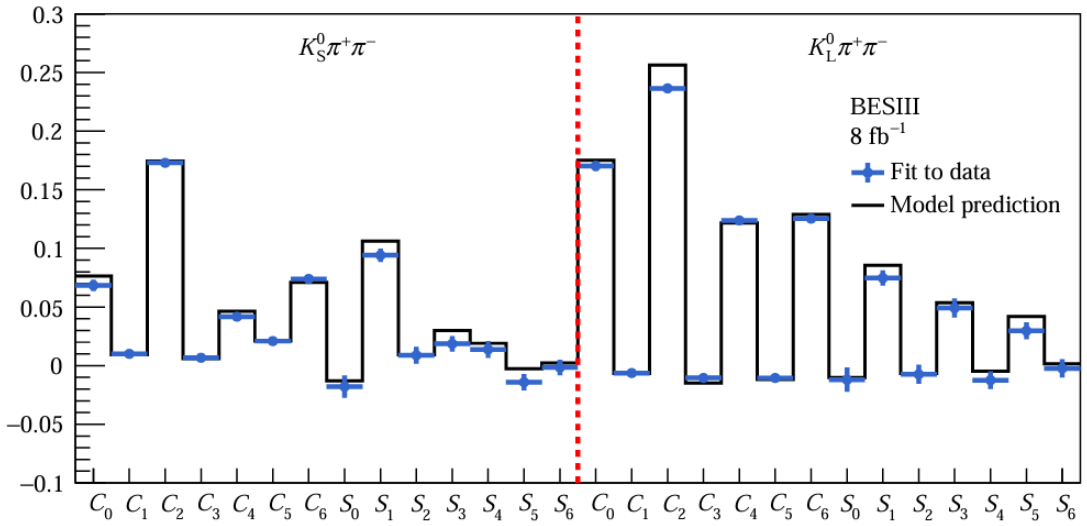
统计误差($\mathcal{L} = 9\ \mathrm{fb}^{-1}$@LHCb): Optimal bin ($K_S\pi^+\pi^-$)+2X2 bin ($K_SK^+K^-$): ~5° [JHEP 02, 169 (2021)]

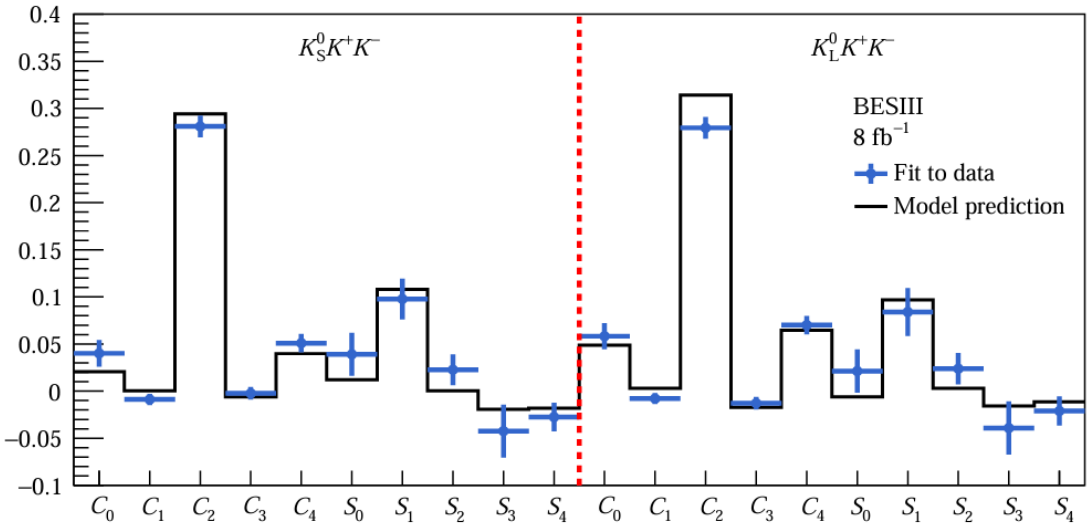


JHEP 06, 086 (2025)

$D^0 \to K_{S/L} h^+ h^-$强相位差测量

- 利用8fb^{-1}的BESIII $D^0\bar{D}^0$阈值产生数据和9fb^{-1}的LHCb数据，通过$K^0_S\pi^+\pi^-$与$K^0_S K^+ K^-$首次完成了BESIII+LHCb联合γ测量
- 首次基于优化傅里叶展开方法测量了$K^0_{S/L}\pi^+\pi^-$和$K^0_{S/L}K^+K^-$的强相位差参数C_n/S_n
- γ测量中相位差的参数贡献的误差:$\left(\mathcal{L} = 8\ \mathrm{fb}^{-1}@\mathrm{BESIII} + \mathcal{L} = 9\ \mathrm{fb}^{-1}@\mathrm{LHCb}\right)$:
  - 统计误差: $4.9°$, 系统误差(LHCb): $0.8°$, 系统误差(BESIII): $0.6°$
- 相比使用相空间分块方法，该方法使LHCb统计精度提高约5%.





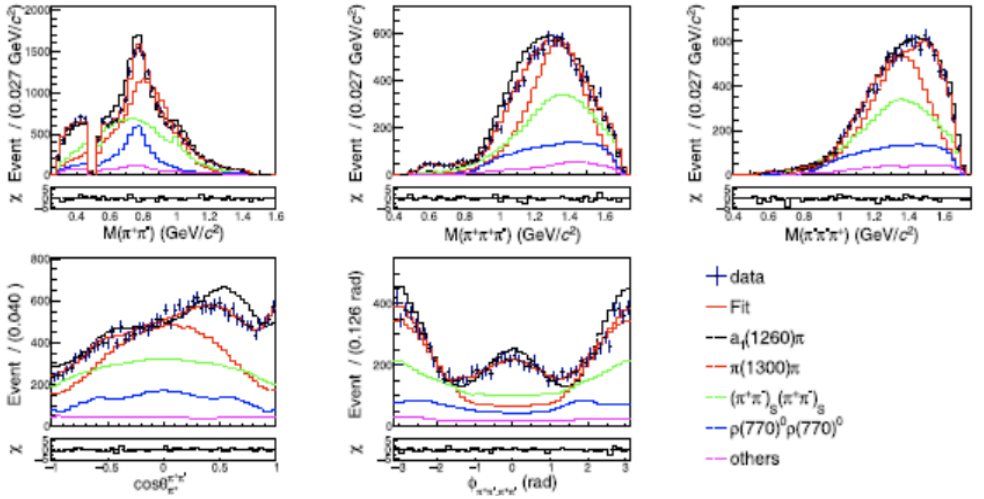
arXiv:2604.05712, arXiv:2604.05701 (Accepted by PRL/PRD)

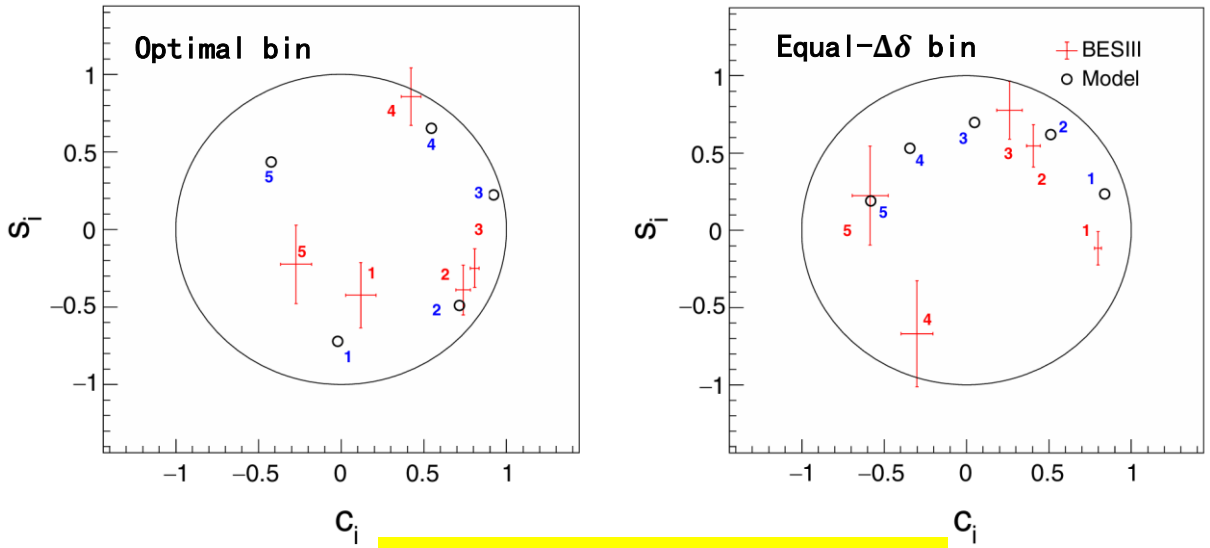
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- 粲味道过程关联因子和强相位差参数测量；

$D^0 \to \pi^+\pi^-\pi^+\pi^-$强相位差测量

- 利用 BESIII 3fb^{-1}的数据提取的振幅模型制定了**全新的相空间分Bin策略**
- 利用$D^0\bar{D}^0$阈值产生的量子关联的特性测量了各区间的**相位差参数c_i/s_i**
- γ测量中相位差的参数**贡献的误差显著降低**





PRD 110,112008 (2024)

误差贡献	BESIII	CLEO
Equal-$\Delta\delta$ bin $\mathcal{L} = 9\ \text{fb}^{-1} (\gg 9\ \text{fb}^{-1})$@LHCb	2.6°(1.5°)	7.2°(4.0°)
Optimal bin $\mathcal{L} = 9\ \text{fb}^{-1} (\gg 9\ \text{fb}^{-1})$@LHCb	2.9°(2.0°)	7.9°(5.0°)

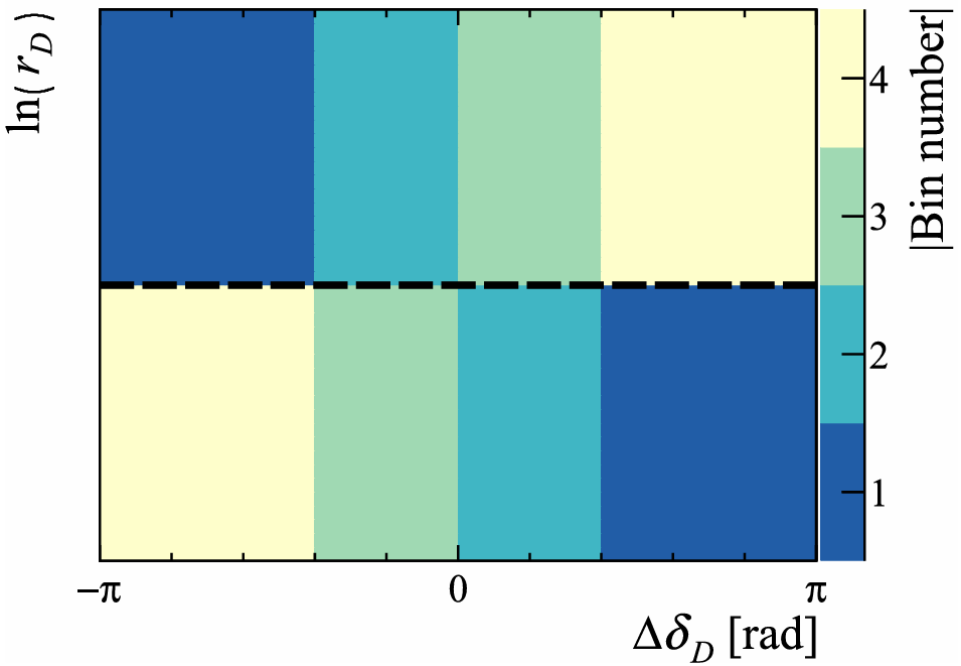
统计误差($\mathcal{L} = 9\ \text{fb}^{-1}$@LHCb):

Equal-$\Delta\delta$ bin: 6.6°　　Optimal bin: 5.8°

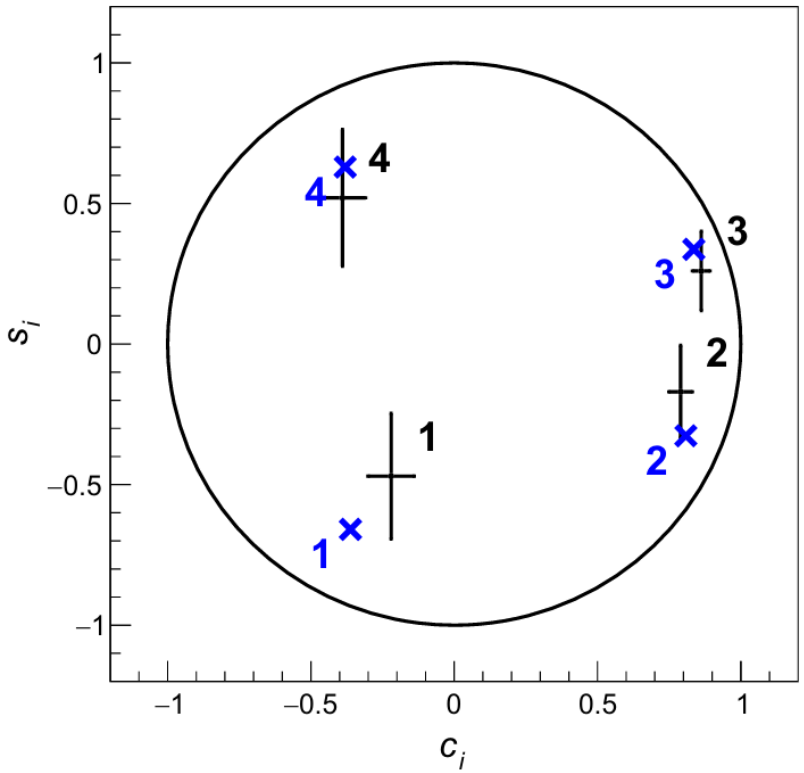
[PRD 110,112008(2024)]　　[JHEP 01 (2018) 144]

$D^0 \to K^+K^-\pi^+\pi^-$强相位差测量

- 利用20fb^{-1}的$D^0\bar{D}^0$阈值产生数据首次测量了相空间分区的相位差参数c_i/s_i
- γ测量中相位差的参数贡献的误差~10°，LHCb 9 fb^{-1}的统计误差~12.7°



[EPJC 83, 547 (2023)]



[PRD 112, 012015 (2025)]

内容提要

- 总体目标和研究内容按计划执行情况；
- 多体自共轭过程的CP本征态成分比例；
- 三体自共轭过程强相位差参数测量；
- 四体自共轭过程强相位差参数测量；
- **粲味道过程关联因子和强相位差参数测量；**

$D^0 \to K^-\pi^+$强相位差测量

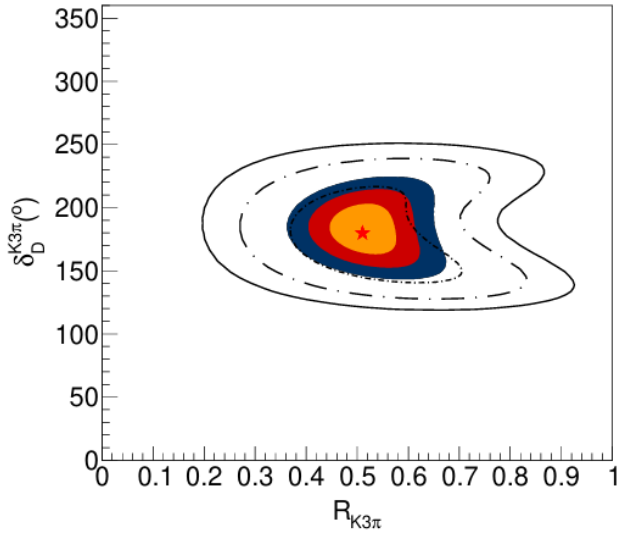
- 利用7.93fb^{-1}的4.13-4.23 GeV产生的数据，使用$e^+e^- \to D\bar{D}$, $e^+e^- \to D^*\bar{D}$和$e^+e^- \to D^*\bar{D}^*$首次确认在$e^+e^- \to XD\bar{D}$系统中存在量子关联
- 首次观测到偶C宇称的$D\bar{D}$系统
- 测量了$K^-\pi^+$的平均强相位差$\delta_D^{K^-\pi^+} = (192.8^{+11.0+1.9}_{-12.4-2.4})^\circ$
- 精度可与3fb^{-1}的BESIII $D^0\bar{D}^0$阈值产生数据测量的$\delta_D^{K^-\pi^+} = (187.6^{+8.9+5.4}_{-9.7-6.4})^\circ$相比
- 两个样本联合拟合得到$\delta_D^{K^-\pi^+} = (187.6^{+6.9+3.4}_{-7.4-3.8})^\circ$
- γ测量和粲混合参数中贡献的误差:$(\mathcal{L} = 4\ \mathrm{ab}^{-1}@\mathrm{STCF})$:
  - STCF: $x: 5.6\times10^{-4}, y: 1.5\times10^{-4}, |q/p|: 2.1\%, \gamma: 1.6^\circ$
  - LHCb: $x: 4.4\times10^{-4}, y: 2.1\times10^{-4}, |q/p|: 1.8\%, \gamma: 1.2^\circ$

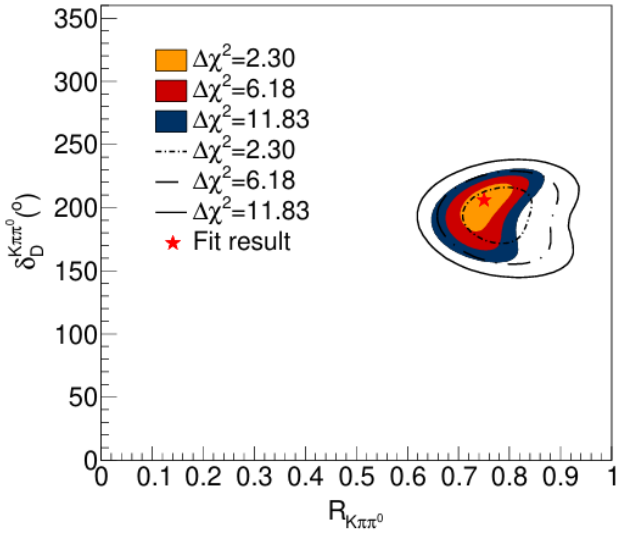
[Report No. CERN-LHCb-CONF-2024-004, CERN, 2024; PRD 112, 013004 (2025)]

PRL 135, 171901 (2025) , PRD 112, 072006 (2025)

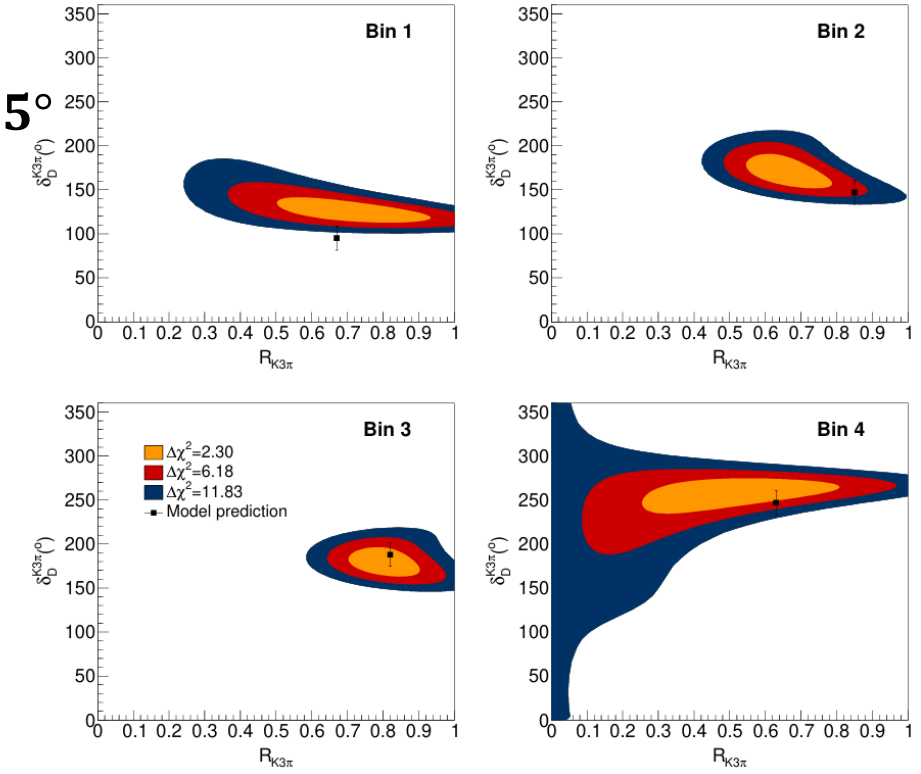
$D^0 \to K^-\pi^+\pi^+\pi^-/K^-\pi^+\pi^0$强相位差测量

- 利用8fb^{-1}的$D^0\bar{D}^0$阈值产生数据精确测量了$K^-\pi^+\pi^0$和$K^-\pi^+\pi^+\pi^-$的关联因子和平均强相位差$R_{Kn\pi}, \delta_D^{Kn\pi}$
- 精确测量了$K^-\pi^+\pi^+\pi^-$的分块关联因子和强相位差$R_{Kn\pi}, \delta_D^{Kn\pi}$
- γ测量中关联因子和相位差的参数贡献的误差:$\left(\mathcal{L} = 9\ \mathrm{fb}^{-1}@\mathrm{LHCb}\right)$:
  - 使用$K^-\pi^+\pi^+\pi^-$的分块$R_{Kn\pi}, \delta_D^{Kn\pi}$
  - 总误差(LHCb+BESIII): $8.5°$, 系统误差(BESIII): $3.5°$





JHEP 08, 038 (2026)



总结

- 阈值处中性粲介子的量子关联精密测量将在非微扰QCD效应、混合参数以及CP破坏等研究中具有独特地位，在CKM矩阵幺正三角形相角ϕ_3/γ的精确测量中扮演关键角色；
- 本课题基于BESIII实验采集的$\psi(3770)$数据，系统性开展多体自共轭过程的CP本征态成分比例、强相位差、关联因子和平均强相位差等关键参数的无模型依赖的精确测量；
- 研究成果将保障未来十年以上国际粒子物理领域ϕ_3/γ相角、$D^0\bar{D}^0$混合参数和CP破坏等精密测量，高精度验证电弱统一理论，探索非微扰QCD的性质、寻找新物理；
- 课题按照计划顺利开展，取得了系列重大进展；课题组也将按照计划完成、高标准完成相关的研究计划，并获得预期成果；

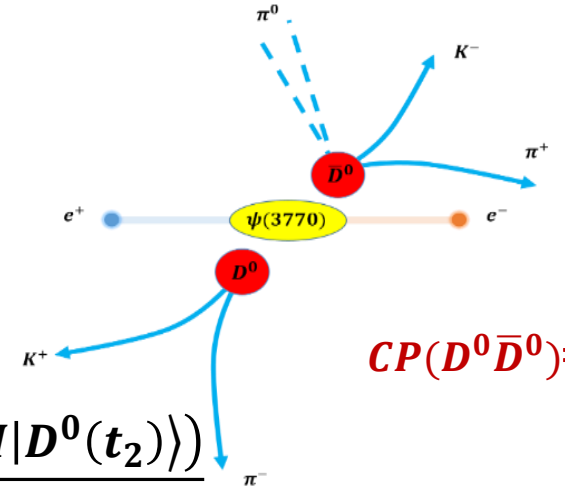
感谢各位老师的长期支持，
请各位专家评委批评指正，
谢谢！

中性粲介子强相位差的测量

$\psi(3770)$ 独特的**量子关联**数据是测量强相角差的**最佳途径**

- $\psi(3770) \to D^0\bar{D}^0$ 衰变振幅：

$$|\psi(3770)\rangle = \frac{\left(|D^0\rangle|\bar{D}^0\rangle - |\bar{D}^0\rangle|D^0\rangle\right)}{\sqrt{2}}$$



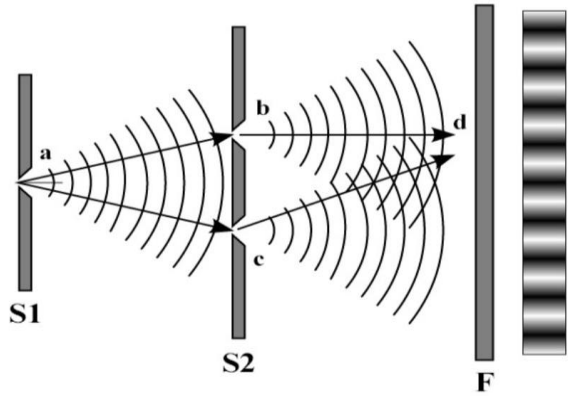
$CP(D^0\bar{D}^0)$=−1

- $\psi(3770) \to D^0\bar{D}^0 \to fg$ 含时间衰变振幅：

$$A(f, t_1; g, t_2) = \frac{\left(\langle f|H|D^0(t_1)\rangle\langle g|H|\bar{D}^0(t_2)\rangle - \langle f|H|\bar{D}^0(t_1)\rangle\langle g|H|D^0(t_2)\rangle\right)}{\sqrt{2}}$$

- 不同相空间区间衰变宽度：

$$\Gamma\left[\psi(3770) \to D\bar{D} \to f_i g_j\right] \propto \left[K_i^f \bar{K}_j^g + \bar{K}_i^f K_j^g - 2\sqrt{K_i^f \bar{K}_j^g \bar{K}_i^f K_j^g}\left(c_i^f c_j^g + s_i^f s_j^g\right)\right]$$



强相位差c_i/s_i出现在**干涉项**

⇒测量**不同相空间**区域的**产额**

便可以提取c_i/s_i

联合分析

BESIII强相位差联合测量（$K^0_{S/L}\pi^+\pi^-$、$K^0_{S/L}K^+K^-$、$K\pi\pi^0$、$K\pi\pi\pi$等）：

- 充分利用各主要双标记衰变数据，提高强相位参数测量精度
- 减少各单独测量中所用双标记数据的重合

LHCb+BESIIIγ角联合测量（8fb^{-1} Unbinned $K^0_{S/L}\pi^+\pi^-$ +$K^0_{S/L}K^+K^-$）：

- 提高γ角测量统计精度
- Memo BAM-00827

BESIII unbinned强相位差测量（20fb^{-1} Unbinned $K^0_S\pi^+\pi^-$）：

- 进一步提高γ角测量统计精度，减少BESIII对γ角贡献系统误差
- report

LHCb-CONF-2024-004
July 26, 2024

Simultaneous determination of the CKM angle γ and parameters related to mixing and CP violation in the charm sector

LHCb collaboration[†]

Abstract

A combination of measurements sensitive to the CP-violation angle γ of the Cabibbo–Kobayashi–Maskawa unitarity triangle, to the charm mixing parameters that describe oscillations between D^0 and $\overline{D}^0$ mesons, and to the CP asymmetries in the $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays is performed. All relevant beauty and charm results obtained with the data collected with the LHCb detector at CERN's Large Hadron Collider to date are included. The charm mixing parameters are determined to be $x = (0.41 \pm 0.05)\%$ and $y = (0.621^{+0.022}_{-0.021})\%$, the magnitude and phase of CP violation in charm mixing to be $|q/p| = 0.989 \pm 0.015$ and $\phi = (-2.5 \pm 1.2)^\circ$, and the CP asymmetries in decay to be $a^d_{K^+K^-} = (6^{+6}_{-5}) \times 10^{-4}$ and $a^d_{K^+K^-} = (22 \pm 6) \times 10^{-4}$, with a correlation of $\rho = 0.88$. The angle γ is found to be $(64.6 \pm 2.8)^\circ$, which is the most precise determination from direct measurements to date.

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[†]Conference report prepared for the 42nd International Conference on High Energy Physics, Prague, Czech Republic, 17–24 July 2024. Contact authors: Jordy Butter, jordy.butter@cern.ch Alex Gilman, alexander.leon.gilman@cern.ch Matthew Kenzie, matthew.william.kenzie@cern.ch, Tommaso Pajero, tommaso.pajero@cern.ch, Mark Whitehead, mark.peter.whitehead@cern.ch.

强相位差对相角γ重要性

LHCb 实验测量相角γ ..

- CLEO-c实验测量结果 $\sigma(c_i/s_i)\sim 4°$

2011 -2016:

$\gamma = (80^{+10}_{-9})^\circ$

σ(stat) ~ 9°　　σ(CLEO) ~ 4°, σ(syst) ~3°



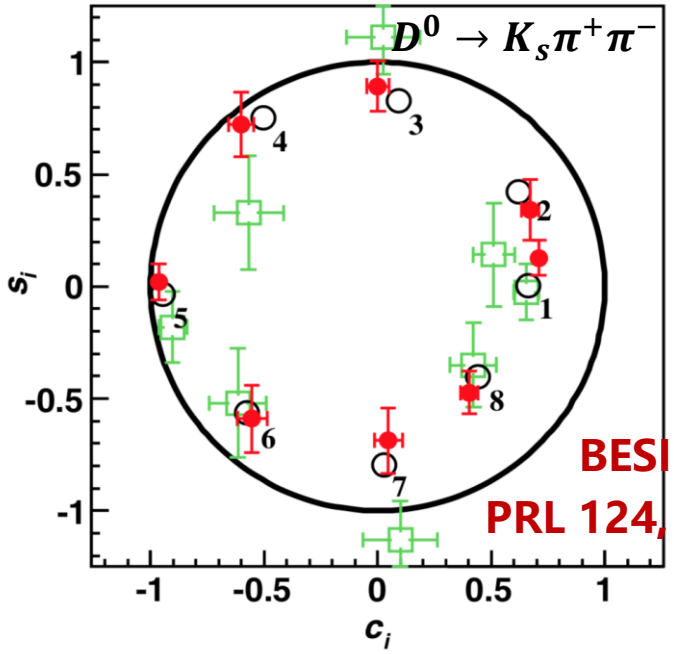
- BESIII实验测量结果 $\sigma(c_i/s_i)\sim 1°$

2011 -2018:

$\gamma = (69 \pm 5)^\circ$

σ(stat) ~ 5°　　σ(BESIII+CLEO) ~ 1°, σ(syst) ~1°





2021

BESIII 强相位差
PRL 124, 241802(2020)

- LHCb和Belle II 继续获取更多的数据，需要更精确的c_i/s_i

Runs	Collected / Expected luminosity	Year attained	γ/ϕ_3 sensitivity
LHCb Run-1 [7, 8 TeV]	3 fb^{-1}	2012	8°
LHCb Run-2 [13 TeV]	5 fb^{-1}	2018	4°
Belle-II Run	50 ab^{-1}	2025	1.5°
LHCb phase-1 upgrade [14 TeV]	50 fb^{-1}	2030	$<1°$
LHCb phase-2 upgrade [14 TeV]	300 fb^{-1}	(>)2035	$<0.4°$

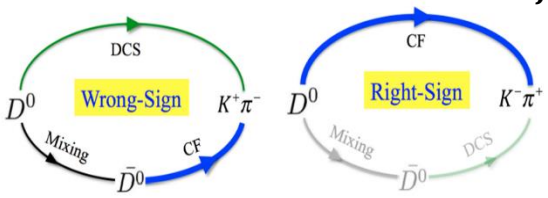
arXiv:1910.11775
Physics Briefing Book : Input for the European Strategy for Particle Physics Update 2020

$\sigma(c_i/s_i) < 0.5°$?

强相角差在其他关键测量中...

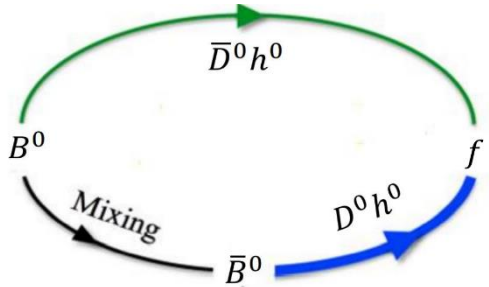
□ $D^0 - \bar{D}^0$混合和CP破坏

$$\frac{d\Gamma(D^0(t) \to f)}{d\Phi_f} \propto |A_f|^2 e^{-\Gamma t}[\frac{1+|\lambda_f|^2}{2}\cosh(y\Gamma t) + \frac{1-|\lambda_f|^2}{2}\cos(x\Gamma t) - Re(\lambda_f)\sinh(y\Gamma t) + Im(\lambda_f)\sin(x\Gamma t)]$$



中性粲介子的强相位差

□ $B^0 \to D^{(*)0}\pi^0$衰变时间依赖的CP破坏以及企鹅图无关的β测量



$$\Gamma(B^0(t) \to f) \propto e^{-\frac{t}{\tau_B}}[1 + \frac{1-|\lambda_f|^2}{1+|\lambda_f|^2}\cos(\Delta m_B t) - \frac{2\mathrm{Im}(\lambda_f)}{1+|\lambda_f|^2}\sin(\Delta m_B t)]$$

$$\mathrm{Im}(\lambda_f) = \left|\frac{A(\bar{B}^0 \to f)}{A(B^0 \to f)}\right| \sin(\delta_f - 2\beta) \qquad \delta_f = \arg\left(\eta_{CP}^{h^0}(-1)^L\right) + \delta_{f_D}$$

该测量结果可与受企鹅图污染的“黄金过程” $B^0 \to J/\psi K^0$ 测量的β结果直接比较，备受关注

中性粲介子的强相位差，是基本观测量，与粲介子内部强相互作用紧密相关，对刻度和理解非微扰QCD具有特殊地位